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Development of Program and Parametric Study of Reinforced Concrete Slab and Composite Steel - Concrete Slab

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***Abstract*—The design of structures for buildings and bridges is mainly concerned with the provision and support of load-bearing horizontal surfaces. These floors or decks are usually made of reinforced concrete as it satisfies the criteria of low cost, high strength, and resistance to corrosion, abrasion, and fire. Moreover the beams are also of concrete, so the monolithic nature of the construction makes it possible for a substantial breadth of slab to act as the top flange of the beam that supports it. At large spans and particularly where the susceptibility of steel to damage by fire is not a problem, for example in bridges and multi-storey car parks, steel beam becomes cheaper than concrete beam. By development of shear connectors, it is practicable to connect the slab to the beam so as to obtain the T-beam action as in concrete construction.**

Composite construction has proven popular because it combines structural efficiency with speed of construction to offer an economic solution for a wide range of building types. Composite slab consist of profiled steel decking with an in-situ reinforced concrete topping. The decking not only acts as a permanent formwork to the concrete, but also provides sufficient shear bond with the concrete. So, when the concrete has gained strength, the two materials act together compositely. The composite interaction is achieved by the attachment of shear connectors to the top flange of the beam. Composite slab is commonly used (with steel beams & columns) in the commercial, industrial, leisure, health and residential building sectors. Although most commonly used on steel framed buildings, composite slabs may also be supported off masonry or concrete components. Above this, it has many beneficiary aspects like speedy construction, structural stability, shallower construction, sustainability etc.

Here, our aim is to study development of program of the design of R.C.C. & Composite slab along with its parametric study. Programming is carried out using powerful MS Excel for design of slabs. Estimation of material quantity and cost are also studied here.

Keywords-abrasion, composite construction, profiled steel decking, shear connectors, framed buildings

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I. INTRODUCTION

Currently in India, most of the structures being designed are reinforced concrete structures. They are suitable for short spans, like residential and commercial buildings. When used in long spans, like in industries, require larger depths. Also after some span, the depth can be so large that it is not feasible. Composite slab is a slab with profiled steel decking and reinforced concrete topping. Decking acts as permanent formwork to the concrete in construction stage and also acts as tension reinforcement in composite stage. It also provides composite action of steel and concrete. This is achieved by the shear bond between the concrete and sheet when concrete gains its strength.

Shear connectors are attached to the top of the beam flange, which provide sufficient longitudinal shear connection between the beam and concrete. This provides the composite interaction. Due to the speed of construction, composite slabs and beams with steel columns are commonly used in the commercial, industrial, health and residential sectors. It may also be supported on masonry or concrete components. [1-2]

Aim of the work is to do a parametric comparison between R.C.C. slab and Composite slab to find the economic and most feasible solution by developing program for the practicing engineers.

Composite slab is structurally cost effective than reinforced concrete slab and should be used practiced with proper codal provisions.

II. TYPES OF SLAB

There are different types of slabs like reinforced concrete slab, composite slab, flat slab, grid slab. The conventional slab with concrete and steel bars is called reinforced concrete slab. Slab with profiled sheet deck and concrete over it is a composite slab. Flat slab is a slab which directly rests on column without any beam under it. Grid slab is a slab with grid of perpendicular beams for increasing aesthetics of the slab.

A. R.C.C. Slab:

In reinforced concrete structures, slabs are made up of reinforced concrete and supported on beams or columns. As per the support condition of the slab and the spanning in the two directions, r.c.c slab can be structurally classified as:

As per supports:

- Simply Supported Slab
- Continuous Slab

As per Spanning in two directions:

- One Way Slab
- Two Way Slab

They are as shown in Fig1:

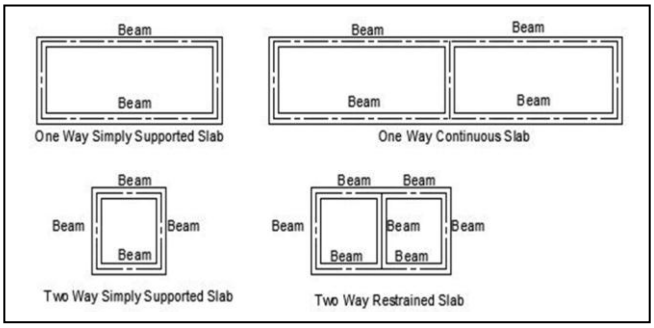

Fig1: Types of R.C.C. Slabs

Design for resistance:

Design is based on limit states method. Design resistance is found out as per the IS Code 456-2000.

Design for serviceability:

As deflection criteria is also a parameter for designing a member as per limit states method of design, the deflection satisfies maximum deflection criteria as per IS 456-2000 for different support conditions.

B. Composite Slab:

A composite slab has steel profiled sheet and concrete topping over it. The slab can either be proped or unproped as per the free area required in the construction stage. For short spans, unproped is suitable and vice versa. The slab can have a depth of around 100 to 250 mm in shallow deck and 250 to 300 mm in deep decking.

The two main structural functions of steel decking are:

- Support the weight concrete and reinforcement, with temporary loads which act during construction stage.
- The composite action of deck with concrete supports the floor loads in composite stage to form a 'composite slab'.

The deck helps the beam against bending laterally due to torsion buckling, and also acts as diaphragm to stabilize the building as a whole to transfer wind loads to column when fixings are provided.

It can be considered as a reinforced concrete slab with deck as the reinforcement. The load carrying capacity of this slab mostly depends on shear bond between the deck and the concrete which is enhanced by the interlock provided by the embossments in the deck. Usually the slab is designed as simply supported without accounting to the continuity offered by reinforcement at the supports.

Design for resistance

Design resistance is found out as per the Eurocode 4- 2004.

Design for serviceability

It is necessary to limit the deflections at the construction stage to limit the volume of concrete that is placed on the decking. Excess deflections will lead to 'ponding' of the concrete, and this will increase the dead loads on the structure. Proper decking and propping are required to reduce ponding.

III. Design Procedure

A. Reinforced Concrete Slab Design

Steps involved in reinforced concrete design are:

- Calculate the moments to be carried by the slab due to loads subjected to it
- Calculate the effective depth required for the moments calculated
- Check for depth provided
- Calculate reinforcement for the moments
- Check for serviceability
- Provision of edge & torsion reinforcement if required

B. Composite Slab Design:

Steps involved in composite slab design are:

- List the decking sheet data
- List the loading
- Design the profile sheeting as shuttering (construction stage)

i. Calculate effective length of Span

$$l_e = \frac{l - B + d_{ap}}{2} \quad (1)$$

Where, B – Width of top flanges of the supporting steel beams

d_{ap} –The depth of the sheeting

l –Actual span of the composite floor

If prop is not provided in construction stage then

$$l_e = l - B + d_{ap} \quad (2)$$

ii. Compute factored moment & vertical shear

iii. Check adequacy for moment

Design moment = M_{pa}/γ_{ap} (3)

Where, M_{pa} –Plastic moment of resistance

γ_{ap} –Partial safety factor (1.15)

iv. Check adequacy for vertical shear

Design vertical shear = V_{pa}/γ_{ap} (4)

Where, V_{pa} –Resistance to vertical shear

v. Check deflections

$$\delta_{max} = \frac{wl_e^4}{185E_aI_p} \quad (5)$$

Where, w –Design load at construction stage

l_e –Effective length of span

E_a–Modulus of elasticity of steel

I_p–Moment of inertia

- Design of composite stage

i. Calculate effective length of span

l_e =Clear distance between the supports + effective depth of the slab (6)

ii. Compute factored moment & vertical shear

iii. Check adequacy for moment

$$M_{p.Rd} = N_{cf}(d_p - 0.42\ x) \quad (7)$$

Where, $M_{p.Rd}$ – design resistance to sagging moment

N_{cf} –compressive force

d_p –depth of centroidal axis

x –neutral axis depth

$$N_{cf} = \frac{A_p f_{yp}}{\gamma_{ap}} \quad (8)$$

Where, A_p–effective area per meter width

f_{yp}–yield strength of steel

$$x = \frac{N_{cf}}{b(f_{ck})} \quad (9)$$

f_{ck}–characteristic strength of concrete

iv. Check adequacy for vertical shear

$$V_{v,Rd} = (b_o/b)\tau_{RD}\ k_v(1.2 + 40\rho) \quad (10)$$

τ_{Rd} – is the basic shear strength of concrete

k_v allows higher shear strength for shallow members

$k_v = (1.6 - dp) \geq 1$ with dp in m (11)

ρ allows a small contribution due to shearing

$\rho = A_p/(b_o\ d_p) < 0.02$ (12)

Ap = effective area of shearing within width b_o

v. Check adequacy for longitudinal shear

$$V_{i.Rd} = bd_p\frac{\left(\frac{mA_p}{bl_s}\right)}{\gamma_{vs}} \quad (13)$$

l_s –shear span = $l_e/4$

γ_{vs} –partial safety factor for shear studs (1.25)

vi. Check serviceability, i.e. cracking and deflection.

Cracking: Provide anti crack reinforcement of 0.4% for propped condition and 0.2% for unproped condition.

Deflection: The span to depth ratio should be limited to 25 for simply supported, 32 for one end continuous and 35 for internal slab. [3-10]

IV. Result Tables

The results from tables 1 - 8 are found based on the design programs developed as per the procedure given in Section 3.

A. *Moment carrying capacity tables:*

Table I ONE WAY SIMPLY SUPPORTED SLAB MOMENT CAPACITY

Span (m x m)	R.C.C. Slab		Composite Slab	
	Depth (mm)	Moment (KNm)	Depth (mm)	Moment (KNm)
2 X 4	100	6.87	110	23.30
2.5 X 5	125	11.58	130	30.42
3 X 6	150	17.68	150	40.99
3.5 X 7	175	25.93	185	65.38
4 X 8	200	35.97	205	76.63

Table II ONE WAY CONTINUOUS THREE SPAN SLAB MOMENT CAPACITY

Span (m x m)	R.C.C. Slab		Composite Slab	
	Depth (mm)	Moment (KNm)	Depth (mm)	Moment (KNm)
2 X 4	100	3.97	100	19.73
2.5 X 5	100	6.12	110	23.30
3 X 6	125	9.43	125	28.64
3.5 X 7	150	13.66	155	48.51
4 X 8	150	17.69	170	56.95

Table III TWO WAY SIMPLY SUPPORTED SLAB MOMENT CAPACITY

Span (m x m)	R.C.C. Slab		Composite Slab	
	Depth (mm)	Moment (KNm)	Depth (mm)	Moment (KNm)
2 X 2	100	3.41	110	23.30
2.5 X 2.5	125	5.74	130	30.42
3 X 3	125	8.16	150	47.64
3.5 X 3.5	150	11.92	185	65.38
4 X 4	175	16.63	205	76.63

Table IV TWO WAY INTERNAL RESTRAINED SLAB MOMENT CAPACITY

Span (m x m)	R.C.C. Slab		Composite Slab	
	Depth (mm)	Moment (KNm)	Depth (mm)	Moment (KNm)
2 X 2	75	1.193	100	19.73
2.5 X 2.5	75	1.845	100	19.73
3 X 3	125	3.159	115	25.08
3.5 X 3.5	125	4.26	140	37.89
4 X 4	125	5.525	160	51.32

B. Structural cost tables:

Table V ONE WAY SIMPLY SUPPORTED SLAB COST

Span (m x m)	R.C.C. Slab		Composite Slab	
	Depth (mm)	*Cost (₹)*	*Depth (mm)*	*Cost (₹)*
2 X 4	100	11480	110	7060
2.5 X 5	125	19990	130	13320
3 X 6	150	31850	150	22290
3.5 X 7	175	48360	185	31770
4 X 8	200	68830	205	46170

Table VI ONE WAY CONTINUOUS THREE SPAN SLAB COST

Span (m x m)	R.C.C. Slab		Composite Slab	
	Depth (mm)	*Cost (₹)*	*Depth (mm)*	*Cost (₹)*
2 X 4	100	33325	100	18810
2.5 X 5	100	50025	110	33060
3 X 6	125	82000	125	54750
3.5 X 7	150	125135	155	74175
4 X 8	150	164600	170	110595

Table VII TWO WAY SIMPLY SUPPORTED SLAB COST

Span (m x m)	R.C.C. Slab		Composite Slab	
	Depth (mm)	*Cost (₹)*	*Depth (mm)*	*Cost (₹)*
2 X 2	100	6260	110	3570
2.5 X 2.5	125	10885	130	6710
3 X 3	125	14915	150	11212
3.5 X 3.5	150	22730	185	15965
4 X 4	175	32970	205	23185

Table VIII TWO WAY INTERNAL RESTRAINED SLAB COST

Span (m x m)	R.C.C. Slab		Composite Slab	
	Depth (mm)	*Cost (₹)*	*Depth (mm)*	*Cost (₹)*
2 X 2	75	6080	100	3170
2.5 X 2.5	75	9000	100	4910
3 X 3	125	15275	115	8300
3.5 X 3.5	125	20300	140	13065
4 X 4	125	26045	160	16950

V. CONCLUSIONS:

The conclusions are made based on moment carrying capacity and structural cost for Fe 415 and M25 as shown in the tables in section IV.

A. Moment Carrying Capacity

- In One Way Simply Supported condition, Composite Slab can carry 2-3.5 times more moment then Conventional R.C.C. Slab.
- In One Way Continuous condition, Composite Slab can carry 3-5 times more moment then Conventional R.C.C. Slab.
- In Two Way Simply Supported condition, Composite Slab can carry 6-6.5 times more moment then Conventional R.C.C. Slab.
- In Two Way Restrained condition, Composite Slab can carry 10-15 times more moment then Conventional R.C.C. Slab.

B. Structural Cost

- Composite slab is 30 – 40 % structurally cost effective than Conventional R.C.C. slab. This difference is due to the formwork provided in R.C.C. slab, where as profiled deck takes care by itself in Composite slab.

C. Deflection

- Deflection is the criteria in Composite slab which governs the overall depth of the slab and so the criteria specified in Eurocode 4 - 2004 for both stages in composite slab requires more depth compared to R.C.C. slab as per IS code 456-2000.

D. Indirect Benefits

The most beneficial consideration of using Composite Slab is it reduces the construction time up to large extent which is far greater than the structural cost.

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