ASTM

Designation: E 1155M – 96
METRIC

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

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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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, 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:

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

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:

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

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,

S_{z_j}, of all $(n_j - 10)$ z_i values.

9.9.1 Add the squares of all $(n_j - 10)$ z_i values as follows:

$$\sum_{i=10}^{n_j-1} z_i^2 = z_{10}^2 + z_{11}^2 + z_{12}^2 + ... + z_{n_j-1}^2 \ (\text{mm}^2) \quad (13)$$

9.9.2 Multiply the sum of all $(n_j - 10)$ z_i values obtained in 9.8.1 by the mean value, z_i, obtained in 9.8.2, subtract this product from the sum of the squares of all $(n_j - 10)$ z_i values obtained in 9.9.1, and divide this difference by $(n_j - 11)$ to obtain the variance, V_{z_j}, of the z_i values in Sample j as follows:

$$V_{z_j} = \frac{\sum_{i=10}^{n_j-1} z_i^2 - \bar{z}_{i_j} \sum_{i=10}^{n_j-1} z_i}{n_j - 11} \ (\text{mm}^2) \quad (14)$$

9.9.3 Take the square root of the variance, V_{z_j}, of the z_i values in Sample j to obtain the standard deviation, S_{z_j}, of the z_i values in Sample j as follows:

$$S_{z_j} = \sqrt{V_{z_j}} \ (\text{mm}) \quad (15)$$

9.10 Estimate the F_F Flatness Number, F_{f_j}, for each Test Sample j as follows:

$$F_{f_j} = \frac{115.8454}{(3 \cdot S_{q_i} + |\bar{q}_{i_j}|)} \ (\text{dimensionless}) \quad (16)$$

where:
S_{q_i} = standard deviation of the q_i values in Sample j (from 9.7.3), and
$\bar{q}_{i_j}$ = absolute value of the mean of the q_i values in Sample j (from 9.6.2).

9.11 Calculate the composite F_F Flatness Number estimate for each test section by combining all of the F_F Flatness Number estimates obtained from the individual test samples within that test section.

9.11.1 The following equation is used to combine the F_F Flatness or F_L Levelness Number estimates derived from two different test samples into a single composite F-Number estimate:

$$F_{j+k} = F_j \cdot F_k \sqrt{\frac{r_j + r_k}{r_k \cdot F_j^2 + r_j \cdot F_k^2}} \quad (17)$$

where:
F_{j+k} = F-Number estimate derived by combining Samples j and k,
F_j = F-Number estimate derived from Sample j,
F_k = F-Number estimate derived from Sample k,
r_j = number of q_i or z_i readings in Sample j used to derive F_j, and
r_k = number of q_i or z_i readings in Sample k used to derive F_k.

9.11.2 Using the equation given in 9.11.1, calculate the composite F_F Flatness Number estimate for each test section by combining (iteratively) all of the flatness F-Number estimates obtained from the individual test samples within that test section. The number of readings to be associated with each successive F_F Flatness Number estimate, F_{j+k}, will be the sum $(r_j + r_k)$.

NOTE 6—Since F_F Flatness Numbers may be combined only with other F_F Flatness Numbers, and F_L Levelness Numbers may only be combined with other F_L Levelness Numbers, the complete description of any floor surface requires the identification of two separate and distinct F-Number

values: F_f Flatness Number and F_l Levelness Number.

9.11.3 *Sample Problem Illustrating F-Number Combination Procedure*—Three test samples containing 40, 60, and 80 readings respectively are collected from a certain test section. Analysis in accordance with 9.10 yields the following individual sample F_f estimates:

Sample One:

F_{f_1} = 20, and
r_{q_1} = number of q_i readings in Sample One = 40.

Sample Two:

F_{f_2} = 30, and
r_{q_2} = number of q_i readings in Sample Two = 60.

Sample Three:

F_{f_3} = 40, and
r_{q_3} = number of q_i readings in Sample Three = 80.

9.11.3.1 To combine these three individual sample results into a single composite F_f estimate for the entire test section, use the equation given in 9.11.1 by first combining the F_f estimates given for any two of the test samples, and then combining this interim F_f result with the F_f estimate from the remaining sample as follows:

$$F_{F_{1+2}} = F_{F_1} \cdot F_{F_2} \sqrt{\frac{r_{q_1} + r_{q_2}}{r_{q_2} \cdot F_{F_1}^2 + r_{q_1} \cdot F_{F_2}^2}} \quad (18)$$

$$F_{F_{1+2}} = 20 \cdot 30 \sqrt{\frac{40 + 60}{60 \cdot 20^2 + 40 \cdot 30^2}}$$

$$= 24.5$$

where:
$F_{f_{1+2}}$ = F_F Flatness Number estimate derived by combining Samples One and Two.

9.11.3.2 Calculate the combined sample size, $r_{q_{1+2}}$, by adding the number of readings contained in each sample as follows:

$$r_{q_{1+2}} = r_{q_1} + r_{q_2} = 40 + 60 = 100 \quad (19)$$

9.11.3.3 Now combine this interim result with the F-Number estimate derived from the remaining sample to obtain the desired composite F-Number estimate:

$$F_{F_{(1+2)+3}} = F_{F_{1+2}} \cdot F_{F_3} \sqrt{\frac{r_{q_{1+2}} + r_{q_3}}{r_{q_3} \cdot F_{F_{1+2}}^2 + r_{q_{1+2}} \cdot F_{F_3}^2}} \quad (20)$$

$$F_{F_{(1+2)+3}} = 24.5 \cdot 40 \sqrt{\frac{100 + 80}{30 \cdot 24.5^2 + 100 \cdot 40^2}}$$

$$= 28.8$$

where:
$F_{f_{(1+2)+3}}$ = F_F Flatness Number estimate derived by combining Samples One, Two, and Three.

9.11.3.4 The combined sample size, $r_{q_{(1+2)+3}}$, is calculated as follows:

$$r_{q_{(1+2)+3}} = r_{q_{1+2}} + r_{q_3} = 100 + 80 \quad (21)$$

$$= 180$$

Therefore, based upon 180 readings of q_i, the subject test section has an estimated Flatness F-Number of F_f 28.8.

9.12 Estimate the F_L Levelness Number for each Test Sample j as follows:

$$F_{L_i} = \frac{314.67}{(3 \cdot S_{z_i} + |\bar{z}_{i_j}|)} \text{ (dimensionless)} \qquad (22)$$

where:

S_{z_j} = standard deviation of z_i in Sample j (from 9.9.3), and

$|\bar{z}_{i_j}|$ = absolute value of the mean of the z_i values in Sample j (from 9.8.2).

9.13 Using the equation in 9.11.1, calculate the composite F_L Levelness Number estimate for each test section by combining (iteratively) all of the F_L Levelness Number estimates obtained from the individual test samples within that test section. The number of readings to be associated with each successive F_L Levelness Number estimate, F_{j+k}, will be the sum $(r_j + r_k)$.

9.14 Calculate the 90 % confidence interval, $CI_{90\%}$, associated with each F_F Flatness and F_L Levelness Number estimate as follows:

$$CI_{90\%} = -1.82 \, (\log_{10} r)^3 + 19.4 \, (\log_{10} r)^2 - 71.69 \, (\log_{10} r) + 92.62 \% \qquad (23)$$

where:

r = total number of q_i or z_i readings used to calculate the F-Number:

$$F\text{−Number 90 \% Confidence Interval} \qquad (24)$$

$$= (100 - CI_{90\%}) \cdot F/100 \text{ to } (100 + CI_{90\%}) \cdot F/100$$

9.15 Within each test surface, combine each test section's F-Numbers by area-weighting to obtain overall F-Numbers as follows:

$$\text{Overall } F_f = \frac{\Sigma \, A_i \cdot F_{f_i}}{\Sigma \, A_i} \qquad (25)$$

$$\text{Overall } F_l = \frac{\Sigma \, A_i \cdot F_{l_i}}{\Sigma \, A_i} \qquad (26)$$

10. Report

10.1 In tabular form, list the calculation results obtained in 9.1, 9.3, and 9.4, and 9.10-9.14 inclusive for each test section. Whenever reporting F_f or F_l estimates for test sections, always show the associated 90 % confidence interval in parentheses immediately following the F-Number estimate.

10.2 An example illustrating correct F-Number reporting format is as follows:

10.2.1 On a particular test section, the estimated F_f value of 24.5 has a 90 % confidence interval of 23.0 to 26.0. Whenever this F-Number estimate appears in the report, it is followed immediately by its associated 90 % confidence interval enclosed in parentheses:

$$F_f \, 24.5 \, (23.0 - 26.0) \qquad (27)$$

10.3 When required by contract specifications, the maximum q_i value on each straight section of construction joint shall be reported.

10.4 List the calculated overall F-Number results for the entire test surface. This is the only F-Number that is reported without a confidence interval.

NOTE 7—A plot of profile elevation as a function of horizontal distance may also be reported from the point elevation readings obtained in 9.1, along any or all sample measurement lines. These plots may be useful in visualizing the F_F Flatness and F_L Levelness of the survey lines.

11. Factors Influencing Precision and Bias of This Test Method

11.1 Since every test section contains an infinity of q_i and z_i values, all of which cannot be measured, estimation of F_f or F_l from a finite sample of q_i or z_i values involves the mathematics of statistical inference. The means and standard deviations of the q_i and z_i values contained in each test sample are calculated and used as estimates for the means and standard deviations of the entire infinite q_i and z_i populations. The equations given in 9.9 and 9.11 translate these estimated population statistics into their corresponding F-Numbers.

11.2 On level floors, as the sample size increases, the mean values, q_i and z_i, approach zero and can be ignored. F_f and F_l are then reduced to functions only of the standard deviations S_q and S_z:

$$F_F = \frac{38.6}{S_q} \qquad (28)$$

and

$$F_l = \frac{104.9}{S_z} \qquad (29)$$

11.3 Since 99.73 % of all values in a normal distribution fall within ± 3 % standard deviations of the population mean, 99.73 % of all q_i readings will have an absolute value less than or equal to the following:

$$q_{max} = 3(S_q) = \frac{115.8454}{F_F} \text{ (mm)} \qquad (30)$$

while 99.73 % of the z_i readings will have an absolute value less than or equal to the following:

$$z_{max} = 3(S_z) = \frac{314.67}{F_L} \text{ (mm)} \qquad (31)$$

11.3.1 These $3(S)$ values have been arbitrarily defined as the dimensional limits that characterize a given F-Number. They provide a simple means for giving the F-Numbers dimensional significance, that are greater than these $3(S)$ values. It is incorrect, however, to think of F-Numbers as directly limiting the magnitudes of q_i or z_i. F-Numbers do not prohibit the incidence of any specific q_i or z_i value; they only limit the percentage of all q_i or z_i readings that can have that value.

11.4 Since F-Numbers are derived directly from the q_i and z_i statistics, the accuracy of the composite F_f and F_l estimates obtained in 9.10 and 9.12 will depend upon the following:

11.4.1 The degree to which the sample q_i and z_i distributions match the actual q_i and z_i distribution, and

11.4.2 The total number of sample q_i and z_i readings used to estimate the means and standard deviations of the entire, infinite q_i and z_i populations.

11.5 As the size of a sample increases, so does the probability that the sample's statistics will accurately represent those of the entire population. Confidence in the ability of a certain size sample to estimate the statistics of an entire population is expressed in terms of confidence intervals. The 90 % confidence interval calculated in 9.13 is a direct measure of the degree of statistical uncertainty that will be associated with each F-Number estimate obtained with this test method. This 90 % confidence interval may be interpreted as follows:

11.5.1 Given a sample size of r readings, nine times out of ten the actual F-Number of the floor will fall between plus or minus $CI_{90\%}$ percent of the F-Number estimate obtained with this test method.

11.6 The F-Number estimate obtained in 9.9 or 9.11 is the midpoint of a range of possible F-Numbers characterizing the test section with some known probability. The width of each such F-Number range will vary directly with the confidence level demanded and inversely with the number of sample readings used to compute the midpoint estimate. The probability that a particular range will actually contain the true F-Number of the floor increases as the width of the range increases. Likewise, the greater the number of sample readings used to estimate the range midpoint, the greater the probability that the true F-Number of the floor will be near that midpoint.

NOTE 8—Since it is impossible to be certain of the exact F_F Flatness or F_L Levelness Number of any floor (no matter how many readings are taken, some statistical uncertainty will always exist), report the results of this test method as a range of possible F-Numbers at the prescribed 90 % confidence level.

11.7 The results obtained with this test method will also vary with the precision and bias of the particular elevation measurement apparatus employed. Instrument inaccuracies will always result in a lowering of the reported F-Numbers.

12. Precision and Bias

12.1 *Precision*—The repeatability standard deviation for both F_f and F_l is less than 0.25.

12.1.1 These values were obtained by conducting repeated measurements of the same test section. For these within-laboratory tests, the same layout pattern was used, with the same operators and apparatus. When operators and equipment models (of the same fundamental type of measurement apparatus) are varied, but the layout pattern is retained, the repeatability standard deviation goes up to about 0.3. The small standard deviation obtained indicates that neither the operator nor the equipment model (within this particular type apparatus) has a very significant influence on repeatability. The results do not vary widely with changes in F_f and F_l. Future versions of this test method will be published with precision and bias as generated by using other measurement apparatus, when sufficient data can be made available.

12.1.2 The reproducibility standard deviation for F_f is as follows:

10	Cz	20	Cz	30	Cz	40	Cz	50	Cz	60	Cz	70	Cz	80
	0.25		0.74		1.22		1.70		2.18		2.66		3.14	

12.1.2.1 These values were also obtained by having various testing agencies across the United States conduct repeated measurements of the same test section, in this case, always with different layout patterns. The larger resulting standard deviations obtained indicate that variation in line placement is the dominant factor in obtaining differing values of F_f. In general, precision of results is best at the lower F_f values, and decreases with increasing F_f-Number. It should be noted that the data used to generate this precision and bias statement was generated through the use of many different instruments, all of which were one of three different models of one Type II instrument. Although several other devices have been used at various times to collect data for this test method, no comparative data is available from any of these devices. Future versions of this test method will be published with precision and bias as generated by using other measurement apparatus, when sufficient data can be made available.

12.1.3 The reproducibility standard deviation for F_l is as follows:

10	Cz	20	Cz	30	Cz	40	Cz	50	Cz	60	Cz	70	Cz	80
	0.70		1.75		2.00		2.75		2.0		2.9		4.5	

12.1.3.1 One way to interpret these results is to state the expected or probable error, that is equal to 0.6746 times the standard deviation. For example, when measuring a floor whose known true F_f value is 15, 50 % of the time it is expected that the test result be greater than 15.23 or less than 14.77, and 50 % of the time, it is expected that the deviation be within this range. Another way to interpret the precision results is to look at the 95 % reproducibility limits, that are 2.8 times the standard deviation. In this case, 95 % of the time, the measured result will fall between 14.05 and 15.95. This test method contains an estimate of the 90 % confidence limits, that are required to be provided in any report with the test result (see 9.13 and Section 10). As the F-Number goes up (either F_f or F_l) the uncertainty regarding the true value also rises, because much smaller errors can create the same amount of difference in the test result. For example, when measuring a floor whose known true F_f value is 35, 50 % of the time it is expected that the test result be greater than 36.1 or less than 33.9, and 50 % of the time, it is expected that the deviation be within this range, and 95 % of the time, the measured result will fall between 30.5 and 39.5.

12.2 *Bias*—The procedure in Test Method E 1155 has no bias because the values of F_f and F_l are defined in terms of this test method.

13. Keywords

13.1 F_f; F_F Flatness; F_l; F_L Levelness; floor; floor profile; floor profilometer; F-Number