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Parametric Study of Inverted Triangle Box Girder for Bridges

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Abstract: A bridge is very important structure nowadays. The bridges have become much more efficient with technological advancements. There are various types of bridges available. The box girders are suitable for a variety of bridges. Box girders are efficient and also economical superstructures. The study presented here shows parametric analysis of an Inverted Triangle Box Girder Bridge. The parametric study is carried out to get the basic idea of section performance under the section depth variation. The longitudinal and lateral (cross-sectional) analyses have been carried out. The longitudinal designing is done using the Simple Beam theory and design ideology is Limit State Design. The section is analyzed and designed for Shear force, Bending moment and Torsional moment. The software used for the analysis in this study are CSi Bridge and Bentley STAAD Pro, while the designing is carried out using Microsoft Excel. The reference codes used are Indian Standards. The section shows satisfactory performance for most of the cases.

Keywords: Inverted Triangle, Triangular Box Girder, Inverted Triangle Box Girder, Bridge, Parametric Analysis, CSi Bridge, STAAD Pro

I. INTRODUCTION

A Bridge is a structure which is used to negotiate the distance between two points with obstructions like rivers, valleys, other means of transportation routes, etc. without the need of a long detour. The Bridges have been around since many years now. During and before the evolution of mankind, there were bridges in form of some natural formation of rocks, sometimes fallen logs of trees, etc. Nowadays we see a lot of development in bridge construction, from construction methodology to structural system. There are various types of bridge superstructures available today, some of which are beam or girder type, truss type, box girder, arch type, etc. These types of superstructures can be used depending upon suitability of structural system. The bridges may be classified in many types, based on functional requirements, span, materials used, the obstruction, etc. A schematic figure of a bridge is shown in Fig. 1.

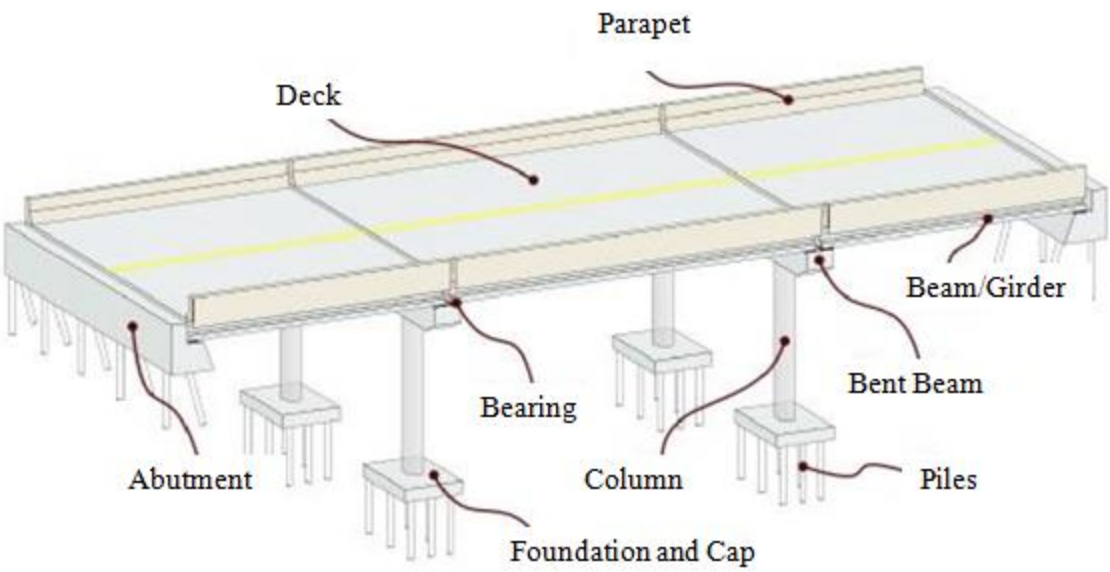

Fig. 1 Bridge and its Components

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The superstructure consists of deck, parapet, beam/girder or the corresponding component and the remaining parts are usually called substructure. Some types based on materials is wooden, metal, concrete, etc. The classification is also done based on type of traffic, pedestrian, vehicle, pipeline, etc. The Sensitivity analysis is used to determine how "sensitive" a model is to changes in the value of the parameters of the model and to changes in the structure of the model. Parameter sensitivity is usually performed as a series of tests in which the modeller sets different parameter values to see how a change in the parameter causes a change in the structural response. By showing how the model behavior responds to changes in parameter values, sensitivity analysis is a useful tool in model building as well as in model evaluation.

II. Summary of Literature

The similar type of cross-section was developed and tested by Sewer Jakubowski [5]. In this paper, the author carried out the theoretical study of local buckling behavior of triangular cross-section steel girder. The loading condition was compound and the section was a thin walled box girder. The load cases were: compression, eccentric compression, pure bending and bending with shear. Parabolic distribution of shear stress was assumed in presence of lateral forces. The deflections of the walls were assumed to be in the form of a combined polynomial-sine series. Total 3 modes of buckling were considered out of which 2 were tested for all the loading and one was tested for only compression case. It was observed that the data from these results and data from the actual literature had only 1.5% error. The author concluded that the results obtained were for end cross-section remaining plane. Pure compression would show both symmetric and asymmetric modes of buckling, mainly dependent upon cross-sectional dimension and not upon segment length. For small value of eccentric loading both modes of failure are possible while for larger eccentricity and pure bending, only symmetrical mode is possible. In the analysis under bending and shear force, 2 different groups were encountered; one with rigid web where the P_{cr} value increased and buckling modes remained same while other one with P_{cr} value decreasing and multiple buckling modes.

Maria Kotełko & Marian Kró1ak [4] studied the collapse behavior of an inverted triangle (cross-section) girder. The girder is assumed to be thin-walled and the analysis carried out is numerical analysis. The aim of this paper was to determine whether the collapse would be brittle or ductile, as thin-walled structures are widely used in various structures. The loading considered was pure bending in this study. The experimental analysis was carried out using cardboard thin-walled girders and the failure mechanisms were developed by the authors. The girder's cross-section was an isosceles triangle. The bending moment was acting in the plane created by the axis of the cross-section symmetry and the longitudinal girder's axis. Therefore, it was causing the uniform compression of the wall of width "a" (unequal side's length). It was assumed that the girder was stiffened by an even number of diaphragms at a distance "c" from each other. Models made for tests had a different "a/b" ratio (b=equal sides' length) and a different distance "c" of diaphragms. It was assumed that plastic zones are concentrated and can be regarded as stationary yield-lines of a global plastic hinge. Plastic mechanisms of failure were assumed to be well developed and in consequence surfaces between yield-lines, i.e. 'walls of the global plastic hinge', were underformed. It was concluded that the method used was appropriate for use with different types of cross-sections. It was also found out that further theoretical as well as experimental work was required to determine the energy absorbed during deformation of Local plastic hinges of the global plastic mechanism. Another thing was pointed out that not all mechanisms were tested; hence in-depth study was also mandated.

Chidolue, C. A et. al. [6] showed the torsional and distortional performance analysis of a box girder. The span taken was 50m and cross-section of the girder is multi-cell trapezoidal box girder. The depth of section taken was 3050mm, width was 9150mm and the web inside were positioned to make triangular boxes. The authors concluded that maximum torsional distortional deformation of a single cell mono-symmetric box girder section of the same overall size and plate thicknesses was 168% higher as compared to the multi-triangle-cell trapezoidal box girder.

III. Methodology

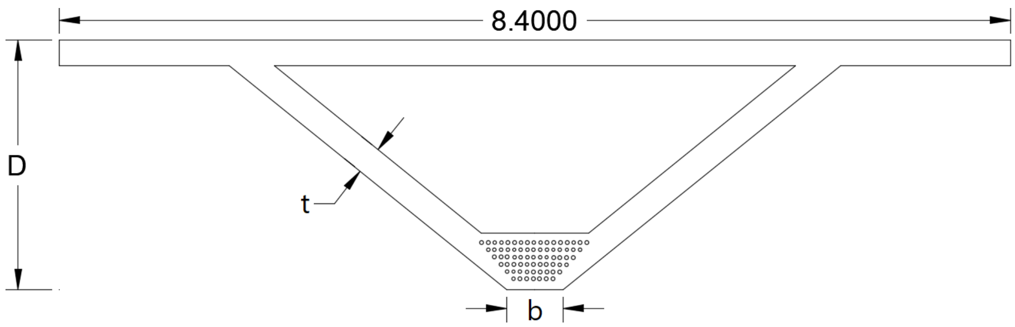

Fig. 2 Cross-section Details (AutoCAD)

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Analysis is carried out for 30m span RCC bridge deck. The concrete grade taken is M35. The overall deck width taken here is 8.4m. No footpath is accommodated and the bridge is a 2-lane bridge.

The depths tested for the study are 1.8m, 2m, 2.2m, 2.4m and 2.6m. The standard followed for analysis conditions and designing is IRC:112-2011. The crash barrier is assumed to be 0.45m wide and 1m tall. The concrete density is taken as 25kN/m^3. The wearing coat thickness is taken 55mm and density is taken as 26kN/m^3. The vehicle loads used for the analysis are 70R wheeled load and Class A load.

The model is prepared in AutoCAD for dimensioning and accuracy. After determining all the dimensions, the model is generated in CSi Bridge Software. The box section and loads are defined and the analyses are assigned. The analysis is run and the output is noted.

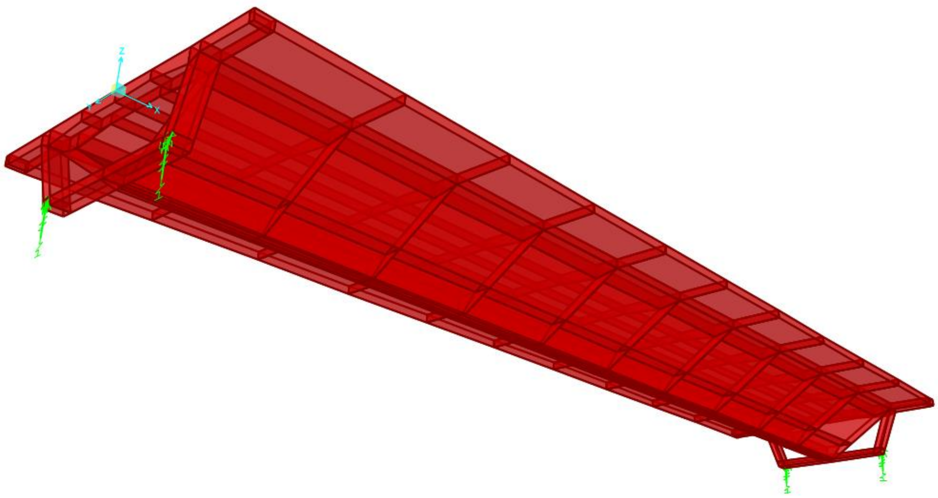

Fig. 3 CSi Bridge Model

The cross-sectional analysis is carried out using Bentley STAAD Pro software. The cross-section is modelled using STAAD Pro and various sections are defined. The wheel configurations used for cross-section analysis are the heaviest for the given vehicles. The initial analysis is to determine the moving load type and position to find out the exact response of bridge cross-section under dispersed loads. After determining that, the dispersed load is calculated and applied to find out the response of various members.

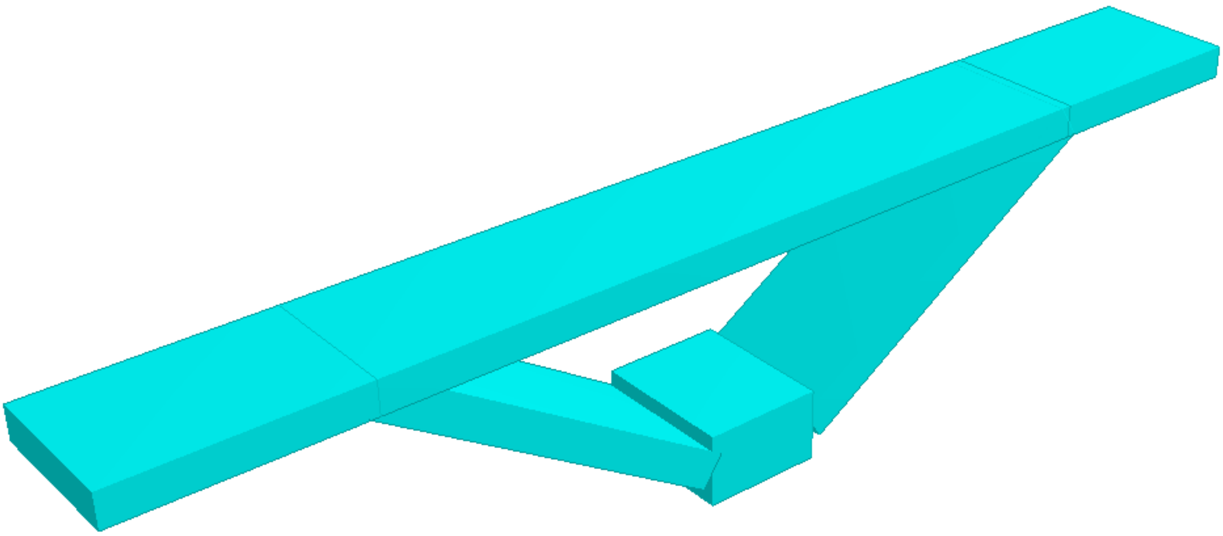

Fig. 4 STAAD Pro Model

The analyses results are obtained for longitudinal and cross-sectional design. The results are factored and then the design is carried out to find out the reinforcement requirements. The design is carried out using Microsoft Excel by programming design sheets using IRC:112-2011. The design methodology used is Limit State design. The bridge deck is designed for flexure, shear, torsion and their combined effects.

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IV. RESULTS

The results of longitudinal analysis are given below:

TABLE I LONGITUDINAL ANALYSIS RESULTS FOR DEAD LOAD

N	Depth	Dead Load		Wearing Coat		Crash Barrier	
	(m)	SF(kN)	BM(kNm)	SF(kN)	BM	SF	BM
1	1.8	1565.369	9675.6579	231.875	1455.168	373.6125	2345.595
2	2.0	1582.637	9778.59	231.875	1455.168	373.6125	2345.595
3	2.2	1601.235	9886.529	231.875	1455.168	373.6125	2345.595
4	2.4	1625.082	10033.34	231.875	1455.168	373.6125	2345.595
5	2.6	1650.956	10190.23	231.875	1455.168	373.6125	2345.595

TABLE II LONGITUDINAL ANALYSIS RESULTS FOR LIVE LOAD

N	Depth	Live Load			Total		
	(m)	SF(kN)	BM(kN)	TM(kN)	SF(kN)	BM(kNm)	TM(kNm)
1	1.8	1504.125	8869.081	3918.895	3674.981	22345.5	3918.895
2	2.0	1504.125	8869.081	3854.049	3692.25	22448.43	3854.049
3	2.2	1504.125	8869.081	3796.425	3710.848	22556.37	3796.425
4	2.4	1504.125	8869.081	3704.703	3734.694	22703.18	3704.703
5	2.6	1504.125	8869.081	3654.591	3760.568	22860.08	3654.591

From the above results it is evident that the dead load moments and shear force change with change in section, while the other parameters remain constant for all the other load cases. The torsional moments also change from one depth to another.

TABLE III LONGITUDINAL DESIGN DATA

N	Depth	Reinforcement			% Increase in Concrete	Shear and Torsion Interaction Check	
	(m)	Longitudinal(n)	% Decrease	Shear(mm c/c)		Check	Failure Cause
1	1.8	44 – 32mmØ	-	175	-	1.069572	>1
2	2.0	40 – 32mmØ	9.09%	200	0.4699%	0.973793	SAFE
3	2.2	35 – 32mmØ	12.5%	225	0.5037%	0.91866	SAFE
4	2.4	32 – 32mmØ	8.57%	250	0.6426%	0.83483	SAFE
5	2.6	29 – 32mmØ	9.375%	275	0.6928%	0.784993	SAFE

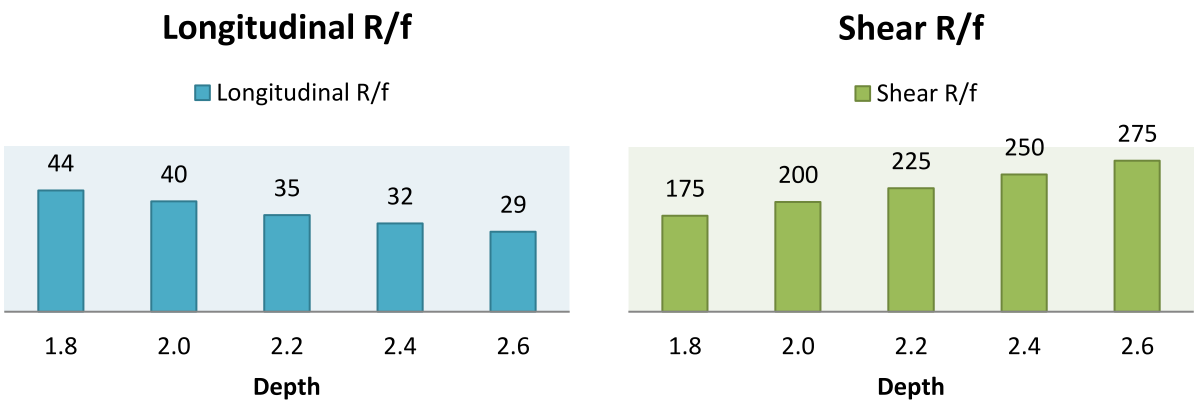

Fig. 5 Longitudinal and Shear Reinforcement trend

The longitudinal design carried out is using 32mm Ø main reinforcing bars of Fe500 HYSD steel and shear design is done using 16mm Ø 4-legged stirrups of Fe500 HYSD bars.

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As per IRC:112-2011, the cross-sectional design carried out using load dispersion doesn't require shear check (for slab only). The analysis results are shown below:

TABLE IV CROSS-SECTIONAL ANALYSIS

Segment	Depth	BM (kNm)			Depth	BM (kNm)		
		6	7	8		6	7	8
Cantilever	1.8	129.07	21.78	21.78	2	129.34	21.83	21.83
Top slab (ends)		264.52	203.89	208.83		265.07	202.57	207.82
Top slab (mid)		-105.091	-138.624	-133.046		-106.228	-139.905	-134.315
Web (top)		-135.45	-182.11	-187.05		-135.73	-180.77	-185.99
Web (bottom)		280.89162.59	149.47	192.81, -42.36		281.86, -166.97	150.5	193.64, -44.96
Bottom slab (ends)		280.89, -162.59	149.47	192.81, -42.36		281.86, -166.97	150.5	193.64, -44.96
Bottom slab (mid)		57.733	79.897	73.8006		56.216	79.225	73.113
Cantilever	2.2	129.61	21.88	21.88	2.4	129.88	21.92	21.92
Top slab (ends)		265.7	139.64	206.82		266.39	200.02	205.83
Top slab (mid)		-107.238	-141.24	-135.516		-108.177	-142.322	-136.692
Web (top)		-136.09	-179.46	-184.94		-136.51	-178.17	-183.91
Web (bottom)		282.53, -170.19	150.51	194.19, -46.83		283.2, -172.56	150.99	194.67, -48.32
Bottom slab (ends)		282.53, -170.19	150.51	194.19, -46.83		283.2, -172.56	150.99	194.67, -48.32
Bottom slab (mid)		55.12	78.675	72.58		54.329	78.238	72.183

Segment	Depth	L/C 6	L/C 7	L/C 8
Cantilever	2.6	130.15	21.97	21.97
Top slab (ends)		267.1	198.76	204.84
Top slab (mid)		-109.07	-143.507	-137.852
Web (top)		-136.95	-176.88	-182.87
Web (bottom)		283.75, -174.48	151.42	195.03, -49.5
Bottom slab (ends)		283.75, -174.48	151.42	195.03, -49.5
Bottom slab (mid)		53.724	77.854	71.857

TABLE V CROSS-SECTIONAL DESIGN

Component	Cantilever	Top Slab Ends	Top Slab Mid	Web Top	Web Bottom	Bottom Slab Ends	Bottom Slab Mid
Reinforcement	16Ø @ 90	16Ø @ 80	16Ø @ 80	20Ø @ 120	20Ø @ 90/170	16Ø @ 130	16Ø @ 210

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V. CONCLUSION

From the results above, we can derive the following conclusions:

- The section here is tested for total 5 different depths, out of which 4 models (80%) are successful. The model which fails is due to "Shear and Torsion Interaction Check" which can be rectified by increasing the overall sectional thickness.
- The longitudinal values of Bending and Shear change only for Dead loads, because the overall section loads remain the same but the cross-sectional changes only reflect in dead loads.
- The Torsional moments are zero for the Dead load, Crash barriers and Wearing coat as these loads are symmetric and hence the torsional effect is not effective.
- The Torsional moments reduce for the Live load with increase in depth, which suggests increase in torsional stability of the section with increasing depth.
- From the graphs it can also be seen that with increase in depth, there is a consistent decrease in longitudinal as well as shear reinforcements. There is 10.68% decrease on an average in shear reinforcement.
- The 70R loading dominates in longitudinal analysis as the axle load is higher, but for cross-sectional analysis 2-lanes of Class-A loading also shows critical placement.
- There is an average increase of 0.5% in Shear force and 0.5757% increase in Bending moment with increase in depth of the section.
- The cross-sectional analysis results show that the change in Bending moment value is not significant and the same reflects in the cross-sectional design as well. Due to this reason, the cross-sectional design is almost identical for all the considered depths of section.
- With increase in concrete (i.e. increase in depth) the decrease in reinforcement is much more significant on an average it is 9.88% as compared to average increase in concrete volume of 0.57725%, which shows that the reinforcement is more sensitive towards a change in depth as compared to concrete.

VI. FUTURE SCOPE

- The study can be carried out using most economical span values for box girders.
- The sections can be revised to give satisfactory performance, therefore a study can be carried out to check whether the increase in various parameters is feasible or not.
- The study can also be carried out to compare the Inverted Triangle section and other available box girder sections.

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