Designation: E 1155M – 96
METRIC

An American National Standard

Standard Test Method for Determining F_F Floor Flatness and F_L Floor Levelness Numbers [Metric][1]

This standard is issued under the fixed designation E 1155M; 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 a quantitative method of measuring floor surface profiles to obtain estimates of the floor's characteristic F_F Flatness and F_L Levelness Face Floor Profile Numbers (*F*-Numbers) using the metric (SI) system of units.

NOTE 1—This is the metric companion to Test Method E 1155.

1.2 The text of this test method references notes and footnotes that provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of this test method.

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 Documents

2.1 *ASTM Standards:*

E 1155 Test Method for Determining F_F Floor Flatness and F_L Floor Levelness Numbers[2]

2.2 *ACI Standard:*

ACI 117-90 Standard Specifications for Tolerances for Concrete Construction and Materials[3]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *elevation*—height, altitude, vertical location in space. Elevation measurements are always made parallel to the direction of gravity.

3.1.2 *flat*—even, plane, homoloidal, free of undulation.

3.1.2.1 *Discussion*—For the purposes of this test method, flatness will be measured by calculating curvature value, *q*, between all 12-in. reading points separated by 24 in. The curvature value is the difference between successive elevation differences. The mean and standard deviation of all the curvature values for a given test section are then converted according to the equations in this test method to get the dimensionless F_F Flatness Number.

3.1.3 *floor profilometer*—a Type I device (see 6.1.1) that produces a continuous record of the elevation of a single point moving along a line on the floor's surface.

3.1.4 *horizontal*—level, normal to the direction of gravity.

3.1.5 *inclinometer*—a Type II device (see 6.1.2) that measures the angle between horizontal and the line joining the two points of contact with the floor's surface.

3.1.6 *level*—horizontal, normal to the direction of gravity.

3.1.6.1 *Discussion*—For the purposes of this test method, levelness will be measured by collecting elevation differences at points spaced 10 ft apart and that will be described by the F_L Levelness number (dimensionless).

3.1.7 *longitudinal differential floor profilometer*, *n*—a Type II device (see 6.1.2) that produces a continuous record of the elevation difference between two points moving along a line on the floor's surface, which two points remain separated by a fixed distance.

3.1.8 *sample measurement line*—a sample measurement line shall consist of any straight line on the test surface along which measurements are taken, with the limitations listed in 7.3.

3.1.9 *sign convention*—where up is the positive direction; down is the negative direction. Consequently, the higher the reading point, the more positive its h_i value, and the lower the reading point, the more negative its h_i value. Similarly, the elevation difference from a low point to a high point (that is, an *uphill* difference) is positive, while the elevation difference from a high point to a low point (that is, a *downhill* difference) is negative.

3.1.10 *test section*—a test section consists of any subdivision of the test surface with the limitations listed in 7.2.

3.1.11 *test surface*—on any one building level, the entire floor area of interest constitutes the test surface, with the limitations listed in 7.1.

3.1.12 *vertical*—parallel to the direction of gravity.

3.2 *Symbols:*

3.2.1 A_i—area of Test Section *i*.

3.2.2 d_i—difference in elevation (in millimetres) between

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[2] *Annual Book of ASTM Standards*, Vol 04.11.

[3] Available from American Concrete Institute, P.O. Box 19150, Detroit, MI 48219-0150.

reading points P_i and P_{i-1} ($i \geq 1$).

3.2.3 F_f—Face F_F Flatness Number (dimensionless).

3.2.4 F_{f_i}—composite F_F Flatness Number for Test Section *i*.

3.2.5 F_l—Face F_L Levelness Number (dimensionless).

3.2.6 F_{l_i}—composite F_L Levelness Number for Test Section *i*.

3.2.7 h_i—elevation (in millimetres) of Reading Point P_i ($i \geq 0$).

3.2.8 n_j—number of reading points in Test Sample *j* ($n_j \geq 12$).

3.2.9 N_{min}—minimum number of 3-m elevation difference readings required per the test section.

3.2.10 q_i—arithmetic difference (in millimetres) between elevation differences d_i and d_{i-1} ($i \geq 2$).

3.2.11 r_{x_j}—number of readings of Variable *x* obtained from Sample *j*.

3.2.12 s_{x_j}—standard deviation of Variable *x* in Sample *j*.

3.2.13 V_{x_j}—variance of Variable *x* in Sample *j*.

3.2.14 z_i—difference in elevation (in millimetres) between Reading Points P_i and P_{i-10} ($i \geq 10$).

4. Summary of Test Method

4.1 Straight lines are marked at various locations on the floor surface. Point elevations are then measured at regular 300-mm intervals along each line. The elevation differences between all adjacent reading points are calculated, and a straight line approximation to the surface profile along each measurement line is produced and evaluated for consistency with visual observation of the floor surface.

4.2 The arithmetic differences between all adjacent 300-mm elevation differences and the elevation differences between all points separated 3 m are then calculated. Estimates of each test section's floors F_F Flatness and F_L Levelness *F*-Numbers are obtained through statistical analyses of these calculated profile values. Finally, the *F*-Numbers for each test section are combined to arrive at a composite set of *F*-Numbers for each test surface.

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 used primarily to:

5.2.1 Establish compliance of randomly trafficked floor surfaces with specified F_F Flatness and F_L Levelness tolerances,

5.2.2 Evaluate the effect of different construction methods on resulting floor surface flatness and levelness, and

5.2.3 Investigate the curling and deflection of floor surfaces.

5.3 Results of this test method shall not be used to enforce contract flatness and levelness tolerances on those floor installations primarily intended to support the operation of fixed-path vehicle systems (for example, narrow aisle warehouse floors).

NOTE 2—When the traffic patterns across a floor are random, (as is generally the case) evaluation of the floor's F_F Flatness and F_L Levelness will necessarily involve a random sampling of the surface, since all of the infinite potential profiles to be seen by the traffic can not possibly be measured. In those instances when the traffic across a floor will be confined to specific paths, however, the requirement for random sampling is eliminated, since the floor can indeed be inspected exactly as it will be seen by all of the traffic. In these special cases, rather than inferring the condition of the traffic paths from a random sample, it is far more useful to measure each of the traffic paths directly using continuous recording floor profilometer configured to run exactly in the traffic wheel paths. Such direct simulation measurements eliminate the inherent uncertainties of statistical sampling and provide profile information immediately applicable to the correction of the surface in way of the future traffic.

6. Apparatus

6.1 *Point Elevation Measurement Device*:

6.1.1 *Type I Apparatus*—If a Type II apparatus (see 6.1.2) is not used for this test, then an apparatus capable of measuring the elevations of a series of points spaced at regular 300-mm intervals along a straight line on the floor surface shall be used. Examples of satisfactory Type I point elevation measurement devices include, but are not limited to the following:

6.1.1.1 *Leveled Straightedge*, with gage (for example, tri-square, dial indicator, etc.) to measure vertical distance from the upper straightedge surface to floor.

6.1.1.2 *Leveled Straightedge*, with graduated wedges or shims to measure vertical distance from lower straightedge surface to floor.

6.1.1.3 *Optical Level*, with vernier or scaled target.

6.1.1.4 *Laser Level*, with vernier or scaled target.

6.1.1.5 *Taut Level Wire*, with gage to measure vertical distance from wire to floor.

6.1.1.6 *Floor Profilometer*.

6.1.2 *Type II Apparatus*—If a Type I apparatus (see 6.1.1) is not used for this test, then an apparatus capable of measuring the elevations of a series of points spaced at regular 300-mm intervals along a straight line on the floor surface shall be used. Examples of satisfactory Type II point elevation measurement devices include, but are not limited to the following:

6.1.2.1 *Inclinometer*, having 300-mm contact point spacing.

6.1.2.2 *Longitudinal Differential Floor Profilometer*, having 300-mm sensor wheel spacing.

6.2 *Ancillary Equipment*:

6.2.1 *Measurement Tape*, graduated in millimetres.

6.2.2 *Chalk Line* (or other means for marking straight lines on the test surface).

6.2.3 *Data Recording Means*—This procedure requires the recording of both verbal and numeric information. Examples of satisfactory data recording means include, but are not limited to the following:

6.2.3.1 *Manual Data Sheet*.

6.2.3.2 *Magnetic Tape Recorder* (voice or direct input).

6.2.3.3 *Paper Chart Recorder*.

6.2.3.4 *Direct Computer Input*.

NOTE 3—Since the bias of the results obtained with this test method will vary directly with the accuracy of the particular measurement device employed, all project participants should agree on the exact test apparatus to be used prior to the application of this test method for contract specification enforcement.

7. Organization of Test Area

7.1 *Test Surface*—On any one building level, the entire floor area of interest shall constitute the test surface.

7.1.1 When this test method is used to establish compliance of randomly trafficked floor surfaces with specified F_F Flatness and F_L Levelness tolerances, each portion of the surface which has a unique specified set of tolerances must be treated as a separate surface.

7.2 *Test Section*—A test section shall consist of any subdivision of a test surface satisfying the following criteria:

7.2.1 No test section shall measure less than 2.4 m on a side, nor comprise an area less than 12 m^2.

7.2.2 No portion of the test surface shall be associated with more than one test section.

7.2.3 When testing a concrete floor, no test section boundary shall cross any construction joint.

7.3 *Sample Measurement Line*—A sample measurement line shall consist of any straight line on the test surface satisfying the following criteria:

7.3.1 No sample measurement line shall measure less than 3.3 m in length.

7.3.2 When testing a concrete floor, no portion of any sample measurement line shall fall within 600 mm of any slab boundary, construction joint, isolation joint, block-out, penetration, or other similar discontinuity.

7.3.2.1 *Exception*—Shrinkage crack control joints formed either by partial depth sawcuts or by partial depth inserts shall be ignored.

7.3.2.2 *Exception*—If the area to be excluded from measurement exceeds 25 % of the test section area, then the 600-mm boundary exclusion shall not apply.

7.3.3 Measurement lines may not be placed parallel to each other closer than 1.2 m.

7.4 *Type I Test Sample (Measured With Type I Apparatus)*—A Type I test sample shall consist of not less than twelve sequential point elevation measurements made at regular 300-mm intervals along a single sample measurement line.

7.5 *Type II Test Sample (Measured With Type II Apparatus)*—A Type II test sample shall consist of not less than eleven sequential measurements of the elevation differences between adjacent reading points spaced at regular 300-mm intervals along a single sample measurement line.

7.6 *Minimum Number of z_i Readings Per Test Section*—The number (or length) of Type I or Type II test samples to be collected within each test section shall be sufficient to yield (in aggregate) not less than N_{min} individual measurements of z_i, where N_{min} is calculated as follows:

$$N_{min} = 2\sqrt{A}\ (12 \leq A \leq 150) \qquad (1)$$
$$= A/3\ (A > 150)$$

where:
A = test section area, m^2.

7.7 *Construction Joints*—Where construction joints are required to be measured, periodic measurements of the 600-mm curvature q_i shall be taken, transverse to and centered on the construction joint. At least one q_i measurement shall be taken on each straight section of joint, with a maximum interval between measurement locations not to exceed 3 m. These measurement locations shall be recorded.

NOTE 4—Since construction joints are a discontinuity in the floor surface, measuring across them would introduce statistical anomalies into this test method. Construction joints are therefore excluded from the generation of *F*-Number statistics. However, since traffic will nevertheless pass across many of the construction joints, a separate measurement and analysis of the joints may be required in order to provide a quantitative measure of the roughness of the joints themselves. Some joints may never see traffic, for example, those along a wall. The particular joints required to be analyzed may be specified in contract specifications, along with a maximum allowable value for q_i.

8. Procedure

8.1 Record the name and location of the subject building; the installation date of the subject floor, if known; the subject floor's specified F_f and F_l values; the make, model, and serial number of the test apparatus to be used; the date of the test; and the name of the individual making the test.

NOTE 5—When this test is used to evaluate the compliance of a new concrete floor with contract flatness and levelness specifications, the timeliness of the test vis-a-vis the date of the floor's installation is of critical importance. Since most concrete floors will change shape significantly within a few days after installation, owing to inevitable shrinkage and deflection, the American Concrete Institute (see ACI 117-90) now requires that specified concrete floor tolerances be checked within 72 h after floor installation in order to ensure that an accurate gage of the surface's "as-built" shape is assessed.

8.2 Lay out the test surface.

8.2.1 Divide the entire test surface into test sections. Assign a different identification number to each test section, and record the locations of all test section boundaries.

8.2.2 Within the restrictions described in 7.3, 7.6, and 8.2.3, determine the number and location of all sample measurement lines to be used in each test section. Assign a different identification number to each sample measurement line, and record the locations of all sample measurement line starting and stopping points. Mark or otherwise physically delineate each sample measurement line on the test surface.

8.2.3 The sample measurement lines within each test section shall be arranged so as to blind the test results (to the extent possible) to any surface profile anisotropies resulting from the floor's method of construction. Accomplish this by distributing the sample measurement lines uniformly across the entire test section and either:

8.2.3.1 Orienting all lines at 45° to the longest construction joint abutting the test section, (not corner-to-corner diagonals), or

8.2.3.2 Placing equal numbers of lines of equal aggregate length both parallel to and perpendicular to the longest test section boundary.

8.2.3.3 When the short dimension (width) of the slab being measured is less than 7.5 m, all measurement lines must be 45° diagonals in accordance with 8.2.3.1.

8.3 Collect Type I or Type II test samples, or both, from each test section sufficient (in aggregate) to satisfy the minimum z_i reading requirement prescribed in 7.6. No upper limit is placed upon the number of test samples that may be collected from a single test section. All data collected on all survey lines measured in a given test section shall be incorporated into the calculations of *F*-Numbers. Data shall only be excluded when it can be demonstrated that the test apparatus reported inaccurate values or that the test procedure of this test method was not followed. In the event that data is excluded, the entire survey line shall be considered unusable; no single measurement of d_i, q_i, or z_i may be excluded.

8.3.1 Subdivide each sample measurement line into 300-mm long intervals. The points marking the ends of these 300-mm intervals are the sample reading points. Designate the starting point of each sample as P_0 and then sequentially number each successive reading point down the sample measurement line as P_1, P_2, P_3, etc.

8.3.2 For each test sample, measure and record in sequence:

8.3.2.1 If a Type I apparatus is used, the elevations (in millimetres) of all sample reading points, or

8.3.2.2 If a Type II apparatus is used, the differences in elevation (in millimetres) between all adjacent sample reading points.

9. Calculation

9.1 Calculate the elevations of all reading points:

9.1.1 If analyzing a Type I test sample, designate the elevation measurements collected at Reading Points P_0, P_1, P_2, ... P_i, etc. as h_0, h_1, h_2, ... h_i, etc.

9.1.2 If analyzing a Type II test sample:

9.1.2.1 Designate the elevation difference measurements collected between Reading Points P_0 and P_1, and P_2 and P_3, ... P_{i-1} and P_i, etc. as d_1, d_2, d_3, ... d_i, etc.

9.1.2.2 Let $h_0 = 0$.

9.1.2.3 Calculate the elevations, h_i, of all reading points as follows:

$$h_i = h_{i-1} + d_i \text{ (mm)} \tag{2}$$

where:
$i \geq 1$.
Each Type II test sample will therefore result in n_j calculated h_i values.

9.2 Produce a straight line graph between each of the n_j calculated h_i values. This is a straight line approximation of the floor surface profile. Evaluate each straight line profile approximation subjectively to confirm that it appears to represent the actual floor surface profile. This serves as a subjective quality control check to ensure that no gross anomalies are present in the data before reporting the results of this test method.

9.3 Calculate the difference in elevation between all adjacent reading points:

9.3.1 If analyzing a Type I test sample, calculate the elevation differences, d_i, between all adjacent reading points as follows:

$$d_i = h_i - h_{i-1} \text{ (mm)} \tag{3}$$

where:
$i \geq 1$.
Each Type I Test Sample j will therefore result in $(n_j - 1)$ calculated d_i values. Whenever Point P_i is higher than Point P_{i-1}, the value for d_i will be positive. Conversely, whenever Point P_i is lower than Point P_{i-1}, the value for d_i will be negative.

9.3.2 If analyzing a Type II test sample, designate all d_i values in accordance with 9.1.2.1.

9.4 For each Test Sample j, calculate the profile curvatures, q_i, between all reading points separated by 600 mm as follows:

$$q_i = d_i - d_{i-1} \text{ (mm)} = h_i - 2 \times h_{i-1} + h_{i-2} \text{ (mm)} \tag{4}$$

where:
$i \geq 2$.

Each test sample will result in $(n_j - 2)$ calculated q_i values. A positive q_i value will denote a *trough*, while a negative q_i value will denote a *crest*.

9.5 For each Test Sample j, calculate the elevation differences, z_i, between all reading points separated by 3 m as follows:

$$z_i = h_i - h_{i-10} \text{ (mm)} \tag{5}$$

where:
$i \geq 10$.

Each test sample will result in $(n_j - 10)$ calculated z values. A positive z_i value will denote an *uphill* change in elevation from P_{i-10} to P_i, while a negative z_i value will denote a *downhill* change in elevation from P_{i-10} to P_i.

9.6 For each Test Sample j, calculate the mean, $\bar{q}_{i_j}$, of all $(n_j - 2)$ q_i values.

9.6.1 Add all $(n_j - 2)$ q_i values in Sample j as follows:

$$\sum_{i=2}^{n_j-1} q_i = q_2 + q_3 + q_4 + ... + q_{n_j-1} \text{ (mm)} \tag{6}$$

9.6.2 Divide this sum by $(n_j - 2)$ to obtain the mean value of the q_i values in Sample j as follows:

$$\bar{q}_{i_j} = \frac{\sum_{i=2}^{n_j-1} q_i}{n_j - 2} \text{ (mm)} \tag{7}$$

9.7 For each Test Sample j, calculate the standard deviation S_{q_j}, of all $(n_j - 2)$ q_i values.

9.7.1 Add the squares of all $(n_j - 1)$ q_i values as follows:

$$\sum_{i=2}^{n_j-1} q_i^2 = q_2^2 + q_3^2 + q_4^2 + ... + q^2_{n_j-1} \text{ (mm}^2\text{)} \tag{8}$$

9.7.2 Multiply the sum of all $(n_j - 2)$ q_i values obtained in 9.6.1 by the mean value of q_{i_j}, obtained in 9.6.2, subtract this product from the sum of the squares of all $(n_j - 2)$ q_i values obtained in 9.6.1, and divide this difference by $(n_j - 3)$ to obtain the variance V_{q_j}, *of the* q_i values in Sample j as follows:

$$V_{q_j} = \frac{\sum_{i=2}^{n_j-1} q_i^2 - \bar{q}_{i_j} \sum_{i=2}^{n_j-1} q_i}{n_j - 3} \text{ (mm}^2\text{)} \tag{9}$$

9.7.3 Take the square root of the variance, V_{q_j}, of the q_i values in Sample j to obtain the standard deviation, S_{qj}, of the q_i values in Sample j as follows:

$$S_{q_j} = \sqrt{V_{q_j}} \text{ (mm)} \tag{10}$$

9.8 For each Test Sample j, calculate the mean, $\bar{z}_{i_j}$, of all $(n_j - 10)$ z_i values.

9.8.1 Add all $(n_j - 10)$ z_i values in Sample j as follows:

$$\sum_{i=10}^{n_j-1} z_i = z_{10} + z_{11} + z_{12} + ... + z_{n_j-1} \text{ (mm)} \tag{11}$$

9.8.2 Divide this sum by $(n_j - 10)$ to obtain the mean value of $\bar{z}_{ij}$ of the z_i values in Sample j as follows:

$$\bar{z}_{i_j} = \frac{\sum_{i=10}^{n_j-1} z_i}{n_j - 10} \text{ (mm)} \tag{12}$$

9.9 For each Test Sample j, calculate the standard deviation,