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Economical Span in Composite Bridges

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Abstract : **A Composite bridge deck consists of a concrete slab and which in conjunction with steel girders resists moving loads on the bridge. This paper mainly focuses on the economical span of the composite bridges and minimizing the number of girders in the composite bridge. By minimizing the number of girders, substantial savings can be achieved in the bridge deck. Fig. 1 represents a structure with 5 girders spaced at 2 m c/c supporting a wide multilane divided roadway. If 2 girders are eliminated and the spacing of the remaining three girders is increased to 4 m c/c, a savings of approximately 30 % in main girder cost would result. This paper refers to obtain the economical bridge deck by minimizing the number of primary girders for different spans of 10m, 15m, 20m, 25m and 30m for a critical load combination. Type of loading considered is IRC Class AA tracked load. As plate girders are used in the composite bridges, size of steel members can be significantly reduced owing to incorporation of the deck into the resisting cross section that is on the compression zone. When the total cost of the sub structure equals the total cost of super structure, that span is considered as economical span. The design has been performed for a number of spans, that is from 10m to 40 m with 5m interval. After calculating the cost analysis for all the 7 spans, most economical span is attained.**

Key words: Composite bridge, Economical Span, Plate Girder, Steel Girders.

1. INTRODUCTION

Composite construction of bridges refers to the use of two dissimilar structural elements in combination in such a way that one acts in consonance with the other. Generally the structural elements used are RCC and Structural Steel. Normally, when these two are cast at different times, there is a point of cleavage at the junction. When this junction is made sufficiently strong to take on the shear force coming on that level, the two elements start acting together and the combine strength becomes effective. This is achieved by providing castellations on top of the girder and shear connectors in the form of stirrups which project from the girder up to the slab which is laid subsequently. The use of steel beams below and concrete slab on top after erection of steel beams, and providing shear connectors welded or riveted on to the top flange of the steel beam gives the effect of their working as a T-beam unit with the concrete slab taking in compression and the bottom flange of the steel girder taking tension.

Composite construction combines the advantages of prefabricated construction and reduced cost of formwork. The flexural stiffness of steel concrete composite beam will be about 2 to 4 times that for a corresponding steel beam and this property results in reduced deflections and vibrations.

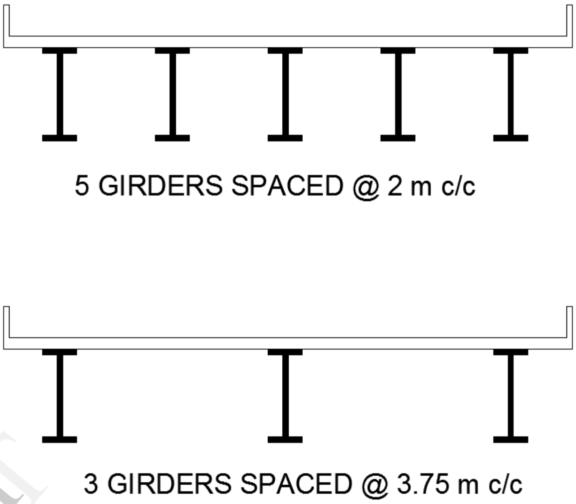

Fig. 1 Cross Section of minimized girders.

II. COMPOSITE ACTION

Composite construction has its roots in mid nineteenth century. To understand how composite construction brings economy in materials, we have to take a look on bending theory. The maximum bending stress in a beam subjected to pure bending is given by,

$$f = \frac{M.y}{I} \qquad ...(1)$$

Where,

f = Bending stress in the beam
M = Bending Moment
y = Distance of the extreme fibre from the neutral axis
I = Moment of Inertia of the resisting section in mm^4

The above equation can be written as

$$f = \frac{M}{Z} \qquad ... (2)$$

Z = Section Modulus ($^{I}/_{y}$)

The section modulus is dependent on the geometry of the cross section of plate girders. From the equation we can know that bigger the value of Z, smaller will be the resulting stress. As the value of section modulus goes on increasing, the stresses will be reduced. Composite sections provide substantial section modulus with minimum material.

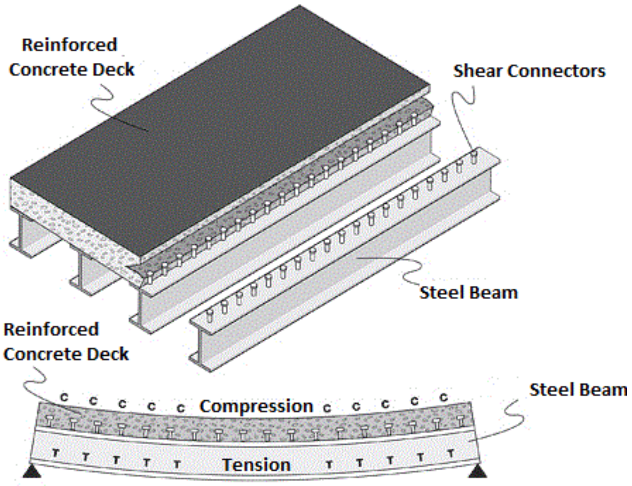

Fig. 2 Composite Bridge Deck

When a reinforced concrete slab is just supported over steel I-beam, the two components have equal deflections, but their deformations and hence stress patterns are different as shown in figure 3. The bottom of the slab will be in tension, while the top of the steel beam will be in compression. The two components act in non composite manner. In the case of composite section, where the total longitudinal shear is fully transferred at the junction of the steel beam and the in situ concrete slab by means of shear connectors. The deformation of the slab and the steel beam at the junction are the same. The stress pattern is shown in the figure 3. The tensile stress at the bottom of the steel beam is now smaller than for the non composite steel beam, because the section modulus for the composite section is larger than for the non composite section. The stress at bottom of the slab is usually compressive. The deflection of composite section is much less than that for the corresponding non composite section due to increased moment of inertia.

The composite slab beam section is converted into a modified section where the concrete slab turns into an equivalent area of steel. This conversion is brought through the use of modular ratio m. The modular ratio is given by,

$$m = \frac{E_s}{E_c} \qquad \text{... (3)}$$

Where,

E_s = Modulus of elasticity of steel
E_c = Modulus of elasticity of concrete.

III. SHEAR CONNECTORS

The shear connectors are the part and parcel of a composite deck system. The need for shear connectors can be understood by considering the interaction between the slab and steel beam. If the slab simply rests on the steel beam, a phenomenon known as slippage occurs. As the loads are placed at the top of the slab and the beam will be in compression while the bottom of the slab and the beam will be in tension. Both the slab and the steel beam behave independently deflecting like a beam. Since the bottom of the slab is in tension and the top of the beam is in compression, the resulting effect is manifested by extension of the slab over the ends of the beam. Therefore, the basic function of shear connector is to transfer the shear force at the interface of the slab and the beam without slip and to prevent the separation of the slab from the steel beam in perpendicular direction.

It is possible to somehow connect the concrete slab and the steel beam such that they resist the loads like a common unit. Such a one to one unity between the two units can be achieved by providing shear connectors between the slab and beam. A shear connector is generally a metal element of particular shape, which extends vertically from the top flange of the supporting beam and gets embedded into the slab. Depending upon the magnitude of the shear force at the interface of the beam and the slab, a number of shear connectors can be placed along the length of the beam. For a stud type of shear connector, the safe shear for each shear connector is given by,

$$Q = 4.8hd\sqrt{f_{ck}} \qquad (\text{if } {}^{h}/_{d} \text{ ratio is less than 4.2})$$

$$Q = 19.6d^2\sqrt{f_{ck}} \qquad (\text{if } {}^{h}/_{d} \text{ ratio is greater than 4.2})$$

Where,

Q = Safe shear resistance
h = Height of the stud
d = Diameter of the stud
f_{ck} = Characteristic Compressive strength of concrete

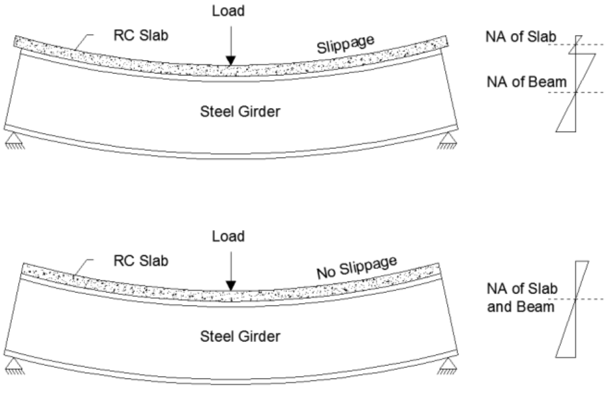

Fig. 3 Composite Action

In general, composite bridges are structures in which material consumption is effectively optimised because:

a) Supporting I-girders offer high structural efficiency.

b) Use of different thickness steel plate enables implementation of only strictly required minimum thickness throughout structure.

c) Deck lightness decreases size of supports and especially foundations.

d) When longitudinal profile is not imposed, higher slenderness ratio allows lower longitudinal profile and thus lower approach embankments.

IV. DESIGN PROCEDURE FOR SELECTING THE CROSS SECTION OF THE PLATE GIRDER

(a) Calculate the Design Bending Moment caused by Dead Load and Live Load.

(b) Calculate the Shear Forces caused by Dead Load and Live Load.

(c) Dimensioning of the girder.

$$\text{Economical Depth, } D = 5\sqrt[3]{\frac{M}{\sigma_{bc}}} \qquad \text{... (4)}$$

(d) Flange area required,

$$A_f = \frac{M}{\sigma_{bc}\, d} - \frac{A_w}{6} \qquad \text{... (5)}$$

(e) Moment of Inertia

(f) Bending Tensile Stress

$$f = \frac{My}{I} \qquad \text{... (6)}$$

(g) Check for Shear and Deflections.

Note: The type of Live Load considered in this paper is IRC CLASS AA Tracked load.

V. COST ANALYSIS

The cost analysis has been done by taking the unit cost of material and man power from standard Schedule Of Rates 2014 (SOR). The cost analysis has been done for each span including super structure and sub structure. Accordingly, the total cost of super structure and the sub structure are shown in the table 2.

VI. RESULTS OBTAINED FROM CALCULATIONS

TABLE 1. CROSS SECTION OF GIRDERS FOR DIFFERENT SPANS AND WIDTHS

Span (m)	Width of Road way (m)	Thickness of Web (t_w) mm	Depth of the Web (d_w) mm	Thickness of Flange (t_f) mm	Width of Flange (w_f) mm
10	7.5	12	1000	22	250
	15	12	1000	25	250
15	7.5	12	1200	30	350
	15	16	1200	30	400
20	7.5	12	1400	30	500
	15	16	1450	30	550
25	7.5	12	1600	30	600
	15	16	1600	30	700
30	7.5	12	1800	30	700
	15	20	1800	30	750
35	7.5	12	1900	32	800
	15	20	2000	32	850
40	7.5	12	2000	36	900
	15	20	2100	36	1000

TABLE 2. COST ANSLYSIS

Span (m)	Cost of Super Structure (Rs)	Cost of Sub Structure (Rs)
10	10,88,474	53,73,920
15	19,22,559	54,84,294
20	29,02,596	54,87,652
25	39,59,124	55,80,222
30	51,46,912	57,25,694
35	65,75,109	58,74,104
40	84,38,006	59,93,126

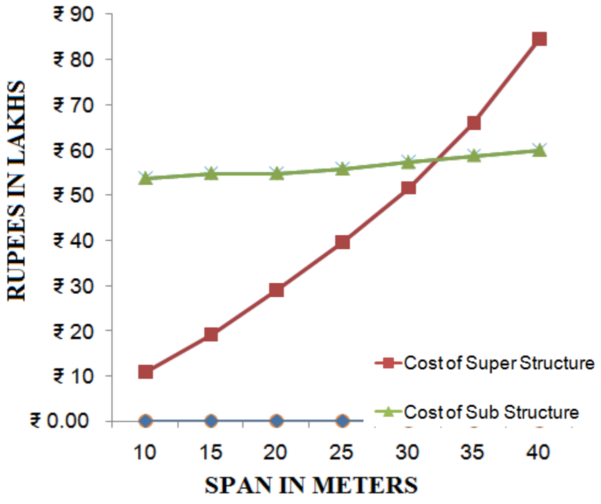

Fig. 4 ECONOMICAL SPAN OF COMPOSITE BRIDGES

VII. CONCLUSIONS

Most of the guidelines developed in this paper are derived from the calculations. By reducing the number of primary girders and increasing the cross sections to meet compatibility conditions, the cost of primary girders can be reduced significantly. When 5 girders are reduced to 3 girders and the cross section has been increased to reduce the cost. From the cost analysis of both these bridges with 5 girders and 3 girders, 30% of the cost reduction in the girders can be seen. It can be concluded that the point at which the cost of super structure equals the cost of sub structure, that span is called as the most economical span in composite bridges. The minimum cross sections of main girders are shown in Table 1. There is no much difference is observed in cost of the sub structure. From the graph, it is seen that the cost of super structure from the span 35m to 40m, the cost has been increased in a capricious manner. This drastic change has not been seen in the spans ranging below 35 m. From the calculations, the most economical span of the composite bridges lies in between 30m and 35m. Application of all these guidelines in the design should lead to economical plate girder composite bridges.

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