CERAMIC TILE INSTITUTE OF AMERICA, INC.

12061 Jefferson Blvd., Culver City, CA 90230-6219

CTIOA FIELD REPORT 2002-7-02

SUBJECT: Concrete Tolerance
By: C.V.Yland, Ph.D

Interpreting an F-Number Specification

While the F-Number measurement method for concrete floors has been used for a number of years, there are still areas of confusion relating to its use. Sometimes the specifications themselves are unclear. What does it mean when only one number such as F_F 20 is specified? The F_F indicates that flatness is specified, but no mention of levelness (F_L) has been made. Does this mean the specification is for an elevated slab and the F_L omission is intentional, or is it for a slab on grade and the omission is a mistake? Is this a Specified Overall Value (SOV) which represents a composite value of all measurements taken on a floor, or is this a Minimum Local Value (MLV) below which the slab or portions of it are not considered acceptable? How does this F-Number specification compare to a traditional gap-under-a-straightedge tolerance? Is the Overall or Minimum Local Value used when making the comparison?

Flatness (FF) and Levelness (FL) F-Numbers

F-Numbers are used to specify flatness and levelness in floors. F_F refers to flatness (bumpiness or waviness) while F_L refers to levelness (tilt). They are always given in the order F_F / F_L. The numbers are linear with the higher the number, the flatter or more level the floor. A floor with a specified flatness of F_F30 is twice as flat as a floor of F_F15. Typically, F-numbers range from 12 to 45. The flatness number controls surface bumpiness by limiting the number of successive 1-foot slope changes measured along sample measurement lines. The levelness number controls conformance to design grade by limiting departures from design grade over distances of 10-ft. The difference between flatness and levelness is shown below in Figure 1[i].

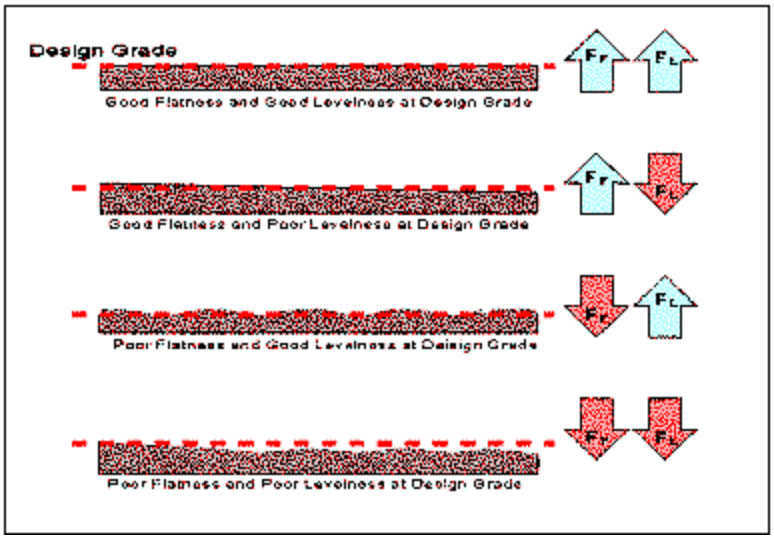


Figure 1. Flatness and Levelness of Floors.

How do F-Numbers compare to straightedge tolerances?

A common question is 'How do the F-Numbers compare to a 1/8" or 1/4" in 10-ft straightedge tolerance'. While there is no direct correlation between F-Numbers and traditional straightedge tolerances, F_F 25 is often used as the F-Number equivalent of a straightedge gap of 1/4" in 10 feet – measured as the maximum "dip" between two high points 10-feet apart.

Care should be taken however, to note these comparisons are for the composite value or Specified Overall Value and do not represent a Minimum Local Value which could be 50% to 67% of the Specified Overall Value. This is why it is important for not just the concrete floor contractor to understand the F-Number system, but also all of the rest of the team including the architect/engineer, the specifier, and the tile installer. The following table shows common specifications of F-Numbers (Specified Overall Values) and their straightedge "equivalents".

Table 1.

Relationship between Straightedge Gap, F-Numbers, and ACI Class of Floor

ACI Class of Floor[ii]	Typical Use	Composite Flatness F_F	10-ft Straight-Edge Gap "Equivalent"	Composite Levelness F_L

1 or 2	Non-critical: mechanical rooms, non- public areas, surfaces to have raised computer flooring or **thick-set tile**, and parking structure slabs.	20	F_F 20 = 5/16”	15
2	Carpeted areas of commercial office buildings or lightly trafficked office/industrial buildings	25	F_F 25 = 1/4”	20
2, 3, 4, 5, 6, 7, or 8	**Thin-set** flooring or warehouse floor with moderate or heavy traffic.	35	F_F 32 = 3/16”	25
9	Warehouse with air-pallet use, ice, or roller rinks.	45	-	35
3 or 9	Movie or television studios.	>50	F_F 50 = 1/8”	>50

How are F-Numbers measured?

The F-Number system measures elevations of the floor at 1-foot intervals along

straight lines. The differences in elevation between adjacent points and between all points 10-ft apart are then calculated. For each 1000 square feet of floor area, at least 34 individual elevation measurements should be taken[iii]. F_F is determined using the elevation differences over two feet, while F_L is determined using elevation differences over ten feet. Statistical analysis is made of the elevation measurements using equations and methods in conformance with the rules set forth in ASTM E1155 to derive the F-Numbers.

ACI 117-90, *Standard Tolerances for Concrete Construction and Materials* requires that F-Number floor measurements be conducted within 72 hours of floor placement to minimize influence of shrinkage or curling on the values. Floor profile information is logged while measuring is performed and reports can be generated the same day.

What type of equipment is used to measure F-Numbers?

There are several different types of equipment for measuring floors. One of the most common is the Dipstick® Floor Profiler produced by Face Companies and shown in Figure 2.

Figure 2. Dipstick® in Action.

This system is used to measure Random Traffic Floors and was developed by Allen Face ("F" of the F-Number). The Dipstick® is an electronic level that measures the elevation difference between two pins. It is walked across the floor pivoting on the front pin to create a series of sequential readings. It produces a point-to-point graph of the surface measured, as well as the data required to compute the F-numbers. A palm-top computer logs the readings as it goes. The software which comes with the Dipstick® automatically calculates the floor area equal to specification, the floor area better than specified, and the floor area worse than the specification. The results are then reported as overall (SOV) and local (MLV) floor flatness and levelness numbers.

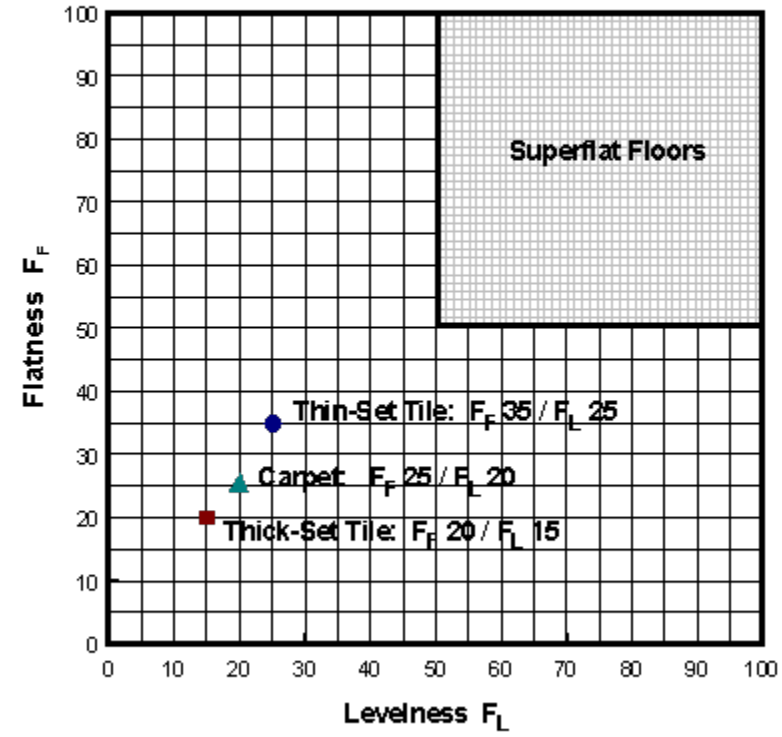
What are composite, Specified Overall, and Minimum Local F-Numbers?

The Minimal Local Value (MLV) is the minimum quality floor that will be accepted by the owner without repair. The MLV generally ranges from 50% to 67% of SOV. The significance of the two-tier specification is that even if a floor does not meet the Specified Overall Value it will not be rejected if it still meets the Minimal Local Value for all sections of the floor. The tile subcontractor needs to be aware that a floor may still be considered acceptable at the lower of the MLV range. Thus, when evaluating a request for bid, it is important that the tile subcontractor verifies that the Minimal Local Value (not just the Specified Overall Value) is a tolerance that will be suitable for the anticipated tile installation. In the figure below[iv], composite values (SOV) are

shown for carpeting and thick-set and thin-set tiles.

Does the Local Minimum F-Numbers specify a flat enough floor for tile?
The tile installer needs to be aware of just what was specified and if the specifications provide the tolerances required to provide a good quality tile installation. What did the owner have in mind for a floor covering? If some portions of the floor are to be carpeted and other areas are to be tiled, do the tiled portions have a higher flatness F-Number? Does the concrete floor contractor have any experience constructing floors to meet F-Number specifications and know what finishing procedures need to be used to achieve the desired tolerances?

Figure 3. Flatness and Levelness - Typical Use Guide.



How to know if the concrete floor contractor can meet the specification.
One advantage of using properly specified F-Numbers to state required flatness and levelness tolerances for a concrete floor is that the result can be measured and this information used in future construction. This assumes the current contractor has past

experience in producing quality floors to similar specifications. However, it is important to know if the previous work was done to the straightedge or F-Number method.

If the F-number method was used by the contractor on earlier similar projects, then the contractor does know the correct forming and finishing skills required to produce the specified floor. If, however, the contractor does not have this experience, how can the owner, architect/engineer, specifier or tile installer be sure that the floor will be constructed to meet the desired tolerances?

The easy answer is to look at some of the contractor's previous installations that required a similar covering to be applied. It is recommended by ACI 302.1 that if a contractor does not have previous experience constructing slabs to F-Number tolerances, that a similar floor be revisited and measured using the F-Number method. It should be noted, that this type of after-the-fact measuring will produce somewhat different readings from measurements taken immediately after the slab was placed. However, if a quality floor was constructed and the owner pleased, it indicates the contractor should be able to reproduce the similar results on the new project, but now knows what actual flatness and levelness were achieved with what forming and finishing techniques. This knowledge can then be used to produce the desired surface of the new floor.
To build a floor that conforms to the F-Number specifications requires the contractor to perform extra planning and arrangements. Hand-screeding will not yield a satisfactory floor. In some cases vibratory screeding will not provide the desired flatness and laser screeding may be required. Similarly, using a bull-float is not recommended. A highway straightedge is said to be the cheapest and most effective way of improving the flatness of a floor. In the last section of this report is a list of additional sources of information on how to achieve floor flatness. The two articles by Eldon Tipping in particular are recommended.

Factors that influence flatness and levelness

F_L Levelness (tilt) is most affected by forming, placement and initial strikeoff. F_F Flatness (bumpiness) is most affected by finishing operations such as floating, restraightening, and troweling. ACI 302.1R-96 lists typical finishing requirements that correlate to specification requirements for both flatness and levelness for slabs-on-grade and suspended slabs. To meet many flatness requirements, finishers must restraighten or cut and fill the top surface of the concrete while it's still plastic. The best tool for this is a 10-foot or 12-foot highway straightedge used repeatedly during the finishing process.

Using the Floor Profile F-Number Report for remediation

Since the report can often be available hours after the measuring is conducted, defective areas (areas not complying with the Minimal Local Value) can be identified quickly. Plans and scheduling can be made in a timely fashion for remediation in the form of repair (grinding, planning, surface repair, retopping) or removal and

replacement. Once remediation of the defective area has been made, it can be remeasured to verify its conformance to specification and work rescheduled accordingly. This is perhaps one of the most cost-effective applications of the F-Number system. In addition, as an accepted standard, use of the F-Number system can reduce conflict and litigation that might otherwise occur when the straightedge method alone is used to determine tolerances.

The advantage of the F-Number system is the availability of timely and accurate information about the constructed floor. While contractors with experience meeting F-Number specifications can consistently produce quality floors, the tile subcontractor should still verify that the Specified Overall and Local Minimum F-Numbers will provide the tolerances required for the tile installation.

Additional Sources of Information

1. ACI International®, PO Box 9094, Farmington Hills, MI 48333 ~ (248) 848-3700.
http://www.aci-int.org

- ACI 117-90, "Standard Tolerances for Concrete Construction and Materials"
- ACI 117R-90, Commentary on Standard Specifications for Tolerances for Concrete Construction and Materials".
- ACI 302.1-96, "Guide for Concrete Floor and Slab Construction".

2. ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken,
Pennsylvania, USA 19428-2959. http://www.astm.org

- ASTM E1155, "Standard Test Method for Determining Floor Flatness and Floor Levelness Numbers".
- ASTM E1486-96, "Standard Test Method for Determining Floor Tolerances Using Waviness, Wheel Path, and Levelness Criteria".

3. Face Companies

- "*The 40 Most Asked Questions about F-Numbers*", and Dipstick® Floor Profiler. Face Companies, 427 West 35th Street, Norfolk, VA 23508, Phone (757) 624-2121, Fax (757) 624-2128. http://www.faceco.com

4. World of Concrete, Hanley-Wood Publications
http://www2.worldofconcrete.com

- Fricks, Terry J. "*Misunderstandings and Abuses in Flatwork Specifications*", Concrete Construction. Publication #C940492

- Halvorsen, Grant T. "*Placing Flat Floors*", Concrete Construction. Publication #C930261, April 1993

- Phelan, William, "*Floors That Pass the Test*," Concrete Construction. Publication #C890005

- No author listed, "*Laser-guided Strike-off Machine Helps Contractor Build Flat Floors Fast*," Concrete Construction. Publication #C890017, January, 1989

- Tipping, Eldon, "*10 Steps to Placing Flat Floors*," Concrete Construction. Publication #C950446

- Tipping, Eldon, "*Bidding and Building to F-Number Floor Specs*," Concrete Construction. Publication #C920018, January 1992

- US Army Corps of Engineers, em 1110 2 2000 c-8 pages 8-4 and 8-5

Alternate Method for Determining Flatness – Waviness Index

- Ytterberg, Carl N., *"Flatness Tolerances for Random-Traffic Floors,"* (ASTM E1486-94) C960042
- Ytterberg, Carl N., "*Using the Waviness Index to Improve Floor Flatness,*" C960359

Superflat Floors

- White, Dean J., "*Quality Control To Achieve A Superflat Floor*," C840291

---

[i] From ssconc@ssconcretefloors.com

[ii] ACI 302.1R-96, *Guide for Concrete Floor and Slab Construction*

[iii] *The 40 Most Asked Questions about F-Numbers"*, Face Companies, Norfolk, VA 23508. Ph. (757) 624-2121.

[iv] ACI 302.1R-96, *Guide for Concrete Floor and Slab Construction*