

# Advanced Design of Composite Steel-Concrete Structural element

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## ABSTRACT:

Composite framing system consisting of steel beams acting interactively with metal deck-concrete slab and concrete encased composite columns, has been as a viable alternative to the conventional steel or reinforced concrete system in the high-rise construction. However, in Indian context, it is comparatively new and no appropriate design codes are available for the same. Complications in the analysis and design of composite structures have led numerous researchers to develop simplified methods so as to eliminate a number of large scale tests needed for the design. In the present work, a simplified method of composite slabs, beams and columns design is used and software is developed with pre- and post- processing facilities in VB.NET. All principal design checks are incorporated in the software. The full and partial shear connection and the requirement for transverse reinforcement are also considered. To facilitate direct selection of steel section, a database is prepared and is available at the back end with the properties of all standard steel sections. Screen shots are included in the paper to illustrate the method employed for selecting the appropriate section and shear connectors and thus to verify the design adequacy.

## I. INTRODUCTION

In the old era the design of a building, the choice was normally between a concrete structure and a masonry structure. But the failure of many multi-storeyed and low-rise R.C.C. and masonry buildings due to earthquake has forced the structural engineers to look for the alternative method of construction. Use of composite or hybrid material is of particular interest, due to its significant potential in improving the overall performance through rather modest changes in manufacturing and constructional technologies.

As per IS 11384 [1] the composite construction consists of the use of prefabricated structural units like steel beams, precast reinforced or prestressed concrete beams in combination with in-situ concrete. The construction should ensure monolithic action between the prefabricated and in-situ components so that they act as a single structural unit. These essentially different materials are completely compatible and complementary to each other; they have an ideal combination of strengths with the concrete efficient in compression and the steel in tension.

In composite construction, composite slab is defined as a slab system comprising normal weight or lightweight structural concrete, placed permanently over cold-formed steel deck in which the steel deck performs dual roles of acting as a form for the concrete during construction and as positive reinforcement for the slab during service. A composite beam is formed by a reinforced concrete

slab attached to the upper flange of a hot-rolled or welded steel beam by shear connectors so that they act together as a single section. A steel-concrete composite column is comprising of either a concrete encased hot-rolled steel section or a concrete filled tubular section of hot-rolled steel and is generally used as a load bearing member in a composite framed structure. With the use of composite column along with composite decking and composite beams, it is possible to erect high-rise structure in an extremely efficient manner.

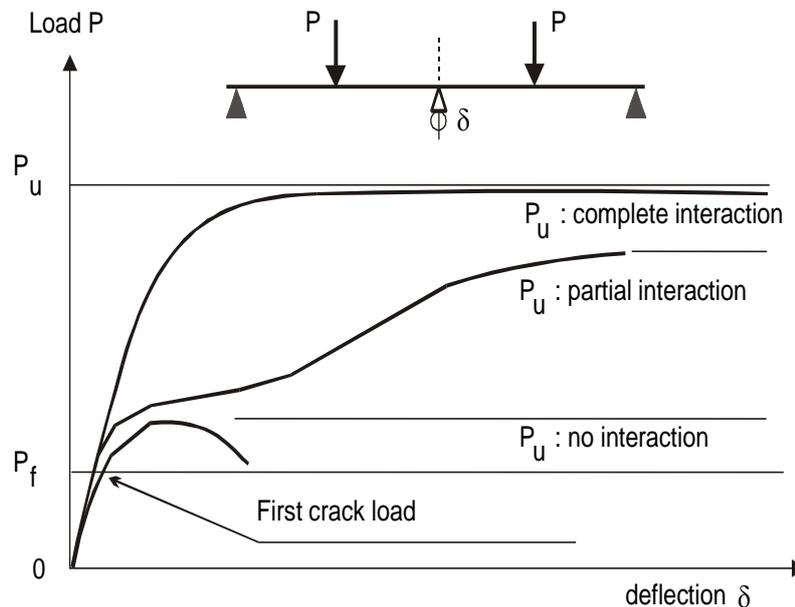
In the present work, for the design of each building component a separate software is developed with pre-, main- and post- processing facilities in VB.NET based on IS code (1985, 2000) and Euro code (2004). The calculation of the limit state of different types of composite structural elements is considered. All principal design checks are incorporated in the software. The full and partial shear connection and the requirement for transverse reinforcement are also considered. To facilitate direct selection of steel section, a database is prepared and is available at the back end with the properties of all standard steel sections.

## II. BEHAVIOUR AND DESIGN ASPECTS OF COMPOSITE SLAB

In floor construction, the use of the solid reinforced concrete slab is being replaced more and more by metal decking, see Fig 1. Modern profiled steel sheeting with additional indentations or embossments acts as both permanent formwork



- Complete interaction between steel and concrete: No global slip at the steel-concrete interface exists. The horizontal transfer of the shear force is complete and the ultimate load  $P_u$  is at its maximum, the composite action is complete. The failure can be brittle, if it occurs suddenly or ductile if it happens progressively.
- Zero interaction between concrete and steel: Global slip at the steel-concrete interface is not limited and there is almost no transfer of shear force. The ultimate load is at its minimum and almost no composite action is observed. The failure is progressive.
- Partial interaction between concrete and steel: Global slip at the steel-concrete interface is not zero but limited. The shear force transfer is partial and the ultimate values lies between the ultimate loads of the previous cases. The failure can be brittle or ductile.



**Fig. 3 Composite Slab Behaviour**

The design of composite slab is carried out based on empirical design formula, available test data and using IS 11384 (1985) and Eurocode 4 (2004). Here plastic analysis of composite section under factor load is also considered. The design for the slab is checked firstly for bending capacity assuming full bond between concrete and steel, secondly for shear bond capacity and finally for vertical shear. Depending upon test data available, the load at construction stage often governs the allowable span rather than at composite slab stage. Shear connectors such as studs, bar and spiral are welded to the top flange of steel section and are intended to transmit the horizontal shear between the steel section and the concrete and also to prevent vertical separation at the interface. Minimum reinforcement is provided to resist shrinkage and temperature stresses.

### III. ILLUSTRATED DESIGN OF COMPOSITE SLAB

Here screen shots of a program developed in VB.NET for design of composite slabs are given. Normally, fabricators of steel sheeting provide engineers and builders with design tables for commonly used spans and thicknesses in order to facilitate the design of composite slabs. Start-up screen form of the developed program is shown in Fig. 4. A form depicted in Fig. 5 is designed for selecting the manufacturer's data for profiled sheet whereas form shown in Fig. 6 is created for entering user defined data. Form for calculating the factor load illustrated in Fig. 7. Check for moment of resistance of section, shear and deflection is carried out as shown in Figs. 8 and 9. After that one can check the neutral axis position and then checking of bending moment and shear for composite stage can be carried out using similar type of forms. Check for serviceability is also included and is carried out automatically.



Fig. 4 Start Up Screen for Composite Floor

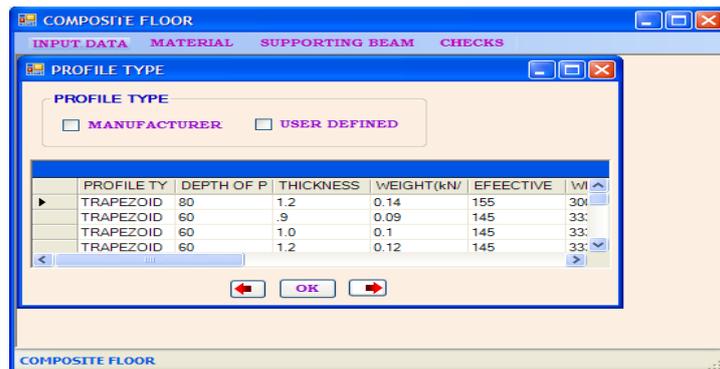


Fig. 6 Form for Selecting Data for Profiled Steel Sheet

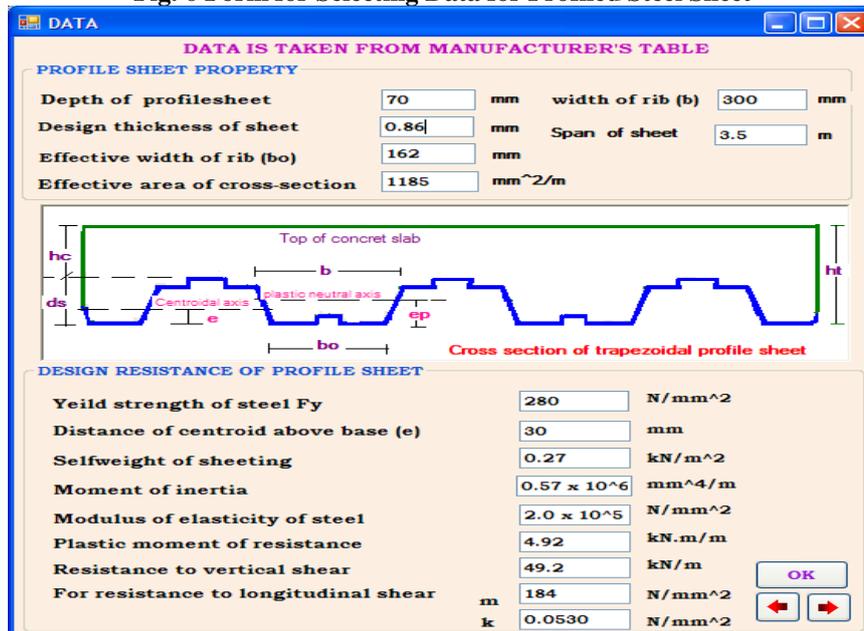


Fig. 6 Form for Entering the Data for Profiled Steel Sheet

**LOADING**

**Loading on the deck**

U-D LOADING IN kN/m<sup>2</sup>

	Unfactored load	Factored load
Imposed load	3.0 kN/m <sup>2</sup>	4.5 kN/m <sup>2</sup>
Self weight of slab	2.14 kN/m <sup>2</sup>	2.88 kN/m <sup>2</sup>
Self weight of sheeting	0.27 kN/m <sup>2</sup>	0.364 kN/m <sup>2</sup>
Construction load	1.5 kN/m <sup>2</sup>	2.25 kN/m <sup>2</sup>
Floor finish	0.5 kN/m <sup>2</sup>	0.675 kN/m <sup>2</sup>
Partition load	1.0 kN/m <sup>2</sup>	1.5 kN/m <sup>2</sup>

Buttons: OK, FACTORED LOAD, ←, →

Fig. 7 Form for Calculating the Factored Load

**CONSTRUCTION STAGE**

**PROFILED STEEL SHEETING AS SHUTTERING AT CONSTRUCTION STAGE**

PROPPED  UNPROPPED

Profiled steel sheeting during construction propped at center

Diagram: Sheeting between two beams (I) with a central prop. Effective length of each span is  $L_e$ .

Effective length of each of two span: 1.71 m

**CHECK FOR MOMENT**

Sagging moment	1.451 kN.m/m
Hogging moment	1.683 kN.m/m
Design moment	4.278 kN.m/m

Buttons: ←, OK, →

popup: decknew safe under bending OK

Fig. 8 Form for Bending Moment at Construction Stage

**CONSTRUCTION STAGE**

**PROFILED STEEL SHEETING AS SHUTTERING AT CONSTRUCTION STAGE**

**CHECK FOR SHEAR**

Vertical shear at support	6.440 kN/m
Vertical shear at prop	7.729 kN/m
Design vertical shear resistance	42.78 kN/m

Button: CHECK

**CHECK FOR DEFLECTION**

Assumed that the prop dose not deflect.

Design load at construction stage	5.143 kN/m <sup>2</sup>
Maximum Deflection	2.085 mm
Allowable Deflection	19.44 mm

Button: CHECK

popup: decknew safe under deflection OK

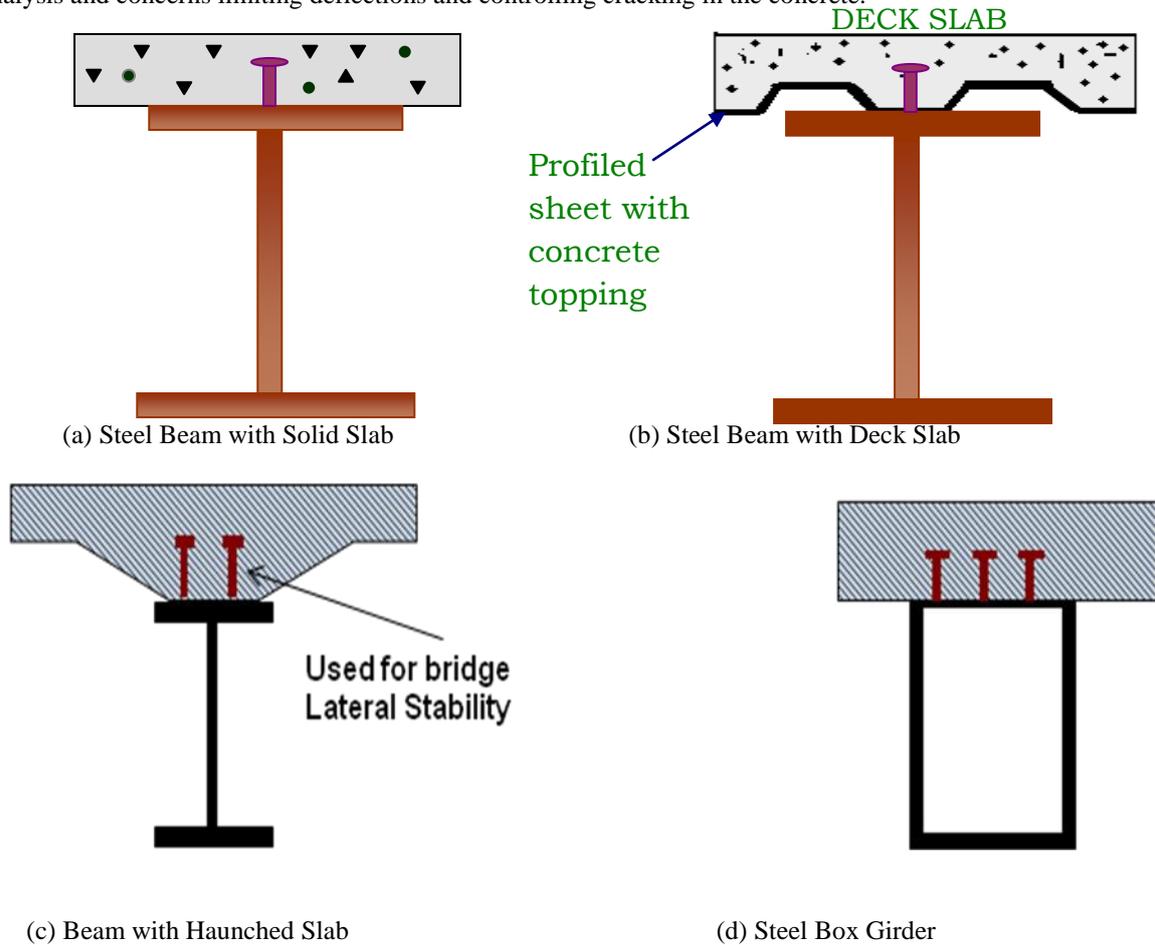
Buttons: ←, OK, →

Fig. 9 Form for Shear and Deflection Check at Construction Stage

#### IV. BEHAVIOUR AND DESIGN ASPECT OF COMPOSITE BEAM

Typical cross-sections of composite beams are shown in Fig. 10. As with steel beams, composite beams must be checked for both ultimate and serviceability limit state. This work covers the principal checks to be applied to simply supported beams and continuous beams. This includes calculation procedures for the moment resistance, which depend on the section classification and position of the neutral axis. The treatment of elastic moment resistance depends on the construction sequence and whether the building is intended mainly for

storage, in which case the loading is predominantly long term. Design checks for vertical shear are similar to those for bare steel beams. The design of the connectors is discussed in relation with full and partial interaction and the requirements for transverse reinforcement are described. Serviceability design is based on elastic analysis and concerns limiting deflections and controlling cracking in the concrete.



**Fig. 10 Typical Sections of Composite Beam**

The behaviour of simply supported composite beams under uniformly distributed load of  $w$ /unit length as shown in **Fig. 11** is best illustrated by using two identical beams (Narayanan and Kalyanraman, 2001), each having a cross section of  $b \times h$  and spanning a distance of  $\ell$ , one placed at the top of the other. For theoretical explanation, two extreme cases of no interaction and 100% (full) interaction are considered and their effect on bending and shear stress distribution is depicted in **Figs. 11 (c)** and **(d)** respectively.

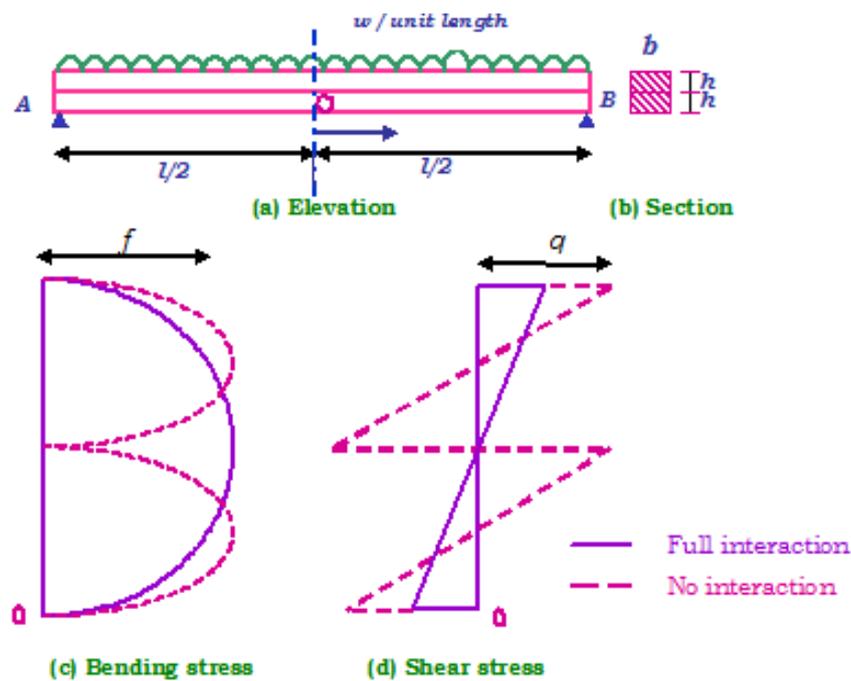


Fig. 11 Effect of Shear Connection on Bending and Shear Stresses

The use of continuous beams in composite construction as an alternative to simply supported beams may be justified by their better load resistance and higher stiffness. However, continuous beams are more complex to design as they are susceptible to buckling phenomena including local buckling and lateral-torsional buckling in the hogging (negative) moment regions.

Tables 1 and 2 depict the equations for moment capacity according to EC4. After selection of type of composite beam, loading, moments and shear forces are calculated at construction stage and composite stage. Sections are checked for ultimate limit state at the construction stage and composite stage for continuous beam. Shear connector can be chosen from the table and one can get the number of shear connectors required for section.

Table 1 Positive Moment Capacity of Section with Full Shear Connection (EC4)

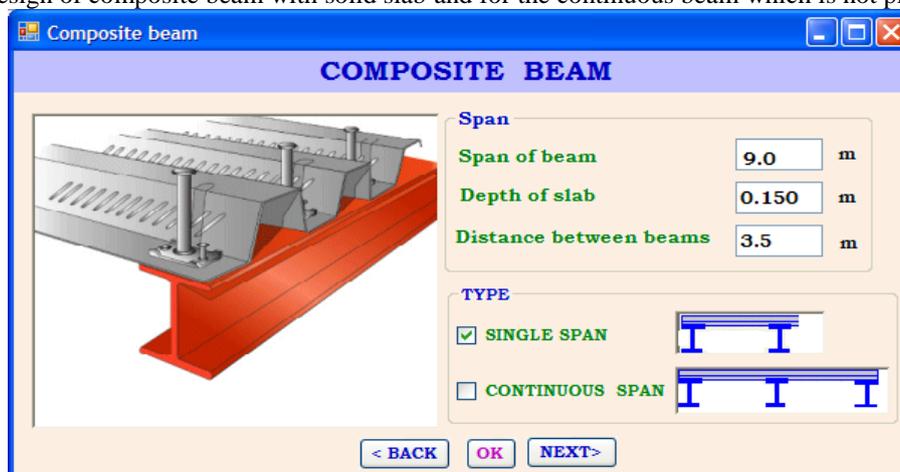
Position of Plastic Neutral Axis	Condition	Moment Capacity $M_p$
Plastic neutral axis in concrete slab	$0.85 \frac{(f_{ck})_{cy}}{\gamma_c} b_{eff} h_c \geq \frac{A_a f_y}{\gamma_a}$	$M_p = \frac{A_a f_y}{\gamma_a} (h_g + h_f - x/2)$
Plastic neutral axis in steel flange	$b_{eff} h_c \frac{0.85(f_{ck})_{cy}}{\gamma_c} < \frac{A_a f_y}{\gamma_a}$	$M_p = N_{a,pl} (h_g + h_t - h_c/2) - N_{ac} (x - h_c + h_t)/2$
Plastic neutral axis in Web	$b_{eff} h_c \frac{0.85(f_{ck})_{cy}}{\gamma_c} + B * T * f_y / \gamma_a < \frac{A_a f_y}{\gamma_a}$	$M_p = N_{a,pl} (h_g + h_t - h_c/2) - N_{ac} (x - h_c + h_t/2) - N_{a,w} (x + h_t + T - h_c)/2$

**Table 2 Negative Moment Capacity of Section with Full Shear Connection**

Position of Plastic Neutral Axis	Condition	Moment Capacity $M_p$
Plastic neutral axis in steel flange	$\frac{A_{aw}f_y}{\gamma_a} < \frac{A_s f_{sk}}{\gamma_s} < \frac{A_a f_y}{\gamma_a}$	$M_p \approx \frac{A_a f_y D}{\gamma_a} \frac{D}{2} + \frac{A_s f_{sk}}{\gamma_s} a$
Plastic neutral axis in web	$\frac{A_s f_{sk}}{\gamma_s} < \frac{A_{aw} f_y}{\gamma_a}$	$M_p = M_{ap} + \frac{A_s f_{sk}}{\gamma_s} \left( \frac{D}{2} + a \right) + \left( \frac{A_s f_{sk}}{\gamma_s} \right)^2 / 4 * t * f_y / \gamma_a$

### V. ILLUSTRATED DESIGN OF COMPOSITE BEAM

A program is developed in Visual Basic for the design of composite beam with R.C.C. slab and design of composite beam with deck slab. A form shown in **Fig. 12** is startup screen for design of simply supported or continuous beam. User can tick mark the checkbox to specify the type of design of composite beam. Program is coded in such a way that the calculations of design of floor deck are transferred directly to the selected beam and loading and moments and shear forces are calculated at construction stage and composite stage. Form of **Fig. 13** gives the choice of section with available section database. Here whole steel table is interfaced so that the user can choose any section available in the market; even user can change the properties in boxes. Selected section properties are automatically added in the boxes. Forms are also developed for checking the section for the ultimate limit state at the construction and composite stages for composite beam as shown in **Figs. 14** and **15**. By entering the diameter and height of shear connector, one can get the number of shear connectors required for the section. Check for stresses in material can be verified by using the form shown in **Fig. 16**. Finally, the calculation is carried out in the program for requirement for transverse reinforcement. Similarly, a design program is developed for the design of composite beam with solid slab for the simply supported and continuous beam. For design purpose, the analysis of composite section is made using Limit State of Collapse Method. As IS: 11384 (1985) code deals with the design and construction of only simply supported composite beams, for continuous beam design criteria are considered as per EC 4 (2004). Various other forms also developed in the program of design of composite beam with solid slab and for the continuous beam which is not presented here.



**Fig. 12 Form for Composite Beam Design**

The screenshot shows the 'COMPOSITE BEAM' software interface. It has three tabs: 'SECTIONAL PROPERTY', 'LOADING', and 'BENDING MOMENT AND CLASSIFICATION'. The 'SECTIONAL PROPERTY' tab is active, showing 'SELECTION OF BEAM SECTION' with radio buttons for 'Single' (selected) and 'Continuous span'. A text field shows 'Depth of composite section' as 600 mm. Below is a table of sections:

DESIGNA	WEIGHT	SECTION	DEPTH	WIDTH	THICKNE
ISMB 450	72.4	92.27	450	150	9.4
ISMB 500	86.0	112.71	500	150	10.0

Below the table, 'Sectional properties' for 'ISMB 450' are listed:

D	450	mm	I <sub>yy</sub>	834	(cm) <sup>4</sup>
A	92.27	(cm) <sup>2</sup>	Z <sub>xx</sub>	1350.7	(cm) <sup>3</sup>
I <sub>ff</sub>	17.4	mm	Z <sub>yy</sub>	111.2	(cm) <sup>3</sup>
T <sub>w</sub>	9.4	mm	R <sub>xx</sub>	18.15	cm
B <sub>f</sub>	150	mm	R <sub>yy</sub>	3.01	cm
b <sub>x</sub>	30390	(cm) <sup>4</sup>	W	72.4	Kg/m

A diagram of an I-section is shown on the right with labels: B<sub>f</sub> (flange width), T<sub>f</sub> (flange thickness), D (total depth), and T<sub>w</sub> (web thickness).

Fig. 13 Form for Selection of Beam Section

The screenshot shows the 'construction stage' software interface. The title is 'CHECK FOR THE ADEQUACY OF THE SECTION AT CONSTRUCTION STAGE'. It has a 'CHECK' button. The design moment at construction stage is 204.90 kN.m. The moment of resistance of the steel section is 334.73 kN.m. A 'decknew' dialog box is open, displaying 'SECTION IS SAFE IN BEANDING' and an 'OK' button. Navigation buttons '<BACK' and 'NEXT>' are at the bottom.

Fig. 14 Form for Check at Construction stage

The screenshot shows the 'composite stage' software interface. The title is 'CHECK FOR ADEQUACY OF THE SECTION AT COMPOSITE STAGE'. It has a 'CALCULATE' button. The effective width of the slab is 2250 mm. The position of the neutral axis is shown as 'neutral axis lies in the slab' with a depth of 65.55 mm. The bending moment at composite stage is 361.71 kN.m, and the moment of resistance of the section is 686.50 kN.m. A 'check' button is present. The design vertical shear is 160.76 kN, and the vertical shear resistance is 275.86 kN. A 'decknew' dialog box is open, displaying 'section is safe' and an 'OK' button. Navigation buttons '<BACK' and 'NEXT>' are at the bottom.

Fig. 15 Form for Check at Composite Stage

**stress**

**CHECK FOR STRESS**

**composite stage**

**Due to Dead Load**

Total dead load: 10.90 kN/m  
 Moment: 110.43 kN.m  
 Depth of neutral axis: 200.58 mm  
 Moment of inertia: 562423981 mm<sup>4</sup>  
 Stress in steel flange: 64.68 N/mm<sup>2</sup>

**Due to Live Load**

Total live load: 14 kN/m  
 Moment: 141.75 kN.m  
 Depth of neutral axis: 155.19 mm  
 Moment of inertia: 676613561 mm<sup>4</sup>  
 Stress in steel flange: 78.52 N/mm<sup>2</sup>

**Stresses**

TOTAL STRESS IN STEEL: 143.20 N/mm<sup>2</sup>  
 ALLOWABLE STRESS IN STEEL: 217.5 N/mm<sup>2</sup>  
 TOTAL STRESS IN CONCRETE: 3 N/mm<sup>2</sup>  
 ALLOWABLE STRESS IN CONCRETE: 10 N/mm<sup>2</sup>

decknew  
 SECTION IS SAFE  
 OK

CALCULATE  
 NEXT> <BACK

Fig. 16 Form for Check for Stress

## VI. BEHAVIOUR AND DESIGN ASPECT OF COMPOSITE COLUMN

Composite columns may be classified into two types (Narayanan and Kalyanraman 2001):

- Open sections partially or fully encased in concrete,
- Concrete-filled hollow steel sections.

Typical cross-sections of composite columns with fully and partially concrete encased steel sections are illustrated in Fig. 17 whereas Fig. 18 shows the three typical cross-sections of concrete filled hollow steel sections.

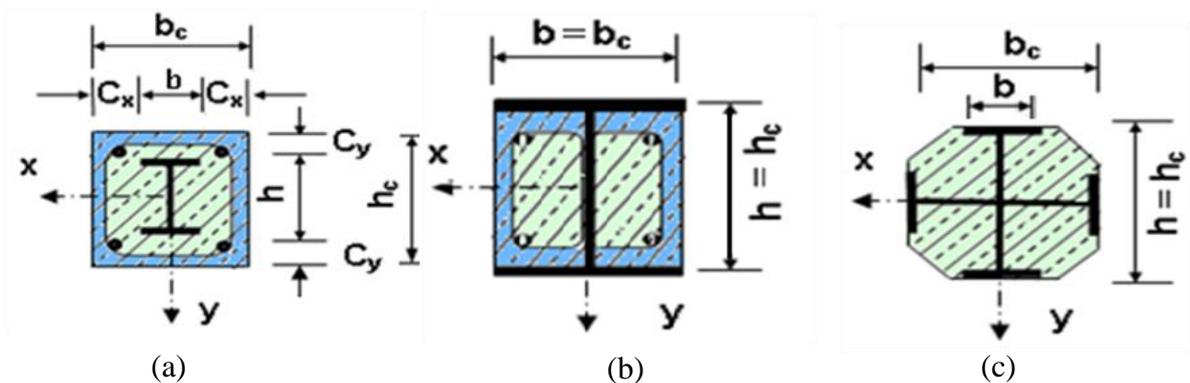


Fig. 17 Cross Section of Fully and Partially Concrete Encased Columns

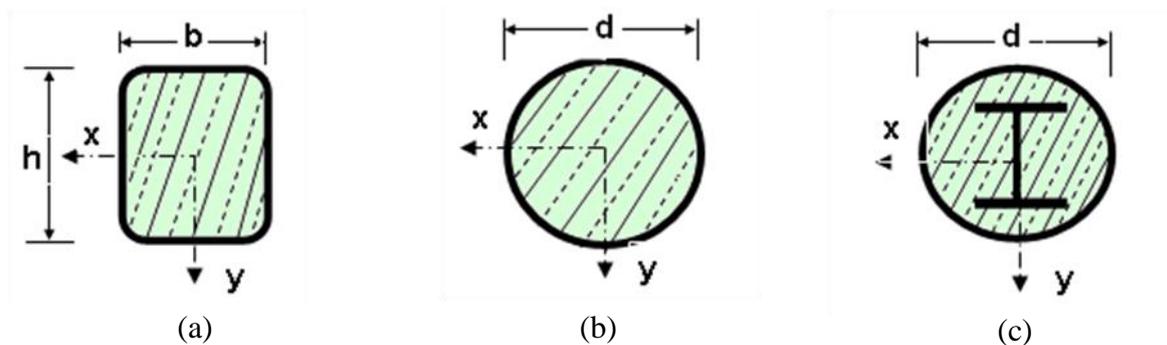


Fig. 18 Cross Section of Concrete Filled Tubular Sections

In composite construction, the bare steel sections support the initial construction loads, including the weight of structure during construction. Concrete is later cast around the steel section, or filled inside the tubular sections. In the case of concrete-filled hollow sections, the steel provides a permanent formwork to the concrete core. This allows, for example, the steel frame to be erected and the hollow column sections subsequently to be filled with pumped concrete. This leads to appreciable savings in the time and cost of erection. In addition, the confinement provided by the closed steel section allows higher strengths to be attained by the concrete. Creep and shrinkage of concrete, are also generally neglected in the design of concrete-filled tubes, which is not the case for concrete-encased sections. On the other hand, complete encasement of a steel section usually provides enough fire protection to satisfy the most stringent requirements without resorting to other protection systems.

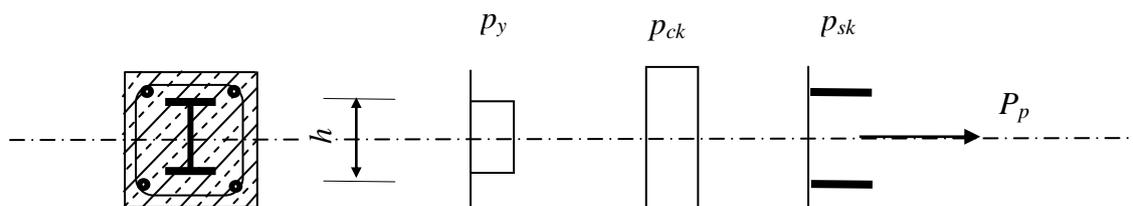
Partially encased sections have the advantage of acting as permanent formwork; the concrete is placed in two stages with the section. In order to ensure adequate force transfer between the steel and concrete it is sometimes necessary to use stud connectors or reinforcement connected directly or indirectly to the metal profile. Another significant advantage of partially encased sections is the fact that, after concreting, some of the steel surfaces remain exposed and can be used for connection to other beams. Thus, concrete and steel are combined in such a fashion that the advantages of both the materials are utilised effectively in composite column. Further, the lighter weight and higher strength of steel permit the use of smaller and lighter foundations.

At present there is no Indian Standard covering composite columns. The method of design largely follows EC4 (1994), which incorporate the latest research on composite construction. Any one of the following two methods can be used for the calculation. The first is a General Method which takes explicit account of both second-order effects and imperfections. This method in particular can be applied to columns of asymmetric cross-section as well as to columns whose section varies with height. The second is a Simplified Method which makes use of the European buckling curves for steel columns, and implicitly takes account of imperfections. Here, Simplified Method is considered, because it is applicable to the majority of practical cases.

**Resistance of Cross-Section to Compression**

The plastic compression resistance of a composite cross-section represents the maximum load that can be applied to a short composite column. Concrete filled circular tubular sections exhibit enhanced resistance due to the tri-axial confinement effects. Fully or partially concrete encased steel sections and concrete filled rectangular tubular sections do not achieve such enhancement.

Encased steel sections and concrete filled rectangular/tubular sections



**Fig. 19 Stress Distribution of Plastic Resistance to Compression**

Figure 19 shows stress distribution of the plastic resistance to compression of an encased I section. The plastic resistance of an encased steel section or concrete filled rectangular section (i.e. the so-called “squash load”) is given by the sum of the resistances of the components as follows:

$$P_p = A_a p_y + A_c p_{ck} + A_s p_{sk} \quad \dots (1)$$

where,

$A_a$ ,  $A_c$  and  $A_s$  = Areas of steel section, concrete and reinforcing steel respectively,

$$p_y, p_{ck} \text{ and } p_{sk} = \frac{f_y}{\gamma_a}, \frac{\alpha_c (f_{ck}) c_y}{\gamma_c} \text{ and } \frac{f_{sk}}{\gamma_s}$$

$f_y, (f_{ck})_{cy}$  and  $f_{sk}$  = Yield strength of the steel section, the characteristic compressive strength (cylinder) of the concrete, and the yield strength of the reinforcing steel respectively, and

$\alpha_c$  = Strength coefficient for concrete, which is 1.0 for concrete filled tubular sections, and 0.85 for fully or partially concrete encased steel sections.

At this stage it should be pointed out that the Indian Standards for composite construction does not make any specific reference to composite columns. The provisions contained in IS: 456 - 2000 [7] are often invoked for design of composite structures. Extension of IS: 456 - 2000 to composite columns will result in the following equation,

$$P_p = A_s p_y + A_c p_{ck} + A_s p_{sk} \quad \dots (2)$$

where,  $p_y = 0.87f_y$ ,  $p_{ck} = 0.4(f_{ck})_{cu}$ ,  $p_{sk} = 0.67f_y$  and  $(f_{ck})_{cu}$  is the characteristic compressive strength (cube) of the concrete.

#### Concrete filled circular tubular sections: Special Provisions

For composite columns using circular tubular sections, there is an increased resistance of concrete due to the confining effect of the circular tubular section.

The eccentricity,  $e$ , is defined as follows

$$e = \frac{M}{P} \leq \frac{d}{10} \quad \dots (3)$$

where,  $e$  = Eccentricity,  $M$  = Maximum applied design moment (second order effects are ignored) and  $P$  = Applied design load.

The plastic compression resistance of concrete filled circular tubular sections is calculated by using two coefficients  $\eta_1$  and  $\eta_2$  as given below.

$$P_p = A_a \eta_2 p_y + A_c p_{ck} \left[ 1 + \eta_1 \frac{t}{d} \frac{f_y}{f_{ck}} \right] + A_s p_{sk} \quad \dots (4)$$

where,  $t$  = Thickness of the circular tubular section,

$$\eta_1 = \eta_{10} \left[ 1 - \frac{10e}{d} \right] \quad \dots (5)$$

$$\eta_2 = \eta_{20} + (1 - \eta_{20}) \frac{10e}{d} \quad \dots (6)$$

The basic values  $\eta_{10}$  and  $\eta_{20}$  depend on the non-dimensional slenderness  $\bar{\lambda}$  (EC4, 2004).

#### **Effective Elastic Flexural Stiffness**

Composite columns may fail in buckling and one important parameter for the buckling design of composite columns is its elastic critical buckling load,  $P_{cr}$ , which is defined as follows:

$$P_{cr} = \frac{\pi^2 (EI)_e}{l^2} \quad \dots (7)$$

Where  $(EI)_e$  is the effective elastic flexural stiffness of the composite column, and  $l$  is the effective length of the column.

## **VII. ILLUSTRATED DESIGN OF COMPOSITE COLUMNS**

Using the features of the VB.Net, a program is developed for the design of composite columns. Selection menu for axially loaded, uniaxially loaded and biaxially loaded column is depicted in Fig. 20 whereas Fig. 21 shows the form in which data for an example of a design of biaxially loaded composite column is shown. Steel table is also interfaced with the software as shown in Fig. 22. After the selection of a particular section, various

checks are carried out by the software according to the code. Software also checks whether the secondary effect and long term loading effects are required to be considered or not as shown in **Figs. 23** and **24**. After that, depth of neutral axis is calculated. This is required for the calculation of the plastic section modulus and finally the plastic moment resistance of the section for adequacy check as shown in **Figs. 25** and **26** respectively.

The screenshot shows a software window titled "COMPOSITE COLUMN DESIGN". Below the title bar, there is a red header with the text "DESIGN OF COMPOSITE COLUMN". Underneath, the text "TYPES OF COMPOSITE COLUMN" is displayed. Three radio button options are listed, each with a corresponding colored box:
 

- COLUMN SUBJECTED TO AXIAL LOAD (green box)
- COLUMN SUBJECTED TO AXIAL LOAD AND UNI-AXIAL BENDING (teal box)
- COLUMN SUBJECTED TO AXIAL LOAD AND BI-AXIAL BENDING (cyan box)

Fig. 20 Form for Selection of Type of Loading

The screenshot shows a software window titled "COMPOSITE COLUMN". Under the "DATA" section, there are input fields for:
 

- LENGTH OF COLUMN (L): 3000 mm
- MOMENT ON COLUMN (M<sub>x</sub>): 120 kN.m
- AXIAL LOAD ON COLUMN (P): 1500 kN
- MOMENT ON COLUMN (M<sub>y</sub>): 120 kN.m

 Below the data fields, there is a section titled "SELECT THE TYPE OF COMPOSITE COLUMN" with four icons representing different column cross-sections: a rectangular section with an I-beam, a square section with four reinforcement points, a circular section with four reinforcement points, and a rectangular section with two reinforcement points. A left-pointing arrow is also visible.

Fig 21 Form for Entering the Data for the Design of Section

The screenshot shows a software window titled "COMPOSITE COLUMN" with the "MATERIAL AND SECTION PROPERTY" section active. It includes tabs for "STEEL SECTION", "CONCRETE", and "REINFORCEMENT".
 

- YIELD STRENGTH (F<sub>y</sub>): 250 N/MM<sup>2</sup> (with a checked "∞ REQUIRED" option) and 1455
- MODULUS OF ELASTICITY (E<sub>a</sub>): 200000 N/MM<sup>2</sup> and AREA REQUIRED: 12500
- STEEL SECTION: ISHB 350
- A "CALCULATE" button is present.

 The "SECTION PROPERTIES" section lists various parameters:
 

- A<sub>a</sub> = 92.21 MM<sup>2</sup>, I<sub>ax</sub> = 19802.8 MM<sup>4</sup>
- T<sub>f</sub> = 11.6 MM, I<sub>ay</sub> = 2510.5 MM<sup>4</sup>
- h = 350 MM, Z<sub>pax</sub> = 1131.6 MM<sup>3</sup>
- T<sub>w</sub> = 10.1 MM, Z<sub>pay</sub> = 199.4 MM<sup>3</sup>
- B = 250 MM

 A "SELECT SECTION" button is located below these properties. At the bottom, there is a table with the following data:
 

	DESIGNATION	Field1	WEIGHT PER METRE	SECTIONAL AREA	DEPTH
	ISHB 350		67.4	85.91	350
	ISHB 400		72.4	92.21	350
	ISHB 400		77.4	98.66	400

Fig. 22 Form for Selection of Section

Fig. 23 Form for Checking Long Term Loading Effect

Fig. 24 Form for Checking Secondary Effect

Fig. 25 Form for Calculation of Plastic Section Modulus

COMPOSITE COLUMN

DESIGN CHECKS

[8] CHECK OF COLUMN RESISTANCE AGAINST COMBINED COMPRESSION AND BENDING

THE DESIGN AGAINST COMBINED COMPRESSION AND BENDING IS ADEQUATE IF FOLLOWING CONDITION IS SATISFIED.

@ MAJOR AXIS @ MINOR AXIS CHECK-2

CONDITION - 2

$(M_x/\mu.M_{px}) + (M_y/\mu.M_{py}) \leq 1$

(Mx/μ.Mpx) 0.3374793 SECTION IS ADEQUATE

(My/μ.Mpy) 0.6112061

CHECK 0.9486853

Fig. 26 Form for Checking the Adequacy of the Section

### CONCLUSIONS

1. VB.NET is totally object oriented and provides managed code execution that runs under the Common Language Runtime (CLR), resulting in robust, stable and secure applications. It also allow easy linking to database created in Microsoft Access which has been found very helpful in providing easy access to properties of different steel sections required for design.
2. Composite steel-concrete section is relatively a new design concept in the Indian context and no appropriate updated codes are available for the design of the same A simplified approach discussed in the present work, not only eliminates costly experimentation required for design purpose but also facilitates design with multiple options for the steel sections and shear connectors with adequacy checks.
3. A number of forms developed, as part of pre- and post- processor, to facilitate design of different types of composite slabs, beams and columns not only make the software very user friendly and versatile but also make the application of the software quite attractive.
4. The proposed computational method, for composite columns with a variety of steel sections encased in concrete and various concrete filled sections, is found to provide accurate results.

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