LTPP Manual for Falling Weight Deflectometer Measurements

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1 Background

A Falling Weight Deflectometer (FWD) is a device designed to simulate deflection of a pavement surface due to a fast moving truck. The FWD generates a load pulse by dropping a weight. This load pulse is transmitted to the pavement through a 300-mm diameter circular load plate.

The load pulse generated by the FWD momentarily deforms the pavement under the load plate into a dish or bowl shape. From a side view, the shape of the deformed pavement surface is often called a "deflection basin".

Based on the force imparted to the pavement and the shape of the deflection basin, the stiffness of the pavement can be estimated using a variety of computational methods. If the thickness of the individual layers is also known, the stiffness of those layers can also be calculated.

In addition, an FWD can be used to determine the degree of interlock between adjacent slabs of a Portland cement concrete (PCC) pavement. This degree of interlock is generally known as "load transfer efficiency" or LTE. In order to measure the LTE, the FWD load plate is placed so that it is tangent to one side of the joint to be evaluated. A load pulse is then generated, and the deflections at equal distances on either side of the joint are measured. For a perfectly efficient joint, these deflections will be equal. For most joints, the deflection on the unloaded slab will be less than the deflection on the loaded slab.

An FWD carries two types of primary measurement devices. The first is a load cell. The load cell is located directly above the load plate, and it measures the force imparted to the pavement. The second is a deflection sensor, also known as a "deflector." The LTPP operated FWDs use geophones as the deflection sensors, although there are other types of deflection sensors used by other FWD designs. The LTPP FWDs have nine deflection sensors, which are placed at fixed distances from the load plate in order to measure the shape of the deflection basin.

In addition to the primary measurement devices, the LTPP FWDs carry two additional types of measurement devices. The first is the Distance Measurement Instrument, or DMI. Essentially, the DMI is a high-accuracy odometer, which measures the distance the FWD has traveled along a roadway. The second type is temperature sensors. The LTPP FWDs carry two temperature sensors - an air temperature sensor and an infrared surface temperature sensor. The data from these two temperature sensors, combined with data from nearby weather stations can be used to estimate the temperature of the various materials that make up the pavement structure.

Knowing the temperature of the materials in the pavement structure is critical. For example, asphalt is hard and brittle at very low temperatures, and soft and ductile at very high temperatures. The stiffness calculated from FWD data for these materials must therefore be corrected for these temperature effects. In addition, the LTE between two PCC slabs varies as the slabs expand and contract or warp due to a difference in temperature between their top and bottom surfaces.

The LTPP FWD operator is also required to perform manual measurements during FWD Testing. These measurements consist of sub-surface temperature measurements using a hand-held probe, and joint width measurements during load transfer testing.

Finally, the LTPP FWD operator must comment on any non-equipment related conditions encountered during testing that might reasonably be expected to cause anomalous measurements. These conditions usually are cracks or other pavement surface distresses.

2 FWD-Related Terminology

The following terminology will be used in the remainder of this document to refer to specific parts of the Dynatest model 8002 FWD, which is the type operated by LTPP. Some of these terms will also be applicable to other types of FWDs.

This list is only as complete as necessary for the purposes of this document. For parts not included here, please see the Owner's Manual. Use of proper terminology will greatly ease the troubleshooting and problem reporting processes.

Buffer: A rubber block attached to the underside of the weight package to control the shape of the generated load pulse. On LTPP FWDs, the buffers are roughly cylindrical, and there are four mounted under on the weight package.

Control Box: The control box is located on the FWD trailer, and has connectors for the geophones, load cell, temperature sensor and other sensors mounted on the FWD. The control box then sends these signals to the signal processor located in the tow vehicle through the multi-signal cable. The control box also has buttons for manual control of the FWD hydraulics.

Geophone: The geophones are the devices used to measure deflection on the LTPP FWDs. They are yellow, roughly cylindrical and about 25 mm in diameter and 50 mm high. The Geophones are mounted in spring loaded sensor support brackets suspended along the sensor bar. Each geophone has a unique serial number that is used to enter critical calibration information in the FWD data collection software. The LTPP FWDs use the 2000 micron (80 mil) geophones.

Load Cell: The load cell is located directly above the load plate and below the swivel. The load cell measures the force imparted to the pavement by the FWD. The load cell has a serial number, which is visible from the rear.

Load Plate: The load plate is 300 mm in diameter, and directly contacts the pavement surface in order to transmit load. The type used by LTPP is solid. It consists of three layers, the topmost of which is steel, the middle is PVC, and the bottommost is a ribbed rubber sheet.

Multi-Signal Cable: The multi-signal cable carries electrical signals from the control box to the signal processor. These signals include the outputs from the transducers on the FWD and the command signals for the FWD hydraulics.

Signal Processor: The LTPP FWDs use a Dynatest 9000 signal processor. It is located in the tow vehicle. It connects to the trailer control box via the multi-signal cable. It connects to the data collection computer via an RS-232 serial cable.

Strike Plate: The strike plate is in the column above the load plate. The top of the strike plate is a flat surface, which the weight package is dropped on during operation of the FWD. Welded to the underside of the strike plate are braces, and a cylinder which houses the center geophone and to which the swivel attaches.

Sensor Bar: The sensor bar is a long bar mounted above the load plate and running towards the trailer hitch. The geophone holders are mounted to this bar. An extension of the sensor bar continues behind the load plate to allow a geophone to be mounted behind the load plate.

Swivel: The swivel connects the load cell to the strike plate. It allows the load cell and load plate to rotate to provide good contact with the pavement surface.

Transducer: Any measurement device that converts a physical response into an electrical signal. Transducers on an FWD include the load cell, deflection sensors and temperature sensors.

Weight: “Weight” refers to the removable weights that are mounted to the weight package. They are steel and 20 kg in mass.

Weight Package: The weight package is the entire assembly that is raised and then dropped to generate load.

3 Test Procedure

The following general procedures shall be performed by FWD operators at each test site. References are made in these instructions to the locations of details contained in other parts of this document associated with each step.

3.1 Prior to arriving on site, the FWD operator must have a filled out copy of Form F05 "FWD Operations Planning." A separate copy of this form must be filled out for each test section.

3.2 Upon arriving on site, inspect the test section for evidence of maintenance activities. Any missing or defaced site markings should be replaced before continuing. If there is evidence of recent maintenance activities, the RSC office shall be contacted, and if quantitative evidence exists of the impact of the maintenance activities upon the layer structure, the temperature hole section of Form F05 shall be reevaluated.

3.3 Prepare the temperature gradient holes as directed in Section 6.1. The hole depths shall be the holes listed on Form F05 which are not crossed out. Previously drilled holes may be used provided that they are blown out and their depths are re-measured and found to correspond to those on Form F05. After the holes are drilled, the depths shall be measured and filled out on Form F01. After filling the holes with mineral oil, at least 20 minutes must pass before the first temperature measurement is performed.

3.4 Perform the before operations activities listed in Section 9.2.

3.5 Perform the standard buffer warm-up sequence or the cold weather buffer warm-up sequence, as appropriate, outside of the test section limits. The buffer warm-up sequences and their appropriate temperature ranges are given in Section 4.3.5.

After completing the buffer warm-up sequence, examine the data from the final four drops to ensure that the load levels are not all trending in the same direction (i.e. consistently increasing or consistently decreasing). If they are trending in the same direction, repeat the standard buffer warm-up sequence until the load levels stabilize.

After the last buffer warm-up sequence, examine the data from the four drops prior to the final four drops to ensure that the load levels for each drop height are within the limits set out in Section 4.2. If they are not, the drop height targets shall be adjusted accordingly, and a further one drop at each drop height shall be performed to ensure that the targets are correctly set. If at any time during testing the load levels stray from the limits for their respective drop heights, testing will be terminated, the targets readjusted and the pass shall be repeated.

A standard buffer warm-up sequence must be performed again if the FWD is idle for more than 15 minutes.

3.6 Position the FWD so that the center of the load plate is on the section start limit (i.e. Station 0+000). The DMI shall be set to 0 feet, ascending. The DMI must be set in units of "feet" for continuity with previous LTPP FWD testing.

3.7 Position the FWD at the first test location. Test locations for the appropriate test plan number (as given on Form F05) are given in Section 5.

3.8 Within the FWD data collection software, set the "Test Setup" as listed on Form F05. Then open a new data file. Use the file name as listed on Form F05.

3.9 Check the local time on the computer, and evaluate whether the test pass can be completed prior to local midnight. If it is not probable that testing can be completed before midnight, testing shall not be started until after midnight. Any test pass that starts before midnight and ends after midnight cannot be uploaded to the LTPP database.

3.10 Perform the first temperature gradient measurement, as per Section 6.1. Subsequent temperature gradient measurements shall be performed every 30 minutes, plus or minus 10 minutes. For GPS sections, temperature gradient measurements shall be taken at alternate ends, with a 60-minute interval between measurements at a given end.

3.11 Enter the Lane Specification appropriate to the test location in the field provided in the data collection software.

3.12 Start the testing sequence.

3.13 Exit the vehicle during testing and examine the pavement surface in the vicinity of the FWD for distresses and defects. Note any distresses in the area around the FWD as per Section 6.3.

3.14 During load transfer testing (i.e. Lane Specifications J4, J5, C4, C5, F4 or F5), the Joint/Crack width should be measured as described in Section 6.2. Joint/Crack widths must be measured for at least 25% of load transfer tests. If time permits, joint/crack widths should be measured for all load transfer tests.

3.15 If the data collection software generates any errors during testing, see Section 7 for further instructions.

After testing, at the "Accept/Reject" prompt, only choose "Accept" if no errors were generated, or after following the error resolution procedures in Section 7.

3.16 After testing is complete and the load plate is up, proceed to the next test point.

3.17 If the next test point is at an even station (i.e. 1+00, 2+00, etc.) check that the DMI corresponds to the pavement markings, and if it does not, correct the DMI.

3.18 Repeat steps 3.11 through 3.17 for each test point in the test pass.

3.19 After completing testing at each test point in the pass, the operator can then close the data file. The data file must be closed and a new data file opened prior to testing in a new test pass.

3.20 Return the FWD to the section start limit (i.e. station 0+000), and re-zero the DMI.

3.21 Perform steps 3.7 - 3.9 and 3.11 - 3.19 for the new pass. The temperature gradient measurement process does not need to be restarted, but must be continued as long as FWD testing is being performed at the section.

3.22 Repeat steps 3.20 - 3.21 for each remaining pass at the test section.

3.23 After completing FWD testing at the section, perform one more temperature gradient measurement, regardless of the time since the previous measurement.

3.24 If traffic control conditions permit, perform data backup and preliminary data processing before leaving the site, as per Section 12.1. Check that forms F01 and F02 have been correctly filled out, and that form F05 has been initialed and dated.

3.25 Perform after operations activities detailed in Section 9.3.

4 Setup

4.1 Physical Setup

The physical setup described herein is mandatory for all LTPP owned FWDs. Other FWDs collecting data on behalf of LTPP may not be capable of the setup as described. In these cases, it should be followed as closely as possible.

4.1.1 Geophone locations

The placement of the geophones on the FWD shall be the same for all LTPP testing. Geophone offsets shall be measured from the center of the load plate to the center of the geophone holder. The location of each geophone shall be measured directly from the center of the load plate, to avoid accumulated error. Offsets in front of the load plate (i.e. in the direction of the hitch) shall be considered positive. Offsets behind the load plate (i.e. in the direction of the rear bumper) shall be considered negative. The required offsets are shown in Table 1.

Table 1 Deflection Sensor Offsets for Nine Sensor FWDs

Deflection Sensor	Offset
D1	0 mm
D2	203 mm
D3	305 mm
D4	457 mm
D5	610 mm
D6	914 mm
D7	1219 mm
D8	1524 mm
D9	-305 mm

If testing is to be performed on behalf of LTPP by an FWD that mounts only seven deflection sensors, the following sensor spacings shown in Table 2 shall be used.

Table 2 Deflection Sensor Offsets for Seven Sensor FWDs

Deflection Sensor	Offset (Flexible Pavements)	Offset (Rigid Pavements)
D1	0 mm	0 mm
D2	203 mm	-305 mm
D3	305 mm	305 mm
D4	457 mm	457 mm
D5	610 mm	610 mm
D6	914 mm	914 mm
D7	1524 mm	1524 mm

Non LTPP-operated FWDs and LTPP-operated FWDs that have undergone overhaul or replacement of the sensor bar or deflection sensor holders must have the deflection sensor offset measured and set accurately, using the following procedure.

First, raise the FWD load plate and engage the transport locks and the hitch pin in front sensor bar guide. Make sure the "Man Key" on the control panel is switched to "ON".

Then, check the springs and foam rubber guides on all deflector holders to ensure they are in good condition. Make sure that spring tensions are properly adjusted such that a force on the end feeler can move the holder and feeler upwards until the feeler is at least 5 mm inside bottom of holder body, and that it returns easily when released (otherwise apply a few drops of silicone oil to top guide rod).

Then, use a steel tape measure with 1 mm graduations and 3 m or greater in length, and zero it on the feeler of the center geophone which projects through bottom of loading plate. Apply constant positive pressure on tape to eliminate any sag in tape throughout its length. Measure the location of every other defection sensor from this zero point to the center of the sensor's feeler. Do not measure just center to center between individual deflector sensors, as this will result in an accumulating error. By measuring from the rear of the contact screw a more repeatable/accurate measurement can be taken. To do this it is necessary to compensate in the measurement for the distance from the outer edge of the contact screw to the center. Check position measurements at least twice.

For LTPP-operated FWDs, once the location of the deflection sensor holders has been properly set they shall be locked in place. To do this, drill through the top of the deflection sensor holder where it passes over the sensor bar and through the sensor bar itself with a 17/64 inch bit. Tap the sensor bar itself to accommodate a 6M x 1.0mm (thread pitch) screw. The deflection sensor holder can now be secured with a 6M x 1.0mm - 20mm stainless steel allen head screw. The screw shall be retained with a flat metal washer and thread locking compound (blue grade Loctite or equivalent).

4.1.2 Weight Package

The weight package shall be configured the same for all LTPP testing. For Dynatest model 8002 FWDs, three standard weights shall be used per side. Two buffers shall be used per side. Whenever new buffers are installed on the FWD, Form F04 must be filled out and submitted to the FHWA LTPP FWD task leader.

If testing is to be performed on behalf of LTPP by an FWD other than a Dynatest model 8002 FWD, select a combination of buffers and weights that achieves the load requirements of Section 4.2 and comes as close as possible to a 13 ms pulse rise time.

4.2 Load Levels

Four load levels are defined here for LTPP testing. The acceptable load range for each drop height is between 90% and 110% of the target value. Experience has shown that drop loads for a given drop height tend to decrease slightly over the course of a day of testing. Setting the drop load at 103% of the target load at the beginning of the day will minimize the deviation over the course of the day for most cases.

Each drop height must be within the acceptable range shown in Table 3 for all testing. Drop heights may not be adjusted during a test pass.

Table 3 Target Loads and Acceptable Ranges

Drop Height	Target Load, kN (kips)	Acceptable Range, kN (kips)
1	26.7 (6.0)	24.0 to 29.4 (5.4 to 6.6)
2	40.0 (9.0)	36.0 to 44.0 (8.1 to 9.9)
3	53.4 (12.0)	48.1 to 58.7 (10.8 to 13.2)
4	71.2 (16.0)	64.1 to 78.3 (14.4 to 17.6)

Note: Drop height 1 is not used for testing on rigid pavements.

4.3 Software Setup

This section includes specific software settings required for LTPP testing. Instructions on how to enter these settings into the data collection software are given in the "LTPP FWD Data Collection Software Manual."

4.3.1 Units

All FWD data collected for LTPP shall be in SI units, with the exception of station units, which shall be in feet. Specifically, temperature shall be recorded and displayed in Celsius (C), load in kilo-Newtons (kN), deflection in microns (um) and deflection sensor offsets in millimeters (mm).

4.3.2 File Format

Data collected with LTPP FWDs shall be in the FWDWin MDB format. Data collected with non-LTPP seven (7) sensor FWDs shall be in the R80-20 format, where possible. For FWDs not supporting either of these formats, contact the FHWA LTPP FWD Task Leader with copy to the TSSC prior to testing for instructions.

4.3.3 Filters

Data shall be collected with all filters and smoothing turned off.

4.3.4 Data Checks

The following checks should be enabled:

Roll-Off
Non-Decreasing Deflections
Overflow
Load Variation - set to +/- (0.18 kN + 0.02X)
Deflection Variation - set to +/- (2 µm + 0.01X)

For further information on what these checks are and what to do when they fail, see Section 6.

4.3.5 Drop Sequences

Two different drop sequences are used for LTPP testing.

For Flexible testing:
C,C,C,1,1,1,1H,2,2,2,2H,3,3,3,3H,4,4,4,4H

For Rigid testing (both JCP and CRCP)
C,C,C,2,2,2,2H,3,3,3,3H,4,4,4,4H

Where "C" is a seating drop (no data saved) from drop height 3,
1 is a drop from drop height 1,
2 is a drop from drop height 2,
3 is a drop from drop height 3,
4 is a drop from drop height 4,
"H" indicates that the full time history for that drop is to be saved.

In addition, one of the following drop sequences is used to warm up the buffers prior to testing:

Standard buffer warm up sequence (to be used in ambient temperatures above 10 degrees C)
(1,2,3,4,4,4,4) repeated 8 times

Cold-weather buffer warm-up sequence (to be used in ambient temperatures below 10 degrees C)
(1) repeated 32 times, followed by the standard buffer warm up sequence

Furthermore, the reference calibration and the relative calibration drop sequences from the "SHRP-LTPP FWD Calibration Protocol" shall be pre-programmed into the LTPP owned FWDs.

4.3.6 File Naming

The file name for an FWD data file shall be eight characters in length. It shall be of the following format:

XXYYYYZN

Where: XX is the state code for the state in which the section is located,
YYYY is the LTPP section ID for the section,
Z represents the site visit ('A' for the first visit, then 'B' etc.) and
N represents the pass number

For example, for the first pass of the first visit to section 3807 in North Carolina, the file name should be '373807A1'. Test passes are further described in Section 5.2.

5 Test Plans

5.1 Selecting the Appropriate Test Plan

Test plans specify the location of test points at an LTPP section. There are several different test plans. The appropriate test plan for an LTPP section is determined by the experiment designation of the section, and in some cases the surface type or other properties of the section. The test plan applicable to a given LTPP section shall be determined according to Table 4.

Table 4 Test Plans by LTPP Experiment and Surface Type

Experiment	Surface Type	Test Plan	Note
GPS 1	Flexible	1	
GPS 2	Flexible	1	
GPS 3	JPCP	2	
GPS 4	JRCP	2	
GPS 5	CRCP	3	
GPS 6	Flexible	1	
GPS 7	Flexible	1	
GPS 9	JPCP	2	
SPS 1	Flexible	4	
SPS 2	JPCP	5	
	JPCP	7	4.3 m lane width sections
SPS 3	Flexible	8	
SPS 4	JPCP	9	
SPS 5	Flexible	4	
SPS 6	JPCP	5	
	Flexible over JPCP	10	Sections 3, 6, 7 & 8
	Flexible over JPCP	11	Section 4
SPS 7	JPCP	5	
	CRCP	6	
SPS 8	Flexible	4	
SPS 8	JPCP	5	
SPS 9	Flexible	4	
	Flexible over PCC	10	

5.2 Description of Test Plans

Each test plan consists of one or more test passes. Data from each test pass shall be stored in a separate data file. Each test pass shall be performed in the direction of traffic, from the section approach limit (0+000) to the section leave limit (0+152.4 (5+00) for most test sections).

Each test pass consists of testing according to one or more “Lane Specifications.” It is critical that the operator enter the lane specification appropriate to the test location in the field provided in the data collection software. The longitudinal offset between test locations vary according to the test plan and test pass.
Table 5 includes detailed information for each test plan and test pass.

Table 5 Details of Test Plans

Test Plan	Pass #	Lane Spec.	Lane Description	Test Type	Test Interval	Number of tests[1]
1	1	F1	ML	Basin	7.6 m (25 ft)	21
	3	F3	OWP	Basin	7.6 m (25 ft)	21
2	1	J1	ML – MP	Basin	20 slabs	20
	2	J2	PE – CR	Basin	20 slabs	20
		J3	PE – MP	Basin	20 slabs	20
	3	J4	OWP – JA	LT	20 slabs	20
		J5	OWP – JL	LT	20 slabs	20
3	1	C1	ML – MP	Basin	20 slabs	20
	2	C2	PE – CR	Basin	20 slabs	20
		C3	PE – MP	Basin	20 slabs	20
	3	C4	OWP – JA	LT	20 slabs	20
		C5	OWP – JL	LT	20 slabs	20
4	1	F1	ML	Basin	15.2 m (50 ft)	11
	3	F3	OWP	Basin	15.2 m (50 ft)	11
5	1	J1	ML – MP	Basin	10 slabs [2]	10 [3]
	2	J2	PE – CR	Basin	10 slabs [2]	10 [3]
		J3	PE – MP	Basin	10 slabs [2]	10 [3]
	3	J4	OWP – JA	LT	10 slabs [2]	10 [3]
		J5	OWP – JL	LT	10 slabs [2]	10 [3]
6	1	C1	ML – MP	Basin	10 slabs	10
	2	C2	PE – CR	Basin	10 slabs	10
		C3	PE – MP	Basin	10 slabs	10
	3	C4	OWP – JA	LT	10 slabs	10
		C5	OWP – JL	LT	10 slabs	10
7	1	J1	ML – MP	Basin	10 slabs	10
	2	J2	PE – CR	Basin	10 slabs	10
		J3	PE – MP	Basin	10 slabs	10
	3	J4	OWP – JA	LT	10 slabs	10
		J5	OWP – JL	LT	10 slabs	10
	4	J7	WLE – CR	Basin	10 slabs	10
		J8	WLE – MP	Basin	10 slabs	10
8	1	F1	ML	Basin	30.4 m (100 ft)	6
	3	F3	OWP	Basin	30.4 m (100 ft)	6
9	1	J4	OWP – JA	LT	Every third joint/slab starting with first joint/slab	varies
		J5	OWP – JL	LT		varies
		J6	OWP – MP	Basin		varies
10	1	F1	ML	Basin	Same as J1/J3 prior to overlay	6
	3	F3	OWP	Basin		6

Test Plan	Pass #	Lane Spec.	Lane Description	Test Type	Test Interval	Number of tests[1]
11	1	F1	ML	Basin	Same as J1/J3 prior to overlay	10
	3	F3	OWP	Basin		10
		F4	OWP – JA	LT	Same as J4/J5 prior to overlay	10
		F5	OWP - JL	LT		10

[1] For PCC testing, if fewer effective slabs exist at a section than the number listed in the "Test interval" column, the number of slabs to be tested shall equal the number of slabs that exist.
[2] Test 20 slabs for 304.8 m (1000 ft.) test sections
[3] 20 tests for 304.8 m (1000 ft.) test sections

Abbreviations:
- ML – Mid-Lane
- OWP – Outer Wheel Path
- PE – Pavement Edge
- WLE – Widened Lane Edge
- MP – Mid-Panel
- CR – Corner
- LT – Load Transfer
- JA – Joint Approach (load plate on approach slab)
- JL – Joint Leave (load plate on leave slab)

Diagrams of these test plans are located in Appendix A.

5.3 Transverse Locations

The transverse location of a test pass is given as a relative position within the lane containing the LTPP test section. These relative positions are mid-lane (ML), outer wheel path (OWP), pavement edge (PE) and widened lane edge. These positions are to be measured from the outside lane edge (OLE) to the center of the FWD load plate as detailed in Table 6.

Table 6 Transverse Locations Relative to OLE

Relative Position	Offset From Outside Lane Edge	
	3.66 m (12 ft.) Nominal Lane Width	4.27 m (14 ft.) Nominal Lane Width
ML	1800 mm ± 150 mm	1800 mm ± 150 mm
OWP	760 mm ± 75 mm	760 mm ± 75 mm
PE	150 mm[1] ± 75 mm	150 mm ± 75 mm
WLE	NA	150 mm[2] ± 75 mm

[1] If proper seating of the load plate at this offset is impossible due to pavement features, the offset may be increased.
[2] Testing in the widened lane edge is referenced to the outer edge of the pavement slab, not the OLE

For a normal paving lane (nominally 3.7 m (12 ft) wide) the OLE is defined as the lane-shoulder interface, unless the outside edge of the painted shoulder stripe is over 150 mm (6 in.) inside the lane-shoulder interface, in which case the OLE is defined as the outside edge of the painted shoulder stripe. For a wide paving lane (nominally 4.0 m (13 ft) or wider), the OLE is defined as the outside edge of the painted shoulder stripe.

This transverse location, within the error band listed, must be maintained for all test locations within the test pass.

5.4 Slab-Referenced Locations

FWD testing on PCC surfaces is referenced to effective slabs, not absolute longitudinal position. If testing has been performed at a PCC-surfaced section previously, then the operator should test the same slabs that have been tested previously. Form F10 shall be used to identify the slabs that have been previously tested. On Form F10, slabs are referenced by the station of the joint or crack which defines the approach end of the slab. If a slab that has been previously tested is sub-divided by a new transverse crack, then that portion of the slab which is bounded by the original approach joint or crack and the new transverse crack shall be tested.

If testing has not been previously performed at a PCC-surfaced section, then the operator shall determine the number of slabs to be tested according to the test plan. Next, the operator shall determine the number of effective slabs that are wholly within the section limits (i.e. only count slabs that begin and end within the test section). Slabs can be bounded by either joints or full-width transverse cracks that are "working."

If the number of effective slabs is less than or equal to the number of slabs to be tested, then all effective slabs shall be tested. If the number of effective slabs is greater than the number of slabs to be tested, then a subset of the effective slabs equal to the number of slabs to be tested shall be selected. The operator shall take care to evenly space the slabs to be tested along the test section. Testing in all test passes at the section shall be done in reference to the same slabs.

The test plans specify test locations relative to the slab to be tested as mid-panel, joint approach, joint leave and corner.

5.4.1 Mid-Panel

Mid-panel testing shall be performed with the load plate located as close to the center of the effective slab as possible. The load plate shall be located within 0.3 m (1 ft.) or 10% of the effective slab length, of the center (as measured along the test pass), whichever is smaller.

5.4.2 Joint Approach

Joint approach testing shall be performed with the load plate tangent to the joint or crack defining the approach end of the slab to be tested. The load plate shall be located on the slab immediately prior to the selected slab. The edge of the load plate shall be within 50 mm (2 inches) of the joint, but should under no circumstances bridge the joint. A diagram of joint approach testing is shown in Figure 1below.

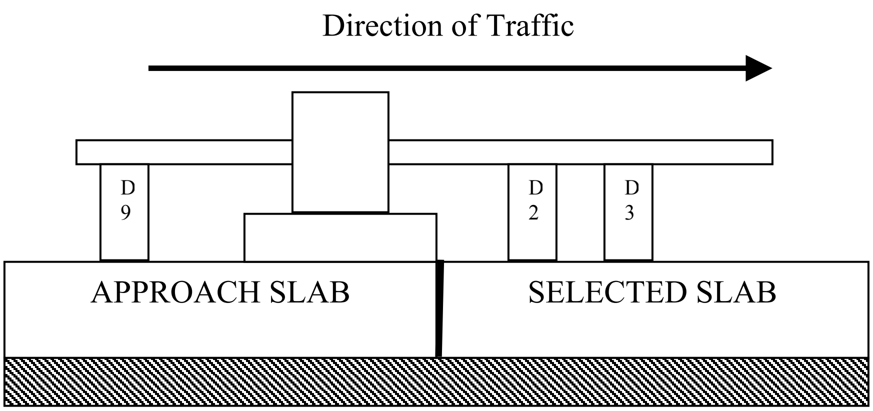


Figure 1 Joint Approach Testing

5.4.3 Joint Leave

Joint leave testing shall be performed with the load plate tangent to the joint or crack defining the approach end of the slab to be tested. The load plate shall be located on the selected slab. The edge of the load plate shall be within 50 mm (2 inches) of the joint, but should under no circumstances bridge the joint. A diagram of joint approach leave testing is shown below in Figure 2.

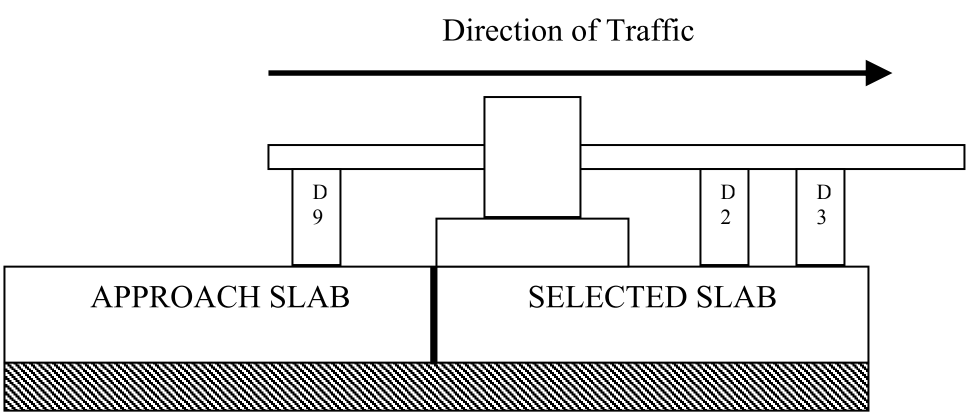


Figure 2 Joint Leave Testing

5.4.4 Corner

For JCP pavements (test plans 2, 5 and 7), corner testing shall be performed the same as joint leave testing except that the load plate shall be tangent to both the joint or crack defining the approach end of the slab and the longitudinal joint defining the outside edge of the slab. The edge of the load plate shall be no more than 75 mm (3 inches) from the joint or crack defining the approach end of the slab and no more than 75 mm (3 inches) from the longitudinal joint.

For CRCP pavements (test plans 3 and 6), corner test shall be performed with the load plate centered on the transverse crack defining the approach end of the effective slab and tangent to the longitudinal crack defining the outside edge of the slab. The edge of the load plate shall be no more than 75 mm (3 inches) from the longitudinal joint.

6 Other Measurements Associated with FWD Testing

6.1 Temperature Gradient Measurements

Up to five holes shall be drilled in the bound layers of the pavement for the purpose of measuring sub-surface temperatures. Only holes that terminate in an unbound layer may be eliminated. Table 7 shows the depths to which the holes shall be drilled.

Table 7 Temperature Hole Depths

Hole Number	Hole Depth (mm)
1	25
2	50
3	100
4	200
5	300

All holes shall be drilled as close as possible to the depths listed in the above table. The tolerance for hole number 1 is ±5 mm. The tolerance for holes 2 through 5 is ±10 mm. The holes shall be drilled in decreasing order of depth, in order to allow extra time for the heat generated during drilling to dissipate.

If a hole is within ±25 mm of the reported bottom of the bound layers, its depth should be decreased to 25 mm above the reported bottom of the bound layers.

The holes shall be drilled in the center of the outer wheel path (OWP), but shall be offset at least 0.5 m from each other in the longitudinal direction. For GPS sections, the holes shall be located on both ends of the test section, just outside the monitoring area. Typically the location of the holes will be near station 0-001 (0-03) and 0+153.4 (5+03) For SPS sections, holes shall be located at only one end of the section, just outside the monitoring area. The operator shall choose the end of the section that is most representative of the monitoring area.

Holes shall be drilled with a portable hammer drill, using a 13 mm diameter bit. After the hole is drilled to the required depth, it shall be cleared of debris and dust by blowing through a short piece of plastic tubing or other suitable device. The actual depth of the hole shall be measured after it is cleared of debris. Then it shall be filled with 15 mm to 25 mm of mineral oil to provide thermal conductivity between the pavement and the temperature probe. Finally, it shall be covered with tape (such as duct tape), which shall be slit to allow the probe to be inserted.

In addition to sub-surface temperature measurements, an infrared (IR) surface temperature measurement shall be obtained at the same time that sub-surface temperature readings are obtained. The measurement location shall also be in the OWP and at least 0.5 m from the nearest hole in the longitudinal direction. The operator shall take care that the area in which the IR surface temperature is taken shall be free of oil, dirt or other foreign debris. During temperature measurements, the hand-held IR device shall be held at a height consistent with the height of the FWD-mounted IR measurement device. IR temperate measurements shall be taken three times in quick succession, and the results shall be averaged and entered on form F01.

6.2 Joint/Crack Width Measurements

Joint/crack width measurements shall only be taken on PCC surfaced pavements, with the exception of testing done in accordance with test plan 11. On flexible surfaced pavements, cracks shall be noted in accordance with the instructions in Section 6.3.

On PCC surfaced pavements, joint/crack width measurements shall be taken for at least 25% of the Load Transfer tests, however operators are encouraged to perform such measurements for all load transfer tests if time permits.

Joint/crack width measurements shall be performed using calipers with tapered jaws for measuring inside dimensions. The resolution of the calipers shall be at least 0.3 mm (0.01 inch).

On transverse cracks, the goal is to measure the minimum width of the opening that extends through the pavement. If the cracks are spalled, the width of the opening may have to be estimated.

On sawed joints, the goal is the measure the sawn width (as opposed to the actual opening). It may be necessary to depress the joint sealant to measure the opening, especially if the joints are spalled.

Joint/crack width openings should be measured at several points in the OWP, and the measurements averaged and rounded to the nearest 1 mm. This average shall be entered into the FWD data collection software in the appropriate field.

Measurements less than 1 mm are hard to make with calipers because the jaws are too wide to enter the opening. In these situations, the measurement shall be recorded as 1 mm. Measurements in excess of 25 mm shall be recorded as 25 mm.

6.3 Distress Identification and Commenting

The type and severity of pavement distress may influence the deflection response of a pavement. Therefore, FWD operators shall record any distress in the area of the pavement from about 0.3 m in front of the forward most deflection sensor to 0.9 m behind the load plate and from 0.3 m on the left of the load plate to 0.3 m on the right of the load plate. This information shall be entered at the 'Comments' prompt immediately following the test sequence. Where possible, operators should use the standard abbreviation list presented in Table 8. Operators should avoid ad-hoc abbreviations unless they are necessary due to space limitations.

Table 8 Standard Abbreviation List - Distress

Category	Full word or phrase	Standard abbreviation
Distress	Bleeding	BLD
	Block Cracking	BCR
	Blowups	BLWUP
	Corner Break	CBRK
	Durability Cracking	DCR
	Edge Crack	ECR
	Fatigue Crack	FCR
	Faulting	FLT
	Joint Seal Damage	JTSD
	Lane-Shoulder Dropoff	LSDROP
	Longitudinal Crack	LCR
	Map Cracking	MAP
	Patch	PATCH
	AC Patch	ACPATCH
	PCC Patch	PCPATCH
	Polished Aggregate	POLAG
	Popouts	POUT
	Pothole	PTHL
	Pumping	PUMP
	Ravelling	RVL
	Rough Surface	RSURF
	Rutting	RUT
	Scaling	SCL
	Shoving	SHOV
	Spalling	SPL
	Transverse Crack	TCR
	Transverse Construction Joint Damage	TCJTD
	Low Severity	LSEV
	Moderate Severity	MSEV
	High Severity	HSEV

Table 8 Standard Abbreviation List – Equipment, Lane Geometry, Miscellaneous

Category	Full word or phrase	Standard abbreviation
Equipment	Load Plate	LP
	Deflection Sensor	DS (or DS1, DS2 ...)
	Excess Variation	EXVAR
	Non-Decreasing Deflections	NDD
	Roll-Off	ROFF
	Rejection	RJCT
	Accept	ACPT
	Sensor Bar	SBAR
	Air Temperature	ATMP
	Surface Temperature	STMP
	Deflection	DEFL
	Load	LD
Lane Geometry	Inner Wheel Path	IWP
	Outer Wheel Path	OWP
	Both Wheel Paths	BWP
	Mid Lane	ML
	Outer Lane Edge	OLE
	Inner Lane Edge	ILE
	Lane Stripe	LSTR
	Shoulder Stripe	SHSTR
	Joint	JT
	Longitudinal Joint	LJT
	Transverse Joint	TJT
Miscellaneous	Between	BTWN
	Core Hole	CHOLE
	Due To Time Limitations	DTTL
	Due To Weather Conditions	DTWC
	Moved Forward	MVFRD
	Test Pit	TPIT
	Truck Traffic	TRKTRF

6.4 Other Comments

In addition to distress comments, other unusual conditions or events shall be commented upon. Data with non-decreasing deflections, excess variation or other software generated errors that could not be cleared by following the instructions in Section 6 of this document, shall be commented on. Operators shall also comment on other events such as delays in testing due to break downs or weather, pavement changes within the section, moisture seeping out of cracks or other conditions which may affect deflection measurements.

7 Error Conditions

As described in Section 4.3.4, several data checks shall be enabled in the FWD data collection software. They are described below.

7.1 Roll-Off

"Roll-Off" is an error condition wherein the deflection of the pavement surface as recorded by a deflection sensor does not return to near zero within 60 milliseconds of the trigger activation. Unless the pavement structure is weak enough to be permanently deformed by the load pulse, this is not a believable measurement. All LTPP test sections have sufficient strength that roll-off can only be due to measurement error.

Roll-off can be caused by poor contact between the deflection sensor and the pavement surface. This error can be incorrectly triggered when magnitude of the deflection approaches the resolution of the geophone. Thus, roll-off when the peak deflection is less than 25 μm is not necessarily indicative of error.

If the roll-off error is triggered on a deflection that is greater than 25 μm, then follow the error resolution instructions in Section 7.6. Otherwise the measurement should be accepted and testing shall continue.

7.2 Non-Decreasing Deflections

"Non-Decreasing Deflections" is an error condition wherein the deflections measured by the deflection sensors do not decrease with increasing distance from the load plate. Deflections should always decrease with increasing distance from the load plate.

This condition can sometimes legitimately occur when there is a transverse crack or other discontinuity between the two sensors that exhibit the non-decreasing deflections. If the operator observes such a crack or discontinuity between the two flagged sensors, then the test shall be accepted, and the observation shall be recorded at the "Comments" prompt.

Non-decreasing deflections can sometimes be incorrectly triggered when the magnitude of the deflections approaches the resolution of the deflection sensor. If the larger of the two deflections is less than 10 μm, then the test should be accepted, and testing should continue.

Non-decreasing deflection may sometimes occur between deflection sensors 1 and 2 on extremely weak pavements due to permanent deformation of the pavement by the FWD. Non-decreasing deflections between deflection sensors 1 and 2 have also been observed on very stiff PCC pavements where the deflection basin is fairly uniform near the load plate and the difference in deflections in that area is less than the random error inherent to the deflection sensors.

If the deflections are not small and there are no cracks or discontinuities, or the non-decreasing deflections are not between sensors 1 and 2 and the pavement is not very weak or very stiff, then this error usually indicates poor seating between one or both of the flagged sensors and the pavement surface. The error resolution instructions in Section 7.6 shall be followed.

7.3 Overflow

"Overflow" is an error condition wherein a measured deflection exceeds the range of the deflection sensor. For the FWDs operated by LTPP, this range is 2000 µm (80 mils). Deflections of that magnitude are only expected on extremely weak pavements or when testing using extremely high load levels. For testing at an LTPP test section using the load levels specified in this document, it is not reasonable to expect that the deflections will exceed 2000 µm.

If this error is encountered during testing, it is likely that the flagged sensor does not have good contact with the pavement surface. The error resolution instructions in Section 7.6 should be followed.

7.4 Load Variation

"Load Variation" is an error condition wherein the peak load for repeat drops at the same drop height varies by more than the amount specified in Section 4.3.4. This condition can legitimately occur on weak pavements where the structure is damaged by FWD testing, or on pavements with a saturated base or subgrade layer (such as during the spring thaw in wet-freeze zones). It may also occur if the load plate is not seated properly on the pavement surface, either due to loose debris or irregularities in the pavement surface.

If this error occurs during testing, follow the error resolution instructions in Section 7.7.

7.5 Deflection Variation

"Deflection Variation" is an error condition wherein the load-normalized peak deflections for repeat drops vary by more than the amount specified in Section 4.3.4. This condition can only legitimately occur if the stiffness of the pavement is changed by the FWD testing itself. This generally only occurs if the pavement is extremely weak or the unbound layers are saturated.

Deflection variations can occur due to uneven pavement surface conditions that result in poor seating of the load plate or deflection sensors or vibrations generated by heavy equipment operating nearby, especially trucks traveling in adjacent lanes.

If this error occurs during testing, follow the error resolution instructions in Section 7.6.

7.6 Dealing with Deflection Errors

If deflection errors occur, the operator must attempt to identify the source of those errors. If the errors are determined to be due to problems with the FWD equipment, then those problems must be fixed before testing continues. If the errors are determined to be due to localized pavement conditions, the operator should reposition the FWD and comment on the condition. If the errors are determined to be due to pavement conditions that are representative of the test section as a whole, or are due to factors such as truck traffic that are out of the operator's control, the operator should accept the error and comment on the condition. Sections 7.1, 7.2, 7.3, and 7.5 detail possible causes of the various types of deflection errors.

If the deflection errors appear to be due to truck traffic in an adjacent lane, the operator should attempt to pause the test sequence to allow the trucks to pass and then continue the sequence during lulls in the traffic. In the event that there are too many trucks for this method to be practical the operator should provide a comment for drop sets that were potentially affected by the truck traffic.

Operators must be very careful to not to overlook the FWD equipment itself as the source of the error. The following troubleshooting process is recommended in all cases, and the operators should deviate from it only when they are confident that they understand the source of the error and that this troubleshooting process is not well suited to that error source.

7.6.1 For the first such error at a test location, it is recommended that the operator get out of the tow vehicle and check the flagged deflection sensor (or sensors). Check that the deflection sensor is seated securely in the sensor holder, that the screws retaining the sensor magnet and sensor holder are tight, that the deflection holder is not resting on a loose stone or crack and that the holder springs and foam bushing are in good shape.

7.6.2 If several sensors are flagged, it is recommended that the operator check all analog connections; sensor to control box, control box to multi-signal cable and multi-signal cable to signal processor.

7.6.3 The data shall be rejected and the test repeated without repositioning the FWD.

7.6.4 If the errors persist, the operator must reject the test and perform the optional activities in Section 7.6.1and 7.6.2. If any problems with the equipment are discovered and corrected, all data collected in this test pass shall be discarded, and the test pass shall be re-started.

7.6.5 If errors persist and the test being performed is a load transfer test or if the FWD can not be moved forward due to a joint or transverse crack, then the results shall be accepted whether they contain errors or not. A comment shall be entered stating "Error could not be resolved".

7.6.6 If the errors persist and the FWD can be repositioned, the data shall be rejected and the FWD shall be moved forward 2 feet. The test shall be repeated a fourth time. If the errors persist then the results shall be accepted, and a comment stating "Error could not be resolved" entered at the prompt.

7.6.7 If the error could not be cleared, then for all subsequent errors of the same type in the same test pass the activities listed in 7.6.1 and 7.6.2 need not be repeated.

7.7 Dealing with Load Errors

If load errors occur, the operator must attempt to identify the source of those errors. If the errors are determined to be due to problems with the FWD equipment, then those problems must be fixed before testing continues. If the errors are determined to be due to localized pavement conditions, the operator should reposition the FWD and comment on the condition. If the errors are determined to be due to pavement conditions that are representative of the test section as a whole, the operator should accept the error and comment on the condition. Section 7.4 details the possible causes of load errors.

Operators must be very careful to not to overlook the FWD equipment itself as the source of the error. The following troubleshooting process is recommended in all cases, and the operators should deviate from it only when they are confident that they understand the source of the error and that this troubleshooting process is not well suited to that error source.

7.7.1 The data shall be rejected and the test repeated without repositioning the FWD.

7.7.2 If the error persists, the operator shall get out of the tow vehicle and check the equipment. All analog connections should be checked; load cell to load cell cable, load cell cable to control box, control box to multi-signal cable and multi-signal cable to signal processor. The weight height targets should be checked to ensure that they are tight. The load plate should be raised, and the swivel shall be checked to ensure that it moves easily. The rubber sheet and pavement surface under the load plate shall be checked for debris, and any such debris shall be removed.

7.7.3 The data shall be rejected and the test repeated again without repositioning the FWD.

7.7.4 If errors persist and the test being performed is a load transfer test or if the FWD can not be moved forward due to a joint or transverse crack, then the results shall be accepted whether they contain errors or not. A comment shall be entered stating "Error could not be resolved".

7.7.5 If the errors persist and the FWD can be repositioned, the data shall be rejected and the FWD moved forward 2 feet. The test shall be repeated a third time. If the errors persist then the results shall be accepted, and a comment stating "Error could not be resolved" entered at the prompt.

7.7.6 If the error could not be cleared, then for all subsequent errors of the same type in the same test pass, the activities under 7.7.2 need not be repeated.

8 Calibration and Verification

Highly accurate load, deflection and associated data are required to meet the requirements of the LTPP program. This section includes several calibration and verification requirements to ensure the accuracy of FWD measurements. If the FWD is unable to meet the requirements of any of these procedures, it may not collect data for LTPP. In such a situation an FWD Problem Report (FWDPR), located in Appendix B of this document, shall be filled out and submitted to the FHWA LTPP FWD task leader with copy to the TSSC.

8.1 Reference Calibration

Every FWD performing data collection on behalf of LTPP shall undergo yearly reference calibration with the exception of units testing in Hawaii, Alaska and Puerto Rico. This calibration must be performed at one of the four calibration centers established by SHRP, or at an equivalent center as determined by the FHWA LTPP FWD task leader. The nominal yearly interval shall not exceed 400 days.

If the FWD load cell or signal processor is replaced, the FWD shall undergo reference calibration before performing testing on behalf of LTPP, regardless of the interval since the previous reference calibration.

If a major component such as a deflection sensor, multi-signal cable or trailer PCB board is replaced, the FWD should undergo reference calibration as soon as practical, but may collect data on behalf of LTPP in the meantime.

The most recent version of the LTPP FWD Calibration Manual shall be followed during reference calibration.

8.2 Relative Calibration

Every FWD performing data collection on behalf of LTPP shall undergo relative calibration at a monthly interval while in service. Data shall not be collected unless the FWD has undergone relative calibration within the previous 42 days.

If a major component such as a deflection sensor, multi-signal cable or trailer PCB board is replaced, the FWD shall undergo relative calibration before continuing to collect data on behalf of LTPP, regardless of the interval since the previous relative calibration.

The most recent version of the LTPP FWD Calibration Manual shall be followed during relative calibration.

8.3 DMI Calibration

Every FWD performing data collection on behalf of LTPP shall undergo DMI calibration on a monthly interval while in service. Data shall not be collected unless the FWD has undergone DMI calibration within the previous 42 days.

If the tow vehicle undergoes maintenance, including replacement of tires, the DMI shall be recalibrated before continuing to collect data on behalf of LTPP, regardless of the interval since the previous DMI calibration.

The FWD DMI is calibrated by driving the vehicle over a known distance. The FWD data collection software can then calculate an appropriate calibration factor.

The section used for DMI calibration must be straight, at least 150 m in length and reasonably level. As the FWD must be stopped at each end of the section, it cannot be performed on an active highway without traffic control. The section must be surveyed prior to the DMI calibration. The section shall be measured using a surveyor's tape (a measuring wheel is not acceptable). Ensure that the proper tension and alignment is applied to the tape.

Immediately prior to DMI calibration, the tire pressure for all tow vehicle tires shall be set to the manufacturer's specification. The vehicle shall then be driven for at least 15 minutes at highway speeds. See the "LTPP FWD Data Collection Software Manual" for instructions on how to operate the FWD data collection software during DMI calibration.

8.4 Temperature Sensor Verification

Every temperature sensor collecting data associated with LTPP FWD measurements shall have its accuracy verified on a monthly interval. Data shall not be collected using such a sensor unless it has been verified during the previous 42 days.

The procedure that follows is a verification procedure. It should not be used as a calibration procedure. If a temperature sensor fails this procedure it shall be returned to the manufacturer for repair or recalibration, or it shall be replaced with a new sensor.

8.4.1 The following equipment is required for this procedure:

NIST traceable mercury thermometer ("reference thermometer")
4 liter (1 gallon) bucket
Hot Plate
Large wooden spoon or paint stirrer
Medium size cooking pot, approximately 125 mm (5 inches) in diameter
Leather heat resistant gloves
Cooking oil
Ice
Copies of Form F08 and F09

8.4.2 Park the FWD and tow vehicle on a smooth surface, in an area with good ventilation and not exposed to direct sunlight.

8.4.3 Start the FWD data collection software and enter a screen from which the air and IR surface temperature measurements can be read. See the "LTPP FWD Data Collection Software Manual" for further instructions, if necessary.

8.4.4 Unclip the FWD air temperature sensor so that it hangs freely.

8.4.5 Prepare ice water bath. Place ice and water in the 4 liter bucket, and stir with wooden spoon. Stir until the temperature as recorded by the reference temperature is less than or equal to 2 degrees Celsius.

8.4.6 Place bucket under FWD IR temperature sensor. Once the reading from the IR temperature stabilizes, record the temperature from both the IR sensor and the reference thermometer on the F08 form. Stir the ice bath for one minute, and record the measurements from both sensors again. If the recorded temperatures vary by more than 2 degrees Celsius for either data set, stir for another minute and then record both temperatures again. If the IR temperature sensor varies by more than 2 degrees Celsius from the reference thermometer for two or more data sets, then the IR temperature sensor is unacceptable.

8.4.7 Repeat the procedure in 8.4.6 for the hand-held IR temperature sensor. Hold the hand-held IR temperature sensor at a height consistent with the FWD-mounted IR temperature sensor.

8.4.8 Stir the ice bath for another minute. Place the FWD air temperature sensor and the reference thermometer in the bath. Once the reading from the air temperature sensor stabilizes, record the readings of both sensors. Stir for another minute and record both temperatures again. If the recorded temperatures vary by more than 2 degrees Celsius for either data set, stir for another minute and then record both temperatures again. If the air temperature sensor varies by more than 2 degrees Celsius from the reference thermometer for two or more data sets, then the air temperature sensor is unacceptable.

8.4.9 Repeat the procedure in 8.4.6 for the hand-held temperature probe.

8.4.10 Prepare the room temperature water bath. Empty the bucket, and fill with warm tap water, and allow it to sit for 10 minutes. Stir for one minute.

8.4.11 Place bucket under FWD IR temperature sensor. Once the reading from the IR temperature stabilizes, record the temperature from both the IR sensor and the reference thermometer on the F08 form. Stir the water for one minute, and record the measurements from both sensors again. If the recorded temperatures vary by more than 2 degrees Celsius for either data set, stir for another minute and then record both temperatures again. If the IR temperature sensor varies by more than 2 degrees Celsius from the reference thermometer for two or more data sets, then the IR temperature sensor is unacceptable.

8.4.12 Repeat the procedure in 8.4.11 for the hand-held IR temperature sensor. Hold the hand-held IR temperature sensor at a height consistent with the FWD-mounted IR temperature sensor.

8.4.13 Stir the water for another minute. Place the FWD air temperature sensor and the reference thermometer in the water. Once the reading from the air temperature sensor stabilizes, record the readings of both sensors. Stir for another minute and record both temperatures again. If the recorded temperatures vary by more than 2 degrees Celsius for either data set, stir for another minute and then record both temperatures again. If the air temperature sensor varies by more than 2 degrees Celsius from the reference thermometer for two or more data sets, then the air temperature sensor is unacceptable.

8.4.14 Repeat the procedure in 8.4.13 for the hand-held temperature probe.

8.4.15 If any IR temperature sensor was determined to be unacceptable in the low temperature or ambient temperature check, then it need not be checked at the high temperature. The high temperature check is optional if it is being performed in the field. The high temperature check is only to be performed for IR temperature sensors.

8.4.16 Prepare the high temperature oil bath. Pour cooking oil into the cooking pot to a depth of approximately 50 mm. Place cooking pot on hot plate and under FWD IR temperature sensor. Warm on the hot plate while stirring, until is stabilizes at a temperature of 60 +/- 5 degrees Celsius, as determined using the FWD IR temperature sensor. Individual stirring oil must be wearing gloves.

8.4.17 Record FWD IR Sensor and reference thermometer temperatures. Wait 5 minutes, then record both sensors again. If the recorded temperatures vary by more than 2 degrees Celsius for either data set, then, after another 5 minutes, record both temperatures again. If the IR temperature sensor varies by more than 2 degrees Celsius from the reference thermometer for two or more data sets, then the IR temperature sensor is unacceptable.

8.4.18 Repeat the procedure in 8.4.17 for the hand held IR temperature sensor. Hold the hand-held IR temperature sensor at a height consistent with the FWD-mounted IR temperature sensor.

8.5 Reporting Requirements

8.5.1 Reference Calibration

For RSC-operated FWD equipment, the reference calibration results shall be submitted to the FHWA LTPP FWD task leader within seven days of the completion of the calibration. For non RSC-operated FWD equipment collecting data on behalf of LTPP, the reference calibration results shall be submitted to the FHWA LTPP FWD task leader within thirty days of the time it first collects data for LTPP with those calibration factors.

A copy of all reference calibration results shall be kept in the RSC office. A paper copy of the most recent reference calibration results shall be kept in the FWD tow vehicle.

8.5.2 Relative Calibration

A copy of all relative calibration results for RSC-operated FWD equipment shall be kept at the RSC office. A paper copy of the results of the most recent relative calibration shall be kept in the FWD tow vehicle. It is not necessary to submit copies to the FHWA LTPP FWD task leader.

8.5.3 DMI Calibration

Form F07 shall be filled out each time the DMI is calibrated. A copy of all completed F07 forms for RSC-operated FWD equipment shall be kept at the RSC office. A paper copy of the most recently completed F07 form shall be kept in the FWD tow vehicle. It is not necessary to submit copies to the FHWA LTPP FWD task leader.

8.5.4 Temperature Sensor Verification

A copy of all completed F08 and F09 forms for RSC-operated FWD equipment shall be kept at the RSC office. A paper copy of the most recently completed F08 and F09 forms shall be kept in the FWD tow vehicle. It is not necessary to submit copies to the FHWA LTPP FWD task leader.

9 Equipment Checks

Due to the extensive use of FWDs within LTPP, routine equipment checks are extremely important. The checks in this section are to be performed each day that the FWD is traveling or in operation. These checks are a minimum: Operators are expected to keep an eye out for other anomalous conditions while performing these checks. These checks are not to supersede the manufacturer's minimum requirements for warranty compliance.

Any deficiencies noted while performing these checks must be addressed before any further transit or testing.

9.1 Before Transit Checks

Prior to the start of travel for the day, the following checks on the FWD and tow vehicle shall be performed:

Tow Vehicle:

- Fluid levels
    - Engine Oil
    - Brake Fluid
    - Power Steering
    - Wiper fluid
    - Coolant
    - Transmission fluid
- Battery connections
- Hose conditions
- Tires inflated properly and in good condition
- Lights operational
    - Headlights
    - Taillights
    - Turn signals
    - Brake lights
    - Strobe lights
- Interior uncluttered, equipment well stowed

Trailer:

- Ball tight
- Safety chains in place
- Breakaway cable connected
- Break fluid level good (for trailers with hydraulic brakes)
- Trailer battery connections good
- Lights operational
    - Taillights
    - Turn signals
    - Brake lights
- Tires inflated properly and in good condition
- Transport locks engaged
- Hitch pin in front sensor bar guide
- Covers and latches secure

9.2 Before Operations Checks

At a minimum, the FWD operator shall perform the following checks after the FWD arrives at the test site and prior to testing:

- Trays removed
- Transport locks unlocked
- Hitch pin removed from front sensor bar guide
- Hydraulic oil level good

- Raise/lower bar cable not frayed and well adjusted
- Geophones well-seated in geophone holders
- Geophone holder springs and foam guides in good condition
- Ribbed rubber sheet on load plate in good condition
- Load plate swivel free-moving
- Pressure switch boots in good condition
- Trailer control box electrical connections tight
- Buffers have no cracks or slits, and are level and tight

In addition, the operator shall observe and listen to the hydraulics during the buffer warm-up sequence to ensure that they are free of air and operating correctly.

9.3 Post Operations Checks

At a minimum, the FWD operator shall perform the following checks prior to leaving the test site:

- Transport locks engaged
- Hitch pin replaced in front sensor bar guide
- Pan replaced and secure
- Trailer access doors locked
- All supplemental testing equipment properly stowed
- Paper forms filed out, dated and signed, and filed

10 Maintenance and Repair

The RSCs are responsible for the maintenance and repair of the FWDs that they operate. This includes annual maintenance and reactive maintenance. A future version of this guide will include minimum monthly and annual maintenance standards.

11 Cold Weather FWD Testing

The FWD tow vehicle shall be warmed to achieve an interior temperature of at least 5 degrees Celsius (40 degrees Fahrenheit) before turning on the signal processor or data collection computer.

For testing in ambient temperatures at or below -10 degrees Celsius (15 degrees F), the standard hydraulic fluid shall be replaced with a lighter weight fluid, such as AMSOIL synthetic. Other oils can be substituted if so recommended by the manufacturer, however some of these oils may not be appropriate for warm-weather operations.

12 Data Handling Procedures

12.1 Field Data Handling Procedures

If conditions permit, all FWD data collected at a site should be processed through FWDConvert and FWDScan before leaving the site. Errors generated by FWDScan should be resolved and any necessary changes to the file should be noted for correction by office personnel. A backup of the PDDX file shall be made on removable media. This backup, along with the original on the FWD data collection computer, shall be kept in the FWD until receipt of the data in the office is acknowledged. If conditions do not allow for this work to be done before leaving the site, it shall be done as soon as convenient, but no more than 24 hours after data collection.

Completed copies of forms F01, F02 and F05 shall be submitted to the office along with the electronic FWD data.

12.2 Office Data Handling Procedures

Electronic data shall be received from the field along with completed copies of forms F01, F02 and F05. RSC office personnel shall verify that the information on these forms correspond to the electronic data received. Discrepancies shall be resolved before any further data processing is performed.

Notwithstanding that the data has been processed with FWDScan in the field, the data shall be processed through FWDScan in the office. The FWDScan output shall be reviewed and any warnings or errors present in the output file shall be investigated. If any modifications are made to the data file it shall be reprocessed through FWDScan. Upload of a file in which FWDScan found errors may cause referential problems in the IMS, and should only be done with the approval of the Regional Database Manager.

FWD data files shall be uploaded to the RIMS using the most recent version of the upload filter provided for that purpose. Manual temperature measurements shall be entered using the RIMS form provided for that purpose.

The PDDX data file and paper forms shall be archived according to the applicable LTPP GO directives.

13 Documentation

The following documentation shall be kept in the FWD tow vehicle whenever it is collecting data on behalf of LTPP. Only the most recent version of each document shall be kept.

LTPP Manual for Falling Weight Deflectometer Measurements
LTPP FWD Data Collection Software Manual
Distress Identification Manual for the Long-Term Pavement Performance Program
SHRP-LTPP FWD Calibration Protocol
FWDConvert Software User's Manual
FWDScan Software User's Manual
FWDCal Software User's Manual

In addition, all active LTPP FWD and applicable GO directives shall be kept in the tow vehicle. Inactive directives shall not be kept in the tow vehicle.

At least five blank copies of all forms in Appendix B of this document shall be kept in the tow vehicle.

14 Version History

14.1 Version 1.0

Initial version, released January 1989 (SHRP reference "SHRP-LTPP-OG-002"). This guide included instructions for testing with Edition 10 of the Dynatest FWD data collection software only. This guide included only three test plans, for flexible, JCP and CRCP sections, and was only applicable to GPS testing.

14.2 SPS 3 and SPS 4 Supplement to Version 1.0

The Pavement Maintenance Effectiveness Program of SHRP published modifications to Version 1.0 of the FWD Guide for testing at SPS 3 and SPS 4 test sections. These modifications were published in SHRP report SHRP-H-358 dated November 1993 (pages 134-137), but were in effect prior to that date.

- SPS 3 sections, testing interval set to 100 feet (30 meters), instead of 25 feet (8 meters)
- For SPS 3 sections, only three drops at each drop height to be recorded, instead of four
- For SPS 4 sections, testing to be performed at every third panel
- For SPS 4 sections, all testing to be performed in the OWP. This includes JA, JL and MP testing (for MP testing on SPS 4 sections, lane specification 'J6' is now used, however this was not specified in the supplement)
- For SPS 4 sections only three drops at each drop height to be recorded for loss of support testing, instead of four

14.3 Version 2.0

Major update, released May 7, 1993.

- Specific test plans included for all SPS experiments in Appendix B
- Relative calibration procedure updated
- Reference calibration procedure added in Appendix A

14.4 Version 3.0

Major update, released January 21, 2000.

- Updated for use with Edition 25 of the Dynatest FWD data collection software
- Deflection sensor spacing updated for nine active sensors
- Added verification procedure for FWD-mounted temperature sensors and TSC form
- Removed relative calibration procedure from main body of document
- Replaced reference calibration procedure with "SHRP/LTPP FWD Calibration Protocol" (dated March 1994) in Appendix F (this protocol includes a relative calibration procedure)

14.5 Version 3.1

Minor update, released October 31, 2000.

- Fixed some figures, typos and formatting
- Updated to reflect further changes to the Dynatest Edition 25 software.

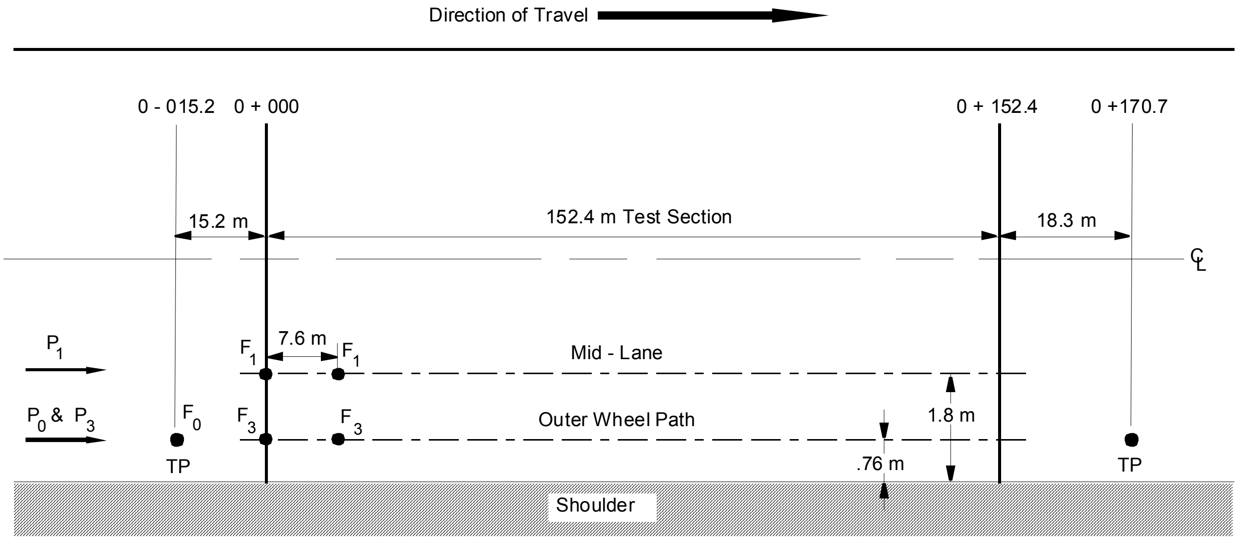
14.6 Version 4.0

Major update, released April 1, 2005. This is the first complete rewrite of the "LTPP Manual for Falling Weight Deflectometer Measurements" since Version 1.0.

- Removed FWD data collection software-specific information (this information was placed in the "LTPP FWD Data Collection Software Manual"
- Integrated test plans in Appendices A and B into main body of document to reduce redundancy (see Sections 5.1 and 5.2)
- Removed Appendix C as SMP testing is no longer being performed
- Removed Appendix D as P59 (subsurface testing) is no longer being performed
- Removed Appendix E as it is copy of LTPP Directive GO-21 that may be superseded in the future

- Removed Appendix F as it is a copy of a separate document ("SHRP-LTPP FWD Calibration Protocol") that may be updated in the future
- Removed Appendices G and H as they are specific to the FWD data collection software.
- Integrated LTPP Directive FWD-24 "Modifications to LTPP FWD Geophone Holders" in body of document (see Section 4.1.1)
- Integrated LTPP Directive FWD-27 "Thermal Gradient Temperature Measurements During Deflection Testing" in body of document (see Section 6.1)
- Integrated LTPP Directive FWD-28 "Storage of LTPP FWD Raw (Peak and Time History) Data" in body of document (see Section 12.2)
- Required all testing to be performed with drop load within 10% of target value (see Section 4.2)
- Required monthly verification of hand-held temperature instruments as well as FWD-mounted temperature instruments (see Section 8.4)
- Added forms F05, F06, F07, F08, F09 and F10 (F08 and F09 replace the TSC form)
- Modified drop sequence for SPS 3 and SPS 4 sections to match standard LTPP drop sequence
- Added "Unit Conversions for common FWD-Related Measurements" (see Appendix B)

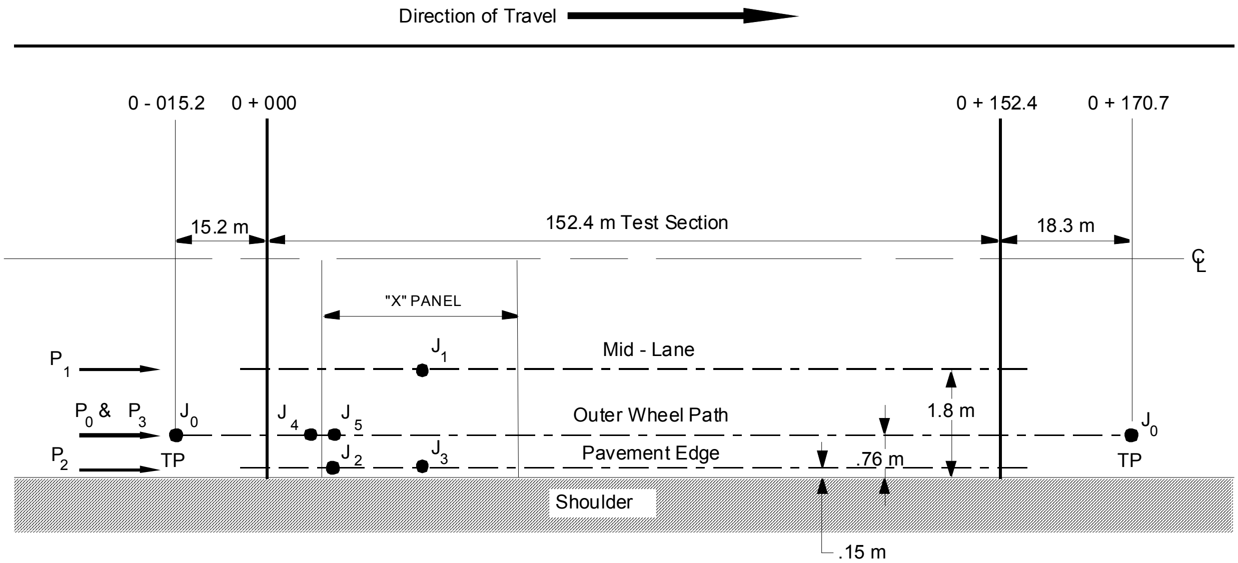
Appendix A: Diagrams of FWD Test Plans



NOTES:

1. FWD tests to be conducted at test pit locations (TP) on P_0 (First set of tests).
2. See Table A-1 for further details.
3. Lateral offsets shown represent nominal distances.

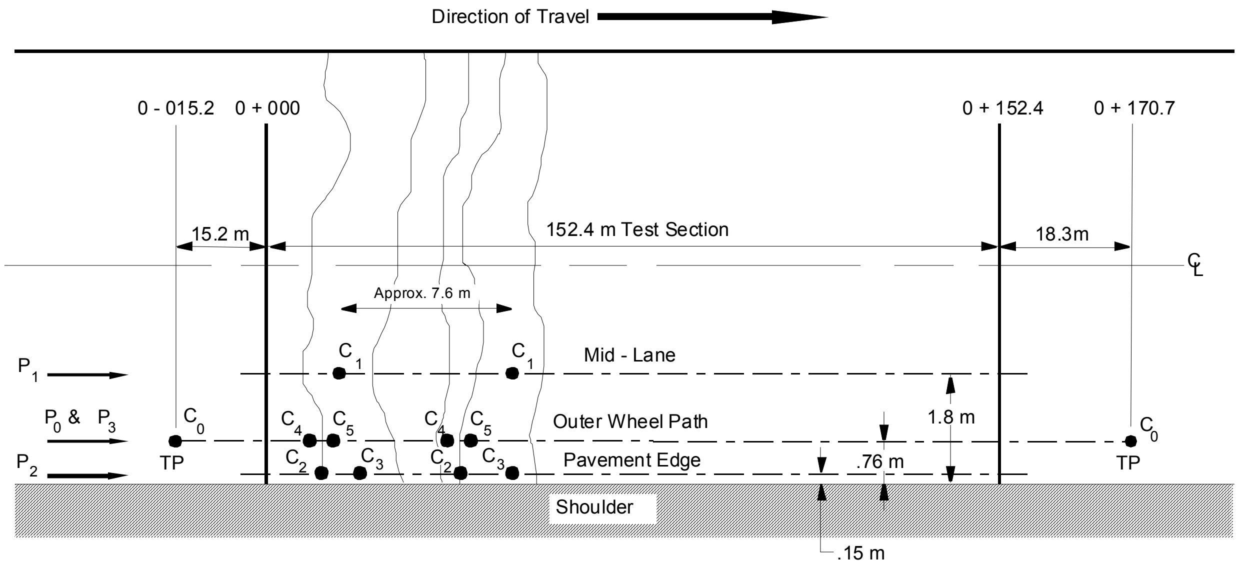
Figure A-1 – Diagram of Test Plan 1



NOTES:

1. 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.
2. Number of panels and panel length (X) will vary depending upon specific joint spacing, transverse crack pattern and pavement type. Operator should refer to test and Table 1 for further details. A maximum of 20 effective slabs (panels) should be tested.
3. Lateral offsets shown represent nominal distances.

Figure A-2 – Diagram of Test Plan 2



NOTES:

1. FWD tests conducted at test pit locations (TP) on P_0 (First set of tests).
2. See Table 1 for further details.
3. Lateral offsets shown represent nominal distances.

Figure A-3 – Diagram of Test Plan 3

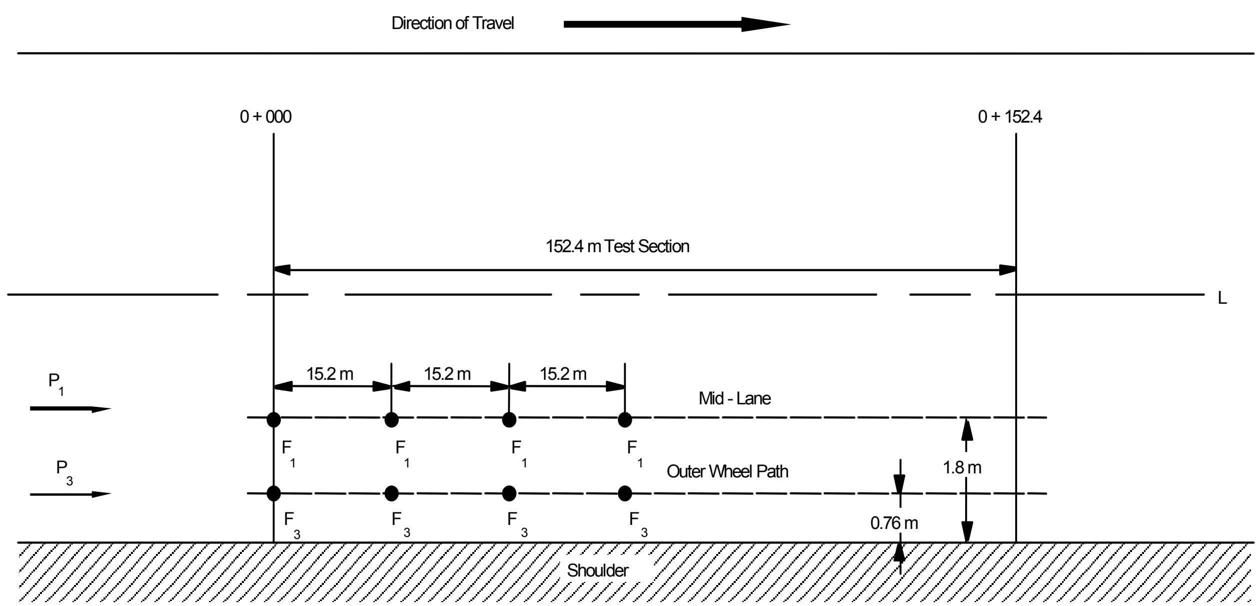
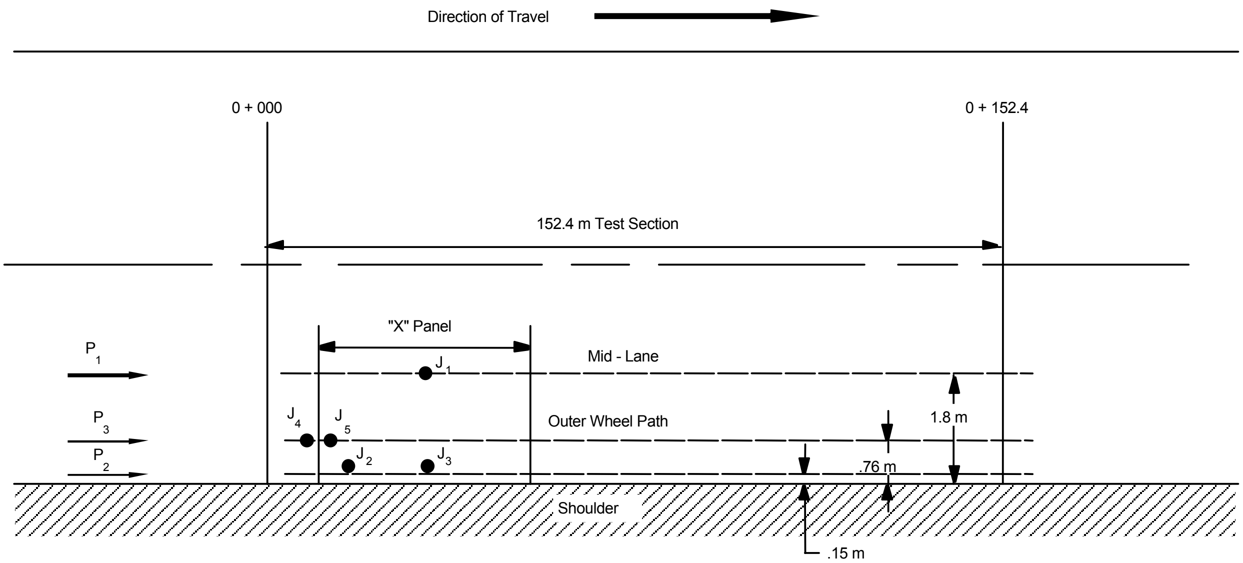


Figure A-4 – Diagram of Test Plan 4



NOTES:

1. Five test points per panel done in three passes.

2. Ten panels should be tested on all sections.

FigureA-5 – Diagram of Test Plan 5

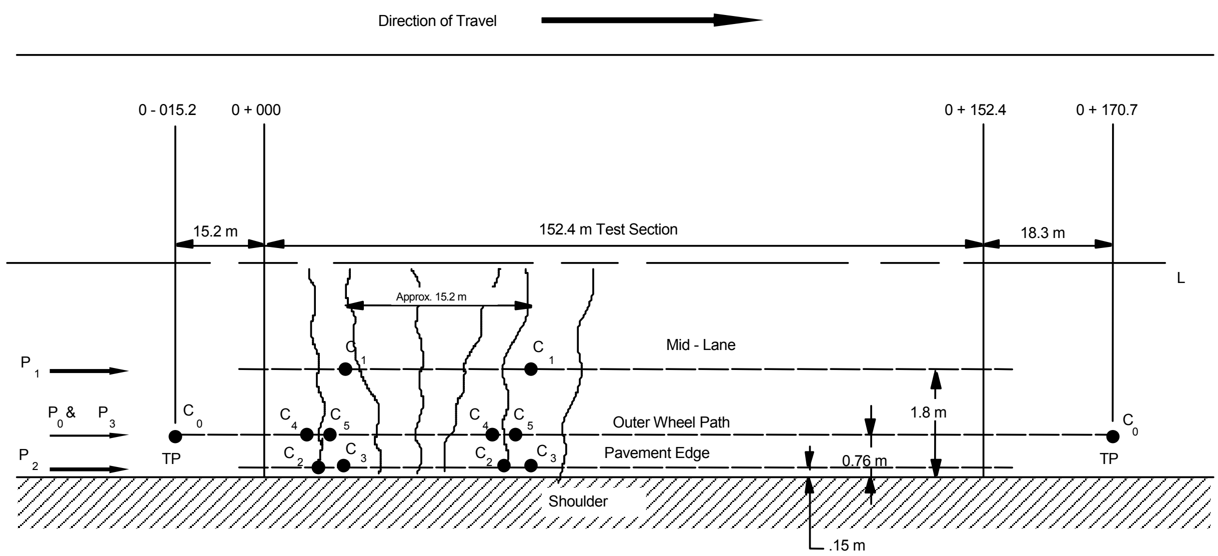
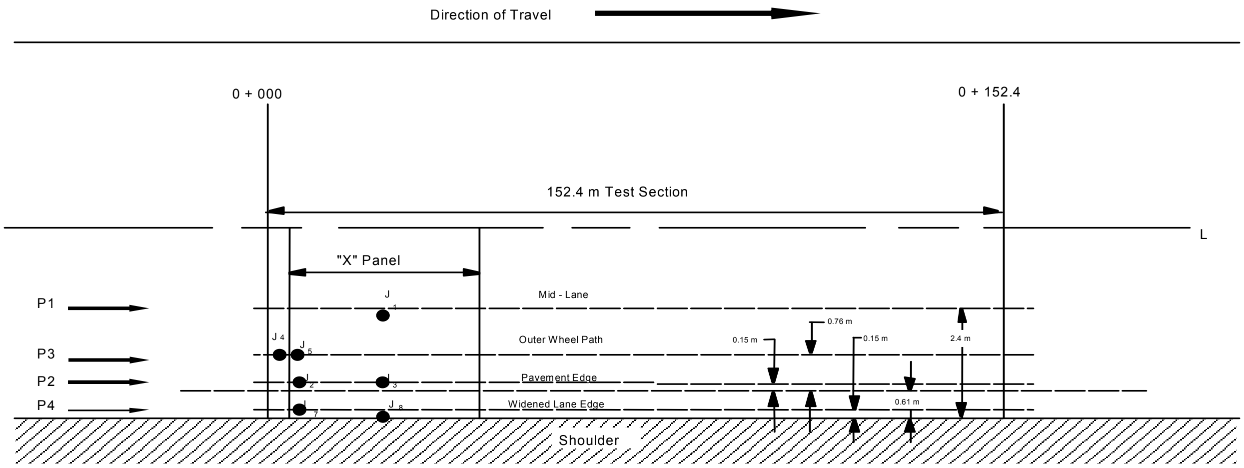


Figure A-6– Diagram of Test Plan 6



NOTES:

1. Ten panels should be tested on all sections.
2. Seven test points per panel done in four passes.
3. Lane specifications J7 and J8 are on shoulder.
4. Lateral offsets shown represent nominal distances.

Figure A-7 – Diagram of Test Plan 7

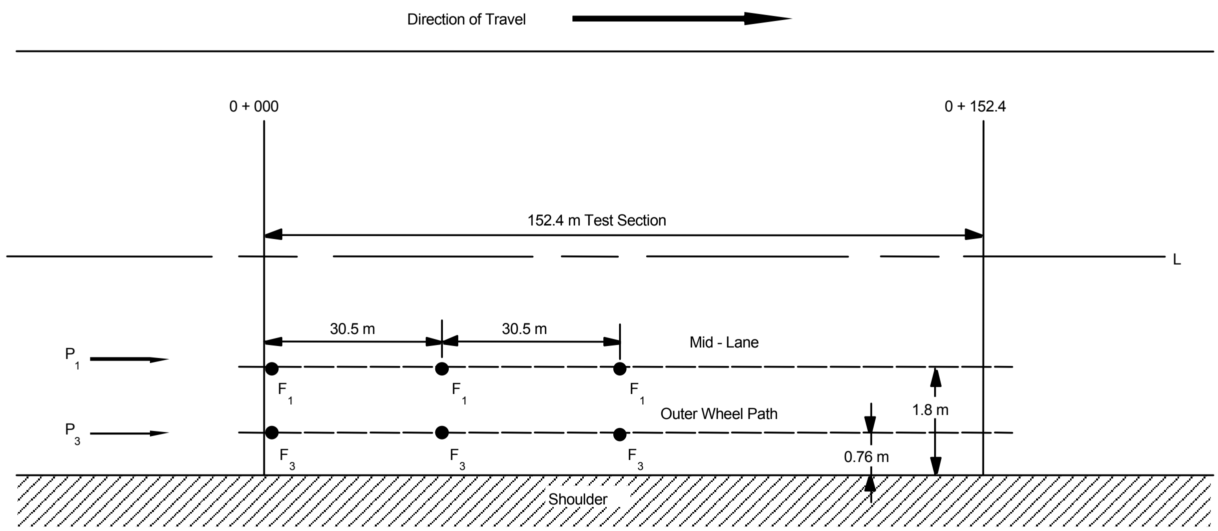
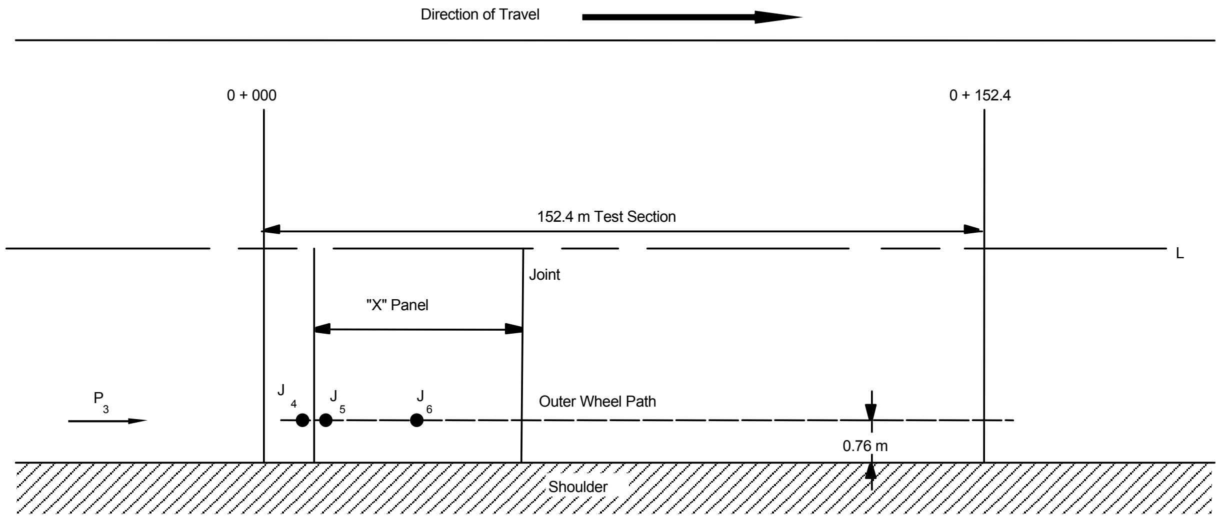


Figure A-8 – Diagram of Test Plan 8



NOTES:

1. Panel Length "X" will be variable depending upon specific joint spacing, transverse crack pattern and pavement type.

2. Test all panels on under seal sections and every third panel on remaining sections.

3. Lateral Offsets shown represent Nominal Distances.

Figure A-9 – Diagram of Test Plan 9

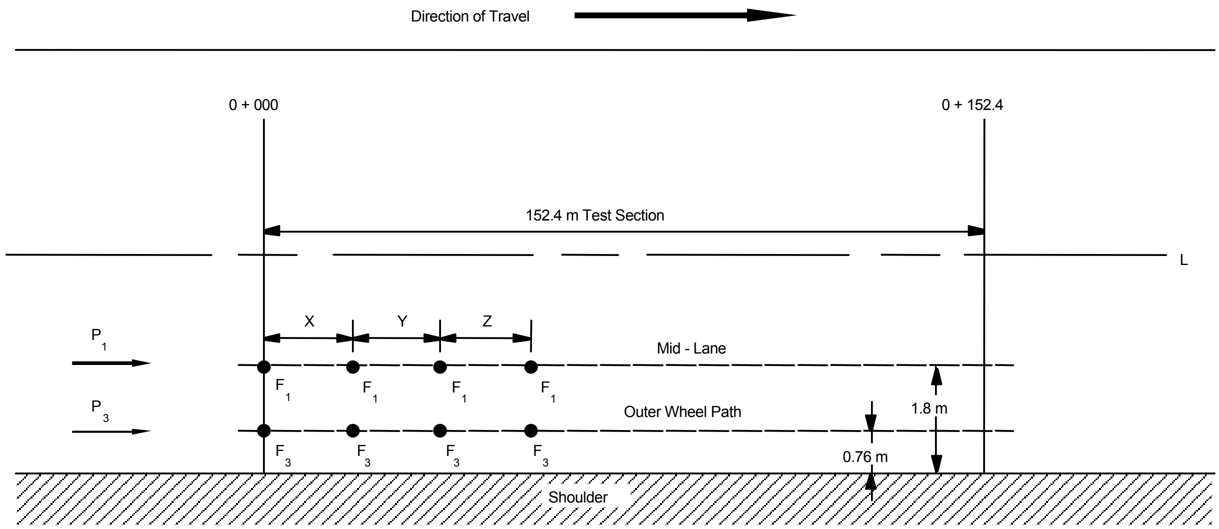


Figure A-10 – Diagram of Test Plan 10

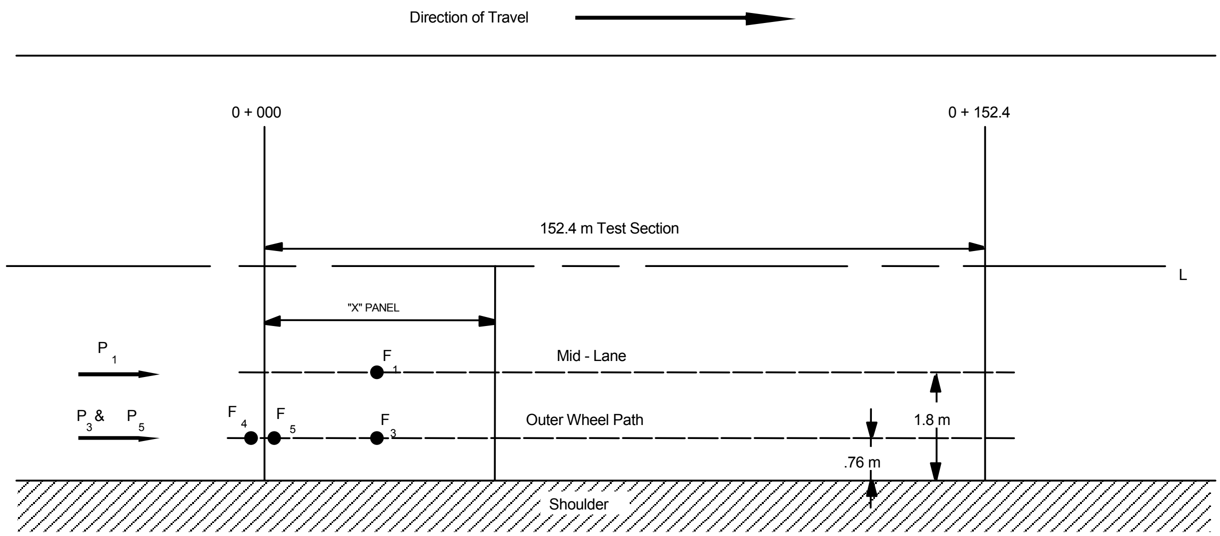


Figure A-11 – Diagram of Test Plan 11

Appendix B: Standard FWD Forms

LTPP FWD Monitoring Temperature Measurements – Form F01	Region [___ ___] State Code [___ ___] LTPP Section ID [___ ___ ___ ___]

AGENCY ______________________ TESTING __________________

LTPP EXPERIMENT CODE ___________ ROUTE / HIGHWAY NUMBER _____________

TESTING DATE ____________ SHEET NUMBER _________ FIELD SET NO. __________

LOCATION STATION _______________

NOMINAL DEPTH	IR Surface	25 mm	50 mm	100 mm	200 mm	300 mm	OPERATOR COMMENT
ACTUAL DEPTH							
TIME	T_0 °C	T_{25} °C	T_{50} °C	T_{100} °C	T_{200} °C	T_{300} °C	

LOCATION STATION _______________

NOMINAL DEPTH	IR Surface	25 mm	50 mm	100 mm	200 mm	300 mm	OPERATOR COMMENT
ACTUAL DEPTH							
TIME	T_0 °C	T_{25} °C	T_{50} °C	T_{100} °C	T_{200} °C	T_{300} °C	

NOTES:
1) T_i = Temperature in Depth i, °C
2) Operator comments shall include weather related comments, and any other comments necessary to explain unusual temperature readings. Additional comments may be included on the back, and must be referenced to station and time, and a note to this effect must be added to the "Operator Comments" field.

Test Completed

____________________ ____- _____ - _____ __________________________

FWD Operator DD - MMM - YYYY Affiliation

LTPP FWD Monitoring Field Activity Report – Form F02	Region [___ ___] State Code [___ ___] LTPP Section ID [___ ___ ___ ___]

AGENCY ________________ TESTING

LTPP EXPERIMENT CODE _______________ ROUTE/HIGHWAY NUMBER

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	________	
TEMP. HOLES DRILLED	________	
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		TRAFFIC CONTROL CREW	
NAMES:	________	AGENCY:	________
	________	NAMES:	________
	________		________
	________		________
	________		________

COPIES: RSC

LTPP Monitoring Maintenance and Repair Summary – Form F03	Region [___ ___] FWD Serial Number 8002- [___ ___ ___]

Date	Odometer	Problem Description [1]	Description of Maintenance	Performed By	Cost		
					Labor	Parts	Total

[1] Enter "Routine" for routine maintenance

LTPP FWD Monitoring FWD Buffer Shape – Form F04	Region [___ ___]

Deflection Unit ID: 8002 – [___ ___ ___]

Buffer Shape:	[___] (see following code descriptions)
Assign Date:	[___ ___ - ___ ___ ___ - ___ ___ ___ ___]
De-assign Date:	[___ ___ - ___ ___ ___ - ___ ___ ___ ___]

Code	Description
1	**Flat** – 100 mm diameter, flat (90º) buffers
2	**Fully Rounded** – 100 mm diameter, “knife cut” variable cone shaped (45º) buffers
3	**Semi-Rounded** – 110 mm diameter, tapered (60º) buffers
9	**Unknown** – buffer shape is unknown

LTPP FWD Monitoring FWD Operations Planning – Form F05	Region [___ ___] State Code [___ ___] LTPP Section ID [___ ___ ___ ___]

Experiment Designation: __ PS __

Test Setup: Flexible / Rigid (circle one)

Total thickness of bound layers: ___ ___ ___ ___ mm

Test Plan Number: ___

Temperature Holes (cross out holes that are not to be used)

Hole Number	Nominal Hole Depth (mm)	Adjusted Hole Depth (mm)[1]
1	25	
2	50	
3	100	
4	200	
5	300	

Note 1 – Only fill out if hole is within ±25 mm of bottom of bound layers

File Names (cross out passes that are not to be used)

Pass Number	Filename
1	___ ___ ___ ___ ___ ___ ___ ___
2	___ ___ ___ ___ ___ ___ ___ ___
3	___ ___ ___ ___ ___ ___ ___ ___
4	___ ___ ___ ___ ___ ___ ___ ___
5	___ ___ ___ ___ ___ ___ ___ ___

Prepared By: ______________________ Date Prepared: ______________________

Tested By: ______________________ Date Tested: ______________________

LTPP FWD Monitoring FWD Test Comments – Form F06	Region [___ ___] State Code [___ ___] LTPP Section ID [___ ___ ___ ___]

Date ___ ___ - ___ ___ ___ - ___ ___ ___ ___

Test Pass ____

Filename ___ ___ ___ ___ ___ ___ ___ ___

Time	Station	Lane Spec	Comment

Note: Time, Station and Lane Spec should match the stored data. Necessary modifications to those values should be noted in the "Comments" column.

Tested By: ____________________________

LTPP FWD Monitoring FWD DMI Calibration – Form F07	Region [___ ___]

Date (DD-MMM-YYYY)	___ ___ - ___ ___ ___ - ___ ___ ___ ___
Deflection Unit ID:	8002 – [___ ___ ___]
Section Length (feet)	___ ___ ___ ___
New Calibration Factor (counts per km)	___ ___ ___ , ___ ___ ___

Performed By: ________________________________

LTPP FWD Monitoring IR Temperature Sensor Checks – Form F08	Region [___ ___]

Date (DD-MMM-YYYY) ___ ___ - ___ ___ ___ - ___ ___ ___ ___

Deflection Unit ID: 8002 – [___ ___ ___]

Location Performed ______________________________

FWD-Mounted IR Sensor Serial No. ______________________________

Hand-Held IR Sensor Serial No. ______________________________

Check	Reading	Reference Therm. (C)	FWD-Mounted IR Sensor			Hand-held IR Sensor		
			Reading (C)	Error	Pass?	Reading (C)	Error	Pass?
Cold	1				Y / N			Y / N
	2				Y / N			Y / N
	3 (opt.)				Y / N			Y / N
Room Temp.	1				Y / N			Y / N
	2				Y / N			Y / N
	3 (opt.)				Y / N			Y / N
Hot	1				Y / N			Y / N
	2				Y / N			Y / N
	3 (opt.)				Y / N			Y / N
Acceptable?			YES / NO			YES / NO		

Performed By: ______________________________

LTPP FWD Monitoring Air/Manual Temperature Sensor Checks – Form F09	Region [___ ___]

Date (DD-MMM-YYYY) ___ ___ - ___ ___ ___ - ___ ___ ___ ___

Deflection Unit ID: 8002 – [___ ___ ___]

Location Performed ______________________________

Serial Numbers			
FWD Air Temp	Hand-held Sensor 1	Hand-held Sensor 2	Hand-held Sensor 3

Check	Reading	Ref. Therm (C)	FWD Air Sensor			Hand-held Sensor 1			Hand-held Sensor 2			Hand-held Sensor 3		
			Reading (C)	Err.	Pass?	Reading (C)	Err.	Pass?	Reading (C)	Err.	Pass?	Reading (C)	Err.	Pass?
Cold	1				Y / N			Y / N			Y / N			Y / N
	2				Y / N			Y / N			Y / N			Y / N
	3 (opt.)				Y / N			Y / N			Y / N			Y / N
Room Temp.	1				Y / N			Y / N			Y / N			Y / N
	2				Y / N			Y / N			Y / N			Y / N
	3 (opt.)				Y / N			Y / N			Y / N			Y / N
Acceptable?			YES/NO			YES/NO			YES/NO			YES/NO		

Performed By: ______________________________

LTPP FWD Monitoring FWD Test Slab Locations – Form F10	Region [___ ___] State Code [___ ___] LTPP Section ID [___ ___ ___ ___]

Number of Slabs to be Tested 10 / 20
(circle one)

Test Slab	Location of joint/crack on approach end of slab (ft)
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	

Date Prepared ___ ___ - ___ ___ ___ - ___ ___ ___ ___

Prepared By ____

FWDPR #:______

LONG-TERM PAVEMENT PERFORMANCE (LTPP) FALLING WEIGHT DEFLECTOMETER (FWD) TESTING FWD PROBLEM REPORT (FWDPR)

Attention: Eric Weaver FAX: (703) 285-2767
Gonzalo R. Rada FAX: (301) 210-5032

Type of Problem: Guidelines ___ Equipment ___ Software ___ Name: ____________ Version: ____________ Other: ____________	Reported by: ________________________ Agency: ________________________ Date: ________________________ Urgent?(Y/N) ___ Page ____ of ____
Description:	

THIS SECTION FOR USE BY FHWA AND TSSC	
Received by: ________________	Date Received: ________________
Referred to: ________________ Date Referred: ________________	Approved by: ________________ Date Approved: ________________
Resolution:	
Notes:	

Unit Conversions for Common FWD-Related Measurements

Deflection	
mils (inch * 10^{-3})	microns (meter * 10^{-6})
16	406
24	610
80	2032
microns = mils * 25.4	

Load		
kips (pound * 10^3)	kN (Newton * 10^3)	kPa (Pascal * 10^3) (for 300 mm diameter plate)
6 (5.4 to 6.6)	26.7 (24.0 to 29.4)	378 (340 to 416)
9 (8.1 to 9.9)	40.0 (36.0 to 44.0)	566 (509 to 662)
12 (10.8 to 13.2)	53.4 (48.1 to 58.7)	755 (680 to 830)
16 (14.4 to 17.6)	71.2 (64.1 to 78.3)	1007 (907 to 1108)
kN = kip * 4.448		
	kPa = kN * 14.15 (for 300 mm diameter plate only)	

Temperature	
Fahrenheit	Celsius
0	-17.8
32	0
70	21.1
100	37.8
Celsius = (Fahrenheit -32) * 5/9	

Distance	
feet	meters
12	3.66
14	4.27
25	7.62
50	15.2
100	30.4
500	152.4
1000	304.8
meters = feet * 0.3048	