

## 2.3 Industrial floors

The industrial buildings are usually one-story structures but some industrial building may consist of two or more storey. Reinforced concrete or steel-concrete composites slabs are used as a floor system. The rolled steel joists or trusses or plate girders support these slabs. The design of reinforced concrete slabs shall be done as per IS 456-2000. Steel-concrete composite slabs are explained in more detail below.

### 2.3.1 Steel-concrete composite floors

The principal merit of steel-concrete composite construction lies in the utilisation of the compressive strength of concrete in conjunction with steel sheets or beams, in order to enhance the strength and stiffness.

Composite floors with profiled decking consist of the following structural elements in addition to in-situ concrete and steel beams:

- Profiled decking
- Shear connectors
- Reinforcement for shrinkage and temperature stresses

Composite floors using profiled sheet decking have are particularly competitive where the concrete floor has to be completed quickly and where medium level of fire protection to steel work is sufficient. However, composite slabs with profiled decking are unsuitable when there is heavy concentrated loading or dynamic loading in structures such as bridges. The alternative composite floor in such cases consists of reinforced or pre-stressed slab over steel beams connected together using shear connectors to act monolithically (Fig. 2.4).

A typical composite floor system using profiled sheets is shown in Fig. 2.5. There is presently no Indian standard covering the design of composite floor systems using profiled sheeting. The structural behaviour of Composite floors using profiled decks is similar to a reinforced concrete slab, with the steel sheeting acting as the tension reinforcement. The main structural and other benefits of using composite floors with profiled steel decking are:

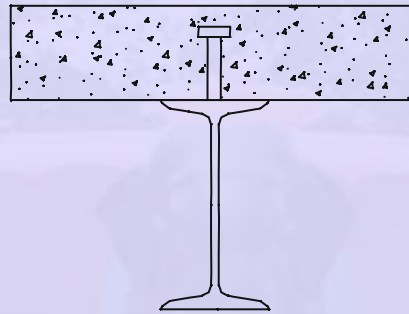
- Savings in steel weight are typically 30% to 50% over non-composite construction
- Greater stiffness of composite beams results in shallower depths for the same span. Hence lower storey heights are adequate resulting in savings in cladding costs, reduction in wind loading and savings in foundation costs.
- Faster rate of construction.

The steel deck is normally rolled into the desired profile from 0.9 mm to 1.5 mm galvanised sheets. It is profiled such that the profile heights are usually in the range of 38-75 mm and the pitch of corrugations is between 150 mm and 350 mm. Generally, spans of the order of 2.5 m to 3.5 m between the beams are chosen and the beams are designed to span between 6 m to 12 m. Trapezoidal profile with web indentations is commonly used.

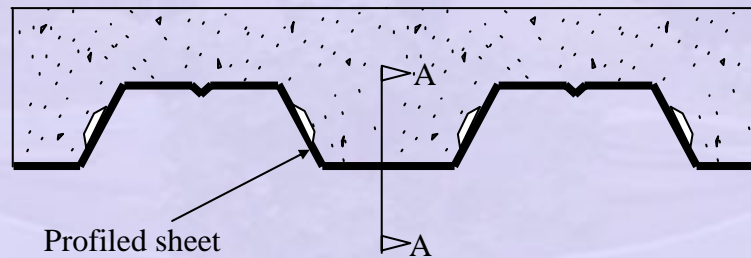
The steel decking performs a number of roles, such as:

- It supports loads during construction and acts as a working platform
- It develops adequate composite action with concrete to resist the imposed loading

- It transfers in-plane loading by diaphragm action to vertical bracing or shear walls
- It stabilizes the compression flanges of the beams against lateral buckling, until concrete hardens.
- It reduces the volume of concrete in tension zone
- It distributes shrinkage strains, thus preventing serious cracking of concrete.



**Fig. 2.4 Steel beam bonded to concrete slab with shear**



**Fig. 2.5 Composite floor system using profiled sheets**

### **Profiled sheeting as permanent form work**

**Construction stage:** During construction, the profiled steel deck acts alone to carry the weight of wet concrete, self weight, workmen and equipments. It must be strong enough to carry this load and stiff enough to be serviceable under

the weight of wet concrete only. In addition to structural adequacy, the finished slab must be capable of satisfying the requirements of fire resistance.

Design should make appropriate allowances for construction loads, which include the weight of operatives, concreting plant and any impact or vibration that may occur during construction. These loads should be arranged in such a way that they cause maximum bending moment and shear. In any area of 3 m by 3 m (or the span length, if less), in addition to weight of wet concrete, construction loads and weight of surplus concrete should be provided for by assuming a load of  $1.5 \text{ kN/m}^2$ . Over the remaining area a load of  $0.75 \text{ kN/m}^2$  should be added to the weight of wet concrete.

**Composite Beam Stage:** The composite beam formed by employing the profiled steel sheeting is different from the one with a normal solid slab, as the profiling would influence its strength and stiffness. This is termed 'composite beam stage'. In this case, the profiled deck, which is fixed transverse to the beam, results in voids within the depth of the associated slab. Thus, the area of concrete used in calculating the section properties can only be that depth of slab above the top flange of the profile. In addition, any stud connector welded through the sheeting must lie within the area of concrete in the trough of the profiling. Consequently, if the trough is narrow, a reduction in strength must be made because of the reduction in area of constraining concrete. In current design methods, the steel sheeting is ignored when calculating shear resistance; this is probably too conservative.

**Composite Slab Stage:** The structural behaviour of the composite slab is similar to that of a reinforced concrete beam with no shear reinforcement. The

steel sheeting provides adequate tensile capacity in order to act with the concrete in bending. However, the shear between the steel and concrete must be carried by friction and bond between the two materials. The mechanical keying action of the indents is important. This is especially so in open trapezoidal profiles, where the indents must also provide resistance to vertical separation. The predominant failure mode is one of shear bond rupture that results in slip between the concrete and steel.

### Design method

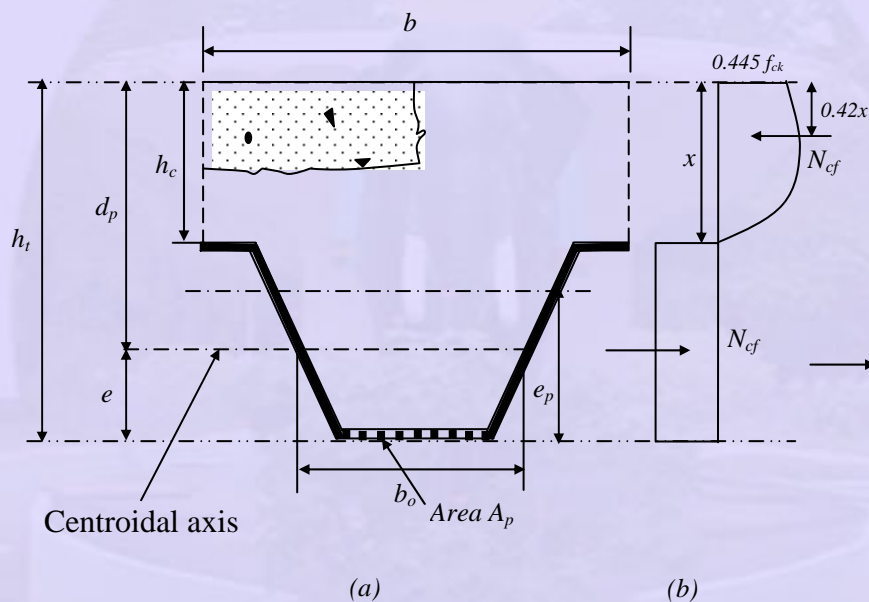
As there is no Indian standard covering profiled decking, we refer to Eurocode 4 (EC4) for guidance. The design method defined in EC4 requires that the slab be checked first for bending capacity, assuming full bond between concrete and steel, then for shear bond capacity and, finally, for vertical shear. The analysis of the bending capacity of the slab may be carried out as though the slab was of reinforced concrete with the steel deck acting as reinforcement. However, no satisfactory analytical method has been developed so far for estimating the value of shear bond capacity. The loads at the construction stage often govern the allowable span rather than at the composite slab stage.

The width of the slab 'b' shown in Fig. 2.6(a) is one typical wavelength of profiled sheeting. But, for calculation purpose the width considered is 1.0 m. The overall thickness is  $h_t$  and the depth of concrete above main flat surface  $h_c$ . Normally,  $h_t$  is not less than 80 mm and  $h_c$  is not less than 40 mm from sound and fire insulation considerations.

The neutral axis normally lies in the concrete in case of full shear connection. For sheeting in tension, the width of indents should be neglected.

Therefore, the effective area ' $A_p$ ' per meter and height of centre of area above bottom ' $e$ ' are usually based on tests. The plastic neutral axis  $e_p$  is generally larger than  $e$ .

The simple plastic theory of flexure is used for analysis of these floors for checking the design at Limit State of collapse load. IS 456: 1978 assumes the equivalent ultimate stress of concrete in compression as  $0.36 (f_{ck})$  where  $(f_{ck})$  is characteristic cube strength of concrete.



**Fig.2.6 Resistance of composite slab to sagging bending**

Full shear connection is assumed. Hence, compressive force  $N_{cf}$  in concrete is equal to steel yield force  $N_{pa}$ .

$$N_{cf} = N_{pq} = \frac{A_p f_{yp}}{\gamma_{ap}} \quad (2.1)$$

$$N_{cf} = 0.36 f_{ck} \cdot b \cdot x$$

where  $A_p$  = Effective area per meter width

- $f_{yp}$  = Yield strength of steel  
 $\gamma_{ap}$  = Partial safety factor (1.15)

The neutral axis depth  $x$  is given by

$$x = \frac{N_{cf}}{b(0.36f_{ck})} \quad (2.2)$$

This is valid when  $x \leq h_c$ , i.e. when the neutral axis lies above steel decking.

$M_{p,Rd}$  is the design resistance to sagging bending moment and is given by:

$$M_{p,Rd} = N_{cf} (d_p - 0.42 x) \quad (2.3)$$

Note that centroid of concrete force lies at  $0.42 x$  from free concrete surface.

The shear resistance of composite slab largely depends on connection between profiled deck and concrete. The following three types of mechanisms are mobilised:

- (i) Natural bond between concrete and steel due to adhesion
- (ii) Mechanical interlock provided by dimples on sheet and shear connectors
- (iii) Provision of end anchorage by shot fired pins or by welding studs (Fig. 2.7) when sheeting is made to rest on steel beams.

Natural bond is difficult to quantify and unreliable, unless separation at the interface between the sheeting and concrete is prevented. Dimples or ribs are incorporated in the sheets to ensure satisfactory mechanical interlock. These are effective only if the embossments are sufficiently deep. Very strict control during manufacture is needed to ensure that the depths of embossments are

consistently maintained at an acceptable level. End anchorage is provided by means of shot-fired pins, when the ends of a sheet rest on a steel beam, or by welding studs through the sheeting to the steel flange.

Quite obviously the longitudinal shear resistance is provided by the combined effect of frictional interlock, mechanical interlock and end anchorage. No mathematical model could be employed to evaluate these and the effectiveness of the shear connection is studied by means of load tests on simply supported composite slabs as described in the next section.

### **Serviceability criteria**

The composite slab is checked for the following serviceability criteria: Cracking, Deflection and Fire endurance. The crack width is calculated for the top surface in the negative moment region using standard methods prescribed for reinforced concrete. The method is detailed in the next chapter. Normally crack width should not exceed 3 mm. IS 456: 2000 gives a formula to calculate the width of crack. Provision of 0.4 % steel will normally avoid cracking problems in propped construction and provision 0.2 % of steel is normally sufficient in un-propped construction. If environment is corrosive it is advisable to design the slab as continuous and take advantage of steel provided for negative bending moment for resisting cracking during service loads.

The IS 456: 2000 gives a stringent deflection limitation of  $\ell/350$  which may be un-realistic for un-propped construction. The Euro code gives limitations of  $\ell/180$  or 20 mm which ever is less. It may be worth while to limit span to depth ratio in the range of 25 to 35 for the composite condition, the former being

adopted for simply supported slabs and the later for continuous slabs. The deflection of the composite slabs is influenced by the slip-taking place between sheeting and concrete. Tests seem to be the best method to estimate the actual deflection for the conditions adopted.

The fire endurance is assumed based on the following two criteria:

- Thermal insulation criterion concerned with limiting the transmission of heat by conduction
- Integrity criterion concerned with preventing the flames and hot gases to nearby compartments.

It is met by specifying adequate thickness of insulation to protect combustible materials. R (time in minutes) denotes the fire resistance class of a member or component. For instance, R60 means that failure time is more than 60 minutes. It is generally assumed that fire rating is R60 for normal buildings.

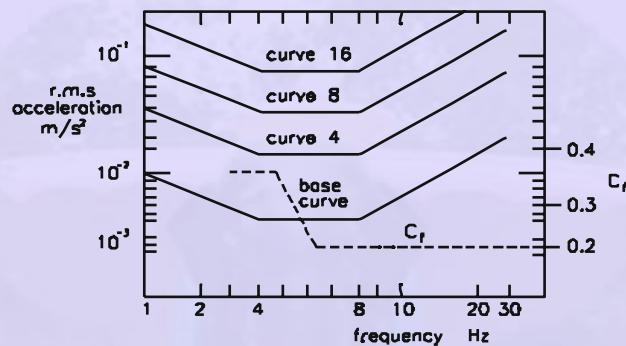
### **2.3.2 Vibration**

Floor with longer spans of lighter construction and less inherent damping are vulnerable to vibrations under normal human activity. Natural frequency of the floor system corresponding to the lowest mode of vibration and damping characteristics are important characteristics in floor vibration. Open web steel joists (trusses) or steel beams on the concrete deck may experience walking vibration problem.

Generally, human response to vibration is taken as the yardstick to limit the amplitude and frequency of a vibrating floor. The present discussion is mainly aimed at design of a floor against vibration perceived by humans. To design a floor structure, only the source of vibration near or on the floor need be

considered. Other sources such as machines, lift or cranes should be isolated from the building. In most buildings, following two cases are considered-

- i) People walking across a floor with a pace frequency between 1.4 Hz and 2.5 Hz.
- ii) An impulse such as the effect of the fall of a heavy object.



**Fig. 2.7 Curves of constant human response to vibration, and Fourier component factor**

BS 6472 present models of human response to vibration in the form of a base curve as in Fig. (2.19). Here root mean square acceleration of the floor is plotted against its natural frequency  $f_0$  for acceptable level  $R$  based on human response for different situations such as, hospitals, offices etc. The human response  $R=1$  corresponds to a “*minimal level of adverse comments from occupants*” of sensitive locations such as hospital, operating theatre and precision laboratories. Curves of higher response ( $R$ ) values are also shown in the Fig.2.7. The recommended values of  $R$  for other situations are

$R = 4$  for offices

$R = 8$  for workshops

These values correspond to continuous vibration and some relaxation is allowed in case the vibration is intermittent.

### Natural frequency of beam and slab

The most important parameter associated with vibration is the natural frequency of floor. For free elastic vibration of a beam or one way slab of uniform

$$f_0 = K \left( \frac{EI}{mL^4} \right)^{\frac{1}{2}} \quad (2.4)$$

section the fundamental natural frequency is,

Where,

$K = \pi/2$  for simple support; and

$K = 3.56$  for both ends fixed.

$EI$  = Flexural rigidity (per unit width for slabs)

$L$  = span

$m$  = vibrating mass per unit length (beam) or unit area (slab).

According to Appendix D of the Code (IS 800), the fundamental natural frequency can be estimated by assuming full composite action, even in non-composite construction. This frequency,  $f_1$ , for a simply supported one way system is given by

$$f_1 = 156 \sqrt{EI_r / WL^4}$$

Where

$E$  = modulus of elasticity of steel, (MPa)

$I_T$  = transformed moment of inertia of the one way system (in term of equivalent steel) assuming the concrete flange of width equal to the spacing of the beam to be effective ( $\text{mm}^4$ )

$L$  = span length (mm)

$W$  = dead load of the one way joist (N/mm)

The effect of damping, being negligible has been ignored.

Un-cracked concrete section and dynamic modulus of elasticity should be used for concrete. Generally these effects are taken into account by increasing

$$\delta_m = \frac{5mgL^4}{384EI} \quad (2.5)$$

the value of  $I$  by 10% for variable loading. In absence of an accurate estimate of mass ( $m$ ), it is taken as the mass of the characteristic permanent load plus 10% of characteristic variable load. The value of  $f_0$  for a single beam and slab can be evaluated in the following manner.

The mid-span deflection for simply supported member is,  
Substituting the value of ' $m$ ' from Eqn. (2.5) in Eqn. (2.4) we get,

Where,  $\delta_m$  is in millimetres.

$$f_0 = \frac{17.8}{\sqrt{\delta_m}} \quad (2.6)$$

However, to take into account the continuity of slab over the beams, total deflection  $\delta$  is considered to evaluate  $f_0$ , so that,

$$f_0 = \frac{17.8}{\sqrt{\delta}} \quad (2.7)$$

Where,  $\delta = \delta_b + \delta_s$

$\delta_s$  – deflection of slab relative to beam

$\delta_b$ - deflection of beam.

From Equation. (2.6) and (2.7)

$$\frac{1}{f_0^2} = \frac{1}{f_{0s}^2} + \frac{1}{f_{0b}^2} \quad (2.8)$$

Where  $f_{0s}$  and  $f_{0b}$  are the frequencies for slab and beam each considered alone.

$$f_{0b} = \frac{\pi}{2} \left( \frac{EI_b}{msL^4} \right)^{1/2} \quad (2.9)$$

$$f_{0s} = 3.56 \left( \frac{EI_s}{ms^4} \right)^{1/2} \quad (2.10)$$

From Eqn. (2.8) we get,

Where,  $s$  is the spacing of the beams.

In the frequency range of 2 to 8 Hz in which people are most sensitive to vibration, the threshold level corresponds approximately to 0.5%  $g$ , where  $g$  is the acceleration due to gravity. Continuous vibration is generally more annoying than decaying vibration due to damping. Floor systems with the natural frequency less than 8 Hz in the case of floors supporting machinery and 5 Hz in the case of floors supporting normal human activity should be avoided.

### Response factor

Reactions on floors from people walking have been analyzed by Fourier Series. It shows that the basic fundamental component has amplitude of about 240N. To avoid resonance with the first harmonics it is assumed that the floor

has natural frequency  $f_0 > 3$ , whereas the excitation force due to a person walking

$$\bar{F} = 240 C_f \quad (2.11)$$

has a frequency 1.4 Hz to 2 Hz. The effective force amplitude is,

where  $C_f$  is the Fourier component factor. It takes into account the differences between the frequency of the pedestrians' paces and the natural frequency of the floor. This is given in the form of a function of  $f_0$  in Fig. (2.19).

$$y = \frac{\bar{F}}{2k_e S} \sin 2\pi f_0 t \quad (2.12)$$

The vertical displacement  $y$  for steady state vibration of the floor is given approximately by,

$$\begin{aligned} \text{Where } \frac{\bar{F}}{k_e} &= \text{Static deflection floor} \\ \frac{1}{2\zeta} &= \text{magnification factor at resonance} \\ &= 0.03 \text{ for open plan offices with composite floor} \\ f_0 &= \text{steady state vibration frequency of the floor} \end{aligned}$$

#### RMS value of acceleration

The effective stiffness  $k_e$  depends on the vibrating area of floor,  $L \times S$ . The width  $S$  is computed in terms of the relevant flexural rigidities per unit width of floor which are  $I_s$  for slab and  $I_b/s$  for beam.

$$a_{\text{r.m.s}} = 4\pi^2 f_0^2 \frac{\bar{F}}{2\sqrt{2}k_e \zeta} \quad (2.13)$$

$$S = 4.5 \left( \frac{EI_s}{mf_0^2} \right)^{1/4} \quad (2.14)$$

As  $f_{0b}$  is much greater than  $f_{0s}$ , the value of  $f_{0b}$  can be approximated as  $f_0$ . So, replacing  $mf_0^2$  from Eqn. (2.9) in Eqn. (2.12), we get,

$$\frac{S}{L} = 3.6 \left( \frac{I_s S}{I_0} \right)^{1/4} \quad (2.15)$$

Eqn. (2.15) shows that the ratio of equivalent width to span increases with increase in ratio of the stiffness of the slab and the beam.

The fundamental frequency of a spring-mass system,

$$f_0 = \frac{1}{2\pi} \left( \frac{k_e}{M_e} \right)^{1/2} \quad (2.16)$$

Where,  $M_e$  is the effective mass =  $mSL/4$  (approximately)

From Eqn. (2.18),

$$k_e = \pi^2 f_0^2 mSL \quad (2.17)$$

Substituting the value of  $k_e$  from Eqn. (50) and  $F$  from Eqn. (2.11) into Eqn. (2.13)

$$a_{rms} = 340 \frac{C_f}{msL\zeta} \quad (2.18)$$

From definition, Response factor,

Therefore, from Equation (52),

$$a_{rms} = 5 \times 10^{-3} R \text{ m/s}^2 \quad (2.19)$$

To check the susceptibility of the floor to vibration the value of  $R$  should be compared with the target response curve as in Fig. (2.19).

$$R = 68000 \frac{C_f}{msL\zeta} \quad \text{in MKS units} \quad (2.20)$$