PARAMETRIC STUDY OF COMPOSITE PLATE GIRDER ROAD BRIDGE

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ABSTRACT

Design of structural members with maximum efficiency and minimum cost has always been a challenge for engineers. Steel concrete composite construction has become increasingly popular in advanced countries and is also fast catching up in developing countries. Steel concrete composite construction is an ideal example wherein there is most effective utilization of materials i.e. compression capacity of concrete and tensile capacity of steel.

In this paper, analysis and design of composite plate girder for four-lane Highway Bridge is considered. The bridge consists of reinforced concrete deck and steel girders. In steel concrete composite bridge, various alternatives have been considered for analysis and design. The alternatives consist of variation in span, span to depth ratio and designs as per IS 800:1984, by which superstructure design is mainly affected. Analysis is carried out using MIDAS civil software for various vehicular load combination specified in IRC-22. A total 15 alternatives were taken considering spans of 15m, 20m, and 25m with various span to depth ratios. Parametric study was done for calculation of most economical L/D ratio for above mentioned spans. For all the alternatives, cost estimation was carried out with prevailing market rates.

From this study, it was found that most economical L/D ratio with minimum cost was 9.9, 13.08 & 13.34 for span of 15m, 20m & 25m respectively. Hence this work provides a direct & simple method for optimal economical design of steel concrete composite road bridge superstructure.

Keyword: Composite plate girder, IS 800-1984.

I. INTRODUCTION

Steel-concrete composite construction is more popular in advanced countries like USA and UK and fast catching up in other countries. This type of few construction is now coming up in India during last decade because of the potential benefits. In all steel-concrete composite construction, composite deck slab of a bridge and flyovers are very popular. In composite construction, there is most effective utilization of materials like concrete in compression and steel in tension. Shear connectors are the main part for resisting horizontal shear in steel-concrete composite road bridge. This type of bridge deck provides for speedy erection of the prefabricated steel girders and considerably reduces the cost of form work. The savings in the overall depth of the beams leads to savings in lengths of approaches in the case of embankments. The flexural stiffness of a composite beam will be about 2 to 4 times that for a corresponding steel beam and this results in reduced deflections and vibrations. In present study bridge model is analyzed by using beam elements. Both girder and deck slab is assumed to consist of beam element. Longitudinal girder is designed as per the IS 800-1984. The effective flange width was the width of concrete T-beam which can be assumed to function as a compression flange under flexural action. The modular ratio is considered as the ratio of modulus of elasticity of steel to the creep-modified of elasticity of concrete which actually depends on the duration of the load, time of loading after concreting, composition of concrete, environmental conditions as well as percentage of reinforcement provided. For analysis purpose class A and class 70R vehicular load are considered. In present study four lane highway composite bridge system is considered with various span to depth ratio. For this the spans considered are 15m, 20m and 25m with different depths of girder. Total 9 such alternative are analyzed for economy and safety with MIDAS civil software. The estimation of cost for any structure includes quantity analysis and rate analysis. The estimation of cost is necessary for selection of final design alternative amongst the available various designs. The alternatives available are required to be evaluated to design the girder by taking most effective span to depth ratio. To obtain the most effective span to depth ratio parametric study was done for 15m, 20m and 25 m span. In this parametric study trials are taken by varying L/D ratio.

II. PROBLEM DEFINATION

In this study, cross section taken for analysis and design is as shown in Fig. 1

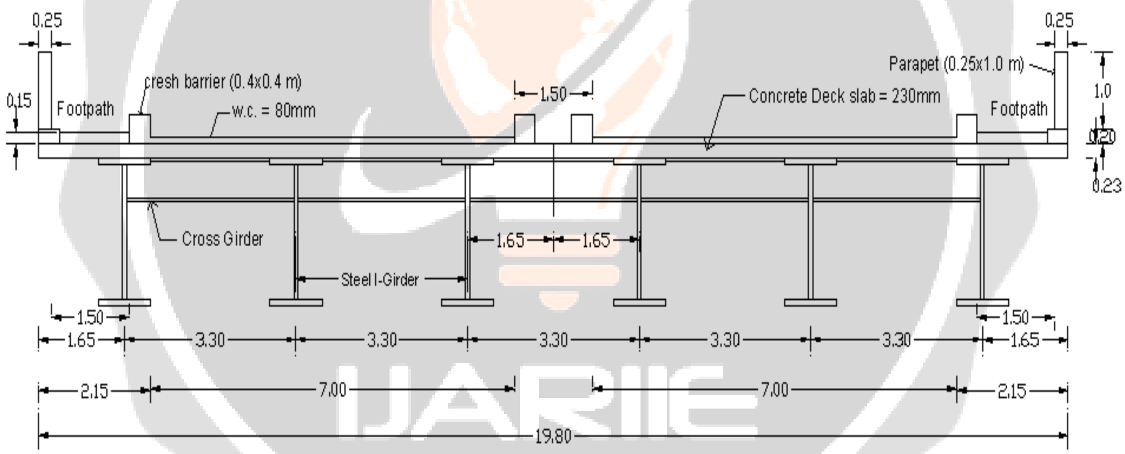

Fig. 1 Cross section of composite I-girder without shear connectors

In this study the four lane bridge is assumed. The width of carriage way is taken as 7.0 m. On both the sides of deck, footpath of width 1.35 m is assumed. The crash barrier is of size 0.4 m width and 0.4 m height, as specified by IRC. The curb is of size 0.4 m width and 0.2 m height. The parapet is of 0.25 m width and 1.0 m height. The median of width 1.5 m including crash barrier is assumed.

The cross sectional dimension of the steel girder is taken from decided L/D ratio. Deck slab thickness is 0.23 m and wearing coat thickness of 0.08 m are considered. Two types of class 70R and class A vehicles are considered for analysis purpose as per IRC 6-2000. The following material properties are considered for design purpose,

- RCC Grade = M25
- Grade of reinforcement = Fe 415
- Grade of structural steel = Fe 250

Table 1 Data of various span and various span to depth ratio

SPANS (m)	c/c dist. between cross girder	No. of cross girder	c/c distance between longitudinal girder	No. of longitudinal girder	Span to depth ratio
15 m	3.75 m	5	3.3	6	9.9, 11.74, 12.74, 13.87, 14.47, 18.08
20 m	4 m	6	3.3	6	9.67, 11.28, 11.92, 13.08, 13.5, 14.37, 15.46, 16.58, 18.46
25 m	4.167 m	7	3.3	6	10.11,10.99,11.91,13.34,14.03, 14.82,16.1,16.54,17.59,18.72

III. LONGITUDINAL GIRDER SIZE

Table 3 Longitudinal girder dimension for different span to depth ratio

span m	L/D ratio	web dimension(mm)	Top flange Dimension (mm)	Bottom flange Dimension(mm)
15	9.9	1250 x 10	300 x 16	400 x 20
	11.74	1000 x 10	300 x 16	500 x 32
	12.74	900 x 12	400 x 16	500 x 32
	13.87	800 x 14	400 x 20	600 x 32
	14.47	750 x 16	500 x 25	600 x 32
	18.08	500 x 25	500 x 40	600 x 60
20	9.67	1800 x 10	300 x 20	500 x 20
	11.28	1500 x 10	300 x 16	500 x 28
	11.92	1400 x 10	300 x 18	500 x 30
	13.08	1250 x 10	300 x 18	500 x 32
	13.5	1200 x 12	300 x 20	500 x 32
	14.37	1100 x 12	400 x 22	500 x 40
	15.46	1000 x 14	500 x 28	600 x 36
	16.58	900 x 16	500 x 32	600 x 45
	18.46	750 x 16	500 x 32	600 x 72
25	10.11	2200 x 12	500 x 20	500 x 25
	10.99	2000 x 12	500 x 20	600 x 25
	11.91	1800 x 10	500 x 20	600 x 25
	13.34	1600 x 10	500 x 20	600 x 25
	14.03	1500 x 12	500 x 22	600 x 30
	14.82	1400 x 12	500 x 22	600 x 36
	16.1	1250 x 12	500 x 28	600 x 45
	16.54	1200 x 12	500 x 32	600 x 50
	17.59	1100 x 14	600 x 32	750 x 60
	18.72	1000 x 14	600 x 40	750 x 66

IV. ANALYSIS RESULTS

Table 3 Maximum Bending Moment in Girder

Span m	L/D Ratio	Moment kNm	Span m	L/D Ratio	Moment kNm	Span m	L/D Ratio	Moment kNm
15	9.90	3308	20	9.67	4911	25	10.11	7169
	11.74	3293		11.28	4878		10.99	7084
	12.74	3267		11.92	4858		11.91	7008
	13.87	3270		13.08	4807		13.34	6886
	14.47	3259		13.50	4787		14.03	6896
	18.08	3286		14.37	4826		14.82	6905
				15.46	4829		16.10	6924
				16.58	4904		16.54	6952
				18.46	4915		17.59	7117
							18.72	7131

Table 4 Maximum Shear Force in Girder

Span m	L/D Ratio	Shear Force kNm	Span m	L/D Ratio	Shear Force kNm	Span m	L/D Ratio	Shear Force kNm
15	9.90	974	20	9.67	1050	25	10.11	1347
	11.74	970		11.28	1049		10.99	1340
	12.74	973		11.92	1050		11.91	1330
	13.87	976		13.08	1049		13.34	1320
	14.47	976		13.50	1049		14.03	1323
	18.08	990		14.37	1055		14.82	1325
				15.46	1061		16.10	1331
				16.58	1067		16.54	1334
				18.46	1077		17.59	1356
							18.72	1361

Above analysis results are obtained from the MIDAS civil software. And for design excel spreadsheet are prepared to prevent the time for repeated work. As per the design section quantity analysis and rate analysis are done as a market rate.

V. DESIGN CONSTRAINTS

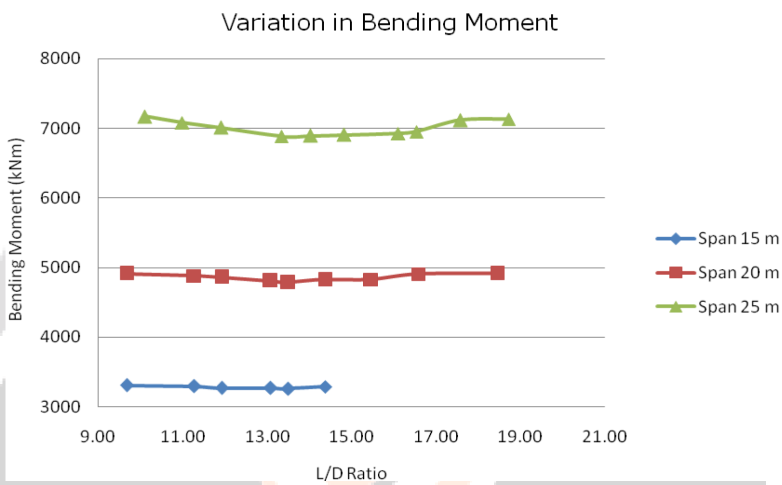

Fig. 2(a) Variation in Bending Moment

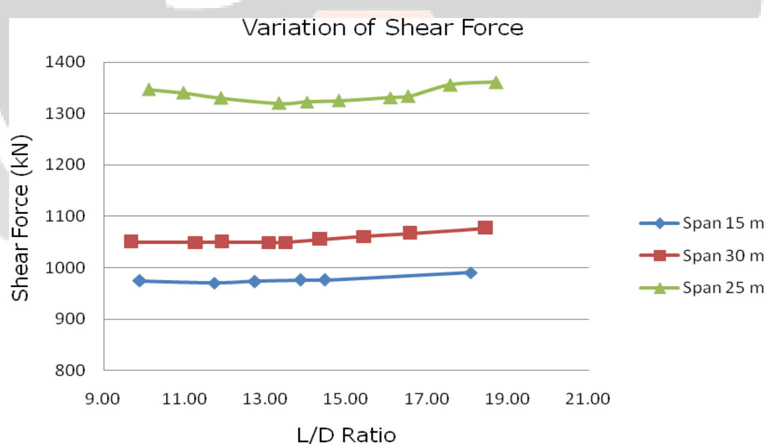

Fig. 2(b) Variation in Shear Force

The analysis was done in MIDAS civil software. Graphical variation of maximum Bending moment and shear force are shown in below. As the L/D ratio increases the depth for given span reduces, thus the total moment decreases but in composite bridge moment is fluctuating with size of longitudinal girder components. It is clearly shown in Fig. 2(a). The shear force variations are shown in Fig. 2(b).

VI. QUANTITY ANALYSIS

The quantity analysis is a schedule or list of quantities of all the possible items required for construction of any structure. These quantities are worked out by reading the drawing of the structure. Thus the quantity analysis indicates the amount of work to be done under each item, which when priced per unit of work gives the amount of cost of that particular item. It should be noted that the quantity analysis mentions all the items in the estimate. The quantity analysis does not give the list of materials required.

VII. RATE ANALYSIS

In order to determine the rate of a particular item, the factors affecting the rate of that item are studied carefully and then finally a rate is decided for that item. With the use of that rate and estimated quantity the total tentative cost of the whole structure can be obtained.

For cost estimate rate analysis of concrete is worked out wherein the rates of cement and other ingredients are considered based on current market rates. The rates of structural steel are based on current market rates.

Particular Item	**Rate**	
Concrete	3000	Rs/m^3
Longitudinal girder steel	35	Rs/kg
Shuttering	200	Rs/m^2
Scaffolding	750	Rs/m^3
Wearing coat	2600	Rs/tone
Connection	250	Rs/m length
Shear connector	50	Rs/No.

VIII. RESULTS OF ESTIMATION AND COSTING

The design was done by prepared spreadsheet. For all the various span lengths structural plate girder steel is designed. The designed results are compared with cost of material required. Recapitulation of results is shown in this para.

Table 5 Cost of different items and total cost per meter for 15m span with L/D ratio

Span 15 m							
L/D ratio	Concrete Rs/m	Shuttering, scaffolding, WC (Rs/m)	Slab Rein. Rs/m	Structural steel Rs/m	Erection Rs/m	Shear connector Rs/m	Total Rs/m
9.90	22770.0	13421.9	18885.9	65456.5	10372.0	10240.0	**141146.3**
11.74	22770.0	13421.9	18885.9	73303.3	9662.0	11520.0	149563.1
12.74	22770.0	13301.9	18885.9	76143.3	7800.0	11520.0	150421.1
13.87	22770.0	13301.9	18885.9	84590.5	7720.0	13120.0	160388.3
14.47	22770.0	13181.9	18885.9	92755.3	7620.0	13120.0	168333.1
18.08	22770.0	13181.9	18885.9	132279.1	7400.0	15040.0	209556.9

Table 6 Cost of different items and total cost per meter for 20m span with L/D ratio

Span 20 m							
L/D ratio	Concrete Rs/m	Shuttering, scaffolding, WC (Rs/m)	Slab Rein. Rs/m	Structural steel Rs/m	Erection Rs/m	Shear connector Rs/m	Total Rs/m
9.67	22770	13421.9	17642.1	74825.0	10486.5	10080	149235.2
11.28	22770	13421.9	17642.1	73565.3	9811.5	10080	147302.1
11.92	22770	13421.9	17642.1	74275.5	9586.5	10080	147787.9
13.08	22770	13421.9	17642.1	73394.0	9495	10080	**146816.1**
13.50	22770	13421.9	17642.1	77516.6	9435	10080	150879.1
14.37	22770	13301.9	17642.1	86284.0	9492	11520	161010.0
15.46	22770	13181.9	17642.1	97344.6	7500	11520	169974.0
16.58	22770	13181.9	17642.1	109908.6	7470	11520	182509.2
18.46	22770	13181.9	17642.1	131874.0	7335	13200	206021.4

Table 7 Cost of different items and total cost per meter for 25m span with L/D ratio

Span 25 m							
L/D ratio	Concrete Rs/m	Shuttering, scaffolding, WC (Rs/m)	Slab Rein. Rs/m	Structural steel Rs/m	Erection Rs/m	Shear connector Rs/m	Total Rs/m
10.11	22770	13182	17630	98890	9831.6	8256	170560
10.99	22770	13182	17630	98401	9782.4	9024	170789
11.91	22770	13182	17630	88628	10090.8	9024	161325
13.34	22770	13182	17630	84467	9682.8	9024	**156756**
14.03	22770	13182	17630	93909	9478.8	10176	167146
14.82	22770	13182	17630	97530	9274.8	11328	171715
16.10	22770	13182	17630	108044	9415.2	11328	182369
16.54	22770	13182	17630	115019	9295.2	12864	190760
17.59	22770	13062	17630	144840	7284	12864	218450
18.72	22770	13062	17630	157423	7212	12864	230961

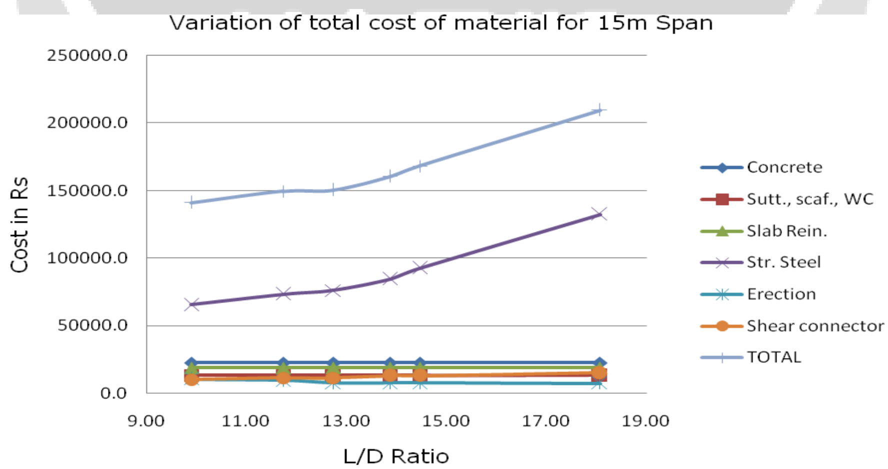

Fig. 3 (a) Variation of Cost of Material and Total Cost with L/D ratio

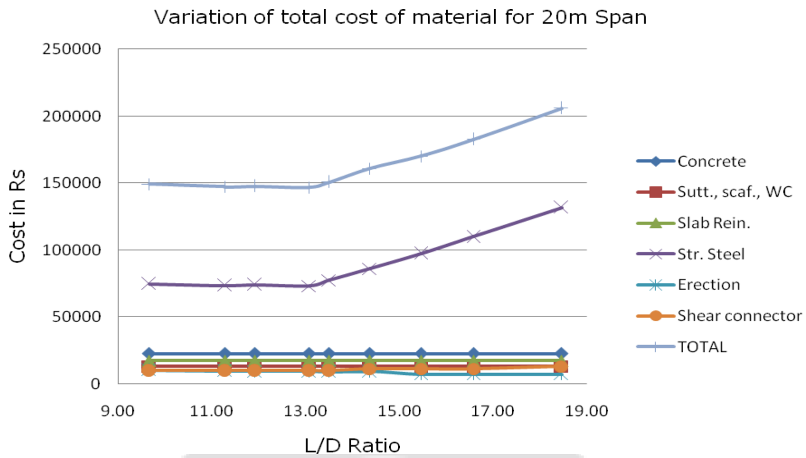

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Fig. 3 (b) Variation of Cost of Material and Total Cost with L/D ratio

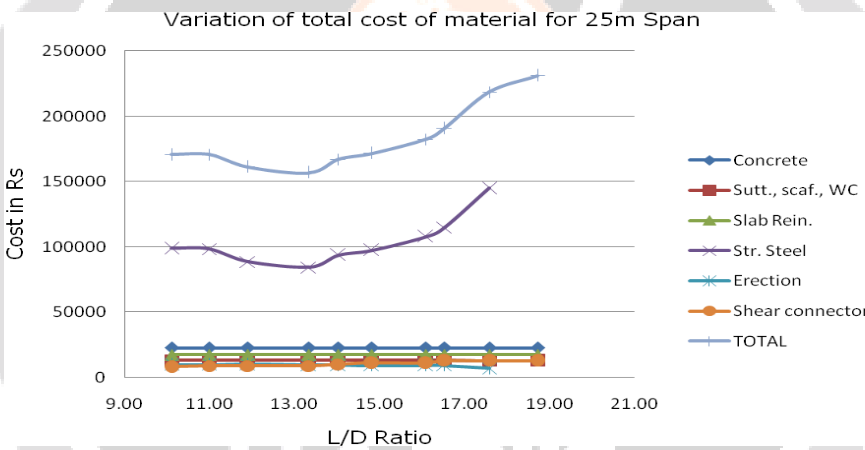

Fig. 3(c) Variation of Cost of Material and Total Cost with L/D ratio

From the Fig. 3(a), Fig. 3(b), Fig. 3(c) it is clear that total cost of super structure is mainly affected by steel cost. Here steel cost is divided in structural steel and Reinforcement Steel (Slab). As the span of bridge increases the cost per meter length of bridge super structure increases .As shown in above Table it is clear that requirement of structural steel in slab per m^3 of concrete is reduces as span increases. As shown in above Table it is clear that connection cost is increase as span increases.

IX. SUMMARY AND CONCLUSION

Above results indicates that there is a correlation between L/D ratio, Span and cost of Super structure.

➢ **Analysis**

- During analysis it is observed that with the increase in span the bending moment and shear force increases.
- For same span with increase L/D ratio not much difference in the bending moment and shear force.
- Torsional moment is much smaller then bending moment so it is not much affected in design.

➢ **Design**

- As the span increases the total cost of super structure per meter increases.
- For higher L/D ratio plate girder section is heavier than lower L/D ratio.
- For 15m span L/D ratio up to 12 there is uniform increase in cost after that rapidly increase in cost is observed.
- For 20m and 25m span L/D ratio up to 13 there is uniform increase in cost after that rapidly increase in is observed.
- For different spans like 15m, 20m and 25m, the economical L/D ratio is found to be 9.9, 13.08 and 13.34 respectively
- Most effective economical L/D ratio for three different span are given in below table,

Span (m)	Economical L/D ratio	Total cost (Rs/m) As per IS 800-1984
15	9.9	141146.3
20	13.08	146816.1
25	13.34	156756

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