Designation: E1448/E1448M − 09 (Reapproved 2015)

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

This standard is issued under the fixed designation E1448/E1448M; 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 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 shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

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
E1926 Practice for Computing International Roughness Index of Roads from Longitudinal Profile Measurements

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 80 km/h [50 mph]. Units are in millimeters per kilometer or inches per mile.

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 80 km/h [50 mph]. Units are in millimeters per kilometer or inches per mile.

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.

[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.

Current edition approved Sept. 1, 2015. Published December 2015. Originally approved in 1992. Last previous edition approved in 2009 as E1448 – 09. DOI: 10.1520/E1448_E1448M-09R15.

[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.

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.

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 80 km/h [50 mph], 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 300 mm [12.0 in.] 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 mm/km IRI [in./mile IRI]	Static Resolution, mm [in.]
0 [0]	0.25 [≤0.01]
500 [30]	0.5 [≤0.02]
1000 [63]	1.0 [≤0.04]
3000 [190]	2.0 [≤0.08]
5000 [317]	3.0 [≤0.12]
7000 [444]	4.0 [≤0.16]

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).

[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.

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 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 0.3 km [0.2 mile] and no greater than 1.6 km [1.0 mile]. The number of sites required depends on the length, as shown below:

Site Length, km [mile]	Minimum Number of Sites
0.3 [0.2]	14
0.5 [0.3]	10
1.6 [1.0]	8

NOTE 4—The residual standard deviation associated with the regression analysis improves as the site length increases from 0.3 km [0.2 mile] to 1.6 km [1.0 mile].

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 90 m [300 ft] in length and an exit portion at least 15 m [50 ft] 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 80 km/h [50 mph] 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 E1926.

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 80 km/h [50 mph], 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 very stiff shock absorbers. If the RTSNs obtained on the calibration sites are more than 20 % greater on the average than the standard roughness index on moderately rough calibration sites, then the shock absorbers should be replaced with stiffer shock absorbers before calibration. The RTSN must be converted to correct engineering units for this comparison. The units are: total millimeters [inches] of accumulated suspension travel (both directions) divided by distance traveled in kilometers [miles] at 80 km/h [50 mph]. Shock absorbers mounted on trailers shall meet the requirements of Specification E1215. Re-calibrate a response-type system whenever shock absorbers are replaced.

8.3 Verify the accuracy of the response-type system's speedometer readings prior to determining RTSNs by measuring the time required to traverse an accurately measured (±0.1 %) level and straight section of pavement at least 0.8 km [0.5 mile] in length at a constant indicated speed. Verify the speedometer readings at the speed or speeds planned to be included in the calibration. A minimum of three test runs at each speed shall be made for verification. The speed indicated by the speedometer shall be within ±3 km/h [±2 mph] of the average measured distance/time for the three test runs.

8.4 Verify the accuracy of the response-type system's distance measuring equipment prior to determining RTSNs by determining the distance recorded after traversing an accurately measured (±0.1 %) level and straight section of pavement at least 1.6 km [1.0 mile] in length at a constant indicated speed. Verify the distance measuring equipment at the speed or speeds planned to be included in the calibration. A minimum of three test runs shall be made at each speed. The average distance indicated by the distance measuring equipment for the three test runs shall be within 1.0 % of the distance actually traversed.

8.5 Operate the response-type system on dry pavement in the manner specified in Test Method E1082.

8.5.1 A single test speed is used throughout a single calibration. If the response-type system is operated at different test speeds, an independent calibration is required for each speed.

8.5.2 Pavement profile and roughness is known to change seasonally and even by time of day. For a valid initial calibration, the profiles of the calibration sites shall be the same when measured by the profiling device and when traversed by the response-type system.

8.5.3 For each calibration site and at each test speed, repeated measures are made with the response-type system. The following minimum number of repeats are recommended, based on test length:

Site Length – km [mile]	Repeats
0.3 [0.2]	5
0.8 [0.5]	3
1.6 [1.0]	2

Depending on the particular response-type system, more repeats may be advisable. The average of the repeated measures for a calibration site is the estimated true RTSN for that site.

9. Regression Analysis and Error Estimation

9.1 Apply an established statistical procedure for least-squares regression to the pairs of standard roughness index and RTSN obtained for each site. The regression should treat the standard roughness index as the dependent variable (*Y* axis) and RTSN as the independent variable (*X* axis). Use conventional practice to estimate the confidence intervals (estimated errors) associated with future fitted values of the standard roughness index obtained by the response-type system being calibrated. Appendix X1 gives an example of acceptable least-squares regression and error estimation procedures which may be followed. Optionally, confidence intervals can be computed for the regression line to estimate the magnitude of remaining bias error (See 4.3.2).

NOTE 9—The standard deviation of the standard roughness index estimate obtained with a calibrated response-type system is approximately the square-root of the sum of the variance of the repeatability error (see 4.3.1) and the standard error of the estimate (see 4.3.3). Depending on the analysis procedure, the standard deviation of the residual error may be either the total standard roughness index standard deviation, or the best reproducibility obtainable with the response-type system. If the regression residuals do not include the repeatability error, the repeatability error should be added when estimating confidence intervals. (See the example test method in Appendix X1.)

10. Response-Type System Calibration Verification

10.1 The user is encouraged to verify the calibration equation(s) periodically. If the verification indicates that the vehicle has changed and the calibration equation is no longer valid, all data obtained since the last verification is suspect. Appendix X3 gives an example of an acceptable verification procedure that may be followed.

NOTE 10—It is recommended that verification be performed at least monthly when the system is in use, or after every 3000 km [2000 miles] of operation. If possible, a daily control check should be made when the system is in use, using a few control sites near the storage area for the equipment.

10.2 The calibration is rendered void if changes are made to the response-type system that affect its response to road roughness. Such changes include, but are not limited to, the following: replacement of tire; shock absorber; other suspension components; towing vehicle (in the case of a towed trailer response-type vehicle); and vehicle damage.

11. Report

11.1 Report the following information:

11.1.1 Standard roughness index obtained for each calibration site,

11.1.2 Type of standard roughness index obtained,

11.1.3 Method used to obtain the standards roughness indices for calibration sites,

11.1.4 Roughness ranges indicated in 6.3 over which the profile resolution requirements are not met,

11.1.5 Date the calibration sites were profiled,

11.1.6 Ambient temperature at the time the calibration sites were profiled,

11.1.7 Individual RTSNs obtained by each response-type system on each calibration site,

11.1.8 Test speed and tire pressure associated with each RTSN and the ambient temperature at the time each RTSN was obtained, and

11.1.9 Average RTSN for each calibration site for each test speed,

11.1.10 Calibration equation(s) for each response-type system calibrated,

11.1.11 Confidence interval (estimated error) associated with each calibration equation, and

11.1.12 Test speed, test temperature(s) and roughness range associated with each calibration equation.

11.2 Report the results of all calibration verification tests.

12. Keywords

12.1 calibration; response-type system; road roughness

APPENDIXES

(Nonmandatory Information)

X1. RESPONSE-TYPE SYSTEM CALIBRATION—LEAST SQUARES REGRESSION AND ERROR ESTIMATION

X1.1 *Estimating the Repeatability of a Response-Type System*—For one test speed, obtain at least ten RTSNs per site on at least two test sites. Select test sites of a length equivalent to the smallest test section to be surveyed by the response-type system. Determine the variance of the RTSNs on each test site and average the variances obtained to determine the variance associated with the operation of the response-type system at the test speed selected. Take the square root of the variance to obtain the repeatability error of the response-type system at that test speed.

NOTE X1.1—Test sections may be calibration sites if they meet the length requirements of 8.5.3. In this case, repeat measurements used for regression analysis may also be used to estimate the repeatability of the response-type system.

X1.2 *Obtaining a Response-Type System's Calibration Equation*—Obtain at least the minimum number of repeat RTSNs specified in 8.5.3 for each of the calibration sites. Average the repeat RTSNs obtained on a site to estimate the true RTSN for the site at the calibration test speed. Pair the mean RTSN obtained for each calibration site with the corresponding standard roughness index for the same site. Perform a regression analysis on all paired results for a given response-type system and determine the coefficients for an equation in the following form:

$$SRI = A + B \times RTSN_x \tag{X1.1}$$

where:

SRI = the standard roughness index (IRI, HRI, or the average of the IRI in the right wheelpath and the IRI in the left wheelpath), and

$RTSN_x$ = the response-type system number obtained at a selected test speed of X km/h [mile/h].

NOTE X1.2—The residual standard deviation associated with the regression analysis improves as the number of repeat roughness measurements increases from three to ten.

NOTE X1.3—The residual standard deviation associated with the regression analysis improves as the length of the calibration sites increases up to 1.6 km [1 mile].

NOTE X1.4—For some response-type systems, a better form for the regression equation is quadratic. See World Bank Technical Paper No. 46[3] for computation details for an equation of the following form:

$$SRI = A + B \times RTSN_x + C \times RTSN_x^{\,2} \tag{X1.2}$$

A *t*-test can be used to determine the statistical significance of the quadratic term. If it is insignificant, the simpler linear model should be used.

NOTE X1.5—The value of the intercept A should be considerably less than the mean value of SRI. A high value of A indicates a large systematic error in the response type system, that renders the device relatively insensitive to the road roughness input and therefore of doubtful validity.

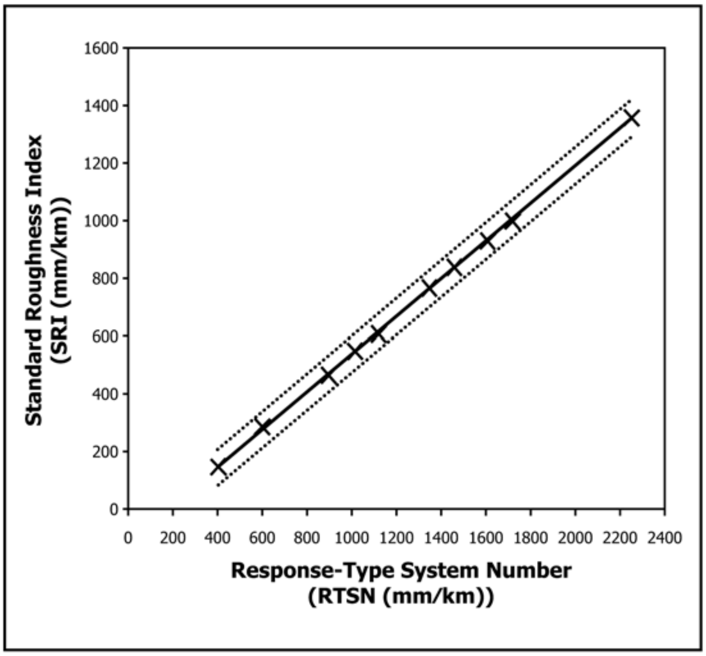
X1.3 *Estimating the Variance Associated with the Regression Analysis*—Calculate the residual standard deviation of the test points associated with the linear regression described in X1.2. Square the residual standard deviation to obtain the variance associated with the regression analysis.

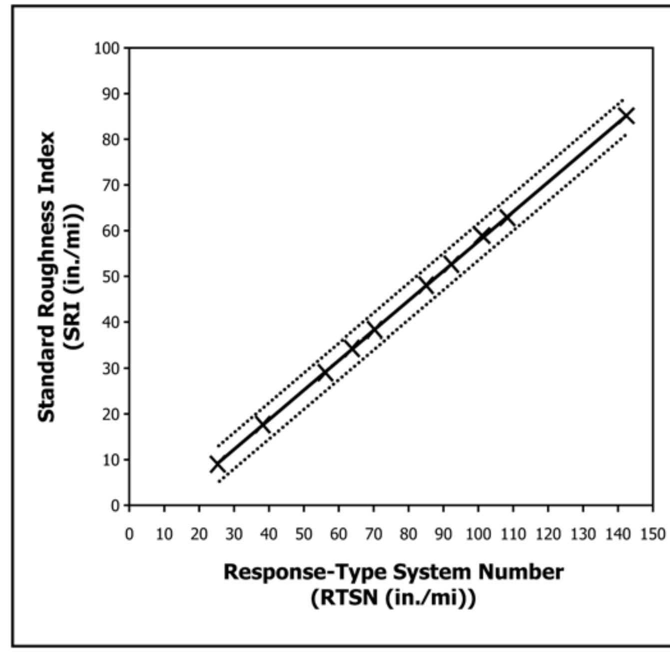
X1.4 *Estimating the 95 % Confidence Interval for the Response-Type System*—Calculate the standard deviation of the total system error by taking the square root of the sum of the variance associated with the regression analysis (see X1.3) and the variance associated with the repeatability of the response-type system (see X1.1):

$$\sigma_{total} = \sqrt{\sigma^2_{rep} + \sigma^2_{res}} \tag{X1.3}$$

Multiply the standard deviation by two to obtain an approximation of the 95 % confidence interval (two-sigma system error) associated with the calibration. A graphical representation of a sample regression analysis is provided in Fig. X1.1 and a table of RTSNs, predicted SRI values, and error estimations is shown in Table X1.1.

NOTE X1.6—It is up to the user or a specifying agency to impose any





Calibration Equation: SRI = - 112 + 0.65 * RTSN
RESSD = 15.8 mm/km
Repeatability Error = 65.1 mm/km
System Error (95% Conf. Int.) = 133.4 mm/km
SRI – Half Car Roughness Index (HRI)
Response-type Device Test Speed = 80 km/h

Calibration Equation: SRI = -7.07 + 0.65 * RTSN
RESSD = 1.0 in/mi
Repeatability Error = 4.1 in/mi
System Error (95% Conf. Int.) = 8.4 in/mi
SRI – Half Car Roughness Index (HRI)
Response-type Device Test Speed = 50 mph

FIG. X1.1 Graph of Sample Regression Analysis

maximum system error limitations.

TABLE X1.1 Sample Response-Type System Calibration Results

RTSN (mm/km)	SRI (mm/km)	% Error, ±	RTSN [in/mi]	SRI [in/mi]
397	146	91.7	25	9
603	279	47.7	38	18
889	465	28.7	56	29
1016	548	24.3	64	35
1111	610	21.9	70	38
1349	765	17.4	85	48
1461	837	15.9	92	53
1603	930	13.6	101	59
1715	1002	13.3	108	63
2254	1353	9.9	142	85

X2. SELECTION OF CALIBRATION SITES

X2.1 First, identify the range of uncorrected RTSN data expected during normal operation, to determine the range required for the calibration. Divide this range into three or more intervals of roughness, from smooth to rough. If the response-type system is used mainly on roads falling in a narrow band of roughness, three intervals are sufficient. If it is used for a wider range of conditions, more than three may be preferable. In terms of calibrated IRI values, the intervals should not be smaller than 475 mm/km [30 in./mile], nor wider than 1588 mm/km [100 in./mile]. The candidate calibration sites are measured with the response-type system. Sites are selected so that each roughness category is equally represented.

X2.2 This method is illustrated for an example. Consider a response-type system that is used on all public highways and which has in the past produced uncorrected readings ranging from three counts per kilometer [five counts per mile] to thirty seven and one-half counts per kilometer [sixty counts per mile]. Fifteen sites of 800 m [0.5 mile] in length are to be used for the calibration. The range of roughness seen by the system is considered to be broad by the user, and five roughness intervals are thought to be appropriate. Thus, each interval has a range of 6.9 counts per kilometer ([37.5–3]/5) [eleven counts per mile ([60–5]/5)]. The ranges for each interval are then defined as follows:

Interval	Roughness Range (“raw” units of counts per mile)	Roughness Range (“raw” units of counts per mile)
1	3 to 9.9	5 to 16
2	9.9 to 16.8	16 to 27
3	16.8 to 23.7	27 to 38
4	23.7 to 30.6	38 to 49
5	30.6 to 37.5	49 to 60

Three sites are selected for each range. After screening for roughness levels, the sites are chosen based on convenience of their locations.

X2.3 After calibration, it is found that the roughness range of the test sites actually covered IRI roughness levels from 50 to 250 in./mile. It is also found that several of the sites are ranked differently by standard roughness index and RTSN. However, the distribution of roughness of the sites is approximately uniform with IRI.

X3. RESPONSE-TYPE SYSTEM CALIBRATION—EQUATION VERIFICATION PROCEDURE

X3.1 *Control Site Selection and Characteristics*—For routine calibration verification select at least three control sites, one site in the middle and at least one site each at the low and high end of the calibration roughness range described in 6.3. The sites selected shall be at least 0.32 km [0.2 mile] long and meet the requirements of 6.1, 6.5, and 6.6.

NOTE X3.1—Control sites may be established in an area near the operation of the response-type system. If a response-type system is being operated near the calibration sites, then three of the calibration sites may be used as control sites.

X3.2 *Obtaining Initial Road Meter Numbers for Control Sites*—Within one week after calibration, obtain five road meter numbers for each control site by operating the response-type system in the manner specified in Test Method E1082.

NOTE X3.2—Operating two or more response-type systems on the same control sites is advisable and will provide an indication of whether the response-type systems or the control sites are changing with time. If two or three response-type system's results are beyond acceptable limits in the same direction at the same time, that is strong evidence that the roughness characteristics of the control site have changed and that the calibration equations for the response-type systems are still valid. If only one response-type system is used and results are beyond acceptable limits, the assumption must be made that the control site has not changed unless there is physical evidence to indicate otherwise, and that the response-type system's calibration equation is no longer valid.

X3.3 *Routine Control Tests:*

X3.3.1 At the desired interval (See 10) obtain five road meter numbers on each control site with the same response-type system(s) used in X3.2 and prepare mean and range control charts from the road meter numbers obtained as described in X3.4.

X3.3.2 If the results of any one of the control tests are beyond acceptable limits, do not apply the calibration equation(s) for the response-type system in equation (see Note X3.2). Recalibrate the response-type system as described in Sections 8 and 9 and establish a new calibration equation(s).

TABLE X3.1 Factors for Computing Three-Sigma Control Limits[A]

Number of observations in sample, n	Factors for Control Limits A_2	D_3	D_4
2	1.880	0	3.267
3	1.023	0	2.575
4	0.729	0	2.282
5	0.577	0	2.115
6	0.483	0	2.004
7	0.419	0.076	1.924
8	0.373	0.136	1.864
9	0.337	0.184	1.816
10	0.308	0.223	1.777

Formulas

	Central Line	Three-Sigma Control Limits
Chart of averages	$\bar{X}$	$\bar{X} \pm A_2\bar{R}$
Chart of ranges	$\bar{R}$	$D_3\bar{R}$ and $D_4\bar{R}$

[A]Adopted from ASTM Manual on Quality Control of Materials.[6]

After recalibration, repeat the calibration equation verification procedures described in X3.2 and X3.3.

NOTE X3.3—Prior to recalibration, check the response-type system thoroughly and consider replacing shocks, tires or suspension hardware such as ball joints and wheel bearings. Replacing any of these components renders the current calibration void, so it is best to make the change just before calibration.

X3.4 *Preparing Mean, $\bar{X}$, and Range, R, Three Sigma Control Charts (n = 5):*

X3.4.1 This appendix assumes that a set of observed values of a variable X is subdivided into k rational subgroups (samples), each subgroup containing $n = 5$ observed values. (See ASTM STP 15D[4] or NIST Handbook 91[5].)

X3.4.2 The range, R of a sample is the difference between the largest observation and the smallest observation.[6]

X3.4.3 For samples of size $n = 5$, the control chart lines are as follows (see Table X3.1):

	Central Line	Control Limits
For averages, $\bar{X}$	$\bar{X}$	$\bar{X} \pm 0.577\ \bar{R}$
For ranges, R	$\bar{R}$	$2.115\bar{R}$ (upper) and 0 (lower)

where:

X = the grand average of observed values of X for all samples:

$$\frac{n_1\bar{X}_1+n_2\bar{X}_2+n_3\bar{X}_3+n_4\bar{X}_4+n_5\bar{X}_5}{n_1+n_2+n_3+n_4+n_5} \tag{X3.1}$$

and:

$\bar{R}$ = average value of range R for the k individual samples:

$$(R_1+R_2+...+R_k)/k \tag{X3.2}$$

X3.4.4 Fig. X3.1 shows control charts for X and R based on the sample data set presented in Table X3.2 for the sixth month of test. The charts indicate that the unit tested should be recalibrated. Charts similar to those shown should be prepared after each verification test.

[4] *Manual on Presentation of Data and Control Chart Analysis*, Part 3, *ASTM STP 15D*, ASTM, 1976.

[5] Experimental Statistics NBS Handbook 91, Issued Aug. 1, 1963.

[6] *Manual on Quality Control of Materials*, ASTM, 1951, p. 115.

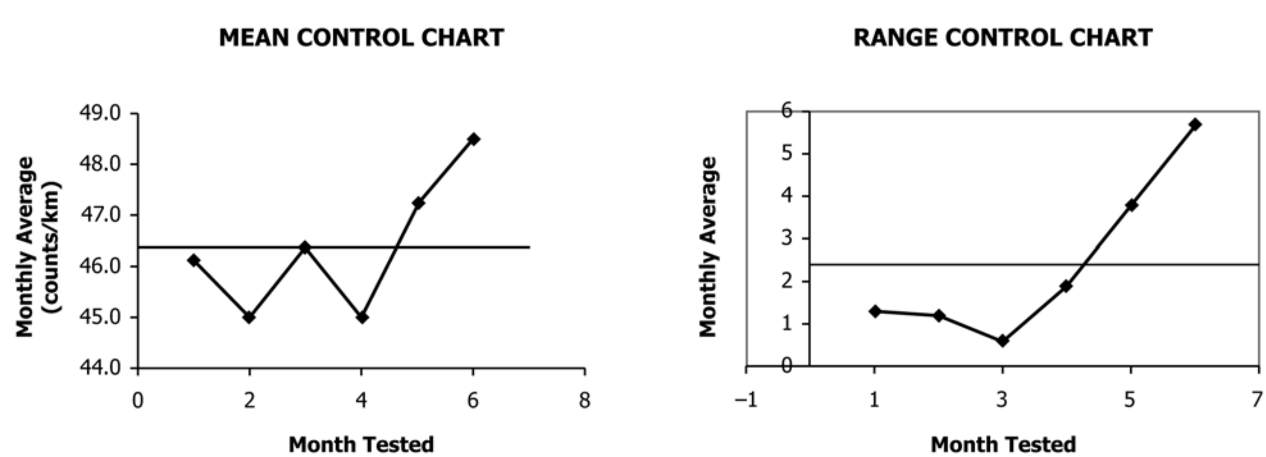


FIG. X3.1 Sample Mean and Range Control Charts (SI Units)

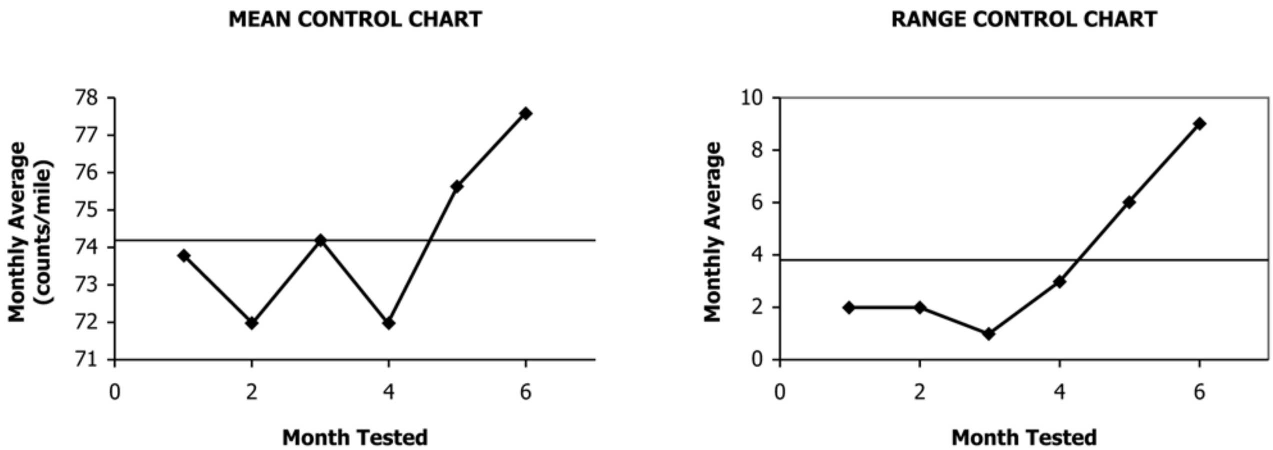


FIG. X3.2 Sample Mean and Range Control Charts [English Units]

TABLE X3.2 Sample Data Set (SI Units)

Month Tested	Road Meter Numbers					Mean Control Chart				Range Control Chart			
	1	2	3	4	5	$\bar{X}$	$\bar{\bar{X}}$	UL	LL	R	$\bar{R}$	UL	LL
1	45.6	45.6	45.6	46.9	46.9	46.1	...	...	...	1.3	...	...	...
2	44.4	45.0	45.0	45.0	45.6	45.0	45.6	46.3	44.8	1.2	1.3	2.6	0
3	46.3	46.3	46.3	46.3	46.9	46.4	45.8	46.4	45.2	0.6	1.0	2.2	0
4	44.4	44.4	44.4	45.6	46.3	45.0	45.6	46.3	44.9	1.9	1.3	2.6	0
5	48.8	48.8	47.5	46.3	45.0	47.3	46.0	47.0	44.9	3.8	1.8	3.7	0
6	50.0	51.3	46.9	45.6	48.8	48.5	46.4	47.8	45.0	5.7	2.4	5.1	0

TABLE X3.3 Sample Data Set [English Units]

Month Tested	Road Meter Numbers					Mean Control Chart				Range Control Chart			
	1	2	3	4	5	$\bar{X}$	$\bar{\bar{X}}$	UL	LL	R	$\bar{R}$	UL	LL
1	73	73	73	75	75	73.8	...	...	...	2	...	...	...
2	71	72	72	72	73	72.0	72.9	74.1	71.7	2	2.0	4.2	0
3	74	74	74	74	75	74.2	73.3	74.3	72.3	1	1.7	3.5	0
4	71	71	71	73	74	72.0	73.0	74.2	71.8	3	2.0	4.2	0
5	78	78	76	74	72	75.6	73.5	75.1	71.9	6	2.8	5.9	0
6	80	82	75	73	78	77.6	74.2	76.4	72.0	9	3.8	8.1	0