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ANALYSIS THE EFFECT OF SUPER-ELEVATION ON STATIC AND DYNAMIC PROPERTIES OF HORIZONTAL CURVED CONCRETE BRIDGE BY FINITE ELEMENT

ALI FADHIL NASER

Al-Furat Al-Awsat Technical University, Al-Mussaib Technical College,
Building and Construction Engineering Techniques Department, Babylon City, Iraq
E-mail: com.ali3@atu.edu.iq

Abstract

The aim of this research is to study the effects of different rates of super-elevation and on the static and dynamic internal forces by using finite element analysis methods. The methodology of this study includes the selecting of suitable bridge model, different rates of super-elevation, static and dynamic analysis by using finite element method. The analysis is carried out by using SAP2000 Ver.14 program. The results of static finite element analysis of bending moment, axial force, and shear force, shown that there is not important effect of super-elevation rates increasing on the static properties of bridge models. The positive bending moment is increased with increasing of super-elevation rates until rate 8%. The maximum value is 35998 kN.m within model has 6% of super-elevation rate and the minimum value of positive bending moment is 35194 kN.m in model that has 0% of super-elevation. For negative bending moment, model of 0 % super-elevation rate has the maximum value which is 37548 kN.m and the minimum value is 35967 kN.m. For vertical deflection due to service load, the models have 0%, 2%, and 4% of super-elevation appear the lower value of vertical deflection that equal to 7.7 mm and the models have 6%, 8%, 10%, and 12% of super-elevation give the higher value of vertical deflection which is equal to 7.9 mm. The values of vertical deflection due to prestressed tendons are decreased from 12 mm to 11 mm, when the super-elevation rates are increased. Therefore, the increasing of super-elevation rates had effect on the upward vertical deflection due to loads of prestressed tendons. Modal analysis results show that the increasing of super-elevation rates has not effect on the natural and the values of natural frequency are 3.07 Hz for all models of bridge structure. The most values of vibration frequency in X and Y directions are less than values of natural frequency, but in Z-direction, the values of natural frequency are less than traffic vibration frequency values, indicating that the increasing of super-elevation rates have significant effect on the dynamic properties and it will lead to decrease the stiffness of bridge structure. Other's vibration parameters such as vibration displacement and vibration acceleration are not affected by increasing of super-elevation rates.

Keywords: Bending moment, Curved bridge, Deflection, Natural frequency, Super-elevation, Vibration frequency.

1. Introduction

A bridge is a structure made and constructed by men to pass up physical obstructions without closing the way beneath such as waterway, valley, or highway. The selection of bridge kind depending on the site properties, vendor preferences, hydraulic of the site and the profile position and cost of construction. The size of bridge structure depends on the density and volume of traffic loads, important of area that bridge connecting between them [1-6].

When geometric restrictions and constriction of limited site space, horizontal curved bridges are an important and the main practical options at complex traffic interchanges or waterway crossings construct complicated the adoption of standard straight bridge superstructure. The curved bridges have advantages such as aesthetic of structure for different types of bridges and it allows for designers to apply longer spans in the construction of this type of bridges. Because of girders spacing and concrete slab hang over are constant along the length of the bridge structure, curved bridges may result in simpler and more uniform construction process. There is problem in the design of curved bridge represent by the complexity in the analysis of curved girders because of the degree of curvature can be caused torsion loads that stress analysis [7, 8].

Comparison with straight bridge, horizontal curved bridge takes action to different types of loads more differently because of the torsion forces will be introduced by the curvature of the longitudinal axis. Also curved bridge will suffer from action of bending, axial, and shear forces. Centrifugal force must be determined and well thought-out when the design of horizontal curved bridge structure. The centrifugal force will also source of torsion effects of deck which may be taken as equal to the centrifugal force multiply by the space from the c g. of the deck to 1.2 m on top of the deck. The torsion moment has important effect on the outer edge of bridge and it will carry more load than outer edge of straight bridge. Super-elevation is used to avoid the overturning of the moving vehicles due to centrifugal force by rising the height of the pedestals towards outer curve but remaining the depth of the bridge girder same for all) or by increasing the depth of the girders towards outer curve (remaining the pedestal height same for all) [9-11].

Generally, super-elevation can be defined as the banking of highway horizontal curves to help the driver to cancel outing the side acceleration produced by pathway of the curve. For horizontal curved bridge structure, super-elevation is the rising of external edge curved bridge to cancel the effect of centrifugal force. Super-elevation is articulated as a decimal and it is ranged between 0.04 to 0.12. Suitable super-elevation permits for a vehicle to safely turn at proper speeds and it will make passengers feel comfortable in movement on horizontal curve. Super-elevation and side friction represents the important factors that helping the vehicles stay stable when passing on horizontal curve and unsuitable super-elevation will cause vehicle to skid when it is travelled on horizontal curve which helping to produce accident by existing the vehicle outside of roadway. Standards of bridges and highways limits the rate of super-elevation because of high rates of super-elevation make routing problems for drivers of vehicles which they are travelling at low speeds, especially during ice or snow environment [12, 13].

Most researchers studied the dynamic responses due to degree of curvature and super-elevation of horizontal curved bridges but they do not study the effect of super-elevation on the static internal forces of horizontal curved bridge. Therefore, there is needs to study the static responses because of sometimes the curved bridge subjected to static traffic load through traffic congestion, leading to distribute the traffic load in transverse direction as un-uniform load on superstructure of bridge. These studies include [14-18].

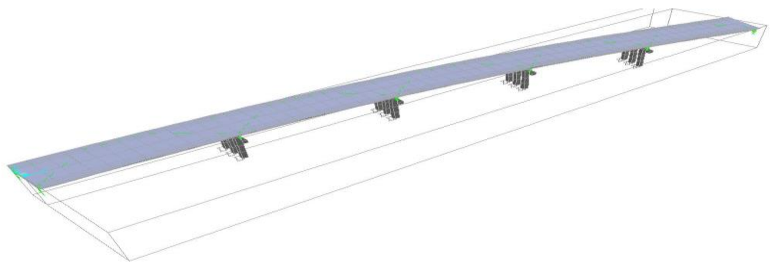
The purpose of this research is to study the effect of different rates of super-elevation and on the static and dynamic internal forces by using finite element analysis methods.

2. Bridge Models and Materials

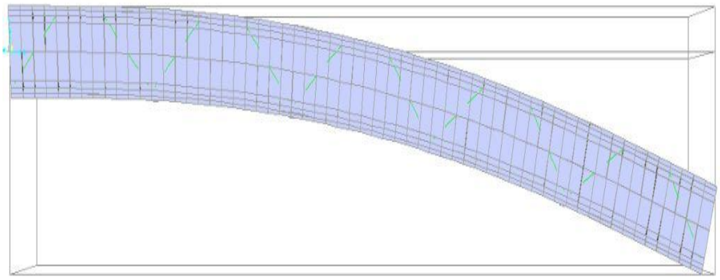
In this study, SAP2000 Ver. 14.2 program is used in the analysis of super-elevation effects on the static and dynamic properties of curved bridge. Horizontal curved concrete box girder bridge (one cell) is selected as a bridge type. Seven bridges models are used with different rates of super-elevation (0%, 2%, 4%, 6%, 8%, 10%, and 12%). For all bridges models, the bridge model consists of five spans. Each span has length is 30 m. Therefore, the total length of bridge is 150 m with total width is 10 m. The radius of curved model is constant for all models which is 430 m. The materials properties include using concrete grade is C40 with weight per unit volume is 23.5631 kN/m^3, Poisson's ratio is 0.2, E is 24855578 kN/m^2, and shear modulus is 10356491 kN/m^2. Prestressed tendons type A416Gr270 with weight per unit volume is 76.9729 kN/m^3, E is 1.965E+08 kN/m^2. Steel reinforcement and re-bar types are A992Fy50 and A615Gr60 respectively. The standard vehicle of live load is HL-93M. The substructure of bridge model combined of three piers which has 8 m height and (1x1) m area, and pier cap has 10 m length. The limitations of bridge model are fixed for super-elevation rats between 0% and 12%. Table 1 list the rate of super-elevation and Fig. 1 shows the bridge model structure.

Table 1. Rate of super-elevation.

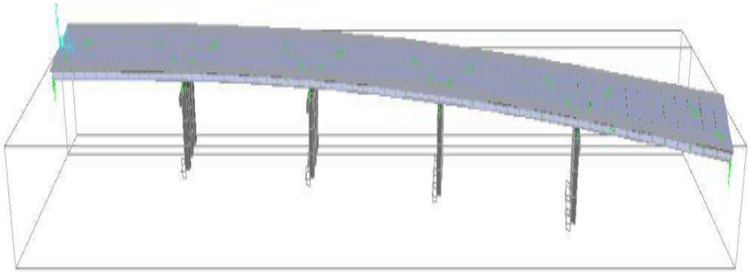
Bridge model No.	1	2	3	4	5	6	7
Super-elevation rate (%)	0	2	4	6	8	10	12



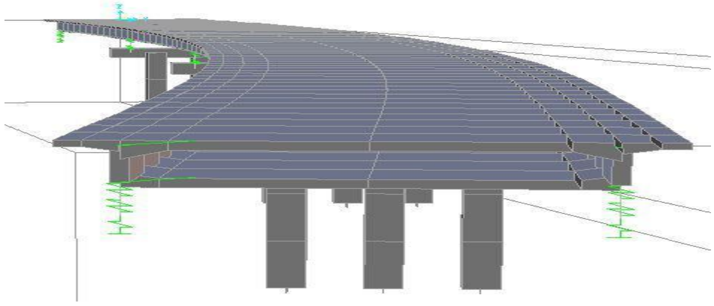
(a) Three dimensions view.



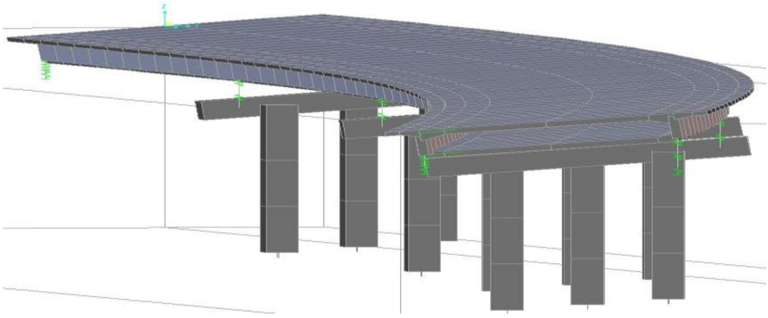
(b) Top view



(c) Side view.



(d) Front view with super-elevation rate= 0%.



(e) Front view with maximum super-elevation rate= 12%.

Fig. 1. Bridge model structure.

3. Static Finite Element Analysis of Super-Elevation

In static analysis, the loads combination (service loads) consists of dead load of bridge structure, prestressed load of tendons, temperature load, and live loads (vehicle load). vehicle type is HL-93M which is a type of theoretical vehicle loading suggested by AASHTO in 1993 and it is adopted as the design load for bridges and highways. It consists of three axles. One axle is known as front axle which has 35 kN and two rear axles which have 145 kN for each one axle. The distance between front and rear axle is 4.3 m and that of two rear axles can be varied between 4.3 m to 9.0 m to obtain the worst design force. The distance between tyre to tyre in any axle is 1.8 m.

3.1. Effect of super-elevation on bending moment

The results of static finite element analysis of bending moment can be shown in Fig. 2. It can be seen that the increasing of super-elevation rates has not significant effects on positive and negative bending moment along the bridges models. The positive bending moment is increased with increasing of super-elevation rates until rate 8%. The maximum value is 35998 kN.m within model which has 6% of super-elevation rate and the minimum value of positive bending moment is 35194 kN.m in model that has 0% of super-elevation. For negative bending moment, model of 0% of super-elevation rate has the maximum value which is 37548 kN.m and the minimum value is 35967 kN.m. In general, the aim of using super-elevation is to reduce the effect of bending moment due to lateral and vertical forces of dead and live loads. Therefore, the values of bending moment are decreased after the super-elevation increased.

3.2 Effect of super-elevation on axial force

Figure 3 shows the values of axial force due to static load analysis. The value of axial force is decreased with increasing of super-elevation rates. The maximum value is appeared in model that has 0% of super-elevation rate which is 17901 kN and the lower values is 17380 kN that is existed in model has 12% of super-elevation rate.

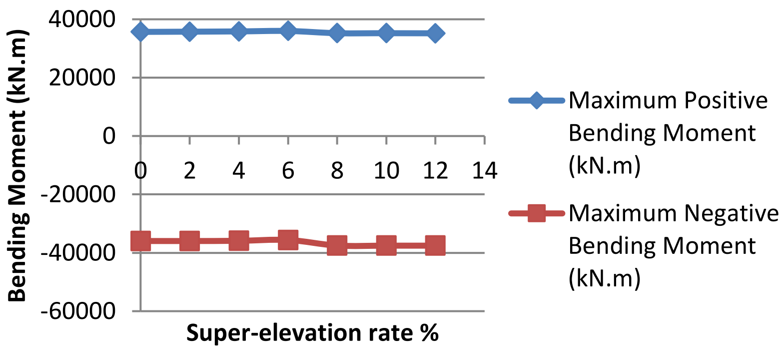


Fig. 2. Bending moment values versus super-elevation rates.

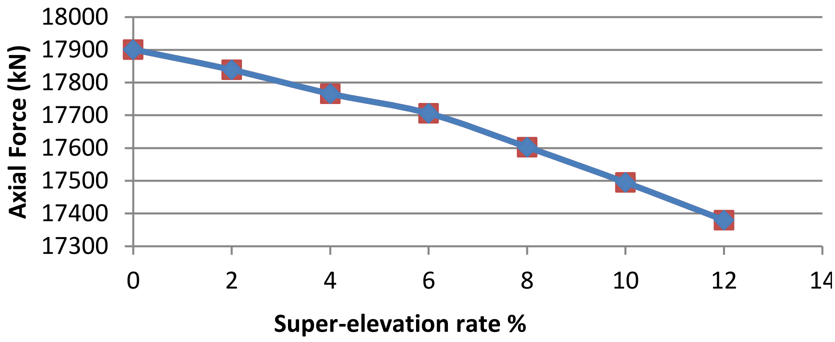


Fig. 3. Axial force values versus super-elevation rates.

3.3. Effect of super-elevation on shear force

The values of shear force (positive and negative) have a lower affect by the changing of super-elevation rates and they are near each other's. The higher value of positive shear force is 7463 kN within models which have 6% and 8% of super-elevation rates and the minimum value is 7445 kN which is appeared within model has 12% of super-elevation rates. Negative shear force values are decreased with increasing of super-elevation rates. Figure 4 lists the values of shear force under different values of super-elevation rates.

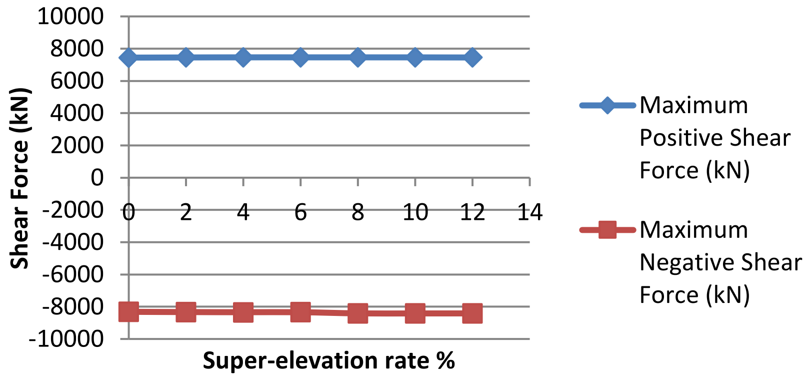


Fig. 4. Shear force values versus super-elevation rates.

3.4. Effect of super-elevation on vertical deflection

Figure 5 shows the values of downward vertical deflection due to service load. These values are increased with rising of super-elevation rates. According to these results, the models have 0%, 2%, and 4% of super-elevation appear the lower value of vertical deflection that equal to 7.7 mm and the models have 6%, 8%, 10%, and 12% of super-elevation give the higher value of vertical deflection, which is equal to 7.9 mm, because of the increasing in dead load of structure in the inside edge of bridge structure due to rise the outer edge of structure.

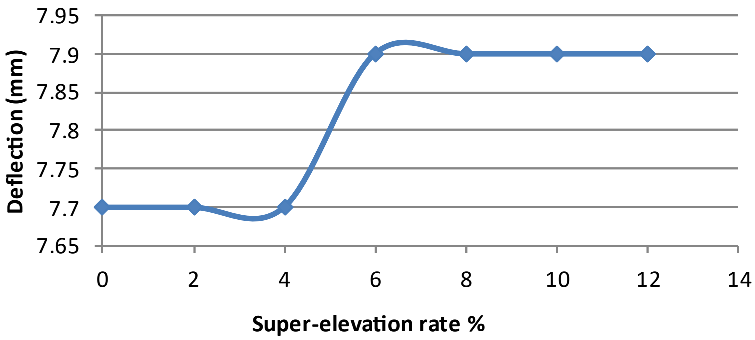


Fig. 5. Downward vertical deflection of service loads values versus super-elevation rates.

3.5. Effect of super-elevation on upward deflection of prestressed tendons

Prestressed tendons load is important in the construction of bridges because of it resists the different types of service loads. Therefore, it is important to study this stage of load. The values of upward vertical deflection due to prestressed tendons can be shown in Fig. 6. From this table it can be noted that the values of vertical deflection due to prestressed tendons are decreased from 12 mm to 11 mm, when the super-elevation rates are increased. Therefore, the increasing of super-elevation rates had effect on the upward vertical deflection due to loads of prestressed tendons.

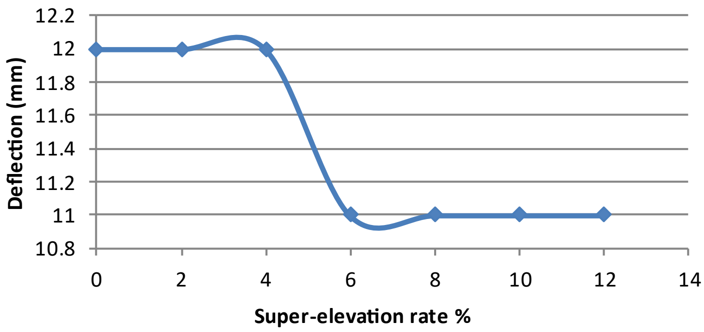


Fig. 6. Upward vertical deflection due to prestressed tendons versus super-elevation rates.

4. Dynamic Analysis of Super-Elevation

Dynamic analysis is carried out under live load (vehicle load) within maximum speed 80 km/hr by using linear direct integration history method. The description of live load (vehicle load) is mentioned in paragraph 3.

4.1. Effect of super-elevation on natural frequency (modal analysis)

Modal analysis shows that the increasing of super-elevation rates has not effect on the natural frequency because of dead load of bridge structure (weight of bridge structure) is the same for all bridges models and it is main parameter that natural frequency depends on it. Therefore, the values of natural frequency are 3.07 Hz for all models of bridge structure. Table 2 lists the values of natural frequency with different super-elevation rates.

Table 2. Values of natural frequency with different super-elevation rates.

Super-elevation rate (%)	0	2	4	6	8	10	12
Natural Frequency (Hz)	3.07	3.07	3.07	3.07	3.07	3.07	3.07

4.2. Effect of super-elevation on traffic vibration frequency

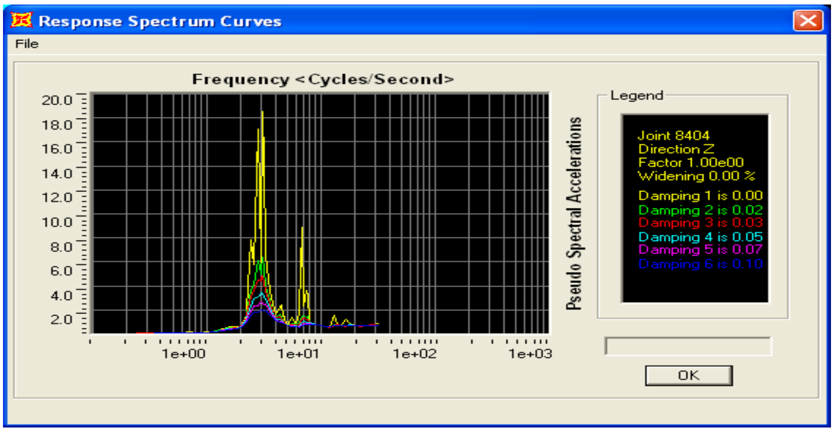
Dynamic analysis is applied in the three dimension of bridges models (X-direction, Y-direction, and Z-direction). X-direction represents the longitudinal direction along the bridge length, Y-direction is the transverse direction along the width of bridge, and Z-direction is the vertical direction along the depth of bridge. The maximum values of traffic vibration frequency in X, Y, and Z are 3.16 Hz, 2.81 Hz, and 4.46 Hz respectively. The higher value is 4.46 Hz in Z-direction within model 12% of super-elevation rate. The most values in X and Y directions are less than values of natural frequency, but in Z-direction, the values of natural frequency are less than traffic vibration frequency values, indicating that the increasing of super-elevation rates have significant effect on the dynamic properties and it will lead to decrease the stiffness of bridge structure. Table 3 lists the values of traffic vibration frequency due to traffic loading in three directions. Figure 7 shows the analysis results curves of traffic vibration frequency.

Table 3. Values of traffic vibration frequency due to traffic loading in three directions.

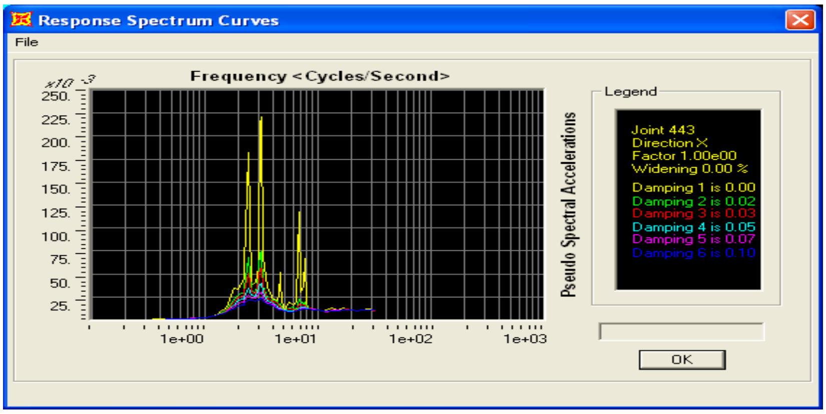
Super-elevation rate (%)	**Traffic Vibration Frequency (Hz)**		
	X	**Y**	**Z**
0	2.98	2.35	3.07
2	3.16	2.73	3.07
4	3.16	2.81	3.07
6	3.16	2.81	3.54
8	3.16	2.73	3.67
10	3.16	2.73	3.96
12	2.23	2.23	4.46

4.1. Effect of super-elevation on vibration displacement

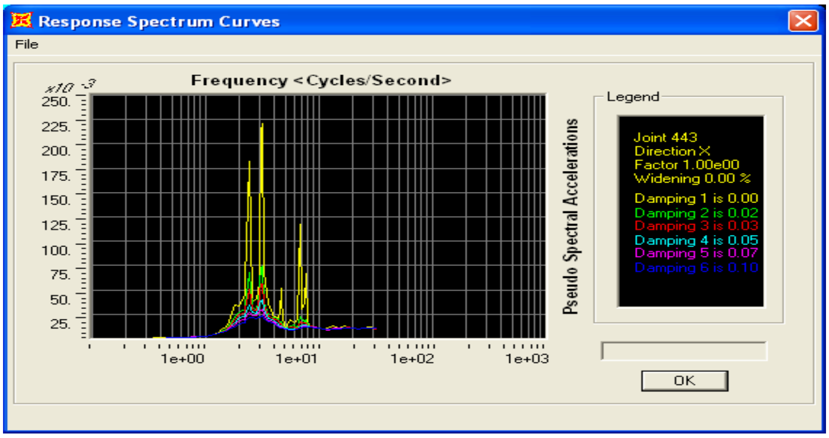
The values of vibration displacement (vibration deflection) are determined in three directions (X, Y, and Z) to recognize the effect of increasing super-elevation rates on vibration displacement when traffic load passes on the surface of bridge structure. For upward vibration displacement, the bridge models appear lower values in three directions. The values of downward vibration displacement are zero in X and Y directions and the maximum values are appeared in Z-direction (vertical direction) which are ranged between 0.0143 m and 0.0155 m. The increasing of super-elevation rates has not important effect on the vibration displacement. Table 4 lists the values of vibration displacement. Figure 8 shows the curves of vibration displacement.



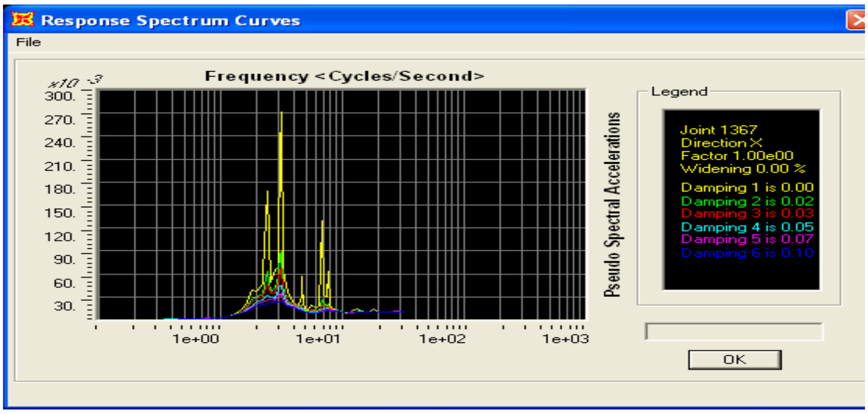
(a) Traffic vibration frequency of 0% super-elevation rate.



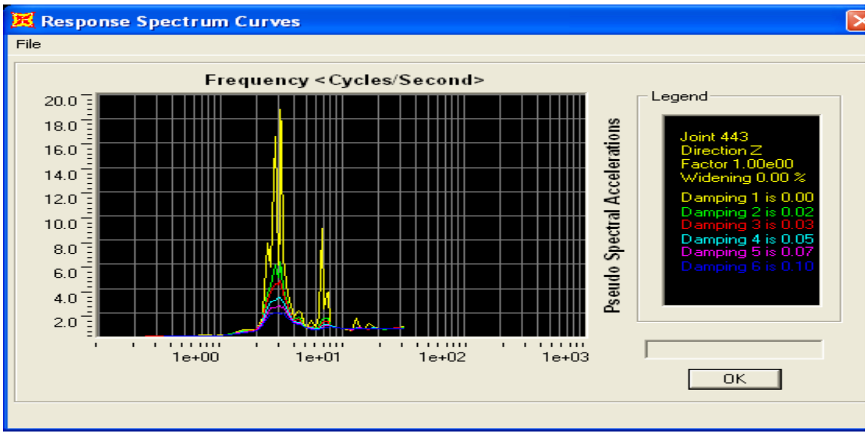
(b) Traffic vibration frequency of 2% super-elevation rate.



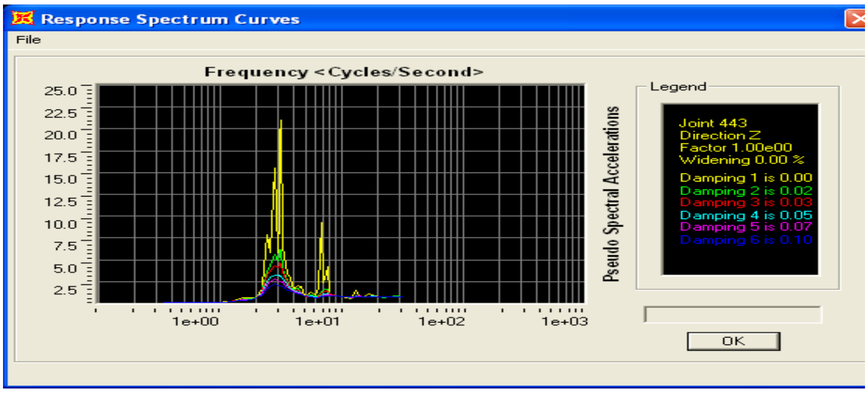
(c) Traffic vibration frequency of 4% super-elevation rate.



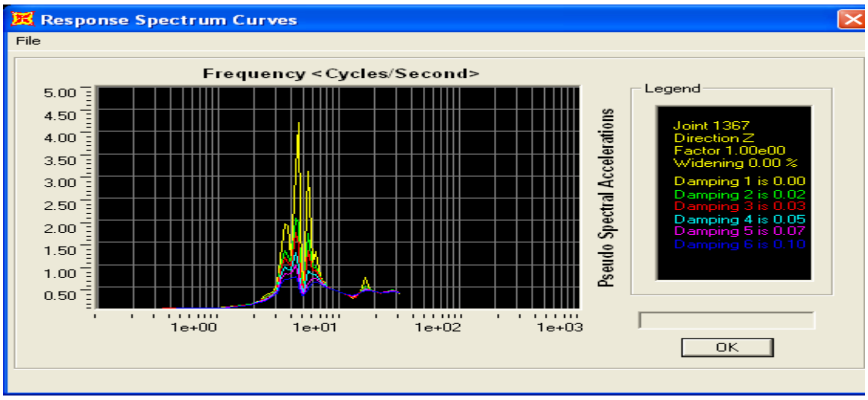
(d) Traffic vibration frequency of 6% super-elevation rate.



(e) Traffic vibration frequency of 8% super-elevation rate.



(f) Traffic vibration frequency of 10% super-elevation rate.

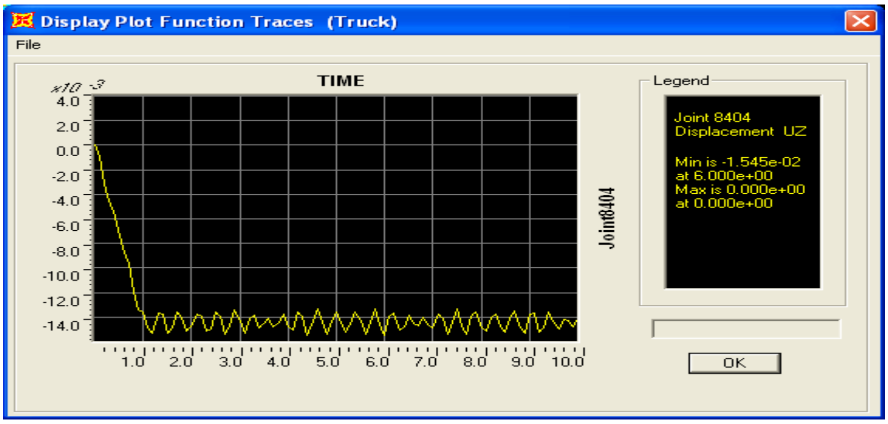


(g) Traffic vibration frequency of 12% super-elevation rate in Z-direction.

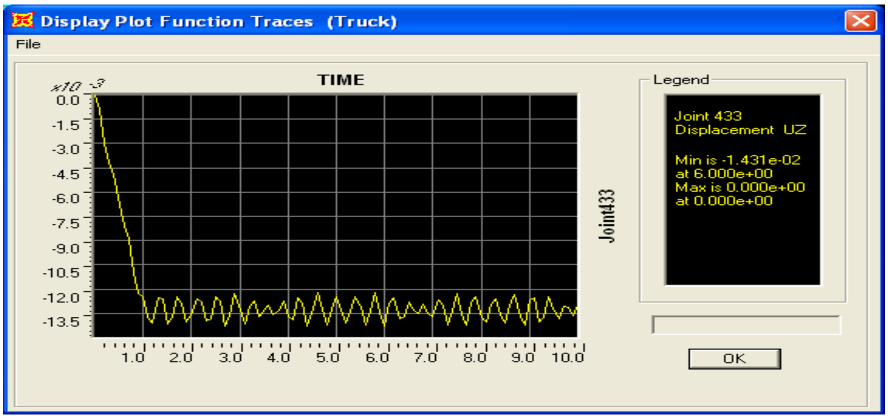
Fig. 7. Analysis results curves of traffic vibration frequency.

Table 4. Values of vibration displacement due to traffic load.

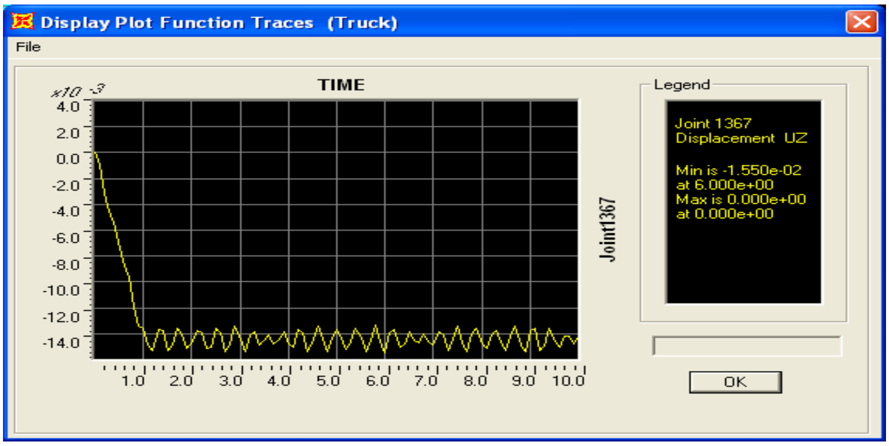
Super-elevation rate (%)	Maximum Upward Dynamic Displacement (m)			Maximum Downward Dynamic Displacement (m)		
	X	Y	Z	X	Y	Z
0	0	0.00417	0	0	0	-0.0154
2	0.000023	0.00178	0	0	0	-0.0143
4	0.000015	0.000219	0	0	0	-0.0155
6	0	0.00256	0	0	0	-0.0155
8	0.0000243	0.00293	0	0	0	-0.0155
10	0.000028	0.0033	0	0	0	-0.0155
12	0.000035	0.0038	0	0	0	-0.0153



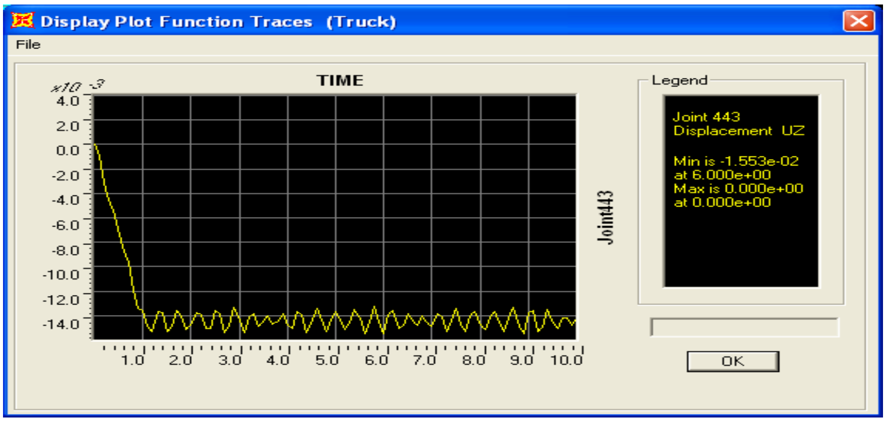
(a) Vibration displacement of 0% super-elevation rate.



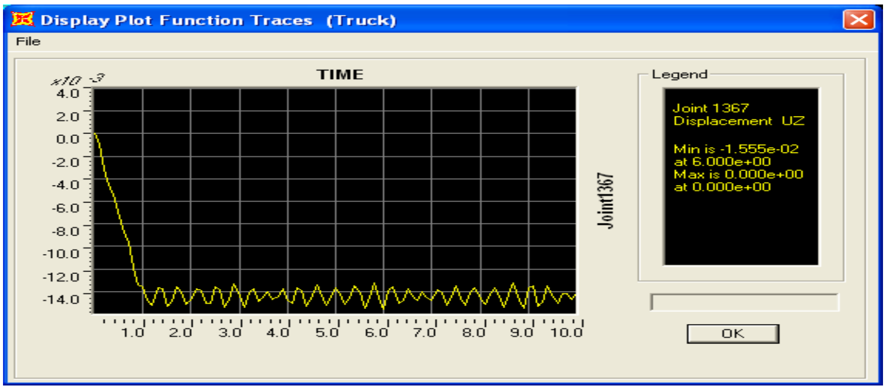
(b) Vibration displacement of 2% super-elevation rate.



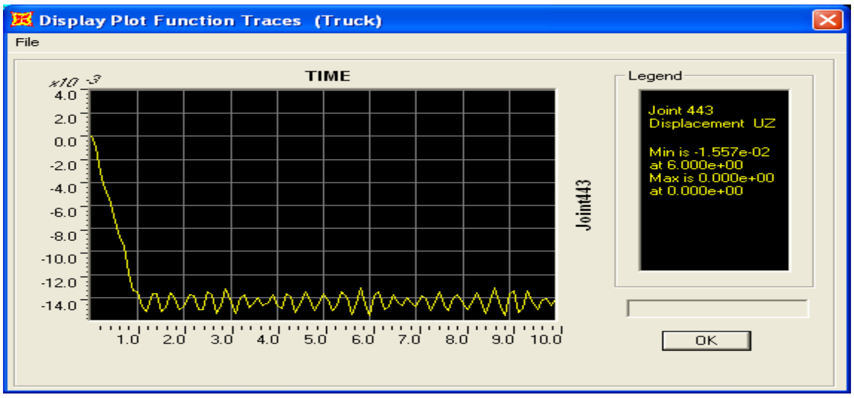
(c) Vibration displacement of 4% super-elevation rate.



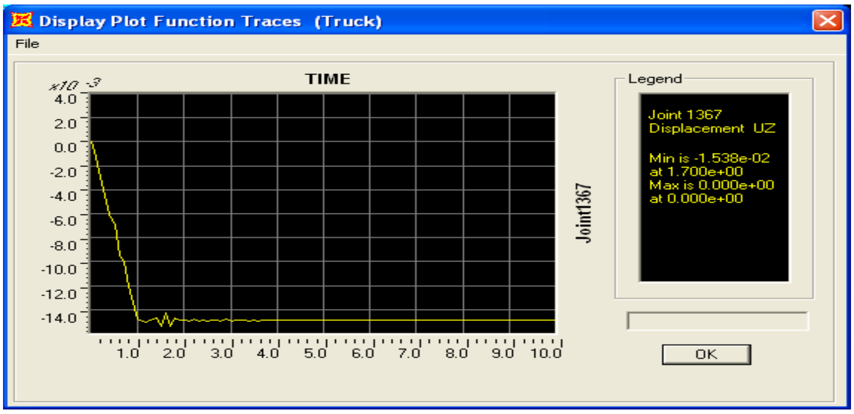
(d) Vibration displacement of 6% super-elevation rate.



(e) Vibration displacement of 8% super-elevation rate.



(f) Vibration displacement of 10% super-elevation rate.



(g) Vibration displacement of 12% super-elevation rate

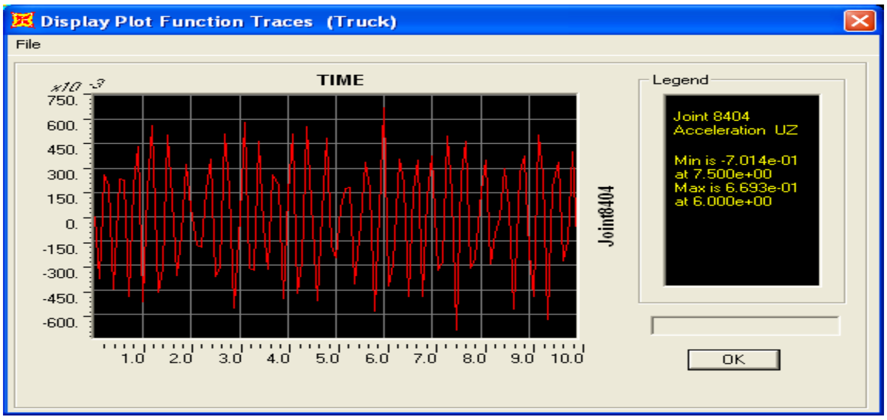
Fig. 8. Analysis results curves of vibration displacement.

4.2. Effect of super-elevation on vibration acceleration

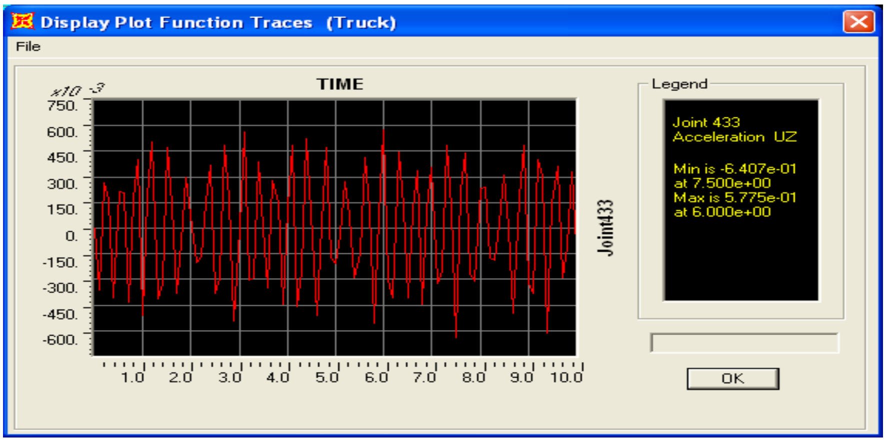
The results of vibration analysis due to vehicle load can be shown in Table 5 and Fig. 9. It can be concluded that the higher values of vibration acceleration are shown in Z-direction and the ranges of values between 0.390 m/s^2 and 0.765 m/s^2. The lower value is appeared within model that has 12% of super-elevation rate. The increasing of super-elevation rates has important effect on vibration acceleration.

Table 5. Values of vibration acceleration.

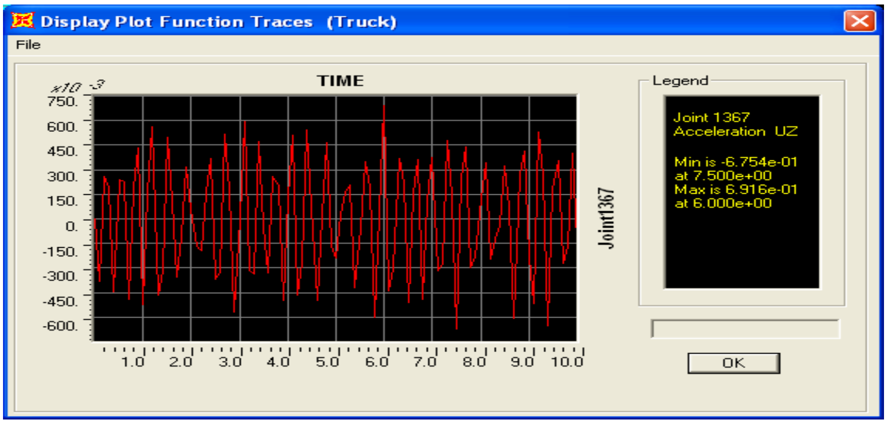
Super-elevation rate (%)	Maximum Upward Dynamic Acceleration (m/s^2)			Maximum Downward Dynamic Acceleration (m/s^2)		
	X	Y	Z	X	Y	Z
0	0.00807	0.0382	0.669	-0.0101	-0.0398	-0.704
2	0.00618	0.0470	0.577	-0.0058	-0.0443	-0.644
4	0.00938	0.0647	0.691	-0.0109	-0.0617	-0.675
6	0.0107	0.0877	0.676	-0.011	-0.082	-0.676
8	0.0119	0.0110	0.744	-0.011	-0.099	-0.702
10	0.0137	0.130	0.776	-0.012	-0.112	-0.765
12	0.000924	0.0711	0.383	-0.0110	-0.086	-0.390



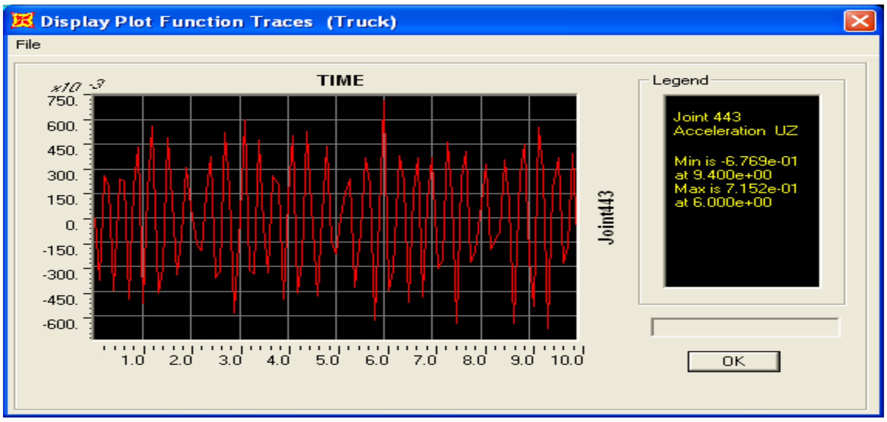
(a) Vibration acceleration of 0% super-elevation rate.



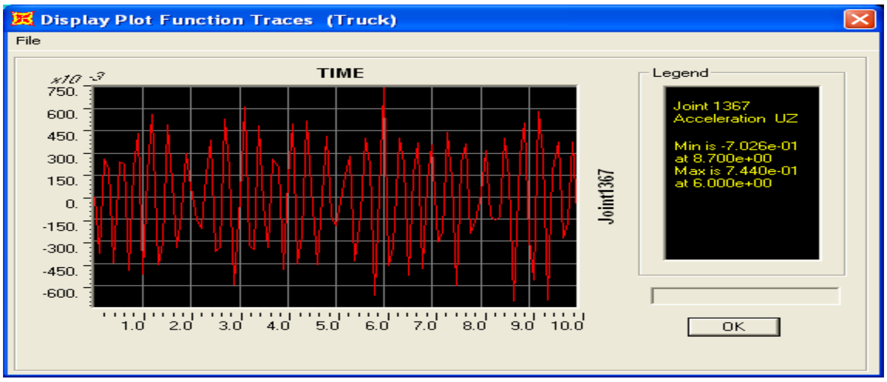
(b) Vibration acceleration of 2% super-elevation rate.



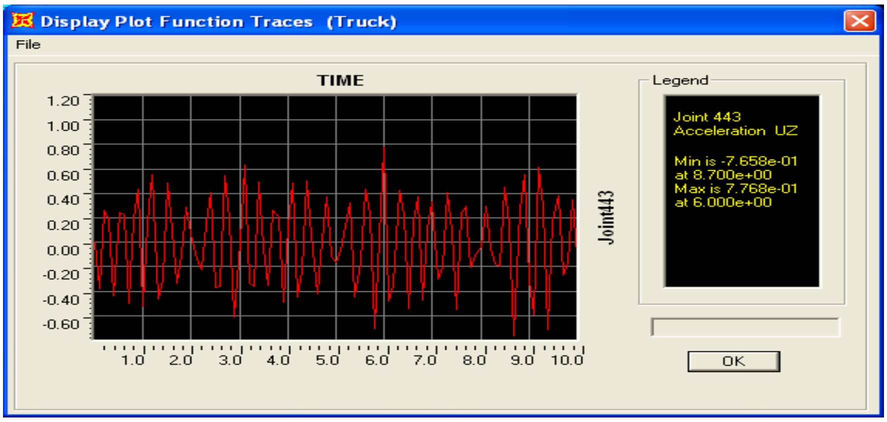
(c) Vibration acceleration of 4% super-elevation rate.



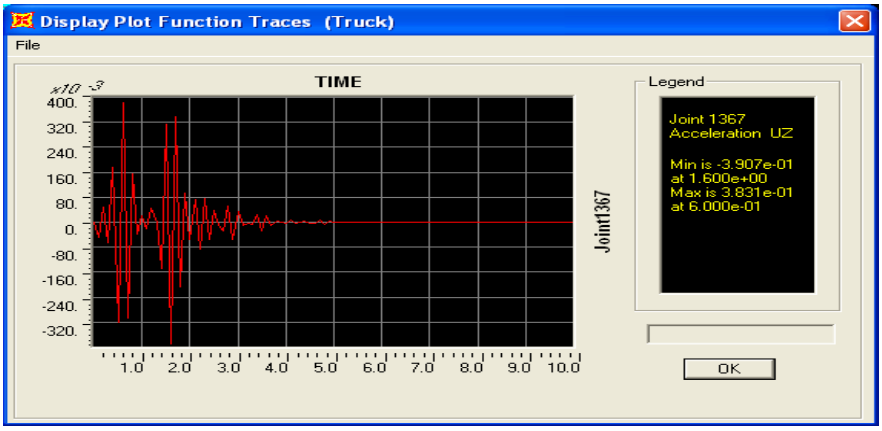
(d) Vibration acceleration of 6% super-elevation rate.



(e) Vibration acceleration of 8% super-elevation rate.



(f) Vibration acceleration of 10% super-elevation rate.



(g) Vibration acceleration of 12% super-elevation rate.

Fig. 9. Analysis results curves of vibration acceleration.

5. Conclusions

In this study, horizontal curved concrete box girder bridge (one cell) is selected as a bridge type. Seven bridges models are used with different rates of super-elevation which is 0%, 2%, 4%, 6%, 8%, 10%, and 12%. For all bridges models, the bridge model consists of five spans. Each span has length is 30 m. Finite element analysis method was used to study the effect of super-elevation on static and dynamic properties of bridge structure by adopting SAP2000 Ver. 14 software. Some concluding explanations from this study are given below:

- The results of static finite element analysis of bending moment, axial force, and shear force, shown that there is not important effect of super-elevation rates increasing on the static properties of bridge models. The positive bending moment was increased with increasing of super-elevation rates until rate 8%. The maximum value is 35998 kN.m within model has 6% super-elevation rate and the minimum value of positive bending moment is 35194 kN.m in model that has 0 super-elevation. For negative bending moment, model of 0% super-elevation rate had the maximum value which is 37548 kN.m and the minimum value is 35967 kN.m. For vertical deflection due to service load, the models have 0%, 2%, and 4% of super-elevation appear the lower value of vertical deflection that equal to 7.7 mm and the models have 6%, 8%, 10%, and 12% of super-elevation give the higher value of vertical deflection which is equal to 7.9 mm. The values of vertical deflection due to prestressed tendons are decreased from 12 mm to 11 mm, when the super-elevation rates are increased. Therefore, the increasing of super-elevation rates had effect on the upward vertical deflection due to loads of prestressed tendons.

- Modal analysis results show that the increasing of super-elevation rates had no effect on the natural frequency and the values of natural frequency are 3.07 Hz for all models of bridge structure because of the natural frequency depending on the total dead load of bridge structure (weight of bridge structure) which was constant for all bridge models and there were no change in bridge models dimensions.
- Dynamic analysis was applied in the three dimension of bridges models (X-direction, Y-direction, and Z-direction). The maximum values of traffic vibration frequency in X, Y, and Z is 3.16 Hz, 2.81 Hz, and 4.46 Hz respectively. The higher value was 4.46 Hz in Z-direction within model 12% of super-elevation rate. The most values in X and Y directions were less than values of natural frequency, but in Z-direction, the values of natural frequency were less than traffic vibration frequency values, indicating that the increasing of super-elevation rates had significant effect on the dynamic properties and it will lead to decrease the stiffness of bridge structure. Other's vibration parameters such as vibration displacement and vibration acceleration were not affected by increasing of super-elevation rates.

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