Surface regularity of industrial floors – a review of TR34 2003

It is nearly two years since the publication of the third edition of Concrete Society Technical Report 34 *Concrete industrial ground floors*[1]. Floor flatness is a fundamental performance requirement in floors and an important consideration in terms of construction. As the materials handling industry is now developing its own European standards, it seems an appropriate time for review and reflection on the topic.

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This article is the first of two by Tony Hulett. The second will be featured in the February issue of *CONCRETE* magazine.

When considering future developments it is useful to see where we have come from. It therefore seems appropriate to look at the development of flatness testing methods and analysis, dealing primarily in this month's article with measurements in Free Movement Areas such as in Figure 1. Defined Movement will be considered in detail in next month's *CONCRETE*. However, before moving on, it is necessary to define these terms.

- In *Free Movement* areas, such as in factories, retail outlets, low-level storage and in areas of wide aisle racking, Mechanical Handling Equipment (MHE) can travel in any direction.
- In *Defined Movement*, MHE uses fixed paths in very narrow aisles (VNA) and is usually associated with high-level storage racking.

Figure 1 above: Free Movement Area.

Figure 2 right: The Face Dipstick.

Free Movement – measurement techniques

Only UK and US Standards are based on methods that measure relative elevational differences over prescribed distances. Other national Standards are based on the use of straight edges and are not considered here.

Elevational difference techniques originated in the USA. In 1976, the Face Floor Profileograph was first demonstrated at the World of Concrete exhibition. Sam and Allen Face, recognising the impracticality of using straight edges on large floors, devised a machine to replicate the wheel configuration and movement of MHE. It remains in use in the same format today and is prescribed in Appendix C of the Third Edition of *Technical Report 34* (TR34). This will be discussed further in next month's article.

In 1982, again at World of Concrete, the Face Dipstick (see Figure 2), was first demonstrated. This instrument measured the elevation difference between two points 300mm apart. The Dipstick was 'walked' across a representative sample of floor, measuring between successive points. The data was collated and two calculations made. One was the first differential of the elevational differences over successive 300mm points (which TR34 refers to as Property II), the other was the accumulated elevational differences over a distance of three metres, equivalent to ten times 300mm (Property IV in TR34). The Dipstick was first seen in the UK around 1983.

These developments represented a great stride forward. For the first time, there were practical methods of gathering usable data on flatness (over short distances) and levelness (over longer distances) for large floors. These methods were documented in the First Edition of TR34[2] in 1988. Free movement survey methods were further developed in the Second Edition of TR34[3] in 1996. In the Second Edition, differences between consecutive elevational differences over a distance of 300mm (Property II) and elevational differences between points on a 3m grid (Property IV) were prescribed. The method remained unchanged in TR34 Third Edition. In the UK, Property II is now commonly measured semi-continuously with a rolling instrument (see Figure 3), and a precise level and staff is used for measuring the elevational differences on the three-metre grid (Property IV).

Free movement – data analysis

The Face system in the US provided a simple statistical analysis of sample data based on the assumption that there will always be a normal distribution of data. Standard deviations of both measurements are calculated and then converted using an inverse constant to produce separate 'F' numbers for flatness and for levelness. These are F_F and F_L and provide surface regularity indicators equivalent to TR34's Property II and IV respectively.

'F' numbers were incorporated into an American Society for Testing and Materials (ASTM) Standard E 1155 with the first metric version E 1155M[4] in 1987. *Higher* 'F' numbers indicate improved regularity, that is, with lower measured variances from a theoretical flat plain. In the UK, TR34 reports on the actual variances and so regularity improves with *lower* Property values.

In ASTM E 1155M, the quality of a floor is assessed on the basis of the standard deviations (in mm) of the random data sets. In TR34, limiting values are applied to 95% and 100% of the sample data sets. The 100% limit is nominally 50% greater than the 95% limit reflecting the assumption of a normal distribution of data, i.e. nominally two and three standard deviations respectively.

It is suggested that the use of the 95 and 100 percentile values as absolute limit values needs to be examined. It is not the usual way of applying a standard statistical method to sample data sets in building. It is more usual to judge accuracy on the basis of a characteristic value, typically the 95 percentile value as in BS 5606[5], or a standard deviation.

(Photos: FACE Consultants.)

In Free Movement surveys, only a sample of measurements is taken, unlike in Defined Movement surveys where every point on the floor is measured. It follows that if we are taking a sample and assessing on the basis of a 95 percentile value, then nominally (but not precisely) 5% of measurements will exceed the 95 percentile value and about 1 in 370 will exceed the notional 100% limit.

The First Edition of TR34[(2)], referring to BS 5606[(5)], states that the data is to be interpreted as being of a normal distribution and states that assessment of quality should be made on the basis of the 95% value (two standard deviations). However, it then goes on to add a requirement for a 100% limit while at the same time stating that 1 in 370 values *will* be greater than this notional 100% limit.

It is suggested that the present method brings unnecessary difficulties as floors can be deemed to have failed on the basis of a few measurements exceeding a purely notional absolute limit. To put this in perspective, a 6000m^2 floor surveyed on a 3m grid may have 1216 Property IV readings and it should be expected that three or four may be higher than the notional 100% limit. Those few measurements will exceed the notional limit by only a small margin in most cases.

There is the theoretical possibility of large 'rogue' errors. If they occur, then a common sense approach should be agreed for dealing with them. Such 'rogue' readings can be easily identified and their significance assessed by competent surveyors. If there is an overall greater proportion of higher readings in the sample survey then there will be a higher standard deviation, which, if it exceeded a prescribed limit, could deem the floor to fail the specification.

A comparison of standard deviations for the Free

Table 1: Free movement tolerances

	Flatness – Property II		**Levelness – Property IV**	
	(Characteristic) accuracy	Standard deviation	95% limit (Characteristic accuracy)	Standard deviation
FM 1	2.5	1.3	4.5	2.3
FM 2 (Special)	3.0	1.5	6.5	3.3
FM 2	3.5	1.8	8.0	4.0
FM 3	5.0	2.5	10.0	5.0

Figure 3: Property II is now commonly measured semi-continuously with a rolling instrument.

Movement classifications is given in Appendix C4 of the Third Edition of TR34 and are shown in Table 1.

Free movement – performance limits

The limits related to required performance are found in Tables 4.2 and 4.4 of TR34, Third Edition. The equivalent document based on 'F' numbers in the US is ACI 302[6]. Although the classifications for use in the two documents are not precisely comparable, there are significantly different requirements for flatness for any given requirement for levelness.

"Floor flatness is a fundamental performance requirement in floors and an important consideration in terms of construction."

In the 1997 supplement to TR34[7], most tolerances were relaxed by a factor of 1.5. This probably brought levelness limits into line with US practice but introduced a considerably relaxed flatness by comparison. Although US practice is a useful guide, it is important to examine performance and construction implications in the UK.

Experience since 1997 suggests that the levelness specification gives required performance, with FM2 as the workhorse specification in much of the warehousing, industrial and retail property. Evidence from surveys suggests that skilled floor layers are generally achieving better standards of flatness than now prescribed in TR34, suggesting that the relaxation in Property II values of 1997 should be re-examined. From a practical viewpoint, it is known that power finishing in the hands of skilled operatives leads to a high standard of flatness, whereas power finishing has less effect on levelness. The Property II requirement for FM2 can be seen to be quite rough, leading to customer dissatisfaction in some cases.

Summary

The Free Movement measurement method and associated performance related values have given generally good service both in the UK and the US. The use of standard deviations should be considered so as to eliminate the problem of floors being deemed to fail because of a few measurements exceeding 'notional' 100% limits. It has been suggested that Property II values might be reappraised so as to bring them more into line with the Standards actually in common use and being achieved by experienced flooring contractors.

Concluding remarks

As European Standards are developed, the basic elements of the TR34 approach seem very practical. Some modifications have been proposed that would bring the additional advantage of compatibility with US methods and a related ASTM Standard that is in common use in many countries. ■

References:

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Superflat flooring, then and now

Permaban have been involved in the construction of superflat floors for high racking installations since the late 70s. In those early days the floor flatness tolerances specified were generally +/- 3mm in 3m but were very rarely measured; flooring contractors simply assumed that they had met the specified tolerances.

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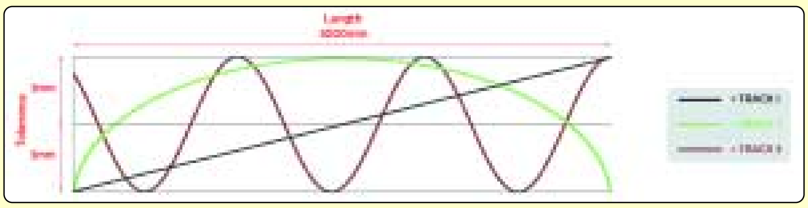
The introduction of the higher rise forklift truck and the VNA (very narrow aisle) truck reaching heights in excess of 12m meant that much greater attention to the flatness specification, its achievement and measurement was required. The traditional specification of +/- 3mm in 3m no longer had any validity due to the reasons shown in Figure 1.

Figure 1: Floor tolerance achievement tracks (FTATs).



Whilst all the floor tolerance achievement tracks (FTAT) shown in the graph comply with the +/- 3mm in 3m tolerance, the truck operating on a floor tolerance as Track 1 would work without a problem. Tracks 2 and 3 can be seen to get progressively worse and would present an increasing problem for the truck to operate successfully.

Methodology and equipment

In the early 80s Permaban examined the methods of constructing and achieving flat floors in the United States and Europe and from this investigation were responsible for introducing much of the methodology and equipment to construct superflat floors as shown below:

- Face Dipstick and Profileograph, 1983.
- Triscreed adjustable level screeding machines, 1983.
- Highway straight edge and adjustable oscillating cross straight edge.
- Permaban concrete and metal top 'leave in place' formwork.

Over the past 25 or so years the design and construction methods involved for superflat slabs have progressed significantly, partly due to the innovative range of products produced by Permaban. The changes that have taken place