Presenting Laser Scan Results for Slabs-on-Ground

Deliverables tailored to the user's perspective

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Joint ACI-ASCC Committee 117, Tolerances, is working on the "Guide to Using Laser Scanning for Concrete Tolerances." Drafts of six chapters were presented and discussed at the second ASCC Workshop on Laser Scanning in Las Vegas, NV, USA, in January 2018. While the six chapters covered the initial part of the document, Chapters 7 and 8 on reporting laser scanning results and deliverables were not addressed. In December 2021, the American Society of Concrete Contractors (ASCC) initiated a study focused on laser scanning results and deliverables for slabs-on-ground. This article presents the recommendations from that study.

Workshops and Studies

ASCC sponsored two laser scanning workshops (January 22, 2018, and January 21, 2019), both in Las Vegas in conjunction with the World of Concrete. More than 30 attendees representing contractors, engineers, laser manufacturers, laser consultants, and laser surveyors participated in each workshop. The first workshop focused on collecting and processing laser data and the application of laser scanning to tolerance compliance. The second workshop presented laser scan results from an ASCC-sponsored study and drafts of six chapters for the new ACI-ASCC 117 guide. ASCC paid for the development of the drafts of the six chapters that have since been turned over to Joint ACI-ASCC Subcommittee 117-L, Laser Scanning.

The first ASCC study was at a construction site in Walnut Creek, CA, USA, on October 6-7, 2018. In the first part of the study, eight teams (each comprising one to three individuals) scanned portions of the project, and their measurements were compared against independently obtained reference data. The second part of the study focused on the use of laser scanning technology to determine F-numbers. The study resulted in two *Concrete International* articles.[1,2]

The second ASCC workshop focused on presenting laser scanning results to be easily understood, readily interpreted, and construction friendly. And while there was preliminary discussion about reporting laser scan data and deliverables, nothing was prepared as recommended practice. ASCC therefore decided to initiate a second study in December 2021 in cooperation with Leo Zhang of The Conco Companies, using a 1600 ft^2 (150 m^2) slab-on-ground test panel constructed as a mockup for broom and swirl finishes.[3]

Issues with Laser Scan Results

ASCC received examples of laser scan results from its contractor members. Three examples illustrate issues with the current deliverables.

Example 1: Reporting measurement precision

A general contractor hired a consultant to use a laser to provide measurements of riser heights and tread depths for a set of concrete stairs. Figure 1 shows measurements reported to the nearest 1/64 in. (0.4 mm). Precision is the level of detail of a measurement, determined by the smallest unit or fraction

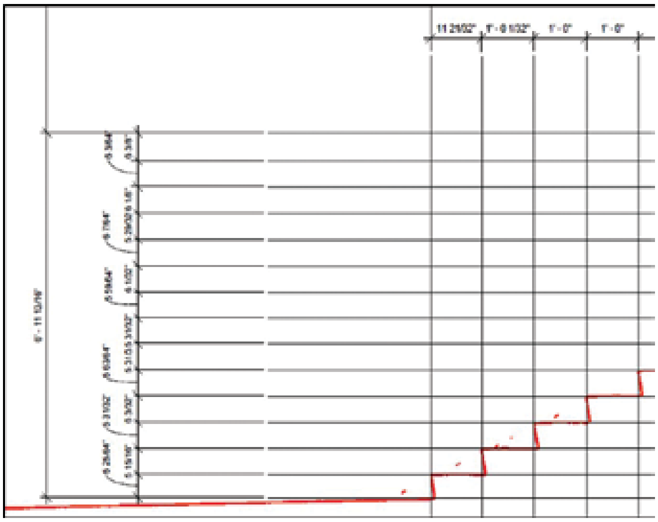


Fig. 1: Laser scanning stair measurements were reported to 1/64 in. (0.4 mm). This "implied" precision is not appropriate. At the best, measurements from laser scanning should be reported at no less than 1/8 in. (3 mm) and, depending on the application, to the nearest 1/4 in. (6 mm) (Note: 1 ft = 0.3 m; 1 in. = 25 mm)

of a unit that can be reasonably measured. Reporting the measurements to 1/64 in. (0.0156 in.) is misleading as none of the laser manufacturers indicate this precision for their instruments. Also, the original measurements can't be repeated or reproduced to 1/64 in. The stairs, of course, can't be constructed to 1/64 in. This report provides a false impression of the instrument, tolerances, construction, and the knowledge of the laser operator.

Based on our experience, and a prior ASCC study,[1] we recommend 1/8 in. (3 mm) to be the smallest fraction reported using a laser scanner. And depending on the application, reporting to the nearest 1/4 in. (6 mm) may be appropriate.

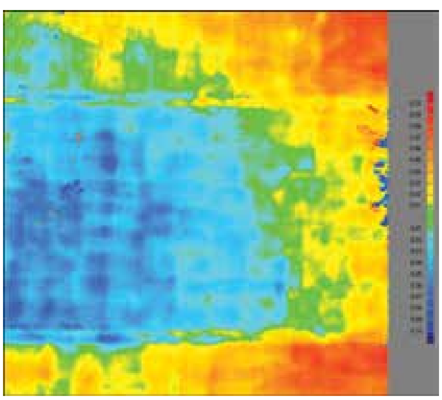


Fig. 2: "Heat maps" are often presented as the sole laser scanning result. Unfortunately, this qualitative graphic does not provide a lot of information and is difficult to even locate it on the project

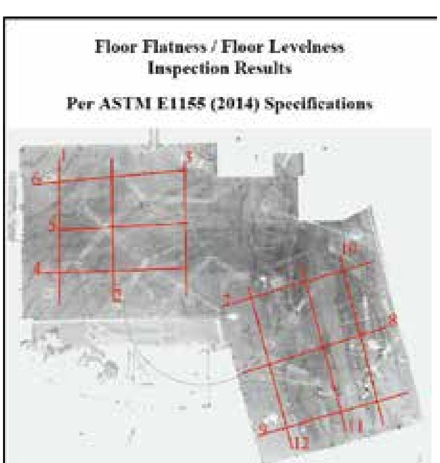


Fig. 3: ACI 117-10(15), Section 4.8.4.7,[4] requires that F-number "test results shall be reported in a manner that will allow the data to be verified or the tests to be replicated." That is impossible to do with the presentation of the measurement lines on this report

Example 2: Heat map

One laser manufacturer describes "heat maps" as color maps that are a powerful tool for presenting captured data of colored individual elevation values. We find the use of the word "heat maps" strange, as the construction industry has been working with elevation and contour maps for years, and there are no heat (temperature) values on the heat map. We prefer to call it an elevation plan view. We received a heat map from a contractor, as shown in Fig. 2, who asked for our thoughts. This heat map presents more questions than answers:

- What area or location does this represent in the building? How many ft^2 or m^2?
- We presume this to be an elevation map, but of what: the subgrade, slab-on-ground, formwork, or suspended slab?
- When was the concrete placed relative to when the scan was taken? If a suspended slab, are the forms still in place? Has the concrete deflected?
- The scale is in 0.01 units. Is that in ft or m?
- What is the zero-mark on the scale relative to: specified elevation, average measured elevation?
- Why was the work performed?

We could only provide one answer: not sure.

Example 3: Floor flatness and levelness report

Proprietary software can be used to process laser data to produce a floor flatness and levelness report. The report provides specified and measured overall and minimum flatness and levelness, which can be viewed as pass or fail results.

An ASCC contractor passed along the report shown in Fig. 3 and 4. The plan view shows measurement lines numbered 1 through 12. The report shows 12 measurement lines numbered 1 through 16. All the measurement lines are included, but it's not clear how to match the plan and report measurement lines. That makes understanding the report data more difficult, if not impossible. Also, the layout of the measurement lines on the plan view doesn't provide enough information for the data to be reproduced.

The measured overall reported value is a combination of all values from the 12 measurement lines. This is appropriate and in accordance with ASTM E1155, "Standard Test Method for Determining FF Floor Flatness and FL Floor Levelness Numbers." The minimum value reported, however, is from a single measurement line. This is not in accordance with ASTM E1155 and is not as described in the July 2008 Concrete Q&A in *Concrete International*.[6] The value from one measurement line can't be used as the basis to pass or fail a specified minimum local value. As required by ASTM E1155, the results from one measurement line do not collect enough data for the minimum local area, blind the test results, collect equal numbers in each direction or orient all lines at 45 degrees.

ACI 302.1R-15, Section 10.15.1.1,[5] states that minimum local values represent the minimum acceptable flatness and levelness by an "individual floor section." It further states that if any individual section measures less than the specified minimum local number: "Sectional boundaries are usually set at the column and half-column lines on suspended slabs and at construction and contraction joints for slabs-on-ground." A value from a single measurement line, as shown in this laser report, would not satisfy the recommendations for a minimum local value for a floor section as described in Section 10.15.1.1 of ACI 302.1R-15.

Recommended Laser Scan Sheet Organization and Information

When presenting any results, but especially laser scan results, the information has "legs" and will make its way to individuals (such as off-site managers, engineers, owners, and lawyers) that may not be familiar with the project. We present examples we hope become standard practice for submitting laser scan results, and that can be incorporated into Joint ACI-ASCC Committee 117 recommendations.

The laser scan information can be presented in a report; however, we decided to present the information in a drawing sheet format like architectural and structural drawings. The reason for the drawing format was that the main graphic element, the heat map, is difficult, if not impossible, to see in a smaller letter paper format. The graphic in report format is usually viewed on the computer screen with the zoom-in function. This limits the ability to communicate the information with others. Thus, we chose drawing format as something familiar, easy to print, and easy to distribute to others.

Figure 5 illustrates a recommended drawing sheet layout to present laser scan results. The overall objective is to provide consistent, organized, and complete information that can be easily found, understood, and interpreted. Within the sheet are information blocks described herein.

Contract Specifications

Reference	Overall Flatness	Minimum Flatness	Overall Levelness	Minimum Levelness
CSI Division 03	25.00	25.00	0.00	0.00

Overall Results

Measured Flatness(FF)	31.89	Measured Levelness(FL)	19.43
FF 90% Confidence	30.67 - 33.10	FL 90% Confidence	18.61 - 20.25
Measured Flatness Test	PASS	Measured Levelness Test	PASS
Minimum Flatness (FF_min)	22.18	Minimum Levelness (FL_min)	13.58
FF_min 90% Confidence	17.84 - 26.53	FL_min 90% Confidence	11.07 - 16.08
Minimum Flatness Test	FAIL	Minimum Levelness Test	PASS

Individual Results

Run #	Flatness (FF)	90% Confidence	Levelness (FL)	90% Confidence
1	29.72	24.76 - 34.69	18.52	15.14 - 21.91
2	33.12	27.54 - 38.70	16.58	13.51 - 19.64
3	29.12	24.07 - 34.18	33.40	27.01 - 39.78
5	55.53	46.08 - 64.98	19.25	15.66 - 22.85
7	33.53	28.17 - 38.88	31.18	25.77 - 36.59
8	31.31	26.27 - 36.36	15.33	12.64 - 18.02
9	41.19	34.56 - 47.83	22.00	18.14 - 25.86
11	39.35	33.42 - 45.28	21.50	18.00 - 24.99
12	32.81	27.70 - 37.92	19.19	15.96 - 22.43
13	38.51	31.89 - 45.13	21.29	17.27 - 25.32
14	22.18	17.84 - 26.53	25.56	19.91 - 31.22
16	23.25	19.33 - 27.17	13.58	11.07 - 16.08

Fig. 4: ACI 302.1R-15, Section 10.15.1.1,[5] states that the minimum local values represent the minimum acceptable flatness and levelness for an "individual floor section." This report incorrectly designates a single measurement line as the minimum local values

Visual data presentation

The objective is to provide the important first impression with a qualitative graphic overview of the issue. Our recommendations include the following items:

- **Graphic**—Typical heat map;
- **Graphic context**—Include column lines, dimensions, and other information to provide context for the graphic;
- **Scale**—Heat maps typically have color scales for the elevation intervals. Make sure to designate the units of the scale and be reasonable on the number of intervals. Most ACI elevation tolerances are ±3/4 in. (19 mm); thus, choosing intervals of 1/4 in. is good. Don't choose 1/2 or 1 in. (13 or 25 mm), where the user needs to evaluate between intervals;
- **Scale zero**—Identify what the zero scale represents (specified elevation or relative elevation). Preferably, use the specified elevation as the zero mark;
- **Title of graphic**—For example, "Concrete Surface Elevation Contours—Plan View." Do not use the word heat map. Be as specific as possible; and
- **Notes**—Under the graphic title, provide any clarifying notes that assist in understanding the graphic presented.

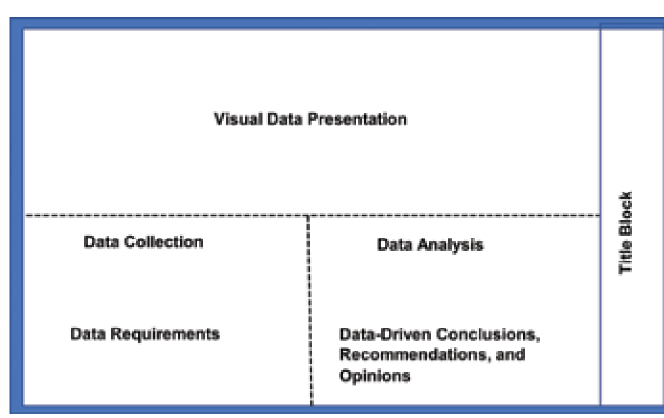


Fig. 5: A recommended drawing sheet layout to provide consistent, easy-to-use information in a medium familiar to construction personnel

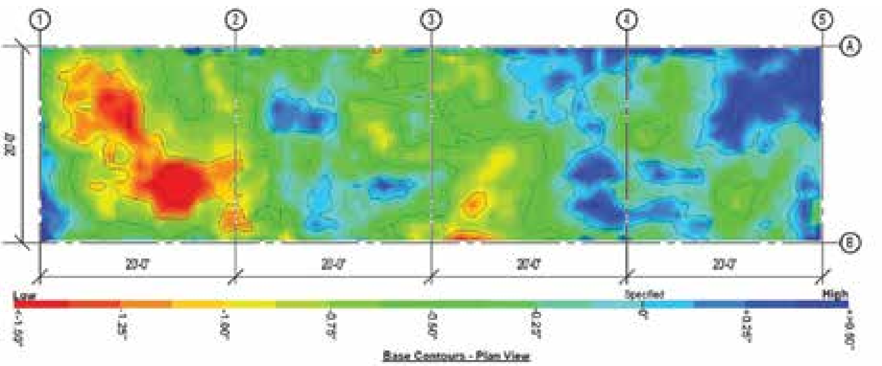


Fig. 6: Plan view with contour intervals for base elevations

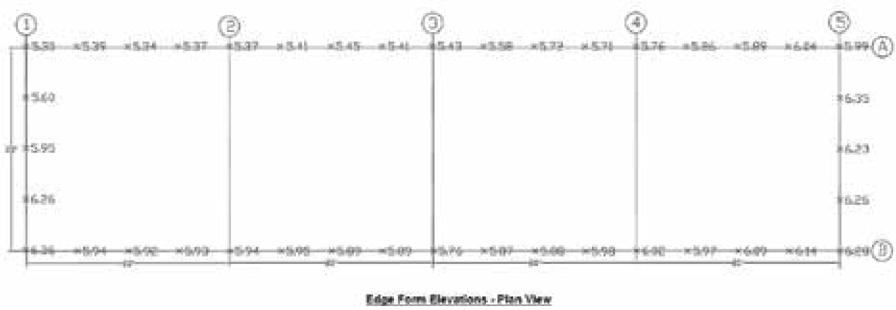


Fig. 7: Edge form elevations marked at 5 ft (1.5 m) intervals

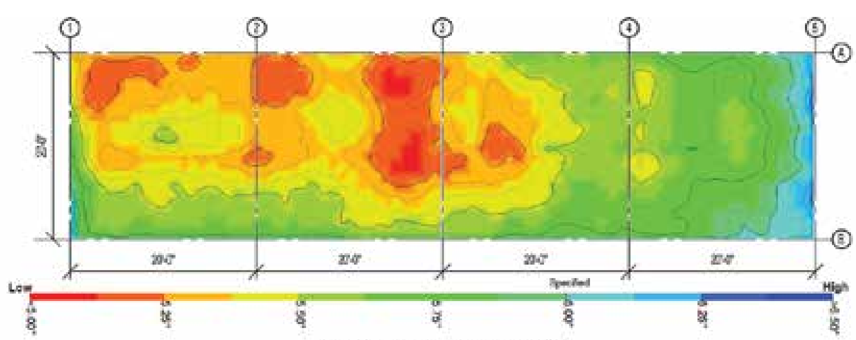


Fig. 8: Plan view with contour intervals for concrete top surface elevations

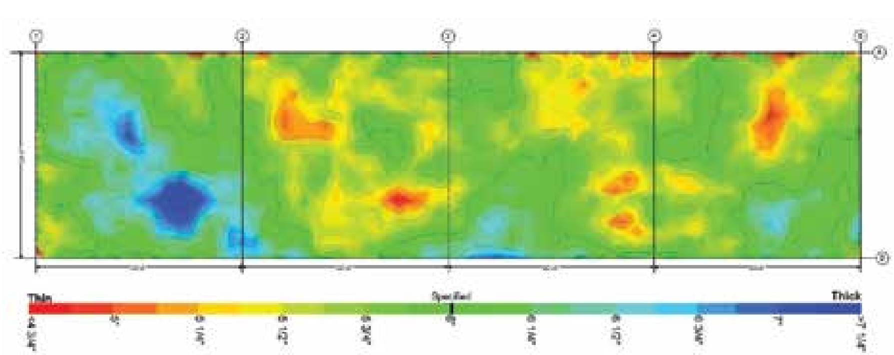


Fig. 9: Plan view with contour intervals for concrete thickness

Figures 6 to 10 show these graphic items for slabs-on-ground:

- Base elevation contours, Fig. 6;
- Edge form elevations, Fig. 7;
- Concrete top surface elevation contours, Fig. 8;
- Thickness contours, Fig. 9; and
- F-numbers and measurement lines, Fig. 10.

Data collection

The objective is to document equipment, methods, and techniques to ensure confidence in the collected data, such that the data can be repeated or reproduced. Our recommendations include the following items:

- **Equipment**—Provide a description of laser scanner, targets, accessories, and software. Provide dates of calibration and checks/adjustments of the equipment;
- **Data acquisition parameters**—Provide control point and scan information. Control points are an important part of tying the laser survey to the structure;
- **Registration**—Provide information on how the point cloud registration was performed. Be as specific as possible;
- **Survey date**—Provide all relevant dates. Because a concrete surface can change with time (curling for slabs-on-ground and deflection of suspended slabs), it's important to know when the laser survey was done relative to the date of placement. Some specifications, such as ACI 117-10(15), Section 4.8.4.4,[4] and ACI 301-20, Section 5.3.4.3,[7] require measurements to be completed within 72 hours after placement;
- **Data manipulation**—Provide information if the raw data was processed prior to presentation; and
- **Data area**—Provide the total area surveyed in ft^2 or m^2 and the condition of the surface prior to scanning. Indicate if certain areas were not scanned and locate where surface debris may have affected the scan.

The data collection for each drawing sheet was generally the same. We repeated it in each drawing to provide the user with the information without having to refer to other sheets. The laser scanning notes for the concrete top surface contours are shown in the text box titled "Laser Scanning Notes."

Data requirements

The objective is to document the project data requirements such that the data collected is appropriate for use. Our recommendations include the following items:

- **Project specification requirements**—Provide the appropriate specification requirements to understand to what the laser scan results are to be compared;
- **Applicable referenced specifications**—Ensure that any applicable requirements are noted. Project specifications often refer to an ASTM standard or a reference specification such as ACI 117 or ACI 301; and
- **Client-supplied information**—Acknowledge client-supplied information or direction with respect to the laser scan survey.

Information from the project and reference specifications, or any contract requirements, should be provided. This is especially important to understand prior to scanning to make sure that data collected is appropriate to compare to the requirements. This is generally easy and requires only one or two sentences, such as:

> "Compliance with top surface elevation tolerances shall be measured by laser scanning. Tolerance shall be as stated in ACI 117-10 (15), Specifications for Tolerances for Concrete Construction and Materials, Section 4.4.1—top surface of slabs-on-ground ±3/4 in."

ACI 117-10(15) thickness tolerance requirements (see the text box titled "Applicable ACI 117 Thickness Tolerances"), however, are more complex and need to be considered when planning the laser scanning, data collection and analysis. Note ACI 117-10(15) has tolerances for

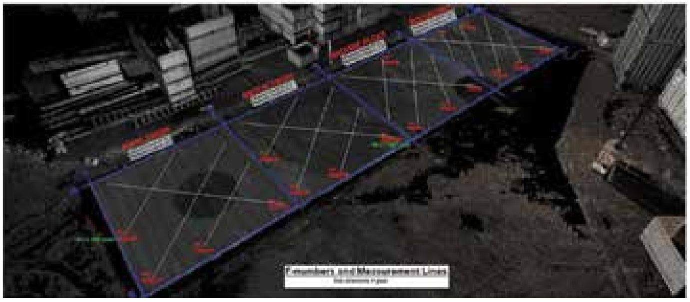


Fig. 10: F-numbers for the individual measurement lines and for the overall area, and the laser-measured length and width of the test panel

Laser Scanning Notes

Equipment and software

- Leica P40 3D Laser Scanner (1851533)—Check/Adjust on December 6, 2021.
- Leica GZT21 4.5-in. Black/White Targets—Calibration on December 22, 2021.
- Leica Cyclone software.
- Autodesk Civil3D software.

Data acquisition parameters

- Four permanent control points were used for concrete surface scans, and these same control points were also used for base scans.
- Three scans were performed for the concrete surface survey with 25 ft between each scan.
- Instrument setup height was approximately 6 ft.

Registration

- Point cloud registration was performed with targets with an error of 0.006 ft (0.07 in.).
- Concrete surface scans were registered with the same four control points.

Quality control

- Point cloud was sliced and virtually checked in addition to the registration error report.

Survey date

- Concrete was placed on January 3, 2022.
- Concrete top surface was scanned on January 4, 2022.

Data collection environment

- Concrete surface was damp but broomed prior to scanning.
- Weather was in the 60°F's and cloudy.

Data manipulation

- Concrete top surface elevation measurements were sampled on a 1 ft grid.
- Contour major spacing was at 1/4 in. and minor spacing was at 1/8 in.
- Project local coordinate origin (0,0,0) was set at base of corner grid A/5.
- Slope correction of 1/8 in. per ft has been applied to concrete top surface elevations.

Data area

- The total slab area was 1600 ft^2, and the entire area was scanned. There was no debris, people, or equipment in the scan.

average and individual measurements in addition to requiring that the average thickness be computed without using any measured value more than 3/4 in. above the specified thickness. If this information was not known in advance, the laser scanning, data collection, and analysis might not be able to confirm specification compliance. No one wants to pay for data collection and analysis that can't be used.

Data analysis

The objective is to document basic quantitative statistical information to supplement the qualitative visual data presentation. Our recommendations include the following items:

- **Basic statistics**—Provide the number of samples, average, standard deviation, coefficient of variation, maximum and minimum, and range;
- **Histogram/cumulative frequency**—Provide data to determine the frequency of the results and cumulative frequency; and
- **Other**—Provide data as appropriate for the issue. For instance, ACI 117-10(15), Section 4.5.4.5, requires the average thickness to be calculated with thickness values not more than 3/4 in. greater than the specified thickness.

The data analysis presentation was generally the same for each drawing sheet. The thickness data analysis, however, was unique because ACI 117-10(15), Section 4.5.4, required tolerance for both the average and individual measurements and required a specific method for calculating the average thickness. The data analysis for thickness is shown in the text box titled "Data Analysis."

Applicable ACI 117 Thickness Tolerances

- ACI 117-10 (Reapproved 2015), Specifications for Tolerances for Concrete Construction and Materials.
- Section 4.5.4—Thickness of slabs-on-ground:
  (A) Averages of all samples –3/8 in. and
  (B) Individual sample –3/4 in.
- Section 4.5.4.1—Minimum number of slab thickness samples, when taken, shall be four (4) for every 5000 ft^2 or part thereof.
- Section 4.5.4.2—Samples shall be taken within seven (7) days of placement.
- Section 4.5.4.3—Samples shall be randomly located over the test area.
- Section 4.5.4.4—Test results shall be reported in a manner that will allow the data to be verified or the test to be replicated.
- Section 4.5.4.5—When computing the average of all samples, samples with a thickness more than 3/4 in. above the specified thickness shall be assumed to have a thickness 3/4 in. more than the specified thickness.
- Section 4.5.4.6—Where corrective action is required, additional samples shall be taken in the vicinity of unacceptable results to establish the extent of corrective action.

Data-driven conclusions, recommendations, and opinions

The objective is to provide the rationale for the conclusions or opinions based on the data collected and the data requirements. Our recommendations include the following items:

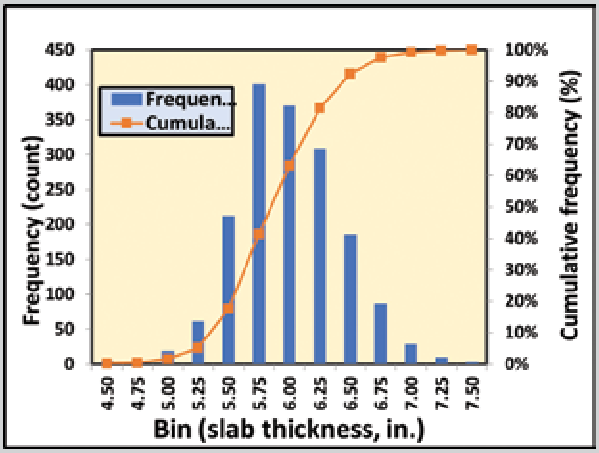
- **Conclusions**—Note that this may not be within the scope of the laser scan consultant. Like a construction testing agency, the laser scan may provide data for other individuals to determine conclusions and recommendations; and

Data Analysis

Descriptive Statistics

Count	1695
Mean	5.87 in.
Standard Deviation	0.42 in.
Coefficient of Variation	7.2%
Range	3.02 in.
Minimum	4.32 in.
Maximum	7.34 in.

Histogram/Cumulative Frequency



ACI Thickness Statistics

1. ACI 117-10(15) requires thickness average to be calculated with thickness values not more than 3/4 in. greater than the specified thickness.
2. There were 42 thickness values greater than 6.75 in. out of the 1695 thickness values. The average, including all true thickness values, was 5.873 in. The ACI average using 6.75 in. for all thickness values greater than 6.75 in. was 5.868 in. The difference between the sample average and the ACI average was 0.005 in.
3. ACI 117-10(15) requires no individual thickness samples to be less than 5.25 in. (3/4 in. less than specified). The cumulative frequency curve indicates about 5% of the slab area is less than 5.25 in. These areas are indicated in the thickness interval contour map by red and orange areas.

- **Opinions**—If an opinion is part of the work, make sure the scope of information presented is in accordance with ASTM E620, "Standard Practice for Reporting Opinions of Scientific or Technical Experts."

Slab-on-Ground Test Panel Results

The drawing sheet used for presenting the laser scan results for the tested slab-on-ground are:

- LS101, represents a plan view of the base elevation contours;
- LS102, represents a plan view of the edge form elevations;
- LS103, represents a plan view of the concrete top surface elevation contours;
- LS104, represents a plan view of the thickness derived from LS103 and LS101; and
- LS105, represents a plan view of F-number measurement lines and plan dimensions.

(Note: These drawing sheets are available in the online version of the article.)

Contractor Decisions

At each stage of laser scanning and the presentation of the results, the contractor will face the following decisions:

- **Base elevations** (LS101)—The data analysis for the base indicates the average is 0.34 in. (9 mm) below the specified elevation. At this point, the contractor's decision is to go forward understanding that if the top surface is at the specified elevation, it will take more concrete or bring in an additional base, then scarify, compact, and get a compaction report. The ACI 117-10(15), Section 4.4.5, base elevation tolerance is ±3/4 in. The histogram/cumulative frequency indicates that about 5% of the area is out of tolerance high and about 20% of the area is out of tolerance low. A total of 25% of the area is out of tolerance;
- **Edge form elevations** (LS102)—The data analysis for the edge forms indicate that they are placed low, at an average of 5.84 in. (148 mm) with a 6 in. (152 mm) specified slab. This would indicate that the top edge forms were not placed to the specified elevation but were more likely placed based on thickness measured off the base. The laser scan on this test panel included both the base and edge form elevations at the same time. Thus, the contractor's decision is to accept a base that is 0.34 in. low and top edge forms that are 0.16 in. (4 mm) low, resulting in an anticipated slab thickness of 5.82 in. (148 mm), or make a change;
- **Concrete surface elevations** (LS103)—The data analysis indicates that the average top surface elevation is 0.47 in. below the specified elevation. The histogram/cumulative frequency indicates that none of the top surface is out of tolerance high (greater than +3/4 in.), but that about 10% of the area is out of tolerance low (greater than −3/4 in.). The contractor would need to ask if that low area is acceptable or place a thin topping to bring the top surface within tolerance;
- **Concrete thickness** (LS104)—The average thickness calculated in accordance with the ACI 117-10(15), Section 4.5.4, requirements was 5.875 in. (149 mm), which is within the −3/8 in. (10 mm) tolerance on average thickness. The minimum thickness for individual measurements of a 6 in. specified slab is 5.25 in. (133 mm). The histogram/cumulative frequency indicates that about 5% of the slab area is below this value. These areas are indicated on the thickness contour map by red and orange areas. The contractor needs to evaluate the thickness in those areas and develop an action plan to send to the engineer; and
- **F-numbers and measurement lines** (LS105)—F-numbers for each measurement line and the overall average is shown for each of the four different textures (swirl, broom, machine float, and bullfloat). In addition, the length and width were measured by laser scanning. The specified 20 ft (6.096 m) length was measured to be 19 ft 11-7/8 in. (6.093 m), and the specified 80 ft (24.384 m) length was measured to be 79 ft 11-7/8 in. (24.380 m).

Slab Thickness and F-numbers Comparison

Laser scanning determined subgrade and concrete surface elevations that were used to calculate slab thickness. Slab thickness was also evaluated using impact echo, ground penetrating radar (GPR), and cores. A comparison of that data was presented in *Concrete International* in July 2022.[8] As discussed in the article, laser scanning for concrete thickness provided results equivalent to impact echo or GPR. An issue with the use of laser scanning for slab-on-ground thickness is the stability of the base. If the base moves during concrete placement, the slab thickness calculated from laser scanning is unlikely to provide the same results as impact echo or GPR, which would account for any base movement that occurred during concrete placement.

Dipstick-measured F-numbers for this test panel with bullfloat, machine float, broom, and swirl finishes were presented in *Concrete International* in May 2022.[3] Table 1 reports laser-measured F-numbers along with the Dipstick-measured F-numbers for different surface finishes. For floor flatness, the laser measurements ranged from 21 to 78% higher than the Dipstick measurements, with an average of 49%. For floor levelness, the laser measurements were up to 5% higher than the Dipstick measurements, with an average of 3%.

Table 1:
Comparison of composite F-numbers for different surface finishes

	Floor flatness				Floor levelness			
			Difference				Difference	
Surface texture	Laser	Dipstick	F-number	%	Laser	Dipstick	F-number	%
Bullfloat	34.40	19.33	15.07	+78	10.40	10.38	0.02	0
Machine float	33.70	22.82	10.88	+48	11.29	10.80	0.49	+5
Broom	36.98	30.51	6.47	+21	9.51	9.27	0.24	+3
Swirl	32.08	21.76	10.32	+47	10.13	9.76	0.37	+4
Average	—	—	10.69	+49	—	—	0.28	+3

Table 2:
Comparison of composite F-numbers for trowel finish

	Floor flatness				Floor levelness			
			Difference				Difference	
Trowel finish	Laser	Dipstick	F-number	%t	Laser	Dipstick	F-number	%
Ground Level	27.34	24.57	2.77	+11	18.23	19.69	−1.46	−7
Podium Level 1	30.47	24.73	5.74	+23	24.04	23.34	0.70	+3
Podium Level 2	30.24	24.75	5.49	+22	23.68	23.20	0.48	+2
Average	—	—	4.67	+19	—	—	−0.09	−1

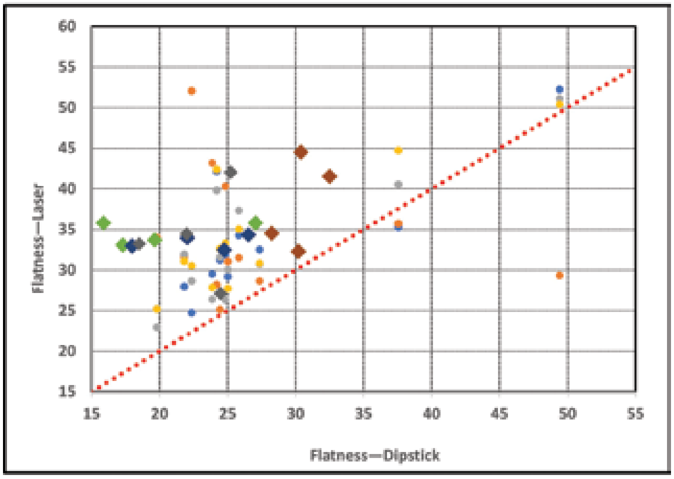


Fig. 11: Comparison of floor flatness measured with Dipstick and laser. The smaller symbols represent the correlation between laser-measured and Dipstick-measured floor flatness for troweled surfaces.[2] The larger symbols represent the correlation between laser-measured and Dipstick-measured floor flatness for different textured surfaces.[3] Laser-measured floor flatness values do not correlate well with the Dipstick-measured values for textured surfaces

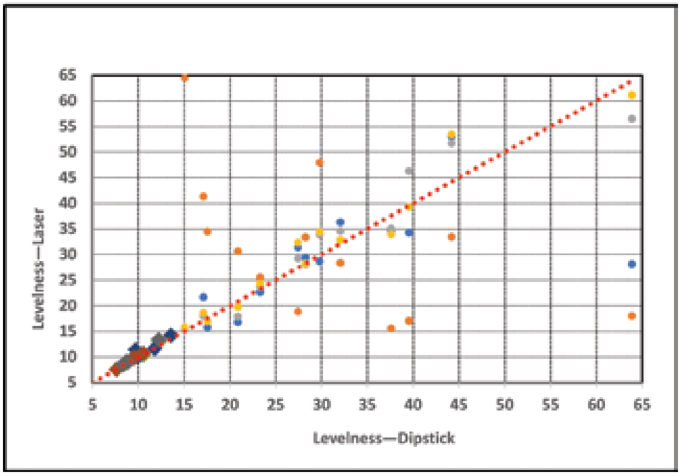


Fig. 12: Comparison of floor levelness measured with Dipstick and laser. The smaller symbols represent the correlation between laser-measured and Dipstick-measured floor levelness for troweled surfaces.[2] The larger symbols represent the correlation between laser-measured and Dipstick-measured floor levelness for different textured surfaces.[3] Laser-measured floor levelness values do correlate well with the Dipstick-measured values for textured surfaces

Table 2 reports laser-measured F-numbers along with the Dipstick-measured F-numbers for troweled surfaces.[2] For floor flatness, the laser measurements ranged from 11 to 23% higher than the Dipstick measurements, with an average of 19%. For floor levelness, the laser measurements ranged from 7% lower to 3% higher than the Dipstick measurements, with an average of −1%.

Tables 1 and 2 show that the comparison of the floor levelness measurements for textured surfaces agrees with that presented for troweled surfaces. The same can't be said for floor flatness measurements.

Figures 11 and 12 compare laser- and Dipstick-measured floor flatness and levelness for textured and troweled surfaces. It is obvious in Fig. 11 that laser-measured floor flatness for textured surfaces is not equivalent to Dipstick measurements, and in fact, it is not sensitive to the surface roughness. Figure 12 shows that laser-measured floor levelness for textured surfaces is equivalent to Dipstick measurements.

Some project specifications require laser scanning to measure F-numbers for both textured and troweled surfaces to determine compliance with specified F-numbers. The data in Tables 1 and 2 indicate that laser measurements for floor flatness are not equivalent to Dipstick measurements on either textured or troweled surfaces. At this time, we recommend that laser-measured F-numbers should not be used for specification compliance, or at the very least, compared to other measurements prior to determining specification compliance.

Final Thoughts

Laser scanning results must be presented to be user-friendly, appropriate for the stated requirements, and credible such that they can be relied on to make decisions to accept or reject work or assess repair.

The authors hope this article encourages others to provide deliverables tailored to the user's perspective.

References

1. Paul, W.; Klinger, J.; and Suprenant, B.A., "ASCC 3-D Laser Scanning Study, Part 1," *Concrete International*, V. 41, No. 1, Jan. 2019, pp. 22-29.

2. Paul, W.; Klinger, J., and Suprenant, B.A., "ASCC 3-D Laser Scanning Study, Part 2," *Concrete International*, V. 42, No. 2, Feb. 2020, pp. 30-36.

3. Zhang, L.; Klinger, J.; and Suprenant, B.A., "F-numbers and Textured Concrete Surface Finishes," *Concrete International*, V. 44, No. 5, May 2022, pp. 33-41.

4. ACI Committee 117, "Specification for Tolerances for Concrete Construction and Materials (ACI 117-10) and Commentary (ACI 117R-10) (Reapproved 2015)," American Concrete Institute, Farmington Hills, MI, 2010, 76 pp.

5. ACI Committee 302, "Guide to Concrete Floor and Slab Construction (ACI 302.1R-15)," American Concrete Institute, Farmington Hills, MI, 2015, 76 pp.

6. ACI Concrete Q&A, "Rejecting Floors Based on One Sample Measurement Line," *Concrete International*, V. 30, No. 7, July 2008, pp. 83-84.

7. ACI Committee 301, "Specifications for Concrete Construction (ACI 301-20)," American Concrete Institute, Farmington Hills, MI, 2020, 69 pp.

8. Zhang, L.; Klinger, J.; and Suprenant, B.A., "Slab-on-Ground Thickness Measurement," *Concrete International*, V. 44, No. 7, July 2022, pp. 37-49.

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

Selected for reader interest by the editors.

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