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Comparison Between Rectangular and Trapezoidal Shapes on Structural Behaviour of Prestressed Box Girder Bridge

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Abstract- In this report the structural behaviour of box girder bridges have been studied regarding bending moment, shear force, bending stresses and deflection in longitudinal and transverse directions. Two box shapes namely, rectangular and trapezoidal have been considered for the study. STAAD PRO, a general purpose finite element analysis software has been used as the basic platform for modeling and carrying out the two dimensional linear elastic finite element analysis of box girder bridges considered in this study. To compare the longitudinal and transverse stresses in both sections, three dimensional finite element analysis has been done using plate elements in STAAD PRO.

This study has shown that as a whole the structural response of bridge with rectangular box section is better than trapezoidal box section in transverse analysis. It is observed that the longitudinal stresses are not significantly influenced by the shape of the section. Therefore it is concluded that the overall structural response in rectangular and trapezoidal sections will not differ much in longitudinal analysis of pre stressed box girder bridge.

Key words- Rectangular section, Trapezoidal section.Box girder, Prestressed concrete.

INTRODUCTION

The prestressed concrete has found extensive application in the construction of long span bridges, gradually replacing steel which needs costly maintenance due to the inherent disadvantages of corrosion under aggressive atmospheric condition. The pre-stressed concrete girders are more economical for long span bridges. The pre-stressed concrete bridge offer high degree of freedom from cracks, low maintenance, long life etc.

The high torsional rigidity due to closed box section and the efficient transverse distribution of load make the box girder

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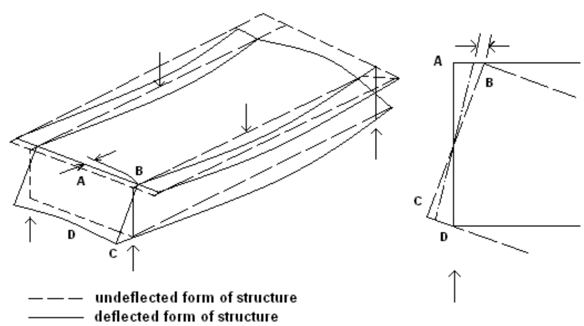
bridges more viable. Also these bridges are more aesthetically pleasing than other bridge types.

The main advantage of pre-stressed concrete for bridges is reduction in weight and slender appearance.

STRUCTURAL BEHAVIOUR OF A BOX GIRDER

The structural action of the box girder deck is more complex than a beam-and-slab type deck and hence also the analysis and design. The forces coming on the decks lead to the longitudinal bending, transverse bending and interaction of longitudinal and transverse bending. Under the self weight as well as for symmetrical loadings, the box section primarily experiences longitudinal and transverse bending. However, in the presence of unsymmetrical loading, the box sections are subjected to torsion in addition to bending in longitudinal and transverse directions and three actions are generally referred to as simple beam actions. Moreover, since the walls of the box girder are made thin in order to reduce the self weight of the bridge, distortion and warping are also developed in the box section in addition to simple beam actions.

The share of the load coming on the deck to be resisted by longitudinal structural action and to be resisted by transverse action could normally be understood from deformed profile of the deck. The interaction of longitudinal and transverse bending and the requirements of compatibility conditions have to be synthesized in the analysis



(a) Shear lag in bending

(b) Enlarged elevation of region of box beam near support showing shear lag in bending

Thus, the structural response of the box girder bridge is a combination of five structural actions namely longitudinal bending, transverse bending, torsion, distortion and warping. Furthermore, in box sections the longitudinal bending stresses in top/bottom slabs in the regions close to the webs are found higher in comparison to other points on the top/bottom slab at that section on respective slabs. The phenomenon associated with this non-uniform longitudinal stress distribution is called shear lag. Simple bending theory is unable to reflect the shear lag phenomenon.

LITERATURE REVIEW

Box girder bridges are becoming increasingly common in the present day highway system as a result of efficient traffic flow requirements. A number of authors have investigated the behavior of straight and curved box sections using finite element techniques, plate theory and finite strip method. Direct applications of the finite element method currently permit the analysis of all structures irrespective of their complexity.

The structural action while resisting the external loads has been clearly explained by Maisel and Roll. The evaluation of shear stresses caused by the variation in warping is first developed by Koll Brunner and Hajdin for the case of torsional warping. This was later developed by Steinle for the case of distortional warping. The idea of introducing the warping stresses as equivalent concentrated forces at the nodes was given by Vlasov.

Many investigations during the past years have attempted to simplify the problem of analyzing a slab, or a slab on a network of beams, subjected to loads. In all of these cases, the slab and beam system is converted into an equivalent grid work of beams or to an equivalent anisotropic slab. Once this is done, the method of analysis varies depending on the investigator.

INFLUENCE OF BOX GIRDER CROSS SECTIONAL SHAPE

Kenneth (1986,1988) has Proposed a method in which the three dimensional behavior of box girder is approximated by superimposing results obtained by simple membrane equations , based on simple strength of materials relationships, and those obtained by frame analysis.

Maisel(1985) has used principle of superposition to analyses the box girder.All the above methods are valid only for design / analysis in the elastic range. However to determine the ultimate strength of the box girder bridge Nonlinear analysis is required.

Influence of geometry on structural design of concrete box girder bridge is studied by

TahaA.Majeed and PasalaDayaratnamto assist the designer in proportioning of the box girder bridge. The relative sizes of segments on forces and design details are assessed. The box is analyzed for various combination of sizes of the segments by elastic theory of folder plates and bending moments and shear forces at critical locations are obtained The recommendations on the optimum relative sizes of box girder are made.

According to Dayaratnam and Majeed, the main geometrical properties that influence the design of cross section of box girder consists of selecting approximate values of the key layout parameters which are over hang ratio Cc, web thickness ratio Cw, web slope S, and soffit thickness ratio Cb where the ratios are

Cc = cantilever over hang / top slab width

Cw = web thickness / top slab width

Cb = soffit thickness / girder depth

The study of Manoj Kumar and Sagar Samaria is concerned with the analytical investigations on influence of box cross-sectional shape on the structural behavior of reinforced concrete (RC) box girder bridges. In this paper the structural behavior of box girder bridges has been studied in terms of deflection, longitudinal and transverse bending stresses, and the shear lag coefficient. To this end two box shapes namely, rectangular and trapezoidal have been considered for the aforementioned study. ANSYS, general purpose finite element analysis software, has been used as the basic platform for modeling and carrying out the three dimensional linear elastic finite element analysis of box girder bridges considered in this study. The outcome of this study has shown that as a whole the structural response of bridge with rectangular box section is better than trapezoidal box section.

Study of straight and curved box girder bridges in the form of single cell, multiple spine and multi cell cross section is donein analysis of box girder bridges by kaled m sennah , assist prof. ryerson university , canada& john b kennedy prof. university of windsorcanad .Theyhave done Elastic analysis and Experimental studies on the elastic response of the box girder bridges Experimental results of 24 models representing a simply supported reinforced concrete box girder bridge subjected to combined bending and torsion are reported in this paper.

Present study

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To study the structural behavior of box girder bridge, a two lane simply supported single cell prestressed box girder bridge of span 34m is considered. Diaphragms are assumed at supports only. In order to study the influence of box shape on structural behavior of box girder bridge, the bridge has been analyzed using the software STAAD PRO for two cross sectional shapes namely rectangular and trapezoidal.

The aim of this study is to understand the response of a prestressed post tensioned box girder bridge deck to variation in its cross section.

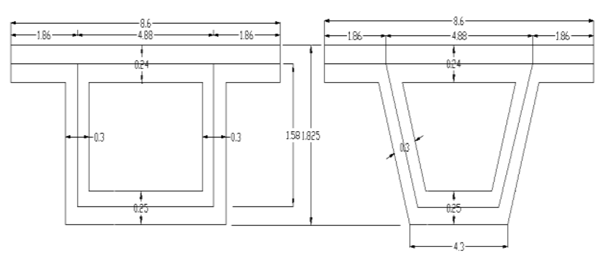
Analysis of the box girder bridges is carried out for rectangular and trapezoidal cross section with same dimensions using Staad Pro for a given span of 34m and width of bridge 8.6m between the supports. Based on the response of the bridge decks, a parametric study is performed to understand the effect of box shape on structural behavior of prestressed post tensioned box girder bridge.

The parameters used in this study are :

1. Maximum Bending Moment
2. Maximum Shear Force
3. Maximum Reactions
4. Maximum Deflection
5. Maximum Longitudinal and Transverse Bending Stresses.

For the finite element analysis using Staad, the modulus of elasticity and poisonsratio for prestressed concrete along with wearing coat have been taken as 3.354×10^7 KN/m^2& 0.15 respectively

Since the present study intends to investigate the effect of shape only, the top slab width, overall depth and thickness of all box elements namely, top slab, bottom slab and webs has been kept constant. The geometrical details of rectangular and trapezoidal sections considered in this study are shown in figure.



RECTANGULAR CROSS SECTION   TRAPEZOIDAL CROSS SECTION

- Grade of concrete = M45

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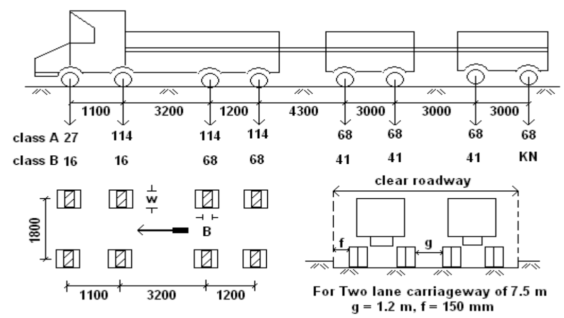
- Value of E = 5000 √fck
- Density of concrete = 25KN/m3

ANALYSIS - USING 2D BEAM ELEMENT

- The beam element is assumed to be straight 2 node element of constant doubly symmetric cross section. The beam is capable of resisting axial force, bending moments and twisting moment. The stiffness properties for a uniform beam element are derived from the differential equations for beam displacements in the beam theory.
- The sectional properties are evaluated for various sections such as end section, running section and diaphragm section.
- IRC class A loading consists of a train of wheels with a total load of 554 KN each in both lanes.



Axle load KN	Ground contact area	
	B (mm)	W (mm)
114	250	500
68	200	380
41	150	300
27	150	200
16	125	175

Fig. IRC Class A and B Loadings

ANALYSIS OF BOX GIRDER RIGHT BRIDGE

The following inputs are given to the software (staad-pro) in the analysis.

1. Geometry of the structure.
2. Member properties of both longitudinal and transverse members. These involve the section properties as well as the material properties.
3. IRC loading.
4. Support conditions of the deck.

ANALYSIS FOR LONGITUDINAL FLEXURAL STRESSES

- The geometry is prepared by using 2D beam elements in staad. Co-ordinates of different nodes are entered at small intervals.

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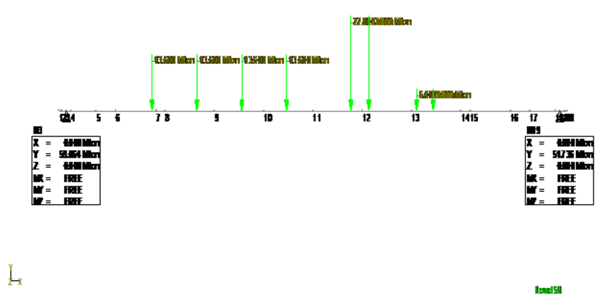
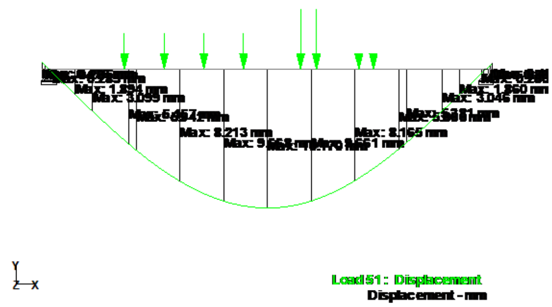
- Total 21 nodes and 20 beam members are considered. Sectional properties, Material properties and Support conditions are added in the Input.
- The DL and SIDL are considered as UDL
- In staad pro input, Load cases 1 to 100 is considered for moving load positions. L/C 101 is for DL and L/C 102 is for SIDL are considered

IRC class A wheel load for two lanes are considered for LL input in staad with moving load option for 100 cases at 0.5m forward movement.
Position for Max. BM for LL and the corresponding reaction from staad result is shown below for trapezoidal section.



EVALUATION OF STAAD OUTPUT
Maximum Bending Moment and Shear Force for DL, SIDL and LL are got from the output file of Staad pro.

Max. BM and deflection occurs at mid-span for LL position of Load case 51.



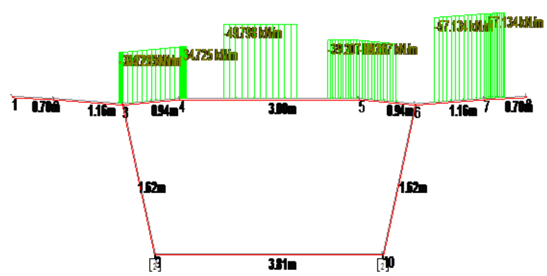
Maximum BM diagram for DL and SIDL at midspan is also studied

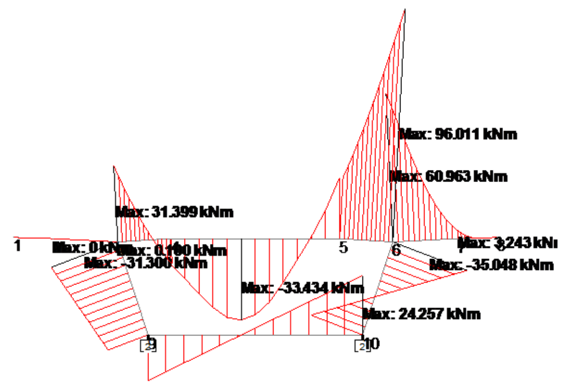
Max. BM and SF for the combination of DL, SIDL & LL is calculated at various sections.

ANALYSIS FOR TRANSVERSE BENDING

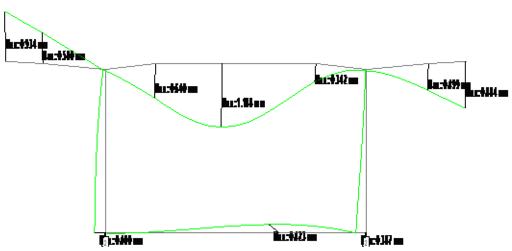
Geometry is prepared with 10 nodes and 9 beam members. Load Cases 1 to 8 are considered for different LL positions. Load Case 9 is given for DL and Load Case 10 is for SIDL. Load Case51 is provided for the load combination of DL and SIDL. L/C 8 is shown below.

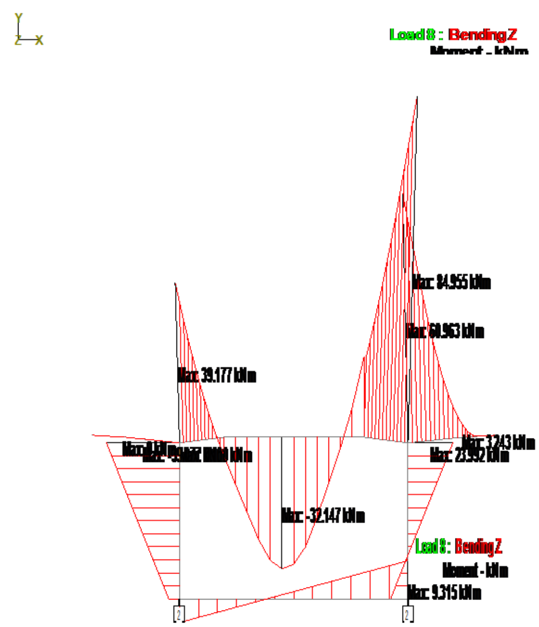
- Class A wheeled loading has been considered at mid span and has been placed at minimum clearance from the inner edge of the kerb to produce maximum torsion in the section.

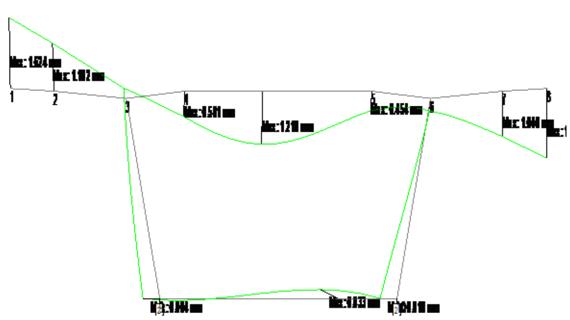




Deflection profile for LL for L/C 8 –max. for LL







BM diagram for LL – L/C 8

BM for combined DL and SIDL also computed.

Comparison of results from staad pro for Longitudinal Analysis

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Parameter	Rectangular section	Trapezoidal section	Cha
Maximum Bending Moment (t-m)			
Due to DL	1547	1493	3.6
SIDL	515	515	0
LL	635	635	0
Maximum Shear Force (t)			
Due to DL	205.77	207.8	1
SIDL	64.42	64.47	0.07
LL	100.32	100.32	0
Maximum Deflection (mm)			
Due to DL	23.53	24.790	5.07
SIDL	7.809	8.507	8.94
LL	9.334	10.170	8.96

Parameter	Top slab		Bottom slab	
	Rectangular	Trapezoidal	Rectangular	Trapezoidal
Max. BM(KNm)				
Due to DL+SIDL	29.475	29.475	9.848	5.701
LL	84.955	96.01	9.315	24.257
Max. S.F(t)				
Due to DL+SIDL	2.52	2.52	1.46	1.14
LL	8.54	8.54	0.32	1.153
Max. Deflection (mm)				
Due to DL+SIDL	0.643	0.630	0.325	0.135
LL	1.243	2.145	0.423	0.882
Max. Transverse stress (KN/m^2)				
Due to LL	5947	6650 (12% more)	1043	2525

Comparison of results from staad pro for Transverse Analysis

FINITE ELEMENT ANALYSIS –USING 3D PLATE ELEMENTS

- The bridges considered in this study were modeled using a three dimensional 4 nodded quadrilateral plate elements. The full model in each case consisted of 180 nodes, 170 plate elements and 4 supports. Meshing has been done for top slab, bottom slab and side walls.

To simplify the model, the thickness variation of top slab and overhangs are neglected by simply using an average thickness of the slab. The DL and SIDL are entered as element pressure in t/m2 .

- The two trains of wheel loads of IRC class A vehicle for two lanes are treated as concentrated loads. Their position for maximum response is taken from

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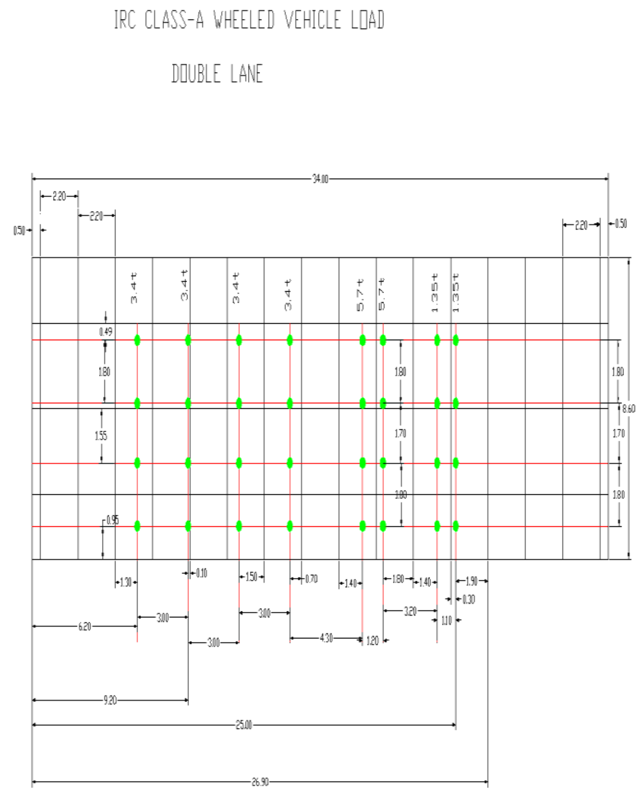
the result of 2D beam analysis. LL in tonnesare entered on respective plate elements so that they are considered as concentrated loads. IRC class AA tracked vehicle is also considered separately. The load cases considered are as follows.

- Load case 1 - DL , L/C 2 - SIDL
- L/C 3 -LL IRC class A wheeled vehicle-Two lanes
- L/C 4 -LL IRC class AA 70-R- One lane
- L/C 11 - Service load (DL+SIDL+LL class A wheeled)
- L/C 12- Service load (DL+SIDL+ LL 70R)



Rectangular section with class A wheeled load for two lanes and Trapezoidal section with 70R tracked load for single lane

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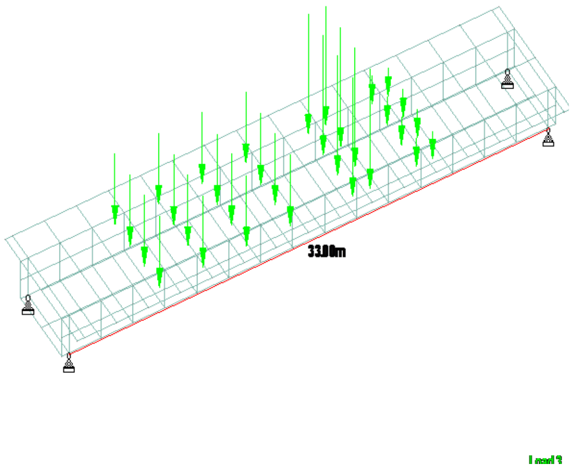
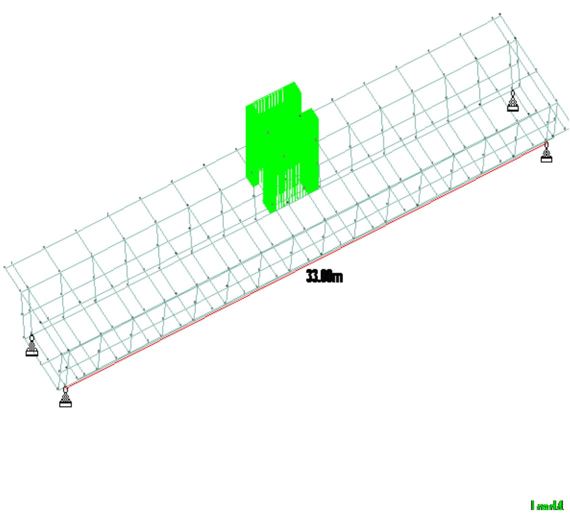


Support Reactions (in M ton)

	Rectangular section		Trapezoidal section	
	2D Analysis	3D Analysis	2D	3D
DL	216.021 (N_3) 216.021(N_{19})	211.344(N92,96) 211.344(N93,97)	207.113(N_3) 207.113(N_{19})	200.196(N92,96) 200.196(N93,97)
SIDL	64.426 64.426	63.05 62.846	64.426 64.426	63.049 62.846
LL- IRC class A wheeled	59.064 51.736	59.063 51.736	59.064 51.736	59.064 51.736



Thus the formulation of the staad pro method for self weight , super imposed load and live load is verified to be correct and the programme can be used for the problem under consideration in 3D analysis.

Validation of Finite Element Analysis Result

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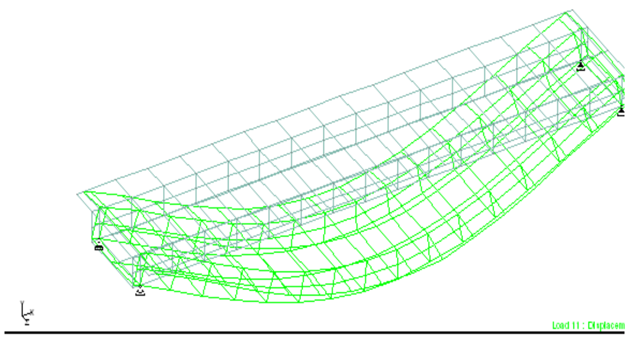
OUTPUT FROM FEM 3D ANALYSIS



Deflection

Node Displacement Summary – Rectangular section

	Node	L/C	X (mm)	Y (mm)	Z (mm)	Resultant (mm)
Max X	47	11:00	**2.443**	-4.3	0.197	4.95
Min X	73	11:00	**-2.413**	-4.246	0.186	4.887
Max Y	114	11:00	-0.6	**0.849**	-0.005	1.039
Min Y	84	11:00	-0.239	**-25.33**	0.296	25.333
Max Z	84	11:00	-0.239	-25.33	**0.296**	25.333
Min Z	32	12:00	-0.234	-23.355	**-0.277**	23.358
Max rX	85	11:00	-0.721	-24.603	0.291	24.616
Min rX	1	12:00	2.191	-0.275	-0.172	2.215
Max rY	94	11:00	0.004	0.671	-0.211	0.703
Min rY	91	11:00	-0.004	0.678	-0.209	0.71
Max rZ	73	11:00	-2.413	-4.246	0.186	4.887
Min rZ	47	11:00	2.443	-4.3	0.197	4.95
Max Rst	84	11:00	-0.239	-25.33	0.296	**25.333**

Plate Centre Stress summary(Rectangular section)

	Plate	L/C	Shear		Membrane				Bending	
			Qx (N/mm²)	Qy (N/mm²)	Sx (N/mm²)	Sy (N/mm²)	Sxy (N/mm²)	Mx (kNm/m)	My (kNm/m)	Mxy (kNm/m)
Max Qx	180	11:00	**0.228**	-0.458	-0.057	-1.179	0.804	-9.521	-7.736	28.253
Min Qx	148	11:00	**-0.231**	-0.455	-0.05	-1.258	-0.8	-9.687	-8.6	-27.71
Max Qy	111	11:00	0.226	**0.56**	-0.061	-1.054	-0.796	9.206	-13.317	29.094
Min Qy	180	12:00	0.207	**-0.52**	-0.058	-0.957	0.736	-8.504	11.779	27.348
Max Sx	83	11:00	0	-0.024	**3.659**	0.124	0.017	-27.919	-4.804	-0.142
Min Sx	66	11:00	0.003	0.078	**-7.417**	0.034	0.012	-5.499	18.039	-0.411
Max Sy	106	11:00	-0.193	-0.04	0.045	**1.496**	0.528	13.934	8.985	-10.102
Min Sy	105	11:00	0.037	0.04	-3.194	**-2.046**	-1.355	15.501	-4.963	5.762
Max Sxy	164	11:00	-0.21	0.244	-6.691	-1.354	**3.161**	-30.293	-29.742	14.276
Min Sxy	150	11:00	0.206	0.246	-6.69	-1.372	**-3.234**	-30.414	-30.388	-14.008
Max Mx	127	12:00	0.195	-0.228	-6.212	-1.264	2.954	**28.318**	29.079	-13.143
Min Mx	150	11:00	0.206	0.246	-6.69	-1.372	-3.234	**-30.414**	-30.388	-14.008
Max My	127	12:00	0.195	-0.228	-6.212	-1.264	2.954	28.318	**29.079**	-13.143
Min My	150	11:00	0.206	0.246	-6.69	-1.372	-3.234	-30.414	**-30.388**	-14.008
Max Mxy	111	11:00	0.226	0.56	-0.061	-1.054	-0.796	9.206	-13.317	**29.094**
Min Mxy	143	11:00	-0.223	0.557	-0.067	-0.988	0.801	9.036	-12.896	**-29.553**

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Comparison of Results from FEM Analysis-Service load condition

Parameter	Rectangular section	Trapezoidal section	% change
Maximum Deflection (mm)	25.333	25.132	<1%
Max. Longitudinal stress (KN/m^2)	3659	3957	8%
Max. Transverse stress (KN/m^2)	1496	1675	12%

CONCLUSION.

- The max. Longitudinal stresses are not significantly influenced by the shape of the section. Transverse stresses are influenced by the shape of the section. Max. Transverse stress is more in trapezoidal section.
- From the results, maximum deflection for trapezoidal section is higher as compared to rectangular section.The difference is more prominent in topslab than bottom slab. Deflection under LL is more in trapezoidal section.
- It reflects higher torsional rigidity of rectangular section than trapezoidal section.
- As a whole the structural response of bridge with rectangular box section is better than trapezoidal box section in transverse analysis.
- In 3D analysis by FEM , the max. deflection does not vary much in both sections
- *Therefore it is concluded that the overall structural response in rectangular and trapezoidal sections will not differ much in longitudinal analysis of pre stressed box girder bridge.*

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