Designation: E 2133 – 03

Standard Test Method for Using a Rolling Inclinometer to Measure Longitudinal and Transverse Profiles of a Traveled Surface[1]

This standard is issued under the fixed designation E 2133; 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 describes the measurement of transverse and longitudinal surface profiles on paved road, bridge, and airport surfaces using a rolling inclinometer traveling at walking speed.

1.2 It is designed to (*1*) quantify the roughness of new pavements and bridge decks; (*2*) Investigate the effect of various construction methods on surface roughness; (*3*) determine the location for corrective grinding; and (*4*) evaluate the effect of corrective grinding.

1.3 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.4 *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.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 867 Terminology Relating to Vehicle-Pavement Systems[2]

E 1274 Test Method for Measuring Pavement Roughness Using a Profilograph[3]

E 1364 Test Method for Measuring Road Roughness by Static Level Method[2]

E 1489 Practice for Computing Ride Number of Roads from Longitudinal Profile Measurements Made by an Inertial Profile Measuring Device[2]

E 1703/E 1703M Test Method for Measuring Rut Depth of Pavement Surface Using a Straightedge[2]

E 1926 Practice for Computing International Roughness Index of Roads from Longitudinal Profile Measurements[2]

2.2 *NCHRP Report:*

NCHRP Report 434 Guidelines for Longitudinal Pavement Profile Measurement[4]

3. Terminology

3.1 *Definitions:*

3.1.1 *elevation*, *n*—vertical distance of a point on a traveled surface relative to the horizontal datum.

3.1.2 *longitudinal profile*, *n*—the perpendicular deviations of the pavement surface from an established reference parallel to the lane direction, usually measured in the wheel tracks.

3.1.3 *slope*, *n*—angular deviation of the traveled surface from the horizontal datum.

3.1.4 *transverse profile*, *n*—the vertical deviations of the pavement surface from a horizontal reference perpendicular to the lane direction.

3.1.5 *traveled surface*, *n*—any man-made, solid surface for vehicular travel, for example, highways, runways, rails, bridge decks, guide ways, race ways.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *contact spacing*, *n*—the fixed distance between the forward and rear measurement supports of the rolling inclinometer device, otherwise known as the wheelbase.

3.2.2 *data reading*, *n*—the average of a series of slope measurements taken over the data reading interval starting at the beginning of every data spacing.

3.2.3 *data reading interval*, *n*—the distance in which a series of slope measurements are taken at regular intervals and the average slope is computed and saved as the data reading.

3.2.4 *data spacing*, *n*—distance between successive slope measurements, equal to contact spacing.

3.2.5 *feet or wheels*, *n*—the appendages that physically contact the traveled surface for the purpose of measuring the slope and/or for providing support to the measurement device.

3.2.6 *inclinometer*, *n*—a precision instrument that measures angular deviations of a pavement surface from a horizontal datum.

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[1] This test method is under the jurisdiction of ASTM Committee E17 on Vehicle-Pavement Systems and is the direct responsibility of Subcommittee E17.31 on Methods for Measuring Profile and Roughness.

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

[3] Discontinued; see 2002 *Annual Book of ASTM Standards*, Vol 04.03.

[4] Available from the Transportation Research Board, 500 Fifth Street, NW Washington, DC 20001.

3.2.7 *inclinometer bias, n*—repeating, uniform error in inclinometer readings.

3.2.8 *measurement line, n*—a reference line along which the rolling inclinometer travels to gather slope data for an elevation profile. Location of the measurement line shall be established at a defined distance from pavement edge or from the centerline or other specified locating reference.

3.2.9 *run, n*—a sequence of readings from a start point along the desired profile measurement line (straight or curved as desired) to the end point.

3.3 Additional definitions of terms related to this standard may be found in Terminology E 867.

4. Summary of Test Method

4.1 Location of longitudinal and transverse profile measurement lines shall be established. The location shall be recorded so that it may be reproduced another time.

4.2 As the rolling inclinometer is moved along the measurement line, an on-board computer sequentially collects and saves slope and distance data from the inclinometer and wheel sensor.

4.3 Starting at one end of a measurement line, elevation differences are automatically summed in the direction of travel to create a one-way run elevation profile along the line.

4.4 Selected roughness indices, such as those listed in Table 1, are calculated, and displayed by the onboard computer screen; and also road "roughness/smoothness" and "must grind areas" can be reported in printed graphical and tabular report form.

5. Significance and Use

5.1 This test method establishes procedures for collecting elevation and distance data of longitudinal and transverse profiles on a traveled surface.

5.2 Results of this test are used primarily to:

5.2.1 Evaluate the roughness of traveled surfaces, using any of several roughness indices shown in Table 1. Equations required for calculations of various indexes are contained in references shown in Table 1.

NOTE 1—When this test is used to evaluate the compliance of a new pavement surface with contract roughness specifications, the timeliness of the test in relation to the date of the surface's installation is of critical importance. Since most Portland cement concrete surfaces will change shape within a few days after installation—due to changes in thermal and moisture gradients which cause curling at joints and cracks and slab edges—for contractor quality control only, it may be desirable to gather profile data within 72 h after pavement installation.

5.2.2 Investigate the effect of different construction methods on resulting pavement surface roughness.

TABLE 1 Wavelength Sensitivity for Various Road Roughness Indices

Index Name	Wavelength Sensitivity	ASTM Reference
Ride Number (RN)	0.5 to 11.0 m (1.5 to 36.0 ft)	E 1489
Int'l Roughness Index (IRI)	1.3 to 30.0 m (4.3 to 98.4 ft)	E 1926
4 m (12 ft) California Bridge Profilograph	3.0 to 15.0 m (9.0 to 48.0 ft)	E 1274
8 m (25 ft) California Profilograph (CPI)	6.0 to 30.5 m (19.0 to 100.0 ft)	E 1274

5.2.3 Investigate the curvature of (*1*) pavement surfaces due to curling, and (*2*) deflection of structural members within bridges and other structures.

5.2.4 Identify the locations in need of corrective grinding.

5.2.5 Measure rut depth using computer simulation in accordance with Test Method E 1703/E 1703M.

6. Apparatus

6.1 *Rolling Inclinometer*, with fixed wheelbase spacing. An inclinometer is mounted such that it can measure vertical slopes (based on voltage output) along a line connecting the centers of the single front and single rear wheels. These slopes are converted to elevation difference by use of trigonometric formulas. The inclinometer chassis is pushed at a uniform walking speed (avoiding rapid speed changes), along a measurement line. Distance traveled is measured by a wheel rotation sensor.

6.2 *Inclinometer Chassis Device*—An inclinometer shall be mounted on a chassis supported by a single front and a single rear wheel in line with each other, such that the chassis is free to rotate in a vertical plane as it travels along the desired profile line, collecting slope measurements at specified data spacing.

6.3 *Inclinometer Wheelbase Spacing*—Rolling inclinometer chassis wheelbase spacing is to be in the range of 150 to 250 mm (6 to 10 in.) The minimum wheelbase is chosen to encourage the use of large diameter wheels that will be less sensitive to imperfections in surface texture of the road. The maximum spacing is chosen to be less than one-half the smallest wavelength sensitivity of a road roughness index. For example, the RN is sensitive to wavelengths as short as 0.5 m (1.5 ft). Other wheelbase spacing may be used when different data spacing is required for a specific purpose.

6.4 *Data Spacing* shall be an integer multiple of inclinometer wheelbase ranging from 150 to 250 mm (6 to 10 in.).

6.5 *Data Reading* shall be conducted according to one of the following procedures:

6.5.1 A series of slope readings shall be taken and averaged in a manner suitable to record at minimum one elevation value at each data reading interval from the start of data collection to the end of data collection. The Data Reading Interval shall not be longer than 50 mm because accurate measurement of the Ride Number Index requires a sample interval of 50 mm or shorter per NCHRP Report 434. The average of the series of slope measurements shall be saved as the recorded data reading.

6.5.2 A series of slope readings shall be taken over the entire measurement session at a data reading interval such that the data spacing interval is an integer multiple of the data reading interval. The data spacing interval as a minimum shall be five times the data reading interval. The collected slope reading shall be filtered with a suitable low-pass digital filter and re-sampled with the data spacing spatial frequency. Each of the re-sampled slope data shall be saved as the recorded data point for the measurement.

6.6 *Distance Tolerance*—The allowable tolerance on the measured distance traveled by the device along a measurement line during profiling shall be $\pm$ 0.05 %.

6.7 *Steering, Propulsion and Speed*—Guidance shall be with or without a steering mechanism. Propulsion may be by hand or motor. Travel speed shall be in the range of 1.5 to 5 km/h (1 to 3 mph), avoiding rapid speed changes. Provision shall be made to correct for changes in velocity.

6.8 *Compensating for Velocity Changes*—Since inclinometers are very sensitive to horizontal acceleration and deceleration, a suitable compensation algorithm must be developed to correct slope data at the end of each run. The velocity of the apparatus throughout the measurements shall be recorded and saved with the recorded slope measurement points. The horizontal acceleration/deceleration shall be calculated for each recorded measurement point. The inclinometer error shall be calculated from the acceleration/deceleration data and the recorded slope measurement data corrected.

6.9 *Data Filtering*—Data from one-way surveys shall be filtered with a second order Butterworth filter, or a filter appropriate for the index being calculated, to calculate roughness indexes and to display filtered profiles (for the purpose of showing location of bumps).

6.10 *Unfiltered Data* from two-way (closed loop) surveys shall be used to generate elevation profiles of measurement lines. Accuracy of unfiltered profiles shall be within ± 3 mm/50 m, plus level error. The reference elevation profile shall be derived under similar temperature conditions and shall be the average of three readings at each data reading point, using an accepted rod and level reference profile measuring method.

6.11 *Operating Conditions*—Device shall be capable of operating in environments with 0 to 90 % relative humidity and −20 to 40°C (0° to 110°F) temperatures.

7. Establishing Measurement Lines

7.1 *Measurement Test Line Locations*—Data may be collected on a line or lines placed anywhere on the pavement or other surface, wherever elevation profiles or roughness indices are desired. For most analysis, the lines will be located along wheel paths, or will be transverse to the longitudinal direction of the traveled surface. Longitudinal wheel path lines may be straight or curved to follow the geometry of the traveled surface, while transverse measurement lines should normally be straight. Distance of test lines from joints or pavement edge shall be part of the recorded data.

8. Procedure

8.1 *Calibration*—Follow manufacturers recommended calibration procedure.

8.2 *Define Location of Measurement Lines*—To ensure reliable and repeatable data the device shall follow the measurement line with a tolerance of ± 25 mm (1 in.).

8.3 *Profile Data Collection*:

8.3.1 *Sign Convention*—Positive slope values indicate a change in elevation opposite to gravity. Negative values indicate a change in elevation in the direction of gravity.

8.3.2 *Longitudinal Profiles in Wheel Paths*—If a longitudinal measurement line lies in a left or right wheel path, the start points of the left and right line shall be established on a line perpendicular to the pavement edge unless otherwise stated in report. A unique identification must be given to each measurement line together with all other information required for report (see Section 9).

8.3.2.1 Collect the elevation differences along the left and right wheel paths. To prevent confusion in interpreting and analyzing the profiles later, it is suggested that one-way runs be made in the same direction as the traffic flow. Devices with a mirror imaging feature can be used to efficiently reorient a profile to the direction of traffic.

8.4 *Calculate Roughness Indices and Must-Grind Areas*:

8.4.1 Specify one or more indices as shown in Table 1 and specify an acceptable range for the index. Specify measurement line length and maximum line length for calculating roughness indexes if they are to be calculated at regular distances along each measurement line, as well as for the entire measurement line. References in Table 1 contain the necessary formulas for calculation of indices.

8.4.1.1 Calculate required Roughness Index for each measurement line using slope or elevation data that is collected by rolling inclinometer device.

8.4.2 Specify the following parameters for calculating "must grind" areas (from California Profilograph data): segment length, blanking band, template length, defect height, safety margin.

9. Report

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

9.1.1 Date and time of day,

9.1.2 Operator,

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

9.1.4 Name, serial number, and manufacturer of Rolling Inclinometer device used; and Contact/Data spacing,

9.1.5 Location and description of each longitudinal or transverse measurement line:

9.1.5.1 Surface description; condition, type of pavement, and jointing,

9.1.5.2 Run number,

9.1.5.3 Lane measured, start and end positions, run length, distance from joints or pavement edge, description of the measurement line, direction measured, and

9.1.6 Roughness Indices, filtered profiles, and location of "must grind" areas for each measurement line and for intervals within measurement lines as noted in 8.4.1.

10. Precision and Bias

10.1 At this time no precision and bias estimate from a statistically designed series of tests at different locations and with different devices has been obtained.

10.2 If precision and bias of profile or distance are desired, refer to the following document under development, "Standard Test Method for Determining the Precision and Bias of Equipment Used to Measure Longitudinal Profile of a Pavement Surface."

11. Keywords

11.1 profiling device; rolling inclinometer; transverse and longitudinal profiles