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Influence of Constructing Transverse Concrete Diaphragms in Different Distances on the Dynamic and Static Behavior of Prestressed Concrete T-Beam Bridge Structure

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Abstract. Structure of diaphragm was defined as a transverse strengthener beam which was located between beams or girders to keep section geometry. It plays a significant role to provide the stability of bridge girders and to distribute the vertical and axial loads. The main objective of this study was to investigate the influence of construction transverse concrete diaphragms between T-beams at different distances on the dynamic and static behavior of T-beam bridge structure. The methodology of this research includes five case studies. The first case had no transverse diaphragms, the second case had transverse diaphragms at the supports of the bridge (abutment and piers), the third case had transverse diaphragms at the center of each span of the bridge, the fourth case had transverse diaphragms at 1/4 of each span of the bridge, and the fifth case had transverse diaphragms at 3 m of each span of the bridge. Three analysis methods were used to determine the dynamic responses by using finite element analysis method in CSI-Bridge ver. 20. These methods included modal analysis, time history analysis, and spectra responses analysis. Dynamic responses consisted of unloaded frequency, loaded frequency, and dynamic displacement. Static analysis was done to find static responses such as bending moment and vertical deflection. The results of dynamic analysis shown that the using of concrete diaphragms has not important effect on the improvement of unloaded frequency (natural frequency) in vertical and horizontal directions, but they had an important effect on the reducing of loaded frequency (vibration frequency) in vertical and horizontal direction and dynamic displacement. For static state, the construction of concrete diaphragms causes to increase bending moment and downward vertical deflection because of these cross diaphragms lead to increase in the dead load (self-weight of structure), resulting the increasing in the static responses due to service loads (dead load, prestressed load, and trucks load). Therefore, there is need to increase the prestressed load to resist the over load due to the construction of transverse diaphragms.

Keywords. *Dynamic, static, T-beam Bridge, transverse diaphragms, frequency, displacement.*

INTRODUCTION

Structures of bridges are one of the weakest links of a safely transportation system to permit safe transportation of traffic and pedestrians. Structures of the bridge are generally valued by using analytical methods based on structural plans, optical investigation, and infrequently tested with loading. In different types, bridges are important civil structures constructed to length and width over some obstacles such as water, valleys, and roads and rails networks. These structures afford main linking between different parts of transportation system. Commonly, all bridges structure involve of two parts. These parts are superstructure and substructure. The superstructure involve all members of the bridge above the substructure such as asphalt pavement surface, the concrete or steel deck, different types of beams and girders. The main job of the superstructure is to accumulate the different types of

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loads (dead load, live load, wind load, and thermal load) and then transferring them into the substructure of the bridge structure. The substructure receipts actions from superstructure as a foundation of the bridge and it included the piles, piles cap, abutments, piers (columns), piers cap, bearings, pedestals, and retaining walls. (1-6)

A simply supported bridge is constructed using beams or girders crossing between only two supports such as abutments or piers. In general, the length of bridge can be separated into numbers of individual spans. For each span, the load carrying part is simply supported at each both end. A simply supported bridges may also be desirable if the bridge can be a part of a facility such as an interchange and there needs be remove or addition of one or other spans. A simply supported bridges are more suitable for short bridges and for places which need higher speed of construction. (7)

T-beam bridge is a prestressed reinforced concrete bridge which consists of the uniform slab (deck) with supporting beams and it has shape of a beam cross section that look like a sequence of T-beams. It is a load-bearing structure that can be produced more effectually by overturning T-beam with a slab or bridge deck by connecting the higher ends of the beam. Prestressed concrete T-beam bridges were usually used in the 1970s and 1980s due to their simple force and suitable design and erection. T-beam girders are reflected as the best appropriate choices for short and intermediate span of bridges structures (8). T-beam girder bridges are ideal up to 25 meters in length for each span (9). Generally, the superstructure of T-beam bridge involves concrete slab, beams or girders, transverse girders, barriers and abutments. The significant effects about selection of bridge superstructure are economy and safety. (10, 11, 12, 13, 14)

The design of the bridge is a significant addition to the difficult approach of structural engineers. The span length and live load are continually significant parameters in the situation of bridge design. These parameters can be affected the concepts phase of design. The effect of live load for different spans are various. The choice of structural system for span is a constraint for research. Structure systems accepted are affected by some factors such as economy and complexity in the erection. There are various methods used in the design of T-beam bridge such as AASHTO specifications, grillage and finite element methods. (15)

Structural diaphragm is a transverse strengthener beam located between beams or girders to keep section geometry. It plays a significant role in providing bridge girders' stability and distributing the vertical and axial loads. It also offers restraint for the horizontal torsional buckling of the girders. Diaphragms can be classified according to their location in superstructure of bridge, materials, and their behavior. For location, end diaphragms are located in the both end of beams or girders and intermediate diaphragms are placed along the girders (1/4 of girder, 1/2 of girder, 3/4 of girder or each knowing distance according design). According to materials, diaphragms can be made by using steel in steel bridges as cross frame form and in the form of a reinforced concrete beam for concrete girder bridges (prestressed and normal concrete bridges). According to their behavior, the cross beam can be classified as bracing and flexural diaphragms. Generally, the diaphragm is a critical structural component of stability for twin girders and it helps the slab in the crosswise path to be rigidified and the stresses on each girder to be transferred. Diaphragms can be used to resist the horizontal wind load. (16, 17, 18, 19, 20)

When structure of bridges subjected to over height traffic of different vehicles types, leading to damage and service disruption of bridges. The using of horizontal transvers intermediate diaphragms to connect the reinforced concrete girders can increase the impact resistance and as a result, long service life of bridges. By using dynamic and static mathematical finite element analysis, the influence of intermediate diaphragms in prestressed concrete bridge girders which are subjected to over height vehicle impacts can be determined. There are several important factors considered in the design of intermediate diaphragm. These factors include the position of intermediate diaphragms within the span of the bridge, dimensions of intermediate diaphragms such as height and width, transverse distance between girders, different kinds of girder, features a ratio of the bridge with the number of girders, vehicle speed, and impact force. (21, 22, 23)

Modal properties of bridge structure such as natural frequencies and mode shapes can be changed when there is a variation in the mass and stiffness of the bridge structure. Theoretically, the natural frequencies and mode shapes of the adapted bridge structure must be satisfied an eigenvalue equation. (The amount of disquiet in natural frequency and mode shape is influenced by the value and how the mass and stiffness of the system are changed. (24)

Bridge structural analysis ordinarily comprises engineering software models. Models can be created using proper material properties, boundary conditions, and different types of loads. Structural supporters and links joints are balanced to transfer all possible loads to the foundation of bridge. These loads include permanent loads, traffic live loads, wind loads, and earthquake actions. (25)

Loaded vibration of bridge structure due to the crossing of traffic loads is imperative in the design of bridge structure. Dynamic responses of the bridge have additional importance with the introduction of faster and heavier vehicles and the use of structural systems and materials that allows the bridge to be more slender. Interaction between the vehicle and the bridge is a difficult dynamic phenomenon. (26, 27)

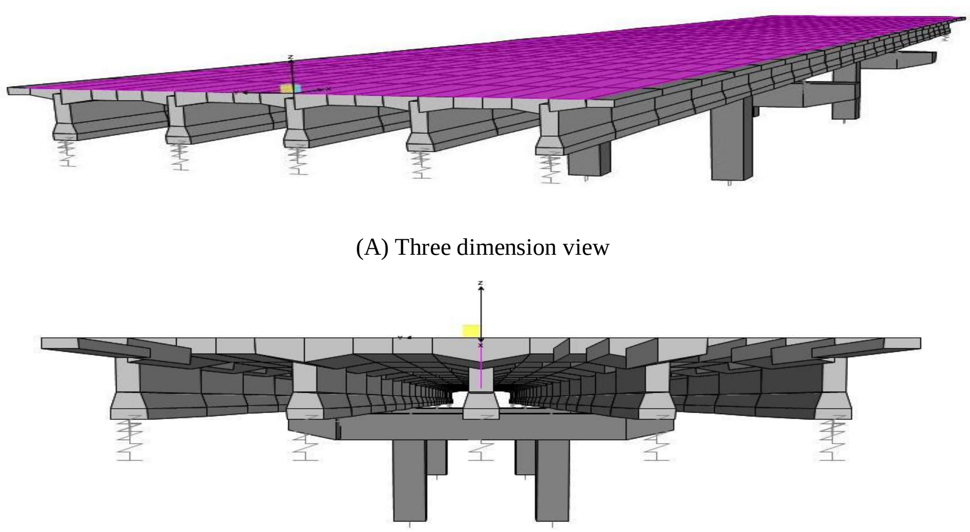
Finite element analysis is an active method to determine the static structural performance of the bridges structures because it can save design time, cost of erection, and increase the structure safety. The finite element assessment considers the main function of any complex analysis. It is very advantageous in the difficult application within geometrical situations, material properties, boundary conditions and loads. Generally, bridge structure is analyzed by adopting static and dynamic methods. There are some factors than can effect on the selection of a suitable method of bridge analysis. These factors include the significance of analysis, significance of structure, kind of the structures, and soil situations. (28, 29, 30, 31, 32)

MODELS OF STRUCTURES DESCRIPTION

This study uses T-beam simply supported bridge to investigate the dynamic and static behavior of bridge structure under trucks and service loads by using different horizontal distance between concrete diaphragms. The total length and width of bridge is 60 m and 11 m respectively. It consists of three spans and each span has 20 m length. The superstructure of bridge includes five prestressed concrete T-beams with 30 cm concrete deck. The substructure of bridge consists of bearing, pier cap (12 m length), two concrete piers (depth=1 m, width= 1 m, height = 5 m), and spring foundation. The type of prestresserd load is a posttensioned. The profile of prestressed tendons is straight with bends. Tendon modeling option is an element. Live load includes truck load type AML. In this study, five case studies are used. The first case has not diaphragms, the second case has diaphragms at the supports of bridge (abutment and piers), the third case has diaphragms at the center of each span, the fourth case has diaphragms at 1/4 of each span, and the fifth case has diaphragms at 3 m of each span. Table 1 list the distance between diaphragms. Fig. 1 shows the bridge model. The thickness of diaphragms is 30 cm. Fig. 2 shows the bridge models with different distance between diaphragms.

TABLE 1. Distance between diaphragms in meter.

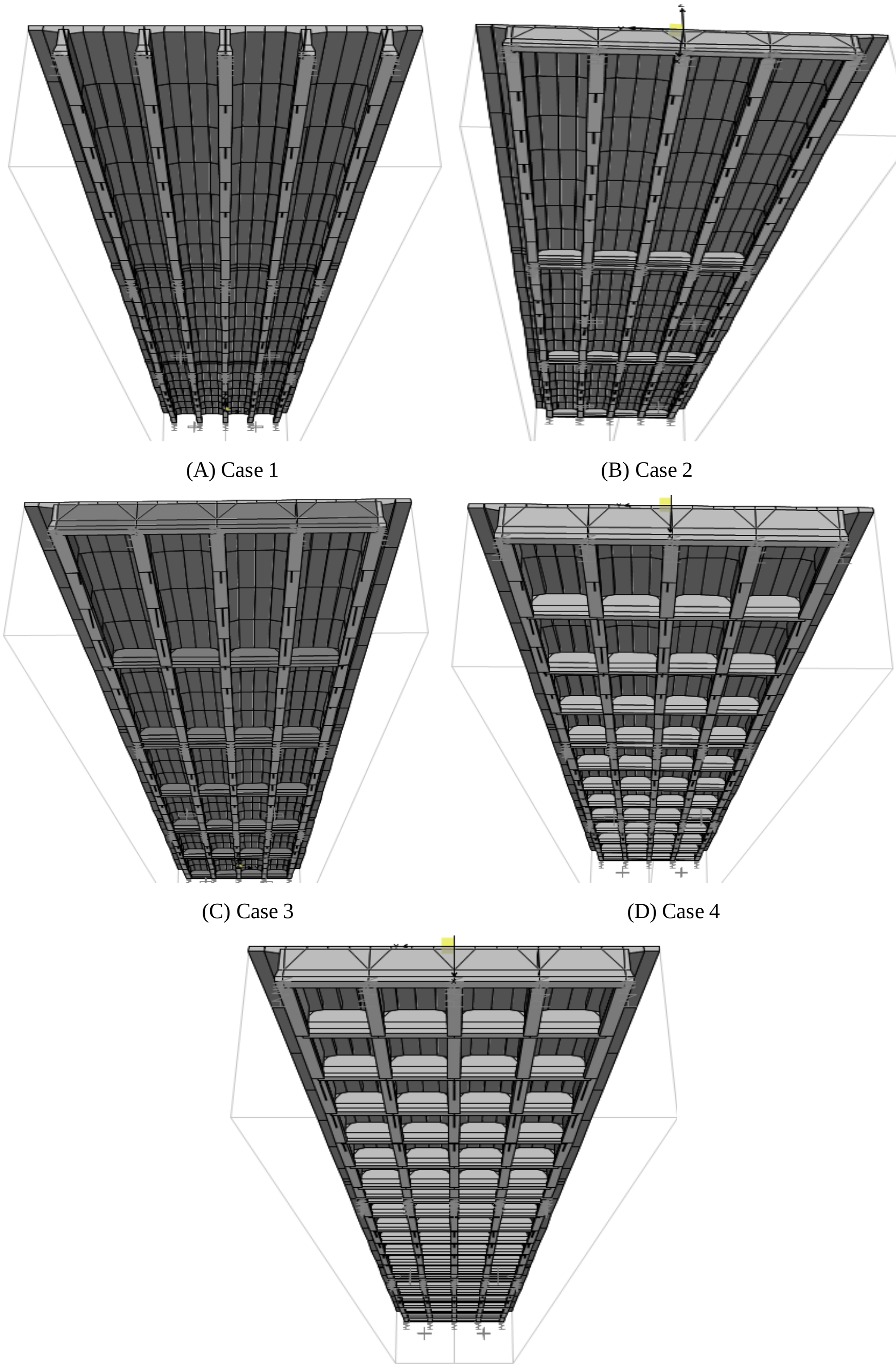
Case study No.	**1**	**2**	**3**	**4**	**5**
Case study symbol	A	B	C	D	E
Distance between diaphragms (m)	No diaphragms	At Abutment and piers	At Center of each span (at 10m)	At 1/4 of each span (At 5m)	At 3 m of each span



(A) Three dimension view

(B) Front view

FIGURE 1. T-beam bridge model



(A) Case 1

(B) Case 2

(C) Case 3

(D) Case 4

(E) Case 5

FIGURE 2. Bridge models with different distance between diaphragm

DYNAMIC ANALYSIS

CSI bridge ver. 20 software is used in the analysis of bridge structure. Three dynamic analysis methods are adopted to find dynamic responses due to using different horizontal distance between diaphragms under trucks and services loads. These methods are modal analysis, time history analysis, and spectra responses analysis. This study will depend on unloaded frequency in vertical and horizontal direction, loaded frequency in vertical and horizontal direction, loaded dynamic displacement in vertical and horizontal direction, and loaded dynamic acceleration as dynamic responses.

Unloaded Frequency in Vertical Direction (Vibration under Dead Load)

Unloaded frequency is the natural frequency representing the natural vibration of the bridge structure under dead load (self-weight) without any moving load (live load). It can be determined by using modal analysis method, depending on the mode shapes of bridge structure. Table 2 and Fig. 3 explain the modal analysis results for the first six modes of bridge models under the effect of dead load for case studies. Fig. 4 and Fig. 5 show the first six mode shapes of cases 1 and 5, respectively. It can be seen that the using of concrete diaphragms has no important effect on the improvement of unloaded frequency (natural frequency). The values of unloaded frequency are increased between case 1 and case 2, but a small percent decreases them from case 3 to case 5. Therefore, the average values of unloaded frequency for all case studies ranged between 5.09 Hz and 5.50 Hz. The construction of concrete diaphragms between beams will lead to an increase in the dead load of the bridge structure, causing a decrease in the unloaded frequency, leading to decreased stiffness of the bridge structure.

TABLE 2. Results of unloaded frequency in the vertical direction of bridge models

Mode No.	Case Study 1	Case Study 2	Case Study 3	Case Study 4	Case Study 5
1	3.18	3.82	3.79	3.72	3.60
2	4.45	5.38	5.32	5.19	5.02
3	5.53	5.56	5.41	5.24	5.05
4	5.72	5.77	5.59	5.43	5.25
5	5.81	6.01	5.82	5.66	5.46
6	5.93	6.50	6.36	6.31	6.19
Average Value (Hz)	5.10	5.50	5.38	5.25	5.09

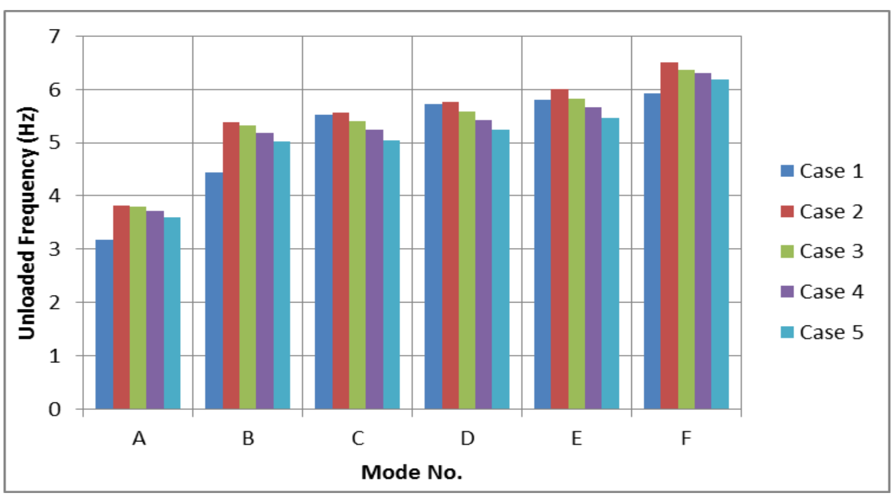
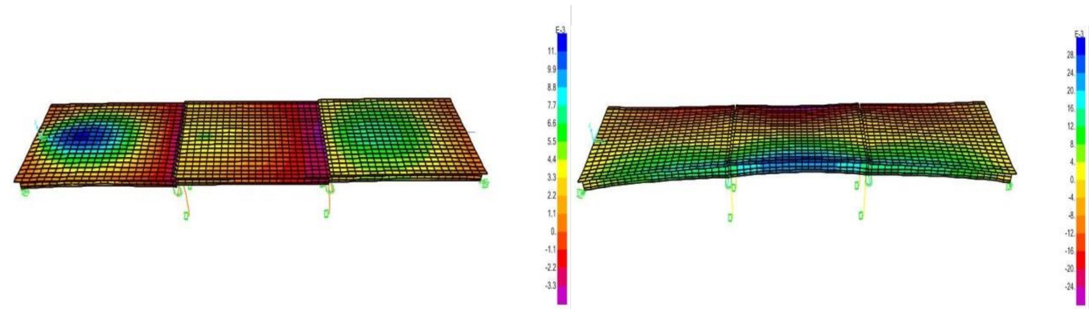
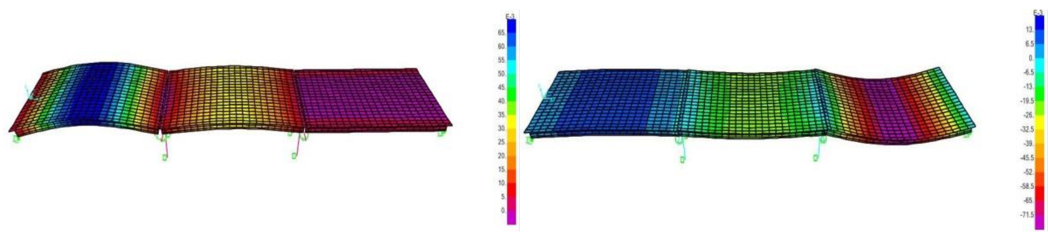


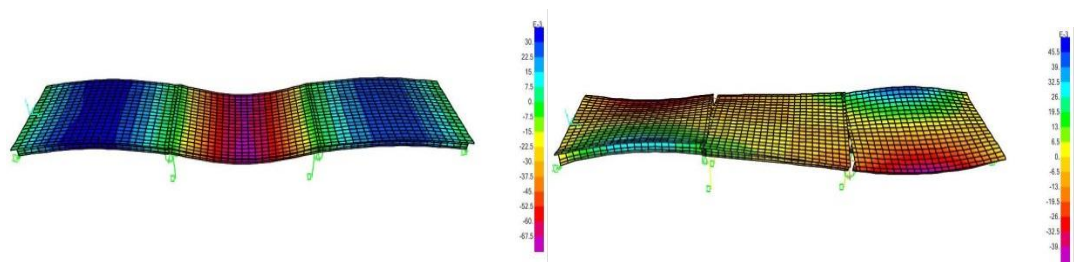
FIGURE 3. Results of unloaded frequency in vertical direction of bridge models



(A) Mode 1 (B) Mode 2

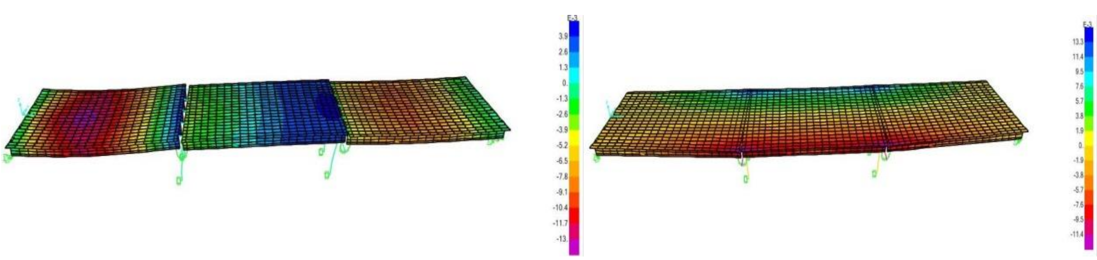


(C) Mode 3 (D) Mode 4

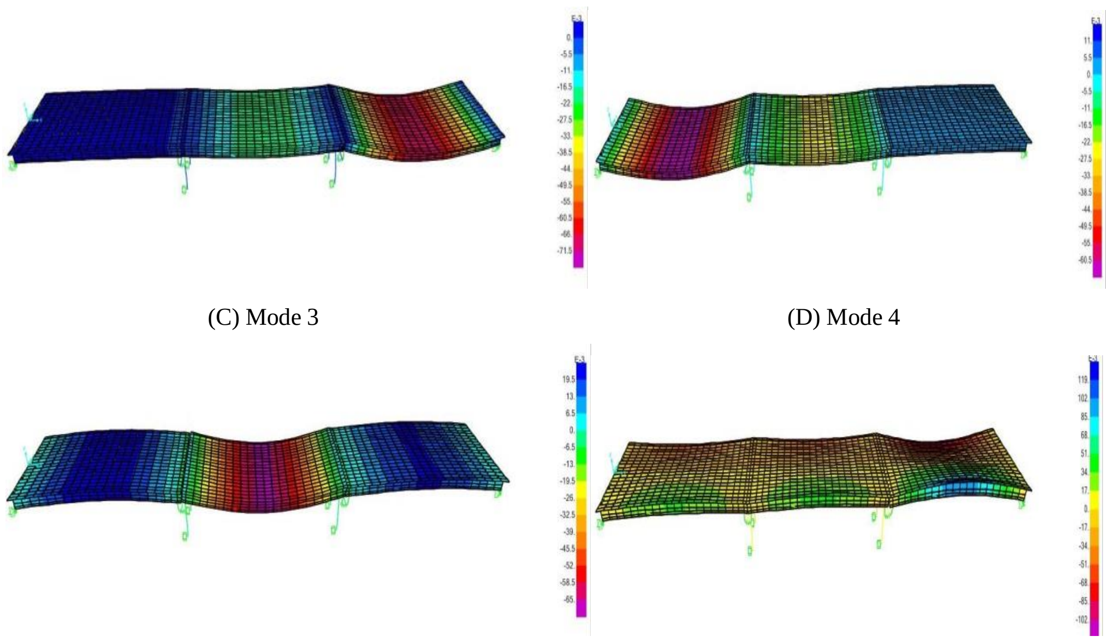


(E) Mode 5 (F) Mode 6

FIGURE 4. The first six mode shapes in vertical direction for Case 1



(A) Mode 1 (B) Mode 2



(C) Mode 3 (D) Mode 4

(E) Mode 5 (F) Mode 6

FIGURE 5. The first six mode in vertical direction shapes for Case 5

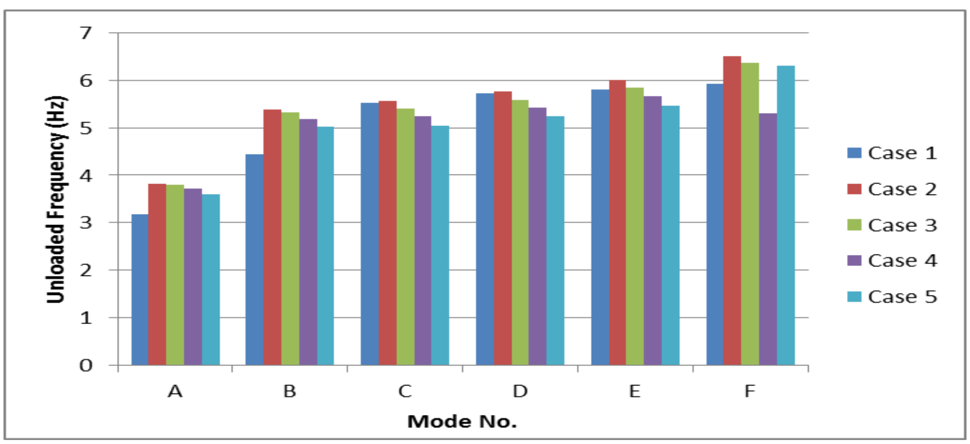


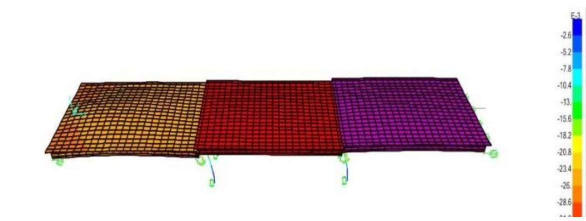
FIGURE 6. Values of unloaded frequency in horizontal direction of bridge models

Unloaded Frequency in Horizontal Direction (Vibration under Dead Load)

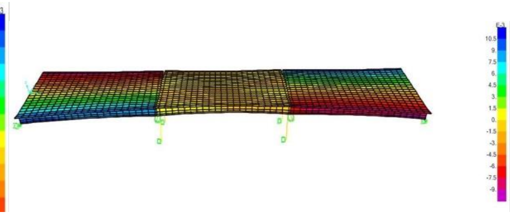
For horizontal direction, the natural vibration of bridge structure under dead load has the same values of unloaded frequencies except for case 4 and case 5. The average values of case 4 are decreased from 5.25 Hz to 5.09 Hz and the average values of caser 5 are increased from 5.09 Hz to 5.11 Hz. Table 3 and Figure 6 explain the modal analysis results for the first six modes of bridge models under the effect of dead load for case studies. Fig. 7 and 8 show the first six mode shapes of case 1 and case 5 respectively.

TABLE 3. Results of unloaded frequency in horizontal direction of bridge models

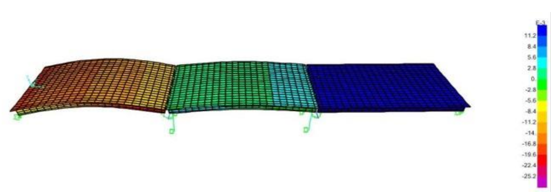
Mode No.	Case Study 1	Case Study 2	Case Study 3	Case Study 4	Case Study 5
1	3.18	3.82	3.79	3.72	3.60
2	4.45	5.38	5.32	5.19	5.02
3	5.53	5.56	5.40	5.24	5.05
4	5.72	5.77	5.59	5.43	5.25
5	5.81	6.01	5.85	5.66	5.46
6	5.93	6.50	6.36	5.31	6.30
Average Value (Hz)	5.10	5.50	5.38	5.09	5.11



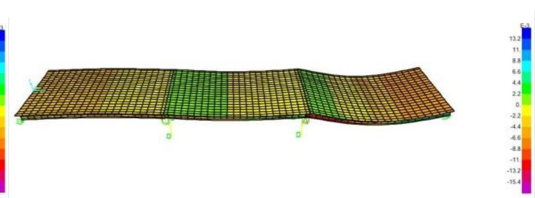
(A) Mode 1



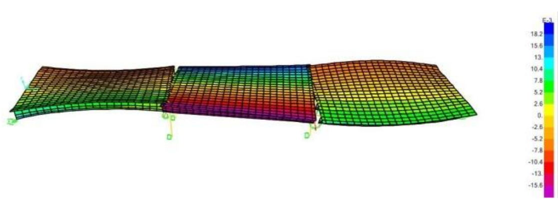
(B) Mode 2



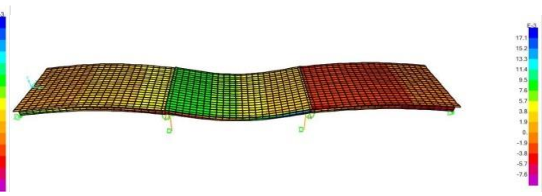
(C) Mode 3



(D) Mode 4

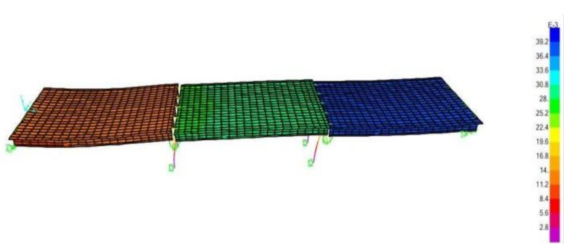


(E) Mode 5

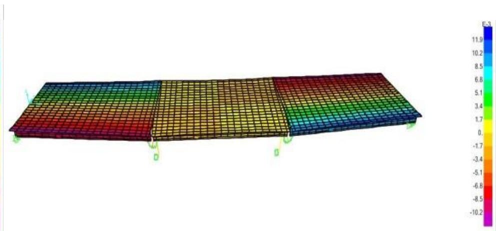


(F) Mode 6

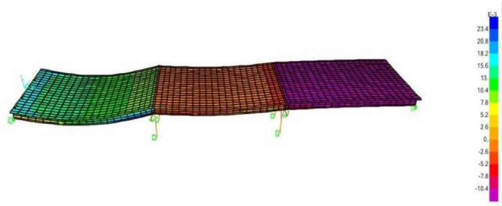
FIGURE 7. The first six mode shapes in horizontal direction for Case 1



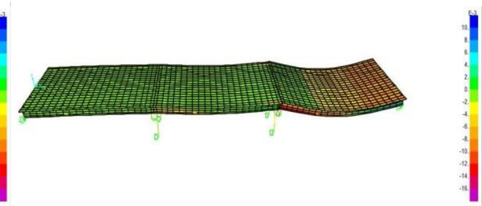
(A) Mode 1



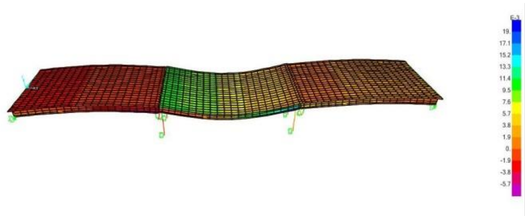
(B) Mode 2



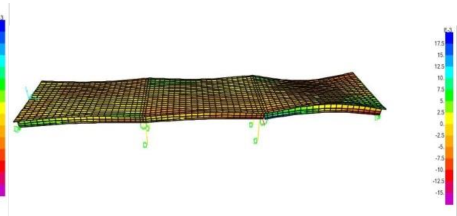
(C) Mode 3



(D) Mode 4



(E) Mode 5



(F) Mode 6)

FIGURE 8. The first six mode shapes in horizontal direction for Case 5

Loaded Frequency in Vertical Direction (Vibration under Truck Load)

Loaded frequency is called vibration frequency which is measured in Hz and it can be determined by using time history analysis under truck loads. It represents the vibration of bridge structure due to pass of traffic loads on the bridge's superstructure. Table 4 and Figure 9 give the loaded frequency values for case studies in the vertical direction. It can be noted that the using of concrete diaphragms in the construction of bridge structure has significant effect on the reducing of loaded frequency (vibration frequency) because of these diaphragms work as connected cross beams and they can increase the stability and stiffness of T-beams. The average values of loaded frequency in vertical direction are 4.69 Hz for case 1, 4.39 Hz for case 2, 4.06 Hz for case 3, 3.75 Hz for case 4, and 3.30 Hz for case 5. (These values are decreased with an increasing diaphragm number or decreasing distance between diaphragms.

TABLE 4. Values of loaded frequency for case studies in vertical direction

Case Study No.	Span No.	Loaded Frequency (Hz)	Average Value (Hz)
Case Study 1	1	4.69	4.69
	2	4.69	
	3	4.69	
Case Study 2	1	4.34	4.39
	2	4.45	
	3	4.39	
Case Study 3	1	4.12	4.06
	2	4.08	
	3	4.0	
Case Study 4	1	3.79	3.75
	2	3.84	
	3	3.62	
Case Study 5	1	3.31	3.30
	2	3.21	
	3	3.39	

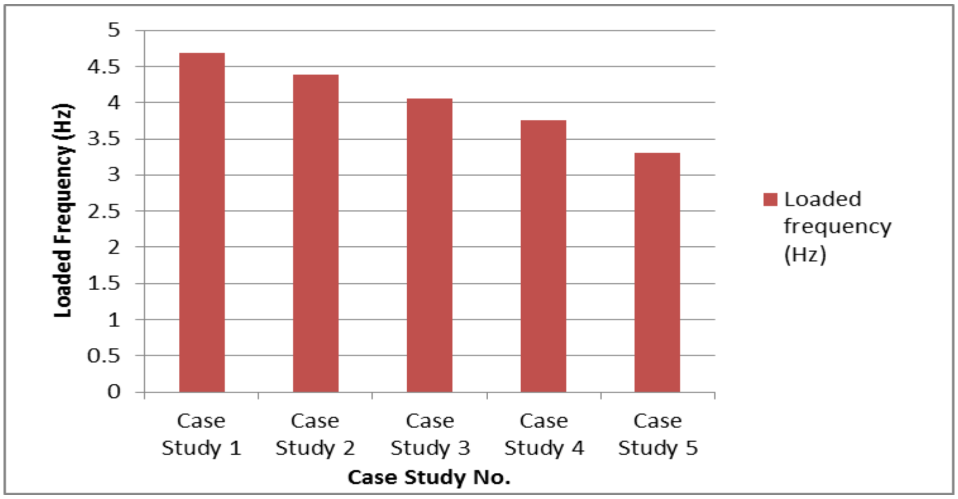


FIGURE 9. Values of loaded frequency for case studies in vertical direction

Loaded Frequency in Horizontal Direction (Vibration under Truck Load)

Table 5 and Figure 10 show the loaded frequency values in the transverse and longitudinal direction (horizontal direction) of the bridge structure for case studies under truck loads. It is indicated that the vibration state in horizontal direction is more than the vibration in vertical direction especially in transverse direction and the construction of concrete diaphragms are effective in reducing the vibration of the bridge structure. Therefore, the diaphragms have important influences on the stability of bridge structure in horizontal direction. Case study 1 (has not diaphragms) appears higher value of loaded frequency in transverse and longitudinal direction which is 5.37 Hz and 4.97 Hz respectively and case 5 which has a higher number of diaphragms gives lower values of loaded frequency which are 3.77 Hz and 3.72 Hz. Fig. 11 shows the values of loaded frequency in three directions.

TABLE 5. Values of loaded frequency in the transverse and longitudinal direction

Case Study No.	Span No.	Loaded Frequency in transverse direction (Hz)	Average Value (Hz)	Loaded Frequency in longitudinal direction (Hz)	Average Value (Hz)
Case Study 1	1	5.42	5.37	4.97	4.97
	2	5.42		4.97	
	3	5.27		4.97	
Case Study 2	1	5.05	5.06	4.15	4.39
	2	5.45		4.64	
	3	4.69		4.40	
Case Study 3	1	4.92	4.92	3.83	3.90
	2	4.92		3.90	
	3	4.92		3.97	
Case Study 4	1	4.42	4.54	3.83	3.87
	2	4.60		3.90	
	3	4.60		3.89	
Case Study 5	1	4.11	3.77	3.69	3.72
	2	3.95		3.69	
	3	3.25		3.79	

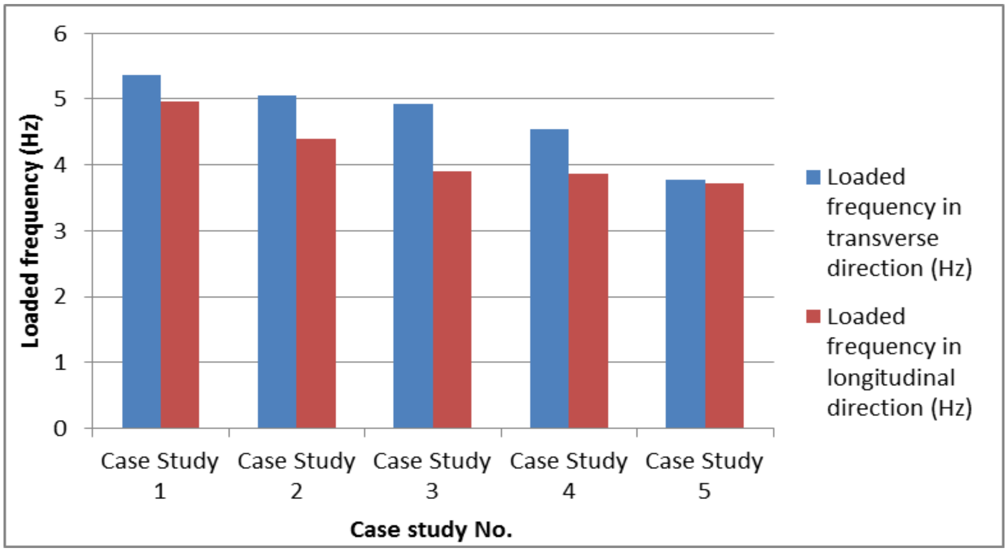


FIGURE 10. Values of loaded frequency in the transverse and longitudinal direction

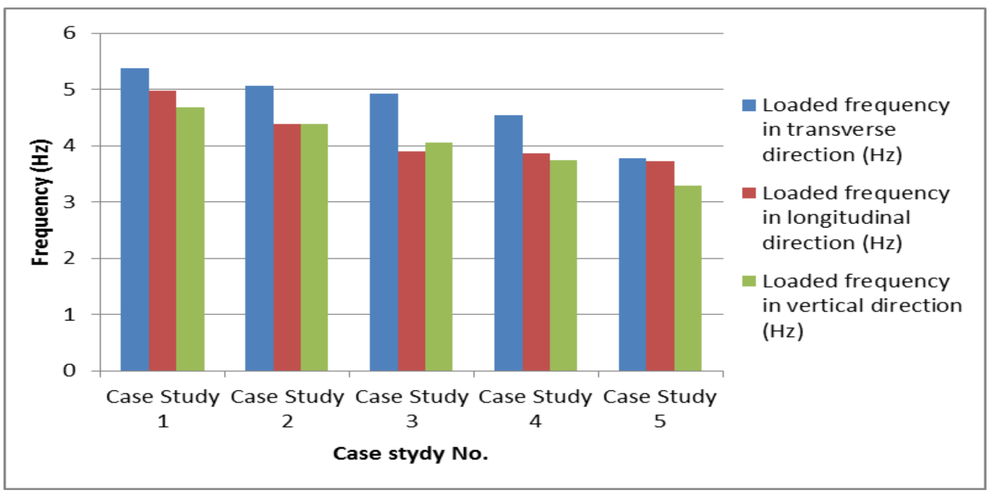


FIGURE 11. Values of loaded frequency in vertical, transverse, and longitudinal direction

Loaded Dynamic Vertical Displacement

Table 6 and Fig. 12 illustrate the dynamic displacement values due to the bridge's vibration in the vertical direction. (The maximum dynamic displacement values appear within case 1, which are 3.61 mm and 3.65 mm in the upward and downward directions. These values are decreased due to construct concrete diaphragms between T-beams to arrive the minimum values in case 5 which are 1.57 mm and 1.88 mm in upward and downward direction respectively. It can be concluded that the increasing of diaphragms number along the spans length of bridge structure leads to decrease the dynamic displacement in upward and downward direction and make the bridge vibrate with minimum level under moving loads.

TABLE 6. Values of dynamic displacement due to vibration of bridge in vertical direction

Case Study No.	Max. Loaded Dynamic Vertical Displacement (mm)	
	Upward	**Downward**
Case Study 1	3.61	3.65
Case Study 2	3.52	3.48
Case Study 3	3.39	3.42
Case Study 4	2.73	2.85
Case Study 5	1.57	1.88

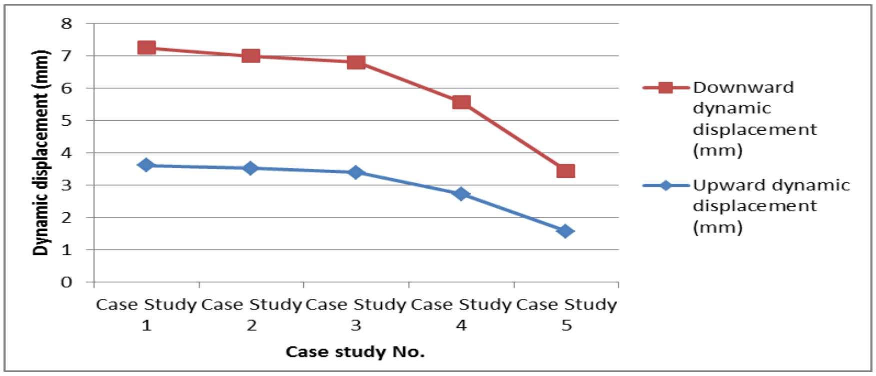


FIGURE 12. Values of dynamic displacement due to vibration of bridge in the vertical direction

STATIC ANALYSIS RESULTS

According to static analysis of bridge structure, the using of concrete diaphragms causes to increase bending moment and downward vertical deflection because of these cross diaphragms lead to increase in the dead load (self-weight of structure), resulting in the rising in the static responses due to service loads (dead load, prestressed load, and trucks load). Therefore, there is a need to increase the prestressed load to resist the over load due the construction of transverse diaphragms. The bending moment values are developed gradually between case 1 and case 5 which are equal to 3967 kN.m and 5200 kN.m respectively. The downward vertical deflection under truck loads still the same for all cases and the use of transverse diaphragms has not to effect on it, but the using of transverse diaphragms has opposite effect on the downward vertical deflection under service loads and the values are increased from 5 mm in case 1 to 8 mm in case 5. Table 7 lists the results of static analysis, Fig. 13 shows the increasing in the values of bending moment in positive and negative state, and Fig. 14 shows the increasing in the values of vertical deflection due to trucks and service loads.

TABLE 7. Results of static analysis

Static Parameters	Case Study 1	Case Study 2	Case Study 3	Case Study 4	Case Study 5
+ Bending Moment	3967	4377.1	4531	4794.3	5200
- Bending Moment	1392	1679.2	1619	1650.3	1734.9
Downward Vertical Deflection of Truck (mm)	2	2	2	2	2
Downward Vertical Deflection of Load Combination (mm)	5	6	6	7	8

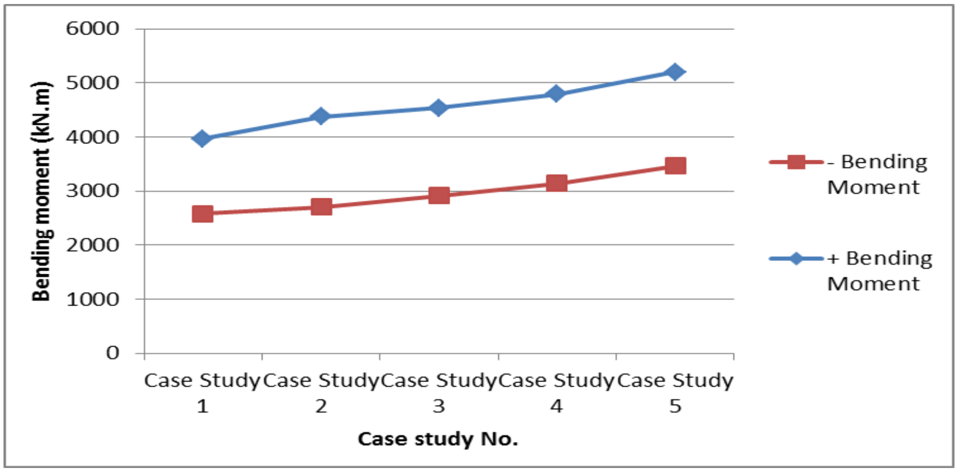


FIGURE 13. The increasing in the values of bending moment

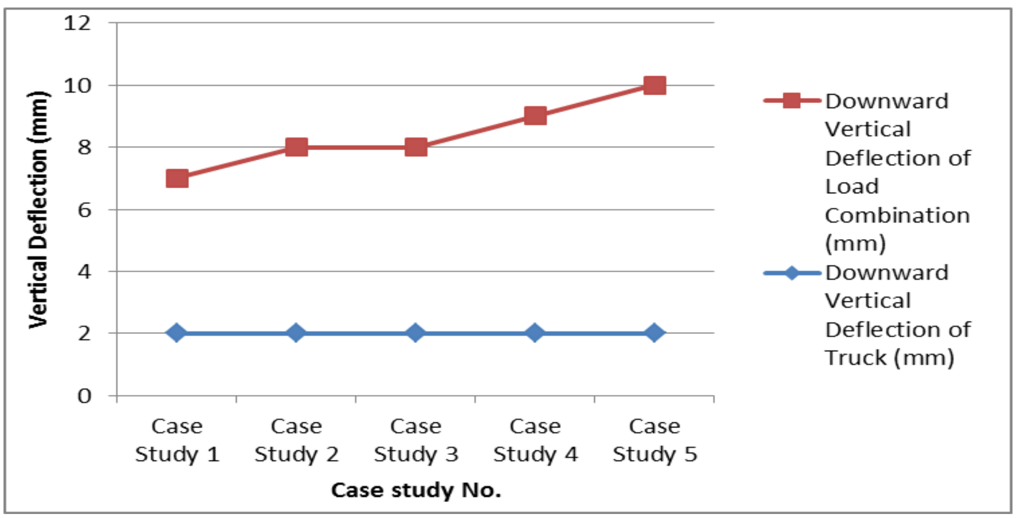


FIGURE 14. The increasing in the values of vertical deflection due to trucks and service loads

CONCLUSION

The conclusions of this study are:

1. The dynamic analysis results show that the use of concrete diaphragms has no important effect on the improvement of unloaded frequency (natural frequency) in the vertical and horizontal directions. The values of unloaded frequency in the vertical direction are increased between case 1 and case 2, but they are decreased by a small percent from case 3 to case 5. Therefore, the average values of unloaded frequency for all case studies ranged between 5.09 Hz and 5.50 Hz. For horizontal direction, the natural vibration of bridge structure under dead load has the same values of unloaded frequencies except for case 4 and case 5. The average values of case 4 is decreased from 5.25 Hz to 5.09 Hz, and the average values of caser 5 are increased from 5.09 Hz to 5.11 Hz.

2. The use of concrete diaphragms in the construction of the bridge structure has significant effect on the reducing of loaded frequency (vibration frequency) in vertical direction. The average loaded frequency values in the vertical direction are 4.69 Hz for case 1, 4.39 Hz for case 2, 4.06 Hz for case 3, 3.75 Hz for case 4, and 3.30 Hz for case 5. These values are decreased with increasing of diaphragms number or decreasing of distance between diaphragms. For horizontal direction, the diaphragms have important influences on the stability of bridge structure in the horizontal direction. Case study 1 (has not diaphragms) appears higher value of loaded frequency in transverse and longitudinal directions which is 5.37 Hz and 4.97 Hz respectively and case 5 (has higher number of diaphragms) gives lower values of loaded frequency which are 3.77 Hz and 3.72 Hz.

3. The maximum values of dynamic displacement are appeared within case 1 which are 3.61 mm and 3.65 mm in upward and downward direction respectively. These values are decreased due to the construction of concrete diaphragms between T-beams to arrive the minimum values in case 5 which are 1.57 mm and 1.88 mm in upward and downward direction respectively. The increasing of diaphragms number along the spans length of bridge structure leads to decrease the dynamic displacement in upward and downward direction and make the bridge vibrate with minimum level under moving loads.

4. The using of concrete diaphragms causes to increase bending moment and downward vertical deflection because of these cross diaphragms lead to increase in the dead load (self-weight of structure), resulting in the rising in the static responses due to service loads (dead load, prestressed load, and trucks load). Therefore, there is a need to increase the prestressed load to resist the over load due to the construction of transverse diaphragms.

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