STANDARD PRACTICE FOR

The Certification and Operation of Inertial Profiling Systems

FLH Designation: T 401 (2024)

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1. SCOPE

1.1. This practice describes a certification procedure for test equipment used to measure a longitudinal surface elevation profile of asphalt concrete pavement (ACP) based on an inertial reference system that is mounted on a host vehicle. The minimum requirements stipulated herein are intended to focus on the need for accurate and repeatable profile measurements for construction quality control/quality assurance and acceptance.

1.2. This practice describes minimum performance requirements for inertial profiling systems to be used on Federal Lands Highway (FLH) projects where a profile-based smoothness specification is applicable.

2. REFERENCED DOCUMENTS

2.1. AASHTO Standards:

- M 328, Standard Specification for Inertial Profiler
- R 56, Standard Practice for Certification of Inertial Profiling Systems
- R 57, Standard Practice for Operating Inertial Profiling Systems

2.2. ASTM Standards:

- E867, Standard Terminology Relating to Vehicle-Pavement Systems
- E1926, Standard Practice for Computing International Roughness Index of Roads from Longitudinal Profile Measurements
- E2560, Standard Specification for Data Format for Pavement Profile

2.3. Other Documents:

- Sayers, M. W. On the Calculation of International Roughness Index from Longitudinal Road Profile. In Transportation Research Record 1501. Transportation Research Board, National Research Council, Washington, DC, 1995, pp. 1–12.

3. TERMINOLOGY

3.1. Definitions: -

3.2. *Path* - the longitudinal distance as traveled by the physical tire of the profiling vehicle.

3.3. *Profile* - the data collected by the vehicularly mounted inertial profiler for a given wheel path.

3.4. *Reference profile* – the data collected by the ASTM E950, Class 1 device for a given wheel path; for the purposes of certifying vehicularly mounted Inertial profilers.

3.5. *high-pass filtering*—reduces the effect of long wavelengths that are associated with gradual elevation changes such as hills.

3.6. *International Roughness Index (IRI)* —a statistic used to determine the amount of roughness in a measured longitudinal profile. The IRI is computed from a single longitudinal profile using a quarter-car simulation at 50 mph (Sayers 1995). Computer programs to calculate the IRI from a longitudinal profile are referenced in ASTM E1926.

3.7. *Mean Roughness Index (MRI)* —The average of the individual IRI's computed from the left and right wheel paths.

3.8. *longitudinal profile*—the vertical deviations of the pavement surface taken along a line in the direction of travel referenced to a horizontal datum.

3.9. *line laser*—a line laser obtains a series of data points along a line, which is typically perpendicular to the travel direction, with the line typically being 4 inches long. A single, bridged elevation value is computed from this data.

3.10. *report interval*—the longitudinal distance between the outputs of a profile index value.

3.11. *sample interval*—the longitudinal distance between data capture points. The data include location, height, and accelerometer values. These data points are combined to create one profile data point. These points, in turn, may be combined to create a final value in the reported profile.

3.12. *roughness*— the deviation of a surface from a true planar surface with characteristic dimensions that affects vehicle dynamics, ride quality, dynamic loads, and drainage.

4. SIGNIFICANCE AND USE

4.1. This practice outlines procedures for the certifying, verifying, and operating of inertial profiling equipment. It also provides guidance for qualifying the equipment operators and inertial profiling equipment mounted on a specific host vehicle make and model.

5. EQUIPMENT

5.1. *Minimum Requirements* — Provide an ASTM E950, Class 1 inertial profiling system, utilizing line lasers, conforming to AASHTO M 328 except the profiler precision and bias shall be measured in accordance with the repeatability and accuracy as described in Section 8 of this method and certified according to Section 8. Provide certifications at least 21 days before profiling begins. Certification documentation detailing the host vehicle make and model, profiler make and model, and individual operators; dates of current certification and dates of expiration shall be kept with the equipment.

5.2. The profiler software must be able to calculate and report the IRI (in inch/mile) from the corresponding measured true profile and permit the operator to:

5.2.1. Automatically trigger the start and end of data collection at the designated locations.

5.3. Upgrades to, or major component repairs to, or replacement to, an inertial profiler that would require the recertification of the equipment according to Section 8 include:

- Components – the accelerometer, noncontact height sensor, and associated hardware.
- Any printed circuit board necessary for the collection of raw sensor data or the processing of the inertial profiles.
- Permanently Mounted Equipment – major repairs to the host vehicle or change of host vehicle.

5.3.1. The operator of the inertial profiler may make minor adjustments to the equipment without having to complete the recertification process as long as the adjustments allow the equipment to fulfill the verification of the calibration process.

- Inspecting, soldering, or replacing electrical connectors
- Cleaning components, normal adjustments to power supply voltage levels as required by the manufacturer.
- Setting software parameters and/or scale factors as required by the manufacturer in a routine calibration procedure; or
- Mounting on different suitable host vehicle(s) in the case of portable equipment.

5.3.2. Record changes in a Calibration Verification Log to be made available upon request.

6. EQUIPMENT CALIBRATION VERIFICATION

6.1. *General*— Perform the block check and bounce test in accordance with the procedure described in Section 6.2.2. The profiler must pass the block test and bounce test criteria in order to proceed with the equipment certification procedures outlined in Section 8. If equipment fails the block check, bounce test, or both tests, the operator should work with the manufacturer to adjust or repair the equipment.

6.2. *Verifying Calibration*—The following verification procedures are required for an inertial profiler used for QC and QA testing of smoothness for ACP construction where required.

6.3. Standards

6.3.1. *Longitudinal:*

6.3.1.1. The longitudinal verification standard shall be a straight and level roadway test section of at least 528 feet in length with sufficient lead-in and lead-out distance for the vehicle to attain a constant speed before the start of the test section and a safe stopping distance after the test section.

6.3.1.2. Measure this length accurately to within 0.05 percent using a steel measurement tape following the pavement path.

6.3.2. *Vertical:*

6.3.2.1. The vertical measurement standard shall be flat plates and blocks of known thickness and low thermal expansion.

6.3.2.2. Mark the blocks with the known thickness. Certify block thickness' accurate to within 0.001 inch Test a smooth base plate and the 0.25-inch, 0.50-inch, 1-inch and 2-inch gauge block.

6.4. Procedure:

6.4.1. Frequency of Verifying Calibration

6.4.1.1. For QC and QA testing of smoothness for ACP construction, perform the longitudinal and vertical verification of calibration of the inertial profiler prior to use on each project in accordance with the manufacturer's recommendation.

6.4.1.2. Check and document the air pressure of the tires on the host vehicle immediately prior to data collection and maintain according to the vehicle manufacturer's recommendations.

Note 1 -As ambient temperatures change measured tire pressure may change. Tire pressure will be affected by general driving. The most accurate measurements will be before the vehicle has been driven for an extended period of time or after an extended period of rest.

6.4.2. Longitudinal Verification of Calibration:

6.4.2.1. Longitudinal verification of DMI is only applicable to Mechanical DMI Systems.

6.4.2.2. GPS DMI systems do not require verification of calibration prior to use on a project, only during annual calibration.

6.4.2.3. Perform the longitudinal verification of calibration by profiling a measured test section of at least 528 feet utilizing an auto-trigger system according to Subsection 6.2.1.1.

6.4.2.4. The inertial profiler's DMI, after tire and electronic warm-up in accordance with the manufacturer's recommendations, must measure the length of the test section to within 0.15 percent of its actual length.

Note 2 -If necessary, adjust the inertial profiler's DMI subsystem according to the manufacturer's guidelines as needed until the DMI is within measurement tolerance.

6.4.3. Failure to meet the specified tolerance, after multiple attempts to adjust have been performed, will require recalibration, and then reverification as described in Section 6.2.2.2.2.

6.4.4. Vertical Verification of Calibration

6.4.4.1. Vertical verification of calibration consists of performing two tests, the block test and the bounce test.

6.4.4.2. *Block Test*—Vertical height sensor check tests shall be performed per the manufacturer's recommended procedures. If no manufacturer's procedures are provided, perform the block test as described below. Vertical height sensor check tests will be run after the profiler has reached operational stability as specified by the manufacturer. This test will be conducted with the inertial profiler on a relatively flat and level area. During the test, do not lean on the profiler or host vehicle or cause it to move laterally in any way.

Note 3 -Under adverse conditions, it may be necessary to perform this test in a sheltered area

The test procedure consists of the following steps:

1. Position a smooth base plate under the height sensor of the profiler and allow the system to take height measurements.

2. Position a 0.25-inch block underneath the height sensor on top of the base plate and allow the system to take height measurements.
3. Remove the 0.25-inch block from the base plate and replace it with a 0.50-inch block. Make another set of height measurements.
4. Replace the 0.50-inch block with a 1.00-inch block and take another set of height measurements.
5. Replace the 1.00-inch block with a 2.00-inch block and take the last set of height measurements.

Measure, using the profiler height sensors, a base plate and the 0.25-inch, 0.50-inch, 1-inch and 2-inch calibrated gauge block. If the minimum measurement tests are out of tolerance range, then perform the full range of measurements to determine system linearity problems, stand-off problems, or complete system failure. The owner of the profiler must furnish their own base plate and gauge blocks for each inertial profiler system.

6.4.4.2.1. Measure the thickness of the gauge blocks at three different positions along each of the longest sides of the block with a calibrated device capable of measuring to the nearest 0.001 inch For each individual block in a set, calculate an average thickness from all thickness measurements made. This average thickness will be used in checking the height sensors. The average thickness shall be clearly marked on each gauge block. The operator of the profiler will tabulate the measurements and record them in a calibration log. Determine the difference between each gauge block measurement and the measurement of the base plate to get the thickness of the gauge block as measured by the height sensor. Repeat this process for each gauge block. Determine the absolute value of the difference between the computed block thickness and the known average block thickness. This absolute difference will be less than or equal to 0.01 inch for each gauge block.

6.4.4.3. *Bounce Test*—To perform the bounce test, park the inertial profiling vehicle on a surface as flat and level as possible. Power on the system and ensure that the profiler has reached operational stability as specified by the manufacturer. Center a thin, smooth, flat, nonglossy material plate under each sensor. Using the equipment's normal data collection software, initiate a data collection run using a simulated travel speed at the midpoint of the manufacturer's recommended data collection speed range.

The bounce test will require a profile collection run with a minimum simulated travel distance of 2184 feet. Allow the profiler to collect a minimum of 828 feet of static profile with the host vehicle as motionless as possible. Next, the sensor(s) will be displaced vertically by approximately 1 to 2 inch keeping the sensors as close to perpendicular to the surface as possible during this movement. This movement must continue until a minimum of 528 ft. of simulated longitudinal distance has been covered. After a minimum of 528 feet of bounce profile is collected, allow the profiler to collect an additional minimum of 828 feet of static profile. The profiles will then be saved and

analyzed using the latest version of *ProVal* software to compute the continuous IRI with a 528-ft base length for each profile collected.

When reviewing the analysis results, ignore the first and last 300 feet of the profile, as it is lead-in and lead-out distance. Ensure the remaining static portions result in an IRI of less than 3 inch/mile and the bounce portion IRI is less than 8 inch/mile. The two static IRI portions should be about the same. This requirement applies to each sensor in the profiler.

6.4.5. For profilers used for QC/QA of ACP construction, control sections can be established by selecting one or more sections measuring 528 feet with a maximum IRI of 120 inch/mile. The selected section will provide a consistent ride profile for the duration of the project. A profiler certified within the past 90 days will be able to determine the IRI of the control section(s) by making at least five profile measurements. The average IRI of the measurements will be used to establish the IRI of the control section(s), provided that the cross-correlation of the measurements, as determined using the latest version of *ProVal*, is at least 88 percent (value is dependent on the filters used, spectral content of the measured surface, operator, etc.). Once established, the control section(s) can be used to validate that an inertial profiler is operating properly daily.

6.5. Checks using the previous day's data can be used when data is being collected on a continuous and daily basis. Under these circumstances, it is possible to rerun sections of pavement measuring 528 feet that were measured on the previous day for comparison purposes. The current day's IRI value should not differ by more than 6 percent from the previous day's IRI value.

6.6. *Calibration Verification Log*—Maintain a log that will be kept with the inertial profiler to provide a verification of calibration history. Include the results of the routine bounce tests and verification runs in this log, record of any repairs, replacement of components, and changes in native software versions. If the log is electronic, a backup copy shall be kept in a secure location.

7. OPERATOR CERTIFICATION

7.1. Operators of inertial profilers used for pavement ride quality measurements must pass a proficiency test and be certified to operate an inertial profiler. FLH will not certify outside operators. Applicants for certification will be tested on the following:

- *Operating inertial profilers,*
- *Collection of profile data, and*
- *Evaluating the quality of the data collected.*

7.2. Applicants for certification will undergo a practical and written examination. Prior to taking the proficiency test, applicants should have completed a profile

training similar to NHI Course 131100 and must have undergone training specifically tailored to the inertial profiler they will be operating in the field. Applicants must know how to initiate and perform profiler checks as described in section 6.2 and collect profile data with the inertial profiler.

7.3. Upon passing the proficiency tests for certification, applicants will be given certifying documentation specific to the type or brand of inertial profiler the operator is certified to operate. Re-certification will be required within the past three years.

8. EQUIPMENT CERTIFICATION

8.1. Certification will be performed every 12 months at a minimum. FLH will not certify outside equipment. The inertial profiler will be recertified after any major component repairs or replacements as identified in section 5.3.

8.2. *Dynamic Certification Testing*—Certification testing will be performed at a location approved by FLH, utilizing test sections, reference profiles, and devices used to establish reference profiles as described by the following:

8.2.1. *Test Sections*—Perform dynamic certification testing on sections of pavement over a range of roughness measured by a reference profiling device conforming to ASTM E950, Class 1. At a minimum, certification will be performed on a test section conforming to the requirements for a medium-smooth IRI, within the range of 95 to 135 inch/mile, or an IRI range less than 90 inch/mile. Each test section will be at least 528 feet in length, with adequate lead-in distance, as recommended by the profiler manufacturer, and safe stopping distance available. Test sections should be generally flat and not include significant grade or grade change. Significant horizontal curvature or super elevation should be avoided.

8.2.2. *Reference Profiles*—A reference device conforming to ASTM E950, Class 1 that can collect data at 1-inch intervals or less and receiving the approval of FLH will be utilized. Reference profile measurements will be completed for the designated wheel paths of each test section.

8.2.3. Five repeat runs of the inertial profiler being certified shall be made at each test speed on the designated profile path of each test section in the prescribed direction of measurement. Make five runs each for the upper and lower certification speeds. Data collection will be automatically triggered at the starting and ending locations of the sections and reported. This automatically triggered section may be used to verify the repeatability and accuracy of the DMI.

8.3. Test Data - Profile data shall be reported in pavement profile format (*.ppf).

8.3.1. During the certification testing, the same reference profile is utilized for comparison of all runs on a given test section in that wheel path. Ensure that the sensor spacing matches the spacing between the paths where reference profile measurements were obtained.

8.3.1.1. The first three characters of the file name are reserved for identifying the profiler tested. This identification will be established by the testing agency and given to the operator of the profiler on or before the day of testing.

8.3.1.2. The fourth character shall be S for runs made on the smooth section or M for runs on the medium smooth section and R for runs made on the medium-rough section.

8.3.1.3. The fifth character shall be L or H for low- or high-speed runs.

8.3.1.4. The sixth character shall designate the wheel path tested. For dual-sensor profilers, the letter B shall be used to indicate that both wheel paths were profiled in the same run.

8.3.1.5. The seventh and eighth characters shall designate the run number (01 to 10).

8.4. Cross-correlation, as described in the following sections, will be used to establish the repeatability and accuracy of the inertial profiler being certified. *ProVal* will be utilized to perform the calculations specified below.

8.4.1. *Equipment Repeatability*—Calculate and evaluate the repeatability of each profile using the cross-correlation of the filtered output as described in Section 8.3.1.9. The IRI filter should be utilized for the evaluation of each profile. On each profile, cross-correlate the profiles to each of the remaining ones. The repeatability agreement score for each profile is the average of all the values for that test section. For IRI, an agreement score of 0.92 or greater is required on all profile to provide IRI values within 5 percent with a 95 percent confidence level.

8.4.2. *Equipment Accuracy*—Calculate and evaluate accuracy using the cross-correlation of the IRI filtered output as described in Section 8.3.1.9. On each profile, cross correlate each of the profiles to the reference profile. The accuracy agreement score for each profile is the average of the individual cross-correlation values. Based on the same rationale as in Section 8.3.1.7, a score of 0.90 or greater is required on all profiles to provide IRI values within 5 percent with a 95 percent confidence level.

8.4.3. *Cross-Correlation*—Cross-correlate profiles as described in Appendix X1 of AASHTO R56. When cross-correlating two profiles, the following processing steps are required:

8.4.3.1. Apply the Low Pass filter to the profile collected with the profiler and not to the reference profile.

8.4.3.2. When comparing a profile from the inertial profiler being certified to the reference profile, interpolate the profile to the recording interval of the reference profile. Perform this step after the filter is applied.

8.4.3.3. Cross-correlate the two profiles several times by shifting one profile over every possible offset up to 3 ft in either direction. When comparing a profile from a device being certified to the reference device, only adjust the profile from the inertial profiler being certified.

8.4.3.4. The cross-correlation of the two profiles is the maximum (best) value found over the 6-ft range.

8.4.4. *Verification of Computed Ride Statistics (IRI)*—The test equipment software must be capable of computing and reporting the IRI of each profile tested. The performance of the calculation software is verified by comparing the calculated values with the values determined by *ProVal*. IRI values generated by the test equipment software should agree with the *ProVal* value with an error less than or equal to 2 percent.

8.5. *Distance Measurement Instrument (DMI) Test*—Verify the accuracy of the DMI on a test section using the procedure specified below.

8.5.1. *Distance Measurement Instrument Test Section*— DMI testing will be performed on a test section of at least 1000 feet in length, with a minimum of a 300 foot lead-in and lead-out distance. This test section may incorporate the test sections that are used for accuracy and repeatability testing. Identify the starting and ending points of the test section for use with an auto-triggering device. Measure the distance between the starting and ending points with a steel measurement tape following the pavement contours.

8.5.2. At least three auto-triggered runs at the lowest and highest test speeds of the inertial profiler being certified shall be made on the designated test section. At the end of each run, record the reading from the profiler's DMI.

8.5.3. *Distance Measurement Instrument Accuracy*—Calculate the absolute difference of the DMI readings and the measured distance of the test section for each run. The average of the absolute differences must be less than 0.15 percent.

8.6. *Test Results*—The results of the certification tests shall be documented by the testing agency. The distribution of the results of the certification shall be determined by the testing agency. Results of certification shall include the following information:

8.6.1. Identification of the profiler tested and host vehicle (i.e., make, model serial number, software version, owner, etc.);

8.6.2. Date of last certification;

8.6.3. Operator of the profiler;

8.6.4. Name of the individual from the testing agency who conducted the test;

8.6.5. Date of test;

8.6.6. Number of paths the profiler can measure in the same run;

8.6.7. Filter type, name of the filter program, and the applicable program version number used to evaluate the profiler accuracy;

8.6.8. Overall determination from the test: Pass or Fail;

8.6.9. Known longitudinal distance of the DMI test section; and

8.6.10. Average absolute difference between the DMI readings and the known distance, expressed in distance unit and as a percentage of the known longitudinal distance.

8.6.11. The following information is to be provided for each profile:

8.6.12. Overall accuracy score.

8.6.13. The report shall also label each test result with a Pass or Fail as applicable. The profiler must pass all tests to be certified. Certification documentation detailing the host vehicle make and model, profiler make and model, and individual operator; dates of current certification and dates of expiration shall be kept with the equipment.

9. MEASURING

9.1. Measure the pavement profile in both wheel paths simultaneously using a sensor path spacing of 65 to 71 inches and centered in the traveled way of the lane. Operate the inertial profiler according to the requirements established herein and the manufacturer's recommendations. Do not apply filters when collecting profile data. Filtering will be applied during profile analysis in *ProVal*. Collect profile data (elevation and distance) at a maximum interval of 2 inches. Provide a lead-in distance of at least 150 feet after reaching the testing speed. Use the profiler's automatic start/stop activation when collecting data.

9.2. Utilize an automatic triggering system for event markers to mark the beginning and ending location of areas to be excluded from profile measurement.

9.3. Export and report each profile (elevation, distance data, header, and marker information) in pavement profile format (.ppf) after profiling is completed. Do not report non-continuous data files.

9.4. Test Data Description and Format

9.4.1. In addition to proprietary file formats, provision shall be made for export of profile data in the format per ASTM E2560 or other *ProVal*-compatible formats.

9.4.2. Export and report each raw profile before applying filtering, exclusions, or other modification.

9.4.3. Use the following naming convention for electronic file submissions:

(a) For Type I and Type II pavement roughness:

[Project Number] _ [starting station_to_ending station] _ [Initial or Final],

Example: WY_NPS_YELL_10(1)_25+50_to_387+35_Initial.ppf.

(b) For Type III pavement roughness:

[Project Number] _ [starting station_to_ending station] ,

Example: WY_NPS_YELL_10(1)_25+50_to_387+35.ppf.

10. EVALUATION AND CALCULATION

10.1. The MRI will be calculated from profile measurements using *ProVal*.

10.2. Using *ProVal*, a high pass filter length of 300 feet and a low pass filter of 250 millimeters will be applied to the profiles. Individual MRI values are determined by averaging the IRI value from each wheel path. Fixed interval MRI values are reported as an average of the individual MRI values over the fixed interval length. An overall MRI value will be determined by averaging the individual MRI values, excluding segments less than 25 feet for Type I and Type II pavement roughness or 528 feet for Type III pavement roughness.

10.3. Areas of localized roughness will be identified by using *ProVal*'s continuous MRI function with a segment length of 25 feet. This will yield an average MRI value and a length for each area of localized roughness which exceeds the localized roughness threshold value of every possible 25-foot segment. Areas for which the continuous report exceeds the threshold MRI value for the specified roughness type will be reported.

10.4. Identify excluded areas.

11. TEST PROCEDURE

11.1. Test procedure outlines the steps for measuring the pavement profile using an inertial profiler for QC/QA testing of smoothness of new construction.

11.2. Clean the roadway path to be measured of all debris and other loose material. Collect data on dry pavement.

11.3. When measuring the pavement profile, operate the inertial profiler at a relatively constant speed within the certified range of the inertial profiler system. All data collected above or below the certified speed range are not acceptable.

Note 4 -(Failure to maintain the minimum certified speed will cause the inertial referencing subsystem to "drop" and the pavement profile elevations will not be usable.)

11.4. Remeasure any pavement segment where the travel speed of the profiler is less than or exceeds the manufacturer's recommended operational speed at any point during data Collection.

11.5. Quality Profiles:

11.5.1. Operate host vehicle at the lower end of the certified speed range when profiling on vertical and horizontal curves when testing for smoothness of new construction.

11.5.2. Higher speeds may cause excessive pitch and roll in the host vehicle and adversely affect the profile measurements.

11.5.3. Rapid longitudinal accelerations and decelerations (e.g., heavy braking) may adversely affect the profile measurements.

11.6. A lead-in length of roadway of up to 450 feet is required to stabilize the inertial profiler's filters and achieve the same accuracy in the first 0.1 mile that is achieved through the rest of the job. The pre-section length is dependent on the filter type, the grade change on entering the test segment, and the accuracy required of the first 0.1 mile of measured pavement. Typically, this pre-section shall be at least 300 feet in length and located immediately before the section of pavement to be tested. Shorter sections have been used when the physical constraints of the project required it and the other project conditions made it acceptable.

11.7. Two longitudinal profiles are specified, set the sensor path spacing between 65 and 71 inch

11.8. Collect measurements in the direction of traffic. If this is not practical and data are collected in the other direction, make a note. Repeat measurements if operator and/or equipment errors are encountered. All runs provided to the CO. After completing data collection, check roughness indices for reasonableness based on the operator's experience.

Note 5 -Note - (Unreasonable roughness values could be an indication of equipment problems)

11.9. Data Collection - Submit a table to FLH that identifies the lane(s), profile(s), and distance location(s) tested for each file created during the QA testing.

11.10. Present the profile elevation data to FLH in an approved electronic file format (.ppf). The format must be readable by *ProVal*. If the submitted profile data files are created from raw profile data using an export option in the manufacturer's software where filter settings for export can be specified, ensure that the filter settings used to create the data files are similar to the settings that were used to create data files during certification.

11.11. Compute a summary roughness statistic. The required index to compute is the continuous MRI reported as a histogram that presents the percentage of the job that falls within MRI categories selected by FLH.

12. REFERENCES

12.1. ASTM Standard E867, Standard Terminology Relating to Vehicle Pavement Systems, ASTM International, West Conshohocken, PA.

12.2. ASTM Standard E950, Measuring the Longitudinal Profile of Traversed Surfaces, ASTM International, West Conshohocken, PA.

12.3. NHI Training Course 131100. Pavement Smoothness: Use of Inertial Profiler Measurements for Construction Quality Control.

12.4. Sayers, M. W., and S. M. Karamihas. The Little Book of Profiling. University of Michigan Transportation Institute, Ann Arbor, MI, 1998.

12.5. Sayers, M. W., T. D. Gillespie, and W. D. O. Paterson. "Guidelines for Conducting and Calibrating Road Roughness Measurements." In The World Bank Technical Paper, Number 46. The World Bank, Washington, DC, 1996.