Feature

Critical Concrete Floor Tolerances

All photos courtesy Geoff Kinney

By Geoff Kinney

Tolerances are commonly used to define the limits of a concrete floor's acceptability but are seldom inspected or enforced. Given this, it is absolutely essential they be practical and relate to an owner's actual needs to be effective. Tolerances must also provide designers with definitive practical limitations for their calculations and contractors with clear-cut performance criteria.

Tolerances are tools used to achieve quality standards. However, they commonly go uninspected until something goes wrong, for reasons such as human error or to reduce costs. Without inspection, tolerances become meaningless and can actually create an environment of indifference and hidden liabilities for all parties. In effect, specifying tolerances without inspection is like a boat without water—useless.

The Canadian Standards Association (CSA) A 23.1, *Concrete Materials and Methods of Concrete Construction*, is the industry's mandatory national concrete bible, as referenced in the *National Building Code of Canada (NBC)*. CSA's focus is to improve and control the production of work in the field. There are two critical tolerances relating to concrete floor construction in this document—slab-on-grade thickness and slab surface profiles.[1]

Slab thickness

Controlling slab-on-grade thickness is the largest problem area in the concrete floor industry today. It is common to find local variations in granular base elevations, which reduce slab thicknesses below allowable limits. Generally speaking, this is the case because too little time is spent checking elevations before a concrete pour is ordered. However, this problem can be easily avoided through proper inspection and correction prior to ordering a concrete floor placement.

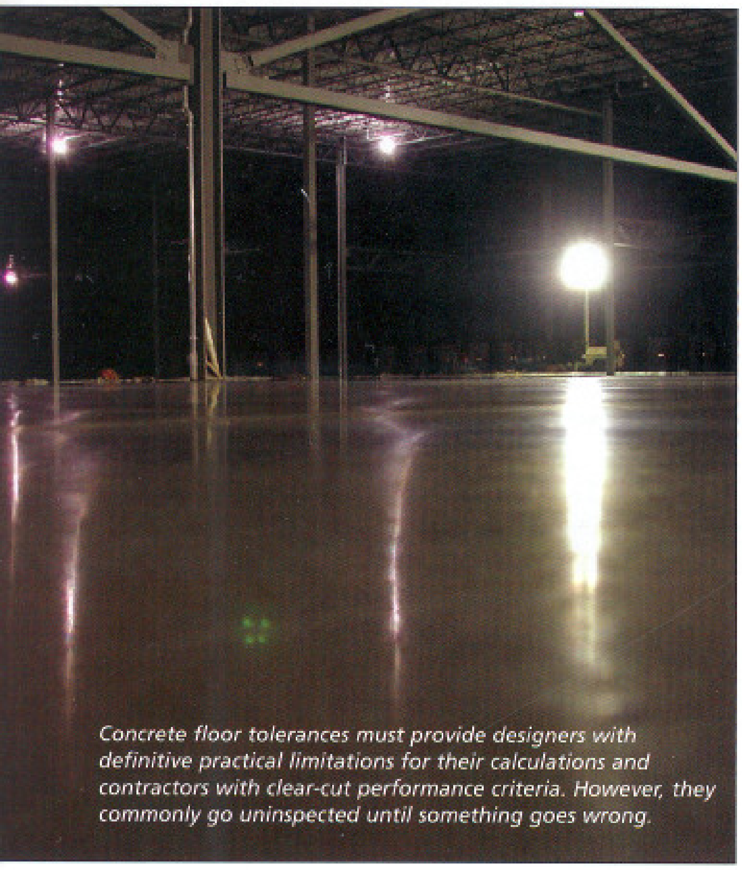
The elevation of the granular base and the floor's surface combine to determine final slab thickness. Both can be problematic on their own or when combined with each other. CSA A 23.1 defines the maximum variation of a granular base as ±10 mm (0.4 in.) from the specified elevation. Granular base elevations are easily inspected using a laser. However, it is often the case these elevations are not inspected thoroughly, especially in these days of fast-track construction. Frequently, there is not enough planning time. In many cases, concrete floor work is awarded immediately prior to the start of the work on-site, which does not allow for sufficient pre-construction planning to avoid common mistakes and achieve desirable results. This can lead to an environment where slab thickness is often compromised, even though this tolerance is practical to specify, inspect, and enforce.

Concrete floor surface elevations can also vary depending on the provision of an accurate benchmark, the method and quality of the screeding operation, the workability of materials, and ambient conditions. The use of laser-guided equipment is going a long way to reduce variations in industrial construction. However, care must always be used to ensure the methods, materials, and environment are controlled to produce the desired results.

The definition of acceptable variations in slab thickness remains controversial. Owners expect a slab thickness as indicated on project drawings. However, experience shows these limits should include normal variations, which occur when constructing granular bases and concrete floors to a good standard of workmanship.

CSA A 23.1 defines a floor as acceptable if its average thickness is no more than 10 mm (0.4 in.) less than the specified thickness. Additionally, this standard permits a maximum local variation of up to 20 mm (0.8 in.) less than the specified thickness. This takes into consideration cases where the granular base is high and a floor's elevation is low in localized areas from time to time.

It is difficult to control slab-on-grade thickness. Local variations in granular base elevations are common, which reduce slab thicknesses below allowable limits. This problem can be easily avoided through proper inspection and correction prior to ordering a concrete floor placement.



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Floor design calculations produce a theoretical slab thickness to specify for a given loading condition. However, it is unrealistic to expect a specified 150-mm (6-in.) thick slab will have perfectly uniform thickness throughout an entire building area. Also, it is neither practical nor realistic to specify this as a 'minimum' slab thickness. The ethical contractor may add additional costs to his price to account for a minimum thickness, but this can put him at a competitive disadvantage. From a practical perspective, it is structural engineers who need to understand variations do occur in the slab thickness and to include this information in their design considerations.

It is critical to define variations and limit them for designers to perform their calculations with confidence, as well as create practical goals for the contractor in the field. Therefore, a minimum 150-mm slab thickness design should be revised to a 160 mm (6.3 in.) specified thickness. This adjustment recognizes and accommodates variations, which naturally occur when constructing granular bases and concrete floors.

Surface profiles

Concrete floor surface tolerances are confusing and generally misunderstood or misused, making their application potentially dangerous for specifiers, contractors, and owners alike.

Although in use for decades, the straightedge method is still problematic today. Straightedge tolerances are generally meaningless, given they do not relate to the methods of construction or the owner's needs in many cases. They are also ambiguous and subjective in their interpretation and application. The traditional specification of '1/8 in. in 10 ft' has been the tolerance of choice for specifiers for every concrete floor surface imaginable, including schools, high-rise buildings, houses, skating rinks, and high-racked, superflat warehouses. However, it should be noted each of these applications has their own unique tolerance requirements, which need to be specified accordingly. Straightedge tolerances should not be used to define a surface profile unless there is no other alternative, and only then should they be based upon current data taken from similar facilities in accordance with the methods listed in CSA A 23.1.

A new system emerges

The Face Company introduced the F number system to the concrete flooring industry in the mid-1970s, creating a practical, meaningful method to define and construct concrete floor surface tolerances. This new system did a number of things to resolve the problems in the specification of floor tolerances:

1. It defined a systematic approach to collecting and reporting data that was repeatable and not subjective (ASTM International E 1155, *Standard Test Method for Determining FF Floor Flatness and FL Floor Levelness Numbers)*.
2. It allowed contractors to associate construction methods to actual tolerance results, making it practical.
3. It allowed owners to specify and obtain similar floor profiles for floors, regardless of project location or contractor.

The F number system is based on a statistical sampling of floor surfaces, using specialized, highly accurate, floor measurement devices (*e.g.* a dipstick and F meter). The data is broken down into floor flatness (FF) and floor levelness (FL) subsets. The system defines FF as the variation in elevation of a floor's surface between two points located 305 mm (12 in.) apart. Similarly, FL is defined as the variation between two points, which are 3.1 m (10 ft) apart. The

Table 1 Examples of F Number Tolerances

	FF	FL
Floor with thick applied finishes	20	18
Floors with thin applied finishes	25	18
Suspended slabs	20	NA
Suspended slabs with thin finishes	25	NA
Warehouse floors	≥30–50	≥25–35

combination of these two facets of a floor has proven extremely effective for defining and constructing floor surfaces. The exception, however, is their use in defined traffic applications.

For clarity purposes, the FF/FL system is used for random traffic environments where people walk or drive in an endless variety of wheel paths or directions. A second F number system called the 'Fmin system' is used for special purpose 'superflat' floor applications in defined traffic, wire-guided floor environments.

A major requirement to come out for the F number system is all floor tolerances must be measured within 72 hours of slab casting. This allows the contractor the opportunity to change methods and materials on subsequent pours to attain the desired tolerance result.

Achieving specified floor tolerances is a function of many concerns, including the quality of ambient conditions, the workability of concrete, and the selection and quality of methods of construction.

The F number system and variations

The specification of a floor under the F number system is commonly defined as an 'overall' FF/FL, meaning an average total value for the entire building area composed of the average results from each individual floor placement.

The system also includes limits for the maximum permissible variation in achieved results, which is known as minimum local value (MLV). This variation is 50 per cent of the specified overall value. In other words, an individual pour placement can vary by up to no more than half the overall tolerance limit, before it is rejected. A floor specified with an overall specified tolerance of FF40/FL30 allows individual pour tolerance results as low as FF20/FL15 to be acceptable without corrective action. However, the overall average of all individual pours combined must exceed FF40/FL30, or financial claw-backs can result. Floor levelness tolerances do not apply to suspended slabs due to expected changes in profile as a result of camber and deflection.

Specifying appropriate floor tolerances

The achievement of specified floor tolerances are complex and a function of:

- the quality of the ambient conditions;
- the workability of the concrete;
- the selection and quality of methods of construction;
- the accessibility of required equipment;
- the use of surface-applied hardeners; and
- the skill of the contractor and their tradespeople.

Care should be taken to consider the impact of all these factors when creating a slab design for a particular usage (Table 1).

Tolerances must be based on an owner's needs for a particular use. Increasing tolerances (*i.e.* reducing the variation and making them harder to obtain) generally results in higher costs. Therefore, it is imperative to define an appropriate tolerance to avoid unnecessary premiums. Measurements can be taken from existing facilities to provide an understanding of current usage acceptability, prior to specifying a tolerance for a new building program.

The profile of a slab-on-grade changes as concrete dries through a process called curling. This is a common problem throughout

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North America in all jointed floors. As a concrete floor dries, the surface shrinks more than the base of the slab, resulting in an upward curvature of the floor at the joints. As a result, great care must be taken to develop a slab design, which reinforces against curling as well as applied loading. Combining a suitable type and quantity of steel reinforcement with low-water-content concrete and a plasticizing admixture, can help reduce these tolerance losses. It should be noted steel fibre has proven to be extremely economical and effective in this regard.

CSA A 23.1 also includes an option to use the waviness index, which allows for the selection of various rates of change in elevation over several lengths of measurement (not just 305 mm and 3.1 m, like the F number system). Despite the fact this system permits a versatile, customized approach to defining tolerances, it is confusing and has not been widely used in Canada. Given this, care should taken to ascertain the correct methods of construction before agreeing to achieve a specified waviness index tolerance limit. The industry standard method of correction for defective tolerance results is to grind the surface.

Conclusions

The specification, construction, inspection, and enforcement of tolerances should be based on helping everyone clearly understand, achieve, and maintain a level of acceptable quality to meet an owner's floor use requirements.

Pre-construction meetings are an invaluable tool to discuss all aspects of concrete floor construction. A thorough review of the owner's expectations at these meetings, particularly in relation to tolerances, generally produces an environment of teamwork and success not facilitated elsewhere. ✍

Notes

[1] Further information on floor tolerances is available from Canadian Standards Association (CSA) A 23.1, ASTM International E 1155, *Standard Test Method for Determining FF Floor Flatness and FL Floor Levelness Numbers*, ASTM E 1486, *Standard Test Method for Determining Floor Tolerances Using Waviness, Wheel Path, and Levelness Criteria*, American Concrete Institute (ACI) 117, *Standard Specifications for Tolerance for Concrete Construction and Materials and Commentary*, ACI 302, *Guide for Concrete Floor and Slab Construction*, and the Concrete Floor Contractors Association of Ontario at www.concretefloors.ca.

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