Jurnal Kejuruteraan 33(4) 2021: 915-926
https://doi.org/10.17576/jkukm-2021-33(4)-14

Elastic Investigation of Piers Numbers Effects in Transverse Direction on the Stiffness of Continuous and Simply Supported Bridges

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Received 15 January 2021, Received in revised form 10 February 2021
Accepted 10 March 2021, Available online 30 November 2021

ABSTRACT

Piers were important structural members between superstructure and foundation of bridge which were designed to transfer and resist the vertical loads and horizontal loads (dead load of structure, traffic loads, water pressure, ice, and wind) to the foundation. The objective of this study was to evaluate the effect of number of piers in transverse direction (horizontal distance or spacing) between piers on the static and dynamic responses for two types of bridges structure which they include continuous and simply supported bridges. Static and dynamic analysis methods were adopted to analyse the bridges structures by using CSI-bridge software. The results of static analysis for two types of bridges models (continuous and simply supported) showed that the increasing of piers numbers had significant effects on the increasing of bridge structure stiffness by decreasing the downward vertical deflection due to service loads, increasing of the resistance of prestressed loads to service loads, and increasing of compression stresses. The results of time history analysis for two types of bridges models showed that the values of natural frequency were increased when the piers numbers were increased. Traffic load frequency (vibration frequency) values were decreased with increasing of bridge piers number because of the bridge structure had more stability. It can be concluded that the values of natural frequency were more than values of traffic load frequency, indicating that the bridges structures had enough stiffness and stability.

Keywords: Bridge piers; continuous bridge; simply supported bridge; moment; deflection; stresses; frequency

INTRODUCTION

Bridge is one of civil engineering structures that is playing a significant function in the economic activities of cities. It is provided that passageway over an obstruction without closing the lower of way. Many kinds of bridges are built in the world can be classified according to types of supports, girders types, materials types, construction methods, and types of using. these kinds of bridges include arch bridge, beam bridge, truss bridge, cantilever bridge, suspension bridge, cable-stayed bridge, fixed and movable bridge, and pedestrian bridge. According to types of supports, bridges can be classified as a simply supported bridge and continuous bridges. For simply supported bridges, the length of bridge can be divided into number of spans which have different or same length and each span is simply supported at both ends with expansion joints. Whereas, continuous bridges spans are continuous over two or more supports and they are statically indeterminate structures. (Mohamed et al. 2019), (Singh et al. 2015), (Ali 2018), (Ali F. 2018), (Ali 2017)

Bridge piers are important members between superstructure and foundation to transfer the vertical loads (dead load of structure, traffic loads, and ice) to the foundation and they are resisting the horizontal loads acting on bridge structure such as water pressure, and wind. Piers are the interior vertical supports at middle points of bridge structure spans. (WISDOT Bridge Manual 2019), (Ahmed and Tahsin 2010)

Piers are generally used as a general expression for substructure of bridges structure which were positioned between longitudinal spans and foundations. There are different kinds of piers according to structural connectivity to the superstructure such as monolithic or cantilevered and according to sectional shape such as solid or hollow, round, octagonal, hexagonal, or rectangular. Also, it can also be classified according to framing configuration such as single or multiple pier, hammerhead, and pier wall. (Wang 2000).

When the bridge structure passed over waterway, piers must be placed in parallel direction with the direction of flood flow to give a minimum interference to flood flow. Also, they make sufficient condition for drift and ice by increasing span lengths and vertical clearances. The distances and positions of piers and abutments are usually controlled by the minimum horizontal and vertical clearances required for the roadway or the railroad. There are several factors can be affected on the position of piers such as environmental factors and sight distance on curved path. Generally, some factors were effect on the spacing of piers such as the kind of superstructure, the spacing between superstructure girders, and the dimensions of the piers. (Chen et al. 2007) (Ali 2016).

In the structural analysis of piers, some of load types which are applied on each pier must be considered the design of the fixed and expansion bearings, the bearing kinds and the relation stiffness of all of the piers. These loads include superstructure loads, horizontal loads. There are two types of bonds between piers and superstructure of bridge. These types are fixed or expansion bearings which they permit the rotation in the longitudinal direction of the superstructure (Amit and Kulkarni 2018).

Piers can be arranged as single row piers groups, displayed normal to main bridges axes, are frequently used to support bridge superstructure. Different arrangements configurations, can be characterized by different groupings of piers shape and distance. Bridge superstructure is frequently supported by single row pier groups (Lança et al. 2012).

Lateral horizontal loads on the pier are transmitted to the soil layers by means of a direct load passageway to the foundation of the impacted pier and an indirect load path through the superstructure to the neighboring piers. There are some factors affected on the resistances of bridge piers which are subjected to lateral horizontal loads such as structural design of piers and soil bearing capacity (Long 2005).

There are two methods of analysis for any structure. These methods include static and dynamic analysis and the election of suitable analysis method depends on some factors such as the objective of analysis, significance of structure, existing of analysis method, soil states, and types of structure. Analysis and design methods of bridge structure have been simplified with the assist of current bridge engineering software such as SAP2000 and ANSYS. Static elastic analysis method is appropriate for bridges structure that subjected to static loads. Dynamic analysis method is generally carried out by using an engineering software (Bhumika 2020), (Baidar and Leslie 1992), (Andrew and Barry 2014).

Analysis methods of bridge model can be used appropriate materials properties, boundary states, and different types of loads. Members and connections joints of bridge structure are proportioned to carry all possible loads (stable loads, traffic loads, wind loads, and earthquake loads), combined and factored in accordance with the requirements of related design standards (Ali and Wang 2011).

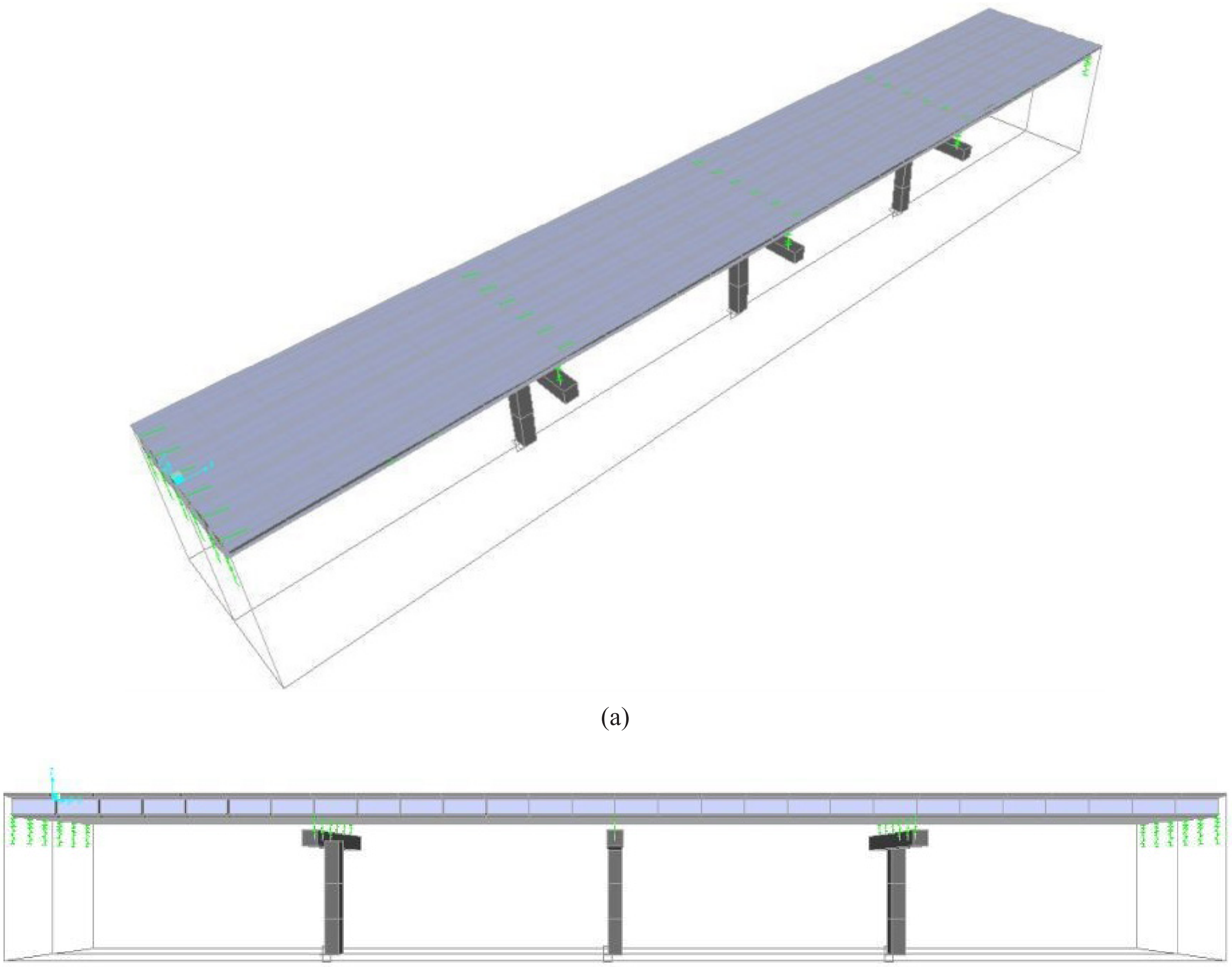
Most of researchers studied the effect of scour on bridge piers and seismic loads by using dynamic analysis. The objective of this study is to evaluate the effect of number of piers in transverse direction (horizontal distance or spacing) between piers on the static and dynamic responses for two types of bridges structure which they include continuous and simply supported bridges.

NUMERICAL MODELS OF BRIDGES STRUCTURES

There are two theoretical models are used in this study. These models include continuous box girder prestressed concrete bridge (five cells) and simply supported I girder prestressed concrete bridge. For two models, the properties of materials, total length, spans length, width, and height of piers are same to compare the results between two types of models. The concrete grade is C-40 and the weight per unit volume is 23.56 kN/m3. The kind of prestressed tendons is A416Gr270 with weight per unit volume is 76.97kN/m3 and minimum yield stress and minimum tensile stress are 1689.9 MPa and 1861.5 MPa respectively. The asphalt pavement layer is 10cm and it covers the deck of bridge. The total bridge length is 80m and it consists of four spans which has 20m length for each span. The total width is 12m including sidewalk for each side and two lanes. Each bridge structure (continuous box girder prestressed concrete bridge and Simply supported I girder prestressed concrete bridge) uses 8 bridge model with different number of piers. Each bridge pier has 8m in height and cross section area is 1m2 (square shape 1m*1m). Table 1 lists the bridge model name and the number of piers for each model. Figure 1 shows bridge model for continuous box girder, Figure 2 shows bridge models with different number of piers for continuous box girder, Figure 3 shows bridge model for simply supported I girder, and Figure 4 shows bridge models with different number of piers for simply supported I girder bridge.

TABLE 1. Models of continuous and simply supported bridges with numbers of piers

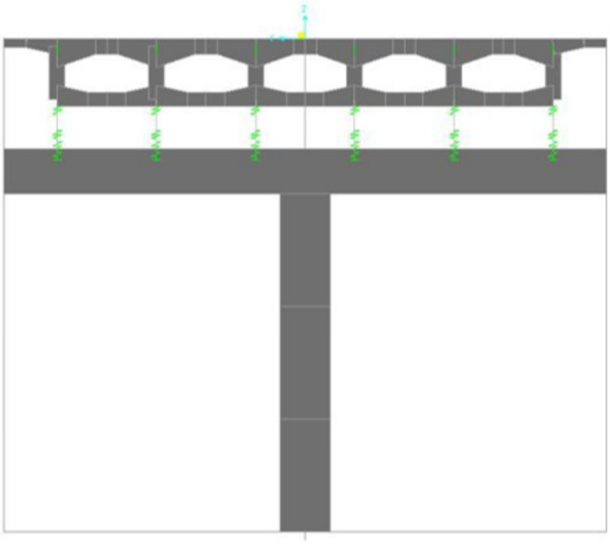
Bridge Model Name	No. of Piers
A	1
B	2
C	3
D	4
E	5
F	6
G	7
H	8



(a)

(b)

FIGURE 1. Bridge model for continuous box girder: (a) Three dimensions view, (b) Elevation view



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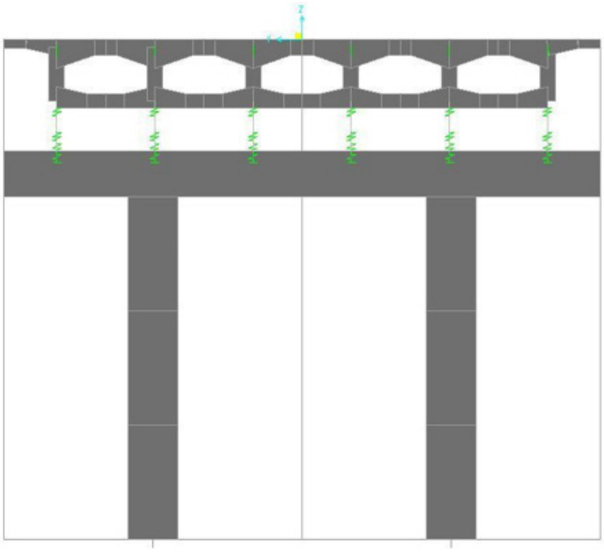

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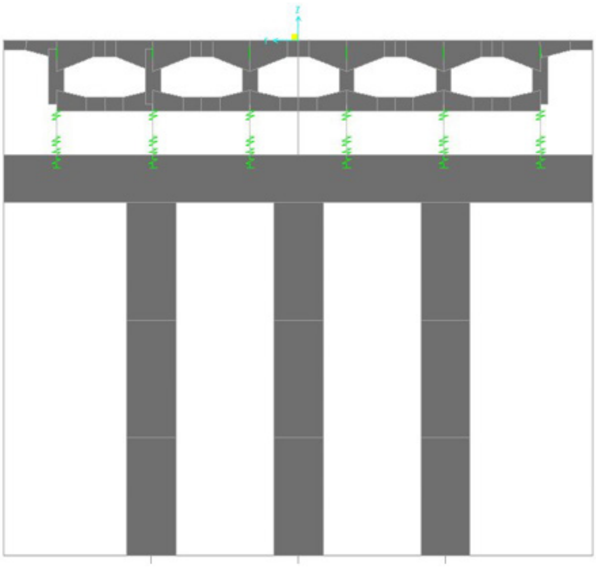

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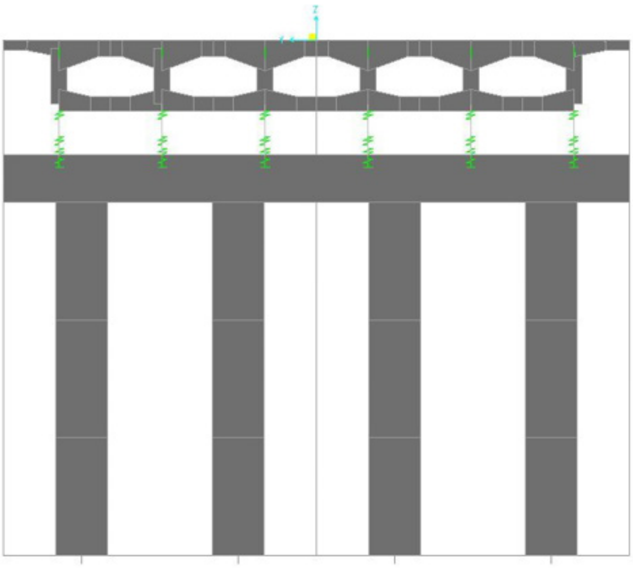

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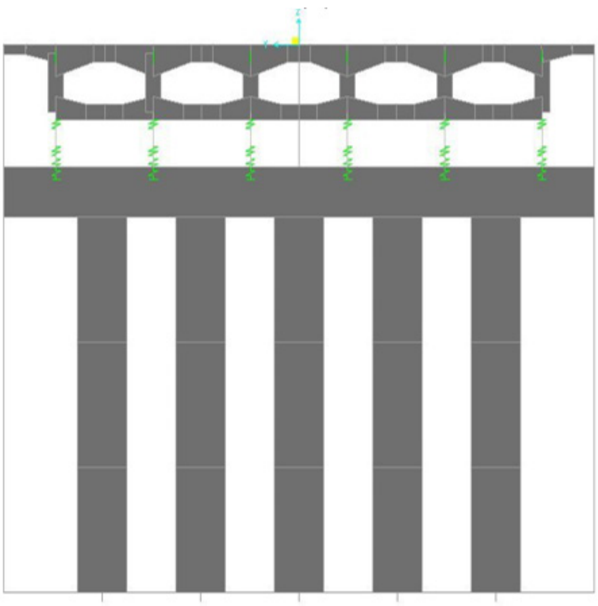

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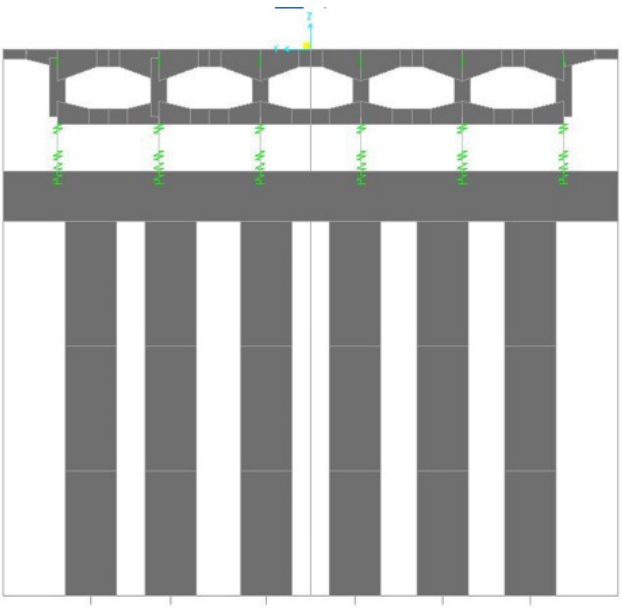
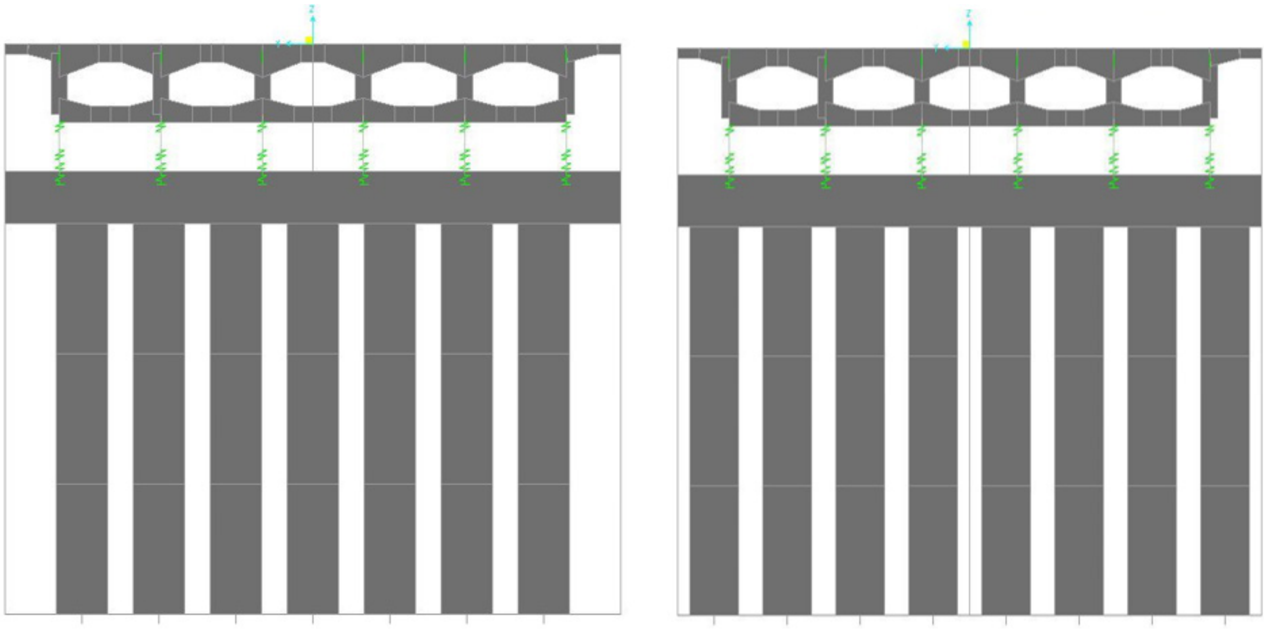
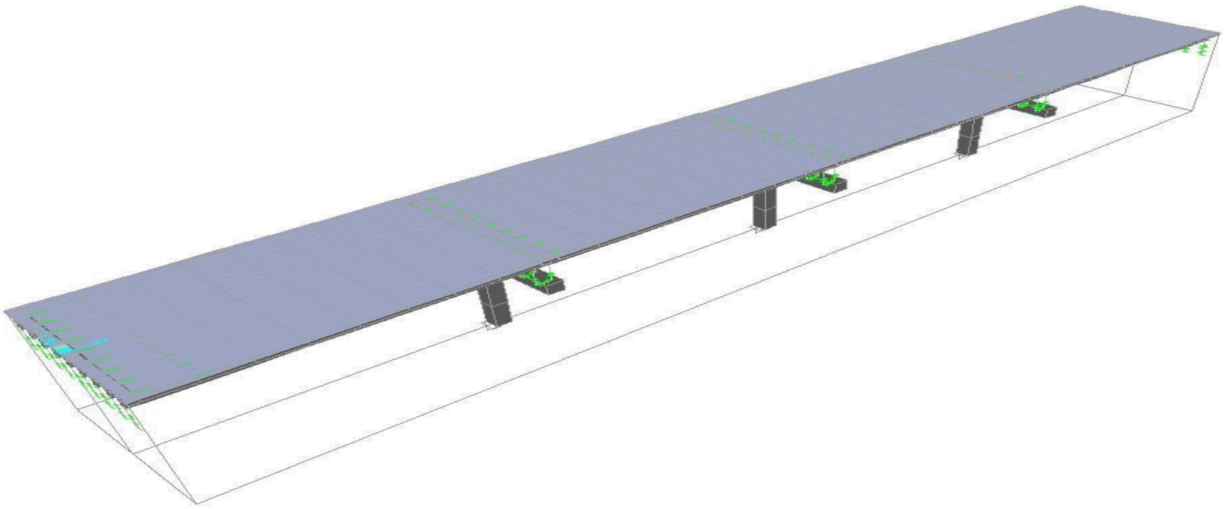


(f)

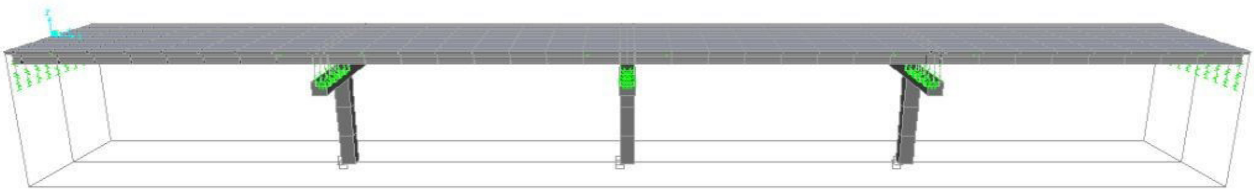


(g) (h)

FIGURE 2. bridge models with different number of piers for continuous box girder: (A): One pier, (B): Two piers, (C): Three piers, (D): Four piers, (E): Five piers, (F): Six Piers, (G): Seven piers, (H): Eight piers

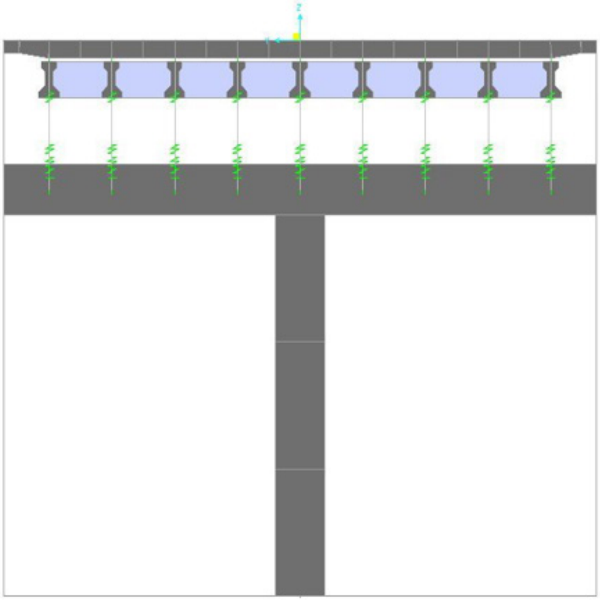


(a)



(b)

FIGURE 3. Bridge model for simply supported I girder: (a) Three dimensions view, (b) Elevation view



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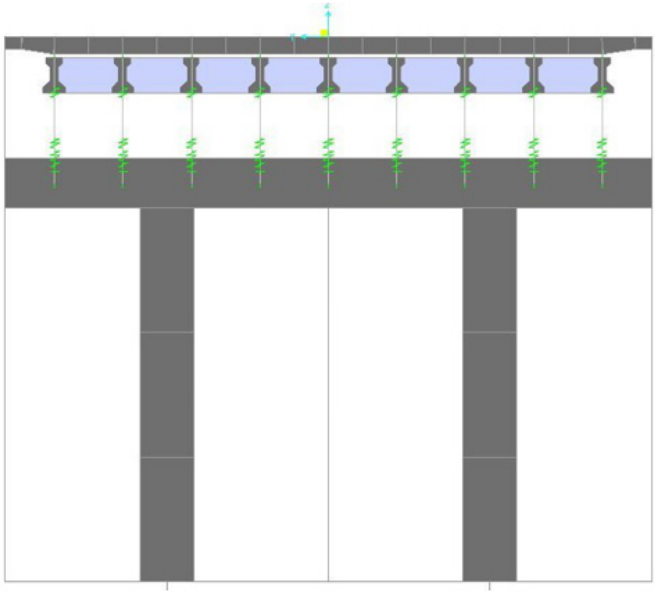

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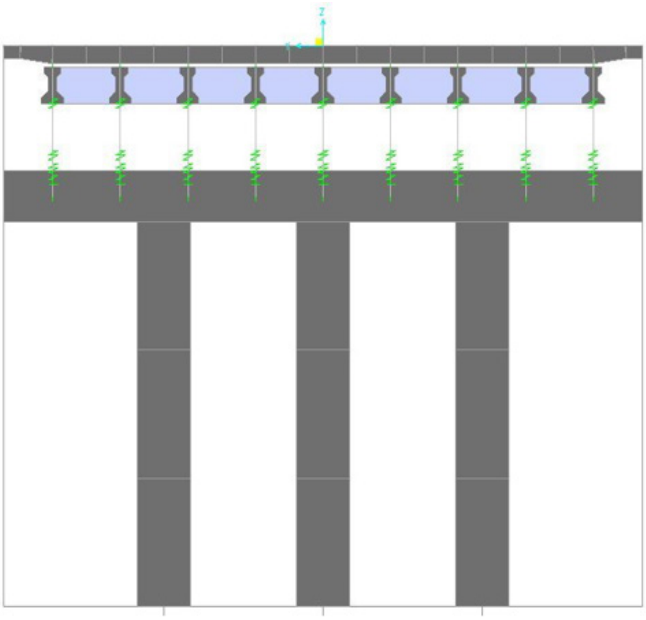

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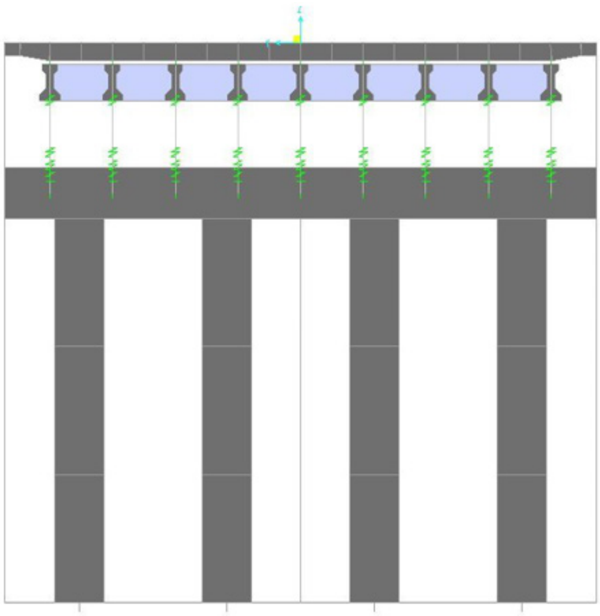

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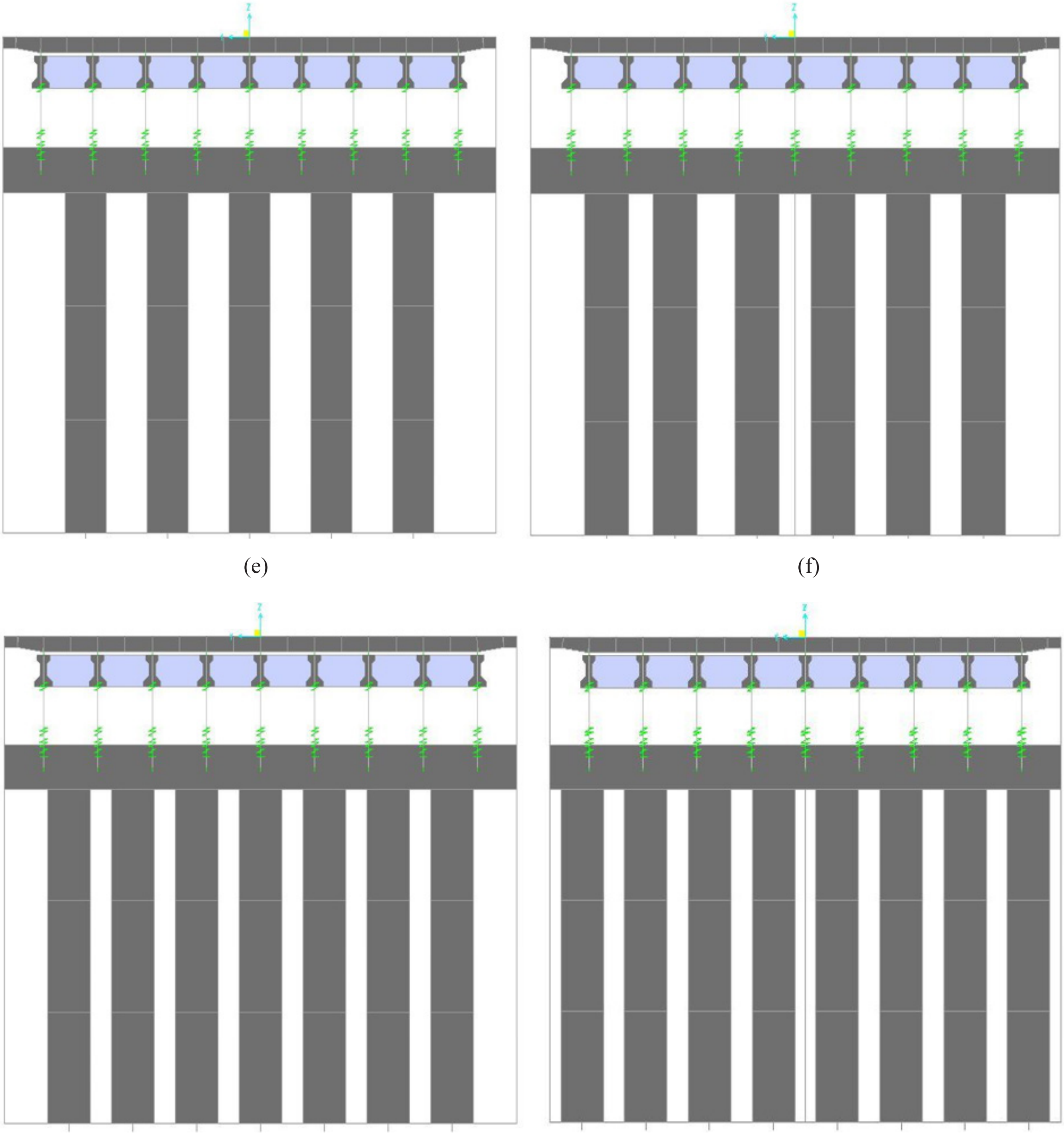

(e) (f) (g) (h)

FIGURE 4. bridge models with different number of piers for simply supported I girder: (A): One pier, (B): Two piers, (C): Three piers, (D): Four piers, (E): Five piers, (F): Six Piers, (G): Seven piers, (H): Eight piers

COMBINATION OF LOADS

Service load stage was used in the analysis of bridges models. This stage includes the combination of different types of loads which were applied on the bridge structure during design life of bridge structure. The combination of loads consisted of dead load (Self-weight), prestressed tendons load, temperature load, traffic load (vehicles load), and others uniform loads. Traffic load is using vehicle type HSn-44L with 20-scale factor. Two lanes are used to pass vehicles on bridge superstructure and each lane has width equal to 3.75m.

STATIC ANALYSIS OF COMBINED LOADS

CSI-bridge software was used in the analysis of bridges models by adopting finite element method. Analysis types was elastic or linear. Three static responses were selected to study the effect of piers number on the stiffness of continuous box girder prestressed concrete bridge (five cells) and simply supported I girder prestressed concrete bridge. These responses included downward vertical deflection due to all loads, upward vertical deflection due to prestressed load, tension and compression stresses, positive bending moment, and negative bending moment.

CONTINUOUS PRESTRESSED CONCRETE BOX GIRDER BRIDGES

The results of downward vertical deflection due to service loads and upward vertical deflection due to prestressed load (resistance of loads) can be shown in Figure 5. From this figure it can be seen that the values of downward vertical deflection due to service loads decreased with increasing of piers numbers. The maximum value of downward vertical deflection is 20mm for model (A) which it has one pier and the minimum value of downward vertical deflection is 8mm for model (H) which it has eight piers. The values of upward vertical deflection due to prestressed load increased with increasing of piers numbers and reducing of piers spacing in transverse direction, indicating that the resistance of prestressed tendons to loads will increase according to increasing of piers numbers. The higher value of upward vertical deflection due to prestressed load is 7mm for bridge models (D) to (H) and the lower value is 3mm for model (A) which it has one pier.

Figure 6 shows the values of bending moment results. It showed that the increasing of piers number has little effects on positive and negative bending moment values. Model (A) appeared lower value of positive and negative bending moment which is 27152kN.m and 953.6kN.m respectively, and model (H) has higher value of bending moment which is 29359kN.m and 2954kN.m respectively.

Figure 7 shows the values of stresses results and it can be shown that the increasing of tension stresses values is not important with increasing of piers numbers. The values of tension stresses are ranged between 4.49MPa for model (A) and 5.09MPa for model (H) and compression stresses values are varied from 11.66MPa within model (A) and 12.53MPa within model (H), indicating that the compression stresses are slightly affected by increasing of piers numbers.

According to static analysis results of continuous box girder prestressed concrete bridge, the increasing of piers numbers has significant effects on the increasing of bridge structure stiffness by decreasing the downward vertical deflection due to service loads, increasing of the resistance of prestressed loads to service loads, and increasing of compression stresses.

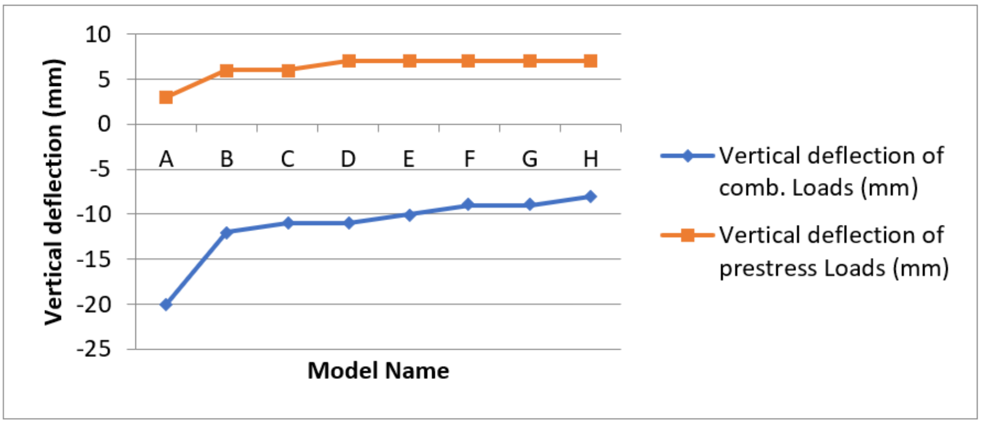

FIGURE 5. Vertical deflection due to service and prestressed loads for continuous box girder

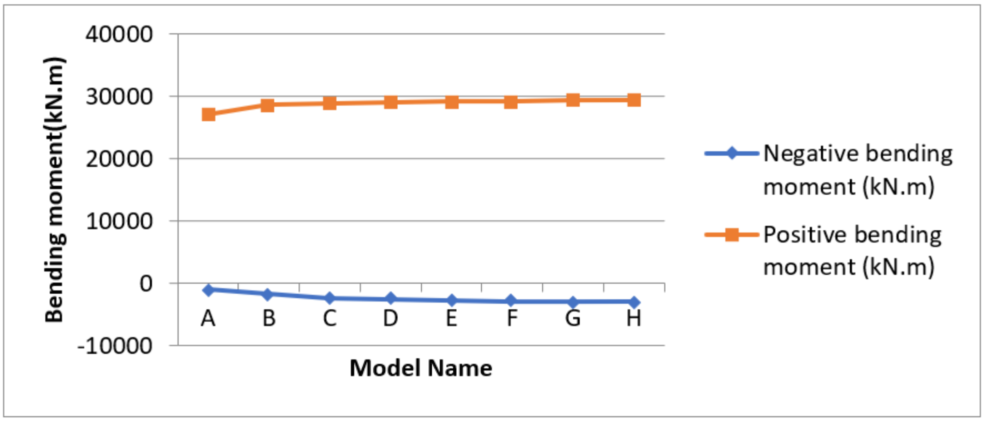

FIGURE 6. Bending moment due to service loads for continuous box girder

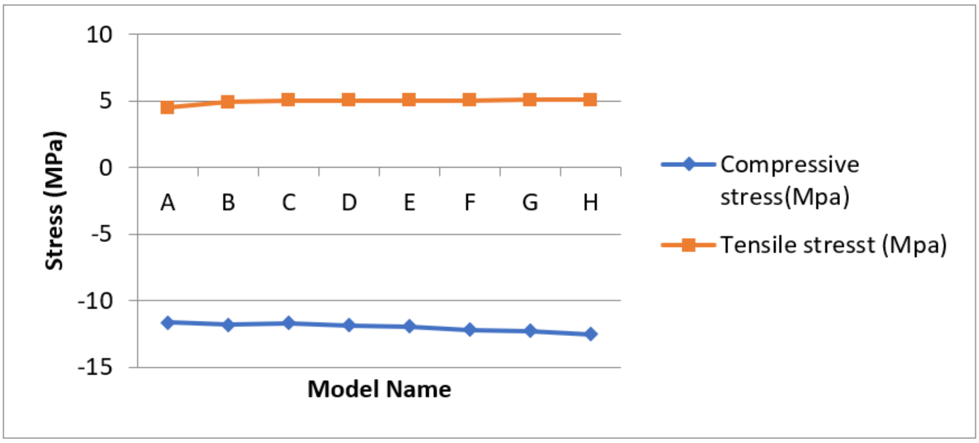

FIGURE 7. Stresses due to service loads for continuous box girder

SIMPLY SUPPORTED PRESTRESSED CONCRETE I GIRDER BRIDGE

This type of bridge appeared static responses values lower than continuous box girder prestressed concrete bridge with the same number of piers. The values of the downward vertical deflection decreased as the number of piers increased. Model (A) has higher value of deflection compared with others models which is equal to 19mm and lower value is 6mm within model (H). The upward deflection of prestressed tendons load increased with increasing of number of piers. Positive bending moment do not appear significant increasing but negative bending moment has important increasing when number of piers increased from one pier to eight piers. The values range between 7967kN.m and 9785kN.m for positive bending moment and from 926kN.m to 1380kN.m for negative bending moment. The values of compression and tension stresses have lower percentage of affecting by increasing the numbers of bridge piers. Figure 8 shows the values of vertical deflection due to service and prestressed loads. Figure 9 shows values of bending moment and Figure 10 shows values of stresses.

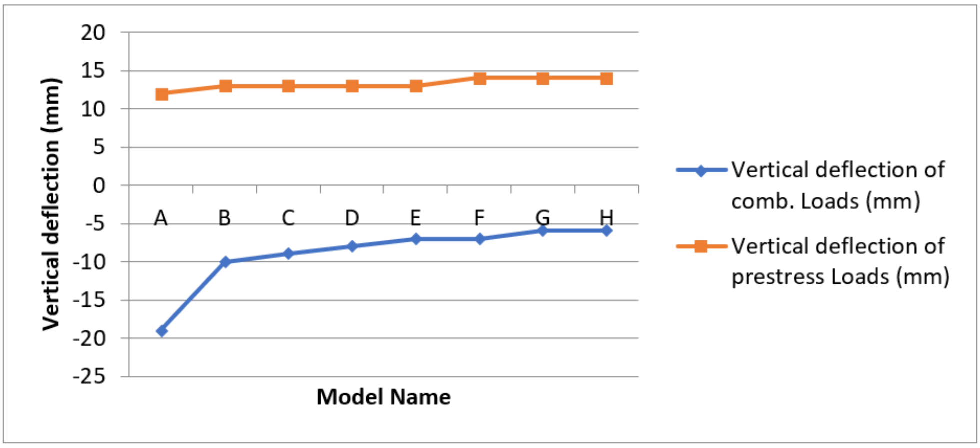

FIGURE 8. Vertical deflection due to service and prestressed load for simply supported I girder

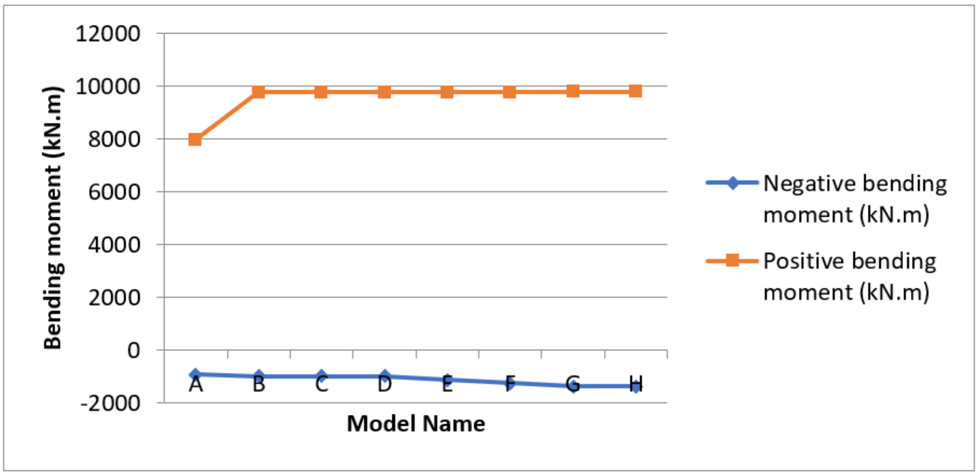

FIGURE 9. Bending moment for simply supported I girder

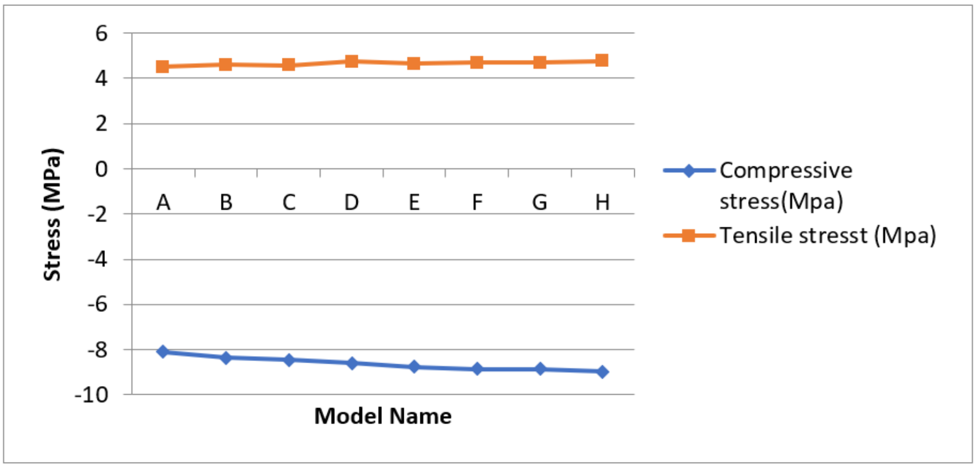

FIGURE 10. Stresses for simply supported I girder

TIME HISTORY ANALYSIS

Time history and modal analysis methods includes two dynamic responses which are natural frequency and traffic load frequency (vibration frequency). Analysis type is linear with direct integration time history. The objective of time history analysis is to compare between natural frequency and traffic load frequency to evaluate the stiffness of bridges models.

For continuous box girder prestressed concrete bridge, the values of natural frequency are increasing when the piers numbers are increased. The maximum value of natural frequency is 8.06Hz within model H (eight piers) and the minimum value of natural frequency is 6.78Hz. Traffic load frequency values are decreasing with increasing of bridge piers number because of the bridge structure have more stability. The higher value of traffic load frequency appeared within model A (one pier) which is 4.66Hz and the lower value is 3.94Hz in model H (eight piers). It can be concluded that the values of natural frequency are more than values of traffic load frequency, indicating that the bridge structure has enough stiffness and stability.

For simply supported prestressed concrete I girder bridge models. The values of natural frequency are ranged from 3.92Hz for model A (one pier) and 5.31Hz for model H (eight piers), indicating that natural frequency increased when number of piers increased. The higher value of traffic load frequency is 3.76Hz for model A and lower value is 3.25Hz for model H, meaning that traffic load frequency is decreasing when numbers of piers increased, leading to bridge structure become more stable. The values of natural frequency are also more than values of traffic load frequency, indicating that the bridge structure has enough stiffness and stability. Table 2 and Table 3 lists values of natural frequency and traffic load frequency.

According to time history analysis results, continuous box girder prestressed concrete bridge has higher values of natural frequency and traffic load frequency comparing with simply supported prestressed concrete I girder bridge models, indicating that box girder bridge has more stiffness than simply supported I girder bridge.

TABLE 2. Values of natural and traffic load frequency for continuous box girder bridge

Bridge Model Name.	A	B	C	D	E	F	G	H
Natural Frequency (Hz)	6.78	7.70	7.87	7.95	7.98	8.05	8.05	8.06
Traffic load Frequency (Hz)	4.66	4.54	4.38	4.23	4.10	3.94	3.94	3.94

TABLE 3. Values of natural and traffic load frequency for simply supported I girder bridge

Bridge Model Name.	A	B	C	D	E	F	G	H
Natural Frequency (Hz)	3.92	4.14	4.25	4.27	4.87	5.04	5.17	5.31
Traffic load Frequency (Hz)	3.76	3.76	3.55	3.47	3.35	3.30	3.25	3.25

CONCLUSION

From this study it can be concluded that:

1. The objective of this study was to evaluate the effect of number of piers in transverse direction (horizontal distance or spacing) between piers on the static and dynamic responses for two types of bridges structure which they include continuous and simply supported bridges.
2. There were two theoretical models were used in this study. These models include continuous box girder prestressed concrete bridge (five cells) and Simply supported I girder prestressed concrete bridge. For two models, the properties of materials, total length, spans length, width, and height of piers were same to compare the results between two types of models. Static and time history analysis methods were used to determine the structural response of bridges models. Each bridge type used 8 bridge model with different number of piers (ranged from one pier to eight piers).
3. The results of static analysis for two types of bridges models (continuous and simply supported) shown that the increasing of piers numbers had significant effects on the increasing of bridge structure stiffness by decreasing the downward vertical deflection due to service loads, increasing of the resistance of prestressed loads to service loads, and increasing of compression stresses.
4. The results of time history analysis for two types of bridges models shown that the values of natural frequency were increased when the piers numbers were increased. Traffic load frequency (vibration frequency) values were decreased with increasing of bridge piers number because of the bridge structure had more stability. It can be concluded that the values of natural frequency were more than values of traffic load frequency, indicating that the bridge structure had enough stiffness and stability.
5. According to time history analysis results, continuous box girder prestressed concrete bridge has higher

values of natural frequency and traffic load frequency comparing with simply supported prestressed concrete I girder bridge models, indicating that box girder bridge has more stiffness than simply supported I girder bridge.

ACKNOWLEGMENT

The authors would like to thank the Al-Furat Al-Awsat Technical University for supporting this research.

DECLARATION OF COMPETING INTEREST

None

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