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Comparative Study of Rectangular and Trapezoidal Concrete Box Girder using Finite Element Method

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Abstract—*In the present study simply supported two lane, single cell concrete box girder bridge is analyzed for dead load and IRC: class 70R live load using Finite element Software SAP2000. The parameters investigated in this analytical study are shape (Rectangle and trapezoidal), span length and total depth of box girder. A total of 70 model of bridges subjected to Dead Load and IRC 70R loading are analyzed. In the first 35 models, rectangular Box girder Bridges are analyzed for different span length of 20m, 25m, 30m, 35m and 40m and also for different total depth of box girders 1.6m, 1.8m, 2.0m, 2.2m, 2.4m, 2.6m and 2.8m. In the second 35 models, Trapezoidal Box girder Bridges are analyzed for different span length of 20m, 25m, 30m, 35m and 40m and also for different total depth of box girders 1.6m, 1.8m, 2.0m, 2.2m, 2.4m, 2.6m and 2.8m.*
The maximum vertical deflection, bending moment, shear force and torsional moment are reported. Results indicate that increase in span causes increase in maximum top flange deflection values for both rectangular and trapezoidal box girder sections, however increase in total depth of box girder causes decrease in maximum top flange deflection values for both sections. Also for span 40m and total girder depth of 1.8m, maximum top flange deflection value for rectangular section is 3.01% lower than that of trapezoidal section having similar conditions and for rectangular section of span 40m and girder depth of 1.8m, maximum deflection value is within span/800 as per Indian codal provisions .

Keywords*: Box girder, SAP2000, Bridge deflection, Bridge force.*

1. INTRODUCTION

Construction and use of bridges is as old as initiation of human civilization, which provides the passage over an obstacle. Bridge is a vital part of the infrastructural system. Much emphasis is to be laid on the higher life span of the bridges constructed. Also at the same time the bridge should ensure safety and should be economical.

2. LITERATURE SURVEY

In the field of bridge engineering ample amount of research work has been carried out. At present the area of interest for study lies in " Box Girder Bridges". In this context we look upon the work carried on box girder bridge deck systems using commercial software and experimental study. The work carried on the comparison of various cross sectional shape of box girder bridges viz., rectangular, trapezoidal and circular sections, and for constant span length of 20m using SAP2000 software[1]. It proposes the use of trapezoidal section and discourages the circular section of box girders based on the stress and deflection values generated. Another work highlights the response of reinforced concrete (RCC) and prestressed concrete (PSC) box girders subjected to standard vehicular loads, wherein deck width and span length are constant using MIDAS civil software[2]. The study comments on the use of multiple cell Box girder bridge and intermediate webs of required thickness to effectively control the maximum bending moments, shear force and displacement values. The literature also says the use of PSC girders for light weight transport systems and use of RCC girders for heavy weight transport systems which are widely adopted in the form of segmental construction. The study carried on the comparison of "T-beam" girder and box girder bridge for span length of 25m and constant deck width using STAAD Pro. software, the work emphasizes on the most economical section based on moment of resistance of the section and consumption of concrete and steel during construction[3]. The above work concludes that T-beam girder is economical than two celled box girder for span 25m on the basis of moment, shear and quantity of materials, however torsion is not accounted for the comparison. Another work is carried out on the experimental investigation of stresses in composite steel concrete box girder bridges and examining of stress patterns using ANSYS[4]. The above work uses the static three dimensional modeling of bridge prototypes and concludes that modeling using software gave mid span deflection value 9.52% higher than the deflection at mid span obtained by experimental test procedure. The present work uses Indian codes viz., IRC:6-2014 and IRC:112-2011 [5,6] to implement standards as mentioned in the above codes and also to apply check for limiting deflection values.

The present study focuses on the comparison of concrete box girder bridge deck system for standard vehicular loads confirming to codal specification for varying depth of girder and span length for rectangular and trapezoidal box girder sections.

The goal of the study is to provide comparison of bridge forces for different depth, span and cross sections and to adopt for further design process the section which satisfies the limiting deflection criteria as mentioned in Indian codes.

3. IRC LIVE LOAD

The standard vehicular live loads for analysis of bridge deck systems, is implemented from "Indian standard codes" IRC:6-2014 standards. In the present study one lane of IRC:class 70R loading is adopted for further analysis. The figures 1and 2 below show the wheel configuration of IRC:class 70R loading as per IRC:6-2014 codal provisions for the analysis of box girder bridge.

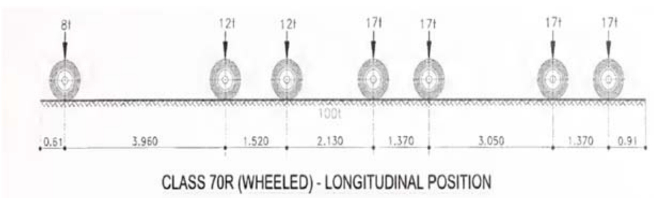

Fig. 1: Longitudinal placement of IRC: class 70R wheel loads.

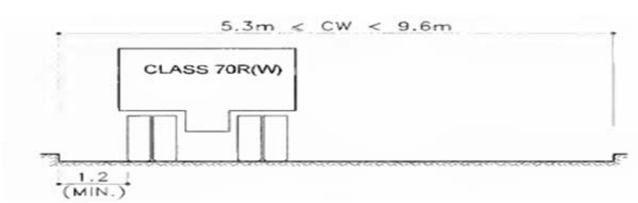

Fig. 2: Transverse placement of IRC:class 70R wheel loads.

4. PRELIMINARY DIMENSIONS

Following minimum dimensions are followed for

Thickness of top deck slab at middle and at cantilever end equal to 0.2m, thickness at junction of web and slab equal to 0.3m. Bottom slab thickness of 0.15m and web thickness of 0.3m to accommodate tendons in prestressed concrete girders. Also for single cellular girders cantilever arm length shall be equal to 0.45 times the distance between webs. The box girders are uneconomical for spans lesser than 20m, concrete box girders can be used upto 50m.

5. PARAMETERS

For the present study single cell concrete box girder bridge of grade M30 concrete and Fe 415 Steel is adopted for both rectangular and trapezoidal section for span varying from (20m, 25m, 30m, 35m and 40m) and total depth of girder varying from (1.6m, 1.8m, 2.0m, 2.2m, 2.4m, 2.6m and 2.8m). Truck load of IRC: class70R as per IRC:6-2014 specifications has been adopted.

Lane width of 7.5m and kerb width of 1.05m on either side has been adopted for analysis. Overhang length of 2.4m for rectangular section and 1.8m for trapezoidal section on either side is being adopted, and for trapezoidal section exterior girder bottom offset on either side is taken as 0.7m. constant girder thickness of 0.3m is adopted for bridge modeling.

6. MODELING DETAILS

Total of 70 models are analyzed for dead load and live load using SAP2000 software. Bridge sections are modelled to their dimensions using "Bridge Wizard" icon available in tool bar of SAP2000 version,14.2.4. Simply support condition is assigned to bridge model using "Joint Restraints" icon available in the software by allocating roller support to one end and hinge to the other end. Mesh size of 0.5mx0.5m and deck segment length of 5m is adopted for all models. Truck load of IRC:class 70R is assigned through "bridge live load" icon in the software and the truck is placed at a distance of 15m from end containing roller support. After completion of necessary assignments the models are analyzed using "Analyze" icon from the software. Figures 3and 4 show box girder models done using SAP2000.

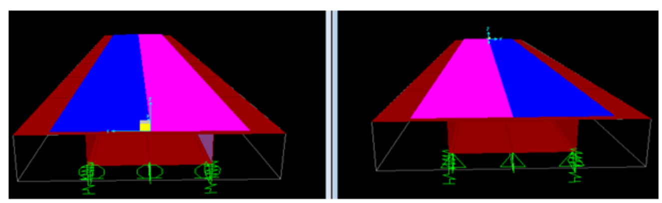

Fig. 3: Rectangular box girder model for span 40m and girder depth of 1.8m

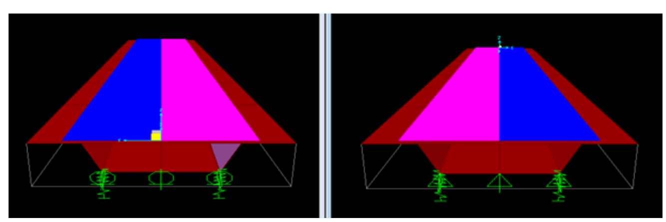

Fig. 4: Trapezoidal box girder model for span 40m and girder depth of 1.8m

7. RESULTS AND DISCUSSIONS

Results for maximum vertical deflection of top flange for bridge deck along the span and maximum value of bridge object forces are graphically represented as shown below. Figures 5 to 10 show the behaviour of top flange deflection for concrete box girders for varying girder depth from 1.6m to 2.8m with increment of every 0.2m, and for spans ranging from 20m to 40m with increment of every 5m. Figures 11 to

16 show the forces in the box girder for span 40m and girder depth of 1.8m.

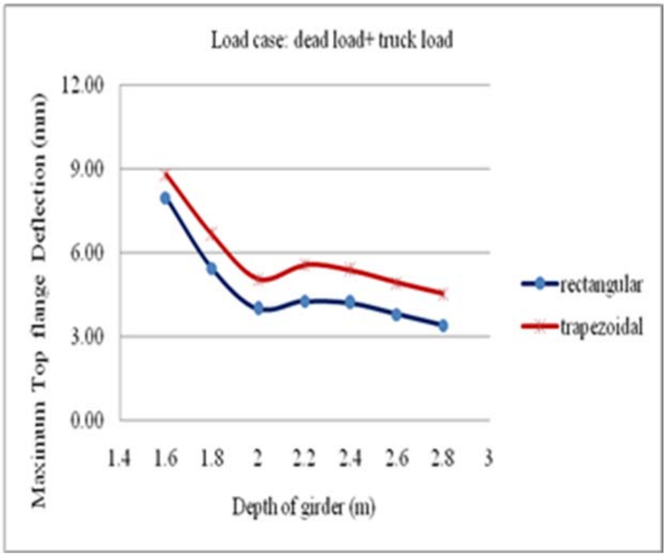

Fig. 5: Maximum deflection for span 20m

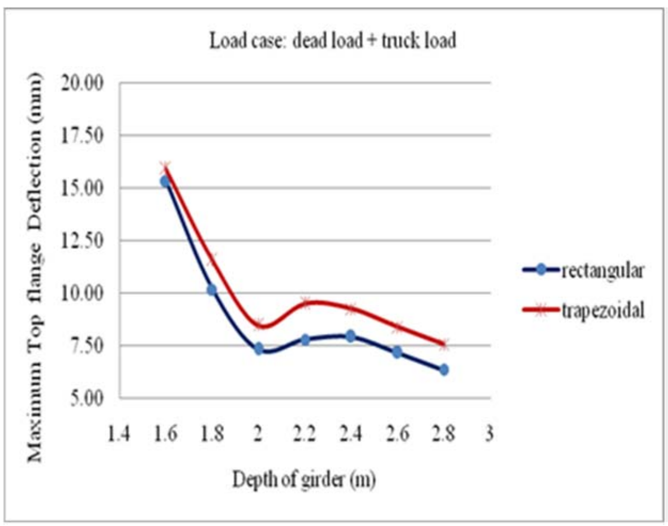

Fig. 6. Maximum deflection for span 25m

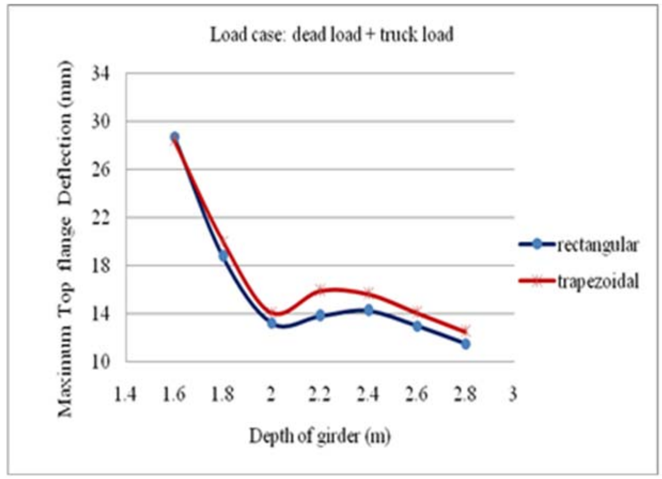

Fig. 7. Maximum deflection for span 30m

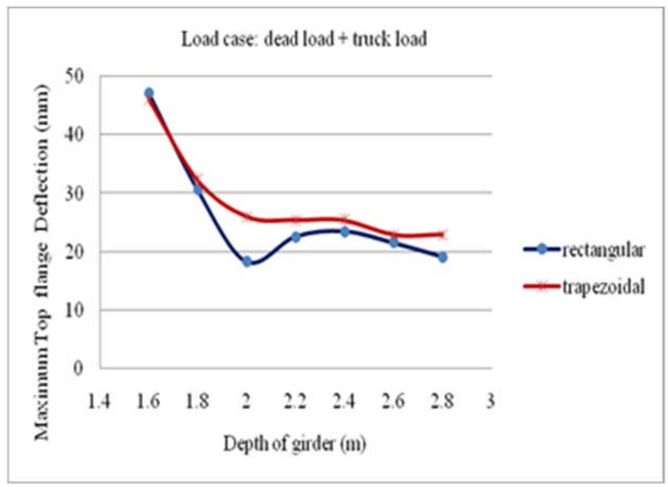

Fig. 8. Maximum deflection for span 35m

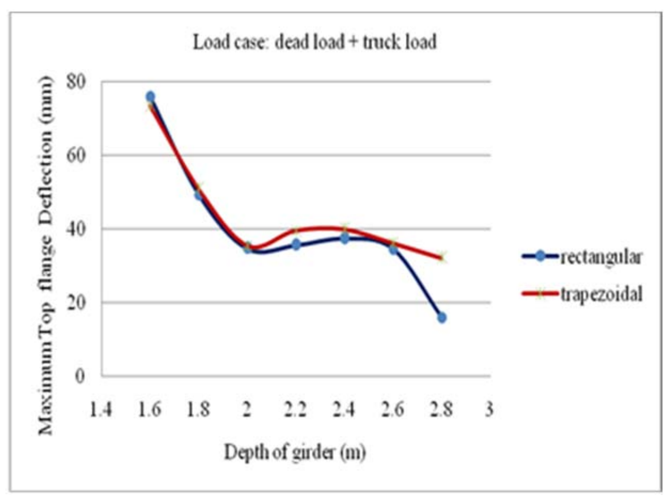

Fig. 9. Maximum deflection for span 40m

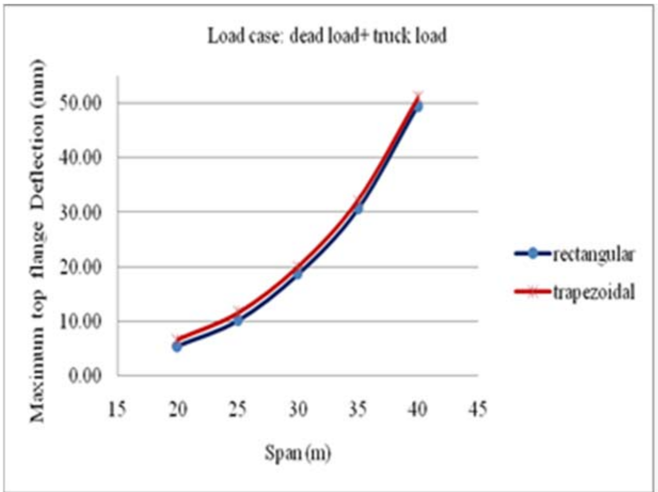

Fig. 10. Maximum deflection for 1.8m girder depth

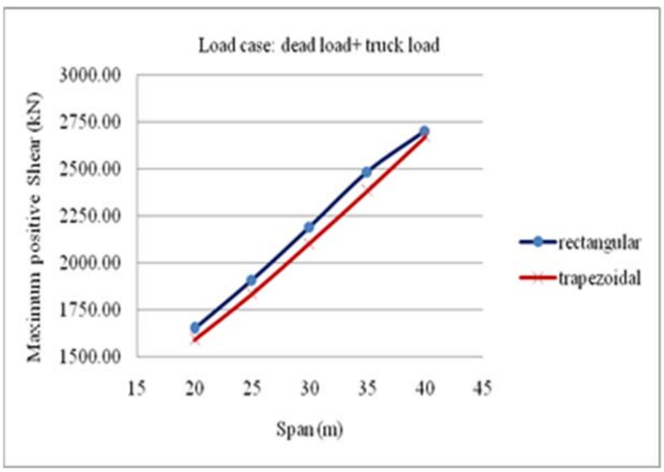

Fig. 11. Positive Shear force for 1.8m girder depth

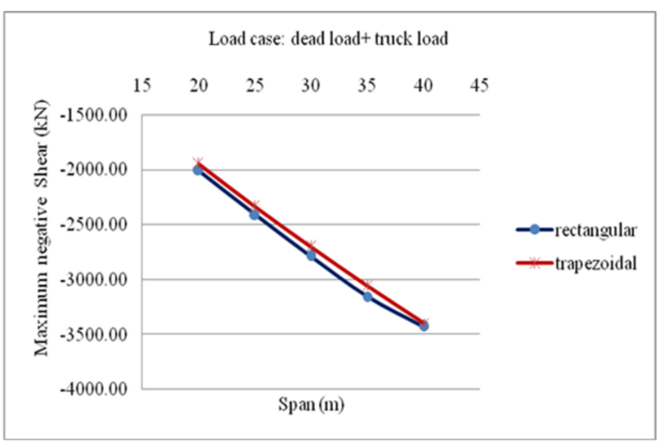

Fig. 12. Negative Shear force for 1.8m girder depth

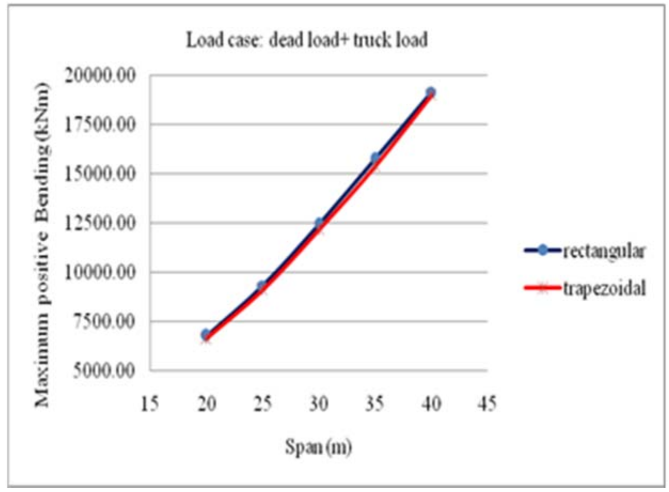

Fig. 13. Positive Bending moment for 1.8m girder depth

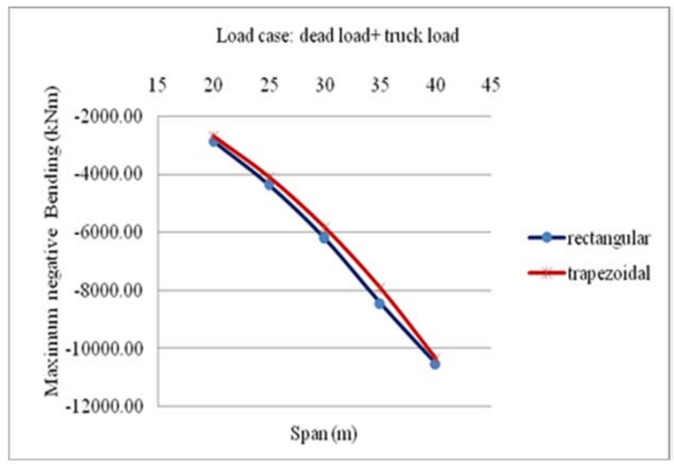

Fig. 14. Negative Bending moment for 1.8m girder depth

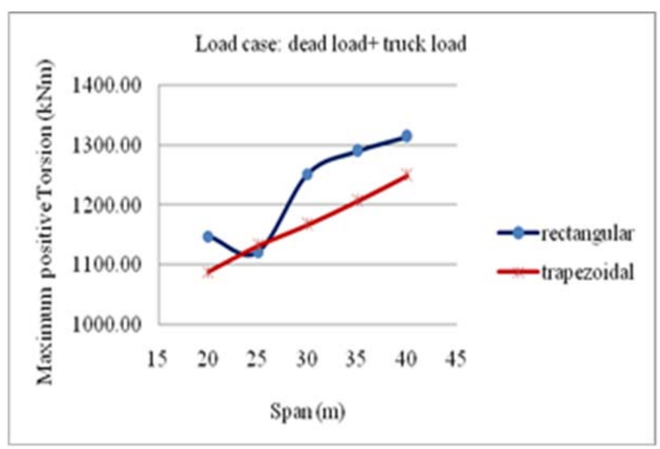

Fig. 15. Positive Torsional moment for 1.8m girder depth

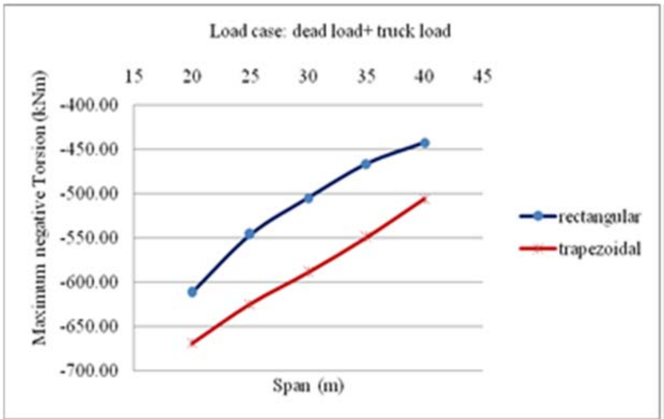

Fig. 16. Negative Torsional moment for 1.8m girder depth

1) Fig. 5 indicates that for span 20m as depth of girder increases, percentage variation in top flange deflection values for trapezoidal box girder section is 10.41% to 32.84% higher than that of rectangular section having same conditions.

2) Form Fig. 6 it is evident that for span 25m and for increment in total girder depth, trapezoidal section has deflection of top flange 3.72% to 19.15% higher than that of rectangular section, but for girder depth of 2.2m trapezoidal section has 21.95% higher deflection value than that of rectangular section.

3) The Fig. 7 indicates, for span of 30m, maximum deflection for trapezoidal section is 1.09% lower than that of rectangular section for girder depth of 1.6m. Further the maximum deflection value for trapezoidal section is 21.95% higher than rectangular section for girder depth of 2.2m. For girder depth of 2.8m trapezoidal section has 19.15% higher deflection value than rectangular section.

4) The Fig. 8 shows, for span 35m, there is 2.45% decrement in maximum deflection value for trapezoidal section in comparison with rectangular section for girder depth of 1.6m, for girder depth of 2.0m the deflection value for trapezoidal section is 41.65% higher than rectangular section. For other girder depths trapezoidal section has deflection values 5.12% to 20% higher than rectangular section.

5) The Fig. 9 indicates, for span 40m, trapezoidal box girder has maximum deflection value 3.55% lesser than that of rectangular box girder, the conditions being same. For depth of girder 2.2m deflection value for trapezoidal girder is 10.2% higher than rectangular box girder, and for 2.8m girder depth deflection for trapezoidal girder is 50.03% higher than rectangular section. For rest of the girder depths trapezoidal section has higher deflection ranging from 2.17% to 6.63%.

6) The Fig. 10 shows, maximum deflection for girder depth of 1.8m and for varying span, percentage difference in deflection values between rectangular and trapezoidal section reduces as the span of box girder increases from 20m to 40m. However, for span of 20m, as indicated in figure8, trapezoidal section has 18.07% higher deflection than rectangular section and for span 40m trapezoidal section has 2.92% higher deflection value than rectangular section.

7) Figures 11 and 12 indicate the variation of shear force value for girder depth of 1.8m and span varying from 20m to 40m. We can infer that as the span increases percentage difference in both positive and negative shear decreases for rectangular and trapezoidal section. For span of 40m, positive and negative shear force in trapezoidal section is 1.10% and 0.90% respectively lesser than that of rectangular section.

8) From the figures 13 and 14 we can infer that, trapezoidal section has positive bending moment values 1.91% to 2.42% lesser than rectangular section for span ranging from 20m to 35m. For span of 40m and girder depth of 1.8m positive bending moment for trapezoidal section is 0.67% lesser and negative bending moment is 1.77% lesser than that of rectangular section.

9) Figures 15 to 16 indicate variation of positive and negative torsional moment for girder depth of 1.8m and varying span from 20m to 40m with every increment of 5m. It is interesting to note that positive torsion for trapezoidal section is 5.46% to 6.95% lower than that of rectangular section, but at the same time negative torsion for trapezoidal section is 8.54% to 12.58% higher than that of rectangular section. for 40m span positive and negative torsion for trapezoidal section is 5.17% lesser and 12.58% higher than that of rectangular section.

8. CONCLUSION

From the above analysis following conclusions can be made.

Increase in span causes increase in deflection and force values for both rectangular and trapezoidal sections, also increment of total depth of girder reduces deflection but increases force values for both sections. Bridge deflection for rectangular section, for total depth of girder equal to 1.8m and span of 40m is within the condition Span/800 as mentioned in IRC112:2011 section 12.4.1.

Bridge forces in rectangular and trapezoidal section for girder depth of 1.8m and span 40m follows closely with 1.76% increment in bending moment value for rectangular section and 2% higher shear force value for rectangular section and net value of 7.41% lower for rectangular section in comparison with trapezoidal section. There is decrease in deflection value for rectangular section by 3.01% for span 40m and total depth of 1.8m than that of trapezoidal section.

Based on the above conclusions we can go for design process of box girder bridge for span of 40m and girder depth of 1.8m.

9. ACKNOWLEDGEMENTS

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