

INDUSTRIAL FLOORING: A REVOLUTION IN CONCRETE FLOORS-FREE MOVEMENT (FM) AND ITS IMPORTANCE

Manoj Didwania

ABSTRACT. Presently with growth and Industrialization, the demand of Industries has been increase and so on the fast-track projects. During this time importance of Floor mainly concrete flooring plays the vital role for the operation of the Industries. Never before has the selection and implementation of the most suitable surface regularity specification been more critical than in today's production, storing and distribution facilities. As the demand for faster, more efficient warehouse technology increases and truck developments continue, surface regularity specifications help to contribute to warehouse operators' peace of mind. As the main production/operation/ movements happen on the Shop floor, the performance of Floor is vital and its key components for factory operations. The Paper is about the Revolution in Concrete floors achieving superior finishing with accurate levels and flatness such Free Movement (Level FM3, FM2, FM1) without any topping or levelling course. To achieve this proper design, planning and executions plays the most important role and the paper is going to take through the same. This paper takes through the case study of Industrial flooring which achieved FM2 Certified floor which is meant for the Reach Truck (RT) Operating for the height upto 13 metre (42 Feet) without Side Shift. There was no expansion joint in the floor where building is 330m long and 50 m wide and over above that there was no PCC (Plain cement concrete) as the base for the floor and these all was achieved after precise pre and post planning and execution steps which are highlighted below:

- 1) Selection of Joints such as Free Movement Joint, Restrained Movement Joints, Tied Joint, Isolation Joints
- 2) Selection of Mix design based on the Load/ sqm of the floor including reinforcement considering thermal movement and selection of Shrinkage admixture to avoid any dry shrinkage.
- 3) Selection of right kind of Floor hardener which gives better abrasion resistance and slip resistance.
- 4) Selection of Construction and Contraction Joint based on the layout of the floor and sequence of Concrete
- 5) Selection of Armour Joints based on the concreting sequence.
- 6) Adaption of Methodology for Concreting including proper level check, proper protection of floor, making area air tight during concreting.
- 7) Adaption of right kind of Equipment for concreting such Laser Screed, Truss Based Screed vibrator, VDF

- 8) Post concreting protection of floor and proper curing.
- 9) Surveying of the floor to check the levelness and flatness of the floor.

Keyword: FM2 flooring, Mix design, Levelness, Flatness, Material handling equipment (MHE)

Manoj Didwania is Professional Technocrat with more than 13 years of experience in various fields of Construction from tendering, Estimation, Procurement, Execution, Value Engineering, Planning and Monitoring and have executed projects in residential, factories, logistic segment. He has extensively worked on supplementary cementitious material and have published paper on sustainability and reckless concrete till date.

INTRODUCTION

Industrial floors play an important role when it comes to the Operation part, as all processes are being operated on the floor. The strength and durability play an important factor but it's not limited to these factors only; the flatness and level play crucial roles when it comes to MHE (Material Handling Equipment's) and to achieve these a precise specification has to be derived and has to be executed. These require attention from design stage to post concreting stage, and various steps and measures have been discussed in this paper in details.

Importance of Flatness and Levelness

The selection of the appropriate specification is crucial as it is common to find over specified floors that are not suited for the clients' specific performance requirements which require more time, resources and money to achieve.

Surface regularity specifications are divided into two main categories according to the type of movement the Materials Handling Equipment (MHE) are able to do.

- i. Free Movement (FM) specifications correspond to MHE that may operate in all directions and undefined paths within the facility.
- ii. Defined Movement (DM) specifications correspond to MHE that may operate within a defined path, area and direction within the facility. These facilities implement a Very Narrow Aisle (VNA) system.

Design Stage

Ground floor slabs in Warehouses and Distribution Centres are integral to the efficient operation of the facility. They are the table top on which an operator runs his business. On the surface they appear to be one of the simplest parts of a structure to construct. However, this simplicity often leads to an underestimation of the design and construction requirements. A well designed and constructed floor will increase productivity, reduce maintenance of the building and increase the life of the equipment using the floor.

A floor design should be performance-based, and this starts with understanding the requirements of how the floor will be used. Most Floor designers will be given a brief from the warehouse owner to ensure the floor will take the imposed loads, be flat, long-lasting and aesthetically pleasing and it will be their responsibility to draw up the performance specification. The specialist flooring contractor should consider the construction methods, programme, cost and any value engineering they can bring to the design. Compromises may have to be made in developing the final design of the floor, but the result should be one that is economically designed and built to meet the performance requirements.

This stage requires designing the total load on floor, base and sub base, grade of concrete, floor hardener, construction joint, contraction joint, expansion joint, type of sealant.

Table 1 Floor classification as TR 34

FLOOR CLASS	TYPICAL FLOOR USE	PROPERTY	
		E	F
FM 1	Where very high standards of flatness and levelness are required. Reach trucks operating at above 13m without side shifts	4.5	1.8
FM 2	Reach trucks operating at 8 – 13m without side shifts.	6.5	2.0
FM 3	Retail floors to take directly applied flooring. Reach trucks operating at up to 8m without side shift. Reach trucks operating up to 13m with side shift.	8.0	2.2
FM 4	Retail floors to take applied screeds. Workshops and manufacturing facilities where MHE lift heights are restricted to 4m.	10.0	2.4

Note: Side shift is the ability of a truck to adjust the pallet transversely to the fork direction. Values mentioned in the table are in mm. Here E Notify as levelness and F Notify as Flatness.

Flatness and Levelness Requirements (Surface Regularity) There are essentially two methods for defining floor flatness requirements. Floors are divided into Free Movement Areas (FM) and Defined Movement Areas (DM).

The FM criteria is where trucks operate at low level when moving, such as marshalling areas, block stacking areas, and aisles greater than 2.8m wide.

NOTE 1: The above values are permissible 95 percentile values for Properties F and E NOTE 2: For all classifications, all points surveyed should be within 15mm from datum.

The ASTM is a comprehensive method of measuring the overall performance of the floor based on statistical analysis known as F numbers. The standard is based on two numbers: FF for flatness (short wavelength) and FL for levelness (long wavelength). However, there is no control to datum and the sample rate is comparatively small.

There are two parts to a floor design:

- A. Structural Design – the ability to withstand the applied loads
- B. Detailed Design – joint design and other performance requirements.

Structural Design

The structural design of a floor will follow engineering principles and calculations and requires knowledge of the following in order to determine the slab thickness and reinforcement.

1) Ground conditions 2) Strength of the concrete 3) Thickness of the concrete 4) Method of reinforcement 5) Load transfer capability of the joints 6) Loading specification and loading pattern

Guidance on the design of a floor is in detailed specified in the UK Concrete Society's Technical Report 34 (TR34)

Detailed design

Detail design covers key performance requirements, including: **1) Joint layout and joint design 2) Construction methods 3) Method of reinforcement. 4) Surface regularity (flatness and levelness) 5) Abrasion resistance** Advice from all the stakeholders of the floor should be sought before the design is finalised.

Sub-grade

Suitable ground conditions are essential for ground supported slabs, and it is therefore important that a ground investigation is carried out and interpreted by a competent geotechnical engineer. The geotechnical engineer must advise on the suitability of the ground along with any recommendations for ground improvements.



Figure 1 Shows the sub base preparation in progress.

The primary purpose of the sub-base is to provide a level base for the floor slab. It should be capable of carrying construction traffic without rutting. The sub-base should be a minimum 200-250mm thick well graded material. The level tolerance of the sub-base is of great

importance. A high sub-base generally means a thinner concrete floor. + Zero to – 25mm is recommended.

Slip membranes

Slip membranes are used to reduce friction between the slab and the sub-base so as to reduce the restraint to drying shrinkage thus reducing the risk of unplanned cracking. A 300 micron plastic sheeting is recommended.

Concrete

Concrete plays significant role, not only plays important role for durability and strength but also levelling course, this shows how much concrete shows flexibility if properly design and executed

There are comprehensive Standards for the specification and testing of concrete. High strength concrete is not needed and should be avoided because it tends to have higher cement content and is more likely to shrink than lower strength concrete. It can also be difficult to finish.

Concrete shrinks as it dries out over the first 12-18 months of its life. Fresh concrete has more water than is needed for the chemical process of hardening and some of this excess water leaves the concrete causing it to shrink. Therefore, the amount of cement and water in the concrete should not be excessive.

Consistency of the material properties and delivery to site is the key to a well finished floor slab. Utmost care has to be taken while executing as “**Final finish is all about the**

Concrete

Grade of Concrete for the floor was M30 Grade, with Cement OPC 53 alongwith 20% flyash and all concrete was batch mix in the fully automated Batching Plant, the temperature of Concrete in never case was allowed to be more than 30 degree and during summer cold water was used to keep concrete temperature within permissible temperature.

Reinforcement

Although reinforcement will give some enhancement to the structural load capacity of the floor slab, the primary function is to restrain the opening of sawn induced joints and maintain good load transfer properties.

The traditional method of reinforcement in jointed ground supported slabs is with steel mesh. The position of the mesh is usually specified 50mm from the bottom of the slab. Alternatively, floors can be reinforced with steel fibres also. The joints can become wider than predicted and load transfer between sections of floor can be lost. This can result in floor movement at the joints and breakdown of the joint.



Figure 2 Show the concreting in progress with reinforcement laid and all opening closed for control concrete.

Importance of Joints

Joints are the most critical element in a floor. Most maintenance requirements are related to the breakdown of joints in some form. Joints create unavoidable discontinuities in a floor which can be damaged by mechanical handling equipment when trafficked.

Joints are provided for two purposes: • To form the boundaries of each day's concrete pour (Construction Joints) • To reduce the risk of cracking as the floor shrinks (Contraction Joints and isolation details) Construction joints must incorporate dowels to provide a load transfer mechanism between the sections of floor.

Contraction Joints

Contraction joints are most commonly created by saw cutting. Sections of cast floor are usually cut into panels of 6m x 6m. The intention is that a crack will then form beneath the saw cut relieving drying shrinkage stresses. The reinforcement must be continuous across the sawn joint to restrain the opening of the engineered crack and maintain adequate load transfer.

Isolation details

Floors must be isolated from fixed elements of the building to allow the floor to contract without cracking. This is achieved by surrounding columns with compressible materials. These are known as the isolation details.

Joint Layouts

Ground supported slabs can be jointed or joint less.

1. Jointed floors have construction joints at the edges of each day's concrete pour, and they typically have sawn joints at 6m intervals.

2. The term jointless is something of a misnomer as all slabs have construction joints at the edges of areas of floor that are poured in any one day. On a jointless floor, these are the only joints. Joints are provided to permit breaks in construction and to allow for shrinkage as the concrete dries out over a period of up to 2 years.

Expansion Joints

Eliminating the Expansion joint on the floor has arisen for the smoothness of the operations of factories mainly warehouse where there is lot of movement of stocks within the shop floor. As per TR 34 (4th Edition) Clause 11.2 States “Expansion joint are not used in Internal floors, except those subject to above ambient temperatures and to large temperature fluctuations”. For this floor the right kind of Mix design, type of Joints, material, methodology, surveying all elements plays the crucial role. We have eliminated the Expansion Joints in this project.

Jointless Floors

Some floors are built without sawn joints. Care must be taken to ensure that all possible steps are taken to minimise the restraint to shrinkage, including mix design, correct curing, and limiting pour sizes.

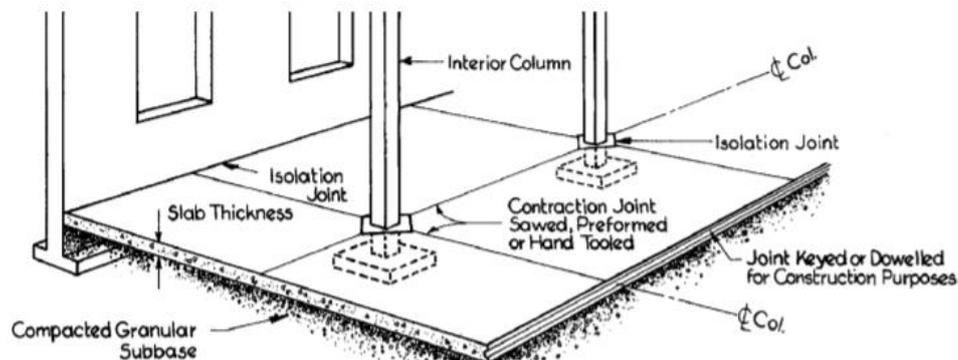


Figure 3 Type of Joints on the Floor

Abrasion Resistance / Durability For most warehouse applications, a self-finished, power-trowelled slab will provide a durable working surface, provided that concrete selection is correct and good finishing techniques are applied. Surface durability is primarily a function of the densification of the surface by power trowelling and most importantly by proper curing.

Construction Methods the floor construction method is critical in determining the overall detailed design, construction programme and cost. The construction method will determine:
 1.) Daily output - programme 2.) Joint layout Surface regularity 3.) The concrete mix design 4.) How the floor is reinforced There are 3 basic methods of construction:

1. Long Strip
2. Large Area Pour – Laser Screed/Truss Screed Vibrator – Jointed
3. Large Area Pour – Laser Screed/Truss Screed Vibrator – Jointless

4. Long Strip

The long strip method of construction is a traditional method of laying industrial floor slabs. The floor is laid in a series of long strips, typically 4-5m wide.

The long strip method is still commonly used when the floor must have a very high level of surface regularity such as VNA. An experienced flooring contractor should be able to achieve a high degree of flatness using the long strip method without corrective grinding. The Single Strip was 55m (L) X 11.3 m (W)

Large Area Pour – Truss base screed vibrator– Jointed

Large pour, laser screed floors can be laid in areas of up to 2,000m² between construction joints in a continuous operation but bay sizes of around 1000 square metres is recommended. The laser screed works across the floor area from left to right in 4-5m widths as shown below



Figure 4 Truss base screed vibrator is run on the Channel both side for proper level and compaction. With Panel Size of 55m (L) X 11.3 m (W).

Finishing

Bull Float

Floor flatness (FF) controls the local bumpiness of the floor surface and is primarily affected by the finishing operations after screeding, including restraightening and power floating. Floor levelness (FL) controls the departure of the floor surface from the specified slope or plane of the surface. FL numbers evaluate the elevation differences along a sample line at 3 m intervals. The higher the FL number, the more level the floor. Levelness of the edge forms and the accuracy of the concrete screeding operation control the overall levelness of the floor.



Figure 5 Bull Floater Work in Progress to remove local bumpiness and straightening of the fresh concrete

For large concrete placements using truss base screeds, these tools are primarily used after screeding and before excess bleed water accumulates on the surface. As shown in Figure 5, always restraighthen the “mend” and “grout” lines. Otherwise, there will be high spots along these lines that will reduce the flatness of the floor. The modified highway straightedge is the tool of choice because it can also be used as a reference line to identify high and low spots on the floor surface. A bull float can smooth the surface but it cannot perform the cut-and-fill process; and due to its short length, its use will reduce the floor flatness.

If you have trouble using the bull floater after screeding because it digs into the surface, then use an 8- to 10-foot-wide channel float or check rod. Do not use a 4- to 5-foot bull float. A bull float can smooth the surface but it cannot perform the cut-and-fill process; and due to its short length, its use will reduce the floor flatness. Also, make sure your straightedge, whether it is modified highway straight edge or not, is straight and true. If warped or damaged, you will make the floor less flat.

If needed, you can angle a restraighthening tool about 45 degrees to the axis of screeding and overlap the previous pass by about 50 percent of the straightedge width. However, be careful not to undo the flatness produced by the laser-guided screed.

Floor Hardener

Surface hardener are applied to concrete surface after it is smoothed and left to dry. The help to improve the concrete’s abrasion and chemical resistance, thus significantly improving the durability of the concrete surface, its non-metallic in nature. Non-Metallic Floor Hardener is designed for use as a surface hardener for concrete floors, which are subject to wear due to abrasion or impact from light to medium traffic.

An uneven surface will make it more challenging for materials handling vehicles to operate, potentially increasing the wear to the vehicle itself. In cases of serious damage the area may

have to be isolated while repairs are undertaken. This can be costly, in terms of disruption to operations, as well as the actual cost of the repair itself. Abrasion can be caused by the constant movement of materials handling vehicles over the surface; or by dragging items across the floor; or by impact damage caused by dropping objects on to the floor. Certain substances can also cause damage, often caused by the chemicals in the substance slowly disintegrating the concrete.

A surface hardener adds a protective layer to the concrete floor, reducing the amount of surface wear and tear caused by abrasion. This helps to extend the life of the concrete floor, reduce repair costs, minimise disruption, and keep the floor's smart appearance for years.

We used **“Rockland Qualidur”** as dry shake floor hardener, the spreading quantity was 5 kg/sqm to achieve better abrasion and slip resistance.

Floater

Floater are circular metal disks that clip on to the blades of either a walk-behind or a ride-on power trowel. Floaters make floors flatter by generating and moving “cream” or surface mortar. Pans easily remove surface imperfections, cut humps and fill in holes and low spots — that’s why power floating with pans is so important. Expect a 10- to 25-point increase in F numbers when floating with pans instead of float blades. Pan floats are wider and flatter than float blades, pans cause less dishing and troughing due to the reduced contact pressure compared to float blades, and pans minimize surface variations due to bent arms and float blades.



Figure 6 The Power floater in Progress to remove imperfection in floor

Pan floats are circular metal disks that clip on to the blades of either a walk-behind or a ride-on power trowel. Pan floats make floors flatter by generating and moving “cream” or surface mortar. Pans easily remove surface imperfections, cut humps and fill in holes and low spots — that’s why power floating with pans is so important. Expect a 10- to 25-point increase in F numbers when floating with pans instead of float blades. Pan floats are wider and flatter than float blades, pans cause less dishing and troughing due to the reduced contact pressure compared to float blades, and pans minimize surface variations due to bent arms and float blades.

It is important to start power floating early while the concrete is still plastic. However, starting too soon can create too much surface mortar reducing the floor flatness, especially when using a truss-guided screed. Delay power floating until you leave no more than a 1/8-inch footprint in the concrete. Otherwise, you increase the risk of cutting troughs and creating surface waves that will reduce the floor flatness.

Joint Cut

The following day, the floor is sawn into panels on a 6m grid to relieve drying shrinkage stresses. This type of floor construction is typically reinforced with a single layer of mesh 50mm from the bottom of the slab. As per the standard and codes the joint has to be cut within 24-36 hrs of Pour to achieve Crack free floor.



Figure 7 Saw Cutting in Progress, Generally depth of 1/3 of Slab thickness and 35 mm width is cut within 12 hrs

Large Area Pour - Laser Screed/Truss Screed Vibrator - Jointless This is constructed in the same manner as the jointed floor described above, but no joints are sawn. Jointless floors require good control of sub-base flatness and levelness to reduce the restraint on the underside of the slab.. The large distances between construction joints can often result in wider openings, and joints can open up as much as 35mm. Careful consideration should be given to the location of these joints and the impact they have on trucks.

Curing and Protection

The floor shall cured properly, the floor shall be submerged in the water for atleast 7 days from the date of Pouring and no vehicle shall allowed to move on the floor before 21 days of the Pour date. There are different way of curing by water flooding the panel or curing membrane, at our site we used to cover the Panel by LDPE Sheets and over and above it we

used pour the water. This way we used ensure that the floor is properly cured and taken care of it.

Survey

It is worth noting that there is no purpose in selecting and implementing an appropriate specification if there is no way to check if this specification is achieved.

The results of this process can be used to check if the contractor has delivered what was promised. Also, to assess the need and the cost involved if correction or an upgrade is required. The role of surveying is to get an accurate reading of the surface regularity of the floor.

All specifications measure flatness (the variability over a short distance i.e.300mm) and levelness (the variability over longer distances i.e. 1,200mm).

Flatness could be considered a measure of smoothness for the truck drivers. Levelness has more effect on the stability of the trucks particularly those in aisles. Variability across the width of the aisle and/or between the front and the rear wheels of a truck can have a significant impact on truck swaying and nodding effects resulting in poor efficiency and even unsafe operation.

The lack of surveying often leads in endless debates about the quality of the floor and its suitability for the Materials Handling Equipment (MHE) to operate on.



Figure 8 The Profile o graph taking the reading of the floor to check level and flatness.
Face Digital Profilegraph within a narrow aisle

The equipment measures the elevation across the load wheels (transverse) and the elevation between the front and rear axles of the truck (longitudinal). In addition to the elevation controls, the rate of change in elevation for both transverse and longitudinal directions is measured for every 300mm of travel down the defined path.

Although the three standards described above measure the floor properties in the same method, the property limits vary. TR34 and CEN 15620 have the same limits.

Recommendations on Surface Regularity TR34 Edition 3 2003 provides the most comprehensive guidance on the subject. For most installations, TR34 Classification FM2 is recommended when specifying a new floor as this represents a good quality floor that can be achieved without excessive cost. For VNA applications a Defined Movement (DM) Specification should be used and the category defined by the racking height.

Results

The Project was Certified FM2 Flooring achieving 97% accuracy level and flatness and it's among the first of its kind of flooring in this much large magnitude, and looking forward with Automatic Retrieval system (ARS) Warehouse coming in future the demand in FM flooring will increase with more higher standards and specification.

Through this paper I mean to highlight that how concrete has become the face of the projects and its requirement is not restricted only for the strength but to achieve levelled and flat floor act as operation floor.



Figure 9 Shows the floor with FM2 Floor with 6.5 mm level tolerance and 2mm flatness tolerance across the floor from Datum

Table 2 Comparison with Normal Floor

DESCRIPTION	NORMAL FLOOR	FM2 FLOOR	ADVANTAGE
Sub base top layer	M10 grade PCC layer	GSB layer	Yes. Time and cost reduction (approximately 65% reduction when compared to cost of PCC layer) in achieving compacted sub base layer. Better levels and ease of fixing formwork.
Dry-shake hardener	Normal Non Metallic floor hardener	Rockland Qualidur	No. Cost increase. Yes. Target was to achieve an abrasion resistance value of 1 instead of 8 on Mohs scale which could not have been achieved as per original design.
Construction joints	Approx @ 5.9m	Approx @ 11.3m	Yes. Cost reduction in dowels as per original design and less number of joints. Jonts designed as tied joints that will open only <1mm wide. Number of pours halved!
Expansion joints	Equal angle armoring , 25 dia smooth rod dowels 500mm long @ 250mm c/c and sealant	NIL	Yes. NIL cost of materials and labor. Not recommended as indoor slabs at existing temperature variance will not expand beyond poured dimensions!
Level / Flatness	No	Yes	At a nominal cost the constructed floor with Proper Planning and Execution for smooth Operation

Conclusion

In an environment where the Materials Handling Equipment (MHE) operates without suspension systems, the warehouse floor is the all-important surface that affects the speed, efficiency, maintenance needs and often the safety and movement of the distribution centre operatives and their manually or automatically operated hardware, for this type of requirement in today's time the FM level floor has become mandatory.

This paper hereby presents that the concrete has moved way ahead in digital India where now for levelness and flatness concrete floor plays the crucial role not only in the part of strength

and durability but even aesthetically, which is the most important part of Warehouse and Manufacturing Industries.

This has been possible by micro level detailing during designing and planning stage and most important during executing to the perfection. Hereby it's proves that the concrete from many centuries has serve in different capacities and requirements and way forward there's going to be more n more invention is going to happen evolving concrete as the main ingredients.

References

1. Guidance on the design of a floor is in detailed specified in the UK Concrete Society's Technical Report 34 (TR34)
2. ACI 224-Joints in Concrete Construction
3. Additional Information
<https://www.concreteconstruction.net>