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Standard Test Method for Determining Floor Tolerances Using Waviness, Wheel Path and Levelness Criteria[1]

This standard is issued under the fixed designation E1486; 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 data collection and analysis procedures to determine surface flatness and levelness by calculating waviness indices for survey lines and surfaces, elevation differences of defined wheel paths, and levelness indices using the inch-pound system of units.

NOTE 1—This test method is the companion to SI Test Method E1486M; therefore, no SI equivalents are shown in this test method.

NOTE 2—This test method was not developed for, and does not apply to, clay or concrete paver units.

1.1.1 The purpose of this test method is to provide the user with floor tolerance estimates as follows:

1.1.1.1 Local survey line waviness and overall surface waviness indices for floors based on deviations from the midpoints of imaginary chords as they are moved along a floor elevation profile survey line. End points of the chords are always in contact with the surface. The imaginary chords cut through any points in the concrete surface higher than the chords.

1.1.1.2 Defined wheel path criteria based on transverse and longitudinal elevation differences, change in elevation difference, and root mean square (RMS) elevation difference.

1.1.1.3 Levelness criteria for surfaces characterized by either of the following methods: the conformance of elevation data to the test section elevation data mean or the conformance of the RMS slope of each survey line to a specified slope for each survey line.

1.1.2 The averages used throughout these calculations are RMS (that is, the quadratic means). This test method gives equal importance to humps and dips, measured up (+) and down (−), respectively, from the imaginary chords.

1.1.3 Appendix X1 is a commentary on this test method. Appendix X2 provides a computer program for waviness index calculations based on this test method.

1.2 The values stated in inch-pound units are to be regarded as standard. No other units of measurement are included in this standard.

1.3 *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 Document

2.1 *ASTM Standards:*[2]

E1486M Test Method for Determining Floor Tolerances Using Waviness, Wheel Path and Levelness Criteria (Metric)

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *defined wheel path traffic*—traffic on surfaces, or specifically identifiable portions thereof, intended for defined linear traffic by vehicles with two primary axles and four primary load wheel contact points on the floor and with corresponding front and rear primary wheels in approximately the same wheel paths.

[1] This test method is under the jurisdiction of ASTM Committee E06 on Performance of Buildings and is the direct responsibility of Subcommittee E06.21 on Serviceability.

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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.

3.1.2 *levelness*—described in two ways: the conformance of surface elevation data to the mean elevation of a test section (elevation conformance), and as the conformance of survey line slope to a specified slope (RMS levelness).

3.1.2.1 *elevation conformance*—the percentage of surface elevation data, h_i, that lie within the tolerance specified from the mean elevation of a test section. The absolute value of the distance of all points, h_i, from the test section data mean is tested against the specification, *dmax*. Passing values are counted, and that total is divided by the aggregate quantity of elevation data points for the test section and percent passing is reported.

3.1.2.2 *RMS levelness*—directionally dependent calculation of the RMS of the slopes of the least squares fit line through successive 15-ft long sections of a survey line, *L*. The RMS LV_L is compared with the specified surface slope and specified maximum deviation to determine compliance.

3.1.3 *Waviness Index Terms:*

3.1.3.1 *chord length*—the length of an imaginary straight-edge (chord) joining the two end points at *j* and $j + 2k$. This length is equal to 2*ks* (see Fig. 1) where the survey spacing *s* is equal to 1 ft and *k* is equal to 1, 2, 3, 4, and 5 to define chord lengths of 2, 4, 6, 8, and 10 ft, respectively, unless values for *s* and *k* are otherwise stated.

3.1.3.2 *deviation* (D_{kj})—the vertical distance between the surface and the mid-point, $j + ks$, of a chord of length 2*ks* whose end points are in contact with the surface.

3.1.3.3 *length adjusted RMS deviation* (LAD_k)—calculated for a reference length L_r of 10 ft, unless otherwise stated, in order to obtain deviations that are independent of the various chord lengths, 2*ks*.

3.1.3.4 *waviness*—the relative degree to which a survey line deviates from a straight line.

3.1.4 Symbols:

A	=	area of test section, ft^2.
d	=	point *i*, of the $(15/s + 1)$ point subset of $i = 1$ to *imax*, where *d* is a point within the $(15/s + 1)$ point subset, used to evaluate RMS levelness.
dh_L	=	number of elevation data points of survey line, *L*, which lie within the maximum allowable deviation from the test section elevation data mean, *dmax*.
D_{kj}	=	deviation from chord midpoint, $j + k$, to the survey line, in.
$dmax$	=	specified maximum allowable deviation from the test section elevation data mean.
EC	=	the percentage of elevation data within a test section complying to a specified maximum deviation, *dmax*, from the mean of all elevation data points within a test section.
EC_L	=	the percentage compliance of each survey line to a specified maximum deviation, *dmax*, from the mean of all elevation data points within a test section.
h_i	=	elevation of the points along the survey line, in.
ha_i	=	elevation of the points along the survey line of the left wheel path of defined wheel path traffic, in.
hb_i	=	elevation of the points along the survey line of the right wheel path of defined wheel path traffic, in.
i	=	designation of the location of survey points along a survey line $(i = 1, 2, 3 \ldots imax_L)$.
$imax_L$	=	total number of survey points along a survey line.
$imax_{Lx}$	=	total number of survey points along one of the pair of survey lines, *Lx*, representing the wheel paths of defined wheel path traffic.
j	=	designation of the location of the survey point which is the initial point for a deviation calculation $(j = 1, 2, 3 \ldots jmax_k)$.
$jmax_k$	=	total number of deviation calculations with a chord length *2ks* along a survey line.
k	=	number of spaces of length *s* between the survey points used for deviation calculations.
$kmax_L$	=	maximum number (rounded down to an integer) of spaces of length *s* that can be used for deviation calculations for $imax_L$ survey points ($kmax_L = 5$ unless otherwise specified).
L	=	designation of survey lines $(L = 1, 2, 3 \ldots Lmax)$.
LAD_k	=	length-adjusted RMS deviation based on points spaced at *ks* and a reference length of L_r.

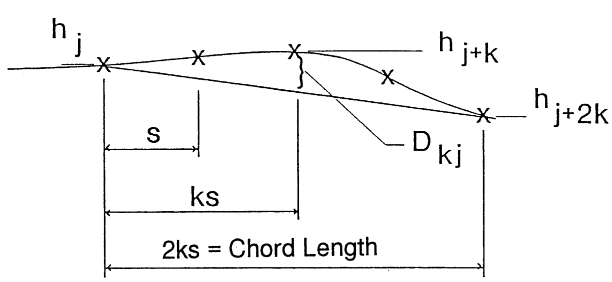

FIG. 1 Explanation of Symbols

Lg = total number of survey spaces between primary axles of a vehicle used as the basis for longitudinal analysis of each pair of survey lines representing the wheel paths of defined wheel path traffic. *Lg* equals the integer result of the primary axle spacing, ft, divided by *s*.
Lmax = the number of survey lines on the test surface.
L_r = a reference length of 120 in., the length to which the RMS deviations, RMS D_k, from chord lengths other than 120 in. are adjusted.
LD_i = longitudinal elevation difference between corresponding pairs of points separated by *Lg* of defined wheel paths, mm $(i = 1, 2, 3 \ldots (imax_L - Lg))$.
LDC_i = incremental change in longitudinal elevation difference, LD_i, along defined wheel path traffic wheel paths, in./ft $(i = 1, 2, 3 \ldots (imax_L - Lg - 1))$.
Lx = designation of the pair of survey lines used for defined wheel path traffic analysis.
mh_d = mean elevation of each 15-ft section of survey line, *L*, mm $(d = 1, 2, 3 \ldots (imax_L - 15/s))$.
ms_d = mean slope of the least squares fit line of each 15-ft section of survey line, *L*, in./ft $(d = 1, 2, 3 \ldots (imax_L - 15/s))$.
n_L = total number of calculated deviations for survey line *L* (equal to the sum of the values of $jmax_k$ for all values of *k* that are used). The symbol n_L is a weighting factor used in calculating both the waviness and surface waviness indices.
RMS D_k = root mean square of chord midpoint offset deviations, D_{kj}, based on points spaced at *ks*.
RMS LD_{Lx} = root mean square of longitudinal elevation differences, LD_i, on paired wheel path survey lines for defined wheel path traffic, with primary axles separated by L_g, in.
RMS TD_{Lx} = root mean square of transverse elevation differences, TD_i, on paired wheel path survey lines for defined wheel path traffic, in.
RMS LV_L = RMS levelness, calculated as the root mean square slope of each survey line, *L*, in./ft.
s = spacing between adjacent survey points along a survey line (1 ft unless a smaller value is stated), ft.
SWI = surface waviness index determined by combining the waviness indices of all the survey lines on the test surface, in.
TD_i = transverse elevation difference between corresponding points of defined wheel path traffic wheel paths, in. $(i = 1, 2, 3 \ldots imax_{Lx})$.
TDC_i = incremental change in transverse elevation difference, TD_i along defined wheel path traffic wheel paths, in./ft $(i = 1, 2, 3 \ldots (imax_{Lx} - 1))$.
WI_L = waviness index for survey line *L* with chord length range from 2.0 to 10 ft unless a different range is stated, in.

3.2 Sign Convention—Up is the positive direction; consequently, the higher the survey point, the larger its h_i value.

4. Summary of Test Method

4.1 *Equations*—Equations are provided to determine the following characteristics:

4.1.1 *Waviness Index Equations:*

4.1.1.1 *RMS* D_k ~~= RMS~~ = RMS deviation (see Eq 4).

4.1.1.2 LAD_k ~~= length-adjusted~~ = length-adjusted deviation (see Eq 5).

4.1.1.3 WI_L ~~= waviness~~ = waviness index (see Eq 6 and 7).

4.1.1.4 *SWI* ~~= surface~~= surface waviness index (see Eq 8).

4.1.1.5 $|D_{kj}|$ ~~= absolute~~ = absolute value of the length adjusted deviation (see Eq 24).

4.1.2 *Defined Wheel Path Traffic Equations:*

4.1.2.1 TD_i ~~= transverse~~= transverse elevation difference between the wheel paths of defined wheel path traffic (see Eq 9).

4.1.2.2 TDC_i ~~= transverse~~= transverse change in elevation difference between wheel paths of defined wheel path traffic (see Eq 10).

4.1.2.3 *RMS* TD_{Lx} ~~= RMS~~= RMS transverse elevation difference between wheel paths of defined wheel path traffic (see Eq 11).

4.1.2.4 LD_i ~~= longitudinal~~= longitudinal elevation difference between front and rear axles on wheel paths of defined wheel path traffic (see Eq 12).

4.1.2.5 LDC_i ~~= Longitudinal~~= Longitudinal change in elevation difference between front and rear axles on wheel paths of defined wheel path traffic (see Eq 13).

4.1.2.6 *RMS* LD_{Lx} ~~= RMS~~= RMS longitudinal elevation difference between axles on wheel paths of defined wheel path traffic (see Eq 14).

4.1.3 *Levelness Equations:*

4.1.3.1 mh_L ~~= mean~~= mean elevation of survey line, *L*, calculated for use only in calculating mh_{TS} (see Eq 15).

4.1.3.2 mh_{TS} ~~= mean~~= mean elevation of a test section, calculated for use only in calculating dh_L (see Eq 16).

4.1.3.3 dh_L ~~= number~~= number of elevation data points of survey line, *L*, passing the specification, *dmax*, used for calculating both EC_L and EC (see Eq 17 and 18).

4.1.3.4 EC_L ~~= percentage~~= percentage of elevation data points on survey line, *L*, that comply with *dmax* (see Eq 19).

4.1.3.5 *EC* ~~= percentage~~= percentage of elevation data points within a test section complying with *dmax* (see Eq 20).

4.1.3.6 mh_d ~~= mean~~= mean elevation of each 15-ft section of survey line, *L*, calculated for use only in calculating RMS LV_L (see Eq 21).

4.1.3.7 ms_d ~~= mean~~= mean slope of the least squares fit line of each 15-ft section of survey line, *L*, calculated for use only in calculating *RMS* LV_L (see Eq 22).

4.1.3.8 *RMS* LV_L ~~= RMS~~= RMS of least squares fit 15-ft slopes (see Eq 23).

4.2 *Waviness Index—Chord Length Range:*

4.2.1 Unless a different range is specified, the waviness index, WI_L, shall be calculated for a 2-, 4-, 6-, 8-, and 10-ft chord length range.

4.2.2 The chord length, 2*ks*, is limited by the total number of survey points along a survey line. To ensure that the elevation of every survey point is included in the deviation calculation that uses the largest value of *k*, the maximum value of *k*, called $kmax_L$, is determined by:

$$kmax_L = imax_L / 3 \text{ (rounded down to an integer)} \tag{1}$$

4.2.3 Reduce the maximum chord length so that $2(kmax_L)s$ is approximately equal to the maximum length that is of concern to the user.

NOTE 3—For longer survey lines, $kmax_L$, which is determined using Eq 1, permits the use of chord lengths, 2*ks*, longer than those of interest or concern to the floor user.

4.2.4 The maximum chord length for suspended floor slabs shall be 4 ft, unless the slab has been placed without camber and the shoring remains in place.

4.3 *Waviness Index—Maximum Number of Deviation Measurements per Chord Length:*

4.3.1 As the values of *k* are increased from 1 to $kmax_L$, the number of deviation calculations decreases.

$$jmax_k = imax_L - 2k \tag{2}$$

4.4 *Waviness Index—Deviation:*

4.4.1 As shown in Fig. 1, the deviation, D_{kj}, is

$$D_{kj} = h_{j+k} - \frac{1}{2}\left(h_j + h_{j+2k}\right) \text{ in.} \tag{3}$$

4.5 *Waviness Index—RMS Deviation:*

4.5.1 RMS D_k is calculated for each chord length using all points along the survey line.

$$\text{RMS}\, D_k = \sqrt{\frac{\sum_{i=1}^{jmax_k} D_{kj}^2}{jmax_k}} \text{ in.} \tag{4}$$

4.6 *Waviness Index—Length-Adjusted Deviations:* LAD_k is calculated for a reference length, L_r, using Eq 5.

$$LAD_k = \sqrt{\frac{\frac{L_r}{2ks}\left[\sum_{i=1}^{jmax_k} D_{kj}^2\right]}{jmax_k}} \text{ in.} \tag{5}$$

4.7 *Waviness Index*—The values of LAD_k obtained for each value of *k* shall be combined with other *LAD* values for each line *L* by weighing the values in proportion to $jmax_k$ to obtain the waviness index, WI_L.

$$WI_L = \sqrt{\frac{\sum_{k=1}^{kmax_L}\left(jmax_k LAD_k^2\right)}{n_L}} \text{ in.} \tag{6}$$

~~where~~where:

$$n_L = \sum_{k=1}^{kmax_L} jmax_k \tag{7}$$

4.8 *Surface Waviness Index*—The individual values of waviness index, WI_L, obtained for each survey line shall be combined to give a surface waviness index, SWI, by combining them in proportion to n_L.

$$SWI = \sqrt{\frac{\sum_{L=1}^{L_{max}} n_L \, WI_L^2}{\sum_{L=1}^{L_{max}} n_L}} \; in. \tag{8}$$

4.9 *Defined Wheel Path Calculations:*

4.9.1 *Transverse Elevation Difference—TD_i* is calculated for a pair of wheel path survey lines, using Eq 9 *(i = 1, 2, 3 . . . $imax_{Lx}$).*

$$TD_i = (hb_i - ha_i) \text{ in.} \tag{9}$$

where TD_i is positive when the right wheel path is higher than the left and negative when the right wheel path is lower than the left.

4.9.2 *Transverse Change in Elevation Difference—TDC_i* is calculated for each pair of wheel path survey lines using Eq 10 *(i* = 1, 2, 3 . . . ($imax_{Lx}$ − 1)).

$$TDC_i = (TD_{i+1} - TD_i)/s \; in./ft \tag{10}$$

where TDC_i is positive when the vehicle tilted left from its previous position and negative when it is tilted right from its previous position *(i* = 1, 2, 3 . . . *$imax_{Lx}$).*

4.9.3 *Transverse RMS Elevation Difference*—RMS TD_{Lx} is calculated for a pair of wheel path survey lines using Eq 11.

$$RMS\,TD_{Lx} = \sqrt{\frac{\sum_{i=1}^{imax_{Lx}} TD_i^2}{imax_{Lx}}} \; in. \tag{11}$$

4.9.4 *Longitudinal Elevation Difference—LD_i* is calculated for a pair of wheel path survey lines using Eq 12 *(i* = 1, 2, 3 . . . *($imax_{Lx}$ − Lg)).*

$$LD_i = \left(\left(\frac{ha_{i+Lg} + hb_{i+Lg}}{2} \right) - \left(\frac{ha_i + hb_i}{2} \right) \right) in. \tag{12}$$

4.9.5 *Longitudinal Change in Elevation Difference—LDC_j* is calculated for a pair of wheel path survey lines using Eq 13 *(j* = 1, 2, 3 . . . (*$imax_{Lx}$* − *Lg* − 1)).

$$LDC_i = (LD_{i+1} - LD_i)/s \; in./ft \tag{13}$$

4.9.6 *Longitudinal RMS Elevation Difference—RMS LD_{Lx}* is calculated for a pair of wheel path survey lines using Eq 14.

$$RMS\,LD_{Lx} = \sqrt{\frac{\sum_{i=1}^{(imax_{Lx} - Lg)} LD_i^2}{(imax_{Lx} - Lg)}} \; in. \tag{14}$$

4.10 *Calculations for Elevation Conformance:*

4.10.1 *Mean Elevation of Survey Line—mh_L* is calculated for survey line, *L*, using Eq 15.

$$mh_L = \sqrt{\frac{\sum_{i=1}^{imax_L} h_i}{imax_L}} \; in. \tag{15}$$

4.10.2 *Mean Elevation of a Test Section—mh_{TS}* is calculated for a test section using Eq 16.

$$mh_{TS} = \sqrt{\frac{\sum_{L=1}^{Lmax_L} mh_L}{Lmax_L}} \; in. \tag{16}$$

4.10.3 *Elevation Points Passing—dh_L*the number of elevation data points that lie within the maximum allowable deviation, *dmax*, from the test section elevation data mean is calculated using Eq 17 and 18.

$$dh_L = \sum_{L=1}^{Lmax} \sum_{imax}^{imax_L} 1/2 \left(1 + \frac{|x|}{x} \right) \tag{17}$$

~~where~~where:

$$x = dmax - |h_i - mh_{TS}| \tag{18}$$

and

$$\frac{|x|}{x} = 0 \quad when\ x = 0$$

4.10.4 *Elevation Conformance of a Survey Line—EC_L*is calculated using Eq 19.

$$EC_L = 100 \left[\frac{dh_L}{imax_L} \right] \text{percent} \tag{19}$$

4.10.5 *Elevation Conformance of a Test Section*—EC is calculated using Eq 20.

$$EC = 100 \left[\frac{\sum_{L=1}^{Lmax} dh_L}{\sum_{L=1}^{Lmax} imax_L} \right] \text{percent} \tag{20}$$

4.11 *Calculations for RMS Levelness—RMS LV_L,*the RMS of the successive 15-ft least squares fit slopes of each survey line, *L*, is calculated using Eq 21-23.

4.11.1 *Mean Elevation over 15 ft—mh_d,*the mean elevation for each 15-ft section of survey line, *L*, is calculated using Eq 21 *(d* = 1, 2, 3 . . . (*$imax_L$* − 15/*s*)*)*.

$$mh_d = \sum_{i=d}^{d+15/s} \frac{h_i}{15/s+1}\ in. \tag{21}$$

4.11.2 *Least Squares Fit Slope over 15 ft—ms_d,*the mean slope of the least squares fit line through each 15-ft section of survey line, *L*, is calculated using Eq 22 *(d* = 1, 2, 3 . . . (*$imax_L$* − 15/*s*)*)*.

$$ms_d = \frac{6}{15} \left[\frac{2 \sum_{i=d}^{d+15/s} (i-d+1) h_i}{(15/s+1)(15/s+2)} - mh_d \right] in./ft \tag{22}$$

4.11.3 *RMS Levelness— RMS LV_L,*the RMS of the slopes of all 15-ft sections of survey line, *L*, is calculated using Eq 23 *(d* = 1, 2, 3 . . . (*$imax_L$* − 15/*s*)*)*.

$$RMS\,LV_L = \sqrt{\frac{\sum_{d=1}^{(imax_L - 15/s)} ms_d^2}{(imax_L - 15/s)}}\ in./ft \tag{23}$$

5. Significance and Use

5.1 This test method provides statistical and graphical information concerning floor surface profiles.

5.2 *Results of this test method are for the purpose of:*

5.2.1 Establishing compliance of random or fixed-path trafficked floor surfaces with specified tolerances,

5.2.2 Evaluating the effect of different construction methods on the waviness of the resulting floor surface,

5.2.3 Investigating the curling and deflection of concrete floor surfaces,

5.2.4 Establishing, evaluating, and investigating the profile characteristics of other surfaces, and

5.2.5 Establishing, evaluating, and investigating the levelness characteristics of surfaces.

5.3 *Application:*