Industrial ground floors

K.K. Ganguly and K. Chatterjee

Discussion on the design of industrial ground floor slab with fibres have been carried out. Different problems associated with industrial floor slabs have been briefly mentioned. Various issues associated with ground floor design such as loads, supporting arrangements, present design trend/assumptions have been briefly covered. Repairing considerations on existing floors with special and selected materials have been discussed. The use of steel fibres along with nominal reinforcement has been recommended for the design and construction of industrial ground floor slabs.

INTRODUCTION

The design of industrial ground supported floors is often associated with concrete slab with reinforcement in layers. The main emphasis of the design of the slab will be to control occurrence of cracks and settlement during the use and to provide complementary joints for eliminating crack development later on. In this connection floor supporting arrangement and loading will be important. However, it has been observed that the loading on the floor slab is not a primary factor when the floor slab is cracked; in extreme cases, however, it may be contributory [1]. The most important cause of floor cracking is due to external restraints to contraction of the concrete floor slab especially during initial stages. Due to this, tensile stresses are developed leading to cracking of the floor. External restraints may develop from the friction at underside the floor slab with the sub-base or anchoring effects from the surrounding structural elements present and when these are not isolated from the floor slab. Natural drying out of the floor slab along with temperature variations may cause stress/strain gradient within the slab thickness also and tensile stresses will be developed from direct contraction. This effect is often described as "Warping" or "Curling". Cracks may develop within a few hours after concreting when the concrete is not fully set or attained its sufficient tensile strength. Such, cracking is referred as "Plastic Cracking" and generally has no serious effect on the structural integrity of the concrete slab.

Various shapes and types of fibres from steel, plastic, carbon, glass and natural materials have been tried with concrete [2,3]. From studies it was found that the ultimate strengths of concrete with fibres did not increase much as compared to normal concrete. However, the tensile strains at rupture did improve [2]. Furthermore, fibre reinforced concrete is much tougher and more resistant to impact as compared to normal concrete. Engineers have been trying to use different fibres in the ground floor slab also primarily to avoid cracking. Joint less floor slabs have been executed with fibres. Both metallic and non-metallic fibres have been used successfully for ground bearing concrete floors [4,5]. An attempt has been made, in this article, to review the design and applications and to highlight the present trend of floor slab design and to comment on the use of reinforcement along with different fibres and especially the steel fibres for the design of ground supported industrial floor slabs.

The design and proper execution of the sub-grade and the built-up sub-base under the concrete slab is also important to avoid settlement.

BASIC CRITERIA ASSOCIATED WITH THE DESIGN OF FLOOR SLAB [6]

The following requirements have to be taken into account for the design of the ground supported floors in most cases :

a. Abrasion resistance - This is related to the ability of the concrete surface to resist wear caused by rubbing, rolling, sliding, cutting and impact forces.

b. Chemical resistance - The resistance is required against the spillage of aggressive chemicals as applicable. The common substances that may come in contact with the concrete floor are acids, wines, beers, milk, sugars and mineral and vegetable oils.

c. Colour and appearance - The final appearance of the floor may not be as uniform as a painted surface finish. More care will be required at finishing stages when appearance is important. For bold and consistent colour, it may be required to use a surface coating or paint.

d. Cracking - Crack free surface will be the requirement from the Client. If cracks develop the investigation for the cause of cracking will be required before providing any treatment. Fine cracks may be of concern related to appearance, the same should be monitored over a period. If it is suspected that cracks have developed due to structural deficiency a thorough reassessment of the design must be done before taking any remedial action. Floor surfaces should be flat and levelled with no wide, sloped or uneven joints.

e. Floor settlement - The floor shall not settle adversely especially to develop differential settlement which may cause difficulty in the operation of the floor. In this respect, results of soil investigation work must be examined and this will be very important. Appropriate steps and precaution as per soil investigation report should be taken in the design accordingly i.e. building up sub-base layers and need for soil improvement etc.

   For heavily loaded floors and large area floors sub-soil exploration should be carried out to determine the CBR value of the sub-grade and existence of any layer below which is prone to settlement.

f. Crazing - This is quite common and associated with mostly power-finished floors. It will be more visible on the floors that are wetted and cleaned as the extremely fine cracks will trap moisture and dust. This is a problem with the appearance only and generally no structural or serviceability issues are associated.

   Appropriate treatment for crazing will be difficult to suggest. However, application of painting/ sealer treatment on the top of the floor may be considered.

g. Curling - This is normally connected with differential shrinkage of the concrete. The top exposed surface will dry and shrink more than the bottom resulting with curling upwards of the floor slab. Curling can not be totally eliminated and often tends to be unpredictable [6]. Curling may cause a loss of sub-base support and should be monitored as part of maintenance work. Under slab grouting if applied will restore the support of the floor slab.

h. Delamination - This is associated with the problem where a thin layer (2-4 mm) gets detached from the surface under trafficking [6]. This is a complex phenomena and connected with several factors including setting of surface concrete, air content of the concrete mix, bleed characteristics of the concrete, accelerated drying of the surface by cross winds etc.

   Delamination may be repaired by cutting/chipping away the top surface of the affected areas and then filling with cement or resin based mortar system.

i Slip resistance - The slip resistance will be connected with the floor surface, footwear worn by people, the tyres on material handling equipment and the presence of surface contaminants. The following types of contaminants may be involved.

- Dust
- Coatings
- Liquids

With the process of power finishing good abrasion resistance surface will be produced but it will tend to create lower slip resistance. Where slip resistance surface will be more important, further surface treatment should be considered. The use of resin-bound aggregate finish may be considered for increasing slip resistance.

j Surface aggregate - The problem occurs when some aggregate particles may be exposed at or very near to the surface. This will not be generally a durability problem but the same may not be acceptable for appearance. The patches should be identified and removed by drilling and filled with resin based mortar.

k Surface fibres - Steel fibres may be exposed at the surface after concreting. This problem can be overcome by using dry shake material and to finish accordingly. Fibres that will affect serviceability may be snipped off when the concrete is hardened.

l Surface finish marks - These may be trowel marks "swirls" or discolouration which may develop from poor finishing such as over trowelling. These marks will wear and disappear with time and use of the floor will not be causing any adverse effect on the surface.

LOADS

For the design of an industrial floor the use of the following loads will be required –

a. Uniformly distributed load - Depending on the use the Client should be able to indicate a load per sqm. that should be used for the design. If the loading is not known, the designer should assume a figure based on his experience. It will be prudent to assume slightly a higher load for the design when the appropriate load/sqm. is not known.

b. Material handling equipment (MHE) loads - Material handling equipment will be used for moving pallet, bulk products, finished goods, ingot, billets etc. related to the use of these loads on the specific areas where flooring has to be designed. All MHE items will generate point loads. For the design of the floors to support these loads the maximum wheel loads, contact areas of the wheels or tyres must be known. Most likely the tyres will be made of hard neoprene rubber, sometimes it may be steel also.

   Equipment configurations, weights and other details may vary significantly with different vendors and hence the details from the manufacturer will be required for the design. MHE loads may be dynamic also and hence this will have an impact in the design consideration.

Sufficient load details are often not available for design consideration of the floor. To understand loads correctly the following details will be required.

- Leg loads and spacing including axle spacing.
- Truck loads showing maximum axle and wheel loads, type of tyres.
- Plans for wire guidance and saw cuts.
- Uniformly distributed loads.
- Other loads from mezzanine or from floating columns to be supported from the floor.

The partial safety factor that may be used for Ultimate Limit State Design are [6]

a. Permanent racking load - 1.2

b. Variable and random loading - 1.5

c. Dynamic loads from material handling equipment & Equipment and machinery subject to vibration - 1.6

The partial safety factor for serviceability Limit State shall be taken as unity.

DESIGN OF GROUND SUPPORTED FLOORS [6]

The design of ground floor slab may be carried out using Westergaard's theory or yield line analysis considering the loads on the slab. However, brief comments will be made on other works in this connection for ground supported slabs. Mayerhof used an ultimate strength analysis based on yield line theory and obtained formula for single, internal, edge and corner loads.

Losberg also proposed yield line analysis and used structurally active reinforcement rather than crack control reinforcement.

Baumann and Weisgerber developed a yield line method to determine the collapse load of the slab covering interior load, free edge load and corner load. Baumann & Weisgerber's approach is conservative.

Rao and Singh presented slab design using rigid plastic behaviour and square yield criteria for failure. They considered two modes of collapse i.e. semi-rigid and rigid.

The design is often carried out with one or two layers of steel reinforcement in the floor slab for controlling the cracks. Steel fabric/reinforcement will also improve the performance of joints within the concrete and will also help in the spanning over any potential soft spots under the concrete slab. From tests it seems lighter steel fabric and thinner-slabs have exhibited better structural effect especially subjected to point loads [1]. Furthermore, slabs containing steel fibres showed increased load carrying capacity compared to slabs with polypropylene fibres [1].

The design will need to be done for both Ultimate Limit and Serviceability Limit States as mentioned. The basic factors for ultimate limit state have already been mentioned. The moment per unit length of the floor slab may be computed using yield line theory and reinforcement may be provided accordingly for satisfying flexural tensile strength capacity. Different conditions are to be looked into for point and uniformly distributed loads. Locations of point loads are to be considered carefully. Punching shear against point loads are to be checked. Some comments will be made now related to serviceability limit state.

It has been mentioned for deflection under serviceability the values of γ_m (load factor for material) and γ_f (load factor for load) as used in the design for ultimate limit state will generally perform adequately under serviceability limit state also [6]. Westergaard's equation may be used to compute approximate slab deflection under a concentrated load.

Regarding movement in the concrete slab the following items are to be considered:

a. Plastic shrinkage and settlement

b. Thermal stresses due to both early contraction and seasonal/daily change of temperature

c. Long term drying shrinkage.

The issues related to design of ground supported floor slabs are explained in Technical Report–34 [6]. Only a few items are highlighted here connected with design issues especially related to steel fibre reinforced concrete slabs.

MATERIAL PROPERTIES [6]

The characteristic flexural strength of plain concrete may be computed as:

$$F_{ctk,fl} = [\,1 + (200/h)^{0.5}]\, f_{ctk,fl}\,(0.05) \leq 2f_{ctk}\,(0.05)$$

where h = total slab thickness, mm (h> 100)

Minimum shear strength of concrete shall be

$$V_{Rd.cl} = 0.035\, k_1^{3/2} f_{ck}^{1/2}$$

$$k_1 = 1 + (200/d)0.5$$

d = Effective depth (mm)

where $f_{ctk}(0.05)$ = characteristic axial tensile strength (5% fractile)

$= 0.7\, f_{ctm}$

f_{ctm} = Mean axial tensile strength

$= 0.3\, f_{ck}^{\;2/3}$

f_{ck} = characteristic compressive strength (cylinder) N/mm^2
f_{cu} = characteristic compressive strength (cube) N/mm^2

BENDING MOMENT (STEEL FIBRE REINFORCED CONCRETE)

Positive bending moment capacity (post cracking) may be expressed as:

$$Mp = f_{ctk,fl} / \gamma_c (Re._3)\{h^2/6\}$$

Ductility is expressed as equivalent flexural strength ratio Re, 3 with a minimum value of Re, 3 as 0.3

And Negative bending moment

$$M_n = f_{ctk,fl} / \gamma_c \{h^2/6\}$$

It has been observed that with a dosage of 0.9 kg/m^3 short synthetic micro fibres do not enhance the ductility [6]. Hence, slabs with such fibres may be considered as made of plain concrete.

Slabs with point loads

Using yield line theory, with a single point load 'P', moment per unit length when flexural tensile strength of concrete is reached and the same may be expressed as

$$M = f_{ctk,fl} (h^2/6)$$

where, h = thickness of the slab (mm)
$F_{ctk,fl}$ = characteristic flexural strength of plain concrete (N/m^2)

And the collapse load Pu ignoring contribution from sub-grade reaction is given by

$$Pu = 2\prod (M_n + M_p)$$

where M_n = ultimate Negative (hogging) moment resistance of the slab
M_p = ultimate Sagging (position) moment resistance of the slab

It is further assumed that the slab has adequate ductility and has not failed in punching from the applied loads.

The equivalent flexural strength ratio Re, 3 (Re, 3 is the measure of ductility and it is the ratio of load to first crack) for fibre reinforced concrete and the value will be dependent on fibre type and dosage. Fibre dosage shall have to be adequate to give a value of Re, 3 of at least 0.3, otherwise concrete shall have to be treated as plain.

SHEAR STRENGTH [6]

Shear at the face of contact area in the slab, irrespective of the amount of any reinforcement is -

$$Vmax = 0.5\, k_2 f_{cd}$$

where f_{cd} = Design concrete compressive strength (cylinder)

$$= f_{ck} / \gamma_c$$

f_{ck} = Characteristic Compressive Strength (Cylinder)
γ_c = Partial load factor for concrete
$k_2 = 0.6 (7 - f_{ck}/250)$

Therefore, the maximum load capacity in puching P_p max may be expressed as

$$P_{p\,max} = V_{max}\ Ú_o d$$

where $Ú_o$ = Length of the perimeter at the face of loaded area
d = Effective depth (mm)

Following RILEM guidance [6], the presence of steel fibres will increase shear capacity over that of Plain Concrete by an amount V_f where $V_f = 0.12\ Re,_3\, f_{ctk,fl}$

where $Re,_3$ = Equivalent flexural strength ratio
$f_{ctk,fl}$ = characteristic flexural strength of plain concrete

DEFLECTION CONTROL [6]

Using Westergaard's equation an approximate slab deflection under a concentrated point load may be expressed as $\eth = c\,(P/k\ell^2)$

where, k = Modulus of sub-grade reaction
ℓ = Radius of relative stiffeness
c = Deflection Co-efficient depending on the position of the load

Note: c = 0.125 - For internal load
= 0.442 - For edge loading
= 1.1 – 1.24 (a/ℓ) - For corner loading

where, a = equivalent contact radius of the load

The values of deflection for a = 56 mm, h = 150 E_{cm} = 33 x 10^3N/mm^2 for a point load of 6^T are shown in Technical Report – 34 [4]

The modules of elasticity of concrete will be affected by creep under sustained loading in the long term. The value may be expressed as $E_{cm(t)} = E_{cm}/(1+\Phi)$

where Φ = Creep factor

The redims of relative stiffness I is given by
$I = \{E_{cm} h^2/12(1 - v^2)k\}^{0.25}$

E_{cm} = Short term modulus of elasticity of concrete in N/mm^2

where, h = slab thickness
V = Poisson's ratio

It may be noted that deflection is inversely proportional to $k\ell^2$ and the value of I will be reduced as the value of E_{cm} decreases

From calculations it has been observed that free-edge and corner deflections are significantly higher than internal values. However, these deflections will be reduced where load transfer is provided.

It may be commented that slabs designed for ultimate limit state shall generally perform well under service load conditions also.

PLASTIC SHRINKAGE

Plastic shrinkage occurs initially and within a few hours after placement of concrete. This effect may be controlled by adjusting the mix design and not exposing the concrete slab after casting to extreme drying conditions. Effective and early curing will have large impact over plastic shrinkage especially during early stages of setting and hardening of concrete. Plastic shrinkage cracks may not pose a problem to industrial floors as the cracks, if developed, will be closed by the finishing operations that will follow later. However, they may still exist below the surface of the floor and the same may be visualised when the floor is shot blasted or ground later.

PLASTIC SHRINKAGE REDUCTION

Experimental trials were conducted in the laboratory using both steel and polymer modified synthetic fibres and simulated under severe environmental surrounding including high temperature and strong winds [7]. The main purpose was to assess the differences in behaviour in relation to early-age plastic shrinkage resistance between different pavement structures reinforced with various short fibres. The results indicated that fibres can not avoid water evaporation from concrete, but can reduce shrinkage. Fibre reinforced specimens exhibited a small length reduction as compared with that of plain specimens. Further observations may be made as given below from the research findings :

a. Weight reduction in all specimens due to water evaporation.

b. Shortening of most specimens.

c. Cracks on surfaces exposed mostly to heating and ventilation.

d. Progressive increase in crack widths over time.

LONGTERM DRYING SHRINKAGE

Drying shrinkage is associated with long term moisture loss from the concrete. This effect covers a long period and related to environment and properties of the concrete. The early hydration shrinkage takes place during first 8 hours or so from mixing. As an example it may be mentioned that a slab exposed to air for three months may have undergone 30% of its long term drying shrinkage. Restraint will be responsible for the development of cracks. Unrestrained shrinkage shortening will be mitigated by creep and restraint. The important factor will be water content in the mix. Attempts must be made to adjust combined grading of coarse and fine aggregates to reduce the water demand. If more water is added to the mix, there will be greater tendency to shrink on drying while evaporating the same excess water. With proper use of admixture and adequate checks on workability and water cement ratio supported by timely application of curing item, the effects of bleeding, segregation and evaporation of water can be controlled and these are all related to shrinkage.

If the movements are restrained stresses will develop leading to development of cracks in the concrete slab when the strain and thus the tensile stress will exceed that of the capacity of the slab.

The main emphasis of design requirement is to avoid formation of cracks on the top surface of the slab.

SHRINKAGE REDUCING ADMIXTURES

Shrinkage reducing admixtures have been used for a long time in different advanced countries to provide water tight in-situ structures free from cracks. This is related to relieving shrinkage at different points in setting and hardening process. The following different ways are involved :

a. Gas generation in plastic state

b. Chemical expansion in the hardened state

c. Shrinkage – reducing admixtures based on organic aliphatic alcohol.

Shrinkage reducing admixtures may be used with other admixtures provided they are added separately. These admixtures perform better when they are used with high range water reducing admixtures.

THERMAL EFFECTS

Thermal contraction will develop about 14 hours to one week after construction and the heat generated during hardening process of concrete will be lost to the environment. The drop of 10^{0}C temperature will be common and this will result in a contraction strain of 100 x 10^{-6}.

COMMON PROBLEMS WITH FLOOR SLAB

Most of the common problems associated with the use of industrial ground floors are –

a. Considerable wear and tear on the floor

b. Cracking

c. Settlement

d. Seepage of water through cracks and the floor slab is often wet.

e. Spillage of oil from moving vehicles and the surface may be oil soaked.

f. Discolouration

INDUSTRIAL FLOOR SUPPORTED ON PILES

It may be possible to have a situation when the industrial concrete ground floor may be supported on piles. The decision for piling is primarily due to soil condition and the nature and application of loads on the ground floor and other requirements. The design of such floors is often done on the assumptions that at working load the section is cracked and the load induced stresses are resisted by reinforcement. The design will be carried out in the conventional manner with reinforcement placed in one or in two layers and in both directions. The cracking of the slab at the upper surface can be anticipated when the slab is loaded. Hence cracks will develop on the floor.

The design of pile supported ground floor slab will be similar to suspended floors, say in an office complex.

Avoiding cracks will be the most important objective in the design. By limiting crack widths only on the floor as in structural design will not be enough. Deliberately using more steel in the slab will lead to more fine cracking on the floor. Such cracking will be too fine to repair and yet may break down under the action of trucks and other vehicles.

The cracking may follow two basic pattern for pile supported concrete floors

Firstly in nominal straight lines co-incident with pile grids [8]. Sometimes in one direction only but in other cases in both orthogonal directions. The cracks will be initiated by drying shrinkage.

Secondly, in some cases crack patterns develop over piles commonly annulus with cracks radiating away from it. The cracks tend to develop slowly as the floor is loaded and very much related to applied loads although drying shrinkage will play its part.

With the development of cracks on the floor the concern will be associated with the long term serviceability of the floor and its use.

With steel fibre reinforced concrete (SFRC)

Normally Yield line analysis is used for calculating moments for ultimate strength. Furthermore punching shear stress is also to be checked. It has been observed that there is strong co-relation between poor performance of the floor and slab thickness. The following items are important for the design especially the slab thickness and the robustness –

a. Effective span - It is often assumed that the yield line will form at a distance half the slab depth away from the edge of the supports. This is a reasonable assumption for the continuous support but for round pile heads this may not be appropriate as noticed form the actual crack pattern on the slab. For the design and for calculating moments the formation of yield line should be assumed well inside the pile [8]. This will increase the effective span by 25% (approx.) and will increase the slab thickness in the order of 10-15% [6].

b. SFRC performance - The performance has been reported to be good [8].

c. Reducing shrinkage stresses - This is well established in ground supported floor slabs. The reduction of shrinkage may be generally managed by avoiding high cement and water contents in the mix and by reducing restraint from sub-base and adequate provision of joints. The same principles are applicable to pile supported floors also with some limitations.

STEEL FIBRE REINFORCED CONCRETE FLOOR SLABS

Steel fibre reinforced concrete (SFRC) slabs can provide crack-less floors. There may be slightly increased risks of cracking with joint less floors compared to saw cut floors but these risks can be overcome [4]. There are a number of advantages to joint less floor and these can not be over looked when deciding or assessing such proposals.

Concrete slab with steel fibres will provide an increase in load bearing capacity and will also improve other mechanical properties as mentioned below [4]:

- Ductility
- Impact resistance
- Fatigue resistance
- High resistance against spalling
- Durability
- Low crack width under service condition
- Flexural strength in all three directions

Fibres may be added either at the batching plant or into the truck mixer at site. Fibres should preferably be added along with the aggregates or after the aggregates have been batched. Fibres with aspect ratio greater than about 50 can be susceptible to agglomeration into balls in the concrete. Manufacturers use special packing methods or equipment to overcome this risk. Checks and quality control procedure shall ensure thorough dispersion of fibres into the mix.

Typical mixing time is 5 minutes at full drum speed (12 rev./min.). When aspect ratio of fibres is less than 50 fibres may be dispensed directly without any risk of balling [9]. With higher aspect ratio special care may be necessary to avoid the risk.

It may be necessary to increase fine aggregate content to improve fibre dispersion and to make the concrete easier to compact and finish [9]. The water demand of the mix will be increased if the content of fibres is increased. The fibres in the mix will have some effect on workability; high range water reducing admixtures are normally used in steel fibre reinforced concrete.

TYPES OF STEEL FIBRES

Steel fibres are generally manufactured from cold-drawn wire, steel sheet and other form of steel. The steel fibres may be classified into four (4) basic categories as mentioned below :

a. Type-1 - Drawn wire

b. Type-2 - Slit sheet

c. Type-3 - Melt extract

d. Type-4 - Others

Further methods of characterization will be –

- Cross section - Round
  Flat
  Crescent

- Deformation - Straight
  Wavy
  Crimped end
  Enlarged end
- Length - 19-60 mm
- Aspect ratio (length/diameter) - 30-100
- Tensile strength - 345-1700 N/sqmm.
- Young's Modulus - 205^{KN}/sqmm.
- Ductility - Can be bent 180^0 without rupture

The factors that will be important for the performance of steel fibres in concrete are:

- Anchorage mechanism (i.e. straight or deformed shape end comes or hooked ends)
- Fibre length and diameter and aspect ratio
- Dosage (Kg./cum.)
- Fibre count (Number of fibres per Kg. of fibre) which is function of fibre size and dosage
- Tensile strength

Different types of steel fibres have been used in concrete construction. As mentioned before, steel fibres in concrete will change the behaviour of concrete by converting the brittle type of material to ductile one. When bridging a crack the properties of the fibre and its anchoring will be important related to snapping of the fibre and its ductility.

Dramix fibres have been used by the engineers covering different applications over many years. In this connection three types of Dramix fibres may be mentioned as Dramix-3D, Dramix-4D and Dramix-5D, Dramix-3D fibres are single hooked fibres [10]. By increasing length/diameter ratio better performance of the fibres has been achieved. It is mentioned that ultra high tensile strength 5D Dramix fibres will be suitable for all structural applications [10].

ADVANTAGES OF USING FIBRES OVER TRADITIONAL METHOD OF CONSTRUCTION

The following advantages [5, 6] over traditional floor construction with reinforcement may be mentioned.

a. Higher quality concrete elements as there will not be any mistakes related to installation of steel and no unexpected variations in the effective depth.

b. Reduced and controlled concrete shrinkage.

c. Improve durability

d. Improve impact and fatigue resistance

e. Improve flexural strength in all three directions

f. No site expenditure for laying or moving fabric/reinforcing bars.

g. No storing, lifting or hoisting of fabric/reinforcement bars on site. Steel fabric/reinforcing bars may have been stored on site for weeks before being used.

h. No corrosion, damage or theft of fabric/reinforcing bars from site.

i. No cutting of fabric/reinforcement at site.

j. No third party accidents or liability.

k. Labour saving during installation as the concrete may be self compacting and does not need poker vibration.

l. No cost for chairs or tie wire.

m. Easier, quicker and simpler concrete pours and concrete can be easily pumped.

n. Lower carbon foot print especially for polypropylene fibres.

o. Potential cost savings on materials.

MATRIX SATURATION

It will be important to saturate the concrete matrix with steel fibres in such a way that the steel fibre spacing in all direction will be equal to at least the maximum aggregate size [11]. The fibre length should be 2.5-3 times the size of aggregate so that the fibre can overlap and bridge fully all large aggregate particles.

The 3D fibre spacing, s, is a function of fibre diameter, d and dosage rate Vm.

$S = 122 \times d/\sqrt{Vm}$
with 50 kg/cum., TABLEX + 1/60 fibres
$S = 122 \times 1/\sqrt{50} = 17.25$ mm.

Often round cross-section, strong, ductile, rather stiff are used with an anchoring shape so that they offer high pull-out loading. 1 mm diameter is limited to a dosage rate of 50 kg/cum.

Smaller diameter fibres are not used although they can saturate the concrete with a dosage rate as low as 25 kg/cum. for a 0.6 mm diameter fibre.

MIX DESIGN [11]

The concrete mix design must ensure that the concrete must be properly mixed and can be satisfactorily transported, pumped, placed and finished. The following items will be relevant

a. Aggregate grading in the mix

b. Cement content and maximum water cement ratio of about 0.5 to 0.55. A super-plasticiser may be required.

c. Slump prior to addition of super-plasticiser and the strength class.

The aggregate grading should be continuous with 20 mm as the maximum aggregate size and with an increased 12 mm maximum size so that the steel fibres are accommodated between aggregate particles. The coarse aggregate/sand ratio should be about 0.9 : 1.0 with at least 475-500 kg/cum. fines smaller than 200 including the cementitous materials.

DURABILITY WHEN STEEL FIBRES ARE USED

Atmospheric humidity after placement of concrete will be important in determining durability of the structures during use [7]. With high temperature and dry conditions, if present, during placement of concrete, water will evaporate quickly and following problems may occur which will affect long term durability –

a. Plastic shrinkage cracking

b. Drying shrinkage cracking

c. Premature cement hydration

Steel fibres in concrete are well protected by the alkalinity of cement paste in the mix. Fibres being discontinuous in the mix, will not be able to produce galvanic corrosion. Small volume of each fibre even if they crack will not be able to produce bursting stresses like large diameter bars when corroded. There are no minimum cover requirements. There may be loose or partially embedded fibres on the concrete surface that may corrode later. In order to produce fibre-free finish surface the following items will be important [9] –

- Fibre type
- Compaction method
- Screed method
- Discharge/placement

Even after taking sufficient care some steel fibres may be present at the surface. The common practice is to snip the ends with wire cutters and fill the surface with resin mortar. Other methods often employed to remove loose fibres from plastic concrete are using brooms and magnetic rollers.

SYNTHETIC FIBRES

Short polypropylene micro fibres and large synthetic fibres are being developed and used like steel fibres for the construction of industrial floors.

Effects of microfibres on concrete properties [5]

The following may be mentioned :

a. Increases homogeneity of the mix, stabilizing the movement of solid particles and blocking bleed water channels.

b. Helps controlling plastic settlement of concrete.

c. Will increase the early age tensile strain capacity of plastic concrete and will restrict the development of plastic shrinkage and drying shrinkage cracks.

d. Will enhance the bahaviour of joints within the concrete.

e. Will improve the surface layer of concrete and thus improves abrasion resistance.

f. Will be effective in distributing impact stresses and delays deterioration.

CONCRETE FLOOR SLAB CONSTRUCTION

As general guide-lines the following items are important for successful execution of the concrete ground floor slab [1, 4].

a. The specification should give clear and precise requirement.

b. The floor shall be designed to carry specified loading with adequate factor of safety.

c. The selected contractor shall be experienced with good track records and with available resources to tackle the execution of the job.

d. Design, drawings and materials specified will be important. The type of concrete and the floor with joints and isolation details or not to be defined clearly.

e. Study of sub-soil condition and water proofing requirement to be ensured.

f. Preparation of well compacted sub-grade and the built-up sub-base layers is important. The layer underlying the concrete slab should have provision to reduce frictional resistance to concrete slab.

g. Shrinkage reducing admixture may be required.

h. The amount of fibres should be minimized to control water demand and cement content and subsequently shrinkage.

i. Control on concrete mix design and proper supervision will be very important.

JOINTS IN FLOOR SLABS [6, 9]

The use of joints in the floor slab will need very careful consideration as the joints may be a significant potential source of problems. The joints are provided for –

- To relieve tensile stresses induced by drying shrinkage or temperature changes.
- To accommodate breaks in the construction process

The joints may be created by

- Sawn induced – cuts should be made to at least $1/3^{rd}$. the slab depth.
- Forming with form work.

JOINTLESS CONSTRUCTION

Jointless construction, in a floor, will mean construction without sawn restrained movement joints. The floor may be constructed for the areas upto 50 m. in each direction [6]. Formed free movement joints are provided at the perimeter of each pour. This method of construction is commonly associated with the design with steel fibres reinforced concrete. Steel fabric reinforcement may be used also and the percentage of steel is often 0.4 to 0.6% in each direction.

The thermal contraction may be computed from the following expression :

$\Delta j = (L \dot{\alpha} T) \times 10^3$

where

Δj = Thermal Contraction in mm

L = Distance between free movement joints (m)

$\dot{\alpha}$ = Co-efficient of thermal expansion of concrete

T = Change of temperature ^{o}(C)

The co-efficient of thermal expansion for concrete is often assumed in design to be $10 \times 10^{-6/oc}$. For other values of concrete for different aggregates, the same may be taken from IS 456 [12].

SELF HEALING OF CONCRETE CRACKS

Some cracks in concrete when exposed to water can heal themselves. White traces at the concrete surface can be noticed signifying formation of calcium carbonate at the cracks. This self-healing is a complicated chemical/ physical process. The following items may be involved in healing the cracks [13]:

a. Hydration of cement paste

b. Precipitation of calcium carbonate crystals

c. Blocking may be caused by water pollution

d. Blocking by concrete particles broken off from the surface of cracks.

The most important factor is the precipitation of calcium carbonate on the crack surface. However, items (c) & (d) above generally may not be involved with industrial ground floor slabs.

MEMBRANES [6]

Polythene sheet at the bottom of concrete slab may be provided to reduce the friction between the slab and sub-base. Membrane shall be over lapped at the edges by at least 300 mm and stitched/welded and to ensure that it is not damaged during construction work. Plastic sheet will inhibit the loss of water and fines from concrete to sub-base. It will also act as a water-vapour-resistant membrane.

APPLICATIONS OF SFRC FLOORING IN PROJECTS

A few applications are mentioned below :

a. 250,000 sqm. of industrial flooring has been completed for a project in Scotland successfully [14]. Joint-less ground bearing SFRC floor slabs were designed and constructed in the chilled and freezer warehouses. However, heavily loaded ground slab has to be fully suspended on concrete piles.

   Joint-less floor with steel fibres as reinforcement was selected for the heavily loaded ware house. For some areas of the ware house individual racking leg loads of 85 KN and a blanket uniformly distributed load of 50 KN/sqm. had been considered.

   The details of the floors are for ground bearing, joint-less SFRC design [8] 150 mm thick 40 MPa concrete reinforced with 40 Kg/cum. of AFT 1/50 undulated steel fibres in the chilled and freezer zones.

   240 mm SFRC in the ambient area reinforced with 45 Kg./cum. of AFT +1/60 undulated steel fibres.

   For external paving area totaling 1,48,000 sqm., the treatment was ground bearing joint-less SFRC design with 180 mm thick slab having construction joints, 40 MPa air entrained concrete reinforced with 40 kg/cum. of AFT undulated steel fibres.

b. Steel fibre reinforced concrete slab had been used, in Belfast [15], for the development of 1200 sq mm. of retail space, 4800 m heavy goods access roads and car parking. Considering soil condition the pile foundation for the suspended floor slab was finalised. The ground floor slab was designed for a loading of 100 KN/sqm. Positioning of formed contraction joints had been adopted and no other joints were provided.

REPAIR OF EXISTING FLOOR SLAB

I. Distress

The common types of distress associated with existing ground floor slabs are -

i. Cracks - Cracks appear on the floor and the same may be wide enough and either single line or wide spread and inter connected. The cracks may be in the floor topping only and sometimes deep enough to penetrate into the concrete slab.

   Such cracks may be caused due to (a) abrasion of wearing course and its separation from the parent concrete, (b) settlement of floor generating cracks in the depressed areas or (c) some of the cracks may be due to the shrinkage of floor topping and further aggravated due to impact from vehicles as well as overloading.

ii. Abrasion and wear & tear - Due to movement of material handling vehicles or dragging of material on the floor, rotational movement of wheels etc. the top wearing course is abraided.

iii. The flooring may be damaged due to ingress of oil from oil spilled on the floor which will weaken the flooring and reduce its resistance to wearing.

iv. The top layer may be damaged due to soaking of water spilled on the floor. The damage may be wide spread or it may form pot holes in weak patches.

v. Settlement of floor and depressions - The floor may settle at places due to non-uniform sub-grade condition and heavy moving loads. In case the execution of the floor was done without proper compaction of the sub-grade leaving weak strata underneath the floor will cause differential settlement from heavy loads and thereby extensive cracking.

vi. Floor may be damaged due to falling of hot objects, hot or molten liquid etc. if appropriate topping to resist temperature is not used.

II. Rehabilitation measures

i. For wide spread cracking, pot holes, oil/water absorption of the floor topping

The existing flooring has to be completely removed and replaced with new floor topping viz non-metallic hardener, polyurathene, silicate, basalt etc. as discussed subsequently depending on the use of the floor.

ii. Cracking of concrete slab at places

Sealing of cracks is to be done with cement or epoxy as recommended. For major damage of the concrete slab, whole or part thickness of the slab to be removed and replaced with new concrete and reinforcement using bonding agent to old concrete. In some cases injection technique with appropriate grouting materials through cracks may be adopted to seal the same.

iii. Settlement of floor

Complete floor in the depressed area and around to be removed and sub-grade to be prepared properly by filling with compacted sand or PCC and the broken part of the slab to be redone with new concrete using bonding agent and overlapping reinforcement.

iv. Extensive cracking, degradation of concrete slab

The concrete slab to be removed to such a depth that a new 150-200 mm slab can be cast. In the case of a heavy duty floor the new RCC slab will have two layers of reinforcement and steel fibres may have to be added to concrete. The concrete grade shall be preferably M40.

PRODUCTS THAT MAY BE CONSIDERED

Common industrial floors are provided with movement joints i.e. expansion and contraction joints at appropriate spacing. However for heavier loading joints should be avoided as much as possible since defects are mostly seen near the joints. The floor should be preferably jointless and the spacing of joints should be preferably not less than 50 m. For jointless floors the RCC grade slab should be provided with two layers of reinforcement at both top and bottom and concrete mixed with steel fibres.

To achieve better workability of concrete with higher content of fine aggregate, used for better dispersion of steel fibres, and for durability the concrete should be admixed with high range water reducing admixture (melamine or naphthalene based) from reputed manufacturer at appropriate dose.

The floor slab should be cast in alternate panels in chequered board fashion. Panel size should be preferably about 3-4 m in each direction but should not exceed 5 m. Therefore, application of old to new concrete bonding agent on the vertical faces of already set concrete will be recommended before pouring concrete in the adjacent panels. The bonding agent shall be preferably epoxy based with long pot life from reputed manufacturer.

For crack sealing and injection grouting application of polymer modified compound is recommended for sealing of chased V-grooves and epoxy mortar to be used for fixing of grouting nozzles/nipples. When injection is done with cement slurry it is mandatory to use non-shrink grout admixture. When epoxy injection is adopted for very fine cracks (say 0.2 mm.) the same should be moisture insensitive and having very low viscosity.

The wearing coat on top or the floor finish items can be anyone of the following depending on the degree of abrasion and wear and tear that it may be required to withstand. In order of increasing toughness the materials recommended are :

i. Non-metallic floor hardener (dry shake quartz based) for less degree of abrasion. This will also have a choice of two to three colours.

ii. Non-metallic floor hardener (dry shake carborandum or emery based) for higher degree of abrasion. Choice is available to select from a few colours.

iii. Polyurathane based floor topping (4-6 mm thick) having a wide choice of colours.

iv. Silicate based impregnating type pore sealers is recommended to be applied on the non-metallic floor topping or on concrete surface when directly used as floor.

v. The toughest and high temperature resistant flooring will be with basalt based grout with thickness ranging from 20 mm to 50 mm depending on severeness of abrasion and heat.

CONCLUSIONS

An attempt has been made to discuss issues related to the design of industrial floors with fibre reinforcement. Different aspects specially loads, supporting arrangements, present design trend/assumptions etc. are briefly covered. General problems associated with industrial flooring are briefly addressed. Both metalic and non-metalic fibres, in floor slab construction, have been mentioned. Repairing considerations along with some basic and special materials have been discussed. The use of steel fibres along with some nominal reinforcement has been recommended for the design and construction of industrial ground floor slabs.

Acknowledgement

The authors would like to thank the management of Development Architects Private limited (DAPL) for the encouragement shown in publishing the paper.

References

1. DEACON, COLIN, Welded Steel Fabric in Industrial Ground Floor Construction, Concrete, November/December, 1991.
2. MEHTA, P.K., Concrete, Microstructure, Properties and Materials, ICI.
3. Ganguly K.K., Fibre Reinforced Concrete, International Conference on Advances in Civil Engineering in association with CAFETINNOVA Technical Society, Hyderabad and IGS, Guntur, K.L. University Vijayawada, AP, 23rd October, 2011.
4. WILLIAMSOM, NEIL, Steel fibre reinforced concrete floors, Concrete, April 2011.
5. BROOK FIELD of ADFIL Construction fibres, The use of macro polypropylene fibres in ground – bearing concrete floors, Concrete April, 2012.
6. Technical Report No. 34, Concrete Industrial Floors, Concrete Society, ACIFC
7. AGOSTINACCHI, MICHELE and CUOMO, GIANLUCA, University of Basilicata, Plastic Shrinkage Reduction in Concrete Pavements due to the Addition of Both Steel and Polymer – modified fibres, Concrete June, 2004.
8. HULETT, TONY, Design and Construction of Pile supported Concrete Industrial Floors, Concrete, September, 2011.
9. Steel fibre reinforced Concrete Industrial Ground Floors, An introductory guide, ACIFC, Concrete.
10. THOOFT, HENDRIK, Reinforcing the future, Concrete, February, 2013.
11. DESTREE, XAVIER, Structural Steel Fibre Reinforced Concrete Construction, Concrete, September, 2007.
12. IS-456, Code of Practice for Plain and Reinforced Concrete.
13. EDVARDSEN, CAROLA, Self-healing of Concrete Cracks, April 1999, Concrete
14. EDDY, DARRYL, UK's biggest-ever SFRC flooring Project, Concrete, March 2008.
15. CAMERON, GREGOR & CLARK, A.J., Steel Fibre Reinforced Pile Supported Car Park in Belfast, Concrete, June 2002.

Dr. Kalyan K. Ganguly is a Civil & Structural Engineer with PhD from England. He is the Director of Development Architects Private Ltd., Kolkata He is a Chartered Engineer and Corporate member of the Institutions of Civil & Structural Engineers, London. He has been associated with different types of projects in India and abroad covering power, fertiliser, chemical plants, educational & commercial complexes, housing & some special projects. He has dealt with repair & restoration work for projects including heritage buildings. He had been an external faculty member of Jadavpur University, Kolkata for a long time. The use of alterative building materials, in projects, is his special interest.

Mr. Kashinath Chatterjee is B.Tech.(Hons.) and M.Tech. in Structural Engineering from I.I.T., Kharagpur. He is the Executive Director of Development Architects Private Ltd., Kolkata. He has been associated with various types of structures for large industrial plants like power, cement, fertilizer, material handling; institutional complexes, multistoreyed buildings, space structures, waterfront and other hydraulic structures, bridges and viaducts. His interests also includes rehabilitation and retrofitting of structures in industrial plants, buildings, bridge and hydraulic structures.