Establishing Thickness Tolerances for Parking Lot Slabs

Measured thickness variations are evaluated

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Prior to the 2006 edition, ACI's construction tolerances standard, the ACI 117 specification, provided the same tolerances for the thickness of *any concrete member*—whether it was a column, beam, pier, wall, or slab. Until then, a concrete member was within tolerance if its thickness was no more than the specified thickness +3/8 in. and no less than the specified thickness −1/4 in.

In ACI 117-06, "Specifications for Tolerances for Concrete Construction and Materials,"[1] however, thickness tolerances for slabs-on-ground were separated from tolerances for other concrete members. This constituted an acknowledgment that construction of a slab-on-ground—an element with its thickness defined by a granular base and an unformed exposed surface—is uniquely different than construction of an element with its thickness defined by formwork.

ACI 117-06 and the following editions of the ACI 117 specification provide thickness tolerances for level concrete slabs-on-ground (that is, horizontal top and bottom surfaces, typical of interior slabs). Recently, ACI Committee 330, Parking Lots and Site Paving, has collectively questioned the applicability of ACI 117-10(15)[2] tolerances to slabs-on-ground for exterior parking lots, which typically have top and bottom surface slopes designed to accommodate drainage. In cooperation with the American Society of Concrete Contractors (ASCC), ACI Committee 330 subsequently collected data from 32 distinct slab-on-ground placements.

This article reports the measured thickness variations for the evaluated slabs. Further, this article reports thickness tolerances for parking lot pavements that we, the authors, have proposed to Joint ACI-ASCC Committee 117, Tolerances, and ACI Committee 330.

Basics of Slabs-on-Ground

For the typical slab-on-ground, the subbase supports the slab as part of the load-carrying capacity for vehicular traffic loads. The subbase also serves as elevation control of the bottom concrete surface, and it functions as the construction work platform for personnel and equipment. A stable, all-weather, working platform minimizes thickness variations caused by local changes in the subbase elevation created during construction.

Proof rolling is an effective quality control procedure recommended by ACI 302.1R-15, "Guide to Concrete Floor and Slab Construction,"[3] and ACI PRC-330-21, "Commercial Concrete Parking Lots and Site Paving Design and Construction—Guide,"[4] to determine if the subbase provides stable, adequate support during and after construction. The procedure is generally conducted by driving a loaded tandem-axle dump truck or a loaded concrete truck over the subbase in a preestablished grid pattern. If the truck leaves no depressions or ruts greater than 1/2 in. deep, the test establishes that construction activities will not result in an unacceptable level of local variation in the subbase elevation.

Variations of the bottom and top surface elevations contribute to thickness variations of concrete slabs-on-ground. The placement of the subbase establishes the overall elevation control of this surface, and construction activities create local elevation differences of this surface. Note that ACI 117-10(15), Section 4.4.5, states the subbase elevation tolerance immediately below the concrete as ±3/4 in.

The unformed top concrete surface elevation is established during concrete strike-off, usually referenced to a horizontal plane determined using a rotary laser level. This sets the overall elevation control of the top surface, and tolerances for floor flatness and levelness establish a level of local variation for finishing activities. The local elevation variation for commonly specified flatness and levelness for hard-troweled surfaces is about 1/8 in. Note that ACI 117-10(15), Section 4.4.1, states the top surface elevation tolerance as ±3/4 in. Figure 1 is a schematic of three different slabs-on-ground discussed in the following.

Level slabs

Level slabs are normally used as building floors. Figure 2 illustrates how the top and bottom overall elevations and local variations establish slab thickness for a level slab, which we identify as a “level hard-troweled slab-on-ground.”

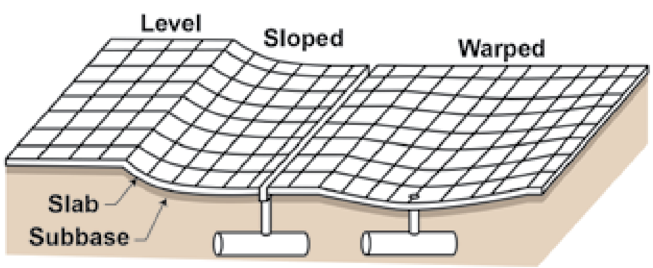

Fig. 1: The top and bottom surfaces of slabs-on-ground can be level, sloped, or warped *(based on an illustration published by Somero Enterprises Inc.)*

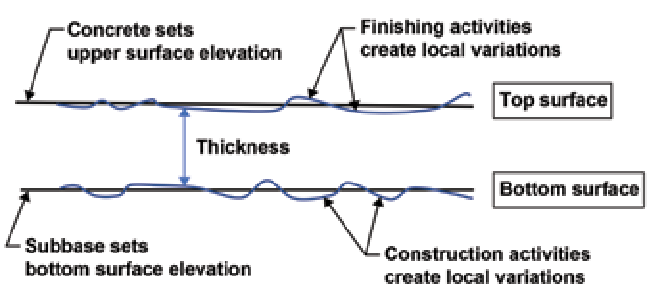

Fig. 2: Schematic illustration of thickness for a level (zero-slope) interior concrete slab-on-ground

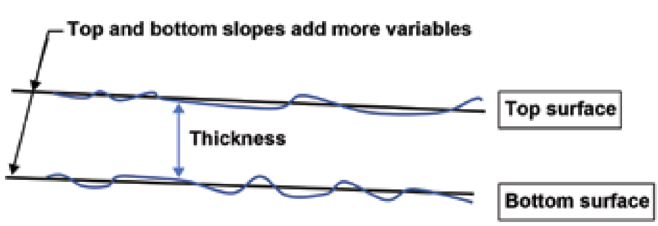

Fig. 3: Schematic illustration of thickness for a sloping exterior parking lot slab

Sloped slabs

Exterior parking lots are sloped to allow drainage (Fig. 1). This slope adds an extra variable for top and bottom surface elevation control. Drainage slopes of 2 to 5% result in elevation changes ranging from about 1/4 to 3/4 in./ft. As shown in Fig. 3, this variable also factors into the thickness. In addition, local flatness variations in the broomed top surface are greater than flatness variations for a hard-troweled interior surface. The local elevation variation for a broomed surface, usually established by measuring the gap under a straightedge, can be as much as 1/2 in. We identify this slab as a “sloping broomed slab-on-ground.”

Warped slabs

An even more complex twist to exterior sloped parking lots is the warped (contoured) concrete surface (Fig. 1). Construction of parking lots with warped surfaces typically requires a three-dimensional control system for both the subbase grading and concrete screeding equipment. The range of challenges and complexity for top and bottom surface control will likely lead to larger thickness variations than concrete slabs with either no slope or a one-directional slope. We identify this slab as a “warped broomed slab-on-ground.”

History of Slab-on-Ground Thickness Tolerances

Table 1 provides the history of slab-on-ground thickness tolerances in the ACI 117 specification. Table 2 provides the history of parking lot thickness tolerances in the ACI 330.1 specification.

In 1989, when the slab-on-ground minus tolerance was 1/4 in. per the ACI 117 specification, Gustaferro recommended that “revised and more realistic tolerances are needed.”[10] He concluded: “A realistic specification could read, ‘The average thickness of a floor slab shall be no less than the thickness shown on the drawings, and not more than 16% of the floor area shall be thinner than 3/8 inch less than that shown on the drawings.’”[10] In an interview published in *Concrete Construction* in 2000, Gustaferro stated that this recommendation was based on the assumption of “an excellent standard deviation in thickness of 3/8 inch.”[11] The

Table 1:
History of slab-on-ground thickness tolerances in the ACI 117 specification

ACI 117	Description	Tolerances
1981[5]	Cross-sectional dimensions of columns, beams, walls, and *slab* thickness	Up to 12 in.: +3/8 in., −1/4 in. More than 12 in.: +1/2 in., −3/8 in.
1990[6]	Members, such as columns, beams, piers, walls (thickness only), and *slabs* (thickness only)	12 in. dimension or less: +3/8 in., −1/4 in. More than 12 in. but not over 3 ft dimension: +1/2 in., −3/8 in. Over 3 ft dimension: +1 in., −3/4 in.
2006[1]	Thickness of slabs-on-ground	Average of all samples: −3/8 in. below specified thickness Individual sample: −3/4 in. below specified thickness
2010 (2015)[2]	Same as 2006	Same as 2006

Table 2:

History of slab-on-ground thickness tolerance for concrete parking lots per the ACI 330.1 specification

ACI 330.1	Description	Tolerances
1994[7]	Thickness	+3/8 in., −1/4 in.
2003[8]	Same as 1994	Same as 1994
2014[9]	Same as ACI 117-10 for slabs-on-ground	Same as ACI 117-10 for slabs-on-ground

data from Gustaferro's 1989 article, however, exhibited standard deviations ranging from 0.47 to 0.90 in. The data also showed that the average slab thickness was less than the specified nominal thickness in all cases.

In that same interview, Tipping recommended a tolerance approach to "impose limitations on the average thickness of core samples taken and limit by which any individual sample falls short of the required thickness."[11] In 2000, the Canadian Standards Association (CSA) adopted slab-on-ground tolerance provisions matching Tipping's recommendation.[12] ACI Committee 117 subsequently adopted the CSA approach

Graphical Thickness Tolerances

The history of slab-on-ground thickness tolerances required by the ACI 117 specification are graphically summarized in Fig. A and B. Prior to the 2006 edition, the thickness of any sample was required to be no more than the specified thickness +3/8 in. and no less than the specified thickness −1/4 in. From 2006 to the present, the specification includes two tolerances: one on the average of the sample thickness values and another on the thickness of an individual sample. The average thickness is to be no less than the specified thickness −3/8 in., and the thickness of an individual sample is to be no less than the specified thickness −3/4 in.

For the contractor, referencing the tolerance on individual sample thickness to the specified thickness is the more challenging criterion. For example, consider a placement that results in a standard deviation of 3/8 in. (as previously noted, Gustaferro[10] considered this to be a demonstration of excellent control of the thickness). Assuming a normal distribution of thickness values, the −3/4 in. individual sample criterion is about one standard deviation to the right of the minimum thickness of all samples and one standard deviation to the left of the central value of all samples (Fig. C). Thus, even when meeting the average thickness tolerance, about 15 to 20% of the pavement will have thickness values below the −3/4 in. tolerance.

Alternatively, if the average thickness was required to be no less than the specified tolerance and the −3/4 in. individual tolerance was referenced to the center of the thickness distribution, only about 3% of the thickness values would fall below the −3/4 in. criterion (Fig. D).

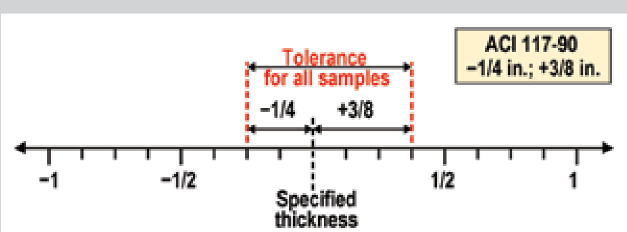

Fig. A: Graphical illustration of the asymmetrical tolerance limits for all concrete members, including slabs-on-ground for member sizes 12 in. or less, in ACI 117-90[6]

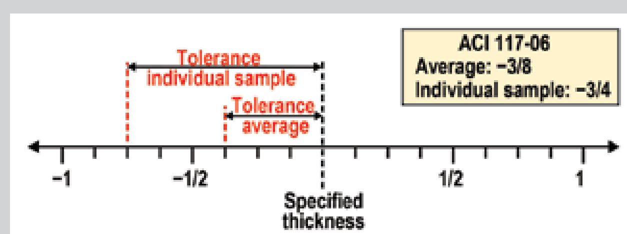

Fig. B: Graphical illustration of the two-tiered thickness tolerances for slabs-on-ground in ACI 117-06[1]

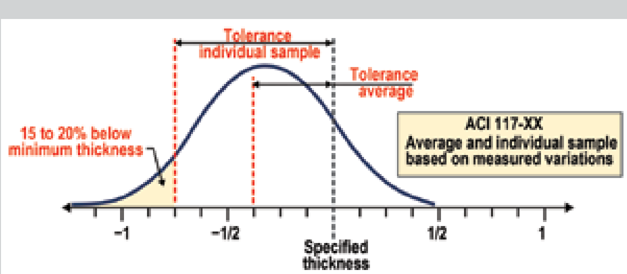

Fig. C: Schematic illustration of the percentage of pavement values below the individual tolerance value of −3/4 in. in a pavement with a standard deviation of 3/8 in. and meeting the average measured thickness limit of −3/8 in. below the specified thickness

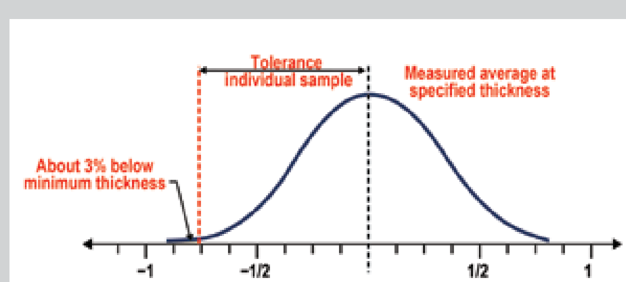

Fig. D: Schematic illustration of the percentage of pavement values below the individual tolerance value of −3/4 in. in a pavement with a standard deviation of 3/8 in. and with the average measured thickness at the specified thickness

for the 2006 revision, and this remains in the ACI 117-10(15) specification.

While the ACI 330.1 specification tolerance provisions have followed those in the ACI 117 specification, ACI 330.2R-17, Section 4.8.3,[13] acknowledges that "warped pavement drainage…makes it more difficult to maintain thickness tolerances."

While ACI Committees 117 and 330 have been working to develop realistic thickness tolerances, ACI 360R-10, "Guide to Design of Slabs-on-Ground,"[14] and ACI 302.1R-15, "Guide to Concrete Floor and Slab Construction,"[15] are both silent on this topic. In our opinion, both documents should make designers and contractors aware of these issues so they can be addressed prior to construction.

ACI Sampling Provisions for Thickness

In addition to thickness tolerances, ACI 117-10(15) provides requirements for sampling as shown in Table 3. Currently, these tolerances also apply to parking lot slabs. The specification also provides instructions for computations and corrective action. Section 4.5.4.5 places an upper bound on the sample thickness used in calculations of the average thickness, and Section 4.5.4.6 calls for additional samples near locations with unacceptable results.

ACI Committee 330 Data Collection

Eldon Tipping, past Chair of ACI Committee 330, developed a spreadsheet program for contractors to use in collecting thickness data for their slab-on-ground pavements. Based on the placement size, the spreadsheet randomly generated 30 survey points at which subbase and top surface elevation data were to be determined using a total station. After the data were entered into the spreadsheet, pavement thickness at each point was calculated as the difference between the surface elevation and the subbase elevation.

Three contractors working in the United States (Texas, New York, and Utah) collected thickness data for 32 different concrete slab-on-ground placements. The contractors classified each placement as level hard-troweled, sloped broomed, or warped broomed. Table 4 provides a summary of the collected data. Tables 5, 6, and 7 provide detailed information for the level hard-troweled, sloped broomed, and warped broomed slabs-on-ground.

Data Analyses

Are slabs-on-ground different?

Table 8 provides a summary of the data analyses for the three types of slabs-on-ground. The weighted averages for the mean deviation from specified (*MD*) and the standard deviation (*SD*) are based on the number of samples for

Table 3:
Sampling requirements for slabs-on-ground and parking lots in ACI 117-10(15)[2]

Section	Statement
4.5.4.1	Minimum number of slab thickness samples, when taken, shall be four (4) for each 5000 ft^2 or part thereof.
4.5.4.2	Samples shall be taken within seven (7) days of placement.
4.5.4.3	Samples shall be randomly located over the test area and shall be taken by coring of the slab or by using an impact-echo device.
4.5.4.3.1	Where concrete core samples are taken, the length of each core sample shall be determined using ASTM C174/C174M.
4.5.4.3.2	An impact-echo device, when used, shall be calibrated using a minimum of three random locations within the test area where the actual concrete thickness is known. The impact-echo test shall be conducted in accordance with ASTM C1383.
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.
4.5.4.5	When computing the average of all samples, samples with a thickness of more than 3/4 in. above the specified thickness shall be assumed to have a thickness 3/4 in. more than the specified thickness.
4.5.4.6	When corrective action is required, additional samples shall be taken in the vicinity of unacceptable results to establish the extent of corrective action.

Table 4:
Summary of slab-on-ground data collected by ACI Committee 330

Description	Level hard-troweled	Sloped broomed	Warped broomed
Total number of projects	12	15	5
Total area, ft^2	210,110	178,960	98,100
Number of measurements	405	522	151
Specified thickness, in.	5, 6, 7, 8, 10	6, 7, 8, 12	6
Weighted average mean deviation from specified, in.	+0.11	+0.16	+0.09
Weighted average standard deviation, in.	0.34	0.52	0.75
Subbase elevation-control	Laser grader: 8 Box blade: 2 Dozer: 1	Motor grader: 9 Robotic grader: 1 Box blade: 3 Dozer: 2	Motor grader: 5
Top surface strike-off	Laser: 12	Manual: 13 Laser: 2	Laser: 5

each placement. The standard deviations are 0.35, 0.52, and 0.75 for level hard-troweled, sloped broomed, and warped broomed finishes, respectively. While the data are limited, an F-test indicates that the standard deviations for the three slab types are different at about the 0.10% level of significance. Based on this determination and the committee's experience, we treated the data as representing three unique types of slabs-on-ground.

How does ACI Committee 330 data set compare to other data sets?

In 2009, Suprenant and Malisch[16] presented data (hereafter termed "ASCC data set") for flat hard-troweled slabs-on-ground (Table 9). The weighted average *SD* was about 5/8 in. and the weighted average *MD* was about −3/8 in. Data for seven of the eight projects in the ASCC data set were obtained from Gustaferro's 1989 article.[10] The *SD* value was higher than the *SD* value obtained in the current ACI Committee 330 study, perhaps because slab-on-ground construction quality has improved since the 1980s and because the two studies used different selection criteria and methods.

There is also a significant difference in the *MD* values. For the eight projects reported in the ASCC data set, all had a negative deviation (average thickness was less than the specified thickness). For the 12 projects reported in Table 5, only four had negative deviations from the specified thickness. The same trend was found for sloped broomed and warped broomed slabs-on-ground (Table 10). Again, this could be simply because construction quality has improved since the 1980s.

Highway pavement thickness variations

The recommendations in this article only apply to interior hard-troweled slabs-on-ground and exterior parking lots and site paving. Data sets obtained by ACI Committee 330 were not collected on highway pavements. State transportation departments have their own thickness and penalty criteria. It can be useful, however, to compare the variation in thickness on highway pavements to the variation observed on parking lots. Kim and McCullough[17] reported measured thickness standard deviations of 0.44, 0.34, 0.44, 0.52, 0.47, and 0.63 in. on individual pavement projects in Texas. The weighted-average *SD* was 0.48 in., which matches well with the 0.52 in. average *SD* for sloped broomed parking lot slabs shown in this study.

It's all about the subbase

Concrete contractors have long identified variations in subbase elevation as the main factor in pavement thickness variations. Table 11 shows *MD* and *SD* values for the bottom and top surface elevations. The *SD* values for the bottom surfaces are greater than the *SD* values for the top surfaces.

The last two placements listed in Table 6 were performed by the same contractor but with different grading equipment. The *SD* for the project with a subbase finished using a dozer (and stringline) was 0.87, while the

Table 5:
Level hard-troweled slab-on-ground data collected by ACI Committee 330

Placement size, ft²	Number of samples	*t*, in.	Bottom surface (subbase), in.		Top surface (concrete), in.		Measured thickness, in.		Construction method	
			MD	*SD*	*MD*	*SD*	*MD*	*SD*	Subbase	Top surface
23,000	39	6	−0.56	0.41	+0.15	0.13	0.71	0.43	Laser grader	Laser strike-off
23,000	38	6	−0.60	0.39	−0.14	0.12	0.47	0.35	Laser grader	Laser strike-off
21,000	40	8	−0.54	0.30	−0.21	0.11	0.33	0.28	Laser grader	Laser strike-off
22,000	50	7	+0.13	0.26	+0.07	0.15	−0.06	0.28	Laser grader	Laser strike-off
41,000	39	8	0.31	0.28	−0.01	0.11	−0.32	0.32	Laser grader	Laser strike-off
1380	20	5	0.08	0.43	0.19	0.10	0.11	0.42	Box blade	Laser strike-off
3600	25	10	−0.17	0.38	−0.06	0.16	0.11	0.36	Laser grader	Laser strike-off
40,830	38	8	0.31	0.28	−0.01	0.11	−0.32	0.32	Laser grader	Laser strike-off
21,400	26	6	0.63	0.36	0.65	0.18	0.01	0.38	Laser grader	Laser strike-off
3000	30	7	0.18	0.40	−0.29	0.26	−0.47	0.32	Box blade	Laser strike-off
3500	30	6	0.04	0.33	+0.44	0.20	0.40	0.33	Box blade	Laser strike-off
6400	30	7	−0.39	0.36	−0.07	0.16	0.32	0.36	Dozer	Laser strike-off

Note: *t* = specified thickness; *MD* = mean deviation from specified; *SD* = standard deviation

Table 6:
Sloped broomed slab-on-ground data collected by ACI Committee 330

Placement size, ft^2	Number of samples	t, in.	Bottom surface (subbase), in.		Top surface (concrete), in.		Measured thickness, in.		Construction method	
			MD	*SD*	*MD*	*SD*	*MD*	*SD*	Bottom surface	Top surface
15,000	40	6	*	*	*	*	0.24	0.38	Box blade	Manual strike-off
21,000	40	7	*	*	*	*	0.52	0.46	Motor grader	Manual strike-off
15,500	40	12	*	*	*	*	0.05	0.56	Motor grader	Manual strike-off
11,000	44	12	*	*	*	*	0.33	0.41	Motor grader	Manual strike-off
7200	36	12	*	*	*	*	0.03	0.46	Motor grader	Manual strike-off
4000	31	12	*	*	*	*	0.17	0.45	Motorgrader	Manual strike-off
11,000	44	12	*	*	*	*	0.37	0.54	Motor grader	Manual strike-off
9500	33	12	*	*	*	*	0.15	0.43	Motor grader	Manual strike-off
5500	32	12	*	*	*	*	−0.31	0.41	Motor grader	Manual strike-off
5500	37	12	*	*	*	*	0.01	0.53	Motor grader	Manual strike-off
1760	25	6	*	*	*	*	0.49	0.54	Dozer	Manual strike-off
2700	20	7	*	*	*	*	0.19	0.62	Box blade	Manual strike-off
27,200	40	7	*	*	*	*	0.30	0.60	Box blade	Manual strike-off
25,800	30	8	0.19	0.87	−0.22	0.29	−0.42	0.94	Dozer	Laser strike-off
25,800	30	8	−0.19	0.20	0.34	0.45	0.52	0.52	Robotic grader	Laser strike-off

Note: t = specified thickness; *MD* = mean deviation from specified; *SD* = standard deviation

*Contractor did not provide data from survey points

Table 7:
Warped broomed slab-on-ground data* collected by ACI Committee 330

Placement size, ft^2	Number of samples	t, in.	Bottom surface (subbase), in.		Top surface (concrete), in.		Measured thickness, in.		Construction method	
			MD	*SD*	*MD*	*SD*	*MD*	*SD*	Bottomsurface	Top surface
21,000	30	6	0.77	0.86	1.13	0.36	0.36	0.59	Motor grader	Laser strike-off
17,600	30	6	0.07	1.10	0.75	0.59	0.68	0.70	Motor grader	Laser strike-off
26,500	30	7	−2.22	1.36	−2.58	0.91	−0.36	0.88	Motor grader	Laser strike-off
16,500	30	7	−1.31	0.67	−1.62	1.11	−0.31	0.95	Motor grader	Laser strike-off
16,500	31	7	2.35	0.67	2.39	0.44	0.03	0.63	Motor grader	Laser strike-off

Note: t = specified thickness; *MD* = mean deviation from specified; *SD* = standard deviation

*Contractor described project as “gnarly, multi-level, multi-sloping parking lot with connecting roads”

SD for the project with a subbase finished using a robotic grader was 0.20—a significant improvement. The thickness *SD* also showed significant improvement, from 0.94 to 0.52.

While the data are limited, they do provide a strong indication that better control of the subbase elevation results in reduced pavement thickness *SD*. The data also show that the ACI 117-10(15) subbase elevation tolerance of ±3/4 in. might be difficult to achieve.

Limiting thickness samples to 3/4 in. of specified thickness

For computation of the average thickness, ACI 117-10(15), Section 4.5.4.5, requires that "samples with a thickness more

Table 8:
Weighted average measured thickness values

Slab type and surface finish	Number of placements	Number of samples	*MD*, in.	*SD*, in.
Level hard-troweled	12	405	0.11	0.35
Sloped broomed	15	522	0.18	0.52
Warped broomed	5	151	0.09	0.75

Note: *MD* = mean deviation from specified; *SD* = standard deviation

Table 9:
Level hard-troweled slab-on-ground data summarized by Suprenant and Malisch (ASCC data set)[16]

Project	Slab area, ft^2	Number of measurements	*t*, in.	*MD*, in.	*SD*, in.
1	240,000	862	4	−0.1	0.60
2	200,000	75	6	−0.5	0.47
3	100,000	186	6	−0.55	0.70
4	100,000	427	6	−0.28	0.60
5	100,000	153	6	−0.38	0.57
6	90,000	79	4	−0.36	0.90
7	100,000	111	4	−0.32	0.77
8	Unknown	60	5	−0.34	0.73

Note: *t* = specified thickness; *MD* = mean deviation from specified; *SD* = standard deviation

Table 10:
Average above or below specified thickness

Slab type and surface finish	Data source	Number of placements or projects	Mean deviation from specified thickness	
			Above specified	Below specified
Level hard-troweled	Suprenant and Malisch[16]	8	0	8
	ACI Committee 330	12	8	4
Sloped broomed	ACI Committee 330	15	13	2
Warped broomed	ACI Committee 330	5	3	2

Table 11:
Weighted average measured bottom surface (subbase) and top surface (concrete) elevation values

Slab type and surface finish	Number of placements	Number of samples	Bottom surface (subbase), in.		Top surface (concrete), in.	
			MD	*SD*	*MD*	*SD*
Level hard-troweled	12	405	−0.07	0.34	0.04	0.15
Sloped broomed	2	60	NA	NA	NA	NA
Warped broomed	5	151	−0.07	0.93	0.14	0.68

Note: *MD* = mean deviation from specified; *SD* = standard deviation than 3/4 in. above the specified thickness shall be assumed to have a thickness 3/4 in. more than the specified thickness." The rationale for this limitation is to discourage using thick concrete at one location to make up for very thin concrete at another location. In other words, this item emphasizes the importance of minimizing large variations in concrete thickness.

Tables 12, 13, and 14 provide the average thickness calculated from all samples and then calculated from all samples with a limit on thickness to no more than 3/4 in. above the specified thickness. Limiting thickness to specified plus 3/4 in. dropped the average thickness in some cases by about 1/8 in. In these cases, the average thickness was already greater than specified so that adjusting the average

Table 12:
Calculated thickness values for level hard-troweled slabs-on-ground

Specified thickness, in.	Average thickness, in.	Number of samples with thickness > 3/4 in. above specified thickness	Average thickness, in.*	Average thickness minus bounded average thickness, in.
6	6.71	15	6.55	0.16
6	6.47	6	6.43	0.02
8	8.37	4	8.35	0.02
7	6.94	1	6.95	0.00
8	7.68	0	7.68	0.00
5	5.11	2	5.09	0.02
10	10.11	1	10.10	0.01
8	7.68	0	7.68	0.00
6	6.01	0	6.01	0.00
7	7.53	11	7.49	0.04
6	6.04	0	6.04	0.00
7	7.32	1	7.30	0.02

*Calculated using bounded sample thickness per ACI 117-10(15), Section 4.5.4.5

Table 13:
Calculated thickness values for sloped broomed slabs-on-ground

Specified thickness, in.	Average thickness, in.	Number of samples with thickness > 3/4 in. above specified thickness	Average thickness, in.*	Average thickness minus bounded average thickness, in.
6	6.02	1	6.01	0.01
7	7.52	0	7.52	0.00
12	12.05	6	12.03	0.02
12	12.33	7	12.29	0.04
12	12.03	2	12.03	0.00
12	12.17	3	12.12	0.05
12	12.37	10	12.27	0.10
12	12.15	1	12.14	0.01
12	11.69	0	11.69	0.00
12	12.01	4	11.98	0.02
6	6.49	8	6.37	0.12
7	7.19	2	7.14	0.05
7	7.30	7	7.22	0.08
8	8.42	10	8.19	0.23
8	7.48	1	7.45	0.03

*Calculated using bounded sample thickness per ACI 117-10(15), Section 4.5.4.5

Table 14:
Calculated thickness values for warped broomed slabs-on-ground

Placement	Specified thickness, in.	Average thickness, in.	Number of samples with thickness > 3/4 in. above specified thickness	Average thickness, in.*	Average thickness minus bounded average thickness, in.
1	6	6.36	7	6.25	0.11
2	6	6.68	2	6.63	0.05
3	7	6.64	4	6.56	0.08
4	7	6.69	3	6.60	0.09
5	7	7.03	6	7.00	0.03

*Calculated using bounded sample thickness per ACI 117-10(15), Section 4.5.4.5

thickness in accordance with Section 4.5.4.5 did not affect specification compliance. For cases where the average thickness was less than specified, *SD*s were sufficiently low such that there were no "thick" samples to exclude. These trends are expected with the good quality control as shown by the standard deviations exhibited by the contractors that participated in the study, but it is unclear how this would apply to the target population.

Sample Bias

The data set collected by ACI Committee 330 represents slab-on-ground concrete construction by contractors on ACI Committee 330 who volunteered to collect data. It was obtained by convenience and therefore is not a random sample. Through their participation in ACI and ASCC activities, these contractors exhibit a high level of interest in quality construction and may not be representative of the total population. Thus, statistical analysis by itself, with this data set, cannot be used to extrapolate to the target population. Judgment is needed to estimate how this convenience sample represents the target population. Figure 4 illustrates that the convenience sample can be expected to represent the "better" half of the target population.

From ACI Convenience Sample to Target Population

The main question is how to address the ACI Committee 330 data, and even the ASCC data, within the target population distribution. The ACI Committee 330 volunteer data are believed to be representative of good to excellent work. The ASCC data, collected from slabs with thickness issues, are believed to be representative of fair to poor work. Figure 5 illustrates the two data sets within a hypothetical thickness population distribution.

We suggest that the levels of thickness control for slabs-on-ground could be expressed similarly to ACI 214R-11, "Guide to Evaluation of Strength Test Results of Concrete,"[18] Tables 4.3 and 4.4, standards of concrete control. That is, the levels of control of thickness—excellent, very good, good, fair, and poor—could be assessed by the standard deviation. Table 15 provides standard deviation values we associate with

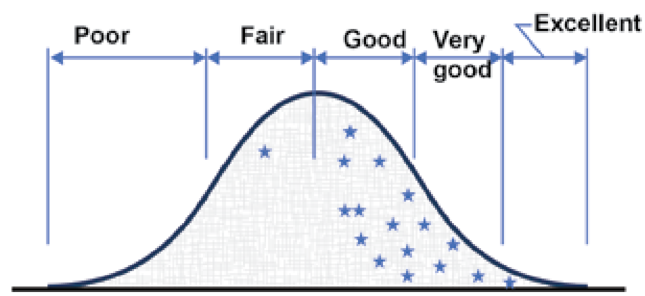

Fig. 4: Expectation of where the ACI Committee 330 data set falls within the target population

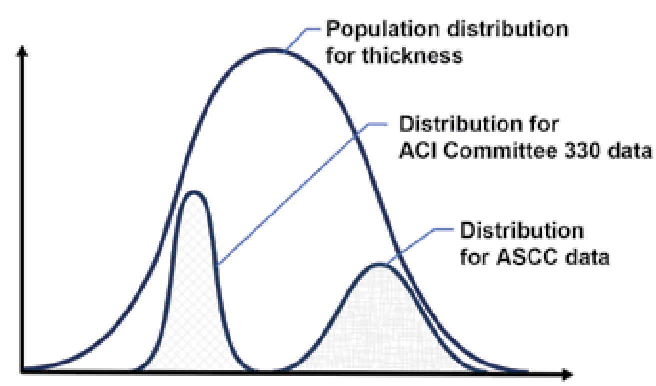

Fig. 5: Schematic illustration of the expected approximate locations of the ACI Committee 330 and ASCC data sets within the population distribution

different levels of thickness control. The main basis for estimating the standard deviation at each level is based on:

- The average standard deviation from the biased convenience sample should be at the "very good" level; and
- The lowest standard deviation from the biased convenience sample should be at the "good" level.

Tolerance Recommendations for Slabs-on-Ground

While some tolerance standards provide different tolerances for different quality levels, the current ACI 117 specification does not. Rather, ACI Committee 117 selected a

Table 15:
Levels of thickness control for slabs-on-ground

Slab type and surface finish	*SD* for different levels of thickness control, in.				
	Excellent	Very good	Good	Fair	Poor
Level hard-troweled	Below 0.30	0.30 to 0.37	0.38 to 0.45	0.46 to 0.53	Above 0.53
Sloped broomed	Below 0.45	0.45 to 0.52	0.53 to 0.60	0.61 to 0.68	Above 0.68
Warped broomed	Below 0.70	0.70 to 0.80	0.81 to 0.90	0.91 to 1.00	Above 1.00

Note: *SD* = standard deviation

Table 16:
Tolerance recommendations for slabs-on ground

	Elevation tolerance, in.	*X* value to be used in computing average thickness, in.	Thickness tolerances below specified thickness, in.	
Slab type and surface finish	Fine grade of soil immediately below	Individual sample thickness = minimum of sample thickness or (*X* + the specified thickness)	Average of all samples	Individual sample
Level hard-troweled	±1	1	−3/8	−1
Sloped broomed	±1-1/4	1-1/4	−3/8	−1-1/4
Warped broomed	±1-1/2	1-1/2	−3/8	− 1-1/2

single tolerance for what it considered to be a reasonable quality level for the variety of concrete slabs-on-ground constructed across the United States. However, the ACI 117 specification does allow the specifier to define an alternative tolerance within the project specifications to provide the necessary project quality level. Thus, we recommend that the initial starting point for selecting a thickness tolerance will be to allow two standard deviations below the specified thickness, based on "fair" level of thickness control (Table 15). This is equivalent to having less than about 3% of the thickness values below the specified thickness minus the tolerance. The tolerance, however, can also be modified based on experience and judgment. ACI Committee 117 has typically been conservative when developing new tolerances based on limited data, and Joint ACI-ASCC Committee 117 can be expected to err on the low side rather than to aggressively change a tolerance.

Therefore, our recommendations for tolerances on individual samples for slab-on-ground construction are:

- Level hard-troweled: 0.53 × 2 = 1.06 (based on our judgment, use 1 in.);
- Sloped broomed: 0.68 × 2 = 1.36 (based on our judgment, use 1-1/4 in.); and
- Warped broomed: 1.00 × 2 = 2.00 (based on our judgment, use 1-1/2 in.).

These tolerances are summarized in Table 16, along with our recommendations for the tolerance on the fine grade elevation of the slab-on-ground subbase and the tolerance on the average thickness. As is currently required in ACI 117, Section 4.5.4, the average thickness is to be calculated using sample values bounded by the specified thickness plus the tolerance on individual samples.

Our recommendations for slab-on-ground tolerances are based on the cited data and our experiences with slab construction and inspection. Recognizing that many of the data were obtained by convenience, we would ask that others share their data and experiences so that these recommendations can be fine-tuned for the industry.

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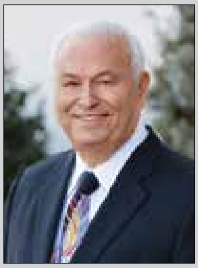

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