Comparative Analysis of Horizontally Curved Prestressed Concrete Multi-Cell Box Girders

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***Abstract**:* The horizontally curved prestressed concrete box girder bridges are extensively used due to structural efficiency, serviceability, excellent stability, aesthetic appearance and economy. Box girder has an additional property of large torsional stiffness and resistance to corrosion. Due to various geometric complexities and interaction between bending and torsion it becomes challenging to analyze this bridge deck. In this paper, horizontally curved prestressed concrete Rectangular and Trapezoidal box girder bridge deck are studied by using finite-element modelling and analysis. For modelling and analysis of structure MIDAS CIVIL 2010 software is used. Varying sectional geometry and Material properties are constant in all direction, while angle of curvature varies from 60° to 120° with different radius of curvature viz. 30m, 40m and 50m. The results of analyses show reduction in forces such as bending moment and torsion considering various curvature angles and radii of curvature along with consideration of trapezoidal box girder section. Also increased deflection and stresses in rectangular box girder are optimized by using trapezoidal box girder. Comparison of results of forces, deflection and stresses without prestressing and with prestressing shows that trapezoidal section gives significant performance.

***IndexTerms* - Curved box girder, Finite element analysis, Prestressing, Varying sectional geometry, MIDAS CIVIL.**

I. INTRODUCTION

Now a day, because of various geometric constraints of urban environment, higher traffic volume and speeds, improved structural forms and freeway interchanges leads to curved structure. In bridge engineering usage of box girder is well-liked because of its structural efficiency, serviceability, excellent stability, aesthetic appearance and economy, in construction of long span bridges, urban highway and horizontal curve. Compared to I-beam girders, prestressed box girders have a number of key advantages. In addition to the large torsional stiffness, box girders provide higher corrosion resistance because a high percentage of the steel surface including the top of the bottom flange is not subjected to the environmental attack. The box girder also has a smooth shape that leads to better bridge aesthetics. The trapezoidal shape, which is more popular now-a-days, offers several advantages over rectangular shaped cross section. The trapezoidal box girder (bath-tub girder) is provided with narrow bottom flange. Near the abutments where the bending moment is low, narrow flanges allow steel savings. The advantages of this type of construction include the efficient use of the concrete and prestress, simple construction where access is easy and possibility of utilizing the space inside the box girder. It offers high torsional stiffness which allows freedom in selection of both the supports and bridge alignment.

Eduardo DeSantiago, et al. [10] analysed a series of horizontally curved bridges using simple finite-element models. Major internal forces developed in members were determined. Specifically, an increase in bending moment and the existence of a torsional moment in cases, where the horizontal angle of curvature is large (about 20°–30°), was observed.

Ali R. Khaloo, et al. [8] studied flexural behaviour of horizontally curved prestressed box bridges using three-dimensional refined finite-element modelling and analysis. The results of analysis show that in curved bridges, stress distribution is significantly different in comparison to straight bridges. It is proposed to vary the distribution of the prestressing tendons across section width in order to optimize the bridge capacity. Results show that by proper redistribution of prestressing in section width, significant reduction in resultant stress is possible.

Khairmode A. S, et al. [5] analysed horizontally curved prestressed concrete box girder bridge deck by using three dimensional modeling and analysis. Various angles of curvature are studied with various radii of curvature. The results for stresses are observed by keeping material properties same.

1.1 Proposed Work

1.1.1 Methodology and Refined Model

Horizontally curved prestressed rectangular and trapezoidal box girder of width 12m and depth 2m is considered. Proposed box girders are of four cells with same material properties in all direction and varying sectional geometry. The various design parameters for prestressing are considered according to IS 14268-1995 and IRC 18-2000**.** Modeling and analysis of box girder is studied with different angles of curvature 60º,90º,120º with varying radius of 30m, 40m and 50m using finite element analysis software MIDAS CIVIL 2010. Comparison of results obtained by software are validated by available literature.

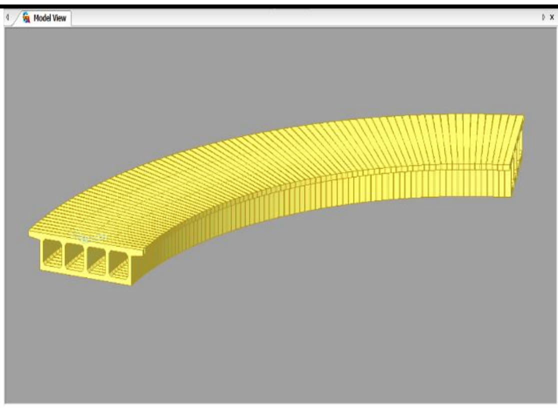

Fig -1: Rectangular BG of Radius of curvature 40m and curvature angle 90°

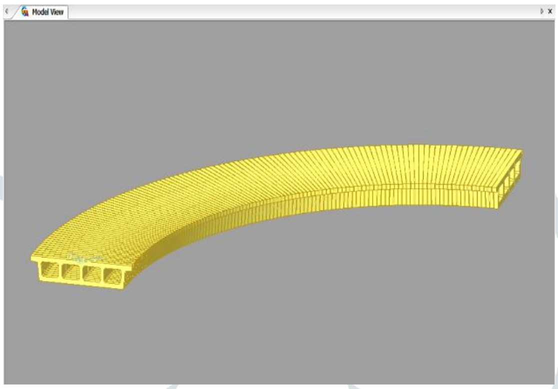

Fig -2: Trapezoidal BG of Radius of curvature 40m and curvature angle 90°

1.1.2 Configuration of Bridge

Cantilever wing of 1m for rectangular cross section and of 0.8m for trapezoidal cross section are provided. Concrete of grade M60 and high strength steel (HYSD) are used.

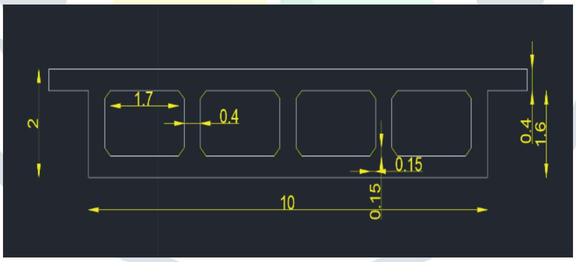

Fig -3: Rectangular cross section of box girder

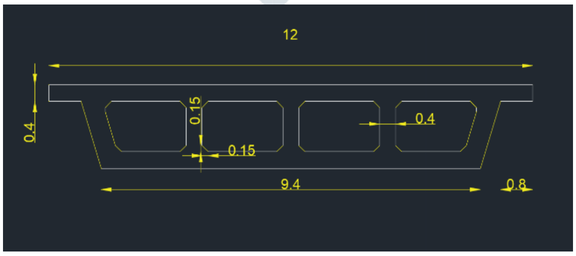

Fig -4: Trapezoidal cross section of box girder

1.1.3 Prestress load consideration and Tendon profile

Considered profiles of prestressing tendons are as shown in the Fig.5. Prestressing tendons are transmitted through five webs and assigned for all elements of box girder. Because of curved profile of girder selected reference axis for tendons is also curved.

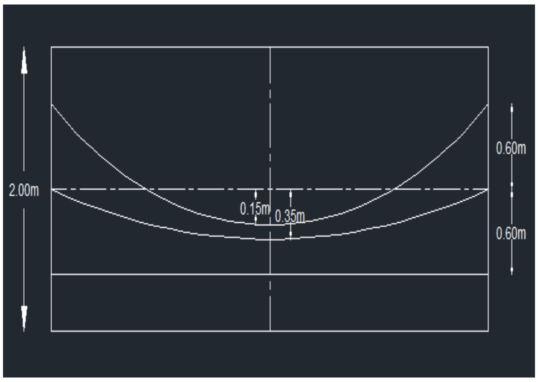

Fig -5: Tendon profile in box girder

II. Analysis

Analysed horizontally curved four cell rectangular and trapezoidal box girder without and with prestressing. Nodes are plotted in respective direction mainly in longitudinal direction. Because of various curvature angle and varying radii of curvature, different spans are calculated, where width and depth cross section are kept constant.

Table -1: Span lengths of different curvature angle and radius of curvature

Radius of Curvature	Curvature Angle	Span
30m	60°	31.41m
	90°	47.12m
	120°	62.83m
40m	60°	41.88m
	90°	62.83m
	120°	83.77m
50m	60°	52.35m
	90°	78.53m
	120°	104.71m

2.1 Time Dependent material properties

Time dependent material properties such as Creep, Shrinkage and Compressive Strength are linked with concrete. These time dependent material properties are provided according to IRC 18-2000. Factors considered in case of creep and shrinkage are: relative humidity, age of concrete at beginning of shrinkage and notational size of member.

$$Notational\ size\ of\ member = \frac{2A_C}{u}$$

Where,
A_C = Cross sectional area
u = Perimeter in contact with atmosphere

2.2 Support Details and Link Configuration

While considering support conditions, displacement degree of freedom in X, Y and Z directions are provided at one end of cross section of box girder and only Y and Z directional displacement degree of freedom at the other end. Rigid link is connection which is used to connect geometric entities such as points, surfaces and curves so that they remain rigidly connected during an analysis. Rigid link constrains geometric and relative movement of structure, where degree of freedom of subordinated node called slave nodes are constrained by particular reference node called master node. Here in considered model one Master node is connected to five slave node, provided at both ends of cross section of girder.

While an elastic link connects two nodes to act as an element, user can proceed with element stiffness. Elastic links of rigid type are fixed below the supports of considered box girder section which is used to simulate rigid behavior.

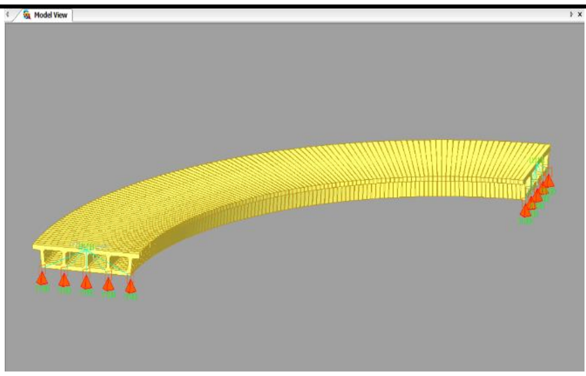

Fig -6: Support Details and Link Configurations

2.3 Loading

Adopted box girders are analysed without prestressing. It means only self-weight and super imposed dead load (SIDL) are considered first.

Super imposed dead load (SIDL) calculation:

$$P = \frac{1}{100}\left[13 \cdot 3 + \frac{400}{L}\right]\left[\frac{17 - W}{1.4}\right]$$

where,

P= Live load in kN/m^2

L= Effective span of the bridge in m.

W= Width of the foot path in m.

Then analysis is carried out with prestressing (Post-Tension) where considered nominal diameter of strand is 12.7mm according to IS 14268-1995. Prestressed tendons are loaded by force of 10000kN with jacking at both ends. Provided tendons are of bonded type with relaxation coefficient according to IRC 18-2000.

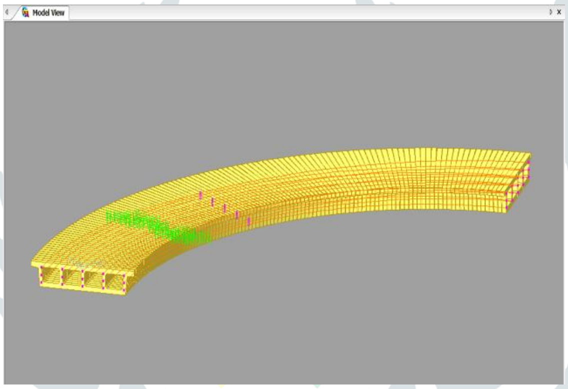

Fig -7: Tendon Location and Profile Details

III. RESULTS AND DISCUSSION

3.1 Maximum Midspan Deflection of Girder

Midspan deflection of girder is obtained under both load cases, with and without prestressing. Increased deflection with increase in radii of curvature and angle of curvature is observed. Hence reduction in deflection of girder is adopted using trapezoidal cross section

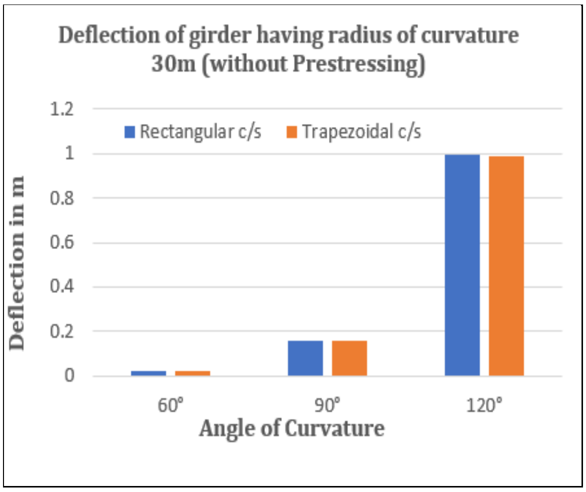

Chart -1: Maximum deflection of girder having radius of curvature 30m without prestressing

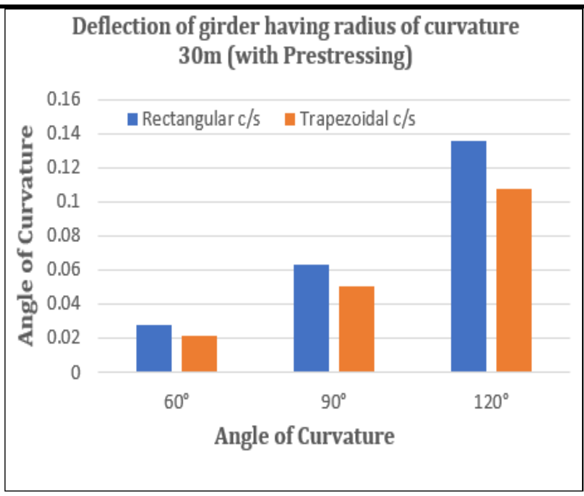

Chart -2: Maximum deflection of girder having radius of curvature 30m with prestressing

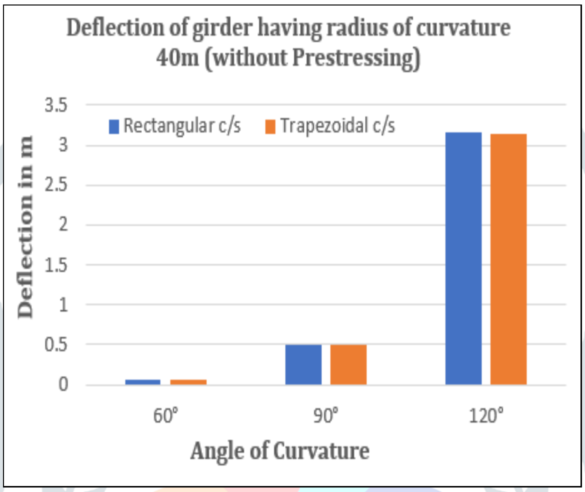

Chart -3: Maximum deflection of girder having radius of curvature 40m without prestressing

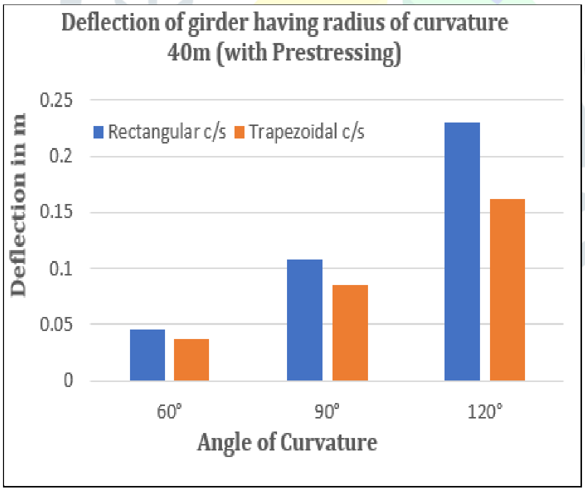

Chart -4: Maximum deflection of girder having radius of curvature 40m with prestressing

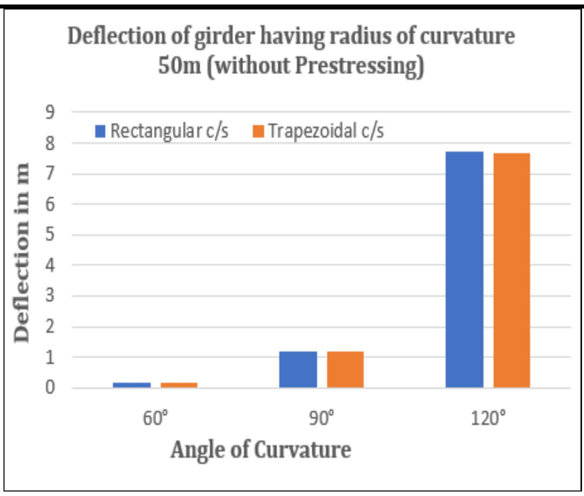

Chart -5: Maximum deflection of girder having radius of curvature 50m without prestressing

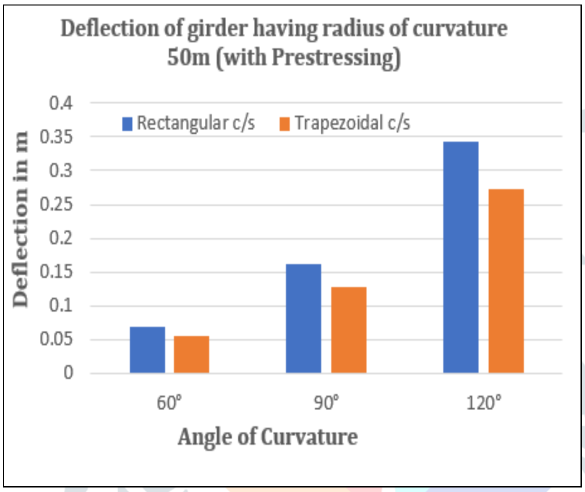

Chart -6: Maximum deflection of girder having radius of curvature 50m with prestressing

3.2 Maximum Bending Moment in Span

It is studied that in case of absence of prestressing constant bending moment of span is observed in both rectangular and trapezoidal cross section. Whereas moment increases with increase in radius of curvature and curvature angle in absence of prestress. Inverse variation is observed when prestressing is considered.

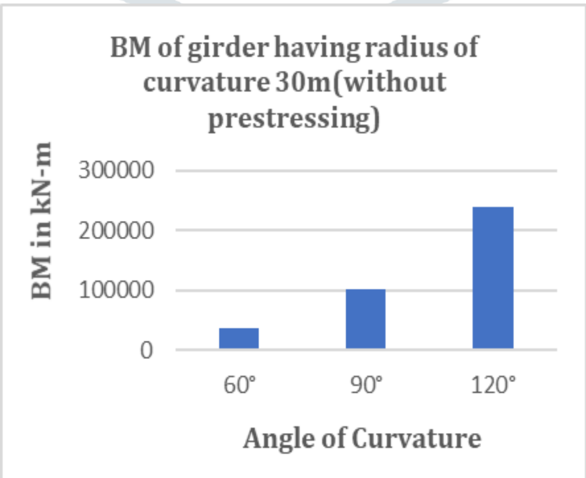

Chart -7: Maximum BM in span without prestressing having radius of curvature 30m

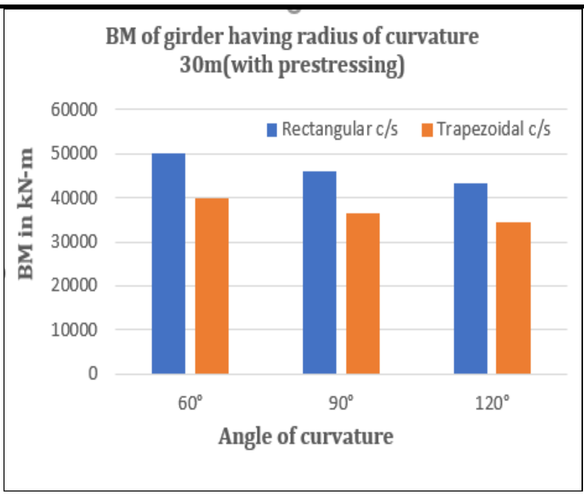

Chart -8: Maximum BM in span with prestressing having radius of curvature 30m

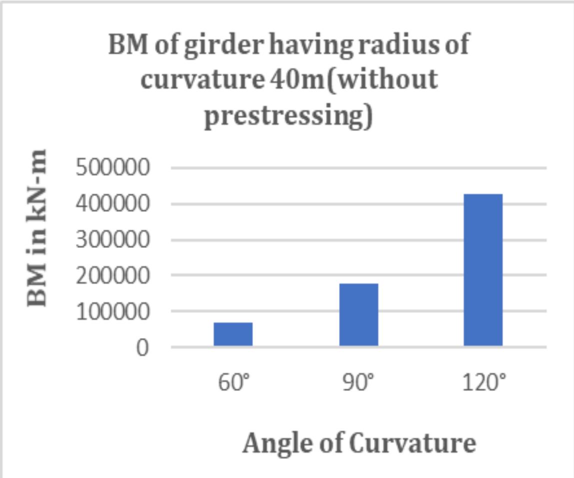

Chart -9: Maximum BM in span without prestressing having radius of curvature 40m

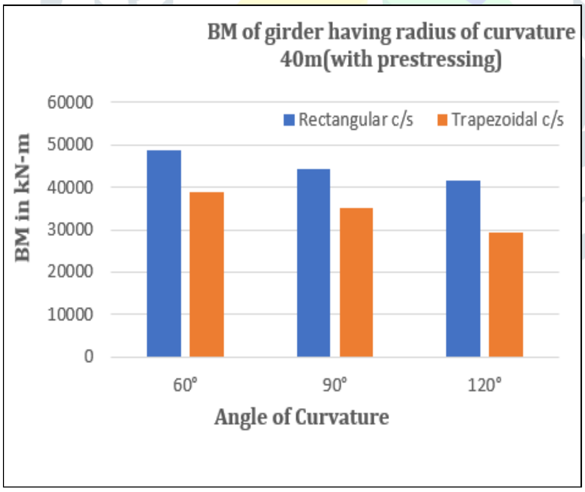

Chart -10: Maximum BM in span with prestressing having radius of curvature 40m

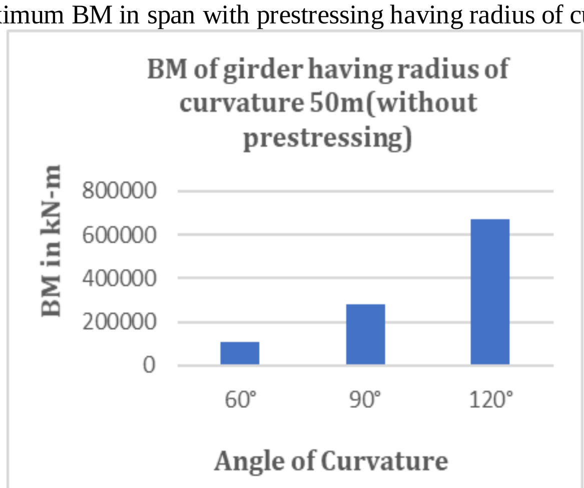

Chart -11: Maximum BM in span without prestressing having radius of curvature 50m

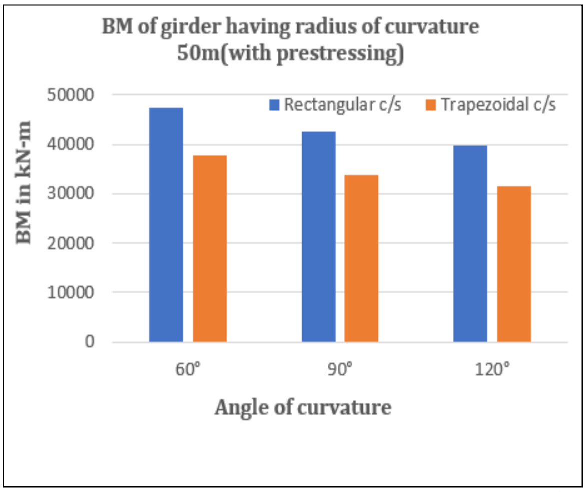

Chart -12: Maximum BM in span with prestressing having radius of curvature 50m

3.3 Maximum Stress Variation in Box Girder

Analysed stresses are increased with increase in radius of curvature and curvature angle in both cases of loading. Here, stresses at slab are greater as compared to soffit stresses and can be reduced by adopting trapezoidal cross section

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Table -1: Stresses in girder without prestressing having radius of curvature 30m

Section of Box Girder	Curvature Angle	Stresses in girder (kN/m^2)			
		Slab		Soffit	
		Interior edge	Exterior edge	Interior edge	Exterior edge
Rectangular	60°	-2.213	2.213	-1.844	1.844
	90°	-6.400	6.400	-5.333	5.333
	120°	-16.47	16.47	-13.73	13.73
Trapezoidal	60°	-2.157	2.157	-1.798	1.798
	90°	-6.223	6.223	-5.194	5.194
	120°	-16.03	16.03	-13.36	13.36

Table -2: Stresses in girder with prestressing having radius of curvature 30m

Section of Box Girder	Curvature Angle	Stresses in girder (kN/m^2)			
		Slab		Soffit	
		Interior edge	Exterior edge	Interior edge	Exterior edge
Rectangular	60°	2.671E02	-2.671E02	2.226E02	-2.226E02
	90°	4.367E02	-4.367E02	3.639E02	-3.6394E02
	120°	5.403E02	-5.403E02	4.503E02	-4.503E02
Trapezoidal	60°	2.257E02	-2.257E02	1.881E02	-1.881E02
	90°	3.492E02	-3.492E02	2.910E02	-2.910E02
	120°	4.531E02	-4.531E02	3.628E02	-3.628E02

Table -3: Stresses in girder without prestressing having radius of curvature 40m

Section of Box Girder	Curvature Angle	Stresses in girder (kN/m^2)			
		Slab		Soffit	
		Interior edge	Exterior edge	Interior edge	Exterior edge
Rectangular	60°	-2.997	2.997	-2.498	2.498
	90°	-8.619	8.619	-7.182	7.182
	120°	-22.31	22.31	-18.59	18.59
Trapezoidal	60°	-2.992	2.992	-2.435	2.435
	90°	-8.395	8.395	-6.995	6.995
	120°	-19.29	19.29	-16.08	16.08

Table -4: Stresses in girder with prestressing having radius of curvature 40m

Section of Box Girder	Curvature Angle	Stresses in girder (kN/m^2)			
		Slab		Soffit	
		Interior edge	Exterior edge	Interior edge	Exterior edge
Rectangular	60°	3.442E02	-3.442E02	2.868E02	-2.868E02
	90°	3.792E02	-3.792E02	2.982E02	-2.982E02
	120°	4.509E02	-4.509E02	3.757E02	-3.757E02
Trapezoidal	60°	2.706E02	-2.706E02	2.255E02	-2.255E02
	90°	2.775E02	-2.775E02	2.312E02	-2.312E02
	120°	3.510E02	-3.510E02	2.925E02	-2.925E02

Table -5: Stresses in girder without prestressing having radius of curvature 50m

Section of Box Girder	Curvature Angle	Stresses in girder (kN/m^2)			
		Slab		Soffit	
		Interior edge	Exterior edge	Interior edge	Exterior edge
Rectangular	60°	-4.061	4.061	-3.385	3.385
	90°	-10.85	10.85	-9.048	9.048
	120°	-28.11	28.11	-23.43	23.43
Trapezoidal	60°	-3.955	3.955	-3.297	3.297
	90°	-10.57	10.57	-8.812	8.812
	120°	-27.36	27.36	-22.80	22.80

Table -6: Stresses in girder with prestressing having radius of curvature 50m

Section of Box Girder	Curvature Angle	Stresses in girder (kN/m^2)			
		Slab		Soffit	
		Interior edge	Exterior edge	Interior edge	Exterior edge
Rectangular	60°	1.839E02	-1.839E02	1.532E02	-1.532E02
	90°	2.994E02	-2.994E02	2.495E02	-2.495E02
	120°	3.906E02	-3.906E02	3.255E02	-3.255E02
Trapezoidal	60°	1.492E02	-1.492E02	1.173E02	-1.173E02
	90°	2.407E02	-2.407E02	2.006E02	-2.006E02
	120°	3.167E02	-3.167E02	2.639E02	-2.639E2

3.4 Maximum Considered Torsion in Box Girder

Constant increase in torsion is observed with increase in radius of curvature and curvature angle, where prestressing is not considered. Whereas in case of prestressing, it is exactly opposite, and it can be reduced by employing trapezoidal box girder section.

Table -7: Torsion in girder with prestressing having radius of curvature 30m

Section of Box Girder	Curvature Angle	Torsion in kN-m	
		Left	Right
Rectangular	60°	-2.088E03	1.892E03
	90°	-1.647E03	1.397E03
	120°	-1.513E03	1.118E03
Trapezoidal	60°	-1.622E03	1.507E03
	90°	-1.290E03	1.114E03
	120°	-1.201E03	8.909E02

Table -8: Torsion in girder with prestressing having radius of curvature 40m

Section of Box Girder	Curvature Angle	Torsion in kN-m	
		Left	Right
Rectangular	60°	-1.252E03	1.159E03
	90°	-1.002E03	8.932E02
	120°	-9.345E02	7.777E02
Trapezoidal	60°	-1.001E03	9.014E02
	90°	-8.002E02	7.118E02
	120°	-6.529E02	5.445E02

Table -9: Torsion in girder with prestressing having radius of curvature 50m

Section of Box Girder	Curvature Angle	Torsion in kN-m	
		Left	Right
Rectangular	60°	-2.084E03	8.482E02
	90°	-7.162E02	6.589E02
	120°	-6.348E02	5.825E02
Trapezoidal	60°	-1.639E03	6.760E02
	90°	-5.712E02	5.248E02
	120°	-5.059E02	4.641E02

IV. Conclusion

From above analysis, it is found that midspan deflection increases with increase in radius of curvature and curvature angle in both cases with and without prestressing. Midspan deflection can be finally reduced by trapezoidal cross section of box girder having an equal area as that of considered rectangular box girder section.

Increase in bending moment is observed with increase in curvature angle and radius of curvature in absence of prestressing whereas it can be reduced by using trapezoidal box girder section along with prestressing.

Slab stresses obtained are greater than soffit stresses in both cases of loading. Increased stresses with increase in radius of curvature and curvature angle can be reduced by adopting trapezoidal box girder section.

In absence of prestressing, it is found that torsion constantly increases with increase in radius of curvature and curvature angle and is same for rectangular and trapezoidal section of girder. Which can be minimized by using trapezoidal box girder section subjected to prestressing.

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