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Behavior of Tubular Flange Girder System in Curved Overpasses

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Abstract: ***Curved overpasses with steel girders are now widely used in Iraq because they add significant flexibility in the determination of highway alignments, especially at congested interchanges inside major cities. The horizontal curvature produces significant torsional effects in the bridge girder system. In this study new types of curved steel girders are proposed to make the system stable against this torsional effect where their behavior in curved bridge systems is investigated and compared with the typical I-section girder under the same geometry and loading conditions. These new types of girders have a tube in place of the bottom flange of the I-section girder. Four models are proposed herein. The finite element program SAP2000 version 14 is used for the linear analysis of the horizontally curved simply supported composite bridge decks with the proposed girder models and the reference I-section girder. The factors considered in the parametric study are: span length, curvature, number of mid diaphragms and girder type. The results include the longitudinal stresses and the vertical displacements in the mid span of the bridge. These results have been compared with those of the reference I-section girder. The results showed that the proposed models give less stresses and deflections than the typical I-section and the most effective model in curved deck bridge is girder model D (the bottom plate is made of steel channel with plates inclined with 45º we lded together instead of the bottom steel plate and filled with concrete) .***

Keywords: Curved Steel tubular flange Girder, SAP2000, AASHTO.

1. Introduction

Traffic jam problems became the most significant concern inside major cities in Iraq; curved overpasses with steel girders are now widely used in Iraq because they add significant flexibility in the determination of highway alignments, especially at congested interchanges inside major cities. The horizontal curvature produces significant torsional effects in the bridge girder system. Four new models of steel girders are proposed. These girders have tubular shapes in place of the bottom flange plate of I-girders and these tubular flanges will be hollow or filled with concrete. The proposed models of tubular flange girders will be studied to investigate their behavior in steel curved bridges for the typical span lengths of overpasses in Iraq. The models behavior will be compared with I- section girders with the same dimensions. The tubular flange girder models and the reference I-section girder are shown in Figure (1).

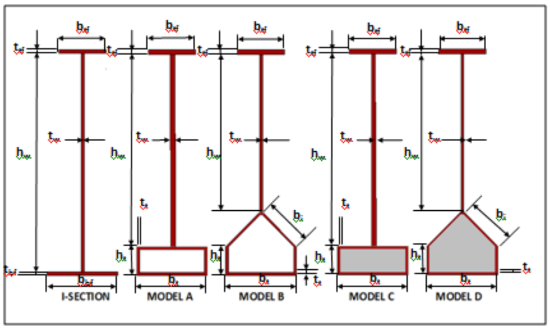


Figure 1: The tubular flange girders types and I-section.

The study is based on the following assumptions
1) Composite Action: the reinforced concrete slab deck will behave in full interaction with the steel girder.
2) The spans under consideration are simply-supported.
3) All materials are linear, elastic and homogenous.
4) Sections selected are designed for section compactness, strength, buckling and local torsional capacities based on AASHTO- ASD, 17th Edition, 2001 **[1]**.
5) The effect of road super-elevation and curbs are neglected.
6) The study does not include the effect of cyclic and fatigue loadings.
7) The effect of friction forces between deck slab and girders is neglected.

Other bridge configurations are listed below:

a) Three spans will be adopted which are the typical spans used in Iraq. These spans are (24, 30 and 36) m.
b) The deck slab thickness (t_s) is taken as (0. 22 m).
c) The carriageway width is taken equal to (7m) with sidewalks of (1m) on each side of the bridge .The total width of the bridge is equal to (9m).
d) Number of girders supporting the deck is 4.
e) The spacing between the girders is 2.2m.
f) Three lines of headed shear stud connectors with (22 mm) in diameter are designed based on article (10.38.2) of AASHTO-ASD specifications 17th Edition ,2001 **[1]**, so that the behavior of the composite action is full interaction (slip is very small and considered negligible). The spacing between shear studs for span (24m) is (0.4m) and the spacing for the spans (30m) and (36m) is (0.3m). These spacings are from sites work information of available bridges in Iraq.
g) The girder web thickness is considered equal to 16mm.
h) Diaphragms are made of K-type truss bracing, the top chord bracing is UPN140 and bottom chord bracings are) L 100*100*10 mm) and the diagonal bracing is (L 75*75*7 mm).
i) The wearing surface density is (22 kN/ m³) and the thickness will be assumed (100 mm).

j) The material properties of the components of the composite bridge deck are specified in Table(1) below:

Table 1: Material properties of composite bridge deck components

	Concrete	
E_c	Young modulus (MPa)	24682
$fc`$	Compressive strength (MPa)	27.58
υ	Poisson's ratio	0.2
γ_c	Density of fill concrete (kN/m³)	24
γ_c	Density of reinforced concrete deck (kN/m³)	24.5
	Steel	
Type	A 50 steel	-
E_s	Young's modulus (MPa)	200000
fy	Yield stress (MPa)	345
υ	Poisson's ratio	0.3
γ_s	Density (kN/m³)	78.6

Figure (2) shows the cross section details of the typical composite bridge deck. K-type cross-bracings with top and bottom chords are utilized in this study. Typical plan of curved girders with the distribution of the radial bracings are shown in Figure (3) for span 24m .

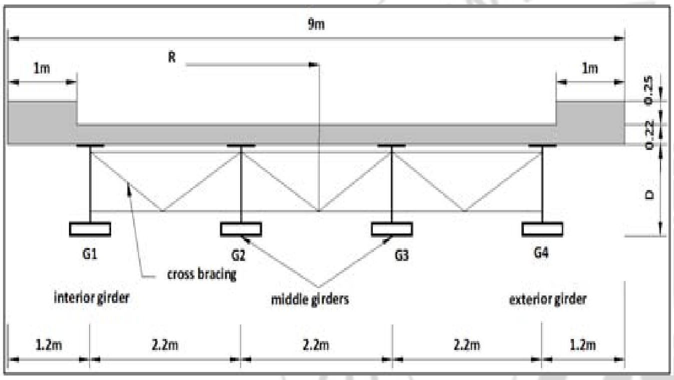


Figure 2: Cross sectional view of composite bridge model with model A steel girders.

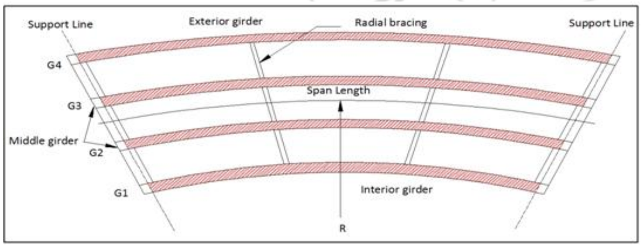


Figure 3: Top plan of curved span of 24m showing radial bracings

2. Bridge Loading

According to AASHTO LRFD -2004**[2]**, the highway live loadings on the roadways of bridges or incidental structures shall consist of standard trucks and lane loads that are equivalent to truck trains. One type of loading is provided in our study, Truck Loading (HL93), the heaviest truck available in AASHTO LRFD -2004. Bridge configurations considered in this study include two full trucks loading one in each notational lane with the other wheel load located 0.6m from the curb at exterior side of deck as considered by AASHTO LRFD specification. Figure (4) shows the transverse location of loading for composite curved bridge.

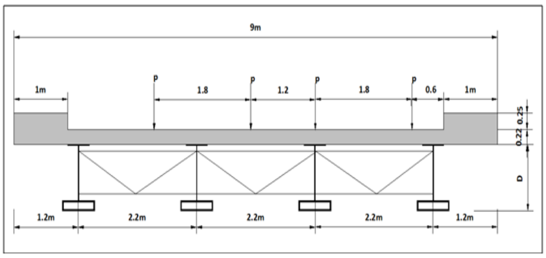


Figure 4: Transverse load location for composite bridge with model A steel girders

Finite Element Analysis

3.1 Finite Element Models

To analyze the composite bridges and to determine their structural behavior, a three-dimensional finite-element model is used. The composite bridge is divided into concrete deck slab, top steel flange, steel web, bottom steel tube, and the cross-bracings. Four-node shell elements with six degrees of freedom at each node are used to model the concrete deck slab, the top flange, bottom tube girder, and finally the web. Frame elements, pinned at both ends, are used to model the cross-bracings with the top and bottom chords. Solid elements are used to model the concrete in the case of tube filled with concrete. Shear stud connectors can be modeled as shell element with same projected area along the top flange of the girder to connect the concrete deck slab to girder top flange .The real composite action where the slab bears slip (even small value) between the concrete deck slab and top steel flange is best simulated in this modeling. Figure (5) shows the three dimensional view of the curved bridge and the coordinate system.

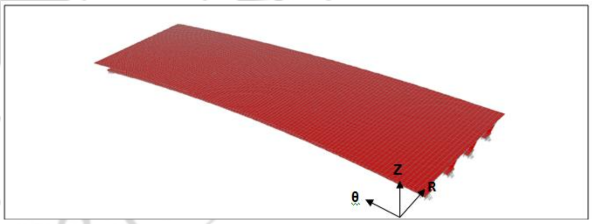


Figure 5: Three dimensional view of the curved bridge and coordinate system.

3.2 Boundary Conditions

The bridge supports modeling used in this study is to select the middle lower nodes of the lower face of the bottom flange of the tube in both x and y directions fixed to represent the bearing pads which have dimensions of (200*200) mm. The interior support at the right end of the bridge is restrained against movements in all directions. The middle supports and the exterior support at the same right end of the bridge are restrained against the vertical movement and against the movement in y-direction (towards the bridge longitudinal direction). For the other end of the bridge (left end), all the supports are only restrained against vertical movement, except for the interior support which in addition to the vertical restraining, it is restrained in x-direction (towards the bridge transverse direction), see Figure (6) .

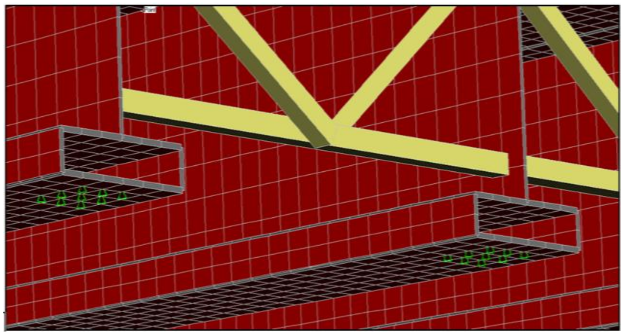


Figure 6: Finite element modeling of the bridge with the boundary conditions

3.3 Applied Loads

The applied loads are shown in Table (2) below:

Table 2: Types of loading

Type of loading	*Values*
Dead load	Self Weight +Weight Of Wearing Coarse
Live load	Truck HL 93 Load

SAP2000 accepts loading the structures at the nodes with concentrated load or on the shell element as uniform loading. For truck loading HL93it is applied as concentrated loads on nodes at the top of the slab in position to get the maximum effect for flexural stresses at the mid-span location as shown in Figure (7).

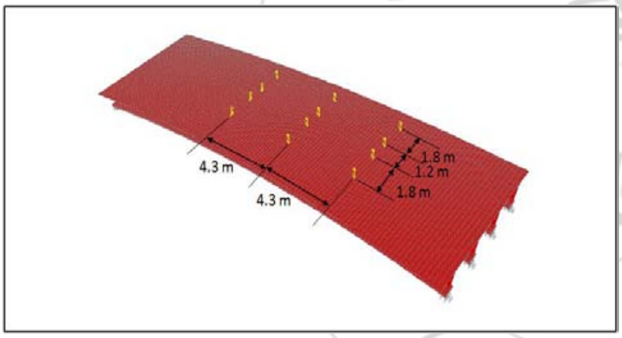


Figure 7: Applied loading of HL93 Truck Load

4. Parametric Study

The horizontal curvature produces significant torsional effects in the bridge girder system. For this purpose, researchers and designers to investigate and find new sections having the ability to resist this torsion and to make the system more stable against the applied load. This is the objective of this study; hence, for this purpose the proposed models described previously will be examined and their results will be compared with the normal I-section girder. The important parameters affecting stresses and displacements. The parameters chosen for this study are the span length, span-to-radius ratio, number of bracings and the steel girder shape and these parameters are shown in Table (3) .The width of bridge; number of girders and the spacing between girders are kept constant in this study.

Table 3: Parameters for all proposed four models and I-section girders with (end bracings only)

Span (m)	*L/R Ratio*	*R (m)*	*number of cross bracing (at ends only)*	*number of cross bracing (additional mid)*
24	0.1	240	2	4
	0.2	120	2	4
	0.3	80	2	4
	0.4	60	2	4
30	0.1	300	2	6
	0.2	150	2	6
	0.3	100	2	6
	0.4	75	2	6
36	0.1	360	2	7
	0.2	180	2	7
	0.3	120	2	7
	0.4	90	2	7

4.1 Results

4.1.1 Stresses

After analysis of the four proposed models and the typical I-section girder, the stresses are calculated. The longitudinal bending stresses in the bottom flange and concrete deck slab of the proposed models are compared with I-section girder stresses to know the behavior of these steel girders under dead and live load (two trucks of HL93). All these results are measured in the mid span for the interior and exterior girders G1 and G4 respectively. Tables (4) to (27) show the bottom longitudinal stresses in bottom flange and top longitudinal stresses in concrete slab deck for the proposed models and I-section and for the exterior G4 and interior G1 girders and for all parameters . The results show that the stresses in the proposed models are in general less than the stresses of I-section girders under the same loading and same parameters. This difference between the results is mostly because the moment of inertia and the torsional rigidity of the proposed models are greater than those in I-section especially in model C and model D. The difference in stresses between proposed models and I-section indicate that the proposed models can carry more loads than I-section. The stresses in I-section girder increase in large amount but in proposed models they are increased but with much smaller amounts. Also the results show how the effect of cross bracing on stresses which show that when there are mid cross bracings the stresses are small in all sections and when the mid cross bracing is removed the stresses are increased in large amount in I-section girder but in very small amount in proposed models. This means that mid bracing in bridges with the proposed models can be minimized. Figures (8) to (17) show the longitudinal stresses in the bottom flange and concrete deck slab for span 36m and (L/R=0.4) which is the critical case in this study for all proposed models including I-sections and for all parameters Figures (18) to Figure (23) show the relation between the longitudinal stresses in the bottom flange of I-section and the proposed models with (L/R) ratio. Notations given in the following table are used:

Notation	***Meaning***
+	Tensile Stresses
-	Compression Stresses
σ_{Bf}	Bending Stresses In Bottom Steel Flange
σ_{ts}	Bending Stresses In Top Face Of Concrete Deck Slab

Table 4: Longitudinal normal stresses in the bottom flange and concrete deck slab For girders of span 24m (N/mm²) (with 2 mid bracings) with (L/R=0.1)

Girder / *L/R ratio*	*G1*		*G4*	
0.1	σ_{bf}	σ_{ts}	σ_{bf}	σ_{ts}
I-SECTION	92.048	-2.22	118.692	-2.964
Model A	70.852	-2.652	91.786	-3.519
Model B	79.226	-2.888	100.824	-3.649
Model C	46.56	-2.038	58.765	-2.464
Model D	46.098	-1.944	55.857	-2.363

Table 5: Longitudinal normal stresses in the bottom flange and concrete deck slab for girders of span 24m (N/mm²) (with 2 mid bracings) with (L/R=0.2)

Girder / *L/R ratio*	*G1*		*G4*	
0.2	σ_{bf}	σ_{ts}	σ_{bf}	σ_{ts}
I-SECTION	118.46	-2.607	174.919	-3.98
Model A	69.453	-2.579	114.521	-3.761
Model B	77.067	-2.919	110.947	-4.147
Model C	55.196	-2.299	78.391	-3.155
Model D	57.845	-2.499	76.469	-3.181

Table 6: Longitudinal normal stresses in the bottom flange and concrete deck slab for girders of span 24m (N/mm²) (with 2 mid bracings) with (L/R=0.3)

Girder / *L/R ratio*	*G1*		*G4*	
0.3	σ_{bf}	σ_{ts}	σ_{bf}	σ_{ts}
I-SECTION	123.23	-2.455	205.529	-4.344
Model A	67.848	-2.474	116.058	-4.1
Model B	74.19	-2.929	118.756	-4.462
Model C	55.395	-2.143	86.547	-3.299
Model D	57.883	-2.368	81.965	-3.225

Table 7: Longitudinal normal stresses in the bottom flange and concrete deck slab for girders of span 24m (N/mm²) (with 2 mid bracings) with (L/R=0.4)

Girder / *L/R ratio*	*G1*		*G4*	
0.4	σ_{bf}	σ_{ts}	σ_{bf}	σ_{ts}
I-SECTION	122.567	-2.308	228.469	-4.461
Model A	64.899	-2.345	124.766	-4.362
Model B	76.572	-3.012	131.742	-4.821
Model C	64.638	-2.103	110.335	-3.632
Model D	61.719	-2.237	91.657	-3.195

Table 8: longitudinal normal stresses in the bottom flange and concrete deck slab for girders of span 24m (N/mm²) (with end bracings only) with (L/R=0.1)

Girder / *L/R ratio*	*G1*		*G4*	
0.1	σ_{bf}	σ_{ts}	σ_{bf}	σ_{ts}
I-SECTION	109.376	-2.501	131.83	-2.984
Model A	77.016	-2.948	94.302	-3.44
Model B	80.913	-2.966	99.505	-3.607
Model C	49.485	-2.099	59.731	-2.391
Model D	45.979	-1.957	54.66	-2.323

Table 9: Longitudinal normal stresses in the bottom flange and concrete deck slab for girders of span 24m (N/mm²) (with end bracings only) with (L/R=0.2)

Girder / *L/R ratio*	*G1*		*G4*	
0.2	σ_{bf}	σ_{ts}	σ_{bf}	σ_{ts}
I-SECTION	166.95	-3.736	202.297	-4.61
Model A	84.357	-3.45	108.881	-3.984
Model B	81.767	-3.262	108.033	-4.324
Model C	64.356	-2.71	81.082	-3.147
Model D	60.367	-2.706	75.988	-3.225

Table 10: Longitudinal normal stresses in the bottom flange and concrete deck slab for girders of span 24m (N/mm²) (with end bracings only) with (L/R=0.3)

Girder / *L/R ratio*	*G1*		*G4*	
0.3	σ_{bf}	σ_{ts}	σ_{bf}	σ_{ts}
I-SECTION	193.539	-4.338	234.952	-5.504
Model A	92.319	-4.048	121.21	-4.709
Model B	82.764	-3.848	114.445	-4.667
Model C	69.909	-2.99	89.579	-3.44
Model D	62.265	-2.716	81.271	-3.189

Table 11: Longitudinal normal stresses in the bottom flange and concrete deck slab for girders of span 24m (N/mm²) (with end bracings only) with (L/R=0.4)

Girder / *L/R ratio*	*G1*		*G4*	
0.4	σ_{bf}	σ_{ts}	σ_{bf}	σ_{ts}
I-SECTION	211.913	-4.975	239.306	-6.294
Model A	118.34	-4.709	152.352	-5.299
Model B	91.903	-4.342	129.515	-5.29
Model C	95.003	-3.538	120.944	-3.932
Model D	69.274	-2.687	91.21	-3.179

Table 12: Longitudinal normal stresses in the bottom flange and concrete deck slab for girders of span 30m (N/mm²) (with 4 mid bracings) with (L/R=0.1)

Girder / *L/R ratio*	*G1*		*G4*	
0.1	σ_{bf}	σ_{ts}	σ_{bf}	σ_{ts}
I-SECTION	97.545	-2.62	131.272	-3.689
Model A	73.46	-2.919	99.921	-4.013
Model B	80.289	-3.115	106.992	-4.153
Model C	53.342	-2.405	69.738	-3.207
Model D	52.013	-2.488	65.364	-3.146

Table 13: Longitudinal normal stresses in the bottom flange and concrete deck slab for girders of span 30m (N/mm²) (with 4 mid bracings) with (L/R=0.2)

Girder / *L/R ratio*	*G1*		*G4*	
0.2	σ_{bf}	σ_{ts}	σ_{bf}	σ_{ts}
I-SECTION	97.286	-2.569	158.529	-4.552
Model A	69.05	-2.51	116.459	-4.512
Model B	74.289	-2.877	112.493	-4.675
Model C	55.757	-2.428	86.562	-4.018
Model D	57.755	-2.766	83.037	-4.167

Table 14: Longitudinal normal stresses in the bottom flange and concrete deck slab for girders of span 30m (N/mm²) (with 4 mid bracings) with (L/R=0.3)

Girder / L/R ratio	G1		G4	
0.3	σ bf	σ ts	σ bf	σ ts
I-SECTION	77.094	-1.783	154.549	-4.406
Model A	54.008	-1.806	112.706	-4.191
Model B	59.247	-1.928	117.945	-4.276
Model C	48.785	-1.807	89.812	-3.77
Model D	47.716	-1.972	88.743	-3.501

Table (15): Longitudinal normal stresses in the bottom flange and concrete deck slab for girders of span 30m (N/mm²) (with 4 mid bracings) with (L/R=0.4)

Girder / L/R ratio	G1		G4	
0.4	σ bf	σ ts	σ bf	σ ts
I-SECTION	94.747	-1.803	215.671	-4.89
Model A	62.696	-1.951	143.698	-4.902
Model B	67.151	-2.402	142.034	-5.189
Model C	53.003	-1.702	88.2	-3.718
Model D	50.875	-2.032	91.604	-3.495

Table 16: Longitudinal normal stresses in the bottom flange and concrete deck slab for girders of span 30m (N/mm²) (with end bracings only) with (L/R=0.1)

Girder / L/R ratio	G1		G4	
0.1	σ bf	σ ts	σ bf	σ ts
I-SECTION	124.654	-3.028	166.244	-4.559
Model A	91.241	-3.405	110.084	-3.803
Model B	89.935	-3.443	108.937	-3.957
Model C	61.9	-2.706	77.763	-3.006
Model D	56.041	-2.616	68.176	-2.998

Table 17: Longitudinal normal stresses in the bottom flange and concrete deck slab for girders of span 30m (N/mm²) (with end bracings only) with (L/R=0.2)

Girder / L/R ratio	G1		G4	
0.2	σ bf	σ ts	σ bf	σ ts
I-SECTION	185.146	-4.439	222.719	-5.643
Model A	108.323	-3.958	137.104	-4.878
Model B	91.587	-3.836	126.327	-4.793
Model C	84.546	-3.422	102.863	-3.849
Model D	72.6354	-3.257	88.976	-4.118

Table 18: Longitudinal normal stresses in the bottom flange and concrete deck slab for girders of span 30m (N/mm²) (with end bracings only) with (L/R=0.3)

Girder / L/R ratio	G1		G4	
0.3	σ bf	σ ts	σ bf	σ ts
I-SECTION	187.38	-4.503	224.261	-6.732
Model A	105.194	-3.812	138.426	-5.282
Model B	100.476	-3.934	133.708	-5.367
Model C	78.9128	-3.177	112.199	-4.149
Model D	72.1428	-3.342	105.429	-3.88

Table 19: Longitudinal normal stresses in the bottom flange and concrete deck slab for girders of span 30m (N/mm²) (with end bracings only) with (L/R=0.4)

Girder / L/R ratio	G1		G4	
0.4	σ bf	σ ts	σ bf	σ ts
I-SECTION	200.017	-6.039	270.597	-7.505
Model A	126.005	-5.522	179.281	-6.358
Model B	114.237	-4.931	153.712	-5.993
Model C	102.847	-3.563	121.59	-3.799
Model D	80.727	-2.911	101.385	-3.367

Table 20: Longitudinal normal stresses in the bottom flange and concrete deck slab for girders of span 36m (N/mm²) (with 5 mid bracings) with (L/R=0.1)

Girder / L/R ratio	G1		G4	
0.1	σ bf	σ ts	σ bf	σ ts
I-SECTION	93.826	-2.534	127.695	-3.546
Model A	77.149	-3.122	108.119	-4.429
Model B	85.493	-3.315	117.024	-4.509
Model C	53.839	-2.397	71.743	-3.192
Model D	50.482	-2.394	64.417	-3.039

Table 21: Longitudinal normal stresses in the bottom flange and concrete deck slab for girders of span 36m (N/mm²) (with 5 mid bracings) with (L/R=0.2)

Girder / L/R ratio	G1		G4	
0.2	σ bf	σ ts	σ bf	σ ts
I-SECTION	86.433	-3.025	140.077	-3.649
Model A	72.647	-2.621	126.227	-4.826
Model B	78.242	-2.878	130.583	-4.98
Model C	50.171	-2.115	78.192	-3.322
Model D	48.207	-2.68	69.417	-3.086

Table 22: Longitudinal normal stresses in the bottom flange and concrete deck slab for girders of span 36m (N/mm²) (with 5 mid bracings) with (L/R=0.3)

Girder / L/R ratio	G1		G4	
0.3	σ bf	σ ts	σ bf	σ ts
I-SECTION	96.989	-1.984	209.378	-6.705
Model A	51.618	-2.146	107.174	-7.133
Model B	67.456	-2.637	143.073	-5.66
Model C	53.793	-2.066	104.119	-5.046
Model D	54.805	-2.508	95.249	-4.82

Table 23: Longitudinal normal stresses in the bottom flange and concrete deck slab for girders of span 36m (N/mm²) (with 5 mid bracings) with (L/R=0.4)

Girder / L/R ratio	G1		G4	
0.4	σ bf	σ ts	σ bf	σ ts
I-SECTION	85.536	-1.493	234.082	-5.944
Model A	55.643	-2.472	153.907	-5.9 61
Model B	61.663	-2.179	149.48	-6.245
Model C	52.067	-1.695	117.466	-5.156
Model D	53.562	-2.620	100.498	-4.627

Table 24: Longitudinal normal stresses in the bottom flange and concrete deck slab for girders of span 36m (N/mm²) (with end bracings only) with (L/R=0.1)

Girder / *L/R ratio*	*G1*		*G4*	
0.1	**σ_{bf}**	**σ_{ts}**	**σ_{bf}**	**σ_{ts}**
I-SECTION	139.024	-2.974	166.262	-3.416
Model A	105.364	-3.775	126.115	-4.145
Model B	101.881	-3.784	122.43	-4.296
Model C	70.017	-2.779	82.631	-2.91
Model D	59.153	-2.591	69.357	-2.799

Table 25: Longitudinal normal stresses in the bottom flange and concrete deck slab for girders of span 36 m (N/mm²) (with end bracings only) with (L/R=0.2)

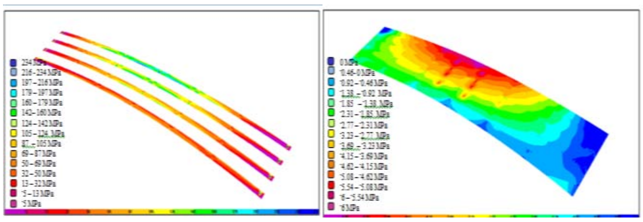
Girder / *L/R ratio*	*G1*		*G4*	
0.2	**σ_{bf}**	**σ_{ts}**	**σ_{bf}**	**σ_{ts}**
I-SECTION	119.563	-2.096	154.889	-3.64
Model A	127.785	-4.211	156.464	-4.977
Model B	113.461	-3.989	142.744	-4.771
Model C	72.358	-2.774	95.403	-2.887
Model D	65.665	-2.509	78.937	-2.702

Table 26: Longitudinal normal stresses in the bottom flange and concrete deck slab for girders of span 36 m (N/mm²) (with end bracings only) with (L/R=0.3)

Girder / *L/R ratio*	*G1*		*G4*	
0.3	**σ_{bf}**	**σ_{ts}**	**σ_{bf}**	**σ_{ts}**
I-SECTION	186.054	-5.828	284.386	-7.227
Model A	151.792	-5.557	191.084	-6.485
Model B	123.012	-4.786	166.356	-6.167
Model C	114.185	-4.128	142.947	-4.423
Model D	91.682	-3.667	115.16	-3.978

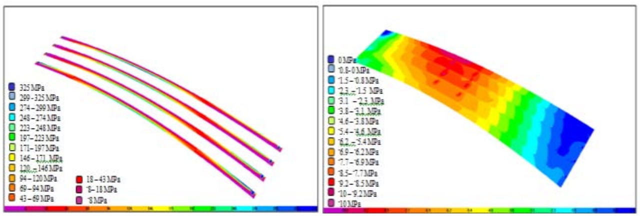
Table 27: Longitudinal normal stresses in the bottom flange and concrete deck slab for girders of span 36 m (N/mm²) (with end bracings only) with (L/R=0.4)

Girder / *L/R ratio*	*G1*		*G4*	
0.4	**σ_{bf}**	**σ_{ts}**	**σ_{bf}**	**σ_{ts}**
I-SECTION	269.547	-7.183	325.323	-8.805
Model A	159.643	-6.511	207.895	-7.436
Model B	128.321	-5.373	177.494	-6.799
Model C	127.75	-4.687	158.938	-4.892
Model D	94.318	-3.663	120.012	-3.909



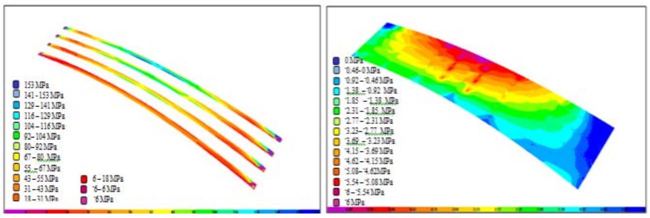
(a) **(b)**

Figure (8): Longitudinal normal stresses (σ) for deck of I-section girders with 5 mid bracings for span 36m (L/R=0.4) in the (a) Bottom flange (b) Deck slab.



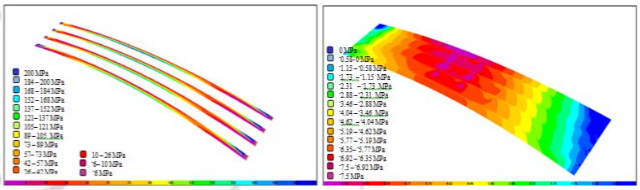
(a) **(b)**

Figure 9: Longitudinal normal stresses (σ) for deck of I-section girders with end bracings for span 36m (L/R=0.4) in the (a) Bottom flange (b) Deck slab



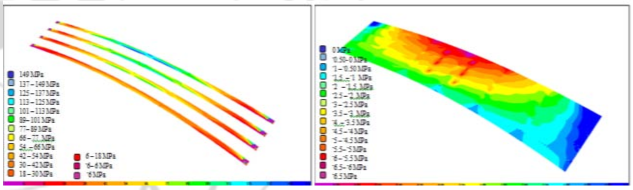
(a) **(b)**

Figure 10: Longitudinal normal stresses (σ) for deck of model A girders with 5mid bracings for span 36m (L/R=0.4) in the (a) Bottom flange (b) Deck slab



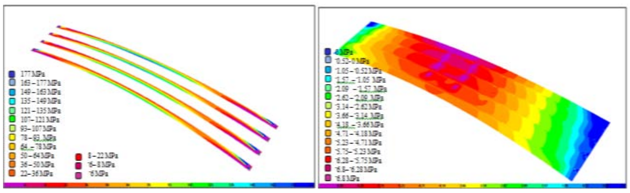
(a) **(b)**

Figure 11: Longitudinal normal stresses (σ) for deck of model A girders with end bracings for span 36m (L/R=0.4) in the (a) Bottom flange (b) Deck slab



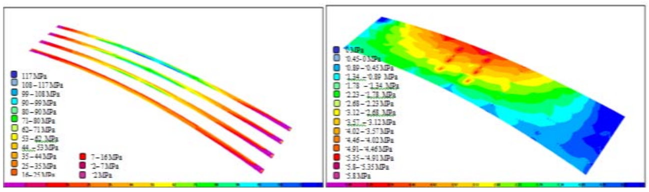
(a) **(b)**

Figure 12: Longitudinal normal stresses (σ) for deck of model B girders with 5mid bracings for span 36m (L/R=0.4) in the (a) Bottom flange (b) Deck slab



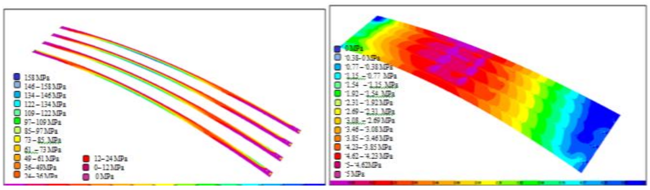
(a) **(b)**

Figure 13: Longitudinal normal stresses (σ) for deck of model B girders with end bracings for span 36m (L/R=0.4) in the (a) Bottom flange (b) Deck slab.



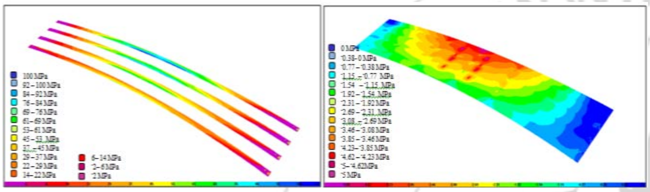
(a) (b)

Figure 14: Longitudinal normal stresses (σ) for deck of model C girders with 5mid bracings for span 36m (L/R=0.4) in the (a) Bottom flange (b) Deck slab



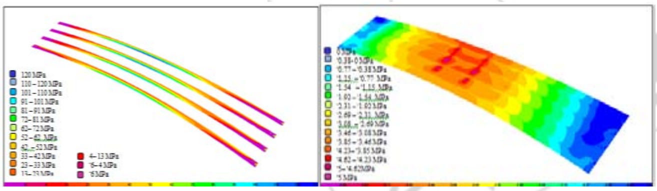
(a) (b)

Figure 15: Longitudinal normal stresses (σ) for deck of model C girders with end bracings for span 36m (L/R=0.4) in the (a) Bottom flange (b) Deck slab.



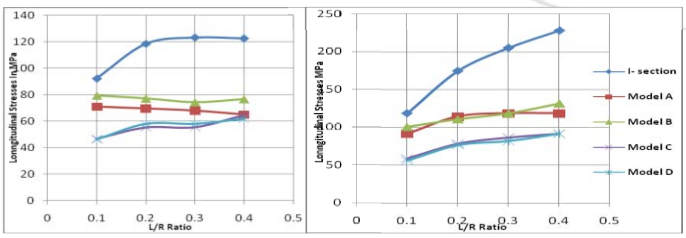
(a) (b)

Figure 16: Longitudinal normal stresses (σ) for deck of model D girders with 5mid bracings for span 36m (L/R=0.4) in the (a) Bottom flange (b) Deck slab.



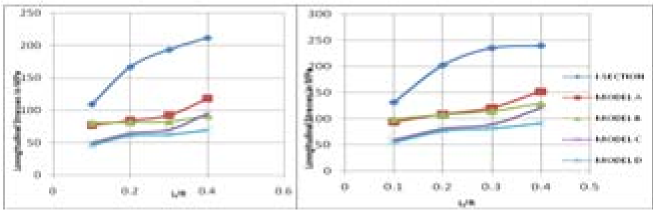
(a) (b)

Figure 17: Longitudinal normal stresses (σ) for deck of model D with end bracings for span 36m (L/R=0.4) in the (a) Bottom flange (b) Deck slab.



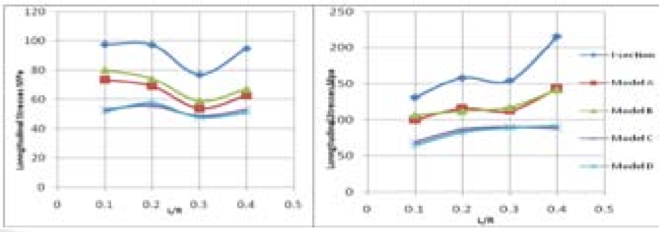
(a) (b)

Figure 18: Longitudinal normal stresses (σ) versus L/R ratio for all proposed models and I-section with 2mid bracings for span 24m (a) Interior girder (G1) (b) Exterior girder (G4)



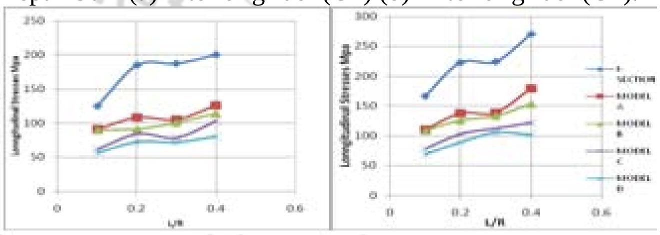
(a) (b)

Figure 19: Longitudinal normal stresses (σ) versus L/R ratio for all proposed models and I-section with end bracings only for span 24m (a) Interior girder (G1) (b) Exterior girder (G4)



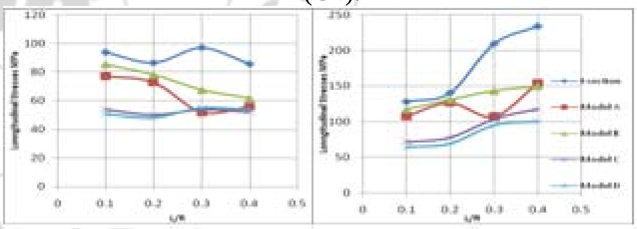
(a) (b)

Figure 20: Longitudinal normal stresses (σ) versus L/R ratio for all proposed models and I-section with 4 mid bracings for span 30m (a) Interior girder (G1) (b) Exterior girder (G4).



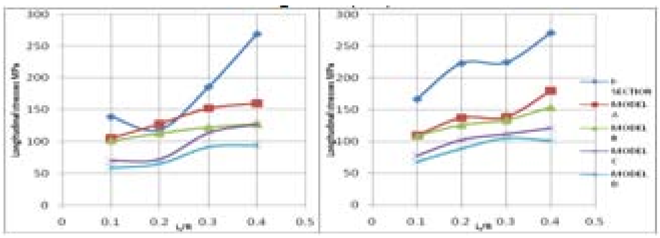
(a) (b)

Figure 21: Longitudinal normal stresses (σ) –L/R ratio for all proposed models and I-section with end bracings only for span 30m (a) Interior girder (G1) (b) Exterior girder (G4).



(a) (b)

Figure 22: Longitudinal normal stresses (σ) versus L/R ratio for all proposed models and I-section with 5mid bracings for span 36m (a) Interior girder (G1) (b) Exterior girder (G4).



(a) (b)

Figure 23: Longitudinal normal stresses (σ) versus L/R ratio for all proposed models and I-section with end bracings only for span 36m (a) Interior girder (G1) (b) Exterior girder (G4).

4.2.2Vertical Displacements

From the parameters above the vertical displacements will be found in the vertical direction at the bottom of the girder. All these results are measured in the mid span for the interior and exterior girders. Tables (28) to (33) show the vertical displacement for all parameters. The results show that the vertical displacement for I-section, model A and model B show large displacement than model C and D because of the presence of concrete in the tube gives the stability and stiffness to the girder and thus to the whole system. Figure (24) and (25) show the distribution of vertical displacements in the bottom of I-section and proposed model D for the span length (36m) with (L/R=0.4). Figures (26) to Figure (31) show the vertical displacements versus L/R ratio in the bottom flange of I-section and the proposed models.

Table 28: Vertical displacement (mm) in mid span of girders for span 24m (with 2 mid bracings)

(L/R=0.1)			(L/R=0.2)		
Section Type	Girder		Section Type	Girder	
	G1	G4		G1	G4
I-section	-33.465	-46.272	I-section	-41.426	-70.15
Model A	-44.833	-63.001	Model A	-45.662	-78.17
Model B	-48.226	-65.440	Model B	-53.112	-83.88
Model C	-26.120	-35.443	Model C	-31.092	-50.88
Model D	-24.906	-32.310	Model D	-33.047	-49.60
(L/R=0.3)			(L/R=0.4)		
Section Type	Girder		Section Type	Girder	
	G1	G4		G1	G4
I-section	-41.637	-81.816	I-section	-41.403	-91.26
Model A	-46.625	-93.333	Model A	-47.078	-106.4
Model B	-57.059	-102.93	Model B	-61.037	-120.5
Model C	-30.612	-58.043	Model C	-32.434	-70.88
Model D	-32.389	-54.810	Model D	-31.324	-58.60

Table 29: Vertical displacement (mm) in mid span of girders for span 24m (with end bracings)

(L/R=0.1)			(L/R=0.2)		
Section Type	Girder		Section Type	Girder	
	G1	G4		G1	G4
I-section	-41.609	-56.527	I-section	-69.790	-107.77
Model A	-49.329	-65.627	Model A	-59.651	-90.694
Model B	-50.636	-66.376	Model B	-68.709	-79.263
Model C	-27.457	-35.766	Model C	-36.896	-54.519
Model D	-25.234	-32.148	Model D	-34.934	-50.043
(L/R=0.3)			(L/R=0.4)		
Section Type	Girder		Section Type	Girder	
	G1	G4		G1	G1
I-section	-87.649	-142.96	I-section	-101.53	-170.34
Model A	-72.130	-119.53	Model A	-84.201	-147.87
Model B	-71.888	-115.97	Model B	-82.912	-141.48
Model C	-40.785	-66.206	Model C	-50.319	-87.808
Model D	-35.713	-56.282	Model D	-36.054	-61.434

Table 30: Vertical displacement (mm) in mid span of girders for span 30m (with 4 mid bracings)

(L/R=0.1)			(L/R=0.2)		
Section Type	Girder		Section Type	Girder	
	G1	G4		G1	G4
I-section	-44.409	-62.705	I-section	-47.62	-84.315
Model A	-52.305	-75.047	Model A	-52.146	-95.271
Model B	-55.553	-77.293	Model B	-58.25	-97.33
Model C	-34.350	-47.915	Model C	-37.427	-66.293
Model D	-34.279	-45.566	Model D	-41.011	-67.187
(L/R=0.3)			(L/R=0.4)		
Section Type	Girder		ection Type	Girder	
	G1	G4		G1	G4
I-section	-40.693	-88.815	I-section	-45.387	-109.96
Model A	-43.329	-98.279	Model A	-50.008	-126.95
Model B	-45.321	-133.69	Model B	-61.973	-139.12
Model C	-31.711	-68.872	Model C	-33.088	-77.295
Model D	-30.123	-67.421	Model D	-34.644	-70.327

Table 31: Vertical displacement (mm) in mid span of girders for span 30m (with end bracings)

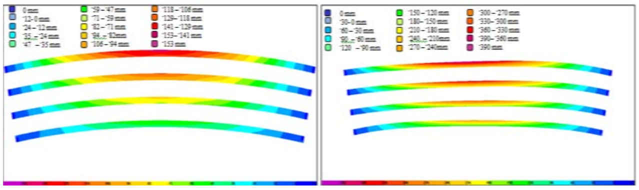
(L/R=0.1)			(L/R=0.2)		
Section Type	Girder		Section Type	Girder	
	G1	G4		G1	G4
I-section	-63.004	-85.662	I-section	-103.42	-154.11
Model A	-61.671	-81.094	Model A	-82.134	-122.90
Model B	-61.828	-80.126	Model B	-79.874	-117.21
Model C	-38.517	-49.671	Model C	-53.694	-78.356
Model D	-36.085	-45.525	Model D	-50.131	-71.396
(L/R=0.3)			(L/R=0.4)		
Section Type	Girder		Section Type	Girder	
	G1	G4		G1	G1
I-section	-129.49	-202.84	I-section	-166.11	-261.54
Model A	-92.197	-150.14	Model A	-128.71	-212.86
Model B	-86.240	-149.22	Model B	-118.41	-192.72
Model C	-58.325	-92.718	Model C	-64.881	-104.79
Model D	-56.348	-89.541	Model D	-50.035	-80.090

Table 32: Vertical displacement (mm) in mid span of girders for span 36m (with 5 mid bracings)

(L/R=0.1)			(L/R=0.2)		
Section Type	Girder		Section Type	Girder	
	G1	G4		G1	G4
I-section	-51.871	-72.722	I-section	-45.94	-78.13
Model A	-64.875	-95.102	Model A	-59.041	-111.63
Model B	-68.681	-97.492	Model B	-64.833	-115.10
Model C	-41.208	-57.572	Model C	-37.313	-63.684
Model D	-39.331	-52.340	Model D	-36.162	-56.672
(L/R=0.3)			(L/R=0.4)		
Section Type	Girder		Section Type	Girder	
	G1	G4		G1	G1
I-section	-61.235	-135.50	I-section	-58.706	-153.98
Model A	-63.308	-148.82	Model A	-60.477	-169.91
Model B	-72.726	-156.91	Model B	-71.508	-177.44
Model C	-45.165	-99.374	Model C	-43.685	-113.01
Model D	-47.030	-92.240	Model D	-64.430	-97.458

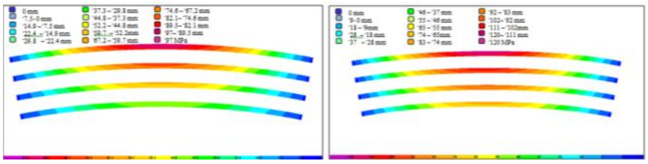
Table 33: Vertical displacement (mm) in mid span of girders for span 36m (with end bracings)

(L/R=0.1)			(L/R=0.2)		
Section Type	Girder		Section Type	Girder	
	G1	G4		G1	G4
I-section	-76.465	-101.37	I-section	-95.234	-131.83
Model A	-80.437	-105.71	Model A	-102.31	-151.20
Model B	-79.398	-102.42	Model B	-94.873	-137.20
Model C	-47.806	-60.774	Model C	-53.849	-74.768
Model D	-42.339	-52.574	Model D	-44.139	-59.805
(L/R=0.3)			(L/R=0.4)		
Section Type	Girder		Section Type	Girder	
	G1	G4		G1	G1
I-section	-202.69	-298.14	I-section	-262.80	-395.92
Model A	-158.53	-247.98	Model A	-197.34	-315.55
Model B	-142.99	-221.24	Model B	-175.31	-278.59
Model C	-92.578	-139.85	Model C	-106.14	-181.69
Model D	-72.845	-108.67	Model D	-77.4	-122.57



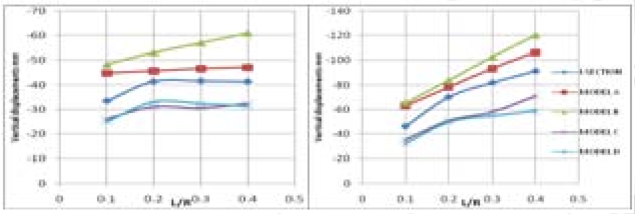
(a) (b)

Figure 24: distribution of vertical displacements in the bottom flange of I-section for the span length (36m) (L/R=0.4) with (a) 5mid bracings (b) End bracings.



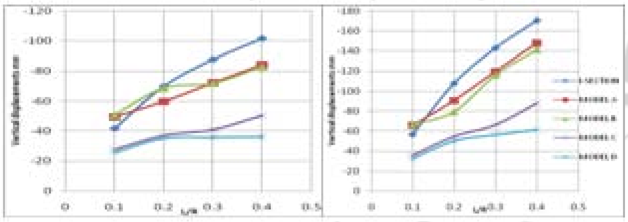
(a) (b)

Figure 25: Distribution of vertical displacements in the bottom flange of model D for the span length (36m) (L/R=0.4) with (a) 5mid bracings (b) End bracings.



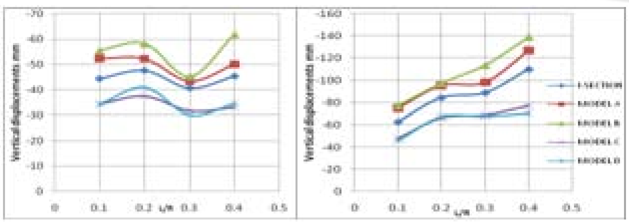
(a) (b)

Figure (26): Vertical displacements versus L/R ratio for all proposed models and I-section with 2mid bracings for span 24m (a) Interior girder (G1) (b) Exterior girder (G4).



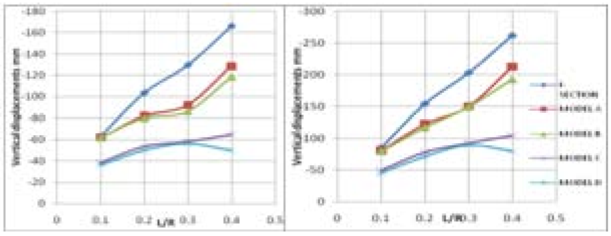
(a) (b)

Figure 27: Vertical displacements versus L/R ratio for all proposed models and I-section with end bracings only for span 24m (a) Interior girder (G1) (b) Exterior girder (G4).



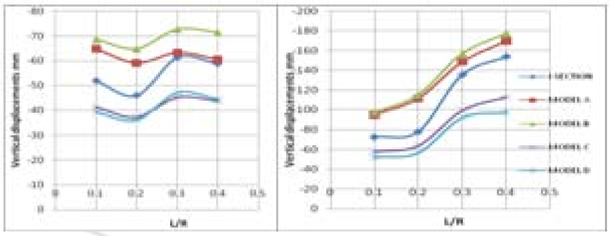
(a) (b)

Figure 28: Vertical displacements versus L/R ratio for all proposed models and I-section with 4 mid bracings for span 30m (a) Interior girder (G1) (b) Exterior girder (G4).



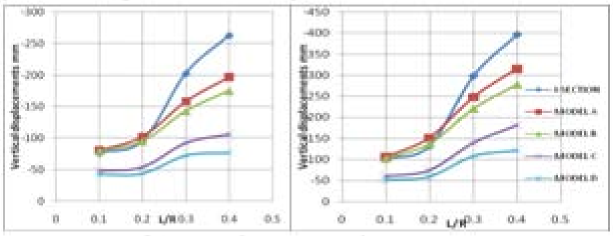
(a) (b)

Figure 29: Vertical displacements versus L/R ratio for all proposed models and I-section with end bracings only for span 30m (a) Interior girder (G1) (b) Exterior girder (G4).



(a) (b)

Figure 30: Vertical displacements versus L/R ratio for all proposed models and I-section with 5mid bracings for span 36m (a) Interior girder (G1) (b) Exterior girder (G4).



(a) (b)

Figure 31: Vertical displacements versus L/R ratio for all proposed models and I-section with end bracings only for span 36m (a) Interior girder (G1) (b) Exterior girder (G4).

4.3 Comparative Study

Tables (34) to **(36)** show the ratio of longitudinal tensile stresses in the bottom flange and compressive stresses in concrete deck slab for the I-section and proposed models between decks modeled with different number of cross bracing. These results are measured at mid span.

Table 34: Span 24m

(L/R=0.1)					
Ratio Of (σ_{Bf}) With(Additional Mid / End) Bracings	**G1 %**	**G4 %**	**Ratio Of (σ_{ts}) (Additional Mid / End) Bracings**	**G1 %**	**G4 %**
I-section	84.16	90.03	**I-section**	88.8	99.3
Model A	92.00	97.33	**Model A**	90.0	102.3
Model B	97.92	101.3	**Model B**	97.1	103.1
Model C	94.09	98.38	**Model C**	97.4	101.2
Model D	100.2	102.1	**Model D**	99.3	101.7
(L/R=0.2)					
Ratio Of (σ_{Bf}) With(Additional Mid / End) Bracings	**G1 %**	**G4 %**	**Ratio Of (σ_{ts}) (Additional Mid / End) Bracings**	**G1 %**	**G4 %**
I-section	70.95	86.47	**I-section**	69.8	86.3
Model A	82.33	105.2	**Model A**	74.8	94.4
Model B	94.25	102.7	**Model B**	84.8	100.1

Model C	85.77	96.68	**Model C**	89.5	95.9
Model D	95.82	100.6	**Model D**	92.4	98.6

(L/R=0.3)					
Ratio Of (σ_{Bf}) With(Additional Mid / End) Bracings	**G1 %**	**G4 %**	**Ratio Of (σ_{ts}) (Additional Mid / End) Bracings**	**G1 %**	**G4 %**
I-section	63.67	87.48	I-section	56.6	78.9
Model A	73.49	95.75	Model A	61.1	87.1
Model B	89.64	103.7	Model B	71.7	95.6
Model C	79.24	96.62	Model C	76.0	95.6
Model D	92.96	100.8	Model D	87.2	101.1
(L/R=0.4)					
Ratio Of (σ_{Bf}) With(Additional Mid / End) Bracings	**G1 %**	**G4 %**	**Ratio Of (σ_{ts}) (Additional Mid / End) Bracings**	**G1 %**	**G4 %**
I-section	57.84	95.47	**I-section**	46.4	70.9
Model A	54.82	81.89	**Model A**	49.8	82.3
Model B	83.32	101.7	**Model B**	59.4	92.4
Model C	68.04	91.23	**Model C**	69.4	91.1
Model D	89.09	100.5	**Model D**	83.3	100.5

Table 35: Span 30m

(L/R=0.1)					
Ratio Of (σ_{Bf}) With(Additional Mid / End) Bracings	**G1 %**	**G4 %**	**Ratio Of (σ_{ts}) (Additional Mid / End) Bracings**	**G1 %**	**G4 %**
I-section	78.25	78.96	**I-section**	86.5	80.9
Model A	80.51	90.77	**Model A**	85.7	105.5
Model B	89.27	98.21	**Model B**	90.5	105.0
Model C	86.17	89.68	**Model C**	89.0	106.7
Model D	92.81	95.88	**Model D**	94.8	104.9
(L/R=0.2)					
Ratio Of (σ_{Bf}) With(Additional Mid / End) Bracings	**G1 %**	**G4 %**	**Ratio Of (σ_{ts}) (Additional Mid / End) Bracings**	**G1 %**	**G4 %**
I-section	52.55	71.18	**I-section**	57.9	80.7
Model A	63.74	84.94	**Model A**	63.4	92.5
Model B	81.11	89.05	**Model B**	75.0	97.5
Model C	65.95	84.15	**Model C**	71.0	104.4
Model D	79.51	93.33	**Model D**	84.9	101.2
(L/R=0.3)					
Ratio Of (σ_{Bf}) With(Additional Mid / End) Bracings	**G1 %**	**G4 %**	**Ratio Of (σ_{ts}) (Additional Mid / End) Bracings**	**G1 %**	**G4 %**
I-section	41.14	68.91	**I-section**	39.6	65.4
Model A	51.34	81.42	**Model A**	47.4	79.3
Model B	58.97	88.21	**Model B**	49.0	79.7
Model C	61.82	80.05	**Model C**	56.9	90.9
Model D	66.14	84.17	**Model D**	59.0	90.2
(L/R=0.4)					
Ratio Of (σ_{Bf}) With(Additional Mid / End) Bracings	**G1 %**	**G4 %**	**Ratio Of (σ_{ts}) (Additional Mid / End) Bracings**	**G1 %**	**G4 %**
I-section	47.37	79.70	**I-section**	29.9	65.2
Model A	49.76	80.15	**Model A**	35.3	77.1
Model B	58.78	92.40	**Model B**	48.7	86.6
Model C	51.54	72.54	**Model C**	47.8	97.9

Model D	63.02	90.35	**Model D**	69.8	103.8

Table 36: Span 36m

(L/R=0.1)					
Ratio Of (σ_{Bf}) With(Additional Mid / End) Bracings	**G1 %**	**G4 %**	**Ratio Of (σ_{ts}) (Additional Mid / End) Bracings**	**G1 %**	**G4 %**
I-section	67.5	76.8	**I-section**	85.2	103.8
Model A	73.2	85.7	**Model A**	82.7	106.9
Model B	83.9	95.6	**Model B**	87.6	105.0
Model C	76.9	86.8	**Model C**	86.3	109.7
Model D	85.3	92.9	**Model D**	92.4	108.6
(L/R=0.2)					
Ratio Of (σ_{Bf}) With(Additional Mid / End) Bracings	**G1 %**	**G4 %**	**Ratio Of (σ_{ts}) (Additional Mid / End) Bracings**	**G1 %**	**G4 %**
I-section	72.3	90.4	**I-section**	144.3	100.2
Model A	56.9	80.7	**Model A**	62.2	97.0
Model B	69.0	91.5	**Model B**	72.1	104.4
Model C	69.3	82.0	**Model C**	76.2	115.1
Model D	73.4	87.9	**Model D**	106.8	114.2
(L/R=0.3)					
Ratio Of (σ_{Bf}) With(Additional Mid / End) Bracings	**G1 %**	**G4 %**	**Ratio Of (σ_{ts}) (Additional Mid / End) Bracings**	**G1 %**	**G4 %**
I-section	52.1	73.6	**I-section**	34.0	92.8
Model A	34.0	56.1	**Model A**	38.6	110.0
Model B	54.8	86.0	**Model B**	55.1	91.8
Model C	47.1	72.8	**Model C**	50.0	114.1
Model D	59.8	82.7	**Model D**	68.4	121.2
(L/R=0.4)					
Ratio Of (σ_{Bf}) With(Additional Mid / End) Bracings	**G1 %**	**G4 %**	**Ratio Of (σ_{ts}) (Additional Mid / End) Bracings**	**G1 %**	**G4 %**
I-section	31.7	72.0	**I-section**	20.8	67.5
Model A	34.9	74.0	**Model A**	38.0	80.2
Model B	48.1	84.2	**Model B**	40.6	91.9
Model C	40.8	73.9	**Model C**	36.2	105.4
Model D	56.8	83.7	**Model D**	71.5	118.4

Tables (37) to **(39)** show the ratio of vertical displacement in the mid span of I-section and proposed models between decks modeled with different number of cross bracings.

Table (37): Span 24m

(L/R=0.1)			**(L/R=0.2)**		
Ratio Of Vertical Displacement With (Additional Mid Bracings / End Bracings) For	G1 %	G4 %	Ratio Of Vertical Displacement With (Additional Mid Bracings / End Bracings) For	G1 %	G4 %
I-section	80.4	81.9	**I-section**	59.4	65.1
Model A	90.9	96.0	**Model A**	76.5	86.2
Model B	95.2	98.6	**Model B**	77.3	105.8
Model C	95.1	99.1	**Model C**	84.3	93.3
Model D	98.7	100.5	**Model D**	94.6	99.1
(L/R=0.3)			**(L/R=0.4)**		
Ratio Of Vertical Displacement With (Additional Mid Bracings / End Bracings) For	G1 %	G4 %	Ratio Of Vertical Displacement With (Additional Mid Bracings / End Bracings) For	G1 %	G4 %
I-section	47.5	57.2	**I-section**	40.8	53.6
Model A	64.6	78.1	**Model A**	55.9	72.0

Model B	79.4	88.8	**Model B**	73.6	85.2
Model C	75.1	87.7	**Model C**	64.5	80.7
Model D	90.7	97.4	**Model D**	86.9	95.4

Table 38: Span 30m

(L/R=0.1)			**(L/R=0.2)**		
Ratio Of Vertical Displacement With(Additional Mid Bracings / End Bracings) For	G1 %	G4 %	Ratio Of Vertical Displacement With(Additional Mid Bracings / End Bracings) For	G1 %	G4 %
I-section	70.5	73.2	**I-section**	46.0	54.7
Model A	84.8	92.5	**Model A**	63.5	77.5
Model B	89.9	96.5	**Model B**	72.9	83.0
Model C	89.2	96.5	**Model C**	69.7	84.6
Model D	95.0	100	**Model D**	81.8	94.1
(L/R=0.3)			**(L/R=0.4)**		
Ratio Of Vertical Displacement With (Additional Mid Bracings / End Bracings) For	G1 %	G4 %	Ratio Of Vertical Displacement With (Additional Mid Bracings / End Bracings) For	G1 %	G4 %
I-section	31.4	43.8	**I-section**	27.3	42.0
Model A	47.0	65.5	**Model A**	38.9	59.6
Model B	52.6	76.2	**Model B**	52.3	72.2
Model C	54.4	74.3	**Model C**	51.0	73.8
Model D	53.5	75.3	**Model D**	69.2	87.8

Table 39: Span 36m

(L/R=0.1)			**(L/R=0.2)**		
Ratio Of Vertical Displacement With (Additional Mid Bracings / End Bracings) For	G1 %	G4 %	Ratio Of Vertical Displacement With (Additional Mid Bracings / End Bracings) For	G1 %	G4 %
I-section	67.8	71.7	**I-section**	48.2	59.3
Model A	80.7	90.0	**Model A**	57.7	73.8
Model B	86.5	95.2	**Model B**	68.3	83.9
Model C	86.2	94.7	**Model C**	69.3	85.2
Model D	92.9	99.6	**Model D**	81.9	94.8
(L/R=0.3)			**(L/R=0.4)**		
Ratio Of Vertical Displacement With (Additional Mid Bracings / End Bracings) For	G1 %	G4 %	Ratio Of Vertical Displacement With (Additional Mid Bracings / End Bracings) For	G1 %	G4 %
I-section	30.2	45.4	**I-section**	22.3	38.9
Model A	39.9	60.0	**Model A**	30.6	53.4
Model B	50.9	70.9	**Model B**	40.8	63.8
Model C	48.8	71.1	**Model C**	41.2	62.4
Model D	64.6	84.9	Model D	83.2	79.9

5. Conclusions

1) The proposed finite element models used for predicting the behavior of the new types of steel girders system in curved simply supported composite decks using SAP2000 v.14 have proved their efficiency in analyses of such types of bridges.
2) The proposed new models of steel girders system show good strength in torsion compared to the typical I-section. The maximum gained strength (in stresses and deflections) is with model D of trapezoidal bottom flange shape filled with concrete.
3) The parametric study was to verify the behavior of proposed models compared to that of I section girders with the same geometry and loading conditions and the conclusions derived from this parametric study are:

5.1 Maximum enhancement ratio of tensile stresses in bottom flange for each proposed model and typical I-section is:

- (47.7%) for model A and typical I-section for span 24m with (L/R=0.3) and with end bracings only.
- (42.76%) for model B and typical I-section for span 24m with (L/R=0.3) and with end bracings only.
- (36.12%) for model C and typical I-section for span 24m with (L/R=0.3) and with end bracings only.
- (32.17%) for model D and typical I-section for span 24m with (L/R=0.3) and with end bracings only.

5.2. Maximum enhancement ratio for vertical displacement is:

- (71.2%) for model A and typical I-section for span 30m with (L/R=0.3) and with end bracings only.
- (66.6%) for model B and typical I-section for span 30m with (L/R=0.3) and with end bracings only.
- (39.1%) for model C and typical I-section for span 30m with (L/R=0.4) and with end bracings only.
- (29.5%) for model D and typical I-section for span 36m with (L/R=0.4) and with end bracings only.

5.3. The maximum percentage of increase of tensile stresses of bottom flange between girders with mid bracings and those with end bracings only is in girder model A with value (34%) for span 36m with (L/R=0.3).

5.4. The maximum percentage of increase of vertical displacements between girders with mid bracings and those with end bracings only is in girder model A with value (30.6%) for span 36m with (L/R=0.4).

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