



FACE CONSULTANTS LTD
Global Flooring Consultants

FACE CONSULTANTS LIMITED

ACI Fmin

PROFILEOGRAPH SURVEYS

Further explanatory information



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Why Flatness is Important:

Flatness is an essential requirement of a ground floor slab in certain categories of industry. Undoubtedly, the most important of these categories is that of very narrow aisles in high warehouses where fixed path 'VNA' forklift trucks operate.

The static lean table (overleaf) indicates how the variations in level across the aisle between the load wheel tracks of the truck are magnified in direct proportion to the height of the racking. However, one can readily appreciate that this value, calculated directly from geometrical considerations, forms only part of the potential movement at the top of the mast of the truck.

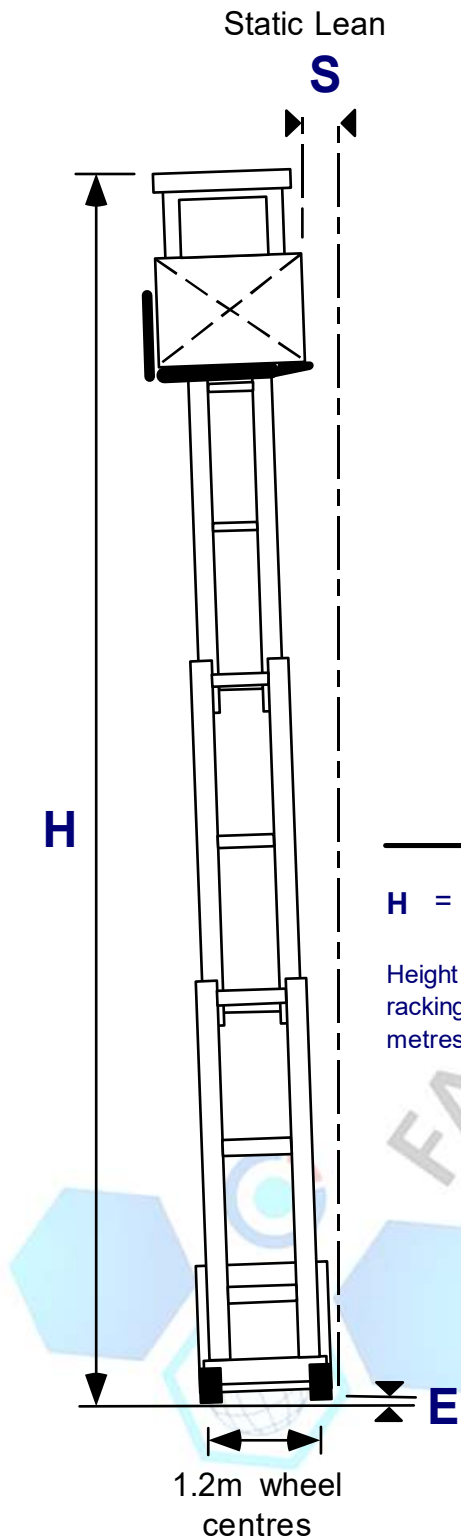
Variations in level, both Transversely across the aisle and Longitudinally down the aisle, induce dynamic flexing movements in the mast which are much greater in magnitude than can be calculated from geometrical considerations alone. The stresses which are set up within both the mast and body sections of the truck can cause premature failure of welds and disrupt the performance of the electronic components that are now an essential feature of all trucks.

Floors with poor flatness characteristics also create conditions whereby there is a high risk of collision between the load on the carrying head of the truck and the stock or racking. As the majority of such collisions cause no serious human injury, there are no statistics recording the frequency of these incidents. It is, however, well known that they are quite numerous in all countries where there are high density warehouses working with typical clearances between the truck mounted load and the racked loads in the order of 100 and 150mm. These clearances are directly related to the floor flatness. If the value of this clearance is limited to 100mm then the requirements to construct the floor to a high standard of flatness becomes even more important.

Warehouses are designed to have a throughput of a given number of pallets per hour. To achieve this, the VNA trucks must operate at their optimum performance at all times. A warehouse manager faced with numerous collisions between the truck and the racking and long periods of down-time during repair has no alternative but to reduce the speed of the VNA trucks to below their optimum speed: this reduces the efficiency of his warehouse operations.



Static Lean Table:



This table shows the relationship between the static lean of a forklift truck due to the difference in elevation between the left and right hand forklift truck load wheels and the height of the racking, assuming that the mast is a rigid structure.

However, due to the mechanical tolerances in the mast and the dynamic considerations when the truck is moving with a load at a height, the figure shown below could **multiply by up to a factor of three.**

This particular set of figures is based on a typical wheel spacing of 1200mm from centre to centre of the outer load wheels.

H = Height of racking in metres	E (mm) =									
	3	4	5	6	7	8	9	10	11	12
6	15	20	25	30	35	40	45	50	55	60
6.5	16	22	27	33	38	43	49	54	60	65
7	18	23	29	35	41	47	53	58	64	70
7.5	19	25	31	38	44	50	56	63	69	75
8	20	27	33	40	47	53	60	67	73	80
8.5	21	28	35	43	50	57	64	71	78	85
9	23	30	38	45	53	60	68	75	83	90
9.5	24	32	40	48	55	63	71	79	87	95
10	25	33	42	50	58	67	75	83	92	100
10.5	26	35	44	53	61	70	79	88	96	105
11	28	37	46	55	64	73	83	92	101	110
11.5	29	38	48	58	67	77	86	96	105	115
12	30	40	50	60	70	80	90	100	110	120
12.5	31	42	52	63	73	83	94	104	115	125
13	33	43	54	65	76	87	98	108	119	130

The difference in elevation between left and right hand VNA truck wheels

The Specification: ACI F-MIN NUMBER SYSTEM

In America, and areas of American influence, surface profiles are controlled differently on floors that have defined traffic patterns compared to free movement floors. The most practical way to measure a defined traffic floor is by making continuous Profileograph measurements of each path. Such direct measurement will usually involve point separations other than 300mm or 3000mm. FF and FL cannot be used since they are random measurements across the entire slab. There is a great probability that significant floor defects in the wheel path will be missed; furthermore, if one did measure each individual wheel paths with a random traffic measuring device the results are an average at best and F-min cannot be averaged. Therefore, there is no direct correlation between FF/FL and F-min. The FF/FL and F-min systems are completely different measuring systems and there is no corresponding index for comparison purposes. A single F-number "F-min" is therefore used to define the worst acceptable flatness and levelness conditions in a VNA aisle, and this F-min value is assigned based on the expected lift truck and rack height as in Table 1.1 overleaf.

The following equations translate F-min into specific dimensional restrictions:

$$dL \text{ max} = \frac{(6.55\sqrt{L+61})-48.3}{F_{\text{min}}} \quad L \geq 300\text{mm}$$

$$EL = \text{max} = \frac{(4.5 \times 10^6) + (2790L) - L^2}{64,500F_{\text{min}}} \quad \text{when } 300\text{mm} \leq L \leq 1400\text{mm}$$

$$\text{If } L > 1400\text{mm} \text{ then } EL \text{ max} = \frac{100}{F_{\text{min}}}$$

Where:

dL = maximum difference in elevation measured over gauge length L, in mm.

EL max = maximum change in dL for each 300mm of travel across the floor.

L = the horizontal distance over which the measurements are to be made (normally the wheelbase and the load wheel track of the forklift truck), in mm.

F min = the face floor profile number for defined traffic surfaces (dimensionless).

The table below, and Table 1.1 taken from ACI 360R-10, "Guide to Design of Slabs-On-Ground" give the F-min number based on Classification and Height of racking.

dL and EL max limits are calculated for both Transverse and Longitudinal components, by using the equations above and inputting the transverse and longitudinal axle separations of the forklift truck, as well as the Fmin number assigned to the floor.

Classification	F-min number
Conventional floor	25
Good	38
Flat	50
Very flat	75
Superflat	100

Table 1.1 - Defined Traffic Values

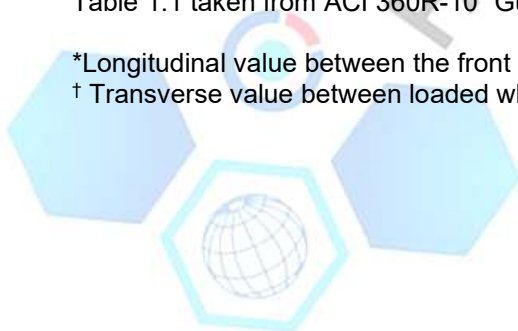
This table shows the recommended F-min values for varying rack heights.

Rack height, ft (m)	Longitudinal* F-min	Transverse† F-min
0 to 25 (0 to 7.6)	50	60
26 to 30 (7.9 to 9.1)	55	65
31 to 35 (9.4 to 10.7)	60	70
36 to 40 (11 to 12.2)	65	75
41 to 45 (12.5 to 13.7)	70	80
46 to 50 (14 to 15.2)	75	85
51 to 65 (15.5 to 19.8)	90	100
66 to 90 (20.1 to 27.4)	100	125

Table 1.1 taken from ACI 360R-10 "Guide to Design of Slabs-On-Ground"

*Longitudinal value between the front and rear axle

† Transverse value between loaded wheel tracks



Test Instruments:

It is recommended that a continuous method of measurement should be adopted in all cases of defined traffic movement.

For continuous measurement the Face Profileograph is used. The Profileograph is a self propelled wheeled instrument which travels across the floor it taking continuous measurements both Transversely and Longitudinally.

These readings are generated by the tilt sensors, which are set up to measure the Longitudinal and Transverse properties of the specification. These readings are collected on a data logger and subsequently downloaded to a PC where Face Consultants' specialised software generates the graphic traces and compliance results.

The Profileograph is set up to measure 4 different properties :

- Property A:** Transverse elevational difference unit value – mm per m of front axle length. **(dl Transverse)**
- Property B:** Transverse rate of change for each 300mm of forward travel. **(EI Transverse)**
- Property C:** Longitudinal elevational difference unit value – mm per m of front to rear axle length. **(dl Longitudinal)**
- Property D:** Longitudinal change in elevational difference for each 300mm of forward travel. **(EI Longitudinal)**

This is achieved by running the Profileograph along the aisle in the wheel tracks of the VNA forklift truck. Each wheel of the Profileograph runs along the centre line of one of the MHE wheel tracks – one for the left, one for the right and two for the rear wheels (configurable for MHE with three or four wheels and to any MHE vehicle footprint) – simultaneously measuring all four properties of the specification in a single operation.



Properties A and B refer to the Transverse tolerances, i.e. differences in elevation of the aisle between the two front load wheels of the MHE.

Property **A** is the maximum difference in elevation of the aisle between the two front wheels of the MHE. This limit is calculated using :

$$dL \text{ max} = \frac{(6.55\sqrt{L+61})-48.3}{F_{\min}} \quad L \geq 300\text{mm}$$

Where:

L is the Transverse load axle length in mm
 F_{min} is the Transverse F-min value taken from Table 1.1, according to the racking height to be installed.

This is represented by a Transverse graphic trace that varies with position along the floor. Where the graphic trace is above the centreline the left side of the aisle is higher by the amount shown and where the graphic trace is below the centreline the right side of the aisle is higher by the amount shown. The red shading indicates where it exceeds the 100% limit (none of the aisle must exceed this limit).

Property **B** is the Transverse rate in change of elevation of the aisle between the two front wheels of the MHE for each 300mm travelled. This limit is calculated using:

$$EL_{\max} = \frac{(4.5 \cdot 10^6) + (2790L) - L^2}{64,500F_{\min}} \quad \text{when } 300\text{mm} \leq L \leq 1400\text{mm}$$

$$\text{If } L > 1400\text{mm then } EL \text{ max} = \frac{100}{F_{\min}}$$

Where:

L is the Transverse load axle length in mm
 F_{min} is the Transverse F-min value taken from Table 1.1, according to the racking height to be installed.

This is represented by a coloured bar above the Transverse graphic trace. Where the bar is shaded red, this indicates where the rate in change exceeds the 100% limit (none of the aisle must exceed this limit).

Properties C and D refer to the Longitudinal tolerances, i.e. differences in elevation of the aisle between the front and rear axles of the MHE.

Property **C** is the elevational difference between the front and rear axles of the MHE. This, again is calculated using:

$$dL \text{ max} = \frac{(6.55\sqrt{L+61})-48.3}{F_{\text{min}}} \quad L \geq 300\text{mm}$$

Where:

L is the Longitudinal axle length in mm

F_{min} is the Longitudinal F-min value taken from Table 1.1, according to the racking height to be installed.

This is represented by a Longitudinal graphic trace that varies with position along the floor. Where the graphic trace is above the centreline the front of the profileograph is higher than the rear by the amount shown (the floor is running uphill) and where the graphic trace is below the centreline the front of the profileograph is lower than the rear by the amount shown (the floor is running downhill). The Red shading indicates the graph exceeds the 100% limit (none of the aisle must exceed this limit).

Property **D** is the Longitudinal rate in change of elevational difference between the front and rear axles of the MHE for each 300mm travelled.

This, again is calculated using:

$$EL = \text{max} = \frac{(4.5 \cdot 10^6) + (2790L) - L^2}{64,500 F_{\text{min}}} \quad \text{when } 300\text{mm} \leq L \leq 1400\text{mm}$$

$$\text{If } L > 1400\text{mm then } EL \text{ max} = \frac{100}{F_{\text{min}}}$$

Where:

L is the Longitudinal axle length in mm

F_{min} is the Longitudinal F-min value taken from Table 1.1, according to the racking height to be installed.

This is represented by a coloured bar above the Longitudinal graphic trace. Where the bar is shaded red, the rate in change exceeds the 100% limit (none of the aisle must exceed this limit).

Understanding the Profileograph Traces:

After downloading the data, Face Consultants' specialised software produces two differential traces for each survey run.

- a) One graph showing the floor compared to Properties A and B, i.e. the two Transverse aspects of the specification.
- b) One graph showing the floor compared to Properties C and D, i.e. the two Longitudinal aspects of the specification.

The Graphic traces are read in the direction of travel of the Profileograph, which is from left to right.

The vertical scale of the graph is in millimetres and each line represents 1mm. The horizontal scale is in metres and each line represents 300mm of travel along the aisle.

A zero line is set along the length of both the Transverse and Longitudinal graphs. The zero line corresponds to a perfectly flat and level floor.



Transverse Properties A and B:

Property A: Red coloured section of graph indicates that the elevational difference between the left and right wheel tracks is too great – 4.0mm at this point – so that the aisle is exceeding the 100% limit.

Property B: Red coloured section of top bar indicates that the elevational difference between the left and right wheel tracks is changing too quickly so that the aisle is exceeding the 100% limit at this point.



Property A: When the graph deviates from the zero line it shows that there is a difference in elevation between the left and right wheel tracks of the amount indicated by the scale. If the graph is above the zero line then the left side of the aisle is at a higher elevation than the right, and if the graph is below the line then the right side of the aisle is at a higher elevation than the left. When a section of the aisle exceeds the 100% limit then the corresponding section of the graph will be coloured red rather than green.

Property B: When the difference in elevation between the left and right wheel tracks changes by an amount that exceeds the 100% limit over a distance of 300mm the bar at the top of the graph will turn red.

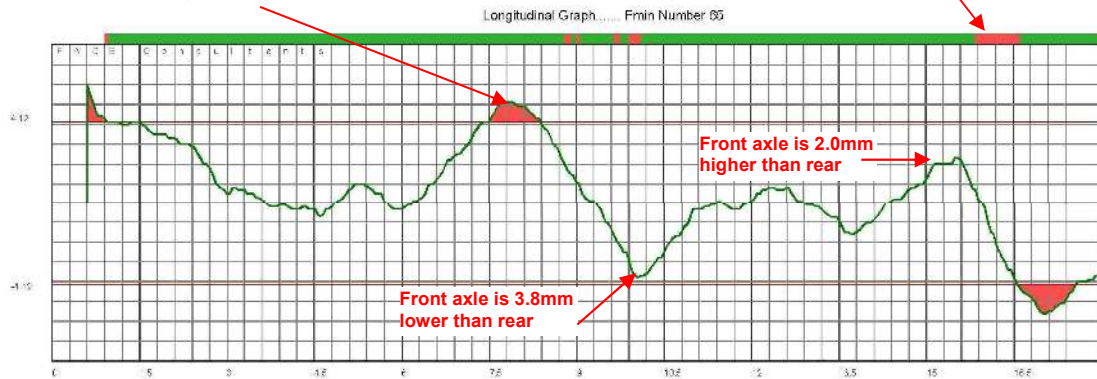
If any section of the graph or any section of the bar above the graph is coloured red then that aisle fails to comply with the specification.



Longitudinal Properties C and D:

Property C: Red coloured section of graph indicates that the elevational difference between the front and rear axle is too great – 5.1 mm at this point - so that the aisle is exceeding the 100% limit.

Property D: Red coloured section of top bar indicates that the elevational difference between the front and rear axle is changing too quickly so that the aisle is exceeding the 100% limit at this point.



Property C: When the graph deviates from the zero line it shows that there is a difference in elevation between the front and rear axles of the amount indicated by the scale. If the graph is above the zero line then the front axle is at a higher elevation than the rear, and if the graph is below the line then the front axle is at a lower elevation than the rear. When a section of the aisle exceeds the 100% limit then the corresponding section of the graph will be coloured red rather than green.

Property D: When the difference in elevation between the front and rear axles changes by an amount that exceeds the 100% limit over a distance of 300mm the bar at the top of the graph will turn red.

If any section of the graph or any section of the bar above the graph is coloured red then that aisle fails to comply with the specification.



Understanding the Summary Sheet:

Below is an example of the summary sheet of results from a Face Digital Profileograph survey.

Fmin value assigned to the floor, based on expected Lift truck and Rack Height (from Table 1.1)

These are the Transverse and Longitudinal limits as automatically calculated for the F-min number assigned to the floor, (based on the proposed rack height) and the particular MHE dimensions.

Summary Of Results

Job Name:	Job Name	Job Number:	FC/XX/XXXX
Location:	Location	Date:	DD/MM/YYYY
Surveyor:	Surveyor		

Specification	Description	Limit
Fmin 65	Transverse, dl max	3.16 mm
Fmin	Transverse, El max	1.54 mm
	Longitudinal, dl max	4.12 mm
	Longitudinal, El max	1.54 mm

Transverse Axle Separation: 1440 Longitudinal Axle Separation: 2265

Run No.	Aisle Ref	Limits	Max Diff	Achieved	Run Length
1	1	Transverse, dl max	2.3 mm	100%	36.2 m
		Transverse, El max	1.9 mm	99.2%	
		Longitudinal, dl max	6.7 mm	91.7%	
		Longitudinal, El max	3.1 mm	88.1%	
2	2	Transverse, dl max	4.0 mm	92.4%	35.8 m
		Transverse, El max	1.5 mm	100%	
		Longitudinal, dl max	7.1 mm	93.3%	
		Longitudinal, El max	2.7 mm	86.6%	
3	3	Transverse, dl max	2.7 mm	100%	35.9 m
		Transverse, El max	1.5 mm	100%	
		Longitudinal, dl max	3.8 mm	100%	
		Longitudinal, El max	4.1 mm	97.4%	
4	4	Transverse, dl max	3.5 mm	96.7%	36.0 m
		Transverse, El max	2.9 mm	98.5%	
		Longitudinal, dl max	4.6 mm	97.8%	
		Longitudinal, El max	2.4 mm	93.0%	
5	5	Transverse, dl max	3.9 mm	92.5%	35.9 m
		Transverse, El max	2.2 mm	97.8%	
		Longitudinal, dl max	4.1 mm	100%	
		Longitudinal, El max	4.1 mm	95.0%	
6	6	Transverse, dl max	4.9 mm	97.0%	35.9 m
		Transverse, El max	2.6 mm	97.0%	
		Longitudinal, dl max	5.2 mm	92.3%	
		Longitudinal, El max	2.5 mm	95.2%	
7	7	Transverse, dl max	6.9 mm	72.9%	35.9 m
		Transverse, El max	1.7 mm	98.8%	
		Longitudinal, dl max	4.6 mm	97.3%	
		Longitudinal, El max	2.6 mm	92.1%	

The Max Diff figures indicate the maximum errors found on the aisle in millimetres. In order to comply with the required Fmin value, the figure should not exceed the 100% limit, which can be compared with the four Limit figures in the top table.

The figures in green indicate the percentage of the aisle that complies with the 100% limit of the required Fmin 65 classification. The figures in red indicate that the aisle fails to comply with the 100% limit of the Fmin 65 classification.

Further queries on these specifications or on any other floor flatness issue can be answered by calling Face Consultants Limited direct on:

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