Specification and Measurement of Floor Surface Regularity

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INTRODUCTION

A concrete floor is an important component of a warehouse, providing the finished surface that material handling equipment operates on. For this reason the surface profile of the floor needs to be carefully controlled to match the planned use of the warehouse. Warehouses with very high racking and/or very narrow aisles or wire guided equipment may require a much tighter control on surface regularity than a standard factory or wide aisle warehouse. If the required standards are not met, equipment may operate less efficiently and productively, and maintenance costs may increase.

Current New Zealand practice for the specification and measurement of floor surface regularity does not allow for accurate control of a floors surface profile. As such owners and occupiers can often not be certain of how a floor will perform until after it is in use – at which point any remediation is extremely difficult and expensive. Guidelines and specifications in the USA, UK and Europe offer practical solutions to control surface regularity. The adoption of one of these specifications as an alternative to current New Zealand practice would provide warehouse owners and occupiers the ability to specify floors based on operational performance requirements.

IMPORTANCE OF FLOOR SURFACE REGULARITY

The concrete floor in a warehouse provides the surface on which material handling equipment (MHE) operates. As such the surface regularity of the floor can impact on both equipment productivity [1-5] and safety [3-5]. To quote the first edition of the UK Concrete Society Technical Report (TR) 34:

> “Warehouses are designed to give throughput of a given number of pallets per hour. To achieve this, the trucks must operate at their peak performance. A warehouse manager, faced with numerous collisions between truck and racking, has no alternative but to reduce the speed of trucks to below their optimum and hence reduce the efficiency of warehouse operations.” [6]

Inappropriate surface regularity can also lead to increased maintenance costs for material handling equipment by increasing the stresses created in the vehicles mast and body [1, 5]. Other issues include increased driver fatigue [7], and the disruption of electronic sensor equipment in sophisticated wire guided MHE [1, 5], where a vehicle can sway outside of the range of its guidance wire.

The influence of floor surface regularity on MHE operation can be well illustrated by considering static lean - whereby any variation in floor level between MHE wheel tracks will be magnified at the top of the mast, proportional to its height. Figure 1 below, taken from the third edition of UK Concrete Society Technical Report (TR) 34, demonstrates this concept – a 2.5 mm difference in elevation across wheel tracks translates into a 20 mm eccentricity in the vehicle.

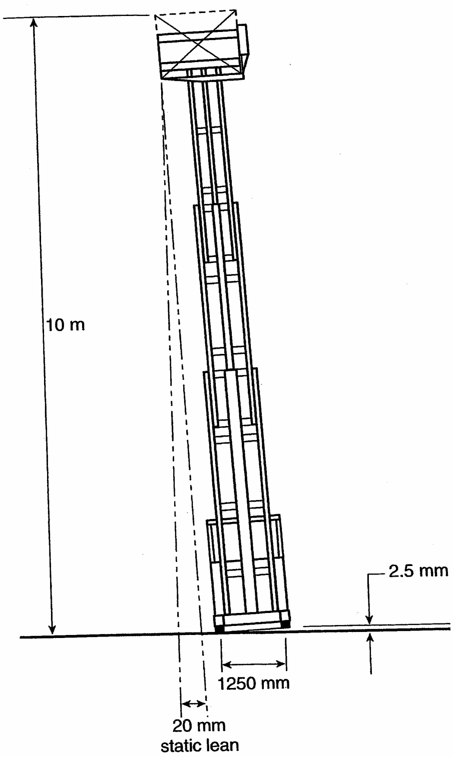

Figure 1 Static Lean, as illustrated in the Third Edition of UK Concrete Society TR 34 [1]

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This effect can be magnified by a factor of 3 - 4 by dynamic movements [1].

LIMITING SURFACE REGULARITY

The surface regularity of a concrete floor can be described in terms of the departures in elevation from a theoretically flat plane [1]. To successfully control surface regularity two properties of the floor should be limited – floor flatness, in order to limit the bumpiness of the floor and provide required MHE stability, and floor levelness to ensure the building and its racking as a whole function as required [1].
The concept of flatness and levelness are illustrated in Figure 2 below, taken from the third edition of UK Concrete Society Technical Report (TR) 34.

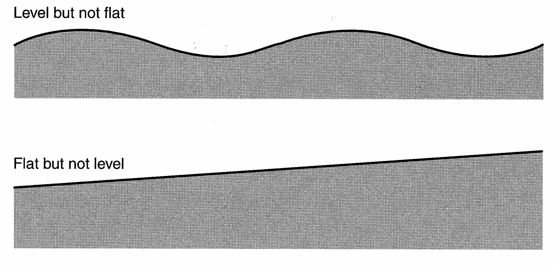

Figure 2 Flatness and Levelness from [1]

Flatness relates to measurements over short distances, traditionally of 300 mm [1, 8] and is a function of both difference in elevation and rate of change of elevation. Flatness is most influenced by straight edging and finishing techniques [9, 10].

Levelness relates to measurements over a longer distances, as well as measurements relative to the buildings datum [1, 8]. Traditionally these measurements have been taken over 3 m lengths [11]. Levelness is most influenced by the accuracy of form setting and strike off [9, 10].

DIFFERENT REQUIREMENTS FOR DIFFERENT OPERATING ENVIRONMENTS

Different MHE operating environments call for different standards of floor surface regularity. Typically floors should be divided into two distinct classifications for this purpose - free-movement traffic areas and defined movement traffic areas [1, 11, 12]. It should be noted that a single warehouse development could combine both free-movement and defined movement areas.

Free Movement Areas

In free-movement areas MHE can travel randomly in any direction [1, 11, 12]. Most warehouses and factories in New Zealand could be described as free movement floors. In warehousing applications, free movement floors typically have wide aisles racking, with MHE generally operating with loads at a low level. The risk of MHE colliding with storage at a high level as a result of an uneven floor is therefore low, so less control of surface regularity is required compared to a defined movement area[1].

Figure 3 A free movement area - MHE may move randomly in any direction

Defined Movement Areas

In defined movement areas MHE travel using fixed paths [1, 7, 12]. Defined Movement areas are normally only seen in specialists facilities, which incorporate high racking, very narrow aisles, and wire guided or man up type equipment.

Figure 4 A defined movement area, with wire guided, very narrow aisle MHE

Very few defined movement warehouses have been constructed in New Zealand. Between January 2005 and July 2007 specialist concrete flooring contractor Conslab Ltd constructed a total of two defined movement warehouses, both of which were constructed in Auckland. Anecdotally these were the only defined movement floors constructed during this period.

This matches the experience of contractor's in the USA, where fewer than 1% of floors constructed are classified as defined movement floors, although the popularity of defined movement floors is reported to be growing [10, 12]

THE COST OF FLATNESS

Put simply, the flatter a floor has to be, the more it will cost [1, 9]. Better control of surface regularity generally requires increased labour costs to allow more accurate setting of formwork and superior placing and finishing techniques. Situations that require very accurate control of surface regularity, such as in defined movement floors for high VNA racking, may require the use of long strip construction techniques in conjunction with Laser Screed or vibrating truss screed technology.

Figure 5 Technology such as Somero Laser guided screeds, can be used to increase control of surface regularity

CURRENT NEW ZEALAND PRACTICE

A typical warehouse specification in New Zealand calls for the surface regularity of the floor to be controlled by NZS 3109 "Concrete Construction" [13] and NZS 3114 "Specification for Concrete Surface Finishes" [14]. NZS 3109 provides tolerances to ensure that structural performance is not compromised, and does not touch on the serviceability/performance of the floor [13, 15].

NZS 3114 provides surface regularity tolerances for 11 different surface finish classes named U1 – U11. The tolerances are based on the use of 3 m long straight edge to measure the difference in elevation between any two points within its length. These values are called "gradual variations" and are limited to a maximum value given for each class of finish and its end use. Figure 6 below, taken from NZS 3114, demonstrates the definition of a "gradual variation".

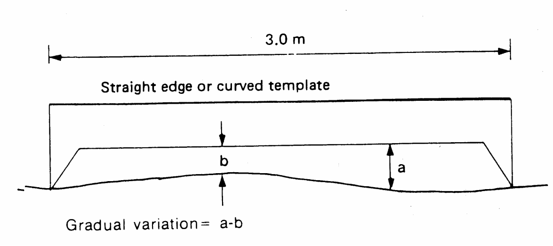

Figure 6 Gradual Variations, as measure using a 3 m straight edge. Reproduced from NZS 3114 [14].

In addition to "gradual variations", NZS 3114 provides limits for "abrupt variations" which are measured as the elevation difference between any two points within a 200 mm length. This is illustrated in Figure 7, taken from NZS 3114.

It is suggested that "abrupt variations" could typically occur at construction joints [14].

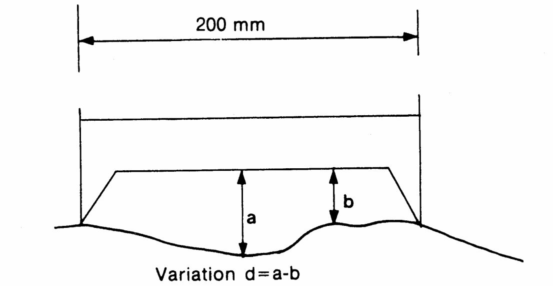

Figure 7 Abrupt Variations, reproduced from NZS 3114 [14].

The U3 "Trowelled" finish is the most specified finish class for warehouse floors. The tolerances provided for this class are:

- Gradual variations limited to a maximum of 5 mm.
- Abrupt variations limited to a maximum of 3 mm.

Often Engineers will specify above these limits, modifying them to: gradual variations limited to a maximum of 3 mm with no abrupt variations. Although this will often represent a deliberate attempt to increase the control of surface regularity of the floor, anecdotally there is a misconception amongst some parties that these figures represent the tolerances provided for a U3 finish by NZS 3114.

Deficiencies with current practice

There are many deficiencies inherent to the "straight edge" method of testing required by NZS 3114 [16, 17]. Specifically:

- It is not practical to measure large areas of floor.
- It is difficult to randomly measure a floor.
- It is difficult to reproduce test results.
- The method does not predict the acceptability of roughness or inconsistencies in a floor. It only measures the amplitude of irregularities, but the frequency of irregularities also influences MHE performance.
- The method does not measure the levelness of a floor over its entire length, or against the datum, only the difference in elevation between points within the 3 m length.

Lack of Testing and Non-Conformance

Because of the impracticality of measuring floors using the straight edge methodology prescribed by NZS 3114 floors in New Zealand are seldom tested for conformance to specification. It is worth noting that this experienced was mirrored in the UK and the USA prior to the development of more sophisticated measurement techniques [17, 18].

While the lack of conformance testing makes specifications meaningless, it has also developed the misconception that the "5 mm within a 3 m straight edge" is an easily achieved specification – the standard New Zealand floor.

Figure 8 The typical NZ floor specification, based on NZS 3114, is often not achievable using wide bay construction techniques

In reality this specification is often not achievable using normal wide bay floor construction methods [16, 17], that involve free screeding, and it would be difficult to find a significant number of floors in New Zealand that actually conform to this standard.

The myth of the "5 mm in 3 m floor" is perpetuated by placing and finishing contractors who do not carry out regular measurements of their own floors and are unaware of how well they really perform. Contractors also understand that the specification won't be tested unless control of floor surface regularity is particularly bad. An example of this would be when the cost of installing racking increases dramatically to cater for the poor levelness of a floor.

Figure 9 Currently the surface profile of most warehouse floors in New Zealand is not tested unless there is a problem encountered during racking installation

Clearly the current New Zealand practice of specifying floors to NZS 3114 standards, does not allow for accurate control of a floors surface profile. As has been demonstrated, "straight edge" methods are inherently flawed, and enforcing NZS 3114 type specifications would be difficult and impractical. Thankfully guidelines in the UK and USA provide practical alternatives for specifying floor surface regularity.

ALTERNATIVES TO STRAIGHT EDGE MEASUREMENT

FREE MOVEMENT FLOORS

Current standards in the UK and USA provide practical alternatives to straight edge methods for specifying and measuring free-movement floors [11]. These standards are based on the measurement of relative differences in elevation over prescribed distances [1, 11, 19, 20] to assess both the "flatness" and "levelness" characteristics of the floor.

Elevational difference techniques were introduced in the USA as early as 1976, and represented a great step forward for flooring, for the first time providing a practical method for assessing the surface regularity of large floors [11].This is achieved through:

- The use of semi - continuous rolling measurement devices, such as the "F-Meter" pictured in figure 10 below, which allow a high frequency of elevation measurements to be taken relatively quickly.
- A statistical approach to measuring the surface regularity of the floor, which allows a representative sample of measurements to be taken.

Figure 10 A "F meter" device rolls along the floor taking semi-continuous measurements of elevation.

F Number System for Free Movement Specifications

In the USA ACI 302 [20] and ACI 117 [19] prescribe a method for the evaluation of free-movement floors that is commonly referred to as the "F number system". The test method is described by ASTM E 1155M "Standard Test Method for Determining F_F Flatness and F_L Levelness Numbers [Metric]" [8]. Elevational difference data is collected at successive 300 mm (for flatness) and 3 m (for levelness) points. Guidelines as to the minimum number of measurements required to assess a given size floor are provided. For areas of over 150 m^2 the number of points to be measured should be the floor area divided by 10.

Measurements should be made within 72 hours of concrete being finished to mitigate the detrimental effect slab curl has on F_L numbers [8, 17]. F_F numbers are not significantly affected by curling or deflection, so there is no time limit on the measurement of this characteristic [17].

Measurements should not be taken across construction joints as these represent discontinuities in the slab and would introduce statistical anomalies into the test method[8]. It is proposed that a separate specification is provided for the maximum allowable curvature between points 600 mm apart, transverse to and centred on joints that will be trafficked [8]. This should be taken at maximum 3 m intervals along the joint.

The system uses a simple statistical analysis of the data based on the assumption that it is normally distributed [8]. The standard deviation of the curvature measured between the 300 mm and 3 m intervals are converted using an inverse constant, to provide dimensionless "F Numbers". The greater the F_F and F_L numbers the better the regularity of the floor surface – with lower variance from a flat plane. F-number specifications are only suitable for free movement type floors.

Specifying F-Numbers

Several authors have provided guidelines as to the f-numbers that should be specified given different floor end uses [9, 15, 21], and ACI 302.1R provides guidelines as to the placing and finishing techniques required to achieve various F-number specifications [20]. Best practice is to work with the floors end users in establishing the F_F and F_L tolerances of similar successful existing projects with [17], and to gather data from the proposed flooring contractor to establish whether they have the ability to achieve the numbers specified.

A floor should be specified with two different sets of f-numbers – overall and local f-numbers [17, 21, 22]. The specified overall value is the desired value for the floor as a whole – the value that is obtained when individual test sections/pours are combined. The local f-numbers represent the minimum standard of surface regularity that is acceptable for any one section of the floor. This could typically represent an individual pour.

Table 1 below, based on [15] provides F_F and tolerances typically specified in the USA.

Table 1 Typical Specified F-numbers, adapted from [15]

Floor profile category	Overall Specified numbers		Minimum local numbers	
	F_F	**F_L**	**F_F**	**F_L**
Offices				
Carpeted	19	13	13	10
Vinyl	25	17	13	10
Warehouse/Factory				
Conventional	38	25	19	13
Flat	50	33	25	17
Very Flat	75	50	38	25
"Superflat"	100	66	50	33

Realistically very few random traffic floors should be specified with values above the "very flat" (F_F

75 and F_L 50) category in table 1 above [23]. Some possible exceptions to this rule would be floors for television studios [10], gymnasiums and floors that will later be converted to defined movement floors.

Based on the experience of the Authors, floors that conform with the “Flat” specification of F_F 50 and F_L 33 perform very well for most logistics type warehouses in New Zealand, with racking heights of up to approximately 8 m, although lower numbers may be suitable for more general low level warehousing.

Specifications of F_F 50 and F_L 33 or above are typically only achievable by experienced flooring contractor’s who either employ Laser Screed technology or reduce individual pour size to approximately 1000 m^2. This is consistent with experiences in the USA where authors have previously stated that achieving these F-numbers wouldn’t be possible for most contractors unless forms were kept to less than 20 feet to 50 feet apart [9, 21].

This would increase the cost of the floor compared to producing a floor with less stringent tolerances.

F-Number’s Compared to NZ Straight Edge Specification

There is no direct correlation between the F-number system and the straight edge type measurements typically specified in NZ [15, 17], however it is possible to draw a rough correlation between the two systems, reproduced from [17] in Table 2 below.

F_F Number	Maximum gap under 3 m straight edge
F_F 12	12.7 mm
F_F 20	7.94 mm
F_F 25	6.35 mm
F_F 32	4.76 mm
F_F 50	3.18 mm

It would therefore stand that an F_F value of approximately 30 would roughly equate to the typical NZ specification that allows a maximum of 5 mm elevation differences between two points under a 3 m straight edge.

It should be stressed that this is a only a rough correlation, particularly because the straight edge value only measures the amplitude of any deviations, whereas the F_F value takes into account the frequency of deviations. A “Straight edge” measurement cannot differentiate between a floor which has one deviation per metre or three deviations per metre if the amplitude of the deviations are the same.

Current Use in New Zealand

Currently there are three proprietary f-number measuring devices operating within New Zealand, all of which are owned by concrete flooring contractors. It follows that the devices are primarily used for internal quality assurance and the development of placing and finishing techniques – although at least one local engineering consultancy specifies using F-number guidelines similar to those presented in Table 1.

Although it is not necessary to use proprietary devices to measure floors to an f-number specification, it is not practical to undertake the measurement without such a device due to the large number of elevation measurements that must be made.

Alternative “Waviness Index” Method for Free Movement Floors

An alternative to the F-number method of measuring floor surface regularity is described by ASTM E 1486 – 94 "Standard Test Method for Determining Floor Tolerances Using Waviness, Wheel Path and Levelness Criteria" [24]. The standard was developed after a review of the F-number system determined that the standard did not provide responsive results for irregularities with wavelengths of between 4 and 15 feet [25, 26]. The “Waviness Index” measures bumps and dips in the floors surfaces as the average deviation from the mid point of 2, 4, 6, 8 and 10 foot chords [25]. The deviations are averaged and combined to produce an index number.

UK TR34 Free Movement Specifications

The UK Concrete Society Technical Report (TR) 34: Concrete industrial ground floors – A guide to design and construction [1] provides guidelines on specifying and measuring surface regularity for free movement floors. Surface regularity is controlled by two properties – property II to control flatness, and property IV to control levelness. Additionally, no point on the floor should deviate by more than 15 mm from datum [1, 11].

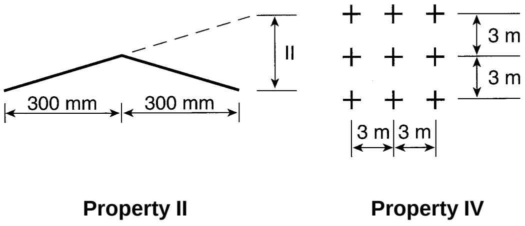

Figure 11 TR34 properties II and IV [1]

Property II is typically measured using a semi-continuous device, in a similar manner to F-numbers. Property IV is measured by setting out a grid of 3 by 3 m points on a floor and using an accurate level and staff [11].

Figure 12 Accurate level and Invar staff are used to measure TR34 property IV

TR34 provides limiting values for properties II and IV based on 95% and 100% data sets [1]. The 100% limit is nominally 50% greater than the 95% limit reflecting an assumption that the data will be normally distributed [11]. Measurements are reported as actual variance from a theoretical flat plain, in mm, as opposed to the f-number system which uses an inverse constant to create dimensionless numbers. As such, a floor displaying better surface regularity characteristics will have lower values for properties II and IV than a floor displaying worse characteristics. The validity of using a 100% limit has been questioned, as this is not the typical way statistical methods are applied to sample data sets in building [11], where characteristic 95 percentile values are used.

Specifying TR34 Free Movement Properties

TR34 provides performance limits for different categories of floor. This are reproduced in Table 2 on page 10 [1]. Category FM2 is defined as the “workhorse specification” seen in much of the warehousing in the UK, and is considered to perform adequately [11]. It should be noted that evidence from floor surveys suggests that skilled flooring contractors in the UK are able to achieve better standards of flatness (Property II) than defined for the given levelness (Property IV) in TR34, and FM2 flatness requirements can be seen as “quite rough” [11], sometimes leading to customer dissatisfaction.

When compared to the F-number specifications described early, the TR34 categories give relaxed standards of flatness compared to equivalent levelness standards. It is noted that an experienced floor contractor in the UK will produce floors with much higher standards of flatness than are typically required by the Property II limits [11]. This experience is correlated by Conslab in New Zealand, where consistently good flatness results have been achieved on floors even when they have low levelness qualities. There have been some calls in the UK for Property II limits to be reappraised and brought into line with equivalent f-number specifications in the USA.[11] This would also bring them into line with values currently being achieved on site.

DEFINED MOVEMENT FLOORS

Defined movement floors, where MHE travel along a singled fixed path, require tighter control of floor surface regularity than free-movement floors, and require different surveying methods be employed [1]. There is no specific guidance for the control of surface regularity for defined movement floors in New Zealand standards. Internationally there are three recognized defined movement floor specification/measurement systems, all of which are based on the measurement of elevation on and across actual MHE wheel paths.

The guidelines are the F_{min} system [10, 12], utilized in the USA, TR34 guidelines utilized in the UK [1, 7, 27], and DIN 15185-1 [28], a German national standard that is used primarily in continental Europe [5]. These guidelines require the wheel path of the MHE to be measured for every aisle on the floor [27]. This contrasts with the measurement of free-movement floors, where only a sample of the floor is tested. Clearly a defined movement specification cannot be used unless aisle locations are known prior to the floor being constructed. If this is not possible it may be necessary to produce a floor with very tight free movement tolerances, and then undertake grinding to achieve the desired result in aisles once there location is known. Typically measurements for defined movement floors are taken using a device called a profileograph [27]. A profileograph is a proprietary device that can be described as “self propelled level sensing instrument” [27].

Figure 13 Face consultants Profileograph is used to take measurements along actual MHW wheel tracks. Photograph courtesy of Face Consultants Ltd.

Figure 13 demonstrates a profileograph in use; note that it has been specifically set up to simulate the wheel configuration of the MHE equipment to be used in the warehouse.

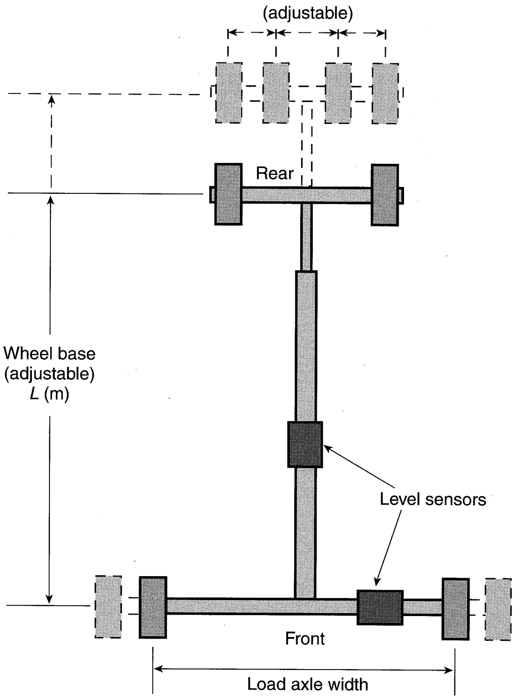

Figure 14 Schematic of a Profileograph measuring device, from [1]

Profileographs typically take measurements at 50 mm intervals, thereby effectively providing data for 100% of measurable points along a path [27].

It should be noted that there are currently no profileographs immediately available for use in New Zealand, although it would be possible to arrange profileograph surveying of a floor given sufficient notice. It is not considered practical to carry out a defined movement floor survey without a profileograph, due to the large number of measurements that would need to be taken.

F_{Min} Guidelines in the USA

The F_{Min} system, utilized for measurement of defined movement floor surface regularity in the USA, is a proprietary system not yet recognized by the ACI or ASTM [10]. It is reported that VNA forklift manufacturers require floors to conform with specifications that incorporate the system for warranty purposes [10]. The system is based on the use of a profileograph device to measure the levelness (elevation difference) between the vehicles longitudinal and transverse wheel tracks [10, 12]. Longitudinally the elevation is measured between the front and back wheels. Transversely the difference is taken between across aisle wheel tracks. The flatness of the longitudinal wheel tracks is also measured [10].

When using the system to specify floor surface regularity a limiting F_{Min} number is given. The number typically specified is F_{Min} 100 [12]. This corresponds to a flatness tolerance of 1/8 inch (3.175 mm) difference in elevation every 10 Feet (3.05 m) [12]. This is adjusted to suit the actual dimensions of the MHE, so for a VNA forklift with front and rear wheel tracks 5 Feet apart, F_{Min} 100 would equate to a tolerance of 1/16 inch (1.59 mm) across the front and rear wheel tracks at any point along an aisle.

The F_{Min} 100 value forms the baseline for other F_{Min} values, and a higher F_{Min} number represents a flatter floor [12]. An F_{Min} value of 50, which would typically be the lowest seen, would represent 1/4 inch (6.35 mm) in 10 Feet, or 1/8 inch in 5 feet [12]. As the F_{Min} number is a limiting value, the floor will fail to meet specification if a single value, in a single aisle, falls outside the limit.

TR34 Guidelines for Defined Movement Floors

The UK Concrete Society Technical Report (TR) 34: Concrete industrial ground floors – A guide to design and construction [1] provides two different sets of guidelines for specifying and measuring the surface regularity of a defined movement floor. The first set of guidelines is based on the measurement of the “front” load carrying wheel track only.

The flatness and levelness along the track are measured, in conjunction with the elevation difference between the wheel track [1]. Both 95% and 100% limiting values are given for each of values measured. Limits are provided for three categories of floor, dependent on the lift height of MHE [1]. Limits represent the actual measurements taken from the floor, so lower values represent tighter tolerances.

The “load wheel” only guidelines have been criticised for not accounting for any difference in elevation between the front and rear set of wheels on MHE [1, 7]. As such a second set of guidelines that take into account front to rear wheel measurements were included in Appendix C of the 2003 edition of TR34 [1]. These guidelines measure the difference in elevation and rate of change of elevation both along and across wheel tracks. The guidelines fall reasonably closely in line with the F_{Min} system utilized in the USA, and it is believed that they produce a better result for warehouse occupiers than the “load wheel” only guidelines [1, 7, 27].

The of measurement of defined movement floors described in TR34 require that measurements continue across joints that run transverse to the aisle [1].

DIN 15185-1

The German national standard DIN 15185-1 “Warehouse systems with guided industrial trucks; requirements on the ground, the warehouse and other requirements” [28] provide maximum permissible limits for the difference in elevation across the wheel tracks of MHE. These are prescribed based on the width of the track and – with wider tracks allowing higher elevation differences [28]. Separate values are also given dependent on whether truck lift height is greater or less than 6 m.

The differences in elevation along the wheel tracks are controlled by the same limits regardless of the MHE employed. The elevation difference at distances 1, 2, 3 and 4 m along the track are measured, and cannot exceed 2, 3, 4 or 5 mm respectively [28].The DIN 15185-1 standard is the preferred method of for specifying and measuring defined movement floors for at least one locally available VNA truck manufacturer [5], and as such has been specified for the construction of a defined movement floor in New Zealand.

REMEDIATION OF OUT OF TOLERANCE FLOORS

The appropriate action to take when a floor is measured and found to be out of tolerance is largely dependent on whether a floor is a free or defined movement area. Decisions about how a floor may be remedied if it fails to achieve specification should be made prior to construction [17].

Free-movement areas

Because MHE can move on an almost infinite number of wheel paths in a free movement area it can be difficult to “correct” an out of tolerance floor by grinding, planning or through surface repair [23]. It is also prohibitively expensive to remove and replace a floor that fails to achieve specification.

As such it is suggested that a pragmatic approach is taken when a free-movement floor has failed to meet specification – for instance a small number of out of specification areas on a floor are unlikely to significantly impact the floors productivity.

Equally, a poor result using the F-number and TR34 guidelines discussed herein could be caused by several “rogue” values that may not have a great influence on the floors performance [11] (for instance they could occur under racking), or may be rectifiable with grinding.

The F-number system provides a mechanism for calculating the percentage of a floor that failed to achieve specification [17], and this is often used in the USA as a basis for proportionally reducing the payment a contractor will receive [22, 23]. As an example, if 5% of the floor failed to achieve specification, the contractor would likely be paid the full sum tendered for the floor. However if a greater percentage of the floor failed to achieve specification, for instance 15%, then the payment the contractor received would be adjusted accordingly. Although this does not necessarily provide owners and occupiers with a floor that meets their performance requirements, it does provide a serious incentive for the flooring contractor to meet specification, something that is currently sorely lacking in New Zealand.

Defined Movement areas

Defined movement floors that are constructed out of specification can be remedied through grinding along the wheel tracks of MHE [29]. It is suggested that laser guided grinding is the best method of bringing a defined movement floor into specification [29], as it is exceedingly difficult to effectively grind a wheel track to the necessary level of accuracy manually. Some defined movement floors are constructed with the intention of being ground into specification; however this will not necessarily give the client the best result. In particular grinding a floor removes the dense top surface, reducing the abrasion resistance. Grinding also impacts negatively on the appearance of the floor.

Figure 15 Laser Grinding equipment for defined movement floors, from www.superflatasia.com

Table 2 Free movement floor categories from [1]

TR34 Classification	Typical Use	Property II limit (mm)		Property IV limit (mm)	
		95%	100%	95%	100%
FM1	Where very high standards of flatness and levelness are required.	2.5	4.0	4.5	7.0
FM2 (Special)	Floors that will be later converted to defined movement flatness*	3.0	4.5	6.5	10.0
FM2	Buildings containing wide aisle racking with stacking or racking over 8 m high, free movement areas and transfer areas	3.5	5.5	8.0	12.0
FM3	Buildings containing wide aisle racking with stacking or racking up to 8 m high. Retail and manufacturing facilities	5.0	7.5	10.0	15.0

CONCLUSIONS

The surface profile of a concrete floor can have a significant impact on the productivity of a warehouse. As such it is important that floors are specified using system and tolerances that ensure the floor will be appropriate for its end use. It is also important that floors are measured to determine whether they achieve specification, and that some form of remediation is planned in advance for situations where specifications are not achieved.

Clearly typical New Zealand practice, of using the “straight edge” based tolerances provided in NZS 3114, is not suitable for accurate control of floor surface regularity.

For free-movement floors the current NZ specifications could be replaced by the ACI/ASTM F-number system or the guidelines provided in the Concrete Society publication TR34 (2003). Defined movement floors could be specified using the F_{Min} system found in the USA, the guidelines in Appendix C of TR34 (2003) or using the German national standard DIN 15185-1, although it should be noted that defined movement floors are still relatively rare in New Zealand.

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