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This article is a continuation of the “What’s This Report For?” series, based on a technical session sponsored by ACI Committee E702, Designing Concrete Structures. In keeping with ACI’s mission to provide knowledge and information for the best use of concrete, the articles will be posted on the ACI Web site (www.concrete.org/education/edu_online_CEU.htm) and, along with sample reports and multiple-choice questions, be used for educational materials.

The Floor Flatness Report

What the designer needs to know

BY MARK A. CHEEK

Floor profile finish quality has traditionally been specified by limiting the gap under either an unlevelled or levelled 10 ft (3 m) straightedge. Some specifications still take this tolerance approach, even though there is no nationally accepted standard either for taking measurements or for establishing compliance of a floor profile. In many specifications, slab finish quality is not addressed at all. Use of a nonstandard test procedure and failure to specify floor profiles often lead to conflict and litigation. For example, if the project specification calls for a 10 ft (3 m) straightedge to determine the quality of the finished floor and the test area is 100 x 100 ft (30 x 30 m), a technician can place the 10 ft (3 m) straightedge at a single location and measure the gaps between it and the floor. Operating without a standard, the technician could simply use the measurement from that one location as representative of the entire test area. It may (by some chance) be representative of the whole floor but most likely is not; thus, the results obtained are essentially useless.

PROFILING STANDARD

The technology for measuring floor profiles has developed in response to the need for a standard method to evaluate them. This technology, called the F-number

system,¹ provides a welcome alternative and a solution to the generally recognized inadequacies of the 10 ft (3 m) straightedge to describe and define floor profiles.

Floor flatness (F_f) and levelness (F_L) numbers determine whether a floor is sufficiently smooth and level, respectively, as constructed. Floor flatness can affect flooring installation, ride quality and safety in warehouses, and drainage. Floor levelness can affect shelf placement and design and a slab’s drainage plan. For example, the levelness of the floor in a warehouse could limit how high pallets of goods can be safely stacked. Typical F_f and F_L values for different applications are shown in Table 1 and Fig. 1.

Appropriate flatness and levelness

As in any other specification, the engineer should determine what is good enough for the application rather than impose a standard that is unnecessarily exacting and costly. Both overall flatness and levelness numbers should be specified, along with the local minimum values (typically 60% of the overall numbers). The test should be conducted within 72 hours of finishing the slab, as the curing process could cause the slab to curl and deviate from the flatness achieved by the finishers. Obtaining these numbers within 72 hours also allows the contractor

to make adjustments to the procedures, if necessary, while the floor is still being placed. Both flatness and levelness numbers can be determined on shored decks, but only flatness numbers can be determined on unshored decks.

Measurement

The F_F number is an indication of how bumpy or wavy the slab surface is, demonstrating the quality of the initial strike off and finishing process. The F-number system uses floor surface curvature calculated from elevation differences over 24 in. (600 mm) increments as a measure of flatness (Fig. 2). The F_L number is an indication of how level the slab is, demonstrating how level the forms were set. The floor slope is measured over a distance of 10 ft (30 m) (Fig. 3).

TABLE 1:

TYPICAL FLATNESS (F_F) AND LEVELNESS (F_L) NUMBERS FOR VARIOUS APPLICATIONS (ACI 302.1R)²

Composite flatness, F_F	Composite levelness, F_L	Typical applications
20	15	Noncritical: mechanical rooms, nonpublic areas, surfaces to have thick-set tile, parking structure slabs
25	20	Carpeted areas of commercial office buildings or lightly-trafficked office/industrial buildings
35	25	Thin-set flooring or warehouse floor with moderate or heavy traffic
45	35	Warehouse with air-pallet use, ice, or roller rinks
>50	>50	Movie or television studios

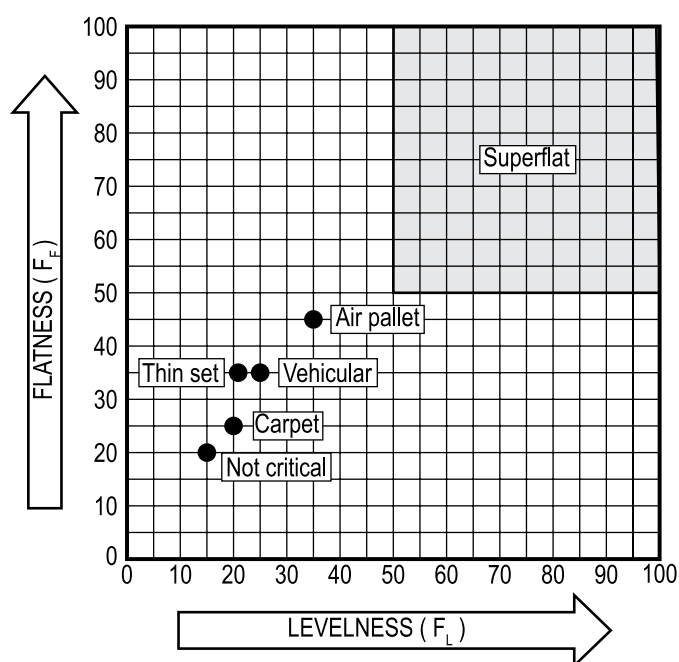


Fig. 1: Typical flatness and levelness requirements for various applications²

ASTM E1155, “Standard Test Method for Determining F_F Floor Flatness and F_L Floor Levelness Numbers,” is a quantitative method of measuring floor surface profiles to obtain estimates of the floor’s characteristic F_F and F_L numbers. Each slab requires a number of individual sample measurement lines (test runs). The quantity of test runs is determined by the area to be tested. The greater the area, the more test runs are required; thus, more data are accumulated and processed to determine F-number values for the slab.

In accordance with ASTM E1155, the test area must be organized into a test surface, test section(s), and test runs (Fig. 4). After the number and length of test runs are determined, the test runs can be laid out and the run path swept clean. Once the test runs are laid out and

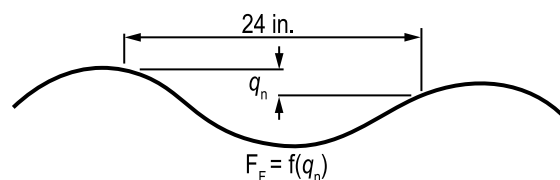


Fig. 2: The flatness is calculated from elevation readings over 24 in. (600 mm) increments

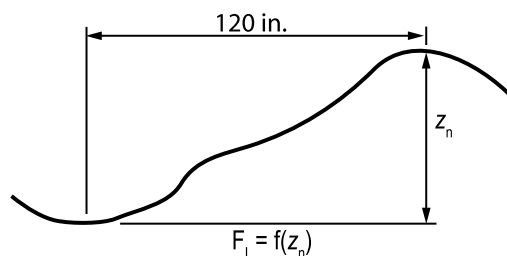


Fig. 3: The floor levelness is calculated from elevation readings over 10 ft (3 m) increments

cleaned, data can be collected using a Dipstick® floor profiler (Fig. 5) or equivalent. Minimum sampling requirements are discussed in ACI 117.²

Reviewing the report

A typical report includes a description of the test surface, test section(s) and location of test runs, the overall F_F and F_L numbers for the slab, the individual F_F and F_L numbers for each test run, and whether any required local minimum was violated. A graph of each test run may be included. The graph (Fig. 6) shows the change in elevation versus distance for the surface.

When reviewing a report, you should first verify that the overall F_F and F_L values meet the specified requirements. For example, suppose your project specification calls for a minimum F_F of 25 and a minimum F_L of 20. The corresponding minimum local values are typically 60% of these values, or 15.0 and 12.0, respectively; these should be spelled out in the specification. Looking at the example data in Table 2, you can see that the overall flatness and levelness requirements have been met.

After checking the overall flatness and levelness values against the specification, check the values of F_F and F_L for

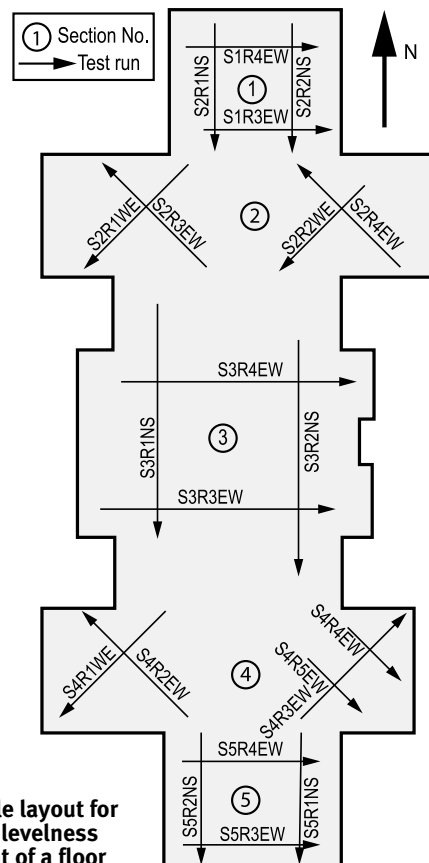


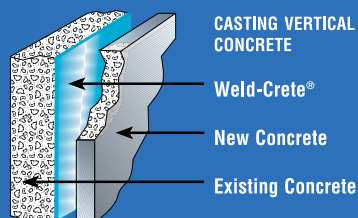
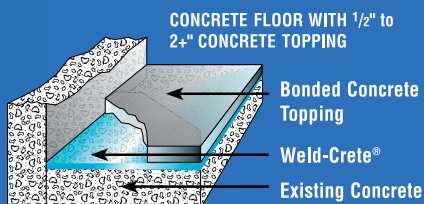
Fig. 4: Sample layout for flatness and levelness measurement of a floor

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the individual test runs. Figure 6 shows an example test run. The vertical scale is exaggerated to show the profile more clearly. In this case, $F_F = 26.71$, higher than the overall requirement and higher than the required local minimum of 15.0, and $F_L = 19.42$, lower than the overall requirement but higher than the required local minimum of 12.0.



Fig. 5: A Dipstick floor profiler is used to collect flatness and levelness data

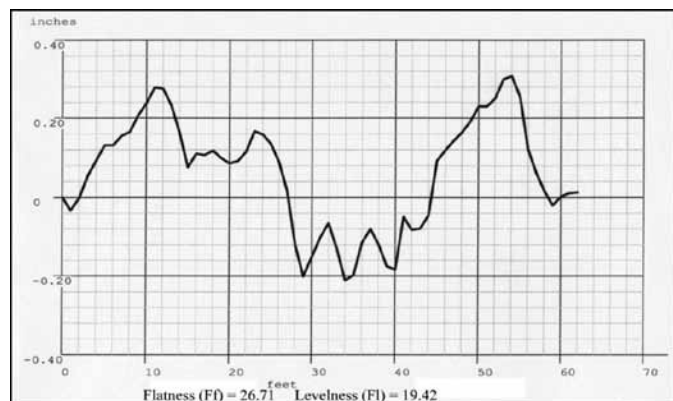


Fig. 6: Profile for one test run (vertical scale is exaggerated)

TABLE 2:
EXAMPLE FLATNESS AND LEVELNESS DATA FOR AN OFFICE BUILDING

Test run	Flatness, F_F	Levelness, F_L
1WE	35.13	24.70
2EW	24.71	11.42*
3WE	44.75	25.96
4NS	39.75	31.92
5SN	39.63	28.39
6NS	26.71	19.42
Overall (25/20)	35.11	23.80

*Does not meet the local minimum value

The last step is to check to see whether any local minimum values have been violated. Reviewing the data in Table 2, you can see that Test Run 2EW violates the minimum local value of F_L because it is only 11.42, less than the minimum local value 12.0. All other test runs meet the minimum local values for both F_F and F_L .

REMEDIES

If the overall F_F and F_L values exceed the minimum specified requirements and the minimum local values have not been violated, there is no need for remediation. However, if—as in the example—the overall values meet the specification and the minimum local values don't, the surface will need remediation in the areas where the minimum local values were out of spec. Additional testing will be required to determine the entire area for remediation. If the specified minimum overall numbers are not met, the entire surface or selected areas should be remediated and the surface retested. Remediation methods vary greatly in surface preparation, application effort, and cost so the selected remediation method varies from project to project.

Some reports may include measurements of the entire slab to quantify a slab that has been found to be out of spec. Different modeling programs can be used to aid in selecting a remediation method. For example, a mesh diagram (Fig. 7) can be very helpful in evaluating a slab surface.

If the results do not meet the specifications, remedial measures may be needed and a reduction in payment as previously agreed upon may be called for. Remedial measures for slabs-on-ground might include grinding, planing, surface repair, retopping, or removal and replacement. For suspended slabs, remedial measures are generally limited to grinding or use of an underlayment or topping material. Contract documents should clearly spell out the penalties to be imposed should the specified tolerances be exceeded. Generally, they will not mandate the remedial measures to be taken, as the Engineer of Record needs to make judgments about the appropriate action(s) in each individual case. In an office that is to be carpeted, a floor leveling compound may provide a sufficiently level surface for the carpet; for a warehouse floor, grinding the high spots may be preferred.

References

1. Face, A., "Floor Flatness and Levelness—The F Number System," *Construction Specifier*, V. 40, No. 4, Apr. 1987, pp. 24-32.
2. ACI Committee 302, "Guide for Concrete Floor and Slab Construction (ACI 302.1R-04)," American Concrete Institute, Farmington Hills, MI, 2004, 76 pp.
3. ACI Committee 117, "Specifications for Tolerances for Concrete Construction and Materials and Commentary (ACI 117-10)," American Concrete Institute, Farmington Hills, MI, 2010, 76 pp.

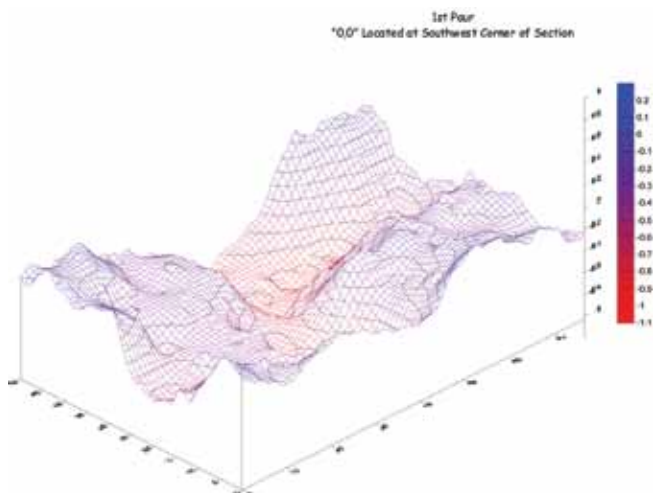


Fig. 7: Mesh diagram showing the profile of the surface. This type of diagram is useful in determining the appropriate repair method

Note: Additional information on the ASTM standard discussed in this article can be found at www.astm.org.

Selected for reader interest by the editors.



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Letters

The Floor Flatness Report

While we applaud the effort to make *CI* readers aware of the contents of floor flatness reports, we are concerned about a number of issues in “The Floor Flatness Report” from the January 2011 *CI* (V. 33, No. 1, pp. 35-39). The article may cause some building owners and others interested in floors meeting flatness and levelness tolerances to have unreasonable or misguided expectations regarding reported floor flatness and levelness results.

Some statements included in the article therefore require correction or clarification.

Quoting from p. 37 on taking measurements with a Dipstick® floor profiler or equivalent:

“Minimum sampling requirements are discussed in ACI 117.”

In fact, the requirements for the minimum number of 10 ft elevation difference readings per the test section, N_{min} , are discussed in Section 7.6 of ASTM E1155, “Standard Test Method for Determining F_F Floor Flatness and F_L Floor Levelness Numbers.” ACI 117, “Specification for Tolerances for Concrete Construction and Materials (ACI 117-10) and Commentary,” provides only minimum sampling requirements for the manual straightedge method (Section 4.8.6.2).

Also quoting from p. 37:

“When reviewing a report, you should first verify that the overall F_F and F_L values meet the specified requirements. For example, suppose your project specification calls for a *minimum* F_F of 25 and a *minimum* F_L of 20. The corresponding minimum local values are typically 60% of these values, or 15.0 and 12.0, respectively; these should be spelled out in the specification. Looking at the example data in Table 2, you can see that the overall flatness and levelness requirements have been met.”

The inclusion of the word “minimum” in the second sentence is problematic. Minimum F_F and minimum F_L could be confused with minimum local values for flatness (MLF_F) and levelness (MLF_L) as described in ACI 117, Section 4.8.5.3, so better wording would have been: “...suppose your project specification calls for a *specified* overall value for flatness (SOF_F) of 25 and a *specified* overall value for levelness (SOF_L) of 20. The corresponding minimum local values for flatness (MLF_F) and levelness (MLF_L) are typically 60% of these values, or 15.0 and 12.0, respectively.”

A similar issue occurs on p. 38:

“If the overall F_F and F_L values exceed the minimum specified requirements and the minimum local values have not been violated, there is no need for remediation.”

This should be phrased as, “If the overall F_F and F_L values meet or exceed the *specified* overall values and the minimum local values have not been violated, on any minimum local

areas, there is no need for remediation.”

In terms of setting unreasonable expectations, the following statement from p. 38 is the most questionable:

“However, if—as in the example—the overall values meet the specification and the minimum local values don’t, the surface will need remediation in the areas where the minimum local values were out of spec. Additional testing will be required to determine the entire area for remediation.”

This statement is true if minimum local values are not met in a local tested area or areas. Unfortunately, the cited example provides only data from a single run, not a complete test section (minimum local area). Thus, the reader is led to believe that a single run with results below the minimum local value requires remediation for violating the minimum local tolerance value. This is not true.

An individual run can be used solely as data—nothing more. The data might indicate a possibility of an issue with flatness and/or levelness in an area around a particular run, but the data cannot be compared against a specified value. As ACI 117, Commentary Section R4.8.5.3, states, “Acceptance or rejection of a minimum local area requires that data collection within the minimum local area in question meet the requirements of ASTM E1155.” ASTM E1155, Section 7.2.1, specifies that “no test section shall measure less than 8 ft on a side, nor comprise an area less than 320 ft².” Because a single test run represents data from a line (not an area), the data in the example cannot be compared against specified MLF_F and/or MLF_L values.

More information on why one sample measurement line of flatness/levelness cannot be used as a means for rejecting a floor is provided in the July 2008 Concrete Q&A (“Rejecting Floors Based on One Sample Measurement Line,” *Concrete International*, V. 30, No. 7, pp. 83-84).

Darrell L. Darrow, Allflat Consulting, Norfolk, VA

Bryan M. Birdwell, Birdwell and Associates, Lakeland, FL

Editor and author’s response

The writers’ comments are appreciated. We agree that minimum sampling requirements are not discussed in ACI 117 and the reference should have been to ASTM E1155. The use of the word “minimum” when referring to specified overall values (SOF), albeit possibly considered problematic, is a correct term in the sense that the SOF is the lowest value tolerable by the specifier. The error on p. 38 was the result of an unfortunate attempt by the Editor to get more value out of a table. A single test run can’t be compared against an SOF , so the clause, “as in the example,” should not have been included in the discussion.

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Concrete Q&A

Rejecting Floors Based On One Sample Measurement Line

Q. *We've just been informed that the owner is rejecting a floor we've recently completed. The basis of the rejection: flatness/levelness measurements taken along one sample measurement line are below the specified minimum value. When minimum F_f/F_L values, as defined in ACI 117-06¹ or ACI 117-90,² are specified for random-traffic floor surfaces, do those minimum values apply to each sample measurement line, as defined in ASTM E1155,³ or do they apply only to the composite of the measurement lines?*

A. Let's first consider what is meant by minimum local values, which are defined only in ACI documents. Section 4.8.5.1 of ACI 117-06, "Specifications for Tolerances for Concrete Construction and Materials,"¹ states that specified overall values for flatness (SO_F) and levelness (SO_L) shall conform to one of the floor surface classifications shown in Table 1, unless noted otherwise. Section 4.8.5.3 of ACI 117-06 states:

Minimum local values for flatness (MLF_f) and levelness (MLF_L) shall equal 3/5 of the SO_F and SO_L values, respectively, unless noted otherwise. Section R4.8.5.3 (the Commentary) of ACI 117-06 states: Acceptance or rejection of a minimum local area requires that data collection within the minimum local area in question meet the requirements of ASTM E1155.

This means that the answer to your question can be found in the data collection requirements of ASTM E1155, "Standard Test Method for Determining F_f Floor Flatness and F_L Floor Levelness Numbers."³ Sections 7.1 through 7.3 of this document define test surface, test section, and sample measurement line as follows:

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

TABLE 1:
FLOOR SURFACE CLASSIFICATIONS IN ACI 117-06¹

Floor surface classification	Specified overall flatness SO_F	Specified overall levelness SO_L
Conventional	20	15
Moderately flat	25	20
Flat	35	25
Very flat	45	35
Super flat	60	40

Questions in this column were asked by users of ACI documents and have been answered by ACI staff or by a member or members of ACI technical committees. The answers do not represent the official position of an ACI committee. Only a published committee document represents the formal consensus of the committee and the Institute.

We invite comment on any of the questions and answers published in this column. Write to the Editor, *Concrete International*, 38800 Country Club Drive, Farmington Hills, MI 48331; contact us by fax at (248) 848-3701; or e-mail Rex.Donahey@concrete.org.

Concrete Q&A

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 8 ft [2.4 m] on a side, nor comprise an area less than 320 ft² [29.7 m²]

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 11 ft [3.3 m] in length.

7.3.2 No portion of any sample measurement line shall fall within 2 ft [0.6 m] of any slab boundary, construction joint, isolation joint, block-out, penetration, or other similar discontinuity.

Now let's assume, for example, that levelness, and specifically MLF_L, is the value of interest. ASTM E1155 requires a minimum number (N_{min}) of elevation difference readings per test section. N_{min} is calculated as follows

$$N_{min} = 2\sqrt{A} \text{ for } 320 \text{ ft}^2 \leq A \leq 1600 \text{ ft}^2 \quad (\text{in.-lb units}) \quad (1)$$

$$N_{min} = 6.56\sqrt{A} \text{ for } 30 \text{ m}^2 \leq A \leq 150 \text{ m}^2 \quad (\text{SI units})$$

or

$$N_{min} = A/30 \text{ for } A > 1600 \text{ ft}^2 \quad (\text{in.-lb units}) \quad (2)$$

$$N_{min} = A/3 \text{ for } A > 150 \text{ m}^2 \quad (\text{SI units})$$

where A is the test section area in ft² (m²). These readings must be taken along sample measurement lines that are at least 10 ft (3 m) long. Thus, the minimum number of elevation difference readings per test section is independent of the number of sample measurement lines but varies with the size of the test section—larger test sections require a larger number of readings. It's common practice to define a single concrete floor placement as the test section. The single placement can be divided into smaller test sections if desired or specified, but this results in more measurements being required and usually higher measurement costs. Whatever the test section area chosen, the minimum number of readings must be taken as required by ASTM E1155.

A further requirement in Section 8.2.3 of ASTM E1155 is as follows:

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.

Using results from only one sample measurement line doesn't blind the test results as required. If sample measurement lines were to be considered separately in determining a floor levelness number, ASTM E1155 would be expected to require that the report include results for each sample measurement line. ASTM E1155 requires only that the F-numbers and associated 90% confidence interval be reported for a particular test section. The rationale for not reporting results on individual lines would seem to be that individual sample measurement lines don't provide enough data to satisfy the statistical requirements of ASTM E1155, nor do they blind the test results as required. Thus, the minimum values don't apply to each sample measurement line. The same reasoning can be used with regard to F_p numbers.

References

1. ACI Committee 117, "Specifications for Tolerances for Concrete Construction and Materials (ACI 117-06)," American Concrete Institute, Farmington Hills, MI, 2006, 70 pp.
2. ACI Committee 117, "Standard Specifications for Tolerances for Concrete Construction and Materials (ACI 117-90) (Reapproved 2002)," American Concrete Institute, Farmington Hills, MI, 2002, 12 pp.
3. ASTM E1155-96, "Standard Test for Determining F_p Floor Flatness and F_L Floor Levelness Numbers (Reapproved 2001)," ASTM International, West Conshohocken, PA, 2001, 8 pp.

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