FLORIDA DEPARTMENT OF TRANSPORTATION
State Materials Office
5007 NE 39th Avenue
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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 single point laser height sensors (laser sensors). The HSIP shall be capable of data collection at posted highway speeds, operating at a minimum of 15 mph and a maximum of 60 mph. This record is analyzed to determine the rate of roughness (or smoothness) and to identify elevation changes in the pavement surface.

2. APPLICABLE DOCUMENTS

2.1 AASHTO R-56 – Certification of Inertial Profiling System

2.2 AASHTO R-57 – Operating Inertial Profiling System

2.3 AASHTO M 328 – Standard Specification for Inertial Profiler

2.4 ASTM E-177 – Recommended Practice for Use of the Terms Precision and Accuracy as Applied to Measurement of a Property of a Material

2.5 ASTM E-178 – Recommended Practice for Dealing with Outlying Observations

2.6 ASTM E-950 – Standard Test Method for Measuring the Longitudinal Profile of Traveled Surfaces with an Accelerometer Establishing Inertial Profiling Reference

2.7 ASTM E-1274 – Standard Test Method for Measuring Pavement Roughness Using a Profilograph

2.8 ASTM E-1489 – Standard Practice for Computing Ride Number of Roads from Longitudinal Profile Measurements

2.9 ASTM E-1926 – Standard Practice for Computing International Roughness Index of Roads from Longitudinal Profile Measurements

2.10 ASTM C 802 – Standard Practice for Conducting an Interlaboratory Test Program to Determine the Precision of Test Methods for Construction Materials.

2.11 ASTM C 670 – Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

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

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

2.14 Federal Highway Administration Order 5600.1A, Appendix J

3. METHOD SUMMARY

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

3.2 The HSIP shall conform to ***AASHTO M 328*** and specifications in ***Section 5, Apparatus***. It shall consist of a minimum of two laser sensors mounted in the front of the host vehicle. Two of the laser sensors shall be mounted 34.5 inches (±0.5 inch) to the left and right of the bumper centerline, respectively, to measure pavement profiles in the two wheel paths of the traveled surface. The HSIP has to meet Class 1 profiler requirements as specified in ***ASTM E950-98***.

3.3 The height sensor shall operate at sufficient sampling rate of 15 samples per inch or finer to provide accurate coverage at maximum operating speed. The interval at which relative profiler elevations are reported must be less than or equal to 1 inch and, if needed, post-processed at a larger profile rate (6 inch) based on the intended data processing and analysis.

3.4 The HSIP shall be driven along the wheel paths or as determined by the Engineer. While the HSIP is driven at highway speed, the sensors shall measure the vertical acceleration of the vehicle, the vertical distance between the accelerometer 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: If the vehicle speed drops below 15 MPH, none of the subsequent profile shall be accepted to determine the ride value of the pavement section traveled.

Note 2: Left and right wheelpaths are defined as longitudinal strips of pavement 3 feet (0.91 m) wide and centered 3 feet (0.91 m) from the centerline of the lane toward the adjacent lane or pavement shoulder, respectively.

3.5 The International Roughness Index (IRI) and the Ride Number (RN) shall be determined in accordance with ***ASTM E-1926*** and ***ASTM E-1489***, respectively. In addition, all raw data used in computing IRI and RN shall be filtered to a 300 ft wavelength.

4. SIGNIFICANCE AND USE

4.1 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 IRI (in/mile) and/or RN.

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

5. APPARATUS

5.1 The HSIP shall consist of a host vehicle that conforms to ***AASHTO M 328*** and is equipped with a specially designed bumper capable of housing the laser sensors and accelerometers. The bumper shall house a minimum of two laser sensors and two accelerometers mounted in tandem with each wheel path laser sensor. The sensors shall be mounted 34.5 inches (±0.5 inch) both left and right of the centerline of the host vehicle, respectively. In addition, 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 data acquisition system to collect and store elevation profile data and a Distance Measuring Instrument (DMI) for measuring longitudinally traveled distance. Optionally, the HSIP may incorporate a Global Positioning System (GPS) unit to provide positioning capabilities. The operational host vehicle shall not exceed the axle loads specified by the vehicle manufacturer. The HSIP has to meet Class 1 profiler requirements as specified in ***ASTM E950-98***.

5.2 All electronic and mechanical components of the profiling system shall be adequately designed and built to meet or exceed the requirements set forth in ***AASHTO M 328***.

5.3 All measuring instruments shall comply with ***AASHTO R56-10***, ***Section 5,*** and the requirements in ***Section 7.2***, Profiler Calibration and Verification. The resolution of the vertical measurement shall be a minimum of 0.001 inch (0.0254 mm) with a measuring range meeting or exceeding 7.9 inches (200 mm). The accelerometer range shall be large enough to accommodate the levels of acceleration expected from bounce motions of the measuring vehicle (minimum of ± 2g) with a resolution compatible with that of the laser sensor. The DMI shall produce a sufficient series of pulses, the intervals which represent a distance along the traveled surface (longitudinal sampling), that would result in a resolution of less than or equal to 1.0 inch (25mm). The data acquisition system shall also operate at a sufficient speed and capacity in order to display sensors' outputs in real time.

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

6. SAFETY PRECAUTIONS

6.1 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. No testing shall be conducted when dangerous conditions exist.

7. CALIBRATIONS AND VERIFICATIONS

7.1 Test Section Requirements

Test sections shall include mainline pavements only and shall exclude bridge structures, railroad crossings, ramps, and intersections.

7.1.1 Distance Calibration – The test section(s) used to calibrate the distance-measuring instrument (DMI) shall be tangent and require a minimum length of 0.1 mile (0.16 km) with minimal grade. In addition, the test section shall include a minimum of 0.1 mile (0.16 km) 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 – The test sections shall be uniform in roughness throughout and tangent with minimal grade. Each test section shall be a minimum of 0.3 mile (0.48 km) long with the first and last 0.1 mile (0.16 km) segments used as lead-in and lead-out, respectively. The middle segment shall be used for verification. The test sections shall not have a grade exceeding 2%, horizontal curvature, or super-elevation. The

triggering mechanism shall be placed at the beginning and end of the test section to capture the location of the section limits.

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 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 (Section 7.2.8).***

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 auto-triggered at the beginning and end of the test section.

7.2.3 Rut Calibration – Perform the rut calibration per manufacturer's recommendation. The equipment shall have features to display and report error for the operator's acceptance.

Note 3: Rut calibration is not required for dual laser systems.

7.2.4 Accelerometer Calibration – Shall be performed per manufacturer's recommendation. The equipment shall have 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 with the exception of the bounce test (***Section 7.2.6***), when no one should be inside the HSIP.

7.2.5 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, and 1.0 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. 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***.

7.2.6 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 7.2.4***. 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. Then a thin, smooth, non-glossy plate shall be centered under the laser sensors. In the field, the operator may utilize a non-glossy surface, such as a sheet of paper. The data shall be collected in simulation mode using a sampling interval 1.0 inch or less. After 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 7.2.4***.

7.2.6.1 Network and Project Level

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 1.0 mile static portion of the test, a 1.0 mile bounce portion of the test, a 0.5-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 for a total displacement between 1 and 2 inches. The bounce test shall be performed with data processed using a 300 ft High-Pass filter and analyzed using IRI interval report with segment length of 528 ft. The bounce test shall be based on the schedule in ***Section 7.2.8***. 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. After resolving failure of the system, bounce test shall be performed per ***Section 7.2.6.2***.

7.2.6.2 Research Level

The bounce test shall be performed and analyzed per AASHTO R-57 using ProVAL with 528 ft continuous report option selected. The bounce test shall be based on the schedule in ***Section 7.2.8***. 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. After resolving failure of the system, bounce test shall be performed per ***AASHTO R-57*** until three consecutive successful tests are achieved.

7.2.7 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, the profiler shall pass a distance calibration (***Section 7.2.2***), a block check (***Section 7.2.5***), and a bounce check (***Section 7.2.6***). Profile data shall be collected using sampling interval 1.0 inch or less. The rut and ride check shall be based on the schedule in ***Section 7.2.8***.

7.2.7.1 Network and Project Level

For network and project level, the collected data shall be first processed to 6 inch intervals with a 300 ft wavelength filter applied. Then, IRI, RN, and rut shall be calculated for the entire test section length. The calculated IRI and RN for any pavement surface type shall be within 5% of the reference value, respectively. Calculated rut values shall be within ±0.03 inches of the reference value. Reference values shall be calculated as an average IRI, RN, and rut values 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, contact the manufacturer for troubleshooting before additional testing is performed.

7.2.7.2 Research Level

For research level, perform the rut and ride check as specified in ***Section 7.2.7.1***.

7.2.8 Frequency – The verification test section(s) roughness shall be verified by the FDOT on an annual basis using an FDOT approved reference device. 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	Minimum Frequency		
	Daily	Every 7 Days	Every 30 Days
Tire Pressure Check (Section 7.2.1)	N, P, R		
Distance Check and Calibration (Section7.2.2)		P, R	N
Rut Calibration (Section 7.2.3)			N, P, R
Accelerometer Calibration (Section 7.2.4)	N, P, R		
Block Test (Section 7.2.5)			N, P, R
Bounce Test (Section 7.2.6.1)		P	N
Bounce Test (Section 7.2.6.2)		R	
Rut and Ride Check (Section 7.2.7)			N, P, R

N – Network Level, P – Project Level, and R – Research Level

8. GENERAL REQUIREMENTS

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

8.2 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.

8.3 All profile data shall be collected at an interval less than or equal to 1.0 inch (25.4 mm). Depending on the application, the data shall be analyzed to determine RN_{300F} and/or IRI_{300F} using 300 ft high-pass filter, 6 inch profile intervals and a 12 inch moving average or they shall be imported unfiltered in 6 inch interval into ProVAL.

8.4 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 60 mph. Data collected below 15 mph shall be discarded.

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

9. PROCEDURE

9.1 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.

9.2 Before reaching 0.1-mile prior to the beginning of the project limit, turn the Distance Measuring Instrument on.

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

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

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

9.6 Discard test results that are manifestly faulty according to ***ASTM Recommended Practice E 178***.

9.7 Do not test pavement if debris or standing water is present.

9.8 Perform testing per manufacturer's operation procedure.

9.9 Raw data, equipment maintenance, and calibration records shall be maintained in a log book located within the host vehicle and made available upon request.

10. CALCULATIONS

10.1 Determine test section location, length, and limits.

10.2 Determine the desired index value (IRI, RN) for the pavement section tested.

10.3 Calculate the index value for pavement roughness in accordance with the project requirements.

11. REPORTS

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

11.1.1 Location and identification of test section(s).

11.1.2 Date and time of day.

11.1.3 Weather conditions as necessary (temperature, wind).

11.1.4 Type of pavement.

11.1.5 Lane tested.

11.1.6 Speed of test vehicle.

11.1.7 Test value.

11.1.8 Operator.

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

11.2.1 Location and identification of test section(s).

11.2.2 Lane tested.

11.2.3 Date of test.

11.2.4 Pavement type.

11.2.5 Test results.