Florida Method of Test for Measuring Pavement Longitudinal Profiles Using a High-Speed Inertial Profiler

Designation: FM 5-549

1. SCOPE

1.1 This test method covers the measurement of pavement surface profiles using a High-Speed Inertial Profiler (HSIP).

1.2 This test method utilizes a pavement surface record generated along the individual wheel paths using an HSIP equipped with laser height sensors. The HSIP shall be capable of data collection at posted highway speeds, operating at a minimum of 15 mph and a maximum of 70 mph. A Zero Speed Profiler (ZSP) can be used in place of an HSIP, there is no minimum speed with the ZSP. This record is analyzed to determine the rate of roughness (or smoothness) and to identify elevation changes in the pavement surface.

2. REFERENCED DOCUMENTS

AASHTO R 56 – Certification of Inertial Profiling System

AASHTO R 57 – Operating Inertial Profiling System

AASHTO M 328 – Standard Specification for Inertial Profiler

ASTM E177 – Recommended Practice for Use of the Terms Precision and Accuracy as Applied to Measurement of a Property of a Material

ASTM E178 – Recommended Practice for Dealing with Outlying Observations

ASTM E950 – Standard Test Method for Measuring the Longitudinal Profile of Traveled Surfaces with an Accelerometer Establishing Inertial Profiling Reference

ASTM E1489 – Standard Practice for Computing Ride Number of Roads from Longitudinal Profile Measurements

ASTM E1926 – Standard Practice for Computing International Roughness Index of Roads from Longitudinal Profile Measurements

ASTM C802 – Standard Practice for Conducting an Interlaboratory Test Program to Determine the Precision of Test Methods for Construction Materials

ASTM C670 – Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

World Bank Technical Paper Number 45 – The International Road Roughness Experiment Establishing Correlation and a Calibration Standard for Measurements

World Bank Technical Paper Number 46 – Guidelines for Conducting and Calibrating Road Roughness Measurements

3. SIGNIFICANCE AND USE

3.1 This test method is to be used for measurements of the pavement smoothness with HSIP on all pavement types.

3.2 This test method provides a means for evaluating the ride characteristics of a new, rehabilitated, or in-service pavement directly from measured surface profiles. The resulting ride quality is quantified in terms of International Roughness Index (IRI) (inches/mile) and/or Ride Number (RN).

The IRI and the RN shall be determined in accordance with ***ASTM E1926*** and ***ASTM E1489***, respectively. In addition, all raw data used in computing IRI and RN shall be filtered with a 300 ft Butterworth (BW) high-pass filter.

3.3 The measured ride values represent smoothness obtained with the subject equipment and procedures stated herein and may not necessarily agree or directly correlate with those obtained by other methods.

.

4. APPARATUS

4.1 All electronic and mechanical components of the HSIP shall be adequately designed and built to meet or exceed the requirements set forth in ***AASHTO M 328***. It shall consist of a minimum of two-line laser sensors with a laser footprint of 4 inches (±0.5 inch) mounted to the host vehicle. These laser sensors shall be mounted 34.5 inches (±0.5 inch) to the left and right of the host vehicle centerline, respectively, to measure pavement profiles in the two-wheel paths of the traveled surface. The ZSP option uses two sets of dual line lasers. A third sensor may be added to the system for rut evaluation and shall be located at the centerline of the host vehicle. The HSIP shall be equipped with a Distance Measuring Instrument (DMI) to measure longitudinally traveled distance and a data acquisition system to collect and store elevation profile data. HSIP shall incorporate a Global Positioning System (GPS) unit to provide latitude and longitude coordinates for all data collected. The operational host vehicle shall not exceed the axle loads specified by the vehicle manufacturer.

4.2 All measuring instruments shall comply with ***AASHTO R 56*** and the requirements specified in ***Section 6.2*** of this test method. The resolution of the vertical measurement shall be a minimum of 0.001 inch with a measuring range meeting or exceeding 7.9 inches. The accelerometer range shall be large enough to accommodate the levels of acceleration expected from the vertical bounce motions of the measuring vehicle (minimum of ± 2 g) with a resolution compatible with that of the laser sensor. The DMI encoder shall produce sufficient pulses such that the longitudinal sampling interval is less than or equal to 1.0 inch. The data acquisition system shall operate at a sufficient speed and capacity to display sensors' outputs in real time.

4.3 The HSIP shall be equipped with an automated triggering system capable of detecting a reference mark to start, stop, and place an event mark in the data collection process.

4.4 The height sensors shall operate at sufficient sampling rate to provide accurate coverage at maximum operating speed. The interval at which relative profile elevations are reported must be less than or equal to 1 inch.

4.5 While the HSIP is driven at highway speed, the sensors shall measure the vertical acceleration of the vehicle, the vertical distance between the vehicle and the pavement surface, and the longitudinal distance traveled as specified in ***AASHTO M 328***. The signals from the sensors shall be combined through a computerized process to generate the longitudinal profile of the pavement surface traveled.

Note 1: Left and right wheel paths are defined as longitudinal strips of pavement 3 feet wide and centered 3 feet from the centerline of the lane toward the adjacent lane or pavement shoulder.

5. SAFETY PRECAUTIONS

5.1 The host vehicle, as well as all attachments to it, shall comply with all applicable State and Federal laws. Precautions shall be taken beyond those imposed by law to ensure the safety of all personnel and the general public. At a minimum, the following conditions must be followed when testing with a HSIP:

5.1.1 All mainline test lanes must be free of any debris and obstructions.

5.1.2 To ensure safety, construction work zone areas including shoulders must meet the requirements of ***Index 600 Series of the Florida Department of Transportation's Design Standards.***

5.1.3 All equipment and personnel must be kept at a safe distance from the profiler testing operation.

6. GENERAL REQUIREMENTS

6.1 Equipment related to profiling quality and the recording system shall be inspected prior to initiating any tests.

6.2 Prior to operation, the profiler system shall be warmed up as specified by manufacturer (or for a minimum of 25 minutes) and calibrated according to specifications described in ***Section 7.2***.

6.3 All profile data shall be collected at an interval less than or equal to 1.0 inch. Depending on the application, the data shall be analyzed to determine RN and/or IRI using a 300 ft BW high-pass filter, or they shall be imported unfiltered into ProVAL (roadprofile.com).

6.4 Testing shall be conducted with the test vehicle tires centered in the wheel paths. Speed shall be maintained at a constant rate throughout the test. Use of cruise control is highly recommended. The testing speed shall be within the posted speed limits. In all instances, the maximum test speed shall not exceed 70 mph. Data collected below 15 mph shall be discarded unless an ZSP is used.

6.5 Profile testing shall be conducted when the ambient air temperature and humidity are within the ranges described in ***AASHTO M 328***.

7. CALIBRATIONS AND VERIFICATIONS

7.1 Test Section Requirements

Test sections for calibration and verification purposes shall include pavements only and shall exclude bridge structures, railroad crossings, ramps, and intersections. They shall be tangent with a grade not exceeding 2 percent, horizontal curvature, or super-elevation.

7.1.1 Distance Calibration – The test section(s) used to calibrate the DMI shall have a minimum length of 0.1 mile. In addition, the test section shall include a minimum of 0.1-mile lead-in and lead-out sections. The length of the test section shall be measured within 0.05 percent of the survey grade measured length. The triggering mechanism shall be placed at the beginning and end of the test section to signal the location of the section limits.

7.1.2 Rut and Ride Verification – Each test section shall be a minimum of 0.3 mile long with the first and last 0.1-mile segments used as lead-in and lead-out, respectively. The middle segment shall be used for verification.

7.2 Calibration and Verification Procedures

Prior to calibration, caution shall be exercised to ensure proper operation of all electronic and mechanical equipment. The pavement shall be free of standing water or debris during testing. All calibrations and verifications shall be performed after the tires and electronic equipment warm-up, as specified by the manufacturer (or after a minimum of 25 minutes warm-up).

7.2.1 Tire Pressure Check – The cold tire pressure shall be checked and maintained as set by the Agency. This check shall be performed before warm-up and according to the schedule in ***Table 1*** shown below.

7.2.2 Distance Check and Calibration – The operator shall measure the longitudinal distance traveled with an HSIP on a test section (***Section 7.1.1***) and report it to ±0.0001 mile. The measured accuracy shall be within ±0.10 percent of the actual test section length. If the measured distance is out of tolerance (for a 1.0-mile test section the acceptable limits are between 0.9990 and 1.0010 miles), the DMI shall be re-calibrated. The calibration shall be performed at the constant speed of 45 mph by traveling the test section in three repeat runs or as recommended by the manufacturer. If the operator deems any run questionable, such run shall be discarded and the distance measurement repeated until the sufficient number of runs with consistent accuracy is achieved. The average of three distance calibration factors (DCF) shall be calculated and saved. The runs shall be automatically triggered at the beginning and end of the test section.

7.2.3 Static Rut Check – Perform the static rut check by simulating vehicle travel with the lasers targeting a rut bar or other suitable flat, level surface approved by FDOT. If any of the following are true, a rut calibration should be performed (***Section 7.2.4***):

- Static rut values are greater than 0.01-inch absolute.
- Can not pass the rut criteria for the rut and ride check specified in ***Section 7.2.8***.
- Tires, suspension components, bumper, or laser sensors are remounted or changed.
- Greater than 6 months since last rut calibration.

7.2.4 Rut Calibration – Perform the rut calibration per manufacturer's recommendation on a rut bar or other suitable surface. The equipment shall have features to display and report error for the operator's acceptance. Following the rut calibration, perform a static rut check as per ***Section 7.2.3***.

Note 2: Rut calibration is not required for systems that do not have a center laser.

7.2.5 Accelerometer Calibration – Shall be performed per manufacturer's recommendation. The equipment shall have the capability to display and report accelerometer error. During the accelerometer calibration, the operator and any other personnel present for daily data collection shall be seated inside the HSIP except for the bounce test (***Section 7.2.7***), when no one should be inside the HSIP.

7.2.6 Block Test – Shall be performed per manufacturer's recommendations while meeting or exceeding the following requirements: Gauge blocks shall be manufactured with thicknesses of 0.25, 0.50, 1.00, and 2.00 inches. The thickness of each gauge block shall be measured at three different positions on each side of the block with a device capable of measuring to nearest 0.001 inch. For each block, nominal thickness shall be determined as an average of measurements made and marked on the block. The nominal thickness shall be used in checking the laser sensors. The tested equipment shall collect number of samples for each gauge block per manufacturer's recommendation. The average difference between nominal thickness and measured values for each gauge block shall not exceed 0.01 inch. The equipment shall have the capability to display and report the error for the operator's acceptance. In the absence of manufacturer's procedures, the block test shall be performed as specified in ***AASHTO R 57***.

7.2.7 Bounce Test – Prior to the bounce test, the HSIP shall be warmed-up as specified by the manufacturer (or for a minimum of 25 minutes). In addition, accelerometer calibration shall be performed as specified in ***Section 7.2.5***. The bounce test shall be performed by positioning the HSIP on a level and flat surface with no wind present. The HSIP's engine shall be switched off with the emergency-brake applied and with the transmission in park. A thin, smooth, non-glossy plate shall be centered under the laser sensors. The data shall be collected in simulation mode using a sampling interval 1.0 inch or less. After the bounce test is successfully completed, accelerometer calibration shall be redone with operator and any other personnel present for daily data collection seated inside the HSIP, as specified in ***Section 7.2.5***.

7.2.8 The data collection shall be performed in simulation mode at a speed set at the midpoint of the manufacturer's recommended data collection speed. At a minimum, data collection shall be performed with a 0.1 mile of lead-in, a 0.3-mile static portion of the test, a 0.3-mile bounce portion of the test, a 0.3-mile additional static portion of the test, and a 0.1 mile of lead-out. During the bounce portion, the laser sensors shall be vertically displaced in a smooth motion. Optimum total displacement is between 1 and 2 inches. The bounce test shall be performed with data processed using a 300 ft BW high-pass filter and analyzed using an IRI interval report with segment length of 528 ft. The static portion IRI results shall be less than 3 inches/mile and the bounce portion IRI results shall be less than 8 inches/mile. If failure is encountered, repeat this procedure three additional times. If threshold values cannot be achieved in all three iterations, contact the manufacturer for troubleshooting before additional testing is performed. The bounce test shall be based on the schedule in ***Section 7.2.11***.

7.2.9 Rut and Ride Check – Shall be performed by collecting data from verification sections of known rut and ride (***Section 7.1.2***). Prior to data collection, complete and pass all previous calibrations (7.2.1-7.2.7). The rut and ride check shall be based on the schedule in ***Section 7.2.11***.

7.2.10 The collected data shall be first processed with a 300 ft BW high pass filter applied. Then, IRI and rut shall be calculated for the entire test section length. The calculated IRI for any pavement surface type shall be within 6 inches/mile of the reference value. Calculated rut values shall be within ±0.03 inches of the reference value. IRI reference values shall be based on an FDOT approved reference device. Reference rut values shall be based on data collected by FDOT HSIPs during the prior one-year period. If failure is encountered, repeat this procedure two additional times. If threshold values cannot be achieved within the three iterations, perform a Rut Calibration (Section 7.2.4).

7.2.11 Frequency – The verification test section(s) roughness shall be verified by FDOT on an annual basis using The frequency of checks and calibration procedures described in ***Section 7.2*** shall be performed in accordance with ***Table 1***.

Table 1. Frequency of Check and Calibration Procedures

Type of Check or Calibration Procedure	Testing Frequency			
	Daily	Weekly	Monthly	Bi-annually
Tire Pressure Check (***Section 7.2.1***)	N, P			
Distance Check and Calibration (***Section7.2.2***)		P	N	
Static Rut Check (***Section 7.2.3***)			N, P	
Rut Calibration (***Section 7.2.4***)				N*, P*
Accelerometer Calibration (***Section 7.2.5***)	N, P			
Block Test (***Section 7.2.6***)			N, P	
Bounce Test (***Section 7.2.7***)	N, P			
Rut and Ride Check (***Section 7.2.9***)			N, P	

N – Network Level, P – Project Level
*Or if needed as per ***Section 7.2.3***

8. PROCEDURE

8.1 Bring the HSIP to the desired speed and alignment prior to beginning test sections. Speed should be maintained as constant as possible throughout the test.

8.2 Before reaching 0.1 mile prior to the beginning of the project limit, turn the DMI on.

8.3 Upon reaching the beginning milepost of the project, start the test section data collection.

8.4 At the end of the project limits, end the data collection.

8.5 Continue driving in the lane that is being tested for a minimum of an additional 0.1 mile and then turn the DMI off.

8.6 Discard test results that are manifestly faulty according to ***ASTM E178***.

8.7 Do not test pavement is wet or if debris is present.

8.8 Perform testing per manufacturer's operation procedure.

8.9 Raw data, equipment maintenance, and calibration records shall be maintained in a logbook located within the host vehicle and made available upon request. If the log is electronic, a backup copy should be kept in a secure location.

9. CALCULATIONS

9.1 Determine test section location, length, and limits.

9.2 Determine the desired index value (IRI) for the pavement section tested.

9.3 Calculate the index value (IRI) for pavement roughness in accordance with the project requirements.

10. REPORT

10.1 Field Report – The field report for each section shall include, as a minimum, the following items:

10.1.1 Location and identification of test section(s).

10.1.2 Date and time of day.

10.1.3 Weather conditions as necessary (temperature, wind).

10.1.4 Type of pavement.

10.1.5 Lane tested.

10.1.6 Speed of test vehicle.

10.1.7 Test value.

10.1.8 Operator.

10.2 Summary Report – As a minimum, the summary report for each test section shall include following items:

10.2.1 Location and identification of test section(s).

10.2.2 Lane tested.

10.2.3 Date of test.

10.2.4 Pavement type.

10.2.5 Test results.

11. PRECISION AND BIAS STATEMENTS

The precision and bias shall be measured in accordance with the repeatability and accuracy determined in ***AASHTO R 56***.