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THREE-DIMENSIONAL ANALYSIS OF GIRDER CROSS-SECTION SHAPES EFFECTS ON STATIC PROPERTIES OF BRIDGES MODELS

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Abstract: *The aim of this study is to select the suitable shape of girder cross section that is used in the design of bridges structure, and to evaluate the effect of cross section shape of bridges girders on the static properties such as vertical displacement, vertical shear force, bending moment, tension stress and compressive stresses.*

Ten bridges models using different types and shapes of girders were used to study the effect of girder cross section shape in the construction of bridges by adopting static analysis.

The results of finite element analysis showed that the bridges models of separated concrete deck over girders have higher value of vertical displacement, positive bending moment, and tensile stress. These models are not suitable for design of bridges that subjected to higher traffic loads because of these bridges structures will not have enough stiffness and higher carrying capacity. Therefore, they will fail under heavy traffic loads. These models include flat slab bridge model, T-girder bridge model, I-girder bridge model, and steel I-girder bridge model. Most box girders bridge models appeared the lower values of vertical displacement, positive bending moment, and tensile stress. Therefore, these models will have enough stiffness and carrying capacity and they will be more elasticity from others models.

This study recommended that using the box girders bridges models in the construction of new bridges structure that have high traffic loads.

Keywords: bridge, moment, cross-section shape, static, stress, vertical displacement

1. INTRODUCTION

Bridges are structures provided that passageway over a barrier without closing the way underneath. The necessary passageway may be for highways, pedestrians, railways, and waterways such as rivers. Therefore, bridges are important part of the transportation system. The volumes and the weights of the vehicles traffic carried by the transportation system can be controlled by the bridges capacity. Generally, bridge structure consists of concrete deck, girders, bearings, cap beam, piers, abutments, and foundation. (Meshrama and Ramtekeb, 2015, Mary et al, 2012, TDT, 2001)

Prestressed concrete consists of concrete material, reinforced steel, and prestressed tendons that is introduced the stresses to concrete to the suitable limit. There are two types of prestressing, pre-tension and post-tension. The main advantages of prestressed concrete structure is delaying cracks, saving materials, reduction of vertical deflection, protraction of steel from corrosion, increasing the durability, has higher stiffness, increasing the shear capacity, modifying the resilience of structure under dynamic and fatigue

loading. After appearing prestressed concrete, it has been widely and increasingly used in long span structures such as bridges with different type of girders depending on the shape of girder such as box girders (different types according shape), T-girder, I-girder, and I-steel girder with prestressed concrete deck. (Concrete Construction, 2016, Suraj, 2006)

Recently, prestressed concrete box girders are widely used in the construction of freeways and bridge structures due to their structural efficiency, good stability, serviceability, construction economy and pleasing aesthetics. However, for analysis and design, box girder bridges are very complex due to its three dimensional behaviors that consist of torsion, distortion and bending in longitudinal and transverse directions. According to the method of construction, the use, and cross section shapes, box girders can be erected as single cell, double cell or multi-cell, rectangular, trapezoidal and circular. The box girder web can be classified as vertical, inclined, and curved which help to reduce the width of the bottom flange. (Laxmi, 2013, Negrao and Simoes, 1999)

The using of prestressed concrete decks over different types of precast girders such as T-girder, I-girder, and I-steel girder are commonly used for bridges construction. The spans length of bridges ranges between 25m and 450m. Therefore, it can provide economic, durable and aesthetic solutions in most situations where bridges are needed. (Nigel, 2003)

The main objective of structural analysis is to assess the static responses of a structure and to find the distribution of internal forces system such as vertical displacement, tension and compressive stresses. Depending on the different applied loads, a linear elastic model is assumed in the structural analysis. The finite element method (FEM) is a suitable implement to solve differential equations for the structural engineering applications. (Mattias, 2012, CSI, 2006)

Static analysis of bridge structure is very important type of analysis. The different types of loads (deck load, prestressed tendons load, temperature load, and static traffic load (vehicle load), are applied without dynamical influences (without moving of vehicles), while, dynamic analysis consists of three types of analysis (without moving load, with tested vehicles load, and with all traffic loads types (service loads)) .(CSI, 2010, Meshrama and Ramtekeb, 2015)

Pindado et al, 2005 used experimental analysis by testing different types of box girder shapes of bridge cross-sections to analyze the yawing moment that was acted on the box-girder deck of reinforced concrete bridges built by using the balanced cantilever method during the erection stage. The results of experimental analysis showed that the coefficient of yawing moment was decreased when the bridge decks become streamlined. When the bridge deck length is nearly twice the deck width, the coefficient of yawing moment was reached the maximum value.

Yuh et al (2005) investigated the effect of deck dimensions and approaching turbulence on the flutter and buffeting behavior of cable-supported bridges by using wind tunnel section model test. They used closed box girder model and plate girder model in their study. The results of analysis showed that the width-to-depth ratio (B/H) of bridge deck plays a significant function in bridge aerodynamics. The bridge stability was improved by increasing the width-to-depth ratio (B/H).

Chirag and Kumar, 2014 explained the effect of changing the basic shape of bridge cross section girder on the stability of the bridge structure by using different lengths of the over-hanging beam section and increasing the thickness of the joints. According to the results of analysis, they found that the increasing in thickness at the fixed end of the cantilever beam leads to increase the thickness at the bottom most portion of the box structure and sloping edges. It provided more thickness at the fixed portions and also it reduced the stress acting on the entire span of the beam. The useful of this state is to reduce the bending moment acting at the fixed end and the beam becomes more stable.

Tiger and Khadiranaikar, 2015 studied the effect of box girder shape on the static bending moment, shear force and vertical deflection for two models of box girder. The first model used four-cell rectangular box girder and the second model used four-cell trapezoidal box girder. They found that the vertical displacement

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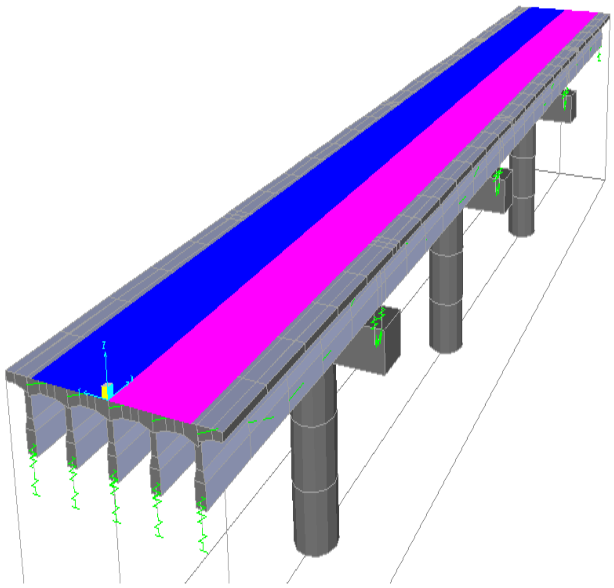
of rectangular box girder is increased by 30% compared with trapezoidal box girder for combined load case (DL+LL+Prestress). Shear force was increased by 11% in rectangular girder compare with trapezoidal box girder in combined load case. The shear stresses are 18% more in trapezoidal box girder because of the area is reduced in trapezoidal section but the stresses are still within allowable limit.

The aim of this study is to optimize the suitable shape of girder cross section that is using in the design of bridge structure, and to evaluate the effect of cross section shape of prestressed concrete bridge girders on the static parameters such as vertical displacement, vertical shear force, bending moment, tension stress and compressive stresses.

2. BRIDGES MODELS OF FINITE ELEMENT ANALYSIS

Ten bridges models are adopted in this study depending on the shape of bridges girders cross section. The spans lengths of bridges models are same and the bridges models are designed to have four spans (15m+20m+20m+15m). The width of cross section for each model is 10m and each bridge model has two lanes. The input data in the analysis of bridges models, such as dimensions of bridge structure (width and height of cross section), traffic loads, prestressed load, and temperature load, are selected to be same for all models because of the results of analysis will be compared for all models to optimize the suitable shape of girder cross section that gives the best results. The substructure components such as abutments, bearings, piers caps, and piers are same for all models. The connection between abutments and girders is using condition of girder bottom only and foundation spring. The piers caps is rectangular shape (1.22m*1.525m) with length is 9.15m. The pier shape is circular with radius is 0.75m.

The bridges models include T-girders shape model (simply supported bridge), I-girder shape model (simply supported bridge), flat slab shape model (continuous bridge), steel I-girder shape (simply supported bridge), box girder with external web clipped shape model (continuous bridge), box girder with external web curved shape model (continuous bridge), box girder with external web vertical shape model (continuous bridge), box girder with external web maximum sloped shape model (continuous bridge), AASHTO-PCI-ASBI standard box girder shape model (continuous bridge), and U-box girder shape model. Finite element analysis is used to analyze the bridges model by adopting static using Sap 2000 Ver. 14.2. Figure 1. shows the bridges models.



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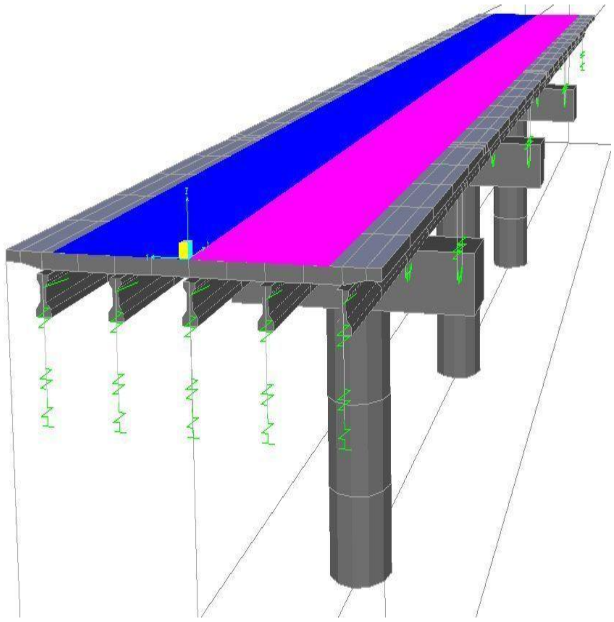

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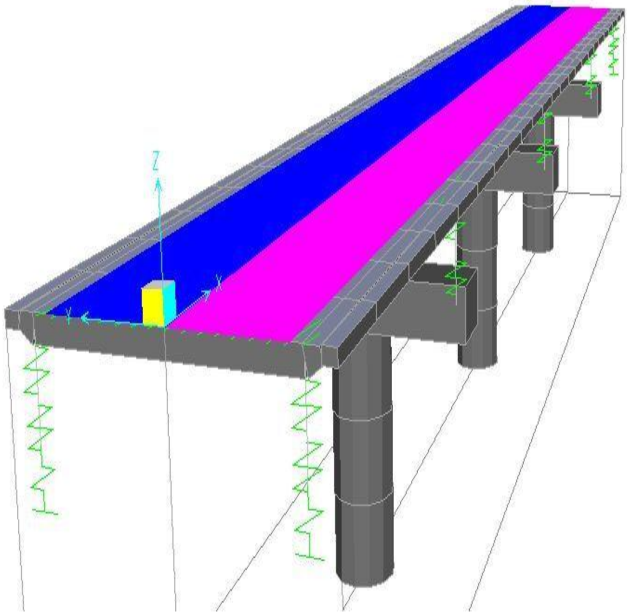

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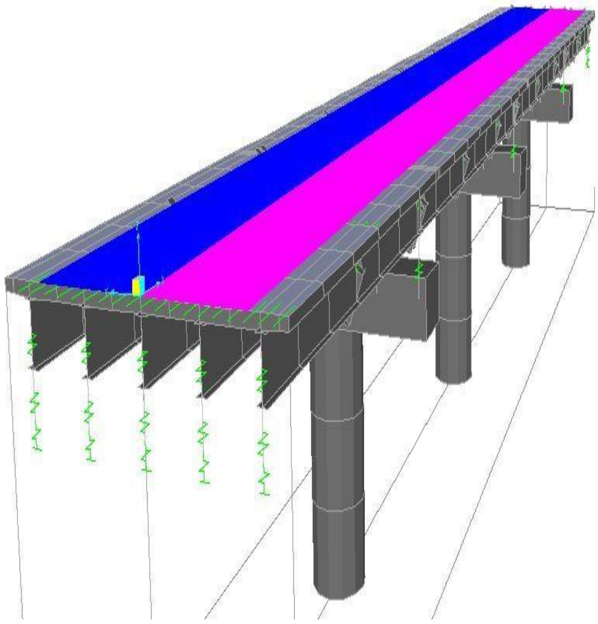

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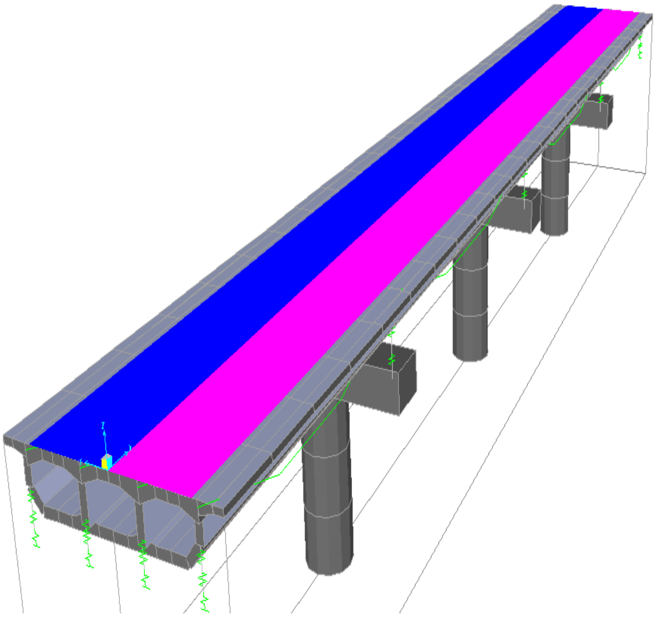

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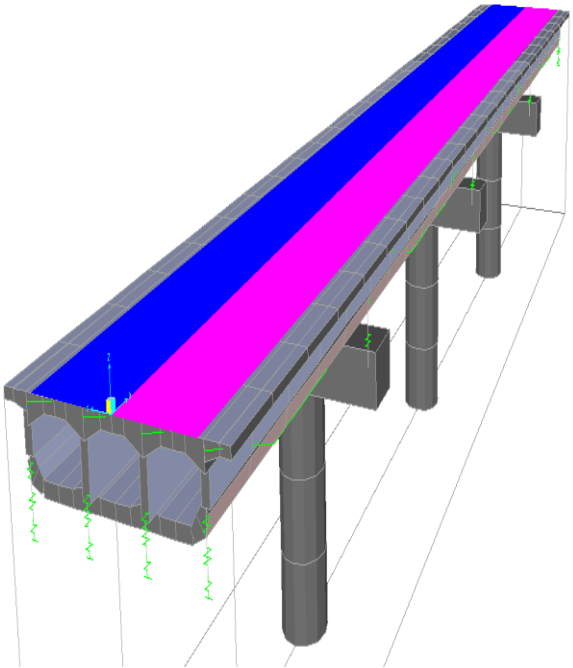

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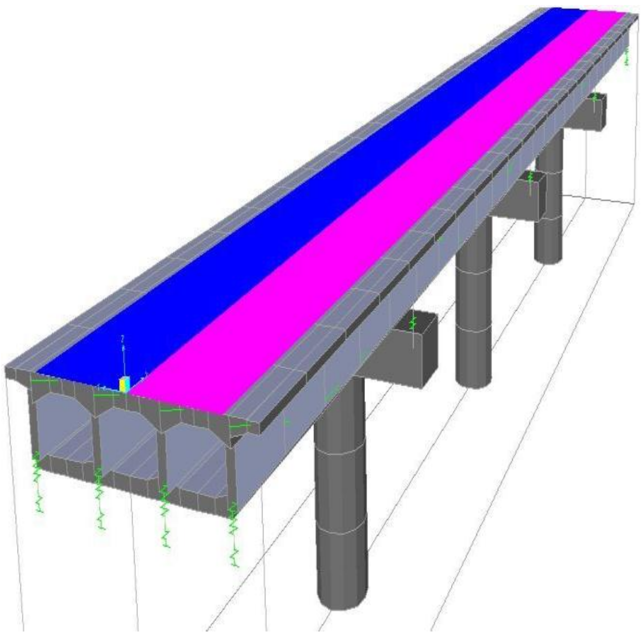

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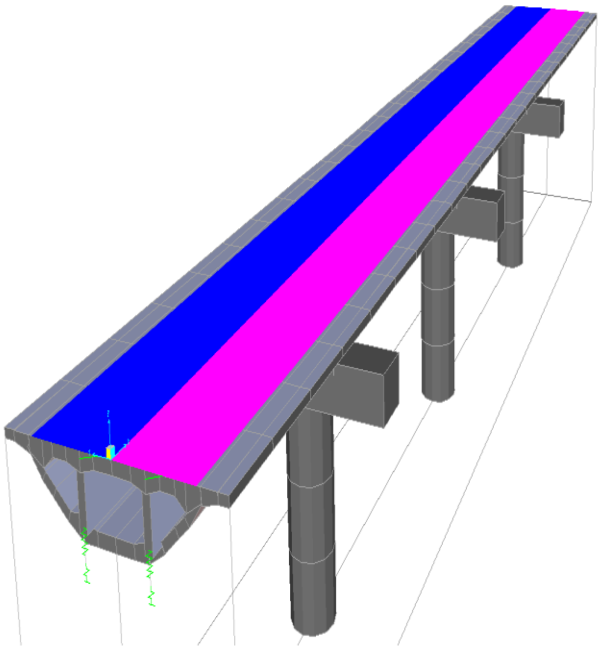

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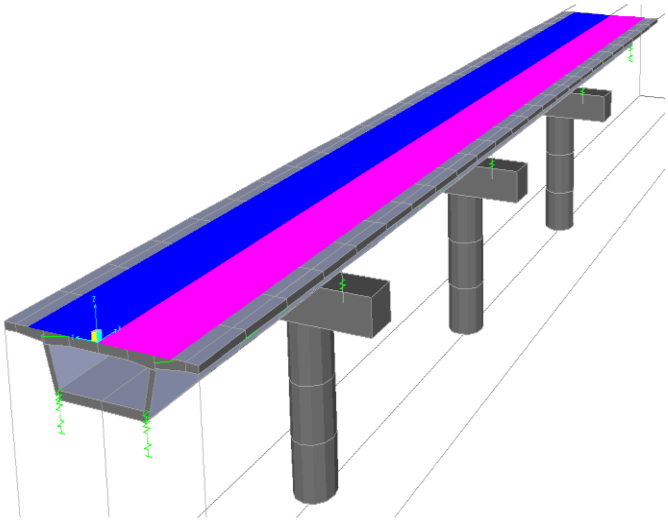

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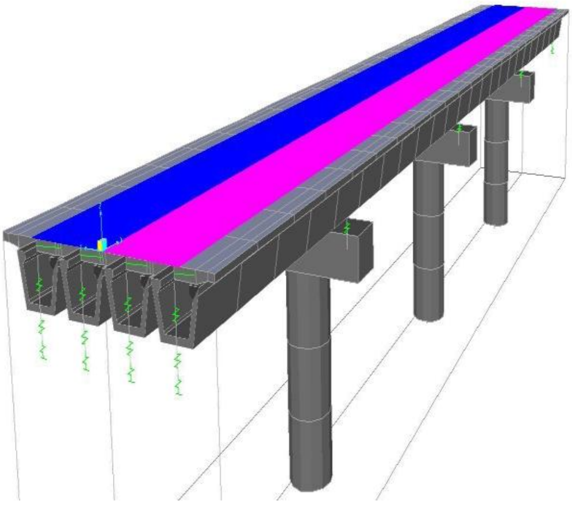

(j)

Figure (1): The bridges models: (a) T-girders shape model, (b) I-girder shape model (precast), (c) flat slab shape model, (d) Steel I-girder shape model, (e) box girder with external web clipped shape model, (f) box girder with external web curved shape model, (g) box girder with external web vertical shape model, (h) box girder with external web maximum sloped shape model, and (i) AASHTO-PCI-ASBI standard box girder shape model, (j) U-box girder model

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3. PROPERTIES OF MATERIALS AND LOADS

Different types of materials are used for modeling analysis. These types include concrete, steel rebar reinforced, steel tendons, and steel girder. Table 1 shows the properties of concrete material. Table 2 shows the properties of steel tendons. Table 3 shows the properties of steel rebar. Table 4 shows the properties of steel girder. The loads of bridges models are applied on the structure are same and consist of dead load of bridge structure (weight of superstructure + weight of substructure), deck load, pedestrian load, pavement load, prestressed load, temperature load, and live load (traffic load). For live load, vehicle type $HS_{20\text{-}44}$ is used in the analysis.

Table (1): Properties of concrete material

Properties of concrete material	Value
Concrete grade	C 40
Weight/volume	23.5631 kN/m^3
Density	2.40 kg/m^3
Modulus of elasticity (E)	32500000 kN/m^2
Shear modulus (G)	13541667 kN/m^2
Factor of thermal expansion (A)	9.90*10^{-6}
Poisson ratio (µ)	0.2
Compressive strength of concrete ($f'c$)	40000 kN/m^2
Directional symmetry type	Isotropic
Ultimate unconfined strain capacity	5*10-3
Strain at unconfined compressive	2.46*10^{-3}

Table (2): Properties of steel tendons

Properties of steel tendons	value
Steel grade	A416Gr270
Weight/volume	76.9729 kN/m^3
Density	7.849kg/m^3
Modulus of elasticity (E)	1.965*10^8 kN/m^2
Minimum yield stress (Fy)	1689905.2 kN/m^2
Factor of thermal expansion (A)	1.17*10^{-5}
Minimum tensile stress (Fu)	1861584.6 kN/m^2
Directional symmetry type	UniAxial

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Table (3): Properties of steel rebar

Properties of steel rebar	Value
Steel grade	A615Gr60
Weight/volume	76.9729 kN/m^3
Density	7.849kg/m^3
Modulus of elasticity (E)	1.999*10^8 kN/m^2
Minimum yield stress (Fy)	413685.5 kN/m^2
Factor of thermal expansion (A)	1.17*10^{-5}
Minimum tensile stress (Fu)	620528.2 kN/m^2
Expected yield stress (Fy)	455054 kN/m^2
Expected tensile stress (Fu)	682581 kN/m^2
Directional symmetry type	UniAxial

Table (4): Properties of steel girder

Properties of steel girder	Value
Steel grade	A992Fy50
Wight/volume	76.9729 kN/m^3
Density	7.849kg/m^3
Modulus of Elasticity (E)	1.999*10^8 kN/m^2
Minimum yield stress (Fy)	344737.9 kN/m^2
Poisson ratio (µ)	0.3
Factor of thermal expansion (A)	1.17*10^{-5}
Minimum tensile stress (Fu)	448159.3 kN/m^2
Effective yield stress (Fy)	379211.7 kN/m^2
Effective tensile stress (Fu)	492975.2 kN/m^2
Shear modulus (G)	76903069 kN/m^2
Directional symmetry type	UniAxial

4. FINITE ELEMENT STATIC ANALYSIS

There are four parameters as an output data of static analysis for ten bridges models have different shapes of girders cross sections. These parameters include vertical displacement, vertical shear force, bending moment, tension and compressive stresses. The shell element model is used in three-dimensional structures analysis of this study. The shell element is one type of area object and it is a three or four nodes formulation that combines separate membrane and plate-bending behavior. In this study. four nodes formulation elements are used in static analysis.

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4.1. LIVE LOAD DUE TO VEHICLES LOAD ANALYSIS

Vehicles load analysis are performed by using vehicle type as HS $_{20-44}$ and load case as linear static. Table 5 lists the results of static parameters due to vehicles load.

4.2. SERVICE LOADS ANALYSIS

The applied service load on the bridges models include the combination of structure dead load, deck load, prestressed tendons load, temperature load, and traffic load (vehicle load). Table 6 lists the results of static parameters due to service loads. Figure 2 to Figure 8 shows the comparison results of static analysis of bridges models.

Table (5): Results of static parameters due to vehicles load

Model No.	Model shape	Vertical displacement (mm)	Bending Moment (kN.m)		Shear force (kN)		Stress (MPa)	
			Max +	Min -	Max +	Min -	Max +	Min -
1	T-girders	3	5183	-2338	1609	-1609	3.57	-10.45
2	I-girder	8	1640	-2267	839.7	-839.7	4.37	-8.24
3	flat slab	16	2417	-4664	1384	-1384	5.65	-8.70
4	Steel I-girder	3	2143	-4294	1385	-1338	6.2	-16.65
5	B.G.external web clipped	2	3929	-7659	2239	-2239	1.44	-2
6	B.G.external web curved	2	4018	-7796	2282	-2282	1.46	-1.91
7	B.G.external web vertical	2	4134	-7947	2323	-2323	1.45	-1.88
8	B.G.external web max. sloped	2	3378	-6836	1985	-1985	1.44	-2.64
9	AASHTO-PCI-ASBI standard	2	2438	-4586	1358	-1358	1.06	-1.98
10	U-Box Girder	6	328	-679	325	-325	3.10	-3.98

Table (6): The results of static parameters due to service load

Model No.	Model shape	Vertical displacement (mm)	Bending Moment (kN.m)		Shear force (kN)		Stress (MPa)	
			Max +	Min -	Max +	Min -	Max +	Min -
1	T-girders	12	77908	-42476	20392	-28228	4.52	-8.20
2	I-girder	20	15088	-9822	5488	-5325	6.30	-15.8
3	flat slab	50	13033	-88372	3712	-3807	8.60	-6.70
4	Steel I-girder	23	54989	-28229	10419	-10580	5.47	-9.85
5	B.G.external web clipped	6	39982	-6715	10367	-7512	5.95	-12.07
6	B.G.external web curved	7	26153	-5777	6298	-6138	3.80	-7.78
7	B.G.external web vertical	6	42408	-2568	9875	-7668	5.67	-12.07
8	B.G.external web max. sloped	8	34321	-1264	5754	-6603	9.91	-10.71
9	AASHTO-PCI-ASBI standard	8	18749	-3002	3856	-3967	4.10	-8.04
10	U-Box Girder	25	14419	-16332	5568	-5568	5.12	-10.7

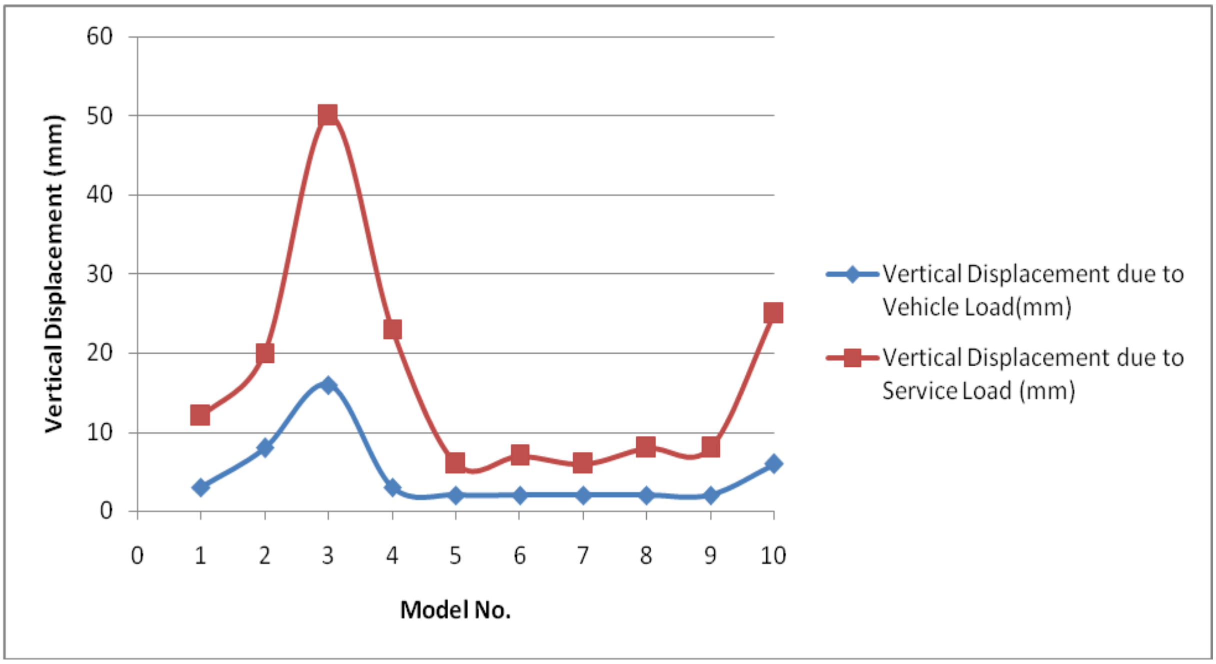

Figure (2): Vertical displacement due to vehicle load

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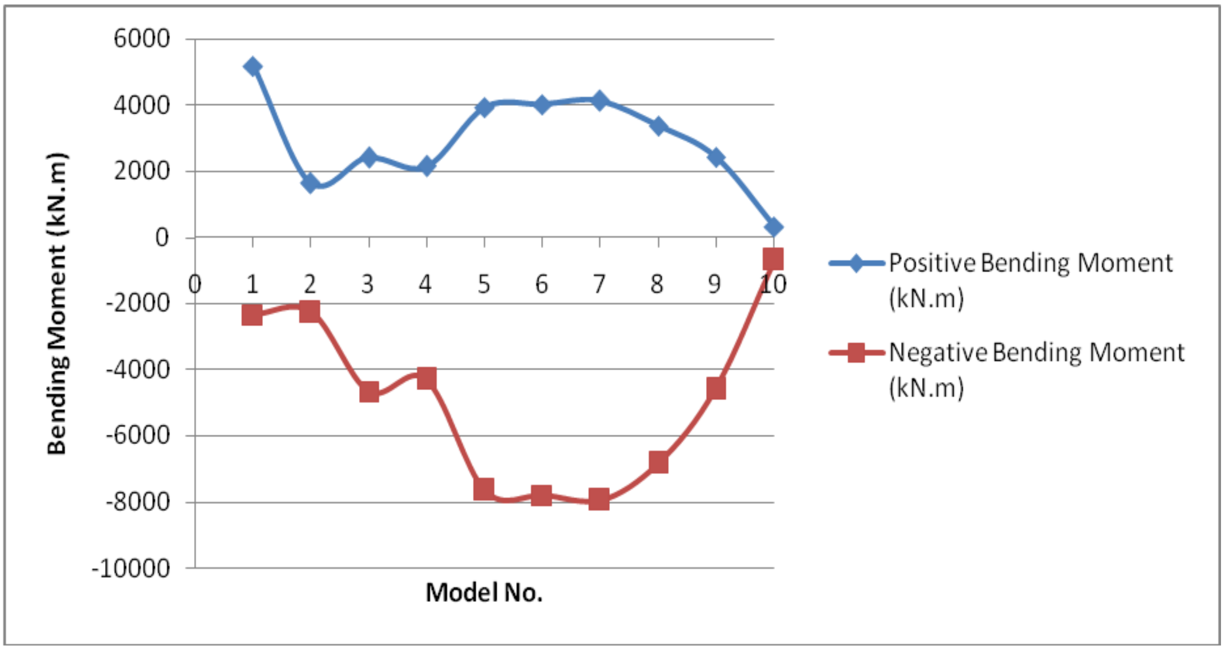

Figure (3): Positive and negative bending moment due to vehicle load

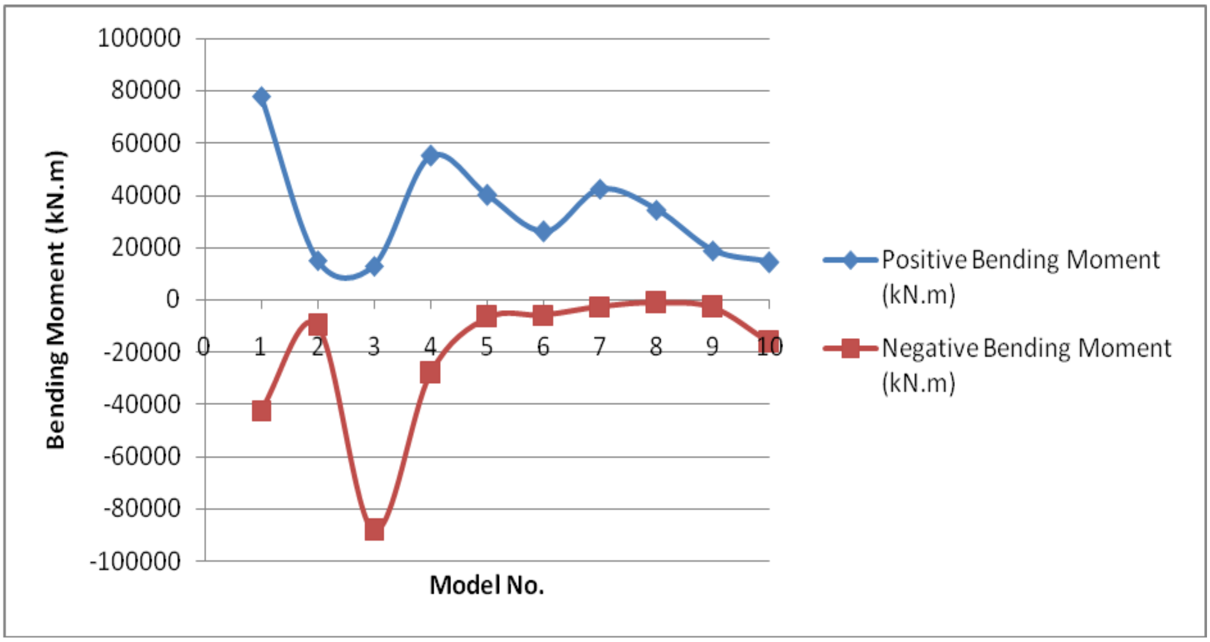

Figure (4): Positive and negative bending moment due to service load

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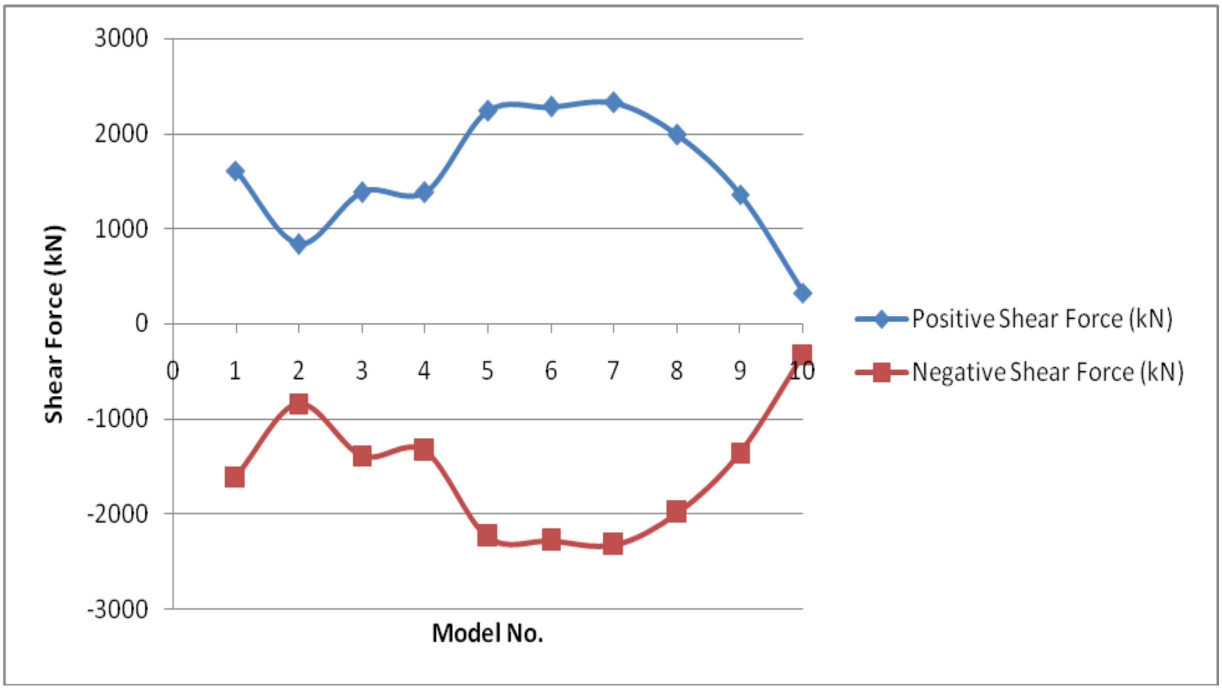

Figure (5): Shear force due to vehicle load

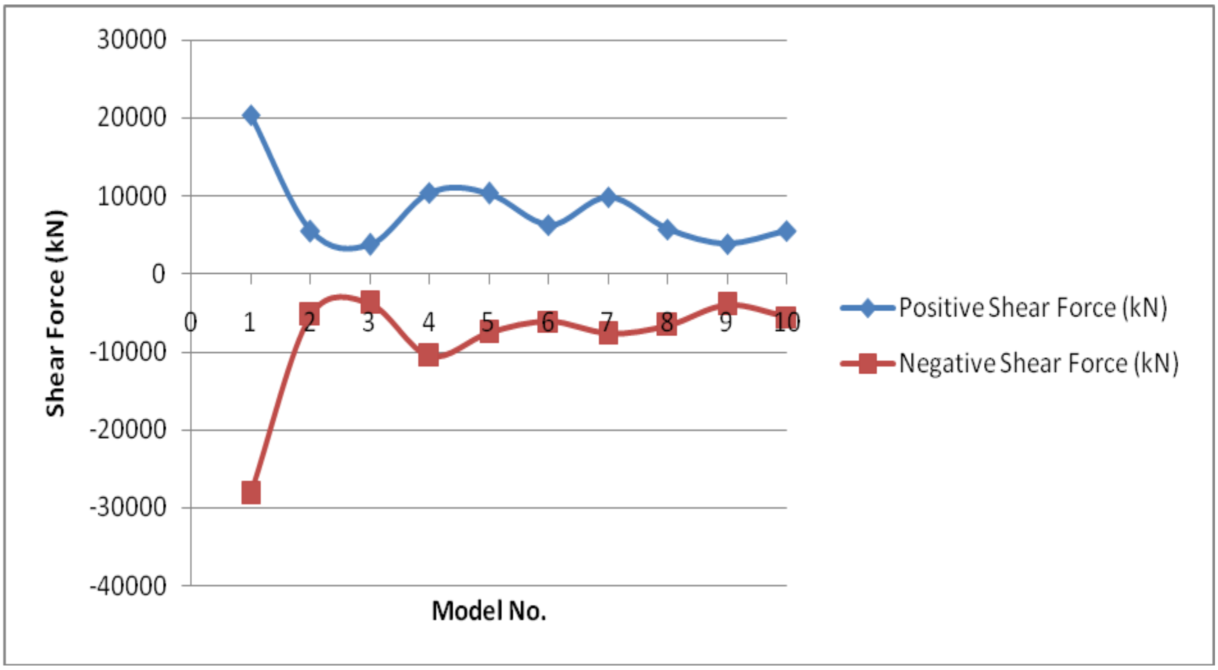

Figure (6): Shear force due to service load

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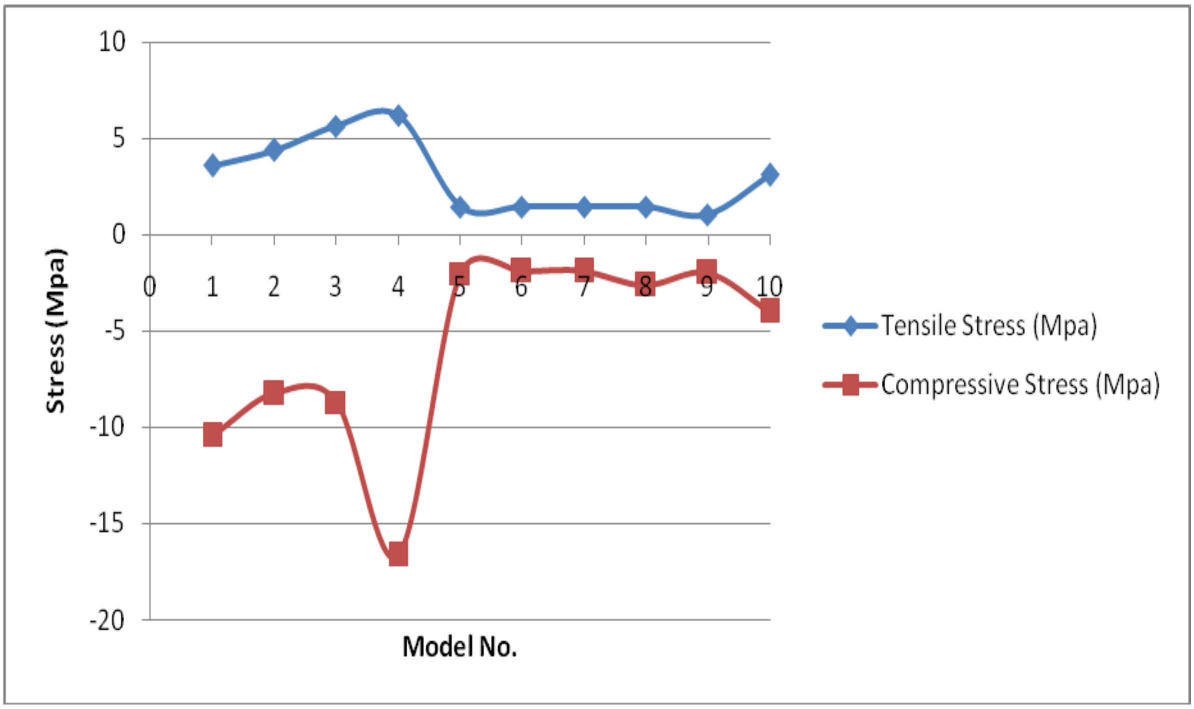

Figure (7): Stresses due to vehicle load

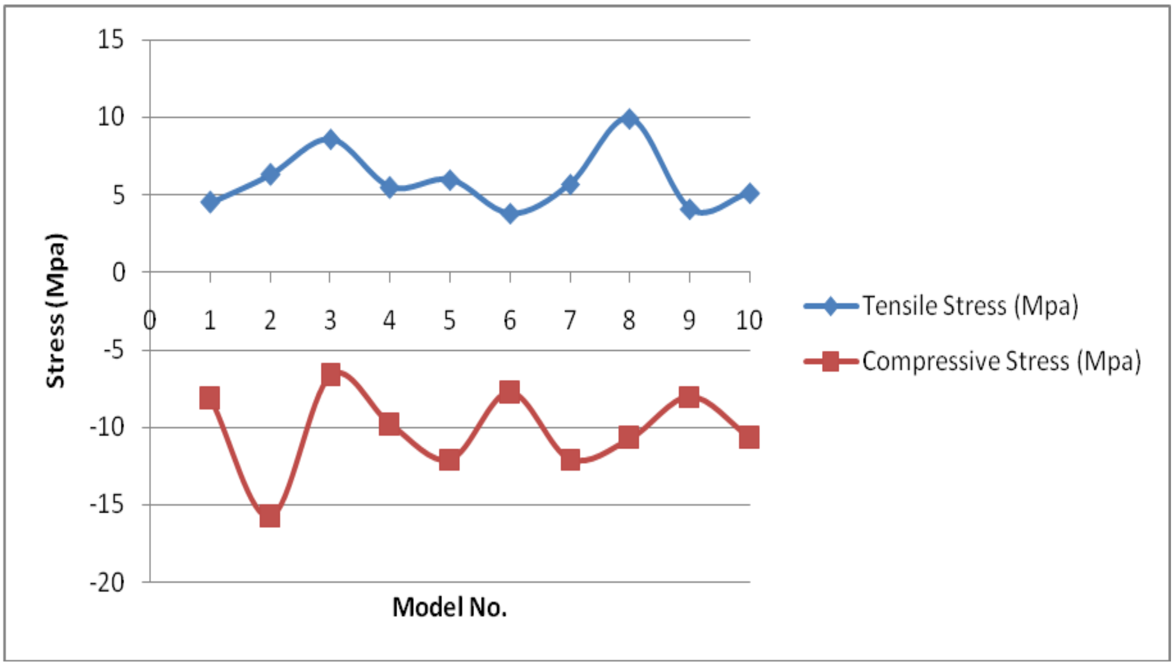

Figure (8): Stresses due to service load

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5. DISCUSSION OF STATIC ANALYSIS RESULTS

According to Table (5), the results of vehicle load show that the maximum vertical displacement is 16 mm within flat slab bridge model and the minimum vertical displacement is 2mm within box girders with different external webs shape. Therefore, the box girders models are suitable to carry vehicle loads. For bending moment, T-girder bridge model appears higher positive bending moment which is equal to 5183 kN.m and box girder with external web vertical bridge model has the higher value of negative bending moment and vertical shear force which that equal to 7947 kN.m and 2323 kN respectively. Flat slab bridge model gives the maximum value of tensile stress and it equal to 5.65 MPa. Therefore, the cracks will appear on this model. The minimum value of tensile stress appears within AASHTO-PCI-ASBI standard box girder bridge model which is equal to 1.06 MPa. The higher value of compressive stress is -16.65MPa within steel I-girder bridge model.

For service loads analysis results which is listed in Table (6), the higher value of vertical displacement is appeared within flat slab bridge model which is 50mm, while the minimum value of vertical displacement is found within box girder with external web clipped bridge model and box girder with external web vertical bridge model which is 6mm. T-girder shape bridge model has maximum value of positive and negative bending moments, and positive and negative shear forces which is equal to 77908 kN.m, -42476 kN.m, 20392kN, and -28228 kN respectively. The maximum tensile stress and compressive stress appears in the I-girder bridge model which is equal to 6.5MPa and15.8 MPa respectively and the minimum tensile stress and compressive stress is equal to 3.80 MPa and 6.70 MPa within box girder with external web curved shape model and flat slab shape model respectively.

According to above results, the models have higher value of vertical displacement, positive bending moment, tensile stress are not suitable to design of bridges that subjected to higher traffic loads because of these bridges structures will not have enough stiffness and carrying capacity. Therefore, they will fail under heavy traffic loads. These models include flat slab bridge model, T-girder bridge model, I-girder bridge model, and steel I-girder bridge model. Most box girders bridge models appears the lower values of vertical displacement, positive bending moment, tensile stress. Therefore, these models will have enough stiffness and carrying capacity and they will be more elasticity from others models. This study recommended that using the box girders bridges models in the construction of new bridges structure that have high traffic loads

6. CONCLUSIONS AND RECOMMANDATION

The conclusion of this study includes:

1. The effect of girder cross section shape in the construction of bridges is studied by adopting finite element static analysis for ten bridges models using different types and shapes of girders.
2. According to output data of static analysis, seven parameters are used. These parameters include vertical displacement, vertical shear force, bending moment, tension and compressive stresses.
3. For vehicle load analysis, the results of finite element analysis show that the flat slab bridge model has the maximum vertical displacement which is 16 mm and the minimum vertical displacement is 2mm within box girders with different external webs shape. Therefore, the box girders models are suitable to carry vehicle loads. For service load, the higher value of vertical displacement is appeared within flat slab bridge model which is 50mm, while the minimum value of vertical displacement is found within box girder with external web clipped bridge model and box girder with external web vertical bridge model which is 6mm.
4. According to bending moment analysis, T-girder shape bridge model has maximum value of positive and negative bending moments, and positive and negative shear forces which is equal to 77908 kN.m, -42476 kN.m, 20392kN, and -28228 kN respectively.
5. The results of stress analysis show that the higher value of tensile stress and compressive stress appears in the I-girder bridge model which is equal to 6.5MPa and 15.8 MPa respectively.
6. The minimum tensile stress and compressive stress is equal to 3.80 MPa and 6.70 MPa within box girder with external web curved shape model and flat slab shape model respectively.

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7. Some models appears maximum values of vertical displacement, positive bending moment, tensile stress. These models include flat slab bridge model, T-girder bridge model, I-girder bridge model, and steel I-girder bridge model. These models are not suitable to resist heavy traffic loads because of these bridges structures will not have enough stiffness and carrying capacity.
8. Most box girders bridge models appears the lower values of vertical displacement, positive bending moment, tensile stress. Therefore, these models will have enough stiffness and carrying capacity and they will be more elasticity from others models. This study recommended that using the box girders bridges models in the construction of new bridges structure that have high traffic loads.
9. The future recommendation is using dynamic analysis to study the effects of girder cross section shape on the dynamic parameters.

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