International Journal of Innovative Research in Science and Engineering
Vol. No.2, Issue 10, October 2016
www.ijirse.com
ISSN (O) 2454-9665
ISSN (P) 2454-0663

COST COMPARATIVE STUDIES ON STEEL CONCRETE COMPOSITE BEAMS

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ABSTRACT

In order to study the effect of spacing of steel joists on the total cost of R.C.C- Steel Composite Beams, Seventy five such composite beams have been designed for spans varying from 5m to 17m and by varying the spacing of steel joists from 0.5m to 3.0m for the three different loadings of 5kN/m^2, 10kN/m^2 and 15kN/m^2. By estimating the cost of construction, the most economical spacing has been identified.

Keywords: Composite beams, Construction load, Prestressed concrete, Plastic neutral axis and Shear connector.

I. INTRODUCTION

Composite structural members are often employed to maximize the benefits of using different materials of construction in combination. A particularly efficient structural form for beams has evolved from the conventional arrangement of a concrete slab supported by a steel beam. If the slab and beam are connected and the slip between them is prevented, the bending strength of the combined unit will be increased. A Structural member composed of two or more dissimilar materials joined together to act as a unit and the resulting system is stronger than the sum of its part is called composite beams.

In Steel-Concrete Composite beams, steel beams are integrally connected to pre-fabricated or cast in-situ reinforced concrete slabs. In conventional construction, concrete slabs rest over steel beams and are supported by them. Under load, these two components act independently and a relative slip occurs at the interface. The appropriate connectionprovided between the beam and slab eliminate, the slip between them. In this case, the steel beam and the slab acts as a “composite beam”. Concrete is stronger in compression than in tension, and steel is stronger in tension than in compression. By the composite action between thetwo, we can utilize their respective strengths to the fullest extent. Composite beams are cost effective for larger spans and taller buildings.

1.1 AIMS of the Study

The aims of this investigation can be briefly stated as follows.

a) To study the relative merits of Steel-R.C.C composite beams.

b) To study the relative merits of Prestressed concrete-Reinforced concrete composite beams.

c) To study the relative merits of Low strength-high strength R.C.C composite beams.

II. DESIGN OF COMPOSITE BEAMS

3.1 Step 1: Design of Cast in-situ Slab

Depth of the in-situ slab is assumed. Bending moments at mid span and support of the slab are computed. The greater of these two moments is taken as the design moment. Limit state moment of resistance of the slab is calculated using the expression.

$$M_{u\,lim} = 0.36\,\frac{X_{u\ max}}{d}\left(1 - \frac{0.42\,X_{u\ max}}{d}\right) b d^2 f_{ck}$$

If $M_{u.lim}$ is less than that of the design moment, the depth of the in-situ slab is increased. The area of the steel is obtained using.

$$M_u = 0.87 f_y A_{st}\ d\left(1 - \frac{A_{st}\ f_y}{bd\, f_{ck}}\right)$$

The area of the steel obtained is compared with the required minimum steel and if it is less, then $A_{st.min}$ is provided. The distribution of the steel is as recommended by IS 456-2000 Code.

3.2. Step 2: Design of Steel Section and Load Calculations

Steel section is assumed. The load is calculated in two different stages. They are Construction Stage and Composite Stage

3.2.1. Construction Stage

The loads considered in this stage are Self-weight of the slab, Self-weight of the beam and Construction load. The total design load at the construction stage is obtained by calculating the sum of the product of the construction load with the partial safety factor and self-weight with the partial safety factor.

3.2.2. Composite Stage

The loads considered in this stage are Self-weight of the slab, Self-weight of the beam and Imposed load. The total design load at the composite stage is obtained by calculating the sum of the product of the imposed load with the partial safety factor and the self-weight with the corresponding partial safety factor. The partial safety factor adopted is according to IS 800-2007.

1.3. Step 3: Calculation of Bending Moment

The two different stages for the calculation of bending moment are

(i) Construction Stage and

(ii) Composite Stage

$$M = \frac{WL^2}{8}$$

Assuming that all the beams are simply supported.

1.4. Step 4: Check for Adequacy of the Section at the Construction Stage

The moment of resistance of steel section is obtained by,

$$= \frac{f_y \times Z_{xs}}{1.15}$$

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If the moment of resistance of steel section is greater than design moment at theConstruction Stage, then the section is safe.

1.5. Step 5: Check for Adequacy of the Section at the Composite Stage

The effective flange width is found out as the least of the following (as per IS 3935-1966 code).

1. $(1/4)^{th}$ span of the beam
2. Centre to centre distance of beam
3. Web thickness + 12 times the thickness of slab

3.6. Step 6: Determination of the position of plastic neutral axis and ultimate moment of resistance

From clause 8.2 of IS 11384-1985 code, In a section of homogenous material, the plastic neutral axis coincides with the equal area axis of the section, that is, the axis which divides the section into two equal areas on either side. The same concept can be used in the case of composite beams also, provided the steel area is converted into equivalent concrete area by multiplying it with the stress ratio.

$$a = \frac{0.87 \times f_y}{0.36 \times f_{ck}}$$

The position of the neutral axis and ultimate moment of resistance is calculated with respect to the following three cases.

3.6.1.Case (i) Plastic neutral axis within concrete slab

If $b_{eff} \times d_s > a \times A_s$

Then, $$x_u = \frac{a \times A_s}{b_{eff}}$$

The compressive force in concrete, $F_{cc} = 0.36 \times b_{eff} X_u f_{ck}$

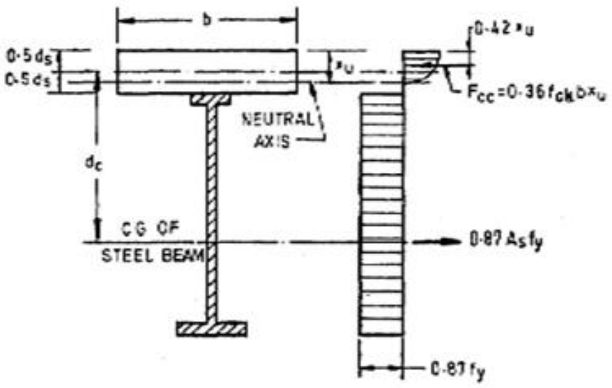

Figure 1. Stress distribution in a composite beam with neutral axis within concrete slab

Taking moment about the concrete compression,

$$M_u = 0.87 f_y A_s (d_c + 0.5 d_s - 0.42 X_u)$$

If the moment of resistance is greater than the bending moment due to the factored load at the composite stage, then the section is safe. If not, it is redesigned.

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3.6.2. Case (ii) - Plastic neutral axis within flange of steel beam

If $b_{eff} \times d_s < a \times A_s < b_{eff} \times d_s + 2 \times a \times A_f$

Then

$$X_u = \frac{d_s + (a \times A_s - b_{eff} \times d_s)}{2 \times b_f \times a}$$

The compressive force in concrete

$$F_{cc} = b_{eff} \times d_s \times 0.87 \times \frac{f_y}{a}$$

Taking moment about the concrete compression

$$\mathrm{M_u} = 0.87 f_y \left[A_s(d_c + 0.08 d_s) - b_f(X_u - d_s)(X_u + 0.16 d_s)\right]$$

If the moment of resistance is greater than the bending moment at the composite stage, then the section is safe. If not then it is redesigned.

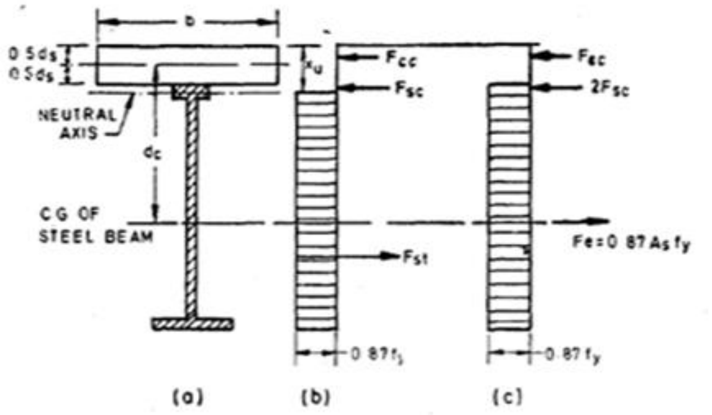

Figure 2. Stress distribution in a composite beam with neutral axis within flange of steel beam

3.6.3.Case (iii) - Plastic neutral axis within the web of the steel beam

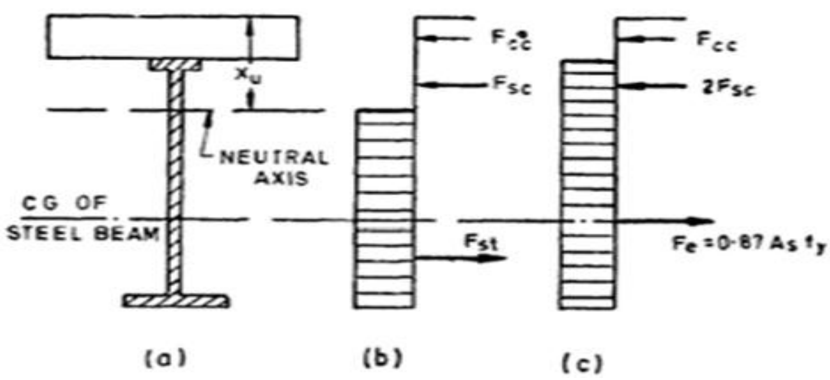

Figure 3. Stress distribution in a composite beam with neutral axis within web of steel beam

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If $a(A_s - 2A_f) > b_{eff} \times d_s$,

Then

$$X_u = \frac{d_s + t_f + a(A_s - 2 \times A_f) - b_{eff} \times d_s}{2 \times t_w \times a}$$

The compressive force in concrete

$$F_{cc} = 0.36 \times b_{eff} \times d_s \times f_{ck}$$

Taking moment about the concrete compression

$$\mathrm{M_u} = \mathrm{A} - \mathrm{B} - \mathrm{C}$$

Where,

$$\mathrm{A} = 0.87 f_y A_s (d_c + 0.08 d_s)$$

$$\mathrm{B} = 2 \times A_f (0.5 t_f + 0.58 d_s)$$

$$\mathrm{C} = 2 \times t_w (X_u - d_s - t_f)(0.5 X_u + 0.08 d_s + 0.5 t_f)$$

If the moment of resistance is greater than the bending moment at the composite stage, then the section is safe. If not then it is redesigned.

3.7. Step 7: Design of shear connectors

The position of the neutral axis is within the slab. The total load is carried by connectors.

$$F_{cc} = 0.36 \times b_{eff} X_u f_{ck}$$

The position of the neutral axis is within the Plastic neutral axis within top flange of steel beam.The total load is carried by connectors.

$$F_{cc} = \frac{b_{eff} \times d_s \times 0.87 f_y}{a}$$

As per table1 IS 11384-1985, the design shear strength of the headed stud is taken. The number of shear connectors required for half of the span is ratio of the total load carried by the connector and the design strength of the stud.

3.8. Step 8: Serviceability check

From clause 12.1 of IS 11384-1985 code. Inthis case the beam is analysed using the elastic theory adopting a modular ratio of 15 for live load and 30 for the dead load, and neglecting any tensile stress in concrete. The deflection should not exceed the value for steel structures as (L/325).

For dead load, deflection is calculated using moment of inertia of steel beam only.

$$\delta_d = \frac{5 W_d L^4}{384 E_s I_{xs}}$$

$$\delta_l = \frac{5 W_l L^4}{384 E_s I_{xc}}$$

The total deflection is the sum of the dead load deflection and the live load deflection.

$$\delta_d + \delta_l < \frac{L}{325}$$

If the deflection obtained is less than (L/325), then the section is safe. If not redesigned.

3.9. Step 9: Transverse reinforcement

According to IS 11384 – 1985 the transverse reinforcement is found out. The shear force in kN/m of beam

$$Q = \frac{N_c X \, \text{load}(P_c)}{\text{Longitudinal spacing of connectors in m}}$$

The shear resistance per metre run of beam

$$= 0.232 L_s \sqrt{f_{ck}} + 0.1 A_t \times f_y \times n$$

or

$$= 0.623 L_s \sqrt{f_{ck}}$$

It should not exceed either of the resistances.If it exceeds then the reinforcement is calculated by finding out the difference between the shear force and shearing resistance. The amount of transverse steel in the bottom of the slab should not be less than $250*Q/f_y$, mm^2 /m run of the beam.

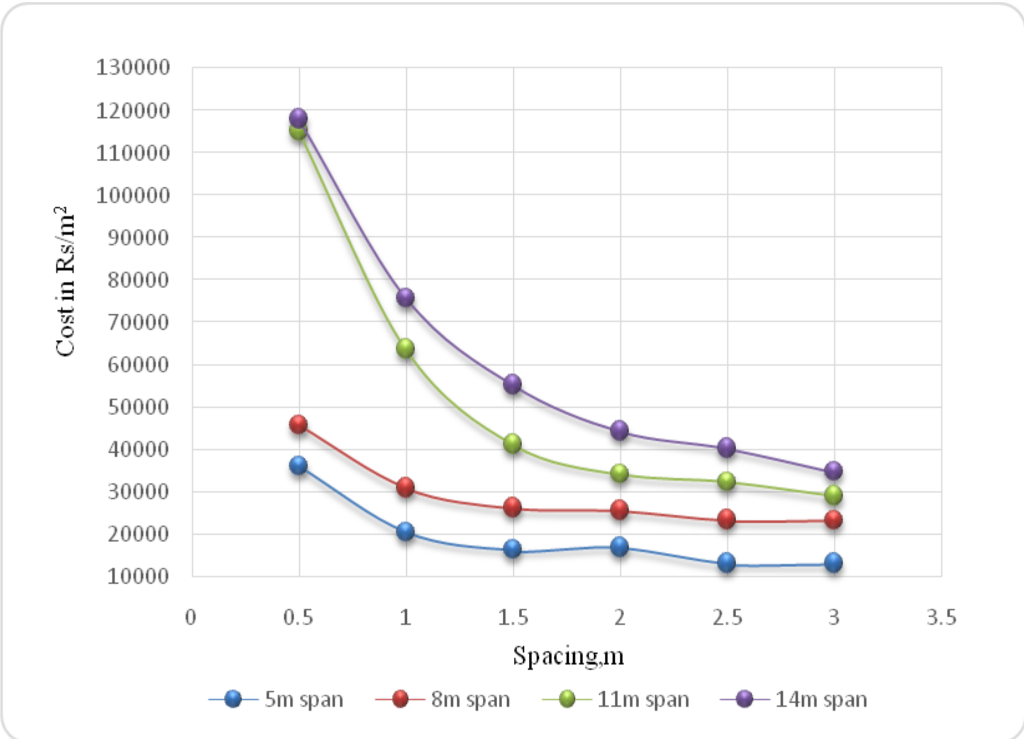

Figure4: Variation of cost with spacing of beams (5kN/m²)

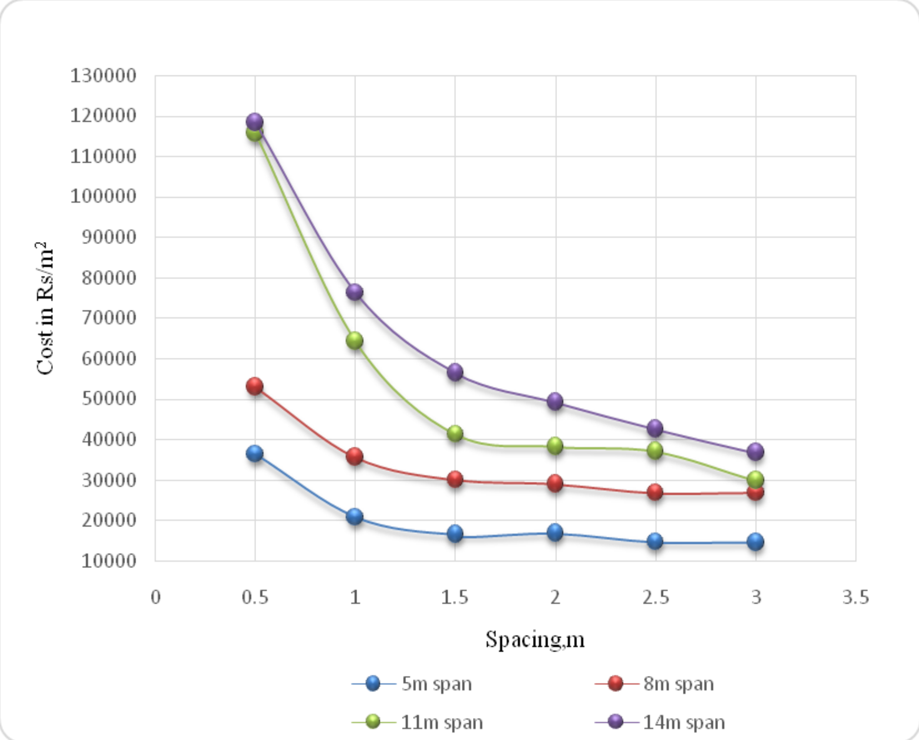

Figure 5. Variation of cost with spacing of beams (10kN/m^2)

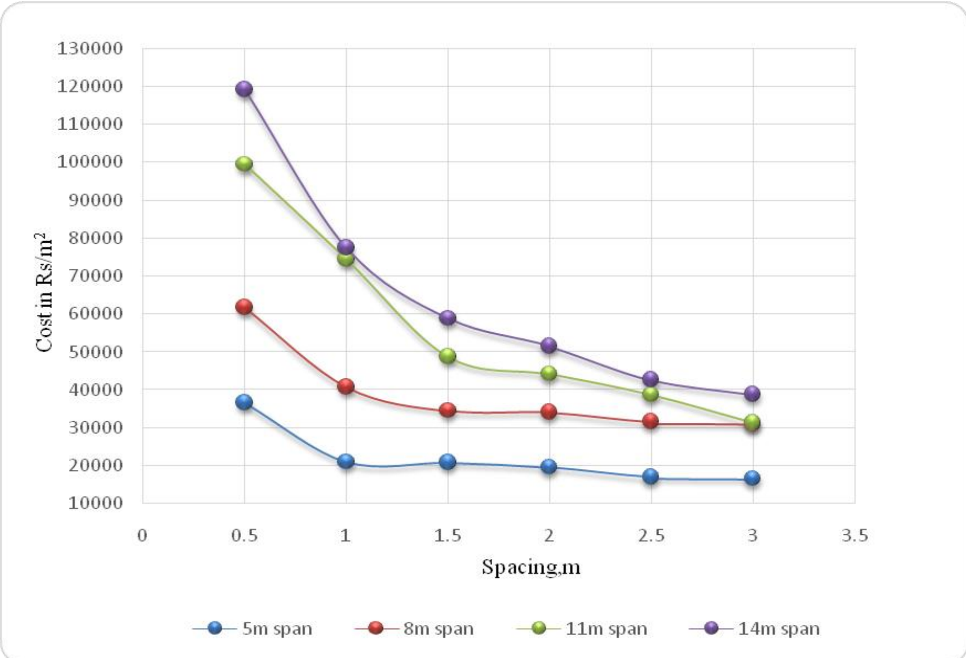

Figure 6. Variation of cost with spacing of beams (15kN/m^2)

Table.1 Design Details of Composite Beams

ISSN (O) 2454-9665
ISSN (P) 2454-0663

S.no	S	S_v	L	Tk	Slab Rft		Rolled steel beam	SC	T Rft	Cost/m^2 Rs
					Ms	Ds				
1	5	0.5	5	110	210	260	ISMB225	185	185	35992
2	5	0.5	10	115	200	260	ISMB225	180	165	36255
3	5	0.5	15	125	190	265	ISMB225	180	160	36577
4	5	1.0	5	110	205	250	ISMB225	175	170	20494
5	5	1.0	10	115	200	265	ISMB225	155	150	20732
6	5	1.0	15	125	195	265	ISMB225	155	150	21008
7	5	1.5	5	110	140	250	ISMB225	150	100	16318
8	5	1.5	10	115	130	260	ISMB225	155	105	16473
9	5	1.5	15	125	195	265	ISMB300	125	85	20848
10	5	2.0	5	110	200	250	ISMB300	125	85	16784
11	5	2.0	10	115	200	250	ISMB300	125	90	16819
12	5	2.0	15	130	195	255	ISMB350	110	75	19571
13	5	2.5	5	110	200	250	ISMB250	125	85	13194
14	5	2.5	10	115	200	265	ISMB300	125	85	14679
15	5	2.5	15	125	195	165	ISMB350	110	75	17015
16	5	3.0	5	110	205	250	ISMB300	125	85	13077
17	5	3.0	10	115	200	290	ISMB350	125	85	14544
18	5	3.0	15	125	195	265	ISMB400	125	80	16484
19	8	0.5	5	110	155	270	ISMB250	225	165	45631
20	8	0.5	10	115	150	265	ISMB300	210	150	52944
21	8	0.5	15	125	150	265	ISMB350	200	140	61650
22	8	1.0	5	110	145	260	ISMB300	215	135	30892
23	8	1.0	10	115	135	265	ISMB350	205	120	35551
24	8	1.0	15	125	130	260	ISMB400	195	115	40732
25	8	1.5	5	110	140	250	ISMB350	220	150	26195
26	8	1.5	10	115	130	265	ISMB400	180	120	29975
27	8	1.5	15	125	115	265	ISMB450	165	110	34464
28	8	2.0	5	115	130	265	ISMB400	130	85	25603
29	8	2.0	10	120	125	275	ISMB450	110	75	28930
30	8	2.0	15	130	110	250	ISMB500	90	60	34094
31	8	2.5	5	110	140	250	ISMB450	200	135	23373
32	8	2.5	10	115	130	290	ISMB500	180	120	26776
33	8	2.5	15	130	110	255	ISMB550	150	100	31619
34	8	3.0	5	110	140	260	ISMB500	200	145	23241

35	8	3.0	10	115	130	265	ISMB550	180	120	26725
36	8	3.0	15	130	110	255	ISMB600	150	120	30943
37	11	0.5	5	110	150	270	ISMB550	265	175	115144
38	11	0.5	10	115	145	275	ISMB550	260	160	115671
39	11	0.5	15	125	145	260	ISMB500	255	165	99404
40	11	1.0	5	110	140	255	ISMB550	255	170	63597
41	11	1.0	10	115	130	250	ISMB550	240	160	64241
42	11	1.0	15	125	130	255	ISMB600	235	150	74353
43	11	1.5	5	115	130	260	ISMB500	250	170	41216
44	11	1.5	10	115	130	260	ISMB500	250	165	41270
45	11	1.5	15	130	110	255	ISMB550	210	140	48654
46	11	2.0	5	115	130	265	ISMB500	225	150	34199
47	11	2.0	10	115	130	265	ISMB550	250	170	38160
48	11	2.0	15	130	130	265	ISMB600	210	140	44094
49	11	2.5	5	110	140	250	ISMB550	275	185	32357
50	11	2.5	10	115	130	265	ISMB600	225	150	36994
51	11	2.5	15	130	110	255	ISMB600	210	140	38608
52	11	3.0	5	110	130	265	ISMB550	275	185	29098
53	11	3.0	10	120	130	265	ISMB550	250	170	29793
54	11	3.0	15	135	105	245	ISMB550	195	170	31483
55	14	0.5	5	110	145	260	ISMB550	290	235	117863
56	14	0.5	10	115	145	255	ISMB550	285	240	118197
57	14	0.5	15	125	140	255	ISMB600	270	230	119105
58	14	1.0	5	110	135	245	ISMB550	275	250	75708
59	14	1.0	10	115	130	240	ISMB600	260	245	76270
60	14	1.0	15	125	120	240	ISMB600	280	240	77362
61	14	1.5	5	110	140	250	ISMB600	350	240	55171
62	14	1.5	10	120	125	275	ISMB600	345	215	56448
63	14	1.5	15	135	105	245	ISMB600	265	180	58812
64	14	2.0	5	105	150	230	ISMB600	380	260	44300
65	14	2.0	10	120	120	275	ISWB600	315	215	49193
66	14	2.0	15	135	105	245	ISWB600	250	170	51497
67	14	2.5	5	120	125	265	ISMB600	290	195	40321
68	14	2.5	10	115	115	265	ISWB600	290	195	42580
69	14	2.5	15	135	105	245	ISMB600	230	170	42592
70	14	3.0	5	110	140	250	ISMB600	350	240	34738
71	14	3.0	10	120	125	275	ISMB600	230	155	36714
72	14	3.0	15	135	105	245	ISMB600	230	155	38726

73	17	0.5	5	110	140	250	ISWB600	850	585	149911
74	17	1.0	5	110	140	250	ISWB600	530	360	83565
75	17	1.5	5	110	140	250	ISWB600	425	295	61570

S - Span, m

Sv - Spacing of beams, m

L - Live load, kN/m2

Tk – Thickness of slab in mm

Ms – Main reinforcement spacing (12mm dia)

Ds – Distribution reinforcement spacing (8mm dia)

SC – Shear connector

Trft – Transverse reinforcement spacing, mm

IV. CONCLUSIONS

1. From the Fig.4 to Fig.6, it could be concluded that cost per unit area covered decreases as the spacing of steel beam increases.
2. In the case of beams of spans 5m to 8m the cost remains same when the spacing of beams in range 2.5 to 3m.The estimated cost of the construction of these composite beams is also given in Table.1.

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