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Standard Practice for Calibration of Systems Used for Measuring Vehicular Response to Pavement Roughness[1]

This standard is issued under the fixed designation E1448; 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 practice describes equipment and procedures for the calibration of systems used for measuring vehicular response to pavement roughness. Such systems are referred to as response-type systems. (See Test Method E1082.)

1.2 The response-type system includes the driven vehicle, the driver and contents of the vehicle, the towed trailer (if one is used with the system), and a device called a road meter that measures the vehicle response to pavement roughness. The road meter may be mounted in an automobile, van, or in a towed trailer. Response-type (road meter) devices covered in this practice include: devices measuring the relative axle-body motion of a vehicle, devices measuring the vertical acceleration of the vehicle body, and devices measuring the vertical acceleration of the vehicle axle.

1.3 The calibration procedures described in this practice are limited to the use of the simulations described in Practice E1170.

1.4 This practice is not intended to apply to pavement roughness measuring equipment whose output is not influenced by the response of the host vehicle.

1.5 The values stated in inch-pound units are to be regarded as the standard. The SI units given in parentheses may be approximate and are for informational purposes only.

1.6 *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:*[2]

E867 Terminology Relating to Vehicle-Pavement Systems

E950 Test Method for Measuring the Longitudinal Profile of Traveled Surfaces with an Accelerometer Established Inertial Profiling Reference

E1082 Test Method for Measurement of Vehicular Response to Traveled Surface Roughness

E1170 Practices for Simulating Vehicular Response to Longitudinal Profiles of Traveled Surfaces

E1215 Specification for Trailers Used for Measuring Vehicular Response to Road Roughness

E1364 Test Method for Measuring Road Roughness by Static Level Method

3. Terminology

3.1 *Definitions:*

3.1.1 *half-car roughness index (HRI)*—an index resulting from a mathematical simulation of vehicular response to the longitudinal profile of two wheelpaths of a pavement using the half-car simulation model described in Practice E1170 and a traveling speed of 50 mph (80 km/h). Units are in inches per mile or metres per kilometre (63.36 in./mile = 1.0 m/km).

3.1.2 *international roughness index (IRI)*—an index resulting from a mathematical simulation of vehicular response to the longitudinal profile of one wheelpath of a pavement using the quarter-car simulation model described in Practice E1170 and a traveling speed of 50 mph (80 km/h). Units are in inches per mile or metres per kilometre (63.36 in./mile = 1.0 m/km).

3.1.3 Additional definitions of terms related to this practice may be found in Definitions E867.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *response type system number (RTSN)*—the raw measured output from a response type system being calibrated. Units are arbitrary, being whatever the road meter in the response type system measures.

4. Significance and Use

4.1 Measures obtained by a response-type system depend primarily on the vehicle design and condition, the load, the measuring speed, and a host of environmental conditions. Even with control of all significant variables, the response of every vehicle is unique. Thus, raw measures from such a system are not reproducible with other systems.

[1] This practice 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] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

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4.2 The calibration described in this practice provides a method for converting the raw output of a particular response-type system to a reproducible standard roughness scale.

4.2.1 The response of a vehicle to road roughness is a complex phenomenon that cannot be summarized in a laboratory test. Therefore, the calibration is made through correlation with standard roughness index values established for calibration sites situated on representative roads. The data from the calibration sites are analyzed to determine an equation to estimate the standard roughness index from an RTSN.

4.3 The estimate of the standard roughness index made by transforming an RTSN is subject to three types of error:

4.3.1 *Random Error of the Response-Type-System (Repeatability)*—This error includes operator error and variability in the response of the vehicle and other components of the response-type system. It can be reduced by performing repeated measurements with the response-type system and averaging the individual measurements to estimate the true RTSN for a site. Appendix X1 describes a test method for determining the magnitude of in-use repeatability error.

NOTE 1—The length of the site or sites used to estimate in-use repeatability shall be equal to the minimum length of the test sections to be surveyed by the response-type system. This may require test sites that are longer than those profiled for the calibration.

4.3.2 *Bias Error in the Calibration Equation*—Estimates of the standard roughness index are biased if the calibration equation is incorrect or if no calibration equation is used. The purpose of this standard practice is to reduce bias to a negligible level. If desired, the magnitude of bias remaining after calibration can be estimated from data collected in the calibration.

4.3.3 *Standard Error of the Estimate (Error Due to Interactions Between Site Effects and Response-Type System Effects)*—This error is constant (a bias) for a particular combination of response-type system and site, but it is random with site selection. Ultimately it limits the accuracy of the estimate of the standard roughness of a site made with a response-type system. The error can be estimated from data collected in the calibration.

4.3.3.1 The standard error of the estimate estimates the error due to physical differences in response between a particular response-type system and the standard roughness index. It cannot be reduced by a mathematical transform.

4.3.3.2 Three physical variables that are controllable and that influence the standard error of the estimate are vehicle test speed, shock absorber damping stiffness, and vehicle tire pressure. For most vehicles, maximum reproducibility of standard roughness index estimates is obtained by adopting a test speed of 50 mph (80 km/h), by equipping the vehicle with stiff shock absorbers, and by maintaining a standard tire pressure. (See also 8.2.)

4.4 Periodic verification is essential to ensure that the calibration remains valid.

5. Apparatus

5.1 Calibration of the response-type system involves the response-type system being calibrated and additional apparatus to measure longitudinal profiles of the calibration sites.

5.2 *Response-Type System*—All response-type systems shall meet the requirements of Test Method E1082. When a road meter is mounted in a car or truck, the host vehicle shall also meet the requirements of Test Method E1082. When a road meter is mounted in a trailer, the trailer shall meet the requirements of Test Method E1215, and although the actual configuration of the tow vehicle is not critical, the same towing vehicle should always be used between calibrations.

5.3 *Pavement Profile Measuring Device*—The measurement of longitudinal profile can be made using static or dynamic methods. The method for measuring shall comply with the requirements below for the resolution of the elevation data and for the precision and bias of the computed standard roughness index, based on guidelines in World Bank Technical Paper No. 46.[3]

5.3.1 *Resolution*—The method used to determine the profile, measured as the sequence of vertical elevation points spaced at 12.0 in. (300 mm) intervals or less, shall have a static resolution (minimum discernable change in the output of the device) within the minimum requirements shown below:

Minimum Valid Roughness in./mile IRI (m/km IRI)	Static Resolution, in. (mm)
0 (0)	≤0.01 (0.25)
30 (.5)	≤0.02 (0.50)
63 (1)	≤0.04 (1.0)
190 (3)	≤0.08 (2.0)
317 (5)	≤0.12 (3.0)
444 (7)	≤0.16 (4.0)

NOTE 2—If the profile measuring device does not meet the resolution required in the lowest ranges over which the calibration is to be performed, the calibration will not normally comply with the precision requirements over these ranges. A note identifying the range over which the profile resolution requirements do not comply with this practice must be included in the calibration report.

5.3.2 *Precision of Computed Standard Roughness Indices*—The precision of the standard roughness index values computed from the profile for each calibration site shall be within 5 % (coefficient of variation). When a static method is used it shall have been demonstrated that it complies with the requirement. When a dynamic method is used the precision shall be determined through repeat measurements.

5.3.3 *Bias of Computed Standard Roughness Indices*—The bias of the standard roughness index values computed from the profile shall be either within 5 % of the "true" standard roughness index or within 3.5 % of the standard roughness index determined by Class 1 measurements (See Note 3).

NOTE 3—For the purposes of this practice, the computation of the standard roughness index values from Class 1 measurements may be made using methods such as described in Test Method E1364.

6. Selecting Calibration Sites

6.1 *General Considerations*—This practice requires that calibration sites have roughness properties representative of the pavements routinely surveyed with the response-type system. Select calibration sites having minimum variation in longitudinal roughness transversely, and that have approximately

[3] International Road Roughness Experiment "Guidelines for Conducting and Calibrating Road Roughness Measurements," World Bank Technical Paper, ISSN 0253-7494, Number 46, p. 54, 1986.

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constant roughness over their length. Locate calibration sites on pavements that are not likely to be repaired during their period of use. Do not select pavements with potholes or extensive localized patching. Mark calibration sites clearly so they can be easily identified. In addition, all measurements should be made on dry pavement.

6.2 *Number and Length of Calibration Sites*—All sites shall be the same length, and that length shall be at least 0.2 mile (300 m) and no greater than 1.0 mile (1600 m). The number of sites required depends on the length, as shown below:

Site Length, mile (m)	Minimum Number of Sites
0.2 (300)	14
0.3 (500)	10
1.0 (1600)	8

NOTE 4—The residual standard deviation associated with the regression analysis improves as the site length increases from 0.2 mile (300 m) to 1.0 mile (1600 m).

NOTE 5—The length of the calibration sites may be different from the length of the typical test sections to be surveyed by the response-type system.

6.3 *Roughness Range*—Select calibration sites that cover the range of longitudinal roughness encountered during normal use. The calibration is valid only over the range of roughness covered by the calibration sites. Extrapolation beyond this range is discouraged.

6.4 *Distribution of Roughness Among Sites*—This calibration method requires a uniform distribution of roughness among the calibration sites. Appendix X2 provides a guideline for selecting sites to achieve this objective.

6.5 *Site Approach and Exit*—Each calibration site shall have an approach at least 300 ft (90 m) in length and an exit portion at least 50 ft (15 m) in length that have a roughness similar to the roughness of the site to ensure that the response-type system is not responding to some nonuniformity in the road surface as it enters the calibration site and to allow for minor variation in the starting and stopping points when profiling or measuring their roughness. If a test speed other than 50 mph (80 km) is adopted, the minimum approach length shall be adjusted to correspond to an approach time of at least 4 s.

6.6 *Geometry*—Locate calibration sites on tangent sections of pavement which do not include bridges, railroad crossings, or intersections. Only if unavoidable should even a slight curvature of the roadway be accepted. There shall be no abrupt change in grade on the site or the approach.

7. Determining the Standard Roughness Index for Calibration Sites

7.1 *Choice of Standard Roughness Index*:

7.1.1 For response-type systems with single wheels, the IRI is recommended. The wheel of the trailer of the response-type system should follow precisely the wheeltrack that is profiled.

7.1.2 For response-type systems based on two-track vehicles (for example, passenger cars, vans, and two-wheeled trailers) either, the average of the IRI in the right wheelpath and the IRI in the left wheelpath, or the HRI may be used.

NOTE 6—For similar pavement types, based on available data, the HRI and the average of the IRI in the right wheelpath and the IRI in the left wheelpath are correlated. Typically, HRI values are lower than IRI-average values due to the cancellation of out-of-phase displacements from the two wheeltracks, with the ratios being about 0.96 for rigid pavements, 0.90 for composite pavements and 0.80 for flexible pavements and unpaved roads. The best post-calibration conversion of HRI values to IRI-average values (that is, standard roughness) can be obtained using the conversion factors specific to pavement type groups as indicated above.

7.2 *Determining the Standard Roughness Index with a Dynamic Profiling Device*—If an inertial profiling device is used to measure pavement profile, operate the inertial profiling device as specified in Test Method E950. Most dynamic profiling systems include software for automatically computing one or more of the recommended standard roughness indices. (The availability of the software may be a practical criterion for selecting the specific standard roughness index.) Care should be taken to locate the profiling device over the established wheeltrack(s) whenever the longitudinal profile of a calibration site is measured. To reduce the effect of random operator error in this measurement, at least five repeat tests shall be made. The average of the standard roughness index values is used as the true reference value or standard roughness index for the calibration regression.

NOTE 7—Repeat tests for estimating the standard roughness index may or may not be required for other profiling devices and should be addressed by the user.

7.3 *Measurement of Standard Roughness Index Using Static Level Survey Methods*—The procedure described in Test Method E1364 (Class 1 or Class 2 measurements) shall be used to obtain pavement profile using the rod and level survey method. Repeat measures are generally not required if the method includes a check for error during measurement and data entry. Details for computing IRI are provided in Appendix X1 of Test Method E1364.

7.4 *Measurement of Standard Roughness Index Using Other Static and Dynamic Profiling Devices*—Other profiling devices (such as the APL, Dipstick, and South Dakota profiling device) may be used if they meet the requirements of 5.3.

7.5 Determine the standard roughness index for each calibration site at least every twelve months. (More frequent determinations of the standard roughness index for calibration sites may be required; see 8.5.2.) During that period do not continue to use a site for calibration if the site has been altered by maintenance work or there is evidence to indicate that the standard roughness index for the site has changed by more than 5 %.

NOTE 8—When new standard roughness index values are needed, old sites may be used or new sites may be selected. Past usage is not a factor. However, the new sites must meet the requirements of Section 6.

7.6 The simulated speed for the standard roughness index shall be 50 mile/h (80 km/h), regardless of the test speed used for the response-type system.

8. Determining the Response-Type System Numbers (RTSNs) for Calibration Sites

8.1 Replace damaged tires or wheels on the response-type system host vehicle and balance tire/wheel assemblies in the manner specified in Test Method E1082 prior to calibration.

8.2 In order to obtain the best reproducibility and accuracy and to avoid errors contributed by hysteresis, equip the host vehicle of the response-type system with vertical shock

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