AMERICAN SOCIETY FOR TESTING AND MATERIALS
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Standard Test Method for Measuring the Longitudinal Profile of Traveled Surfaces with an Accelerometer Established Inertial Profiling Reference[1]

This standard is issued under the fixed designation E 950; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the measurement and recording of the profile of vehicular-traveled surfaces with an accelerometer established inertial reference on a profile-measuring vehicle.

1.2 The test method uses measurement of the distance between an inertial plane of reference and the traveled surface along with the acceleration of the inertial platform to detect changes in elevation of the surface along the length being traversed by the instrumented vehicle. In order to meet a particular class, the transducers must meet accuracy requirements and the calculated profile must meet the specifications of that class.

1.3 The values measured represent a filtered profile measured from a moving plane of reference using the equipment and procedures stated herein. The profile measurements obtained should agree with actual elevation measurements that are subjected to the same filtering. Selection of proper filtering allows the user to obtain suitable wavelength information for the intended data processing.

1.4 Either metric or inch-pound units may be used, but must be used consistently and not mixed.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* Specific precautionary information is given in Section 7.

2. Referenced Documents

2.1 *ASTM Standards:*

E 178 Practice for Dealing with Outlying Observations[2]

E 867 Terminology Relating to Traveled Surface Characteristics[3]

E 1166 Guide for Network Level Pavement Management[3]

E 1364 Test Method for Measuring Road Roughness by Static Level Method[3]

F 457 Test Method for Speed and Distance Calibration of a Fifth Wheel Equipped with Either Analog or Digital Instrumentation[4]

3. Terminology

3.1 *Definitions:*

3.1.1 *aliasing—in the context of this practice,*—the spectrum of a digitized data record exists over the range of frequencies from zero to one half the sampling frequency. If the spectrum of the original signal extends beyond one half the sampling frequency, then those components of the signal at frequencies higher than one half the sampling frequency will, when digitized, be folded back into the spectrum of the digitized signal. The excessively high frequency components will thus be "aliased" into low frequency components.

3.1.2 *anti-aliasing filter*—a low-pass analog filter applied to the original analog profile signal to suppress those components of the signal at frequencies higher than one half the intended digital sampling frequency.

3.1.3 *frequency domain filtering*—a filtering operation performed by first calculating the the spectrum of the profile record and then multiplying the spectral components by the frequency response transfer function of the filter.

3.1.4 *profile record*—a data record of the surface elevation, slope, or acceleration, of arbitrary length.

3.1.5 *profile segment*—that part of a profile record for which the profile index will be calculated.

3.1.6 *spatial domain filtering*—a filtering operation performed directly on the profile record

4. Summary of Test Method

4.1 The test apparatus consists of a vehicle equipped with the necessary transducers, computing, and recording equipment to measure and record elevation profile of the traveled surface **(1)**.[5]

4.2 The sampling rate is selected and depends on the anticipated roadway conditions and data requirements for the intended data processing.

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[2] *Annual Book of ASTM Standards*, Vol 14.02.

[3] *Annual Book of ASTM Standards*, Vol 04.03.

[4] *Annual Book of ASTM Standards*, Vol 09.02.

[5] The boldface numbers in parentheses refer to the list of references at the end of this standard.

4.3 The test apparatus is driven in the wheel tracks or in the correct lateral location over the section of traveled surface to be profiled. Transducers measure vertical acceleration of the vehicle and the vertical distance between the accelerometer and the traveled surface and the longitudinal distance. These transducer signals are combined by a computer to produce the longitudinal profile of the traveled surface.

5. Significance and Use

5.1 The measurement of vehicular traveled surfaces using an instrumented vehicle with an inertial plane of reference provides a satisfactory method for acquiring traveled surface profile data **(1)**.

5.2 The profile data can be processed to produce, by simulation, the outputs of other devices. This can be done on line in real time or can be computed as a post process. Some of the devices that can be simulated include road meters **(2)**, various straightedge devices **(3)**, profilographs, **(4)**, as well as pavers and grinders. Comparisons of various equipment and their profile computer programs are given in reference **(5, 6)**.

5.3 The raw data or the profile data can also be recorded for data processing at a later time and for analysis by more complex data processing procedures.

6. Apparatus

6.1 The test apparatus consists of a vehicle equipped with transducers and profile computing and recording equipment. The transducers are used to measure vertical acceleration, displacement, and the distance traveled. The computer is used to process the transducer outputs to produce the computed profile of the traveled surface. The test apparatus must have transducer capability for one or more tracks and a mass storage device for long term storage of the data. If two wheel tracks are measured, the displacement transducers shall be mounted 1.5 to 1.8 m (58 to 71 in.) apart so that they measure in the two wheel tracks of the traveled surface. A set of gage blocks must be included to calibrate and validate static transducer operation. Other supporting apparatus can include a driver speed display and a graphical display of the profile or data. Some form of data display is recommended to ensure correct data is being collected.

6.2 *Vehicle Requirements*—The vehicle is the platform for the mounting of the profile-measuring equipment. The vehicle shall be large enough to accommodate all the required equipment without major structural modifications. The engine, steering mechanisms, and suspension components shall be adequate to allow smooth maintenance of speed and direction of travel. The environment of the interior of the vehicle shall be maintained within tolerable limits of the instrumentation and operators.

6.3 *Transducers*:

6.3.1 *Accelerometer*—The accelerometer measures the acceleration used to establish the inertial reference. A high-quality accelerometer shall be used that meets the class requirements of the profiling device. The accelerometer shall be mounted on the measuring vehicle with the accelerometer's sensitive axis perpendicular to the traveled surface. The accelerometer range shall be large enough to accommodate the levels of acceleration expected from the bounce motions of the measuring vehicle (typically ± 1 g). The accelerometer shall be biased to account for the 1-g acceleration of gravity. The accelerometer or external circuitry shall contain a self-calibration external voltage source which, on command, causes the output of the acceleration signal level to change a predetermined value. The accelerometer shall have a minimum resolution to allow profile calculation and accuracy and bias to meet the class requirements as given in this standard.

6.3.2 *Displacement Measurement*—A displacement transducer measures the distance between the accelerometer and the traveled surface. The transducer shall be mounted on the vehicle with its measuring axis perpendicular to the traveled surface and in line with the sensitive axis of the accelerometer. The displacement transducer shall measure the vertical distance to the traveled surface continuously, or sample at intervals not greater than that needed to allow calculated profile as given in Table 1. The vertical resolution is that necessary to meet the class given in Table 2.

6.3.3 *Distance Measurement*—The distance transducer may be of the type that produces a series of pulses, the intervals of which represent a distance along the traveled surface to a resolution needed to satisfy Table 1. The pulses are used to measure speed and can be used to convert from a function of time to a function of distance traveled. Any distance transducer that produces analog or digital signals with sufficient accuracy may be used. The accuracy of the distance measurement is established by calibration (see 9.2.3).

6.3.4 *Location Markers*—Use of a section start, intermediate feature location(s), and section end shall be identified by location marks that can be accurately detected by an automatic means, such as magnetic detection, photocells detection of reflective tape or similar means.

6.4 *Profile Computation*—A computer shall be used to process acceleration, and distance transducer outputs to produce measured traveled surface profile. There are two basic methods of computing measured traveled surface profile:

6.4.1 *Spatial Based*—In the spatial based method, the transducer outputs are acquired and profile data points are computed as a function of the distance traveled. In the spatial-based method, the computation of measured road profile is independent of the vehicle measuring speed.

6.4.2 *Time-Based*—In the time-based system, the transducer outputs are acquired and profile data points are computed as a function of a fixed-time interval. In the time-based method, the computation of measured road profile is not independent of the vehicle measuring speed.

6.4.3 Filtering that permits the computation of measured elevation profile with no attenuation or amplification of road profile wave lengths at least 60 m (200 ft) long at test speeds of 25 to 95 km/h (15 to 60 mph) shall be provided. The computer and system shall not add noise in excess of 10 % of the displacement measuring transducer resolutions given in Table 2.

TABLE 1 Longitudinal Sampling

Class 1	less than or equal to 25 mm (1 in.)
Class 2	greater than 25 mm (1 in.) to 150 mm (6 in.)
Class 3	greater than 150 mm (6 in.) to 300 mm (12 in.)
Class 4	greater than 300 mm (12 in.)

TABLE 2 Vertical Measurement Resolution

Class 1	less than or equal to 0.1 mm (0.005 in.)
Class 2	greater than 0.1 mm (0.005 in.) to 0.2 mm (0.010 in.)
Class 3	greater than 0.2 mm (0.010 in.) to 0.5 mm (0.020 in.)
Class 4	greater than 0.5 mm (0.020 in.)

6.4.4 As part of the profile computation equipment, a computer terminal shall be provided that will allow the operator to perform system calibration, select system parameters, and monitor system outputs.

6.5 *Driver Speed Display*:

6.5.1 The vehicle speed shall be displayed conveniently for the driver to assist in maintaining the desired measuring speed on systems requiring constant speed during measurement. Some systems, especially in the case of spatial based systems, are independent of speed and the speedometer is sufficient.

6.5.2 The displayed vehicle speed, when required, may be computed by the profile computer from the distance pulses. Other means of measuring vehicle speed are acceptable.

6.6 *Display*—A display should be used that allows visual monitoring of the systems outputs. The display should allow profile amplitudes to be displayed as a function of time or distance traveled. Amplitude and distance scaling shall be controlled by the operator through the profile computer terminal.

6.7 *Storage Device*—A device shall be provided for the recording and long term storage of data or computed profile, or both. The device shall have play back ability for additional on-board processing or for later processing. Profile data for recording shall be scaled by the computer to maintain storage resolution of the computed profile and to accommodate the full range of amplitudes encountered during normal profile measuring operation. Signal to noise (S/N) ratio shall be 10 or better.

6.8 *Event Marker*—The operator shall be provided the means to event mark location data as part of the data records. The system may use a transducer (optionally) to automatically sense and automatically record location markers that have been placed on the traveled surface.

7. Safety Precautions

7.1 The test vehicle, as well as all attachments to it, shall comply with all applicable state and federal laws. Necessary precautions imposed by laws and regulations, as well as vehicle manufacturers, shall be taken to ensure safety of operating personnel and other traffic.

8. Digital Profile Recording

8.1 The computed profile shall be recorded at adequate intervals for accurate representation of the traveled surface for the intended use of the data. Also, antialiasing filters are required when the folding frequency (½ of sampling frequency) is close to the upper frequency of interest (see Terminology E 867). Identical antialiasing filtering must be applied to both the accelerometer signal and to the displacement measurement signal before computing profiles. The upper filter frequency depends upon the intended use of the profile.

8.2 Where two or more paths of traveled surface are measured, the recorded profile data for the paths shall be at the same longitudinal location. This requirement is not necessary if the analysis to be used is independent of the wheel tracks (for example, only quarter car analysis used).

9. Calibration Procedures

9.1 Due to the level of performance required of the class of traveled surface profile measuring apparatus, it is important that the system and its components be calibrated periodically as recommended by the manufacturer.

NOTE 1—Due to the complexity of the calibration, it is recommended that the calibration procedure be automated to reduce or eliminate operator involvement and decision making.

9.2 *Transducers*:

9.2.1 *Acceleration Transducer*—The acceleration transducer shall have an internal or external calibration feature. A measure of the accelerometer error shall then be displayed for the operator's acceptance. As an alternative, the acceleration transducer may be calibrated separately in the laboratory. In either case, an error larger than that allowed for the class shall not be accepted.

9.2.2 *Displacement Transducer*—The displacement transducer shall be statically calibrated by introducing an accurately measured step of displacement. The displacement step shall be at least 25 mm (1.0 in.) and accurate within class requirement. A measure of the displacement transducer error shall be displayed for the operator's acceptance or adjustment.

9.2.3 *Distance Transducer*—The distance transducer shall be calibrated by measuring a predetermined distance on a straight section in a similar manner as given in Test Method F 457. The measured distance shall be long enough to determine any significant difference between the measured distance and the predetermined actual distance. A measure of the distance transducer error shall be displayed for the operator's acceptance or adjustment. An error larger than 0.1 % of the actual distance shall not be accepted. The transducer shall be calibrated at the measuring speed(s) to be used.

10. Procedures

10.1 *General*:

10.1.1 *System Power*—Turn on electronic equipment prior to testing to allow electronic components to stabilize (see manufacturer's operating manual).

10.1.2 *System Parameters*—If required, select the system parameters that define the wavelength content of the surface profile to be measured (see manufacturer's operating manual).

10.1.3 *Calibration Checks*—Perform calibration checks at the beginning of a day of operation and at any other time the operator may suspect changes of system performance since the last calibration. Also, calibration checks should be made at the end of each day or prior to departing a region to ensure collected data is valid.

10.1.3.1 *System*—Check the calibration by using the simple procedure of bouncing the vehicle, while it is stationary, on a flat surface. This checks the major portion of the system. In this mode of operation, the surface profile is unchanging and the system output should be less than 1 % of the vehicle bounce amplitude. A measure of the traveled surface profile measuring system error shall be displayed for the operator's acceptance.

10.2 *Measuring Speed*:

10.2.1 Better quality profile calculations are generally obtained at higher measuring speeds because of the filters used. Higher measuring speeds may, however, be limited by the ability of the apparatus to measure an extremely rough surface at high speed. Measuring speed might have to be reduced for sampling of shorter intervals **(7)**.

10.2.2 Avoid measuring speeds below 25 km/h (15 mph) since the quality of the long wavelength content of the measured profile will be affected or a much higher resolution accelerometer must be used. Measuring speeds as low as 2 m/s (5 mph) may be used where higher speeds are not practical and long wavelength content is not important; such as, on very rough roads, railroad crossings, or other special conditions.

10.2.3 Avoid sudden speed changes to minimize unwanted input to the acceleration transducer and transients to the filters.

10.3 *Test Sections*—In preparation for measuring short test sections of a traveled surface, the operator should become acquainted with the test section to be measured including the beginning, end, and any other features that should be identified within the test section. If identifying features within the test section are to be sensed automatically, the operator shall place the proper marker on the traveled surface at the locations to be identified. It is very important that the wheel tracks be identified on the roadway so that the measurements are made in the wheel tracks or in the paths that are to be measured.

10.4 *Data Acquisition*:

10.4.1 Enter information about the test section and conditions of the test (see Section 12).

10.4.2 At least 150 m (500 ft) (or at manufacturer's specified lead-in) prior to the beginning of the test section, bring the apparatus to the desired speed.

10.4.3 Prior to reaching the test section, at least 150 m (500 ft) or as needed because of the long wavelength filter, switch the system to the test mode.

10.4.4 At the start of the test section, identify its beginning as part of the recorded data. This can be done automatically or manually with an event marker.

10.4.5 Measure the surface profile within a traveled lane as close as possible to the track established by normal traffic. If a single track is measured, it should be in the center of the wheel track of the normal traffic track for that side or in the center of the path to be measured. If more than one path of the traveled surface is measured, then one track should be in the center of the normal traffic track (left or right, but should be the same each time the test section is measured). Note that if the distance between sensors is not that of the actual wheel tracks, then only one measurement is actually centered in a wheel track and should normally be the right track.

10.4.6 Observe and check that the data is reasonable as it is recorded. If profile data is collected for multiple wheel tracks, traces for the right and left wheel tracks should be very similar except for short wavelengths.

10.4.7 Identify, as part of the recorded data, other physical features or known reference points within the test section that will assist in relating the calculated profile to actual traveled surface profile.

10.4.8 Identify the end of the test section.

10.5 *Data Evaluation for Correctness*:

10.5.1 If there is a question about the performance of the test apparatus for the test run, make an immediate check by measuring the test section again. The calculated profile or a point by point basis for the two runs should be within that specified by the class the apparatus is to meet.

10.5.2 Occasionally, evaluate the profile or raw data recorded on the storage device by playing the recorded data back to the recorder or display. The calculated profile or raw data played back to the display should be identical to the data recorded on the display when it is first calculated. Any difference between the profiles indicates an equipment problem with the storage device. A printing recorder is especially helpful here.

11. Faulty Tests

11.1 Any observable differences between the measured profiles of the left and right wheel tracks (see 10.4.6) that cannot be attributed to actual differences in the roadway mandate a repeat measurement. Any observable differences between the two identical runs, in accordance with Practice E 178, other than differences due to differences in the paths that were measured, indicate an equipment problem and invalidate the tests.

12. Report

12.1 The field report for each test section shall contain data on the following items:

12.1.1 Date and time of day,

12.1.2 Operator, driver, and vehicle identification,

12.1.3 Weather conditions; principally temperature, cloud cover, and wind,

12.1.4 Location and description of test section,

12.1.5 Surface description; type of pavement and condition,

12.1.6 Run number,

12.1.7 Measuring speed,

12.1.8 Direction measured,

12.1.9 Lane measured, transverse position,

12.1.10 Profile data, and

12.1.11 Other system specific measurement options, for example, filter wavelength data interval, and resolution.

13. Precision and Bias

13.1 The accuracy of pavement profile measuring equipment can be defined by a statement on the precision and bias of the measuring equipment.

13.2 *Precision*—Precision in the measurement of pavement profile elevations is related to the closeness of agreement between repeat measurements of the same pavement profile.

13.2.1 Precision in the measurement of pavement profile is considered to be a specified combination of the repeatability standard deviation of observed values at specified locations along the measured profile.

13.2.2 The repeatability standard deviation of multiple observed values at one specified location along the measured pavement profile is expressed as a standard deviation of the multiple observed values about the computed mean value for that location.

13.2.3 The precision of a pavement profile measuring system is expressed as the mean of multiple repeatability standard deviations (SD) of the observed values at the multiple specified locations along the measured pavement profile.

13.2.4 For comparable statements of precision, the length of the measured pavement profile, the number of specified locations along the measured pavement profile, and the number of observed values at each specified location shall be maintained.

13.2.4.1 The length of the measured pavement profile to be used in the development of the precision statement shall be 320 m (1056 ft).

13.2.4.2 The number of specified locations along the measured pavement profile shall be one thousand fifty seven at 0.30 m (1.00 ft) intervals.

13.2.4.3 At least ten repeat pavement profile measurements shall be used in the development of the required precision statement.

13.2.4.4 In the development of the precision statement for the pavement profile measuring equipment, the independent variables that affect the pavement profile measuring process shall be tightly controlled.

13.2.4.5 The variation in the measurement of longitudinal profile can be minimized by selecting a pavement test section with minimal variation in the transverse pavement profile.

13.2.4.6 The variation in the measurement of longitudinal profile due to variations in transverse pavement profile can be minimized by following as closely as possible the same path during the required repeat profile measurements.

13.2.4.7 To ensure that the repeat pavement profile measurements are made at the same specified locations along the measured pavement profile, the longitudinal location of the pavement profile measurement shall be tightly controlled, for example, automatic location marks.

13.2.5 The precision requirements for equipment for the measurement of pavement profile by equipment classification shall not exceed the precision listed below.

Equipment Classification	Precision (1 SD)
1	0.38 mm (0.015 in.)
2	0.76 mm (0.030 in.)
3	2.50 mm (0.100 in.)

13.3 *Bias*—Bias in the measurement of pavement profile is related to the consistent or systematic difference between the mean value of repeat pavement profile measurements at specified locations along the measured pavement profile and an accepted reference value for those specified locations.

13.3.1 Bias in the measurement of an individual profile data point at one specified location is the computed mean value for that specified location minus the accepted reference value for that specified location.

13.3.2 An accepted reference value for a specified location along the measured pavement profile shall be derived from an accepted reference pavement profile measuring method (for example, rod and level, Test Method E 1364, etc.).

13.3.2.1 To provide the maximum confidence in the accepted reference value, it would be highly desirable to repeat the reference profile measurements enough times to determine a valid mean value and standard deviation about that mean value for the measurements made at each specified location along the measured pavement profile.

13.3.3 An accepted reference value shall be derived from the reference pavement profile measurements using the identical processing (linear filtering, etc.) as the pavement profile measuring equipment being evaluated as long as the original amplitude and phase relationship of the reference pavement profile measurements are not affected over the specified wave length range of interest.

13.3.3.1 For comparable statements of bias, the original amplitude and phase relationship of the reference pavement profile measurements shall be unaffected for pavement profile wave lengths up to 100 m (300 ft).

13.3.4 Bias in the measurement of pavement profile is considered to be a specified combination of the biases of observed values at specified locations along the measured pavement profile.

13.3.5 The bias in the measurement of longitudinal profile shall be the summation of the absolute value of the individual biases at the multiple specified locations along the longitudianl profile measurement divided by the number of specified locations.

13.3.6 For comparable statements of bias, the length of the measured pavement profile, and the number of specified locations along the measured pavement profile shall be maintained.

13.3.6.1 The length of measured pavement profile to be used in the development of the bias statement shall be 350 m (1056 ft).

13.3.6.2 The number of specified locations along the measured pavement profile shall be one thousand fifty seven at 0.3 m (1.00 ft) intervals.

13.3.7 The bias requirements for equipment for the measurement of pavement profile by equipment classification shall not exceed the biases listed below.

Equipment Classification	Bias
1	1.25 mm (0.050 in.)
2	2.50 mm (0.100 in.)
3	6.25 mm (0.250 in.)

14. Keywords

14.1 longitudinal profile; profiling device; profilometer

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