FHWA-NJ-2009-006

2009 NJDOT FWD Procedures Manual

This NJDOT FWD procedures manual is based on a modified LTPP FWD Procedures Manual

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1 BACKGROUND and FWD-RELATED TERMINOLOGY

A falling weight deflectometer (FWD) is a device designed to simulate deflection of a pavement surface caused by a fast-moving truck. The FWD generates a load pulse by dropping a weight onto the pavement surface. This load pulse is transmitted to the pavement through a 300 (mm) 11.8 inch 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 (Figure 1). Envisioned from a side view, the shape of the deformed pavement surface is a deflection basin.

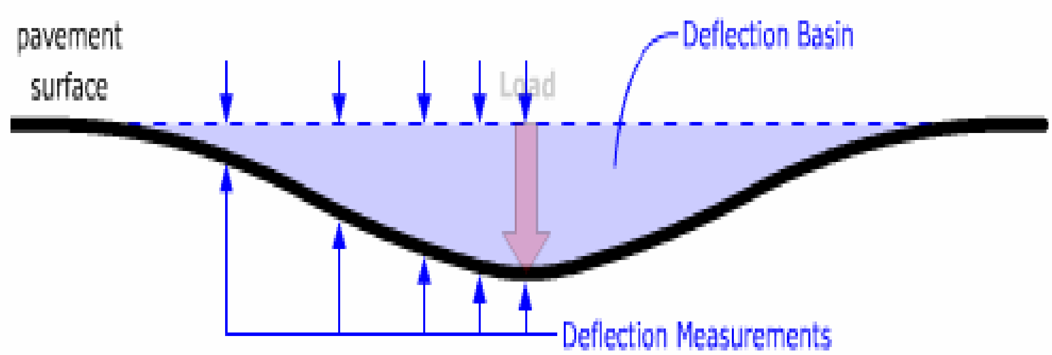


Figure 1. FWD Deflection

Based on the force imparted to the pavement and the shape of the deflection basin, it is possible to estimate the stiffness of the pavement by using various 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. Measurement of the LTE is obtained by placing the FWD load plate 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. In a perfectly efficient joint, these deflections are equal. For most joints, the deflection on the unloaded slab is less than the deflection on the loaded slab.

An FWD has two types of primary measurement devices. The first is a load cell, 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 FWDs operated by the NJDOT use geophones as the deflection sensors, although there are other types of deflection sensors used in other FWD designs. The NJDOT FWD can be set up for seven or nine deflection sensors placed at fixed distances from the load plate to measure the shape of the deflection basin.

In addition to the primary measurement devices, the NJDOT FWD has two additional types of measurement devices. The first is the distance measurement instrument (DMI), a high-accuracy odometer that measures the distance the FWD has traveled along a roadway. The second type is a temperature sensor. The NJDOT FWD has two categories of 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, are useful for estimating the temperature of various materials in 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; therefore, the stiffness calculated from FWD data for these materials must be corrected for these temperature effects. In addition, the LTE between two PCC slabs varies as the slabs expand and contract or warp resulting from a difference in temperature between their top and bottom surfaces.

NJDOT FWD operators are also required to perform manual measurements during FWD testing. These measurements consist of subsurface temperature measurements taken with a hand-held probe and joint width measurements taken during load-transfer testing.

NJDOT FWD operators also must comment on 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.

Use of proper terminology greatly eases troubleshooting and problem reporting. This manual uses specific terminology to refer to specific parts of the Dynatest® model 8002 FWD or Dynatest HWD, which is the type operated by NJDOT. Some of these terms also apply to other types of FWDs. This list is complete only for this manual. Parts not included here may be found in the FWD/HWD owner's manual.

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

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

Geophone—Device used to measure deflection. It is yellow, roughly cylindrical, and about 25 mm (0.98 inch) in diameter and 50 mm (1.97 inches) high. 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 identify critical calibration information in the FWD data collection software. The NJDOT HWD use 2,000-micron (80-mil, or 0.8-inch) geophones.

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

Load Plate—Directly contacts the pavement surface to transmit the load. The type used by NJDOT is solid split plate, and it has a 300-mm (11.81-inch) diameter. It consists of three layers: the topmost is steel, the middle is polyvinyl chloride (PVC), and the bottommost is a ribbed rubber sheet.

Multisignal 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—Connects the trailer control box through a multisignal cable to the data collection computer using an RS-232 serial cable. The NJDOT FWDs use a Dynatest 9000 signal processor located in the tow vehicle.

Strike Plate—A flat-surfaced column above the load plate. The weight package is dropped on the strike plate during operation of the FWD. Braces and a cylinder, housing the center geophone, and to which the swivel attaches, are welded to the underside of the strike plate.

Sensor Bar—A long bar mounted above the load plate where the geophone holders are mounted. An extension of the sensor bar continues behind the load plate toward the trailer hitch to allow a geophone to be mounted behind the load plate.

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—Removable steel weights that can be mounted on the weight package to increase the loading on the pavement.. Their mass is 20 kilograms (kg) (44.1 pounds (lb)) each.

Weight Package—The entire assembly that is raised and then dropped to generate load.

2 CALIBRATION AND VERIFICATION

Highly accurate load, deflection, and associated data are necessary to meet the requirements of the NJDOT program. This section includes several calibration and verification requirements to ensure the accuracy of FWD measurements. If the FWD cannot meet the requirements of any of these procedures, it may not be used to collect data for NJDOT. In such a situation the operator should fill out and submit an FWD Problem Report (FWDPR) (see appendix A) to the NJDOT FWD task leader.

2.1 REFERENCE CALIBRATION

Every FWD performing data collection on behalf of NJDOT should undergo yearly reference calibration. This calibration must be performed at one of the four calibration centers established by the Strategic Highway Research Program (SHRP), or at an equivalent center as determined by the NJDOT FWD task leader. The nominal yearly interval should not exceed 400 days.

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

If a major component such as a deflection sensor, multisignal cable, or trailer printed circuit board (PCB) board is replaced, the FWD should undergo reference calibration as soon as practical, but in the meantime it can be used to collect data on behalf of NJDOT.

2.2 RELATIVE CALIBRATION

Data should not be collected by an FWD on behalf of NJDOT unless the FWD has undergone relative calibration within the previous 42 days. If the FWD is in regular use, relative calibration should be performed on a nominal monthly interval. Relative calibration should not be performed during periods when the FWD is idle.

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

2.3 DMI CALIBRATION

Every FWD performing data collection on behalf of NJDOT should undergo DMI calibration monthly while in service. Data should 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 should be recalibrated before continuing to collect data on behalf of NJDOT, 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 500 ft in length, and reasonably level. Because the FWD must be stopped at each end of the section, it cannot be performed on an active highway without traffic control. The section length must be surveyed or measured using a surveyor’s tape (a measuring wheel is not acceptable).

Immediately before DMI calibration, the tire pressure for all of the tow vehicle tires should be set to the manufacturer’s specification, and then the operator should drive the vehicle at least 15 min at highway speeds.

2.4 TEMPERATURE SENSOR VERIFICATION

Every temperature sensor collecting data associated with NJDOT FWD measurements should have its accuracy verified monthly, and unless the temperature sensor has been verified during the previous 42 days, data should not be collected.

Following is a summary of a verification procedure; it should not be used as a calibration procedure. If a temperature sensor fails this procedure, it should be returned to the manufacturer for repair or recalibration, or it should be replaced with a new sensor.

2.4.1 The following equipment and supplies are required for this procedure:
• National Institute of Standards and Technology (NIST) traceable mercury thermometer (reference thermometer).
• 4-liter (L) (1-gallon (gal)) bucket.
• Hot plate.
• Large wooden spoon or paint stirrer.
• Medium-sized cooking pot, approximately 5 inches in diameter.
• Leather heat-resistant gloves.
• Cooking oil (about 1 pint).
• Ice.
• Water.

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

2.4.3 Start the FWD data collection software and enter a screen from which the air and IR surface temperature measurements can be read.

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

2.4.5 Prepare an ice water bath. Place ice and water in the 1 gal bucket and stir with the wooden spoon or paint stirrer. Stir until the reference temperature records a temperature that is less than or equal to 35.6 °F.

2.4.6 Place the bucket under the FWD-mounted IR temperature mounted sensor. Remove the reference thermometer, then stir the ice bath for 1 min, and record the measurements from both sensors. If the recorded temperatures vary by more than 3.6 °F for either data set, stir for another minute, and then record both temperatures again. If the IR temperature sensor varies by more than 3.6 °F from the reference thermometer for two or more data sets, then the IR temperature sensor is unacceptable.

2.4.7 Repeat the procedure in 2.4.6 for the hand-held IR temperature sensor. Hold the handheld IR temperature sensor at a height consistent with the FWD-mounted IR temperature sensor.

2.4.8 Stir the ice bath for another minute. Place the FWD-mounted air temperature mounted sensor and the reference thermometer in the bath. When 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 3.6 °F for either data set, stir for another minute, and then record both temperatures again. If the air temperature sensor varies by more than 3.6 °F from the reference thermometer for two or more data sets, then the air temperature sensor is unacceptable.

2.4.9 Repeat the procedure in 2.4.8 for the hand-held temperature probe.

2.4.10 Prepare the room temperature water bath. Empty the bucket and fill it with warm tap water. Allow it to sit for 10 min and then stir for 1 min.

2.4.11 Place the bucket under the FWD-mounted IR temperature mounted sensor. Stir the water for 1 min and then record the measurements from both sensors again. If the recorded temperatures vary by more than 3.6 °F for either data set, stir for another minute and then record both temperatures again. If the IR temperature sensor varies by more than 3.6 °F from the reference thermometer for two or more data sets, then the IR temperature sensor is unacceptable.

2.4.12 Repeat the procedure in 2.4.11 for the hand-held IR temperature sensor. Hold the handheld IR temperature sensor at a height consistent with the FWD-mounted IR temperature sensor.

2.4.13 Stir the water for another minute. Place the FWD air temperature mounted sensor and the reference thermometer in the water. When 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 3.6 °F for either data set, stir for another minute and then record both temperatures again. If the air temperature sensor varies by more than 3.6 °F from the reference thermometer for two or more data sets, then the air temperature sensor is unacceptable.

2.4.14 Repeat the procedure in 2.4.13 for the hand-held temperature probe.

2.4.15 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 to be performed only for IR temperature sensors.

2.4.16 Prepare the high-temperature oil bath. Pour cooking oil into the cooking pot to a depth of approximately 2 inches. Place the cooking pot on the hot plate and under the FWD-mounted IR temperature mounted sensor. Stir the oil while it is warming on the hot plate. The operator who is stirring the oil must wear gloves. Heat until the oil temperature stabilizes at 140 °F (±3.6 °F), as determined using the FWD-mounted IR temperature sensor.

2.4.17 Record the FWD-mounted IR temperature sensor and reference thermometer readings. Wait 5 min, and then record both sensors again. If the recorded temperatures vary by more than 3.6 °F for either data set, then wait 5 min and record both temperatures again. If the FWD-mounted IR temperature sensor varies by more than 3.6 °F from the reference thermometer for two or more data sets, then the FWD-mounted IR temperature sensor is unacceptable.

2.4.18 Repeat the procedure in 2.4.17 for the hand-held IR temperature sensor. Hold the handheld IR temperature sensor at a height consistent with the FWD-mounted IR temperature sensor.

2.5 REPORTING REQUIREMENTS

2.5.1 Reference Calibration

For NJDOT-operated FWD equipment, the operator should submit the reference calibration results to the NJDOT FWD task leader within 7 days after the calibration is completed. For non NJDOT-operated FWD equipment collecting data on behalf of NJDOT, the reference calibration results should be submitted to the NJDOT FWD task leader within 30 days of the time it first collects data for NJDOT with those calibration factors.

A copy of all reference calibration results should be kept in the NJDOT Pavement office. A paper copy of the most recent reference calibration results should be kept in the FWD tow vehicle.

2.5.2 Relative Calibration

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

2.5.3 DMI Calibration

The operator should fill out Form F07 each time the DMI is calibrated. The RSC office should keep a copy of all completed Form F07s for NJDOT-operated FWD equipment. A paper copy of the most recently completed Form F07 should be kept in the FWD tow vehicle. It is not necessary to submit copies to the NJDOT FWD task leader.

2.5.4 Temperature Sensor Verification

A copy of all completed Forms F08 and F09 for NJDOT-operated FWD equipment should be kept at the NJDOT Pavement office. A paper copy of the most recently completed Forms F08 and F09 should be kept in the FWD tow vehicle. It is not necessary to submit copies to the NJDOT FWD task leader.

3 EQUIPMENT CHECKS

Because of the extensive use of FWDs in NJDOT, routine equipment checks are extremely important. The FWD operator should perform the checks in this section 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.

An operator must address any deficiencies noted while performing these checks before any further transit or testing.

3.1 BEFORE-TRANSIT CHECKS

The operator should perform the following checks on the tow vehicle before the start of travel for the day:

- 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 stowed well.

The operator should perform the following checks on the FWD trailer before the start of travel for the day:

- 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.

3.2 BEFORE-OPERATIONS CHECKS

At a minimum, the FWD operator should perform the following checks after the FWD arrives at the test site and before testing begins:
• 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.

** Perform some of these checks prior to leaving the garage, which is easier and safer. Lane closure is for FWD testing only and has to be picked up if FWD has some problems.*

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

3.3 POST-OPERATIONS CHECKS

At a minimum, the FWD operator should perform the following checks before 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, signed, and filed.

4 FIELD TEST PROCEDURES

The following list summarizes the general procedures FWD operators are to perform at each test site. The step summaries refer to sections in this manual that give the details of each step.

4.1 Before arriving at the site, an 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.

4.2 When an FWD operator arrives at the site, he or she should inspect the test section for evidence of maintenance activities. If there is evidence of recent maintenance activities, contact the NJDOT Pavement and Drainage Management office.

4.3 Prepare the temperature gradient holes as directed in manual Section 7.1. The operator drills holes, the depths should be measured and filled out on Form F01. The operator then fills the holes with mineral oil and waits at least 20 minutes (min) before taking the first temperature measurement.

4.4 Perform the before-operations activities listed in manual Section 3.2.

4.5 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 5.3.5.

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 before the final four drops to ensure that the load levels for each drop height are within the limits given in Section 5.2. If they are not, adjust the drop height targets accordingly and make an additional drop at each drop height 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, stop testing, readjust the targets, and repeat the pass. If the FWD is idle for more than 15 min, again perform a standard buffer-warm-up sequence.

4.6 Position the FWD so that the center of the load plate is on the section start limit (i.e., Station 0+000). Set the DMI to 0 centimeters (cm) (0 feet (ft)), ascending. The DMI must be set in units of “feet”.

4.7 Position the FWD at the first test location. Test locations for the appropriate test plan number (as given on Form F05) are listed in manual Section 6.

4.8 In 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.

4.9 Check the local time on the computer and evaluate whether the test pass can be completed before local midnight. If it is not probable that testing can be completed before midnight, break the file into two files in the office.

4.10 Perform the first temperature gradient measurement as described in Section 7.1. Perform subsequent temperature gradient measurements every hour, plus or minus 10 min.

4.11 Enter the lane specification appropriate to the test location in the field provided in the data collection software.

4.12 Start the testing sequence.

4.13 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 described in Section 7.3. Throughout testing, the following comments should be added to the datafile: the direction of travel; any unusual features (e.g. patch area, start of different pavement type, change in slab panel size, reason test couldn't be performed, such as off ramp, on-ramp, bridge, rest area entrance, etc.); and condition of pavement in terms of distresses. For LTE testing, joint/crack widths should be measured.

4.14 During load transfer testing (i.e., lane specifications J4, J5, C4, C5, F4 or F5) measure the joint/crack width as described in Section 7.2. Joint/crack widths must be measured for at least 25 percent of load transfer tests. If time permits, measure joint/crack widths for all load transfer tests.

4.15 If the data collection software generates errors during testing, follow the instructions in Section 8. After testing, at the "Accept/Reject" prompt choose "Accept" only if no errors were generated, or after following the error resolution procedures in Section 8.

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

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

4.18 Repeat steps 4.11 through 4.17 for each test point in the test pass.

4.19 After completing all test point in the pass, close the data file. The data file must be closed and a new data file opened before beginning in a new test pass. Record the location of the last test point.

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

4.21 Perform steps 4.7–4.9 and 4.11-4.19 for the new pass. The temperature gradient measurement process does not need to be restarted, but it must be continued as long as FWD testing is being performed at the section.

4.22 Repeat steps 4.20–4.21 for each remaining pass at the test section.

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

4.24 If traffic control conditions permit, perform data backup and preliminary data processing before leaving the site as described in Section 11.1. Check that Forms F01 and F02 are correctly filled out, and that Form F05 is initialed and dated.

4.25 Perform after-operations activities described in Section 3.3.

5 SETUP

5.1 PHYSICAL SETUP

The physical setup described in this manual is mandatory for all NJDOT-owned FWD. Other FWDs collecting data on behalf of NJDOT may not be capable of the setup described. In those cases, the setup should be followed as closely as possible and discussed with the NJDOT.

5.1.1 Geophone Sensor Locations

For all NJDOT testing, maintain the same placement of the geophones on the FWD. Measure geophone offsets from the center of the load plate to the center of the geophone holder. Measure the location of each geophone 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) are considered positive. Offsets behind the load plate (i.e., in the direction of the rear bumper) are considered negative. The required offsets are shown in Table 1. For Joint load transfer testing, the offset from the load center is plus and minus 12 inches.

Table 1. Deflection Sensor locations, inch.

Sensor	D1	D2	D3	D4	D5	D6	D7	D8	D9
9-Sensor Configuration	0	-12	8	12	24	36	48	60	72
7-Sensor Configuration	0	-12	12	24	36	48	72	n/a	n/a

1 mm = 0.039 inch

Figure 2. FWD Load Plate and Sensors

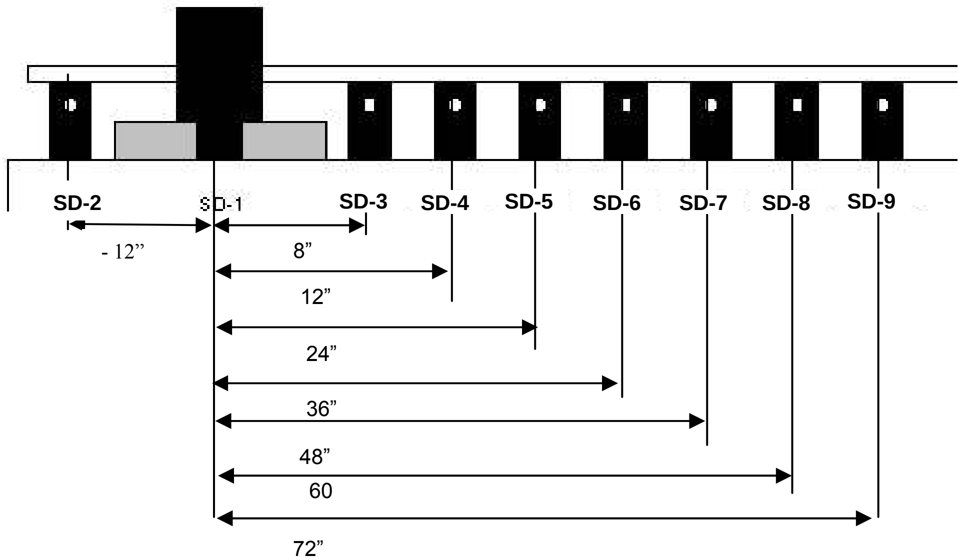


Figure 3. FWD Sensors Spacing (9 Sensors)

Non-NJDOT FWDs and NJDOT-operated FWD 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.

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

2. 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 so that a force on the end feeler can move the holder and feeler upward until the feeler is at least 5 mm (0.2 inch) inside the bottom of the holder body, and that it returns easily when released. (If this does not occur, apply a few drops of silicone oil to the top of the guide rod).

3. Use a steel tape measure with 1 mm (0.039 inch) graduations and 3 meters (m) (9.84 ft) or greater in length, and zero it on the center geophone feeler that projects through the bottom of the 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. It is not adequate to measure only from center to center between individual deflector sensors; this measurement alone will result in an accumulating error. By measuring from the rear of the contact screw, a more repeatable and 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.

4. When the location of the deflection sensor holders is properly set, lock them in place.

5.1.2 Weight Package

Three standard weights and two buffers should be used on each side and configured in such a way as to generate the recommended load levels. Configure the weight package the same for all NJDOT testing. For Dynatest model 8002 FWDs, use three standard weights per side. Use two buffers per side. When new buffers are installed on the FWD, fill out Form F04 and submit it to the NJDOT FWD task leader.

If testing is to be performed on behalf of NJDOT by an FWD other than a Dynatest model 8002 FWD or Dynatest HWD, select a combination of buffers and weights that achieves the load requirements described in manual Section 5.2 and comes as close as possible to a 13-millisecond (ms) pulse rise time.

5.2 LOAD LEVELS

Four load levels are defined here for NJDOT testing. The acceptable load range for each drop height is between 90 percent and 110 percent 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 percent of the target load at the beginning of the day will minimize the deviation over the course of the day for most cases.

The recommended target load levels for New Jersey are shown in Table 2. To be acceptable, equipment must be configured in such a way that the actual load applied is within 10% of the target load. During testing, one seating drop should be performed, followed by one drop at each of the recommended load levels.

Table 2. Recommended Target Loads

Height	Target Load
Seating	9,000 lbs
1	6,500 lbs
2	9,000 lbs
3	12,000 lbs
4	16,000 lbs

5.3 SOFTWARE SETUP

This section includes specific software settings required for NJDOT testing. Instructions on how to enter these settings into the data collection software are given in the *NJDOT Dynatest HWD Data Collection Software Manual.*

5.3.1 Units

All FWD data collected for NJDOT should be in English units. Specifically, temperature should be recorded and displayed in English units (°F), load in pounds-force (lb-f), deflection in mils one thousandth of an inch), and deflection sensor offsets in inches.

5.3.2 File Format

Data collected with NJDOT FWDs should be in the FWDWin MDB format or PDDX file format. Data collected with non-NJDOT seven -sensor FWDs should be in the R80-20 format, where possible. For FWDs not supporting either of these formats, contact the FHWA NJDOT FWD task leader for instructions with a copy to the NJDOT Pavement Office before testing begins.

Raw FWD Data File Format

Consultants performing FWD Testing on behalf of NJDOT shall format and process the FWD raw data files according to the specifications outlined in this document. The objective is to standardize the procedure for quality control purposes.

Raw data files are to be provided (in English units) in AASHTO Pavement Deflection Data Exchange 1.0 (PDDX) or latest version. In addition to the required PDDX file format the raw data shall also be provided in one of the following formats: Dyantest MS Access 2000, Version 25 (P25) and FWD Field Program Edition 9, 10 and 20: KUAB FWD testing field program version 3.x. For some these formats adequate information is required and must be provided to determine slab testing locations (i.e. Midslab, approach joint, leave corner, edge, etc...) and any other information that is not available in the given file but needed for backcalculation. The test location must be either clearly stated within the raw data file itself or a separate table must be provided to identify the site location.

These *files* will be required as an original data source and can be used in backcalculation analysis programs such as Elmod, Modulus, BAKFAA, DARWin 3.0 and EverCalc.

5.3.3 Filters

Collect data with all filters and smoothing turned off.

5.3.4 Data Checks

Enable the following checks:
• Roll-off
• Nondecreasing deflections
• Overflow
• Load variation—set to +/− (40.5 lbs + 0.02X),
where X = average load for all drops at that height
• Deflection variation—set to +/− (0.08 mils + 0.01X),
where X = average ***normalized*** deflection for a geophone for all drops at that height.

Further information on what these checks are and what to do if they fail appears in Section 6.

5.3.5 Drop Sequences

Two different drop sequences are used for NJDOT testing:
• Flexible testing: C,C,1,1,1H,2,2,2H,3,3,3H,4,4,4H
• Rigid testing of both jointed concrete pavements (JCP) and continuously reinforced concrete pavements (CRCP): C,C,2,2,2H,3,3,3H, 4,4,4H

Where *C* is a seating drop (no data saved) 12,000 lbs,
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, the following drop sequences is used to warm up the buffers before testing:

• Standard buffer warm-up sequence (in ambient temperatures above 50 degrees Fahrenheit (°F):

A warm up sequence of minimum of 64 drops including load levels (1,2, 3, 4) are required before starting testing.

• Cold-weather buffer warm-up sequence (in ambient temperatures below 50 °F: drop height (3) repeated 20 times, followed by the standard buffer warm-up sequence.

5.3.6 File Naming

The following file naming convention will be used to maintain consistency with previous data collection efforts in New Jersey:

RtDirMPLaneDatePavement Type

001N12-2101202009B

Where

001 is Rt 1

N is North

12-2 is MP 12.2

1 is Lane 1 from the center outward

01202009 is January 20, 2009

B is Bituminous Concrete, R is Rigid, C is Composite

A new data file must be started for each test pass and data for the entire test pass should be contained in that file.

6 TEST PLANS

6.1 SELECTING THE APPROPRIATE TEST PLAN

It is recommended that a project be tested in the direction(s) in which the pavement is to be repaired. Typically, testing should take place in the outside travel lane. However, NJDOT engineers may require that the inside lane to be tested if one or more of these conditions exist:

- The pavement structure of the inside lane is different than the outside lane.
- More load-related distress is present in the inside lane than in the outside lane.
- Heavy truck traffic uses the inside lane (e.g. the lane is prior to a left exit).

FWD testing at an intersection may be impractical due to traffic however, the testing should still be conducted at approaches and leaves to an intersection wherever possible.

The testing frequency depends on the project length – in terms of directional, rather than centerline length. For projects that are 3 miles or more in length, 20 tests should be conducted per mile – approximately one test every 250 ft – in the right wheel path (RWP) of the slow lane (measured as 3 ft from the lane/shoulder). For projects of less than 3 miles, the recommended test spacing is shown in Table A.3.

Table A.3. Recommended project-level test spacing.

Project Size (miles)	Test Spacing (feet)	Minimum Number of Tests
< 0.5	50-100	25
0.5 – 1.0	100-150	30
1.0 – 3.0	150-250	40
> 3.0	250	60

For flexible pavements, FWD testing should be conducted in the wheel path closest to the nearest shoulder, i.e. in the right wheel path for outside lanes and the left wheel path for inside lanes. Crack free and patch free areas, as much as possible, or as specified in the project scope.

6.2 DESCRIPTION OF TEST PLANS

Three types of testing may be required for rigid pavements. These locations should be:

- Basin Testing – should be conducted near the middle of the slab (i.e. mid-point between two joints) in wheel path closest to the nearest shoulder. If necessary, the test point can be moved slightly to be at least 10 ft from nearest active transverse crack.

- Joint/Crack Testing – should be conducted in the wheel path closest to the free edge of the slab
- Corner Testing - should be conducted at the slab's free edge corner, i.e. the right edge corner for outside lanes and the left edge corner for inside lanes. The testing should be conducted on the leave side of the joint, where voids are typically located.

6.3 TRANSVERSE LOCATIONS

The transverse location of a test pass is given as a relative position in the lane containing the NJDOT test section. These relative positions are midlane in the outer wheel path (ML-OWP), Joint testing (approach and leave) in the outer wheel path (OWP), and Corner. As shown in table 6, these positions are to be measured from the outside lane edge (OLE) to the center of the FWD load plate.

Table 4. Transverse locations relative to Outside lane edge.

Relative Position	Nominal Lane Width 12 ft
ML-OWP	2.5 ft ± 0.5 ft *
Joint testing (approach and leave)	2.5 ft ± 0.25 ft
Corner	0.5 ft ± 0.25 ft

***If proper seating of the load plate at this offset is impossible due to pavement features, the offset may be increased.**

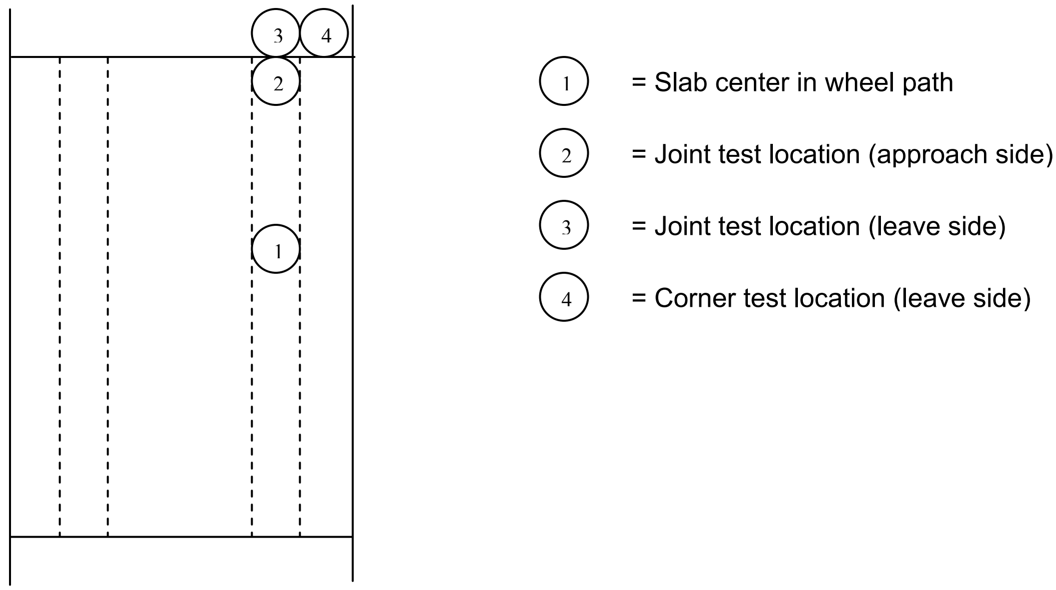
For a normal paving lane (nominally 12 ft wide), the OLE is defined as the lane/shoulder interface unless the outside edge of the painted shoulder stripe is more than 150 mm (6 inches) inside the lane shoulder interface, in which case the OLE is defined as the outside edge of the painted shoulder stripe. 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 must be maintained within the error band listed for all test locations.

6.4 SLAB-REFERENCED LOCATIONS

FWD testing on PCC surfaces is referenced to effective slabs, not absolute longitudinal position. When testing has been performed at a PCC-surfaced section previously, then the operator should test the same slabs again as those tested previously. The operator should use Form F10 to identify slabs tested previously. On Form F10, slabs are referenced by the station of the joint or crack that defines the approach end of the slab. If a previously tested slab is subdivided 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 should be tested.

Figure 4 . Illustration of testing locations.



If testing has not been performed previously at a PCC-surfaced section, then the operator should determine the number of slabs to be tested according to the test plan. Then the operator should determine the number of effective slabs that are wholly within the section limits (i.e., only count slabs that begin and end in 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 should 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 should be selected. The operator should take care to evenly space the slabs to be tested along the test section. Testing in all test passes at the section should 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.

6.4.1 Mid-Panel

Mid-panel testing should be performed with the load plate located as close to the center of the effective slab as possible. The load plate should be within 5 ft or 10 percent of the effective slab length of the center (as measured along the test pass), whichever is smaller.

6.4.2 Joint Approach

Joint approach testing should 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 should be located on the slab immediately before the selected slab. The edge of the load plate should be within 2 inches of the joint, but under no circumstances should it bridge the joint. Figure 5 shows a diagram of joint approach testing.

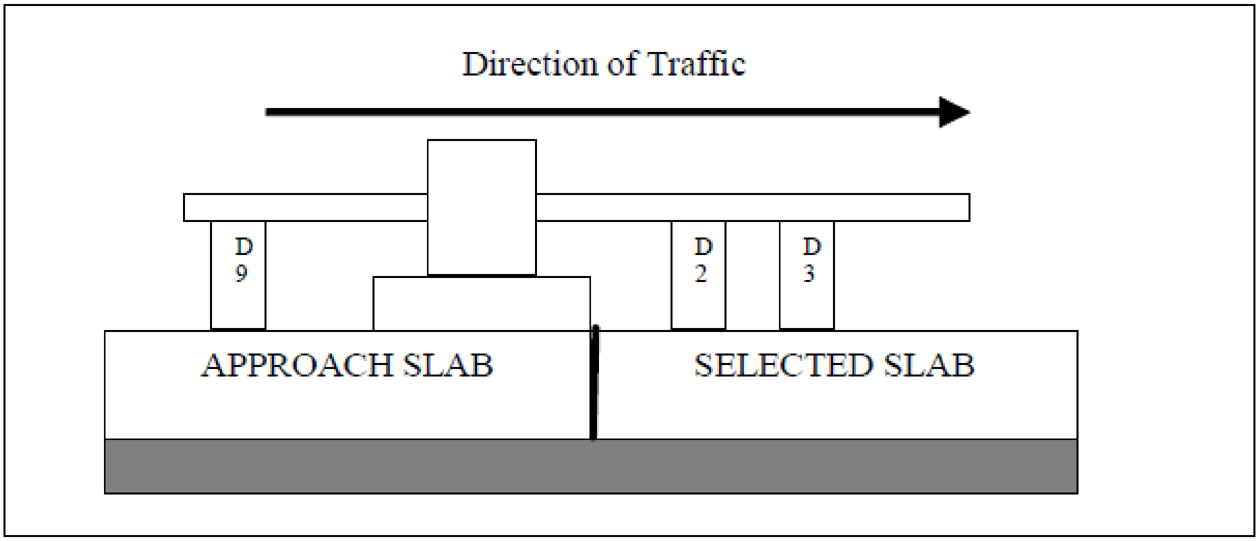


Figure 5. Diagram Joint Approach Testing Diagram

6.4.3 Joint Leave

Joint leave testing should 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 should be located on the selected slab and the edge of the load plate should be within 2 inches of the joint, but under no circumstances should it bridge the joint. A diagram of joint leave testing is shown in Figure 6.

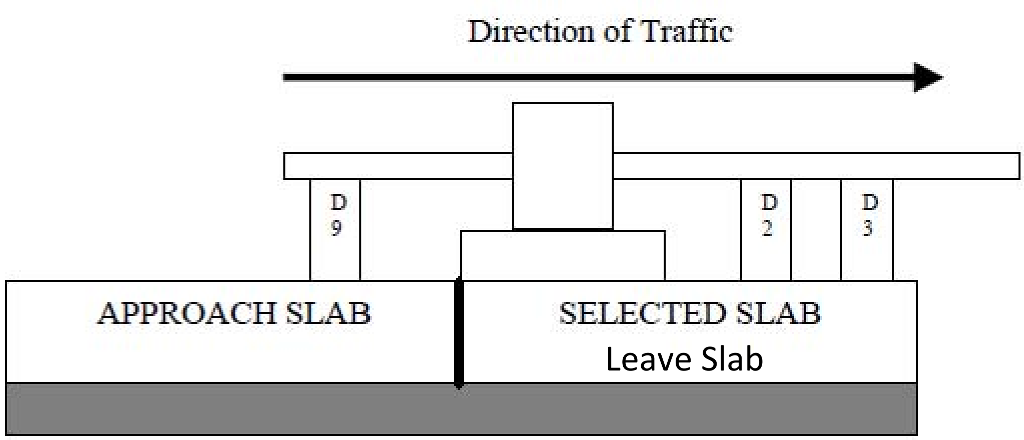


Figure 6. Diagram Joint Leave Testing Diagram

6.4.4 Corner

For JCP pavements, corner testing should be performed the same as joint leave testing except that the load plate should 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 should be no more than 3 inches from the joint or crack defining the approach end of the slab and no more than 3 inches from the longitudinal joint.

7 OTHER MEASUREMENTS ASSOCIATED WITH FWD TESTING

7.1 TEMPERATURE GRADIENT MEASUREMENTS

Pavement temperature test holes should be prepared for mid-depth of the pavement bound (HMA) layers based on core thickness. The first air and pavement surface temperature measurements should be taken before testing begins. These measurements must be taken approximately every hour throughout testing. All holes should be drilled in the wheel path as close as possible to the depths identified. The tolerance for hole is ±0.5 inch.

Holes should be drilled with a portable hammer drill using a 0.5 inch diameter bit. After the hole is drilled to the required depth, it should 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 should be measured after it is cleared of debris. Then it should be filled with 0.5 to 1 inch of mineral oil to provide thermal conductivity between the pavement and the temperature probe. The hole should be covered with tape (such as duct tape) and the tape slit to allow the probe to be inserted.

In addition to subsurface temperature measurements, an infrared (IR) surface temperature measurement should be obtained at the same time that subsurface temperature readings are obtained. The location of the measurement should also be in the testing wheel path and at least 1.5 ft from the nearest hole in the longitudinal direction. The operator should take care that the area where the IR surface temperature is taken is free of oil, dirt, and other foreign debris. During temperature measurements the hand-held IR device should be held at a height consistent with the height of the FWD-mounted IR measurement device. IR temperate measurements should be taken three times in quick succession.

7.2 JOINT/CRACK WIDTH MEASUREMENTS see Sections 4.13 and 4.14

Joint/crack width measurements should be taken only on PCC surfaced pavements. On flexible surfaced pavements, cracks should be noted according to the instructions in Section 7.3.

On PCC surfaced pavements, joint/crack width measurements should be taken for at least 25 percent 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 should be performed using calipers with tapered jaws for measuring inside dimensions. The resolution of the calipers should be at least 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 need 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 testing wheel path, and the measurements averaged and rounded to the nearest 0.05 inch. This average should be entered into the FWD data collection software in the appropriate field.

7.3 DISTRESS IDENTIFICATION AND COMMENTING

The type and severity of pavement distress may influence the deflection response of a pavement; therefore, FWD operators should record any distress within the lane tested from about 12 inches in front of the forward most deflection sensor to 36 inches behind the load plate and from 12 inches on the left of the load plate to 12 inches on the right of the load plate.

7.4 OTHER COMMENTS

In addition to distress comments, other unusual conditions or events deserve comments. Operators should comment on data with nondecreasing deflections, excess variation, or other software-generated errors that could not be cleared by following the instructions in Section 8. Operators should also comment on other events such as delays in testing because of breakdowns or weather, pavement changes within the section, moisture seeping out of cracks, or other conditions that could affect deflection measurements.

8 FIELD DATA QUALITY CHECKS/ERROR CONDITIONS

As described in Section 5.3.4, several data checks should be enabled in the FWD data collection software. They are described in the following paragraphs.

8.1 ROLL-OFF

"Roll-off" is an error condition that results when the deflection of the pavement surface as recorded by a deflection sensor does not return to near zero within 60 ms 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 NJDOT test sections have sufficient strength that roll-off can only be to the result of 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 0.001 inch is not necessarily indicative of error.

If the roll-off error is triggered on a deflection that is greater than 0.001 inch, then the operator should follow the error resolution instructions in Section 8.6. Otherwise the measurement should be accepted and testing should continue.

8.2 NONDECREASING DEFLECTIONS

"Nondecreasing deflections" is an error condition that results when 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 occur legitimately if there is a transverse crack or other discontinuity between the two sensors that exhibit the nondecreasing deflections. If the operator observes such a crack or discontinuity between the two flagged sensors, then the test should be accepted and the observation should be recorded at the "Comments" prompt.

Nondecreasing deflections can sometimes be triggered incorrectly when the magnitude of the deflections approaches the resolution of the deflection sensor. If the larger of the two deflections is less than 0.39 inch, then the test should be accepted, and testing should continue.

Nondecreasing deflection may sometimes occur between deflection sensors 1 and 2 on extremely weak pavements because of permanent deformation of the pavement by the FWD.

Nondecreasing 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 nondecreasing 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 operator should follow the error resolution instructions in Section 8.6.

8.3 OVERFLOW

"Overflow" is an error condition that results when a measured deflection exceeds the range of the deflection sensor. For the FWDs operated by NJDOT, this range is 80 mils, or 0.08 inch). Deflections of that magnitude are only expected on extremely weak pavements or when testing using extremely high load levels. For testing at an NJDOT test section using the load levels specified in this document, it is not reasonable to expect that the deflections will exceed 80 mils, or 0.08 inch.

If this error is encountered during testing, it is likely that the flagged sensor does not have good contact with the pavement surface. The operator should follow the error resolution instructions in Section 8.6.

8.4 LOAD VARIATION

"Load variation" is an error condition that results when the peak load for repeat drops at the same drop height varies by more than the amount specified in Section 5.3.4. This condition can occur legitimately 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 because of loose debris or irregularities in the pavement surface.

If this error occurs during testing, the operator should follow the error resolution instructions in Section 8.7.

8.5 DEFLECTION VARIATION

"Deflection variation" is an error condition that results when the load-normalized peak deflections for repeat drops vary by more than the amount specified in Section 5.3.4. This condition can occur legitimately only if the stiffness of the pavement is changed by the FWD testing itself. This generally occurs only if the pavement is extremely weak or the unbound layers are saturated.

Deflection variations can occur as a result of uneven pavement surface conditions causing 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, the operator should follow the error resolution instructions in Section 8.6.

8.6 DEALING WITH DEFLECTION ERRORS

If deflection errors occur, the operator must attempt to identify the source of those errors. If the errors caused by the FWD equipment, then those problems must be fixed before testing continues. If the errors result from localized pavement conditions, the operator should reposition the FWD and comment on the condition. If the errors are the result of pavement conditions that are representative of the test section as a whole, or due to factors beyond the operator's control such as truck traffic, the operator should accept the error and comment on the condition. Sections 8.1, 8.2, 8.3, and 8.5 detail possible causes of the various types of deflection errors.

If the deflection errors appear to be to the result of 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. If 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 list is a summary of the troubleshooting process that is recommended in all cases, and the operator should deviate from the process only when confident of the source of the error, and the error source is not well suited for resolution using this troubleshooting process.

8.6.1 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.

8.6.2 If several sensors are flagged, it is recommended that the operator check all analog connections: sensor to control box, control box to multisignal cable and multisignal cable to signal processor.

8.6.3 The data should be rejected and the test repeated without repositioning the FWD.

8.6.4 If the errors persist, the operator must reject the test and perform the optional activities in Section 8.6.1 and 8.6.2. If problems with the equipment are discovered and corrected, all data collected in this test pass should be discarded, and the test pass should be restarted.

8.6.5 If errors persist and the test being performed is a load transfer test, or if the FWD cannot be moved forward because of a joint or transverse crack, then the results should be accepted whether or not they contain errors. The operator should enter a comment stating "Error could not be resolved."

8.6.6 If the errors persist and the FWD can be repositioned, the operator should reject the data and move the FWD forward 2 ft. The operator should repeat the test a third time. If the errors persist the operator should accept the results and at the prompt enter a comment stating "Error could not be resolved."

8.6.7 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 Sections 8.6.1 and 8.6.2 need not be repeated.

8.7 DEALING WITH LOAD ERRORS

All of these conditions can be legitimately caused under certain specific circumstances. For example, non-decreasing deflections can be legitimately caused by a transverse crack or other discontinuity between two sensors, amongst other reasons. The operator must attempt to identify the source of the errors. If the errors appear to be caused by the FWD equipment, then the test (or entire test pass) should be discarded, the equipment fixed, and testing resumed. If the errors result from localized pavement conditions, the test should be discarded, the FWD repositioned, and the test rerun. If the errors are the result of pavement conditions across the test section as a whole, or are due to factors beyond the operator's control, the error should be accepted and a comment made on the pavement condition.

If load errors occur, the operator must attempt to identify the source of those errors. If the errors result from problems with the FWD equipment, then those problems must be fixed before testing continues. If the errors are caused by localized pavement conditions, the operator should reposition the FWD and comment on the condition. If the errors are caused by pavement conditions that are representative of the test section as a whole, the operator should accept the error and comment on the condition. Section 8.4 gives details of 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 summary of the troubleshooting process is recommended in all cases, and the operator should deviate from it only if confident of the source of the error and the error source is not well suited for resolution using the troubleshooting process.

8.7.1 The data should be rejected and the test repeated without repositioning the FWD.

8.7.2 If the error persists, the operator should 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 multisignal cable and multisignal 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 checked to ensure that it moves easily. Check the rubber sheet and pavement surface under the load plate for debris, and remove any.

8.7.3 Reject the data and repeat the test without repositioning the FWD.

8.7.4 If errors persist and the test being performed is a load transfer test, or if the FWD cannot be moved forward because of a joint or transverse crack, then accept the results whether or not they contain errors. Enter a comment stating "Error could not be resolved."

8.7.5 If the errors persist and the FWD can be repositioned, reject the data and move the FWD forward 2 ft. Repeat the test a third time. If the errors persist then accept the results, and enter a comment stating "Error could not be resolved."

8.7.6 If the error could not be cleared, then for all subsequent errors of the same type in the same test pass, the operator need not repeat the activities in step 8.7.2.

9 MAINTENANCE AND REPAIR

The Pavement Office is responsible for the maintenance and repair of the FWD that they operate. This includes scheduled maintenance and reactive maintenance. FWDs should be maintained in accordance with the manufacturer's recommendations All maintenance and repair activities performed on NJDOT-operated FWDs should be documented using Form F03.

Other organizations that perform FWD testing on behalf of the NJDOT, are responsible for the maintenance and repair of the FWD that they operate.

10 COLD WEATHER FWD TESTING

The FWD tow vehicle should be warmed to achieve an interior temperature of at least 40 °F before turning on the signal processor or data collection computer.

For testing in ambient temperatures at or below 15 °F, the standard hydraulic fluid should be replaced with a lighter-weight synthetic fluid or other oils as recommended by the manufacturer. Some oils may not be appropriate for warm-weather operations.

11 DATA HANDLING PROCEDURES

11.1 FIELD DATA HANDLING PROCEDURES

Field Data Handling

Operators must perform the following data handling tasks:

- Print hard copies of FWD data on daily basis, if required by NJDOT engineer.
- Copy FWD data files onto disc and label properly.
- Make additional back-up copy of above disc.
- Check field logs for completeness; fill-in any missing information.

Send all above data to office on regular basis, as required by NJDOT engineer. The back-up disc should not be sent, it should be kept with vehicle in case of loss during transit.

If conditions permit, the operator should process all FWD data collected at a site using FWDConvert and FWDScan (or other software allowed by NJDOT) before leaving the site. The operator should resolve errors generated by FWDScan and note any necessary changes to the file for correction by office personnel. A backup of the Pavement Deflection Data Exchange (PDDX) file should be made on removable media. This backup, along with the original on the FWD data collection computer, should be kept in the FWD until the office acknowledges receipt. If conditions do not allow the operator to do this work before leaving the site, the operator should do the work as soon as convenient, but no more than 24 hours after data collection.

The operator should submit completed copies of Forms F01, F02, and F05 to the office along with the electronic FWD data.

11.2 OFFICE DATA HANDLING PROCEDURES

Electronic data should be received from the field along with completed copies of Forms F01, F02, and F05. Pavement office personnel should verify that the information on these forms corresponds to the electronic data received. Office personnel should resolve discrepancies before processing further data.

Office Data Processing

Once received by the office, transmittals should be checked for inclusion of all required documentation. The raw data files should be loaded to the designated directory in two copies – one as raw data back up and the other for review and analysis. The original disc should be archived.

Data files should then be checked for completeness and accuracy of data, including:

Correct file naming and numbering for each project and each FWD test location.

Proper highway definition and project identification.

Target loads and testing locations, etc.

Testing patterns.

Reasonableness of data.

If anomalies are identified, the operator should be contacted immediately for clarification and corrective action (where appropriate). Any anomalies that cannot be resolved should be reviewed by the Quality Assurance Manager, who should take all necessary measures to resolve them, including manual upgrade of FWD data, if required. The file should then be re-reviewed to confirm it that it meets all data reasonableness checks. At this point, data will be considered ready for analysis.

11.3 FWD Analysis..

Recommendations for Analysis Procedures

Pavement Sectioning

The variability of pavement structures within the project limits identified by NJDOT will be analyzed based upon pavement type, in-situ structural parameters of the pavement within the layer thickness, pavement structural capacity and subgrade condition using statistical methods (t- test, cumulative sum, etc...). Limits of structurally homogenous sections within the specified project limits will be identified based on these parameters with consideration of practical minimum and maximum section lengths using engineering judgment. In addition to the pavement type, the following are the criteria that may be used to identify the limits of structurally homogeneous sections.

Limits of structurally homogeneous sections should be identifies based on the temperature corrected, normalized deflections. The term "Homogeneous" is used here to refer to pavement sections that are candidate for receiving the same rehabilitation treatment. For flexible pavements, a new section should be consider if more than 2 testing points show difference in D1 (zero offset) or 60 inch offset of more than 25% of the corresponding averages of the previous section.

An alternative to this approach is to use Ground Penetrating Radar (GPR) data to gather layer profile data. A pre-processing of GPR data can be performed to determine the initial limits of homogeneous sections, which can then be used in the analysis of FWD data. The only exception is when a section length is less than the minimum section length (0.25 mile).

Flexible Pavement,

- Normalized maximum deflections
- Layer thickness, in terms of As-built Structural Numbers (as obtained from core/bore logs, GPR surveys or As-built records)
- In-situ structural capacity — in terms of the backcalculated effective SN (SN_{eff})
- Effective Subgrade condition — in terms of the backcalculated subgrade modulus

Rigid Pavement

- Normalized maximum joint deflections
- Structural capacity in terms of the deflection basin area.
- Load Transfer Efficiency (LTE)
- Intercept values for void detection

Composite Pavements

Composite pavement sections will be treated based on the reflective cracks condition In case reflective cracks cannot be identified, the section will be treated as a flexible pavement section

If reflective cracks can be identified and tested, the section will be treated similar to a rigid pavement section, and the limits of the homogenous sections will be identified using the following criteria:

- Normalized maximum joint deflections

- In-situ structural capacity in terms of the deflection basin area

- Load Transfer Efficiency (LTE)

- Intercept values for void detection

Layer Thickness Data

Typical practice within backcalculation analysis is to gather layer thickness information from as-built records/plans or through destructive testing, such as coring/boring. However, as-built documents, as well as often being difficult to locate, provide only general layer thickness information that is in many cases different than what is actually built. Cores/bores provide extremely accurate layer thickness data, but it is point specific and valid only for the area close to the core's location.

A valuable alternative, then, to the use of as-built documents and/or cores to provide layer thickness information for backcalculation analysis is GPR. GPR vehicles collect continuous layer profile information while traveling at highway traffic speeds, thereby having no need for traffic control. This is a non-destructive pavement testing method that will not affect the integrity of the pavement structure. However, it is important to note that GPR data needs to be calibrated using core data. Although this means that cores still need to be taken, their number can be significantly fewer than if they are used as the sole indicator of layer thickness.

It is recommended that NJDOT use GPR data to provide layer thickness information for backcalculation analysis.

Temperature Correction

It is recommended to use the seasonal and temperature correction factors previously developed specifically for New Jersey conditions in the New Jersey Seasonal Study1, which are:

$$TCF_i = \frac{a_i * T_m + b_i * t_{ac} + c_i}{a_i * T_s + b_i * t_{ac} + c_i}$$

Where,

TCF_i = Temperature Correction Factor for the deflection of sensors 1 to 8, Mr and Ep to a standard temperature (e.g., 20o C)

T_s = Standard temperature, 20°C

T_m = Mid-depth AC Temperature, °C (from probe hole)

t_{ac} = Thickness of AC layers, inch

ai, bi and ci = Régression Coefficients

The regression coefficients for this equation can be found in Table 5 below and in the "Material Characterization and Seasonal Variation in Material Properties", Final Report (NJDOT 2005) 2.

Table 5. Deflection and Layer Moduli Regression Coefficients for North Region
[Thin Pavements Sections (AC < 10") and Thick Pavement Sections (AC >= 10")]

[2] Stantec Consulting. Material Characterization and Seasonal Variation in Material Properties. Final Report. NJDOT, 2005.

Independent Variable	Thickness Class	a	b	c
D_1	Thin	-0.0132	-0.2490	2.9311
D_2	Thin	-0.0092	-0.2102	2.4900
D_3	Thin	0.0028	-0.2369	2.5118
D_4	Thin	0.0031	-0.2516	2.7755
D_5	Thin	0.0053	-0.2563	3.0021
D_6	Thin	0.0096	-0.2164	3.3498
D_7	Thin	0.0103	-0.1357	3.5993
D_8	Thin	-0.0104	-0.1148	4.5976
M_r	Thin	0.0015	0.0159	0.9059
E_p	Thin	0.0042	0.0128	0.9649
D_1	Thick	-0.0280	0.0000	2.2361
D_2	Thick	-0.0183	0.0000	1.7770
D_3	Thick	-0.0160	0.0000	1.7062
D_4	Thick	-0.0149	0.0000	1.7650
D_5	Thick	-0.0186	0.0000	2.0277
D_6	Thick	-0.0169	0.0000	2.5521
D_7	Thick	-0.0056	0.0000	2.8447
D_8	Thick	0.0002	0.0000	3.3269
M_r	Thick	0.0023	0.0000	1.2926
E_p	Thick	0.0351	0.0000	0.5250

Table 5. (continued) Deflection and Layer Moduli Regression Coefficients for South Region

[Thin Pavements Sections (AC < 10") and Thick Pavement Sections (AC >= 10")]

Independent Variable	Thickness Class	a	b	c
D_1	Thin	-0.0113	0.0000	1.6289
D_2	Thin	-0.0049	0.0000	1.2024
D_3	Thin	-0.0027	0.0000	1.1650
D_4	Thin	0.0027	0.0000	1.1862
D_5	Thin	0.0073	0.0000	1.3482
D_6	Thin	0.0212	0.0000	1.7371
D_7	Thin	0.0352	0.0000	2.2210
D_8	Thin	0.0343	0.0000	2.8677
M_r	Thin	-0.0106	0.0000	1.1736
E_p	Thin	0.0129	0.0000	0.9678
D_1	Thick	-0.0265	-0.0221	2.2838
D_2	Thick	-0.0157	-0.0299	1.9746
D_3	Thick	-0.0110	-0.0403	2.0220
D_4	Thick	-0.0051	-0.0605	2.2681
D_5	Thick	0.0024	-0.0853	2.6055
D_6	Thick	0.0153	-0.1457	3.5775
D_7	Thick	0.0267	-0.1845	4.3694
D_8	Thick	0.0313	-0.1825	4.7931
M_r	Thick	-0.0084	-0.0056	1.2401
E_p	Thick	0.0336	0.0055	0.5608

After correcting for temperature, deflection should be adjusted for other seasonal factors (other than temperature), using the following equation:

Standard Deflection = Temperature Corrected Deflection * SDCF
Where,

SDCF is the appropriate Seasonal Deflection Correction Factor based on the thickness class, region and testing date

These SDCFs can be found in table 6 and the study report listed above.

Table 6. Summary of Seasonal Deflection Correction Factor

Region	Month	Total Thick. Class	CF_1	CF_2	CF_3	CF_4	CF_5	CF_6	CF_7	CF_8	CF M_r	CF E_p
N	1	Thin										
N	2	Thin	1.16	1.17	1.18	1.18	1.15	1.07	1.02	0.92	0.77	1.06
N	3	Thin	0.99	0.96	0.97	0.99	0.99	0.96	0.95	0.94	1.19	1.10
N	4	Thin	1.03	0.99	0.97	0.96	0.94	0.92	0.92	0.94	0.98	0.87
N	5	Thin	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
N	6	Thin	1.01	1.00	0.99	1.00	1.02	1.02	1.06	1.08	0.91	1.11
N	7	Thin	1.08	1.07	1.03	1.05	1.05	1.05	1.05	1.09	1.06	0.91
N	8	Thin	1.12	1.10	1.07	1.02	1.05	1.06	1.05	1.09	0.79	0.90
N	9	Thin	1.21	1.21	1.15	1.12	1.11	1.08	1.08	1.11	0.90	0.82
N	10	Thin	1.08	1.07	1.07	1.06	1.04	1.04	1.06	1.05	0.85	0.85
N	11	Thin	1.06	1.10	1.12	1.13	1.28	1.21	1.23	1.27	0.76	1.17
N	12	Thin										
N	1	Thick										
N	2	Thick	1.00	0.98	1.15	1.12	1.14	1.02	1.00	1.10	0.93	0.87
N	3	Thick	0.95	0.90	0.95	0.96	0.95	0.89	0.96	1.04	1.00	1.03
N	4	Thick	0.96	0.95	1.01	1.01	1.01	0.94	1.01	1.05	0.98	0.99
N	5	Thick	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
N	6	Thick	1.10	1.12	0.98	1.00	0.98	0.94	1.02	1.05	0.94	1.05
N	7	Thick	1.18	1.19	1.05	1.09	1.06	1.02	1.04	1.07	1.09	0.92
N	8	Thick	1.37	1.38	1.10	1.12	1.06	1.06	1.10	1.20	0.84	0.97
N	9	Thick	1.21	1.20	1.17	1.14	1.12	1.03	1.07	1.12	0.91	0.83
N	10	Thick	1.01	0.99	1.13	1.10	1.11	1.00	1.03	1.02	1.00	0.85
N	11	Thick										
N	12	Thick										
S	1	Thin										
S	2	Thin	1.20	1.22	1.25	1.30	1.33	1.41	1.47	1.41	1.02	1.92
S	3	Thin	0.99	0.99	0.99	0.98	0.92	0.93	0.96	0.96	1.00	0.96
S	4	Thin	1.02	1.02	1.01	1.04	1.01	1.00	1.04	1.03	0.98	0.97
S	5	Thin	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
S	6	Thin	1.10	1.07	1.05	1.08	1.02	1.00	1.03	1.01	0.92	0.92
S	7	Thin	1.10	1.08	1.06	1.10	1.06	1.04	1.07	1.06	0.91	1.00
S	8	Thin	1.04	1.03	1.04	1.05	1.05	1.07	1.09	1.10	0.86	1.03
S	9	Thin	1.12	1.12	1.11	1.12	1.08	1.08	1.11	1.12	0.87	0.91
S	10	Thin	1.28	1.33	1.32	1.39	1.37	1.40	1.40	1.36	1.06	1.70
S	11	Thin	1.19	1.19	1.17	1.17	1.13	1.08	1.10	1.12	0.86	0.79
S	12	Thin	1.14	1.15	1.13	1.12	1.07	1.03	1.03	1.03	0.89	0.80
S	1	Thick										
S	2	Thick										
S	3	Thick	0.93	0.94	0.94	0.95	0.91	0.96	0.97	0.96	1.05	1.12
S	4	Thick	0.95	0.95	0.94	0.97	0.92	0.93	0.98	0.99	1.00	1.08
S	5	Thick	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
S	6	Thick	0.87	0.90	0.91	0.94	0.89	0.89	0.93	0.95	0.95	1.07
S	7	Thick	0.96	0.98	0.97	1.01	0.97	0.99	1.02	1.03	0.96	1.07
S	8	Thick	0.94	0.95	0.96	0.97	0.97	1.02	1.03	1.06	0.91	1.08
S	9	Thick	1.00	1.01	1.00	1.02	0.99	1.03	1.06	1.07	0.93	1.04
S	10	Thick	0.97	0.99	0.99	1.01	1.00	1.02	1.05	1.08	0.97	1.40
S	11	Thick	1.02	1.02	1.02	1.04	1.02	1.05	1.06	1.05	0.95	1.03
S	12	Thick	1.04	1.08	1.08	1.09	1.08	1.10	1.08	1.04	0.94	0.96

[Thin Pavements Sections (AC < 10") and Thick Pavement Sections (AC >= 10")]

Considerations for PCC Pavement

Void Detection

For rigid pavements, FWD analysis can also be conducted to determine the presence of voids underneath concrete slabs. As the New Jersey Seasonal Study showed that the phenomenon of slab curling/warping can be misidentified as a void, special testing procedures were specified for concrete pavement in Section 5 that should help to minimize these erroneous results.
Three methods are commonly used under the 1993 AASHTO Design Guide for the detection of voids. These are: corner deflection profile, variable load corner deflection analysis, and void size estimation procedure.

Corner Deflection Profile – this method can only be used if corner deflection measurements at a constant load (preferably 9,000 lbs) are available. Approach and leave corner deflections are plotted on a profile and the corners with the lowest deflections (i.e. those likely to have full support) are identified. By examining these plots, a reasonable maximum allowable deflection value can be selected. Corners with deflections above this value would be selected for subsealing. Once a corner is subsealed, the deflection at that location should be measured again, preferably at a similar temperature to the prior test. Corners with deflections still above the maximum allowable value should be subsealed again. The AASHTO 1993 Guide does, however, note that this should be considered only an approximate approach for void detection that may not identify voids accurately if load transfer varies greatly from joint to joint. Also, it does estimate the size of the identified voids.

Variable Load Corner Deflection Analysis – in this method, corner deflections need to have been measured at three different load levels. Load vs. deflection response can then be plotted (linear regression) for each test location and the intrcept value (deflection corresponding to a zero load) can be calculated. For a corner slab without void, the deflection should be zero for zero loading or the intercept value should be theoretically zero or pracically close to zero (less than 0.002 in). Voids are indicated for corners that the intercept value is higher than 0.002 in. The AASHTO 1993 Guide again notes that this method cannot be used to estimate the size of the voids present.

Void Size Estimation Procedure – for this procedure, deflection measurements are needed from the slab center and slab corner; the calculated transverse joint load transfer is also necessary. The center slab deflections are used to standardize the corner deflections and load transfer. The standardized corner deflections are then plotted against the adjusted load transfer. A ‘zero voids band’ is plotted, and deflections falling within this band indicate ‘no voids’. Deflections falling outside the band are used to determine the approximate size and location of the voids at each joint.

BACKCALCULATION ANALYSIS

The 1993 AASHTO procedure should be used to perform the backcalculation analysis for flexible, rigid and composite pavements. The following are the required backcalculation analysis parameters:

Flexible Pavements

- Effective pavement modulus **(E_p,)**
- Effective asphalt modulus (E_{AC}) @68'F
- Effective SN (SN_{eff})
- Effective subgrade modulus (M_r)
- Remaining structural life in terms of ESAL's (RSL)
- Rehabilitation needs ($SN_{Overlay}$ or SN_{New})

Concrete Pavements

- Area of the deflection basin (Area)
- Modulus of Subgrade Reaction (k_{Static})
- Concrete Modulus of Elasticity (Epcc)
- Concrete Modulus of Rupture (Sc)
- Intercept Values for Void Detection
- Rehabilitation Needs (AC overlay thickness and/or required slab thickness)
- Load Transfer Efficiency (LTE) in percent
- Maximum deflections at transverse joint/crack locations

Composite pavements

- Pavement may be treated as a composite or flexible type pavement depending on the specific pavement conditions.
- Corresponding parameters for flexible or rigid pavements

Appendix A: Standard FWD Forms and Common Unit Conversions

This appendix is a collection of forms applicable to the operation and recordkeeping for NJDOT FWDs.

Following is a list of the forms included:
- Form F01, NJDOT FWD Monitoring Temperature Measurements.
- Form F02, NJDOT FWD Monitoring Field Activity Report.
- Form F03, NJDOT Monitoring Maintenance and Repair Summary.
- Form F04, NJDOT FWD Monitoring FWD Buffer Shape.
- Form F05, NJDOT FWD Monitoring FWD Operations Planning.
- Form F06, NJDOT FWD Monitoring FWD Test Comments.
- Form F07, NJDOT FWD Monitoring FWD DMI Calibration.
- Form F08, NJDOT FWD Monitoring IR Temperature Sensor Checks.
- Form F09, NJDOT FWD Monitoring Air/Manual Temperature Sensor Checks.
- Form F10, NJDOT FWD Monitoring FWD Test Slab Locations.
- FWD Problem Report (FWDPR).

Form F01 - NJDOT FWD Monitoring Temperature Measurements

Route	Dir	Lane	MP Location	Test Date
	N, S, E, W	1, 2, 3*		MM-DD-YYYY

* Lanes marked for centerline of route

Nominal Depth	IR-Surface	Mid-depth of Bound Layer	Operator Comments
Actual Depth			
Time	T_o °F	T_{MD} °F	

Notes: 1) Operator comments should 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.

2)Time 2400 clock (8:00 am – 0800 hours, 8:00 pm – 2000 hours
Test Completed

FWD Operator	MM - DD - YYYY	Affiliation

Form F02 - NJDOT FWD Monitoring Field Activity Report

Route	Dir	Lane	MP Location	Test Date
	N, S, E, W	1, 2, 3*		MM-DD-YYYY

* Lanes marked for centerline of route

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)

ADDITIONAL REMARKS REGARDING TESTING

FIELD SAMPLING AND TESTING CREW NAMES:	TRAFFIC CONTROL CREW NAMES:

Form F03 - NJDOT Monitoring Maintenance and Repair Summary

Date		Odometer	

MM - DD – YYYY

Problem Description *

* Enter “routine” for routine maintenance

Description of Maintenance

Performed By: ___ ___ ___

____

Cost

Labor: ____________________________________
Parts: ____________________________________
Total: ____________________________________

Form F04 - NJDOT FWD Monitoring FWD Buffer Shape

Deflection Unit ID: ___________________________________

Buffer Shape: (see following code descriptions)	
Assign Date: MM - DD – YYYY	
De-assign Date: MM - DD – YYYY	

Code	Description
1	**Flat**—4-inch diameter, flat (90º) buffers.
2	**Fully Rounded**—4-inch diameter, "knife cut" variable cone shaped (45º) buffers.
3	**Semi-Rounded**—4.33-inch diameter, tapered (60º) buffers.
9	**Unknown**—buffer shape is unknown.

Form F05 - NJDOT FWD MonitoringFWD Operations Planning

Route:	
Test Setup:	Flexible / Rigid (circle one)
Total thickness of bound layers:, inch	
Test Plan Number:	

Temperature Holes

Hole Number	**Nominal Hole Depth** **Mid-depth of bound layers**	**Adjusted Hole Depth1**
1		
2		
3		
4		

File Names

Dir	Lane	MP Location	Filename

Prepared By:	
Date Prepared: MM - DD – YYYY	
Tested By:	
Date Tested: MM - DD – YYYY	

Form F06 - NJDOT FWD Monitoring FWD Test Comments

Date:	
	MM - DD – YYYY

Dir	Lane	MP Location	Filename/Comments

Tested By:	

Form F07 - NJDOT FWD Monitoring FWD DMI Calibration

Date:	
	MM - DD – YYYY

Deflection Unit ID:	
Section Length (feet)	
New Calibration Factor (counts per mile)	

Performed By: ____

Form F08 - NJDOT FWD Monitoring IR Temperature Sensor Checks

Date:	
	MM - DD – YYYY

Deflection Unit ID:	
Location Performed:	
FWD-Mounted IR Sensor Serial No.	
Hand-Held IR Sensor Serial No.	

Check	Reading	Reference Therm. (°F)	FWD-Mounted IR Sensor			Hand-held IR Sensor		
			Reading (°F)	Error	Pass	Reading (°F)	Error	Pass
Cold	1				Y/N			Y/N
	2				Y/N			Y/N
	3				Y/N			Y/N
Room Temp	1				Y/N			Y/N
	2				Y/N			Y/N
	3				Y/N			Y/N
Hot	1				Y/N			Y/N
	2				Y/N			Y/N
	3				Y/N			Y/N
Acceptable?			Y/N			Y/N		

Performed By: ____

Form F09 - NJDOT FWD Monitoring Air/Manual Temperature Sensor Checks

Date:	
	MM - DD – YYYY

Deflection Unit ID:	
Location Performed:	

Serial Numbers	
FWD Air Temp	Hand-held Sensor

Check	Reading	Reference Therm. (°F)	FWD-Mounted IR Sensor			Hand-held Sensor		
			Reading (°F)	Error	Pass	Reading (°F)	Error	Pass
Cold	1				Y/N			Y/N
	2				Y/N			Y/N
	3				Y/N			Y/N
Room Temp	1				Y/N			Y/N
	2				Y/N			Y/N
	3				Y/N			Y/N
Acceptable?			Y/N			Y/N		

Performed By: ____

Form F10 - NJDOT FWD Monitoring FWD Test Slab Locations

Number of Slabs to be Tested:	

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	

Prepared By:	
Date Prepared: MM - DD – YYYY	

NJDOT Falling Weight Deflectometer (FWD) Testing

FALLING WEIGHT DEFLECTOMETER (FWD) TESTING
FWD PROBLEM REPORT (FWDPR)

Attention: Pavement and Drainage Management Unit

Type of problem:

Reported By:	
Date Reported: MM – DD – YYYY	
Urgent? (Y/N)	
Description:	

THIS SECTION FOR USE BY NJDOT PAVEMENT AND DRAINAGE MANAGEMENT UNIT	
Received by:	
Date Received:	
Referred to:	
Date referred:	
Approved by:	
Date approved:	
Resolution:	
Notes:	