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MATHEMATICAL ASSESSMENT OF VEHICLES TYPES AND LOADS INFLUENCES ON THE STRUCTURAL PERFORMANCE PARAMETERS OF CONCRETE AND STEEL BRIDGES

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Abstract

The main purposes of this study are to assess the influences of vehicle types and loads on the structural performance of concrete and steel bridges by using the finite element method of SAP2000 software. Two methods of analysis are adopted. The first and second method is static and dynamic analysis respectively. The results of static analysis shown that HB-AH1 vehicle is the heavy vehicle, which was passed on the bridges structures and it can be caused higher bending moment and vertical displacement. Whereas, Hn-44 vehicle is the light vehicle comparing with other types of vehicles. Concrete slab bridge produced the maximum value of vertical displacement and concrete box girder bridge appeared minimum value of vertical displacement. The results of dynamic analysis illustrated that concrete slab bridge model had natural frequency (3.52 Hz), which was less than dynamic frequency (4.64 Hz), indicating that bridge model had not enough stiffness and elasticity. Therefore, this type of bridge structure was not suitable to carry heavy traffic loads. The dynamic frequency of steel bridge model was 4 Hz. This value was less than a natural frequency value (6.82 Hz), showing that the bridge model had suitable stiffness and elasticity. Concrete bridge model had 8.58 Hz of natural frequency, which was more than dynamic frequency (4.12 Hz), resulting that bridge structure has enough stiffness, elasticity, resistance for loads, and bearing capacity. This study recommended that using concrete box girder bridges model in the building of bridges structures.

Keywords: Bending moment, Frequency, Slab bridge, Steel bridge, Vehicles, Vertical displacement.

1. Introduction

Structure of bridge is offered a pathway over an obstacle without closing the way below. The essential pathway for railways, pedestrians, highways, and rivers. bridges structure is a significant portion of the transportation engineering system. the bridge's capacity can control the volumes and the weights of the vehicles traffic carried by the transportation system. Generally, the bridge structure consists of the concrete deck, girders, bearings, cap beam, piers, abutments, and foundation [1-4].

Bridges constructed by using concrete material are a common answer and it is one of the simplest and widely used for short and mid-span bridges in the world. The main advantage of concrete bridges is that can be moulded for suitable shapes with altered uses. The essential types of the concrete bridge include frame and slab bridges, beam-slab bridges, and box girder bridges. Concrete slab bridges are a common bridge type for short spans. In general, slabs can be distributed loads in two directions such as longitudinal and transverse. When such a bridge is to be designed, these effects need to be described correctly using numerical models. The actual vertical deflection is increased when the moment of inertia is reduced [5- 7].

Steel structures have many advantages more than other construction materials. These advantages are high strength and ductility, a ratio of higher strength to cost intension, lower strength to cost ratio in compression when compared with concrete. The superstructures of steel bridges are light comparing with concrete bridges and have economical foundations. They can be produced in different sections in a factory with exacting quality control. they transported to site in manageable units and bolted together in situ to form the complete bridge structure [8].

The primary impartial of structural analysis is to assess the static reactions of a structure and to discover the distribution of internal forces systems such as vertical displacement, bending moment, shear force, tension and compressive stresses. According to applied loads, a linear elastic model is assumed in the structural analysis. The finite element method is an appropriate appliance to solve differential equations for the structural engineering applications [1, 9, 10]. Generally, static analysis of bridge structure is very essential in the analysis process of bridges structure to assess the structural performance of bridges parts. The loads include deck load, prestressed tendons load, temperature load, and static traffic load (vehicle load), are applied without moving of vehicles. The dynamic analysis consists of moving load analysis with constant or different values of vehicles speeds [1, 2, 11].

Bridge structural performance is dependent on bridge materials, bridge system, loads types and environmental factors. Vehicles loads are a significant element that can be affected by structural performance and the safety and usability of bridges. When vehicles pass on bridges structures, dynamic parameters will be appeared such as vibration frequency, dynamic displacements in three dimensions, dynamic bending moment, dynamic shear, and dynamic stresses and strain. Dynamic parameters, which are bigger than static parameters because of the interaction between the moving vehicles and bridge structure hence it can accelerate the deterioration process of the bridge [12-14]. Dynamic vehicle load on the bridge structure can be influenced by vehicles dynamic properties, bridges dynamic properties, bridge surface roughness, and vehicle speed. When a dynamic load is increased gradually, there are not main bridge failures but dynamic vehicle load can be caused damages that later lead to fatigue. [15, 16].

2. Literature Review

Bemard and Oelphine [17] presented and compared the lifetime of bridges structures in fatigue according to many heavy traffics loads by using Weigh-In-Motion (WIM) systems data. They used CASTOR-LCPC software to study the influence of traffic loads on bridges. They adopted seven existing bridges structures and three traffics loads with different vehicle flows and mean loads.

Altan et al. [18] assessed the influence of vehicle loads on bridges structures by adopting three-dimensional girder models of the bridges. They compared the results of strain that calculated from load tests of five steel girder bridges and three pre-stressed concrete I-girder bridges. They found that when the vehicle load increasing by 20%, leading to a reduction in the remaining life in these older steel bridges of up to 42%.Therefore, the increasing vehicle loads by 10%, causing a 25% reduction in fatigue life.

Abraham [19] investigated different load effects on bridges structure such as vertical deflection at mid-span, beam distribution factor, and longitudinal stress. The results of the analysis showed that the vehicle load models according to codes provided maximum load effects compared to the actual vehicle load effects.

Christopher and Denson [20] evaluated the influence of internal force due to six-axle semitrailers with a 97-ki vehicle moving on simple and continuous span bridges. They stated that the design live loads according to AASHTO Standard Specifications do not produce suitable shear and moment to fully envelope the effects of the proposed 97-kip vehicles. They concluded that the LRFD notional loads denote important advantages to bridge design applies concerning the probable for heavier vehicles on the highway system. Additionally, the total vehicle length and axle spacing show a vital role in the longitudinal force effects created in the bridge by the 97-ki vehicles.

Paeglite and Smirnovs [15] studied the interaction between a bridge structure and a vehicle passing over it. They discussed different dynamic parameters such as natural frequency, bridge logarithmical decrement, dynamic acceleration, and dynamic amplification factor. The results showed that the bridge structure roadway's conditions significantly influence the dynamic amplification factor.

Jun et al. [21] studied the influences of vehicle load on the long spans' bridges. They explained that vehicle load is one of the main live loads for bridges structures and the vehicle load is the essential factor that affects the reliability and serviceability of bridges structures. They found that the main characteristics of the vehicle loading effects are vehicle density, loaded length, and the heavy vehicle percentage. An increase in vehicle density will be led to higher average and extreme values for the loading effect.

Paeglite et al. [14] discussed the effect of the traffic load on the bridge structure. they evaluated the influence of vehicle moving on the bridge structure by multiplied static live load and dynamic amplification factor. The results showed that irregular pavement condition had an important effect to increase dynamic amplification factor values according to low vehicle speed.

Vinay et al. [22] developed a suitable and dependable analysis procedure of finite element to analysed bridge models that can be calculated the static and dynamic parameters of bridges. The results of their study showed that the deflections and stresses at the zero deflection point and decompression are modelled well using a finite element method.

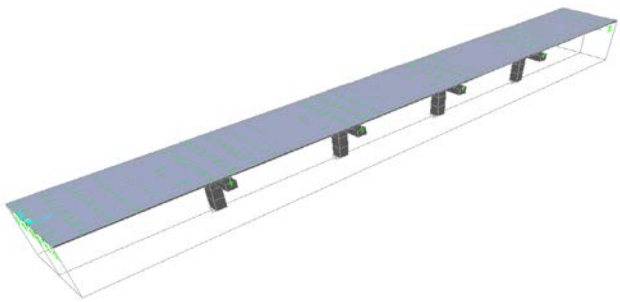
Deng et al. [13] stated that vehicle loads are an essential factor that can be affected by the safety and structural performance of bridges structures. They investigated and analysed the vehicle load data of Tianjin Haibin highway bridge. The results of theoretical and experimental (load tests) were compared. The vehicle type was HL-93 (AASHTO LRFD). The results of analyses showed that the total vehicle load follows a distribution with a weighted sum of four normal distributions. The maximum vehicle load during the design reference period follows a type I maximum distribution.

Sang et al. [23] developed a simulation procedure to evaluate the effects of vehicle loads for bridge safety assessment based on the maximum load effects that may be occurred during the service life of bridge structure. Two types of bridges models were used in their study. These models were pre-stressed concrete and steel box girder bridges. They found that the maximum load influences tended to increase with either the traffic volume or proportion of heavy vehicles.

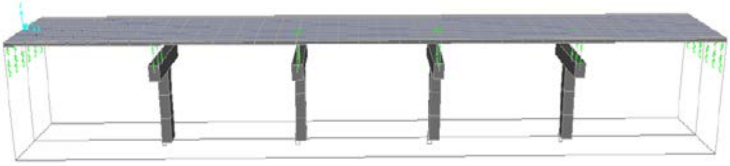
The purposes of this study are to assess the influences of vehicle types and loads on the structural performance of concrete and steel bridges, to determine the static parameters due to different types of vehicle loads (static analysis) such as vertical displacement and bending moment, and to determine the dynamic parameters according to moving loads of vehicle types (dynamic analysis) such as natural frequency, dynamic frequency, dynamic vertical displacement, and dynamic bending moment.

3. Description of Models

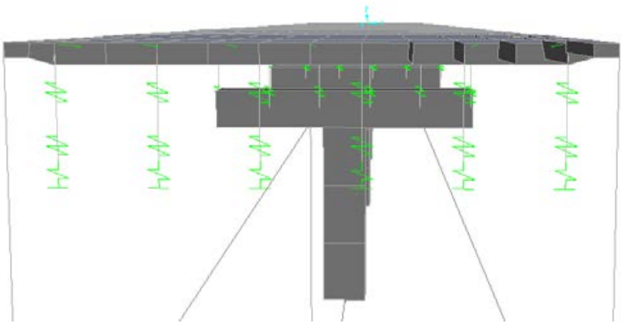
Three types of bridges structures models are selected in this study. The first model is a concrete slab bridge model and the second and third models are concrete box girder bridge model (5-cells) and I-steel girder bridge model respectively. The models have same number of spans, same span lengths, total length, and total width. The number of spans is equal to 5 spans (each span has a length is 20 m). The total length of each model is 100 m and the total width is 11 m. Figure 1 shows a concrete slab bridge model, Fig. 2 shows a concrete box girder bridge model and Fig. 3 shows I-steel girder bridge model. The concrete type is C-40 and the weight per unit volume is 23.5631, modulus of elasticity is equal to 24855.578 MPa, and the Poisson ratio is 0.2. For steel tendons, the types are A416Gr270, the weight per unit volume is 76.97, and modulus of elasticity is equal to 196500.6 MPa.



(a) 3D view.

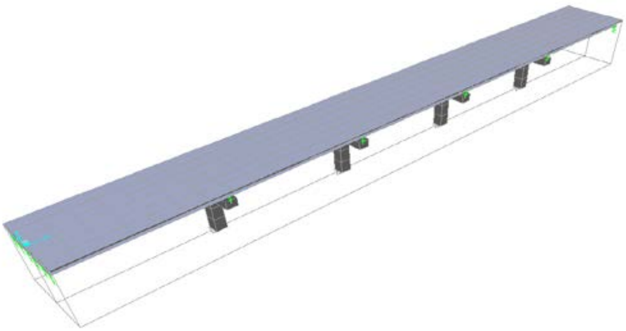


(b) Elevation view.

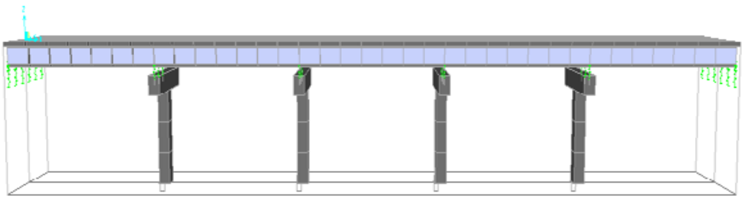


(c) Front view.

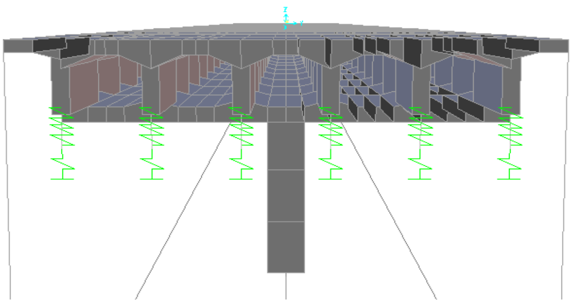
Fig. 1. Concrete slab bridge model.



(a) 3D view.

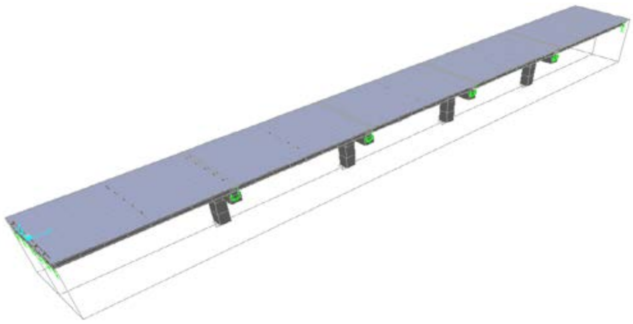


(b) Elevation view.

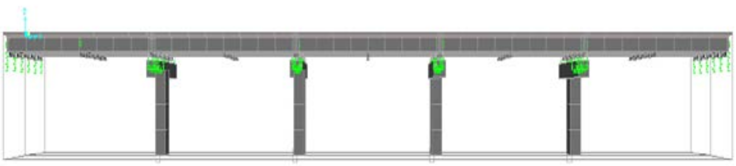


(c) Front view.

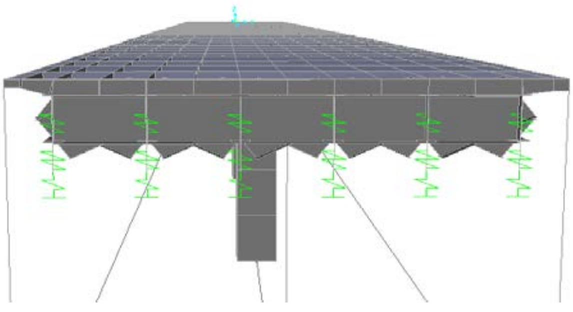
Fig. 2. Prestressing concrete box girder bridge model.



(a) 3D view.



(b) Elevation view.



(c) Front view.

Fig. 3. I-steel girder bridge model.

4. Vehicles Types and Loads

For static and dynamic analysis, ten types of vehicles are used. Table 1 lists the types of vehicles.

Table 1. Vehicle types models.

Vehicle type no.	Vehicle name	Axle width type	Axle width (m)	Front axle load (kN)	Rear axle load (kN)	No. of rear axle
1	AML	Two points	1.8288	106.75	106.75	1
2	Hn-44	Two points	1.8288	35.58	142.34	1
2	Hn-44	Two points	1.8288	35.58	142.34	1
3	HL-93F	Two points	1.8288	40.92	163.69	2
4	P-9	Two points	1.8288	115.65	213.54	4
5	P-9F	Two points	1.8288	133.05	276.23	4
6	P-13	Two points	1.8288	115.65	213.51	6
7	P-15	Two points	1.8288	144.56	300	7
8	HB-AH1	Four points	3	300	300	3
9	IRC-A-TR	One point	0	54	508	1
10	JTG04-TRUCK	Two points	1.80	30	520	1

5. Analysis of Structural Parameters

In this study, two methods of analysis are adopted to study the influences of using different kinds of vehicles on the structural performance parameters of concrete and steel bridges. The first and second method is static and dynamic analysis respectively. Finite element method is used in the analysis by adopting SAP2000 software. The load case type is multi-step static for static analysis and time history (linear-direct integration) for dynamic analysis. The static structural performance parameters include bending moment (kN.m) and vertical displacement (mm). The dynamic parameters consist of natural frequency, dynamic frequency, dynamic vertical displacement, and dynamic bending moment.

6. Results of Static Analysis

6.1. Bending moment

Figure 4 shows the maximum values of a positive bending moment for each type of vehicle on a concrete slab bridge, steel bridge, and box girder bridge. From this figure, it can be seen that vehicle type (HB-AH1) appears maximum values of a positive bending moment for all bridges models, which equal to 3860 kN.m for concrete slab bridge within distance 8.5 m, which is near the centre of span No.2, 6004 kN.m for steel bridge within distance 12.5 m, which is near the centre of span No. 5, and 5500 kN.m for box girder bridge within distance 11.5 m, which is near the centre of span No. 5. Therefore, these positions of spans may be subjected to higher values of tensile stresses then cracks will appear. While Hn-44 vehicle type shows minimum values of the positive bending moment for concrete slab bridge, steel bridge, and concrete box girder bridge.

The maximum values of the negative bending moment can be seen in Fig. 5. The maximum value of the negative bending moment is appeared within the concrete slab bridge (4588 kN.m) due to P-15 vehicle type. For other bridges model, P-15 vehicle gives maximum values of negative bending moment (1321 kN.m for steel bridge and 4292 kN.m for concrete box girder bridge).

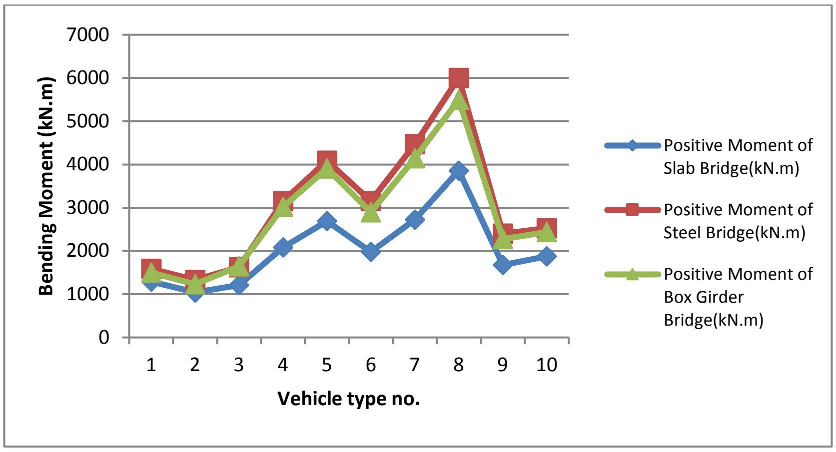


Fig. 4. Maximum positive bending moment values.

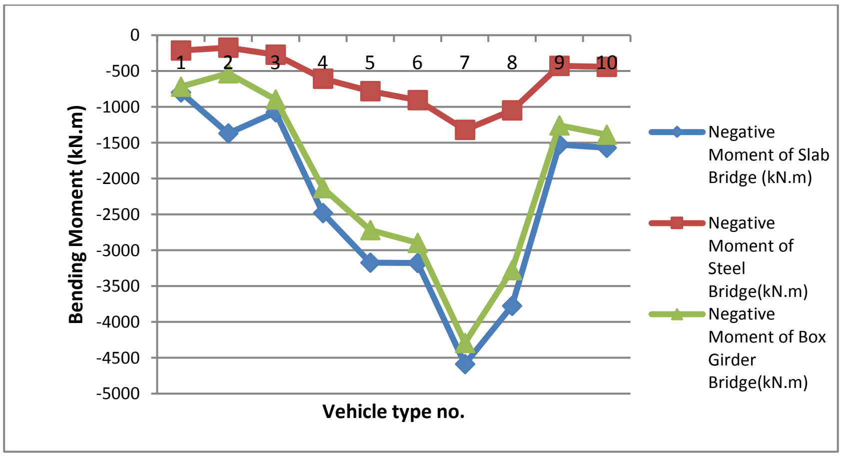


Fig. 5. Maximum negative bending moment.

6.2. Vertical displacement

Vertical displacement due to vehicle load is an important factor in the assessment of the structural performance of bridge structure. Figure 6 illustrates the maximum value of vertical downward displacement due to different vehicle types on the structure of the bridge. HB-AH1vehicle type products maximum value of vertical displacement, which is equal to -74 mm within concrete slab bridge in the centre of span No. 2 and -2 mm for box girder bridge in the centre of span No. 5 and -5mm for steel bridge in the centre of span No. 1 and span No. 5. The minimum value of vertical displacement is equal to -0.4 mm within a concrete box girder bridge due to Hn-44 vehicle types.

According to vehicle types loads analysis, HB-AH1 vehicle is the heavy vehicle passes on the bridges structures and Hn-44 vehicle is the light vehicle comparing with other types of vehicles. For bridge structure type, concrete slab bridge gives the maximum value of vertical displacement.

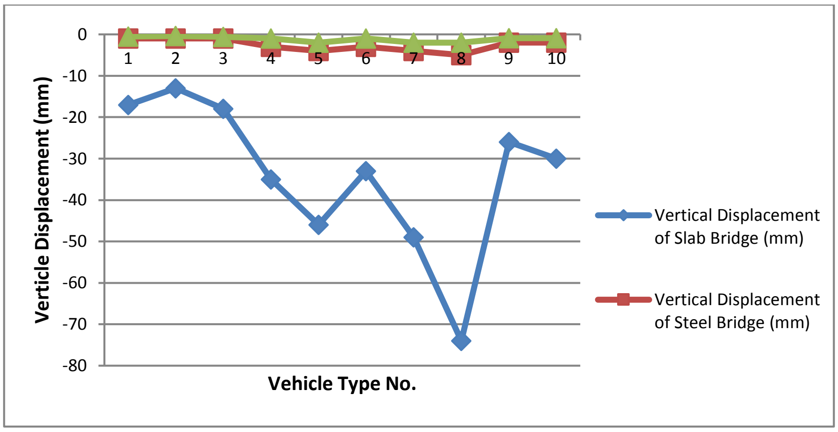


Fig. 6. Maximum vertical displacement.

7. Results of Dynamic Analysis

7.1. Natural frequency

Modal load case is used in the dynamic analysis to determine the natural frequency of bridges structures models. The number of dynamic modes is 12. Natural frequency can be measured when the bridge structure is closed for traffic load.

Figures 7 shows the values of natural frequency for each mode of bridge structure models. The average values of natural frequency are 3.52 Hz, 6.82 Hz, and 8.58 Hz for concrete slab bridge, steel bridge, and concrete box girder respectively. According to previous results, concrete box girder bridge appears the higher value of natural frequency.

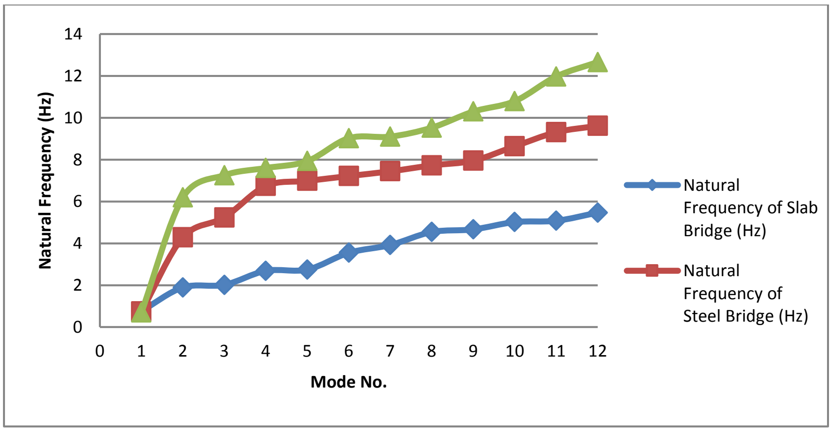


Fig. 7. Natural frequency for concrete slab bridge.

7.2. Dynamic frequency

Dynamic frequency is determined when the bridge structure subjected to traffic loads. Figure 8 shows the values of the dynamic frequency of bridges structures due to vehicles types and loads. Concrete slab bridge model produces a higher value of dynamic frequency (4.64 Hz) due to HL-93F vehicle type. Steel bridge model appears 4 Hz of dynamic frequency due to P-13 vehicle type and the maximum dynamic frequency value of concrete box girder is 4.12 Hz due to P-13 vehicle type.

7.3. Dynamic vertical displacement

Figures 9 and 10 give the maximum values of dynamic downward and upward displacement. From these figures, it can be concluded that the maximum value of dynamic downward and upward displacement is -82 mm and 83 mm due to HB-AH1 vehicle type within concrete slab bridge model, whereas steel bridge model gives the maximum value of dynamic downward and upward displacement is -5 mm and 5 mm due to HB-AH1 vehicle type. For concrete box girder, the higher value of dynamic downward displacement is -2mm and upward value is 2mm according to HB-AH1 vehicle type.

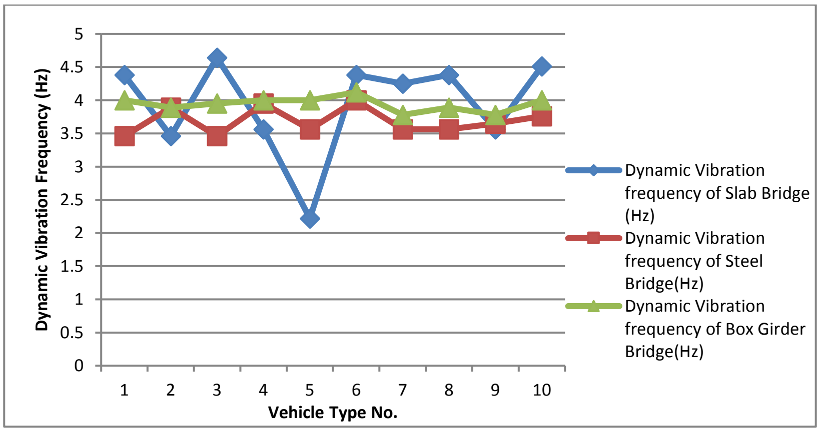


Fig. 8. Dynamic frequency of bridges structures.

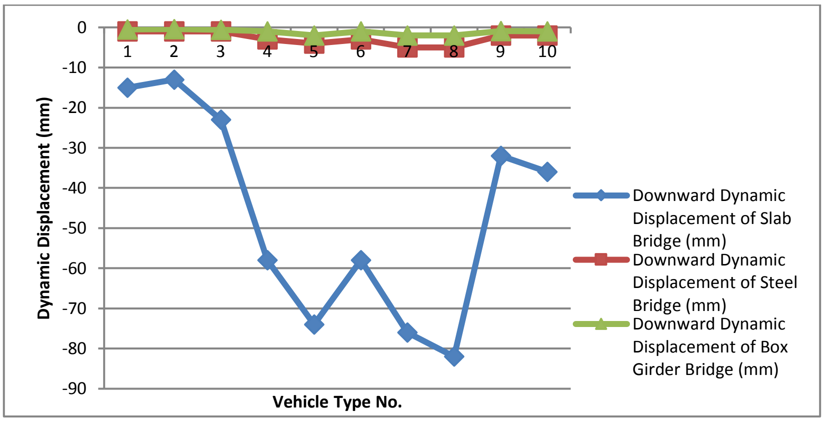


Fig. 9. Maximum values of dynamic downward displacement.

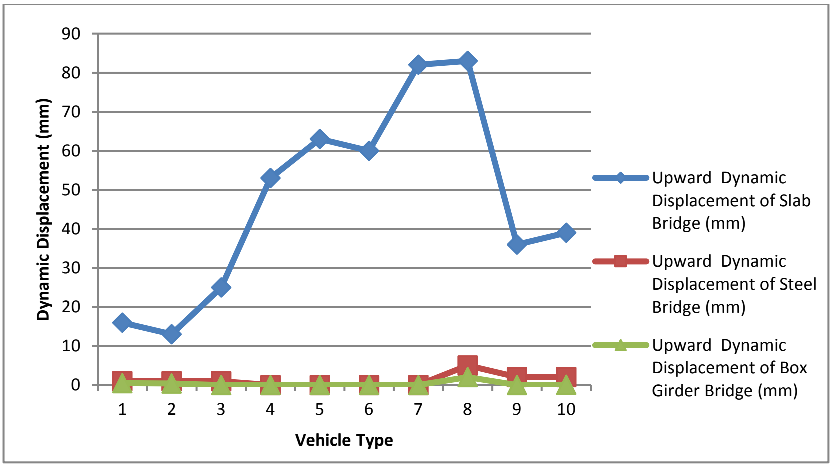


Fig. 10. Maximum values of dynamic upward displacement.

8. Assessment of Structural Performance

The aim of static and dynamic analysis results assessment is to know the bearing capacity, stiffness, elasticity, and resistance to traffic loads. The static analysis has shown that concrete slab bridge model produced higher values of vertical displacement and the heavier vehicle (HB-AH1) had important effects on the structural performance of the bridge model. For dynamic analysis, the assessment of structural performance depends on the comparison process between natural frequency and dynamic vibration frequency. For concrete slab bridge model, the values of natural frequency is equal to 3.52 Hz, which is less than dynamic vibration frequency, which is equivalent to 4.64 Hz, indicating that the bridge model has not enough stiffness and elasticity. Therefore, this type of bridge structure is not convenient to carry heavy traffic loads. For steel bridge model, the dynamic frequency is equal to 4 Hz, which is less than the natural frequency value, which is 6.82 Hz, indicating that the bridge model has suitable stiffness and elasticity. Also, concrete box girder bridge model has 8.58 Hz of natural frequency, which is more than dynamic vibration frequency, which is 4.12 Hz, resulting that bridge structure has enough stiffness, elasticity, resistance for loads, and bearing capacity. Therefore, this study recommended that using steel or box girder bridges in the building of bridges structure.

9. Conclusions

The conclusions of this study include:

- Three bridges models with ten vehicle types were selected to assess the influences of passing different vehicles types on the static and dynamic structural performance of bridges models such as concrete slab bridge, steel bridge, and concrete box girder bridge.
- The number of spans, span lengths, total length, and total width was same for all bridge models. The total length of each model is equivalent to 100 m and the total width is 11 m. The number of spans is equal to 5 spans (each span has 20 m in length).

- The results of static analysis shown that HB-AH1 vehicle was the heavily vehicle passed on the bridges structures and it can be caused higher bending moment and vertical displacement. Hn-44 vehicle was the light vehicle comparing with other types of vehicles. concrete slab bridge produced the maximum value of vertical displacement and concrete box girder bridge appeared minimum value of vertical displacement.
- According to dynamic analysis results, the average values of natural frequency was 3.52 Hz, 6.82 Hz, and 8.58 Hz for concrete slab bridge, steel bridge, and concrete box girder respectively. Concrete box girder bridge appeared higher value of natural frequency. Concrete slab bridge model produced a higher value of dynamic frequency (4.64 Hz) due to HL-93F vehicle type. Whereas steel bridge model appeared 4 Hz of dynamic frequency due to P-13 vehicle type and the maximum dynamic frequency value of concrete box girder is 4.12 Hz due to P-13 vehicle type. The maximum value of dynamic downward and upward displacement is -82 mm and 83 mm due to HB-AH1 vehicle type within the concrete slab bridge model.
- Concrete slab bridge model had natural frequency was equal to 3.52 Hz, which was less than dynamic frequency, which was 4.64 Hz, indicating that the bridge model had not enough stiffness and elasticity. Therefore, this type of bridge structure was not suitable to carry heavy traffic loads. For steel bridge model, the dynamic frequency was equal to 4 Hz, which was less than natural frequency value, which was 6.82 Hz, showing that the bridge model had suitable stiffness and elasticity. Concrete bridge model had 8.58 Hz of natural frequency which was more than dynamic frequency, which was equal to 4.12 Hz, resulting that bridge structure had enough stiffness, elasticity, resistance for loads, and bearing capacity.

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