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Expert Opinion Article

Comparative Study And Behavior Of Box Girder Bridges Using Sap2000

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Abstract: In modern highway system normally box girder bridges are used because they are structurally efficient, cost effective and aesthetically pleasing too. The non-uniform stress distribution of box girder section in transverse and longitudinal direction gives the complex behavior, most of the recent researchers suggested that the FEM method is best suitable for analyzing box girder bridges. According to the Indian Road Congress (IRC) provisions, linear analysis of Rectangular, Circular and Trapezoidal box girders has performed by using finite element analysis software i.e. SAP2000 for Dead Load (Self Weight), IRC Class 70 R loading and IRC Class A live loading for maximum eccentricity case. It has been analyzed that how the box girders behave with uniform depth increments. For different parameters such as longitudinal bending stress, shear stress and deflection. The accuracy of results and validation of work has been checked by comparing SAP2000 results with manual results for all sections of box girders. The comparative study has carried out for parameters like longitudinal and transverse bending stresses, shear stress distribution and deflection in girder. For analysis of box girders effectiveness of four nodded shell element is alsochecked.

Keywords: Box girder bridges, SAP2000, Eccentricity, IRC, IRC Class 70R, IRC Class A

1) Introduction to Box GirderBridges

Box girder sections are made up of pre-tensioned concrete as well as it can be made of post tensioning process with different composite sections, and an in situ concrete slab. Box girders are commonly used in construction of bridges because of it has several advantages as compared to solid sections. They are very great efficient in structural form, also the use of box section gives better stability to the structure and the use of box section gives aesthetically pleasant view to the construction. Box girder bridge usually in hollow trapezoidal or rectangular in cross-section, these are commonly used for highway flyovers and bridges in modern highway system. When bridge is in curved and horizontal plan then torsional rigidity of box bridge girder makes proper solution in that case. Box girders are suitable for longer spans and it allows larger span to depth ratios.Many variations are possible in standard cross section of box girder section, if depth variation of box girder is in between 1/5th to 1/6th of the bridge width then single cell box girder can be preferred. A two or multicell box girders are used where depth to roadway slab width. To achieve the better transverse load distribution of 2 or more box girders the girders are placed next to each other if only top flanges connected, they will be highly stressed due to bending moments in transverse direction in that case it is better to separate two boxgirders.

Advantages of Box Girder Bridges

The advantages of box girder section for bridges over solid I beam are given as follows:

1. The space inside the box-girder could be used for passage, utilities, or otherpurposes.
2. Since the box section is closed section, therefore shear center of section is located inside the box section which causes least amount of torsional stresses in section i.e. in other word it gives higher torsionalstiffness
3. Box girder has the lowest maintenance cost as compared to other types of sections because the exposed area to atmosphere is lower inproportion.
4. Because of the slender and attractive pier design, the appearance of a box girder is usually pleasing.
5. When the girder is curved in plan, torsional rigidity is advantageous. Without the use of lateral bracing, the torsion coming on structure due to vertical and horizontal loading is easily resisted by sectionitself.
6. For achieving greater stiffness in the form of torsion the aerodynamic form of box girder is very desirable in case of large and long cable stayedbridges.
7. The pier cap width is smaller in case of box section which resists and reduces the moment coming on substructurepart.

2) OBJECTIVES OF THERESEARCH

The study is about the analysis and behavior of the different box girder bridges (rectangular, trapezoidal, circular) under Dead load (Self Weight) and Live Load IRC 70R loading and IRC Class A live Loading. The objectives and scope for the study are given below:

1. Literature review of previous experimental and theoretical research work, and the analytical methods with general behavior of box girderbridges.
2. Develop the three-dimensional finite element beam and shell models of different straight box girder bridges using the commercially available finite element computer program"SAP2000".
3. Study the behavior of different straight box girder bridges and compare the computer program model results with the analytical method. i.e. validation of analytical and SAP modelresults.
4. Perform the parametric investigation utilizing the FEM model of the straight box girder to determine the effect of different cross-section on theparameters.
5. Study the effects of depth of cross-section and the cross-sectional shape on the behavior in terms of development of deflection and stresses in different boxgirders.

Find the most optimum section which will be better for stiffness and strength criteria which will be helpful for designers under the effect of assumed loading.

3) METHODOLOGY

ANALYTICAL METHODS FOR BOX GIRDER BRIDGES

Various researchers worked on different theoretical methods, analytical methods and computer program methods which has been discussed here. This section is divided into three groups of methods of analysis of box girder bridges. First section covers the simplest theoretical methods to analyze box girder sections by simple beam theory, second section describes the exact theoretical modelling technique methods available for analysis of box girder section, and third group of method covers the work done by various researchers on finite element techniques for different box girder sections.

Grillage Analogy Method

This method uses the stiffness matrix approach which is taking care of shear lag also. Grillage method is very useful and versatile when the slabs are on girder decks. This method also applicable to skew bridges, stiffened edge and cantilever bridges and also it is less time consuming as compared to finite element method which will gives accurate results even in small time span.During the analysis procedure first, we need to discretize the structure into number of rigidly connected beams and the deformations causing on the beam element are in the form of torsional and bending. By using transformation matrix, the displacements in local coordinate systems are converted to global stiffness matrix for satisfying equilibrium of whole structure. In horizontal plane bridge does not contribute any displacements because they are very stiff in that plane therefore the rotation about vertical axis will be neglected. In grillage analogy the total load is calculated and which is converted to equivalent nodal forces and which is applied at each node and transferred to global axis of structure. Normally the complex bridges like skew bridges or curved bridges are easily analyzed by using this method. The bridge analysis done by space frame is nowadays commonly used which is extension over grillagemethod.

To solve the problems by using this method we need to follow below steps.

1) Idealize the structure and divide it into number of sub divisional elements like main beam and transverse beam element as shown in Figure 1.1. Normally grid lines are plotted right angles to each other.
2) Finding out the equivalent inertias of each element in elasticform.
3) Converting whole load to nodal loads and applying to each and everynode.
4) Finding the stress strain and design parameters and verification and validation of calculated results will bedone.

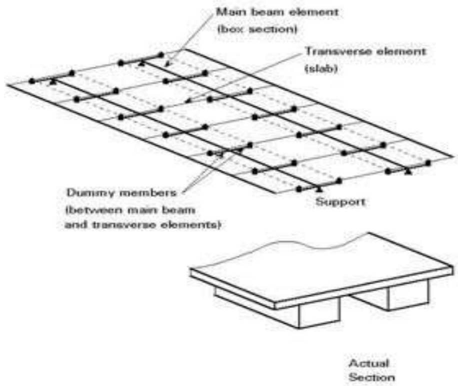


Figure 3.1 Twin box bridge section with equivalent grillage (Hambly and Pennelts 1975)

Courbon's Method

This method had invented by French Engineer Courbon's. In this method the distribution factors are calculated by using different parameters like total live load, eccentricity of wheeled vehicle, number of girders and spacing between them. From distribution factor we can easily calculate the reaction and moments under any girder by varying the position of load. In case of an eccentric load, the deflection profile of the girders assumes the form as shown in Figure 1.2, Since the load carried by the girders depends on the magnitude of the deflection. the load distribution proportions also vary linearly. The method for evaluating the load coming on each web owing to concentric or eccentric load on the pile cap should be applied for determining the load on each girder.

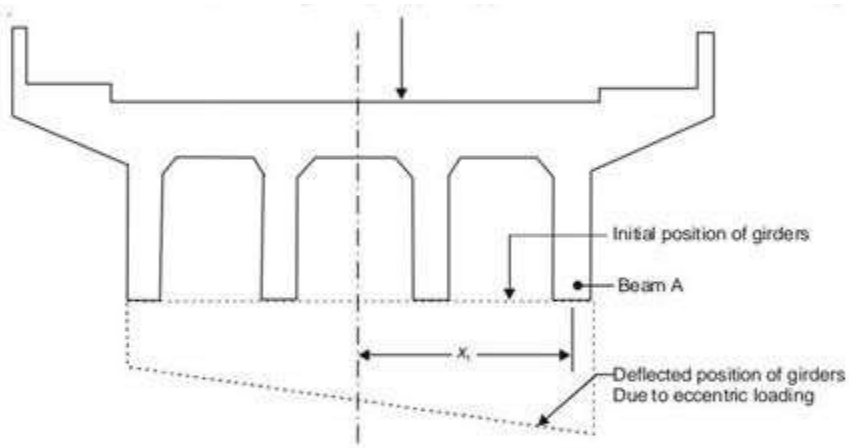


Figure 3.2 Deflection of girders with application of eccentric load. (Jagdeesh T.R. and Jayaram M.A. 2009)

$$\text{Load on beam A} = \frac{W}{n} + \frac{WeX_1}{\sum X^2}$$

$$\text{Distribution coefficient (K)} = \frac{\text{Load carried by beam A}}{\text{Average load per beam}} = \frac{\frac{W}{n} + \frac{WeX_1}{\sum X^2}}{\frac{W}{n}}$$

If a number of wheels are positioned on the transverse deck, then K is given by Eq. (1)

$$K= \frac{\sum W}{n}\left[1+\frac{neX_1}{\sum X^2}\right] \quad (1)$$

For bridge decks which are having different moments of inertias, the distribution coefficients are given by following Eq. (2)

$$K= \frac{\sum W}{m}\left[1+\frac{neI_1X_1}{\sum IX^2}\right] \quad (2)$$

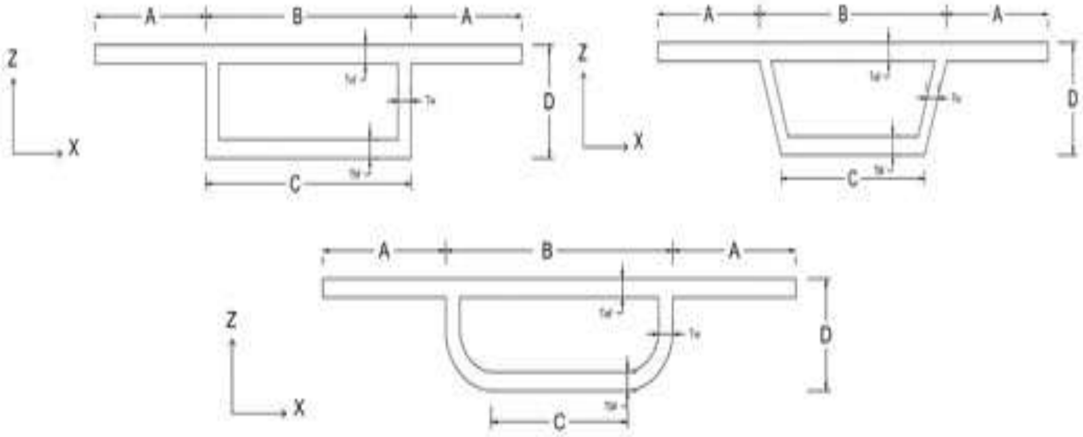
Where,
W= the total wheel load placed eccentrically
n = the number of girders along longitudinal direction
e = eccentricity of load considered from road center line
$X1$ = distance from center line of deck to the point of interest
$\sum X^2$= the sum of the distances from center line of deck to the point of interest
$I1$ = moment of inertia of section under point load consideration
I = total moment of inertia of section of number of girders(n).
For applying Courbon's theory the following conditions should satisfy.
1. The span -width ratio should be maintained between two tofour.
2. This theory is applied when minimum girders present in deck should bethree.
Normally, Courbon's method can be used for finding out distribution coefficients or reaction factors for longitudinal girders.

Finite Element Method
Finite element method is a most powerful and versatile tool for analysis. It is a numerical procedure for analyzing structures by computer program. In the finite element the whole structural geometry is divided into number of regions which is called as element. The element size used in FEM should be nearly equal to square section which will gives accurate and optimum results. The element is connected at each and every node with the help of nodal points. For each and every element the displacement functions are assumed during analysis of girders.

The nodal displacement of each element is calculated based on compatibility conditions and by use of equilibrium equations. After the nodal displacement calculation, the strain matrix is to be calculated with the help of strain displacement relationships the stresses in structure are calculated. With the help of rectangular and triangular shape element we can solve any plane stress problems but for analysis of three-dimensional structure we need to use tetrahedron element. Therefore, this method widely used to analyze any complicated structure.

Increase in number of elements in same structure which leads to gives more accurate results as compared to a smaller number of elements, sometimes we may have to use different sizes elements in the same body for accurate and effective analysis. There will be a limit to how much accuracycan be improved beyond a specific number of elements for any specific situation. Therefore, for storing the resulting matrices in the available computer memory is difficult when we use the large number of elements which involves a large number of degrees of freedoms.

4) PROBLEMSTATEMENT
In the present study, three different cross-sections namely Rectangular Trapezoidal and Circular box girder bridges are analysed for different loading conditions. The model configuration shown in Figure 5.4 and geometrical properties for all the cross-sections used in the study are shown in Table 5.4.



Tuf, Tbf and Tw are assumed as 0.25 m same for all cross-sections

Figure 5.4 (a) Rectangular, (b) Trapezoidal and (c) Circular geometry of box girder bridge Table 5.4 Geometric configuration used in comparative study (Gupta et.al 2010)

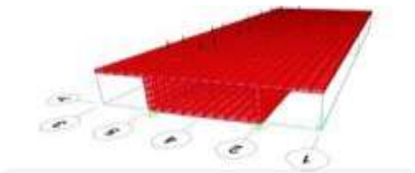
Box Girder Depth(m)	Rectangular Box Girder			Trapezoidal Box Girder			Circular Box Girder		
D(m)	A(m)	B(m)	C(m)	A(m)	B(m)	C(m)	A(m)	B(m)	C(m)
2.0	2.4	4.8	4.8	1.8	6.0	4.6	2.0	5.6	3.2
2.4	2.4	4.8	4.8	1.8	6.0	4.7	2.2	5.2	2.8
2.8	2.4	4.8	4.8	1.7	6.2	4.6	2.0	5.6	2.8

Analysis of bridge is carried out with the same cross-section area for 25 m span. Lane width is taken as 9.6 m throughout constant. Material used is M40 concrete and Poisson ratio is assumed as0.15 and uniform thickness throughout the section is assumed as 0.25 m and the variable parameter is taken as sectional shape and depth of girder. Depth variations are taken as 2.0m, 2.4m, and 2.8m. The Linear analysis is performed on Rectangular, Trapezoidal and Circular section with Dead load (Self Weight), Class 70R live load and Class A live load conditions according to IRC 6 for all cases using finite element method with the help of four noded shell element in SAP 2000 and deflection and stresses for various cross-sections are calculated and a comparison and study of the three different box girder bridges is carried out.

5) ANALYSIS OF RECTANGULAR BOXGIRDER

Linear Analysis of the rectangular box girder, trapezoidal box girder and circular box girder bridge has been carried out for the different depth conditions(i.e. 2.0, 2.4 & 2.8 m) and graphical comparison has made to study and analyze different parameters like longitudinal bending stress in top flange, transverse bending stress, shear stress and vertical deflection within the span and acrossthe box section in top flange section and bottom flange section for different loading conditions like self-weight and IRC live loads which are placed eccentrically in transverse direction.

(a) Rectangular Box Girder (Depth 2.0m)



(b) Rectangular Box Girder (Depth 2.4m)

c) Rectangular Box Girder (Depth 2.8 m)

Figure 7.1 Rectangular box girder models in SAP2000

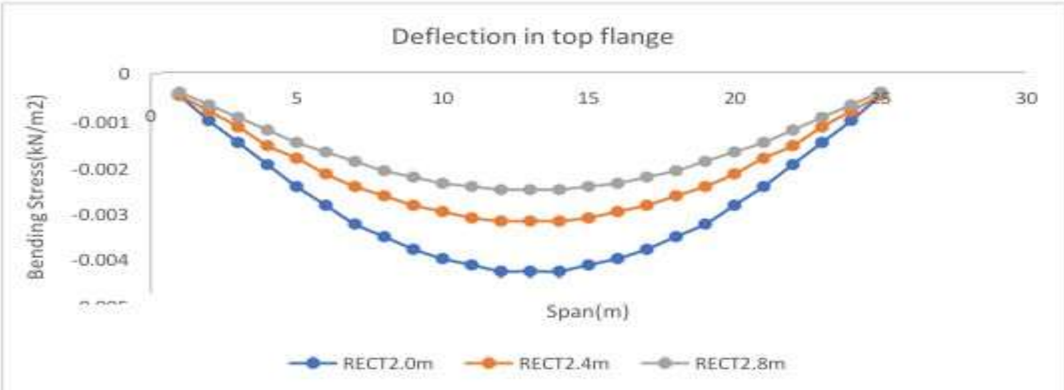


Figure 7.2 Deflection in top flange of rectangular box girder due to Dead Load

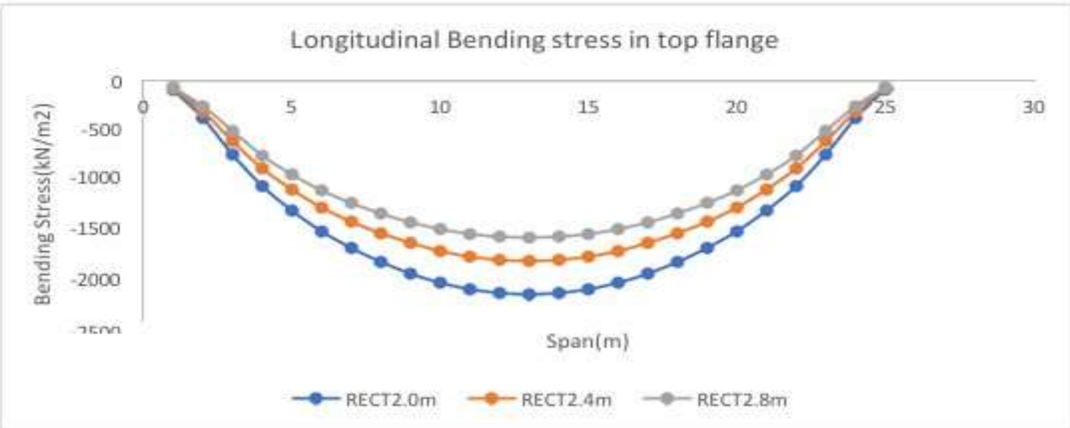


Figure 7.3 Longitudinal bending stress distribution in top flange of rectangular box due to Dead Load

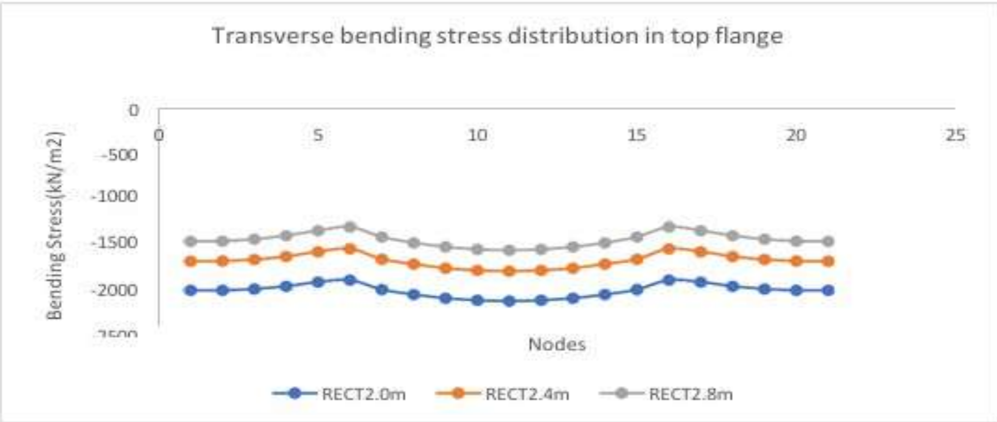


Figure 7.4 Transverse bending stress distributions in top flange at mid span due to Dead Load

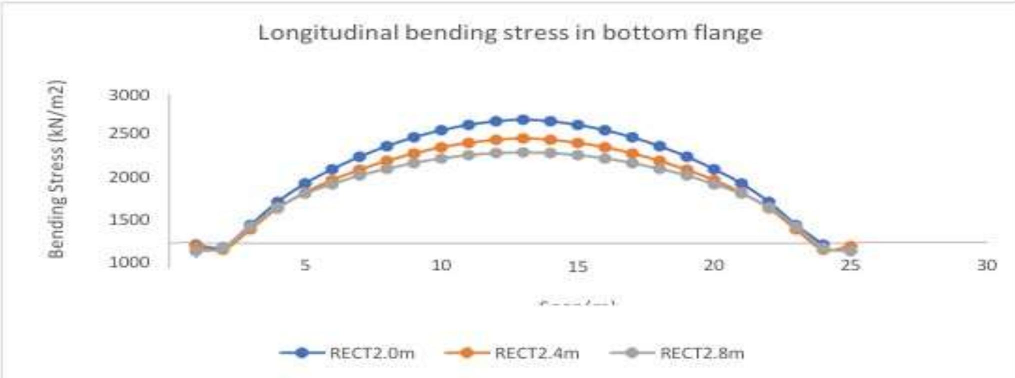


Figure 7.5 Longitudinal bending stress distribution of rectangular box in bottom flange due to Dead Load

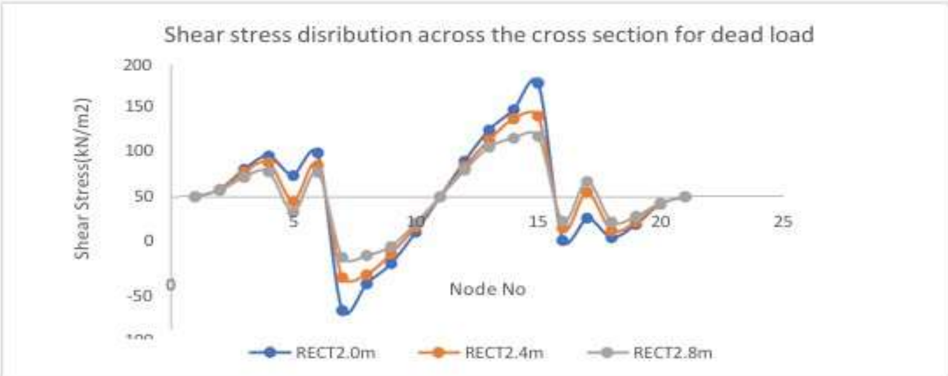


Figure 7.6 Shear stress distribution in top flange across the span due to dead load

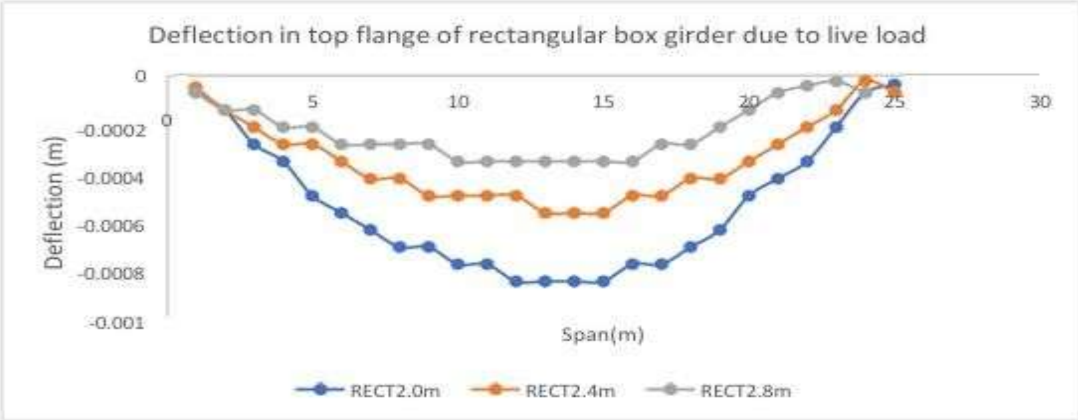


Figure 7.7 Deflection in top flange of rectangular box girder due to IRC 70 R live load

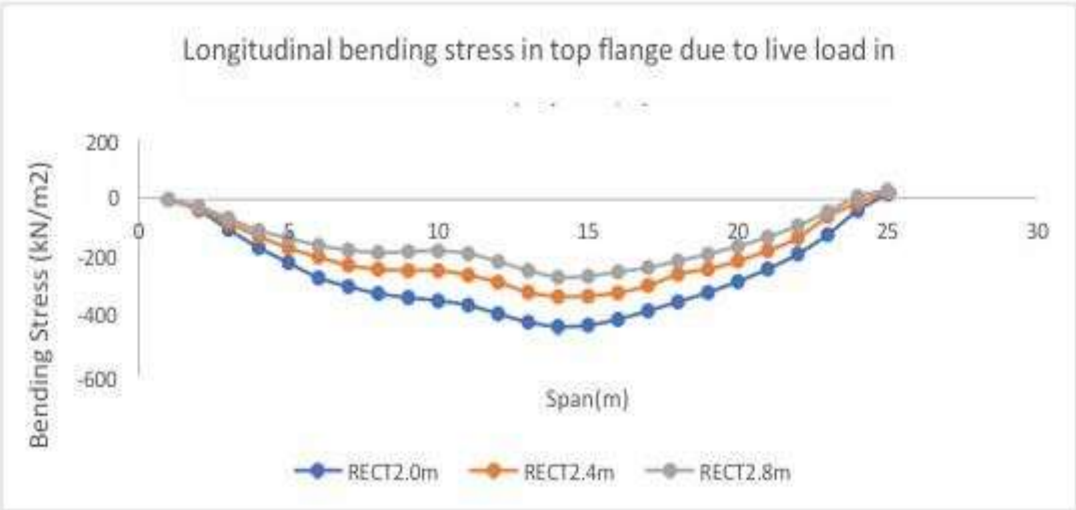


Figure 7.8 Longitudinal bending stress in top flange due to Class 70R live load in rectangular box girder

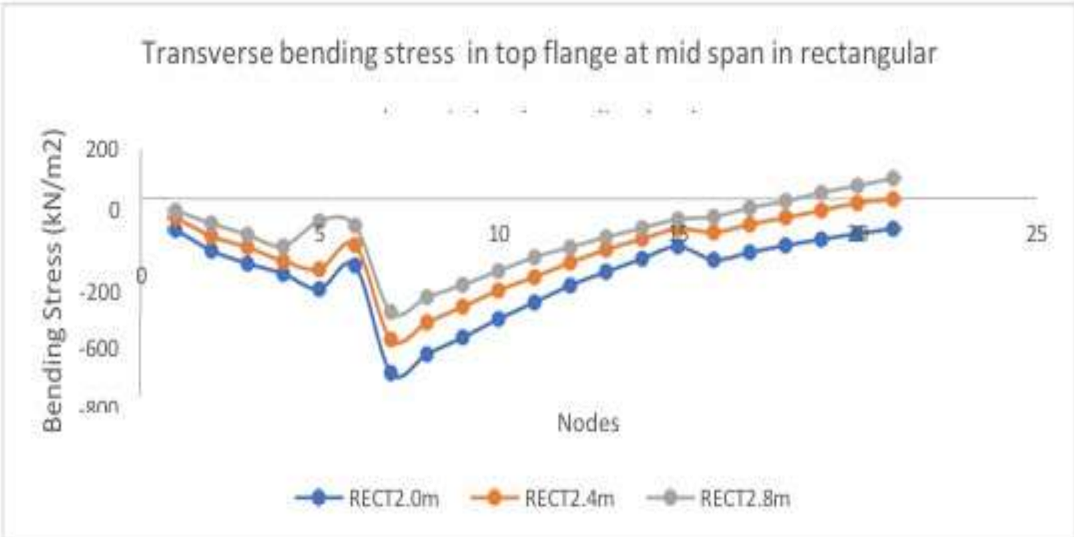


Figure 7.9 Transverse bending stress in top flange at mid span in rectangular box girder due to Class 70 R live load

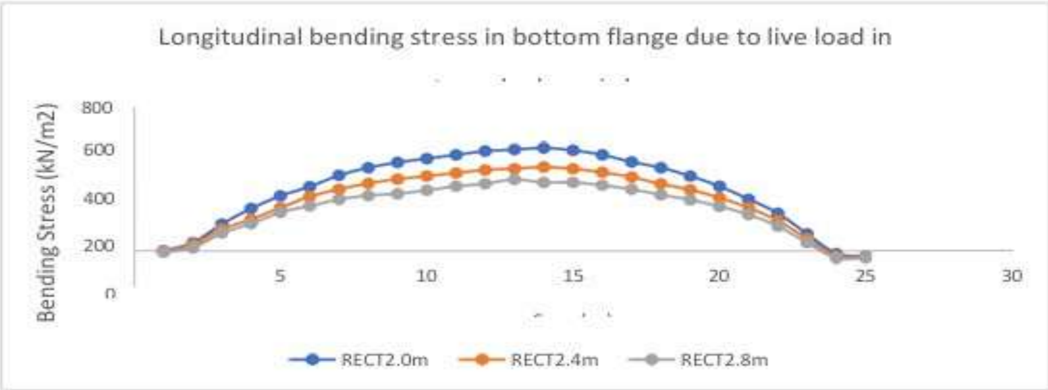


Figure 7.10 Longitudinal bending stress in bottom flange due to Class 70 R live load in rectangular box girder

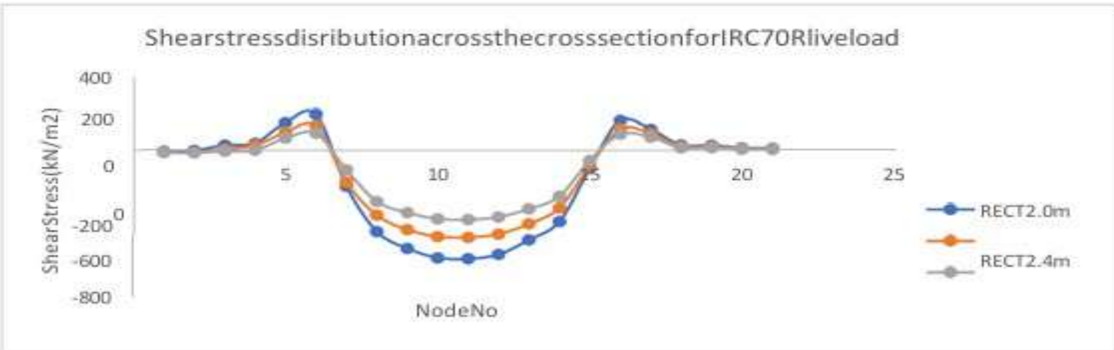


Figure 7.11 Shear stress distribution in top flange due to dead load across the span

The results of live load and dead load are represented in above Figure 7.2 to Figure 7.11 which are showing the variation of different stresses (longitudinal bending, transverse bending and shear) and deflections in top flanges and bottom flanges.

6) Observations andResults

After studying Figure 7.2 to Figure 7.11, it can be stated that with increment in depth of rectangular, trapezoidal and circular box girders the deflection in all girders decreases with small increment in depth of box girder section. Similarly, the longitudinal, transverse bending stress and shear stresses also decreases with increase in depth of girder. And also, this conclusion of variation in bending stresses, shear stresses and deflection are applicable to other to sections i.e. trapezoidal and circular box sections.

The Table 7.1 to Table 7.3 shows the comparison results of variation in deflection and stresses in rectangular box girder for both load cases i.e. live load and dead load (placed eccentrically) with different depth conditions. It is observed from this table that with increment in depth of section the deflection and stress values are also decreases for both load cases for all sections.

Table 7.1 Comparison of Rectangular box girder for Dead Load condition

Section	Deflection (mm)	S_{ltf} (MPa)	S_{lbf} (MPa)	S_{stf}(MPa)
RECT2.0m	6.3	2.214	2.480	0.171
RECT2.4m	4.7	1.866	2.102	0.121
RECT2.8m	3.7	1.624	1.820	0.091

Table 7.2 Comparison of rectangular box girder for IRC 70R live load eccentrically placed condition

Section	Deflection (mm)	S_{ltf} (MPa)	S_{lbf} (MPa)	S_{stf}(MPa)
RECT2.0m	3.2	1.278	1.332	0.590
RECT2.4m	2.3	1.059	1.095	0.474
RECT2.8m	1.8	0.909	0.924	0.378

Table 7.3 Comparison of rectangular box girder for IRC Class A live load eccentrically placed condition

Section	Deflection (mm)	S_{ltf} (MPa)	S_{lbf} (MPa)	S_{stf}(MPa)
RECT2.0m	3.2	1.666	1.190	0.636
RECT2.4m	2.4	1.569	0.986	0.555
RECT2.8 m	2.0	1.475	0. 828	0.495

Table 7.1 to Table 7.3 represents the comparison results of maximum deflection, maximum bending stress at bottom flange S 1bf stress in top flange S stf (MPa), maximum bending stress attop flange S ltf (MPa) and maximum shear (MPa) in rectangular box girder of different depths for dead load condition (self weight) and Class 70R live load which are placed eccentrically, Similarly the variation of stresses for all the sections can be seen in SAP2000.

7) RESULTS ANDDISCUSSION

The finite element method is used to perform a comparative study analysis and behavior of box girder bridge sections. The validation for Finite Element Analysis model is carried out by comparing the SAP2000 model results with analytical method for all girder sections. Linear Analysis of the rectangular box girder, trapezoidal box girder and circular box girder bridge has been carried out for the different depth conditions(i.e. 2.0, 2.4 & 2.8 m) and graphical comparison has made to study and analyze different parameters like longitudinal bending stress, transverse bending stress, shear stress and vertical deflection within the span and across the box section in top flange section and bottom flange section for different loading conditions like self-weight and IRC live loads which are placed eccentrically in transverse direction.

8) CONCLUSIONS:

i) With increase in depth of rectangular, trapezoidal and circular box girders the deflection in all girders decreases with small increment in depth of box girdersection.

ii) The longitudinal, transverse bending stresses and shear stresses values in top flangeand bottom flanges for all the sections also decreases with increase in depth ofgirders.

iii) After comparison of above all section of different shapes i.e. rectangular, trapezoidal and circular cross section the deflection, bending stress and shear stress values are less in rectangular as compared to trapezoidal and circular section and circular section gives the maximum values of deflection and bending stresses amongst allsections

iv) Deflection variation in rectangular and trapezoidal box girders due to IRC class A loading and IRC 70 R loading is very small as compared to the circular section for constant depthcondition

v) From the above study, it can be concluded that the rectangular box girder has more strength and stiffness as compared to circular and trapezoidal box girder under the assumed loadingconditions.

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