

Comparative Analysis and Modeling of Bridge Superstructure Using SAP 2000 Software

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ABSTRACT: T beam bridges and box girder bridges are the most commonly used beam/ girder bridges. The aim of the study was to compare T beam and box girder bridges and identify the structurally stable, efficient, serviceable and economical section for different spanning conditions. Various IRC loading namely IRC class A, class AA, and 70R loading was applied and the worst loading was found by modeling and analysis using SAP 2000 software. The value of Bending Moment, Shear Force and deflection was tabulated. The volume of concrete for different sections and design of the T beam was done manually. Graphical representation of the data was used for comparison. The most stable and economical section, l/d ratio, choice between deep/shallow sections and span range for T beam & Box Girder Bridges were found from the analysis.

KEY WORDS: T beam bridge, Box Girder Bridge, IRC loading, SAP 2000 software

I. INTRODUCTION

The core structure of the bridge determines how it distributes the internal forces of tension, compression, torsion, bending, and shear. Based on type of superstructure bridges are classified as arch, girder, truss and suspension bridges. The development of the nation is mainly from agricultural and industrial activities, so, it is required to facilitate the proper transportation by providing the Flyovers and Bridges. For constructing the flyovers or the bridges we find many types of section among which T beam and box type are very popular. In order to find out the most suitable and economic section, this project looks at the work of analysis, modelling and comparison of T-Beam and Box girders for different spans. The purpose of this study is to identify the suitable and economical section for bridges of different spans. The analysis is done using the CSI bridge software SAP 2000

II. METHODOLOGY

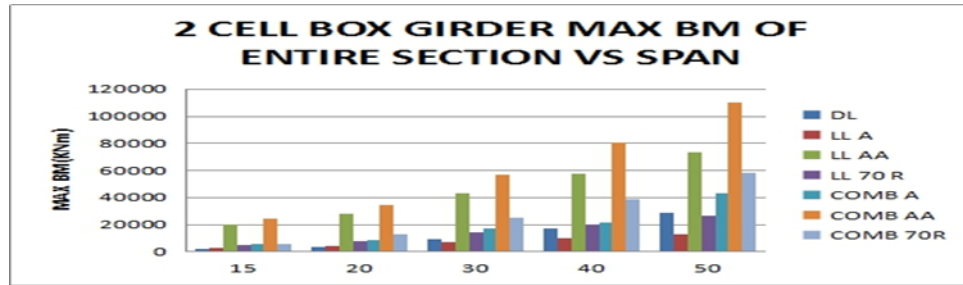
A study on the structural forms of bridges, bridge superstructure especially T and Box girder, IRC loading, impact factor for design and the SAP 2000 software were studied. The various IRC loadings, say IRC class A, class AA and 70R loading were applied on an arbitrary cross section of T and Box Girder Bridge and the worst loading was found using SAP 2000 software. The impact factor for the respective spans was estimated by using the IRC 6 2000. After fixing the cross-section dimensions, span range, impact factor and grade of concrete, the modeling and analysis was done using SAP 2000 software. The values of bending moment, shear force and displacement obtained from the software were tabulated. The volume of concrete for different sections and design of the T beam were worked out manually. The obtained data was graphically depicted for comparison and suggestion of the stable and economic sections. The stable and economic section, l/d ratio, selection between shallow or deeper sections and span range suitable for T and Box Girder Bridge were found out from analysis.

III. DETERMINATION OF THE CRITICAL IRC LOADING

The highway bridge decks have to be designed to withstand the loading as specified by Indian Road Congress. As per IRC 6:2000 all the bridges located on state and national highways have to be designed for IRC Class AA loading. In addition to this bridges designed for AA loading should be checked for A loading also. Alternatively, IRC also suggests 70R loading instead of AA loading. In order to determine the most critical loading, an arbitrary section is analyzed for spans ranging from 15m to 50m for both the T beam and box girder. The bending moment and shear force is analyzed to select the critical loading.

3.1 Box Girder Bridge:

15m span 2 celled box girders with 200mm thick web and flange and 500mm overhang is modeled and analyzed for different IRC loadings given below:

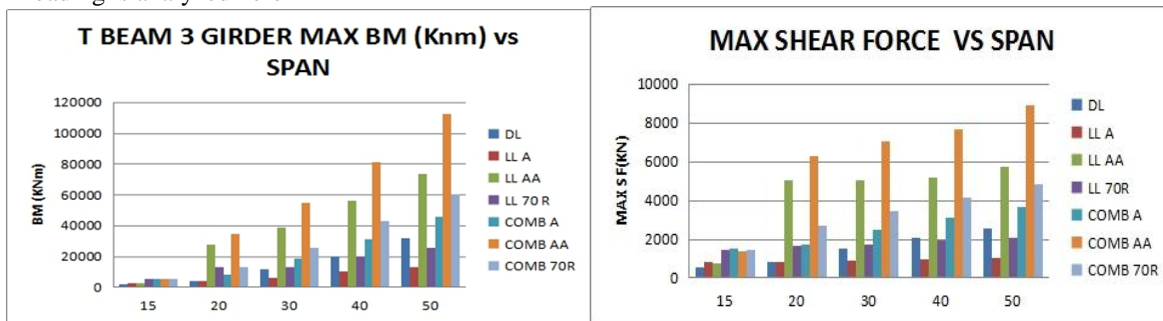


(a)

Fig 1 (a) bending moment vs span

3.2 T Beam Bridge:

5m span 3 longitudinal girder 300mm thick T beam with 2500mm flange width is analyzed for different IRC loading is analyzed here

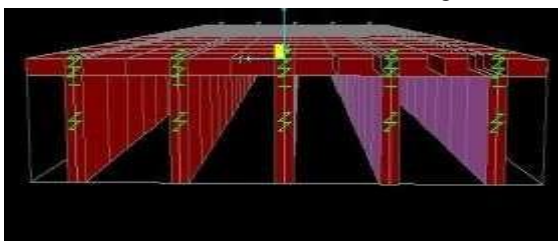


(a)

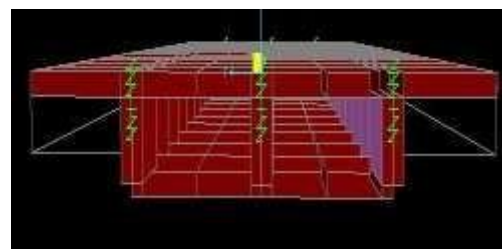
(b)

Fig 2 (a) bending moment vs span (b) shear force vs span

It is inferred from the above analysis that the bending moment and shear force values are greater for combination of dead load and IRC class AA loading. Therefore, all other analysis are carried out for IRC AA loading.



(c)



(d)

Fig 3 (c) longitudinal girder t beam bridge SAP (d) 2 cell box girder SAP

IV. DETERMINATION OF IMPACT FACTOR

As per IRC 6 2000, the impact factor for I.R.C. Class AA or 70R loading

- (i) For span less than 9 meters



- For tracked vehicles- 25% for a span up to 5m linearly reduced to a 10% for a span of 9m.
- For wheeled vehicles-25% (ii)For span of 9 m or more

For tracked vehicle- for R.C. bridges, 10% up to a span of 40m. For steel bridges, 10% for all spans.

The span considered here ranges from 10 to 40m. IRC class AA loading produced the worst effect and hence modeling is for IRC class AA loading. Therefore the impact factor to be considered is 10 % as per IRC 6 2000.

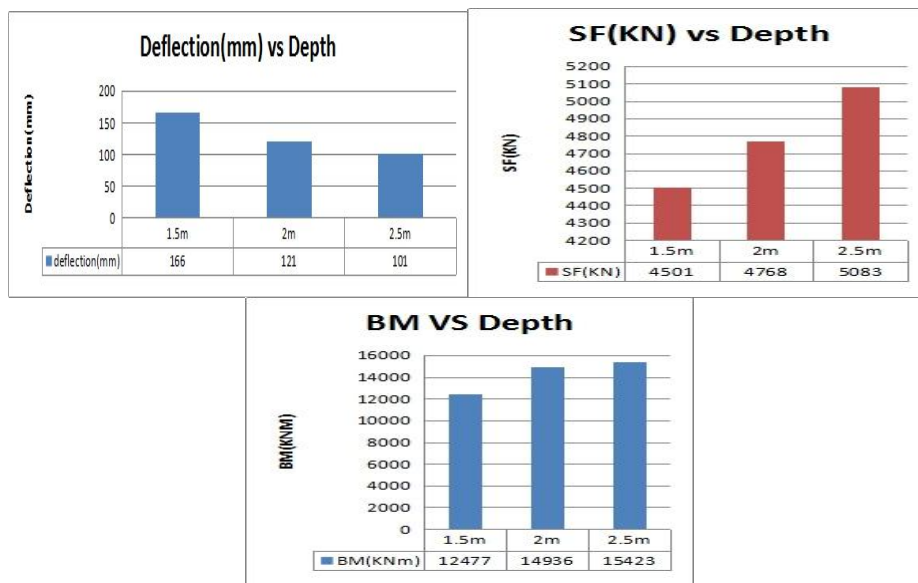
V. THE EFFECT OF CROSS SECTION ELEMENTS ON ECONOMIC DESIGN

The analysis is carried out on a span range of 10 to 40m. Only representative samples are depicted below. All the other spans were analyzed in a similar manner and the same results were obtained.

5.1 T beam bridge:

5.1.1Effect Of Depth Of Longitudinal Girders:

15m span T beam bridge superstructure with 3 longitudinal girders of 300mm thickness and 2.5m width of flanges were analyzed at various depths of 1.5m, 2m and 2.5m. The variation of deflection, shear force and bending moment are plotted below:

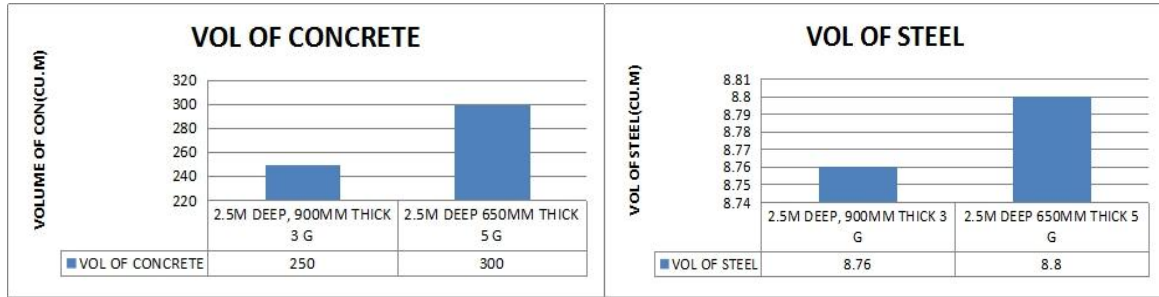


(a) (b)
Fig 4. (a) deflection vs depth (b) bending moment and shear force vs depth

When the depth of the girders was increased from 1.5m to 2m, the deflection value was reduced. Moment of inertia of the girder is mainly governed by the depth of the section. Also, the deflection is inversely proportional to the moment of inertia. This is the reason why the deflection values were reduced on increasing depth.

5.1.2.Comparison Between Effect of Thickness and No. Of Longitudinal Girders:

In order to determine the most effective and economical way of fixing the dimensions, the effect of no. of longitudinal girders and thickness of longitudinal girders are compared. The 40m span T beam bridge superstructure 2.5m deep is analyzed with 3 no. of 900mm thick longitudinal girders and 5 no. of 650mm thick longitudinal girders, both with a constant overhang of 500mm.

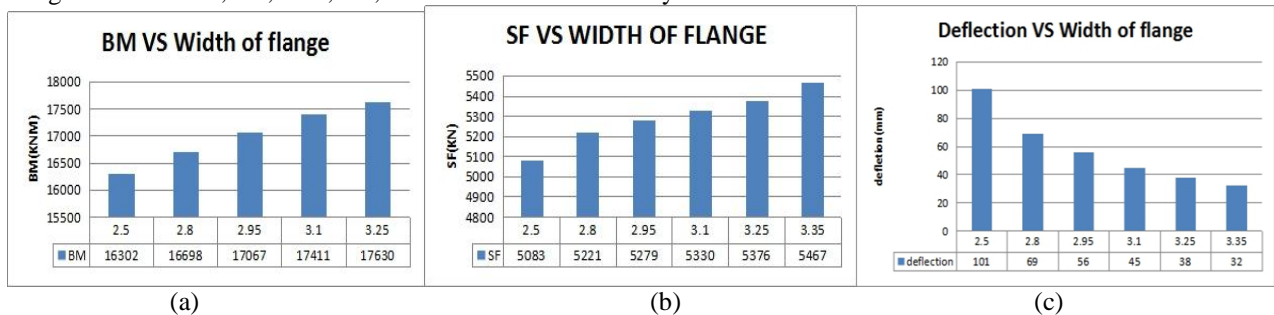


(a) (b)
Fig 5 (a) volume of concrete (b) volume of steel

It can be inferred from the above analysis that providing more no. of longitudinal girders with less thickness consumes larger quantities of steel and concrete as compared with less no. of thick girders. So it is economical to increase the thickness than providing more girders to control deflection.

5.1.3. : Effect Of Width Of Flange:

2.5M deep T Beam with 3 no.of longitudinal girders of 300mm thick are analysed with different width of flanges. The flange widths of 2.5, 2.8, 2.95, 3.1, 3.25 and 3.35m were analysed



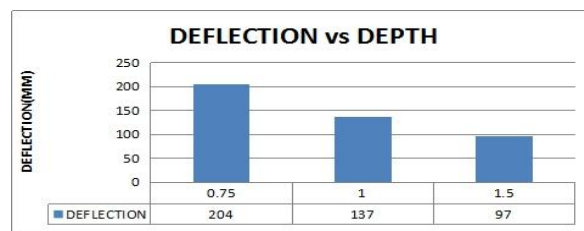
(a) (b) (c)
Fig 6 (a)bending moment vs width of flange(b) shear force vs width of flange (c) deflection vs width of flange

When the width of flanges was increased, the moment of inertia was increased and the deflection was reduced. As the width of flange increased, the dead load BM and SF was increased and hence the total BM and SF. Increasing flange width is effective in controlling deflection in an economic way.

5.2 Box Girder Bridge

5.2.1 Effect Of Change In Depth Of Section

15m span 2cell box girders with 200mm thick web and flanges and 2.5m width of flange are analyzed with 0.75m, 1m, 1.5m depths



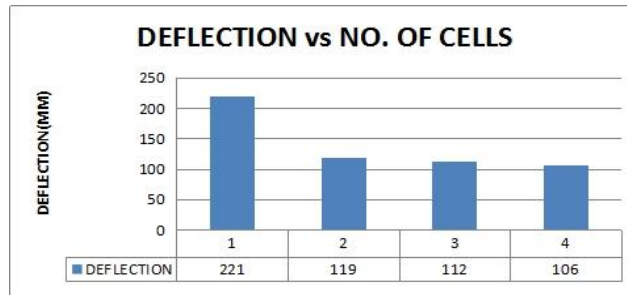
(a)
Fig 7 (a) deflection vs depth

On analyzing T beam and box girder for the same cross section parameters, say for a depth 1.5m, box girder produces a

deflection of 97mm whereas T beam produces a deflection of 166mm. So, it can be concluded that more shallow sections can be constructed economically using box girders.

5.2.2 Effect Of Change In No. Of Cells:

30m span box girder ,2 m deep 200mm thick with 850mm overhang is analysed for 1, 2,3 and 4 no. of cells.



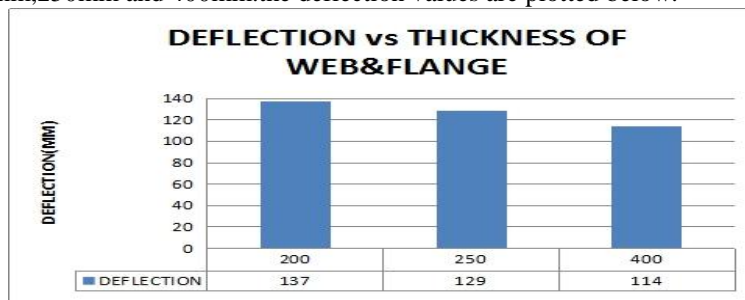
(a)

Fig 7 (a) deflection vs no. of cells

Deflection reduces on increasing no. of cells. Single celled box girders produce excessive deflection as compared to other sections. Therefore, single celled box girders are not preferred. The deflection reduces drastically from 221 to 119mm on increasing the no. of cells to 2. But, the reduction in deflection is not proportional to increase in no. of cells. The reduction in deflection is not considerable with increase in quantity of materials for 3 and more no. of girders. So, for 2 lane width road of 7.5m width, 2 celled box girders are more appropriate.

5.2.3 Effect Of Thickness Of Web And Flange:

15m span 2 celled box girders of 1m depth and 1700mm overhang are checked for different thickness of web and flanges, say 200mm,250mm and 400mm.the deflection values are plotted below:



(a)

Fig 9 (a) deflection vs thickness of web and flange

The deflection value reduces as thickness increases. The 400mm thick girders produce a deflection of 114mm which is most near to the limiting value of 60mm. So an increased flange width may be possible to reduce the deflection at 60mm economically rather than further increasing the thickness.

VI. DETERMINATION OF MOST ECONOMICAL SECTION

The maximum possible deflection for the section as specified in the IS456:2000 is span/250. Therefore, the maximum possible deflection values for 10m, 15m, 20m, 30m and 40m are 40mm, 60mm, 120mm and 160mm respectively. An arbitrary depth is chosen and minimum cross sections parameters are fixed as per Indian Standard code provision. Deflection values are checked and cross section parameters are changed such that deflection criteria are almost met. Thereafter, the flange width is adjusted and BM and SF of longitudinal girders are analyzed using the CSI bridge software SAP 2000. The quantity of concrete and reinforcements are calculated by manual design.

The most stable and serviceable section found by modeling is presented in given table:

SPAN	T Beam Bridge				Box Girder Bridge			
	N	Df	Bf	Tw	N	Df	OH	Tw
10m	3	1.2	3.5	0.5	2	1	0.8	0.2
	5	1	1.85	0.3	4	0.8	0.5	0.2
					2	0.8	0.5	0.3
15m	3	2.5	1.25	0.3	2	1.5	0.5	0.2
	3	1.5	1.25	0.4	2	1	0.9	0.4
	5	1.5	1.775	0.3	4	1	0.85	0.2
20m	3	2.5	3.7	0.3	2	1.5	0.9	0.2
	5	2	1.85	0.3	2	1.25	0.5	0.3
30m	3	3	2.9	0.3	2	2	1	0.2
	5	2	1.775	0.6	2	1.7	0.7	0.3
40m	3	3	3.7	0.3	2	2.5	1	0.2
	5	2.5	1.76	0.65	2	2.35	0.5	0.2
	3	2.5	3.4	0.9	5	2	0.5	0.2

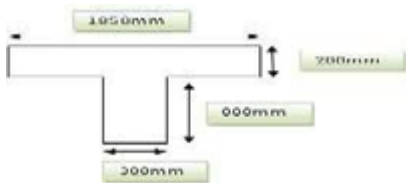
Table 1: Economic section details of T and Box girder

N= No. of cells/ longitudinal girders Df= Depth of flange

Bf= breadth of flange Tw=thickness of web OH= Overhang

VII. MANUAL DESIGN OF T BEAM

Manual design of 10m span T beam longitudinal girder is written below. Similarly, other models were designed.



(a)

Fig 10 (a) cross section dimension of T beam bridge

$$M_u = 5637 \text{ kNm}$$

$$d = 1000 - 80 = 920 \text{ mm}$$

$$X_{u \text{ max}} = 0.48d = 0.48 * 920 = 441.6 \text{ mm}$$

Assuming $x_u < D_f$

$$M_u = 0.36f_{ck} * b_f * x_u (d - 0.42x_u)$$

$$5637 * 10^6 = 0.36 * 25 * 1850 * x_u * (920 - 0.42x_u)$$

$$X_u = 467.9 > D_f$$

ie, NA is outside the flange

$$M_{u_i} = 0.36f_{ck} * x_{u \text{ max}} * b_w (d - 0.42x_{u \text{ max}}) + 0.45f_{ck} (b_f - b_w) D_f (d - 0.5D_f)$$

$$\text{Substituting } M_{u_i} = 3735.54 \text{ kNm} < M_u$$



$$D_f/d=200/920=0.2<0.2$$

$$X_u/d>0.48$$

$$X_u>441.6$$

For $D_f/x_u < 0.43$, x_u should be $> D_f/0.43$

$$X_u > 200/0.43$$

$$X_u > 465$$

Here $x_u > 441.6$

The conditions are $D_f/d < 0.2$, $D_f/x_u < 0.43$

$M_u > M_{u_{lt}}$, doubly reinforced

For $M_{u_{lt}}$, finding A_{st}

$$A_{st1} = \left\{ \frac{0.36f_{ck} \cdot b_w \cdot x_{u_{lt}}}{0.87f_y} \right\} + \left\{ \frac{0.45f_{ck}(b_f - b_w)D_f}{0.87f_y} \right\}$$

$$= \frac{0.36 \cdot 25 \cdot 300 \cdot 441.6}{0.87 \cdot 415} + \left\{ \frac{0.45 \cdot 25 \cdot (1850 - 300) \cdot 200}{0.87 \cdot 415} \right\}$$

$$= 12961.7 \text{ mm}^2$$

$$M_u - M_{u_{lt}} = 5637 - 3735.54$$

$$= 1901.46 \text{ kNm}$$

$$E_{sc} = 0.0035(x_{u_{max}} - d)/x_{u_{max}} = 0.0035(441.6 - 80)/441.6$$

$$= 0.0028$$

$$M_u \text{ balance} = f_{sc} \cdot A_{sc}(d - d')$$

$$A_{sc} = 1901.46 \cdot 10^6 / 350 \cdot (920 - 80)$$

$$= 6467.55 \text{ mm}^2$$

$$A_{st2} = A_{sc} \cdot f_{sc} / 0.87f_y = 6467.55 \cdot 350 / 0.87 \cdot 415 = 6269.6 \text{ mm}^2$$

$$\text{Total tension steel} = A_{st1} + A_{st2}$$

$$= 12961.7 + 6269.6$$

$$= 19231.3 \text{ mm}^2$$

$$\text{Volume} = 0.192 \text{ m}^3$$

$$\text{Compression steel} = 6467.55 \text{ mm}^2$$

$$\text{Volume} = 0.0646 \text{ m}^3$$

$$\text{Total volume} = 0.256 \text{ m}^3$$

Total volume for 5 longitudinal girder = 1.28 cu.m

Deep section with less no. of cells consumes less quantity of material than shallow section with more no. of cells. Here, the 1.7m deep section consumes about 1.5times the material as 2m deep section.



Use of a deeper section of T beam with 3 longitudinal girders or box girder with 2 cells is an economic way of reducing the cost of material required for construction of a 2 lane 7.5m wide bridge deck. Shallow sections require large quantities of concrete and steel.

VIII. COMPARISON BETWEEN SHALLOW SECTIONS AND DEEPER SECTIONS

8.1.T Beam Bridge

15m span a no. of shallow sections and deep sections satisfying the deflection criteria and having the least bending moment and shear force are found out. The volume of materials is compared in order to suggest most economic design.

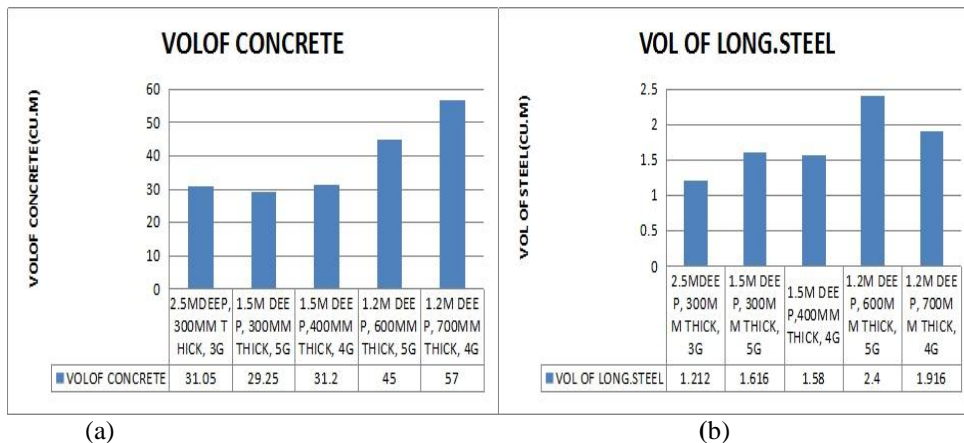
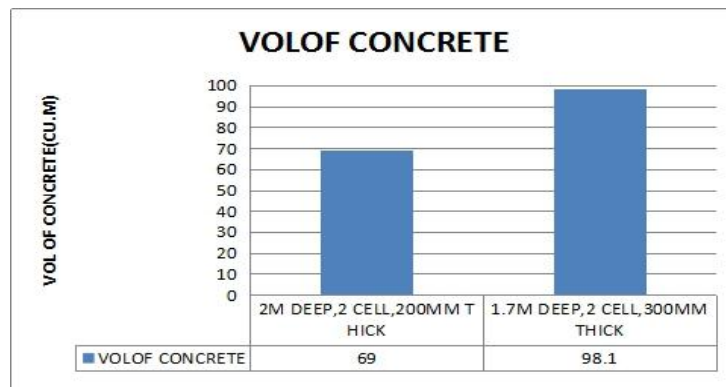


Fig 11 (a) volume of concrete (b) volume of longitudinal steel

It can be inferred from the graph that deeper sections consume relatively lesser amount of material than shallow sections. In the above graph when L/d ratio is increased from 10 to 12, volume of material is increased about twice.

8.2. Box Girder Bridge

The volume of concrete required for the 30m span box Girder Bridge for shallow sections and deep sections is compared here.



(a)
Fig 12. (a) volume of concrete

Deep section with less no. of cells consumes less quantity of material than shallow section with more no. of cells. Here, the 1.7m deep section consumes about 1.5times the material as 2m deep section.

Use of a deeper section of T beam with 3 longitudinal girders or box girder with 2 cells is an economic way of reducing the cost of material required for construction of a 2 lane 7.5m wide bridge deck. Shallow sections require large quantities of concrete and steel



IX.DETERMINATION OF SUITABLE L/D RATIO

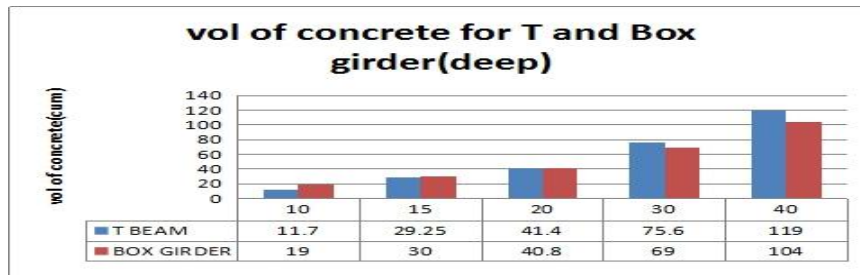
The possible range of L/D ratio that can be adopted for T beam and box girder is found by results of the best economic section found in previous analysis. The criteria considered for selection is the deflection limit ie, span/250, BM, SF of girders and the practical possibility of casting.

SPAN	T BEAM	BOX GIRDER
10-20m	8 to 10	6 to 8
20-30m	10 to 15	13 to 18
30-40m	12 to 16	16 to 20

Table 2: L/d ratio for T and box Girder Bridge

IX. DETERMINATION OF SUITABLE SPAN RANGE FOR T BEAM AND BOX GIRDER

The results of modeling of bending Moment, Shear force and Deflection of T beam and Box girder bridges is used to find the suitable section for respective spans. The span range considered for analysis is 10 to 40m. The least volume of concrete required for each of the span for T beam and box girders is compared below:



(a)

Fig 11. (a) volume of concrete for t and box girder

T beams require lesser quantity of material for span less than 20m and box girders consume less material for span 20m and above. Therefore, T beams are economical for span less than 20m and box girders for span 20m and above

X1. CONCLUSIONS

The increase in depth of girder, width of flange and thickness of girders reduces deflection and increase moment carrying capacity. 3 longitudinal girder T beam and 2 celled Box girders are ideal for 2 lane road. Deeper sections consume less material as compared to shallow sections. The analysis was also very effective in determining the most economical sections for T beam bridges and box girder bridges.

The l/d ratio and economic span range suitable for T beam and Box Girder Bridge was also found. Adopting these sections can be used for the construction of safe, stable and economic bridges.

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