Jurnal Kejuruteraan 34(1) 2022: 59-71
https://doi.org/10.17576/jkukm-2022-34(1)-06

Comparative Study of Seismic Design for Different Bridges Structures

Ali Fadhil Naser

Faculty of Building and Construction Engineering Techniques Department, Al-Mussaib Technical College, Al-Furat Al-Awsat Technical University, Iraq

Corresponding author: com.ali3@atu.edu.iq

Received 13 April 2021, Received in revised form 5 May 2021
Accepted 5 June 2021, Available online 30 January 2022

ABSTRACT

The main objective of this study is to compare the structural members capacity between different types of bridges structures under seismic load. The results of seismic modal analysis showed that the models of box girder bridge, precast T girder bridge, and U steel girder bridge had the higher values of natural frequency comparing with others bridges structures under seismic load. Pushover analysis in transvers direction showed that bent No. 2 of bridges structures which was located in the middle of bridges superstructure was displaced in transvers direction more than bent No. 1 and bent No. 3. In longitudinal direction, Precast I girder bridge had higher value of longitudinal displacement comparing with others bridges structures, and it was more than the maximum value of transvers displacement. The results of demand and capacity ratio showed that bent No. 2 was the critical structural member which had values of demand/capacity ratio more than 1.0 or near from it especially precast I girder bridge, precast T girder bridge, and U steel bridge, indicating that these types of bridges will be subjected to failure in bent No. 2. Therefore, there was needing to redesign the bents of these types of bridges by increasing the numbers of piers, using high strength materials in construction of bents, and increasing of dimensions of piers and pier caps. The results of internal forces showed that bent No. 2 was subjected to the maximum values of axial force, horizontal shear, and bending moment for all types of bridges structures. Also, it can be seen that the models of precast I girder bridge, precast T girder bridge, and U steel bridge had the higher values of forces comparing to others models, indicating that these results agree with results of demand/capacity ratio and pushover analysis method.

Keywords: Seismic load; bridges; pushover analysis; demand; capacity; displacement

INTRODUCTION

Bridges structures are momentous and proficient civil structures and they contains on different types of structural members. These members can be divided into two groups. The first group is called superstructure and it includes the bearings, girders (beams), deck (including sidewalks), joints, asphalt pavement layer, security barrier, and drainage system. The second group is known as substructure which is contained on the foundations (piles and piles cap), piers, and pier caps. In general, bridges are important part of the transportation engineering system. It presents the connection way over urban congestion, waterways, and valleys. The bearing capacity of bridges control the weight and the volume of traffic loads which are passed by the transportation system. (Ali F. 2018), (Ali. F. N. 2018), (Mohan A. 2017), (Hussam A. and Ali F. 2020)

An earthquake can be defined as the movement of the earth layers by means of vibration, distortion, and sliding. The movement of the earth coating can be caused the maximum of powerful earthquakes. Firstly, the layer may bend and then can be subjected to rupture and settle and moves to a new location. The process of rupture and vibrations is known as seismic waves. The seismic waves can be generated after rupture of the fault. There are two types of seismic waves. The first type is body waves which are including longitudinal P waves and transversal S waves, and the second type is the surface waves. The loads due to earthquake which are applied on the abutments and bent of bridges structures can be large and special detailing of the back wall and their foundations is necessary to resist these loads (Julio A. et al 2000), (Wood H. 2015).

A seismic wave due to earthquake can be caused many damages which are affected and collapsed civil structures such as buildings, bridges, railways, and highways. Bridges structures must be designed for life loss avoidance due to higher seismic demand to prevent structural collapse under maximum cyclic demands. The determination of bridges responses to earthquake (ground motion) is difficult and it needs hard analyses. The collapse of a bridge structure provides risks for users of structure and it must be substituted after the earthquake unless another transportation paths are identified (Thomas W. 2013), (Moehle P. and Eberhard M. 2003).

The damages due to earthquake of bridges structures may be occurred in the superstructure and substructure members. The earthquake associated structural damages to a bridge superstructure are very rare because of the superstructures of bridges are very strong and have enough stiffness in their own plane also because of earthquake loads are mainly horizontal in plane loads. The horizontal loads have important effects on the substructures of bridges. Substructure damages contain of the structural disaster of the piers, abutments, piles and footings. The damages of bridge piers can be caused by flexural disaster, shear disaster, and anchorage disaster of the longitudinal reinforcement (Jan 1991; Hong 2020).

The seismic design of bridges structures must be implemented by depending on two levels of evaluation. The first level is the higher level which is called as safety evaluation earthquake (SEE) and the second level is the lower level which is known as functionality evaluation earthquake (FEE). The bridge structure must continue serviceable after a safety evaluation earthquake. The earthquake load and response spectra must be considered at as safety evaluation earthquake and functionality evaluation earthquake. The purposes of seismic design of bridges are to save the critical structural parts in the fundamentally elasticity area during the safety evaluation earthquake (SEE), to complete safety, reliability, serviceability, constructability, and maintainability when the energy dissipation and isolation devices are installed in bridges. to contrive expansion joint assemblies between bridge frames that either retain traffic support or, with the installation of deck plates, and to offer ductile load routes and describing to certify bridge safety in the event that upcoming demands may be exceed those demands resulting from current safety evaluation earthquake ground motions (Duan and Reno 1999; Caltrans 1996).

Pushover analysis is an effective method to assess the expected non-linear behavior and resulting disaster shape in different structural members of the bridges. Moreover, it is a new process which uses to assess the old and new bridges structures which may be subjected to seismic loads. It is a nonlinear static analysis process. Pushover analysis is a method which depend on the self-weight of the structure. Structural model exists a certain distribution in a direction along the structural height. In general, internal forces and displacement increases due to action of horizontal loads or lateral displacement with a regularly increasing movement. The maximum bend under the design seismic load is considered as displacements. The results of seismic design can be obtained according to the combination of static elastic analysis (linear), static plastic analysis (non-linear), and response spectrum method. It was designed to evaluate the structural performance due to earthquake quickly. Essentially, pushover analysis is established on two theories. Firstly, responses of the structure are controlled by depending on the first mode of natural frequency (natural vibration) and mode shape. Secondly, by depending on the first few modes of natural frequency, and this shape stays constant during the elastic and inelastic responses of the bridge structure. This provides the basis for transforming a dynamic problem to a static problem which is theoretically flawed (Parimal 2013; Fulin 2016; Chopra & Goel 2002; Huang 2008; Huai et al. 2012; Liu 2014).

There are four analysis methods can be used for seismic design of bridges according to the seismic zone, geometry, and significance of the bridges. These methods include the single-mode method which means single-mode spectral and uniform load analysis, the multi-mode spectral analysis, The multiple support response spectrum, and Time history method. It is absolute that nonlinear dynamic analysis is the perfect method to evaluate the response of bridges structures which are subjected to earthquake loads (Wei 2014: Rui 2005).

The objectives of this study are to support methodology of comparison between different types of bridges structures based on seismic design, to evaluate the seismic design of different types of bridges structures under earthquake load, to determine modal responses for the first six modes of bridges models due to seismic, to determine the capacity curve based on shear force and displacement for bents in transverse and longitudinal direction by using seismic pushover analysis, to determine the demand/capacity ratio for bents in transverse and longitudinal direction, and to determine design internal forces of demand for bents under seismic load.

BRIDGES MODELS

In this study, six different types of bridges structures are selected according to superstructure type (simply supported and continuous) and girders shapes. The bridges models consist of four spans. Each span length is equal to 20m. Therefore, the total length of each bridge is 80m and the total width is 11m. Each bridge has three concrete bents and each bent has two piers with piers cap. The shape of pier is circle with 1.5m diameter. The high of pier is 8m. There are two abutments which are locating in the starting and ending of bridges. The construction materials include concrete grade 40 and steel grade 50 for tendon and for steel girders. CSI bridge ver. 20. 2 is used in the design and analysis of bridge structure under seismic load. Figure 1 shows bridges models in three dimensions.

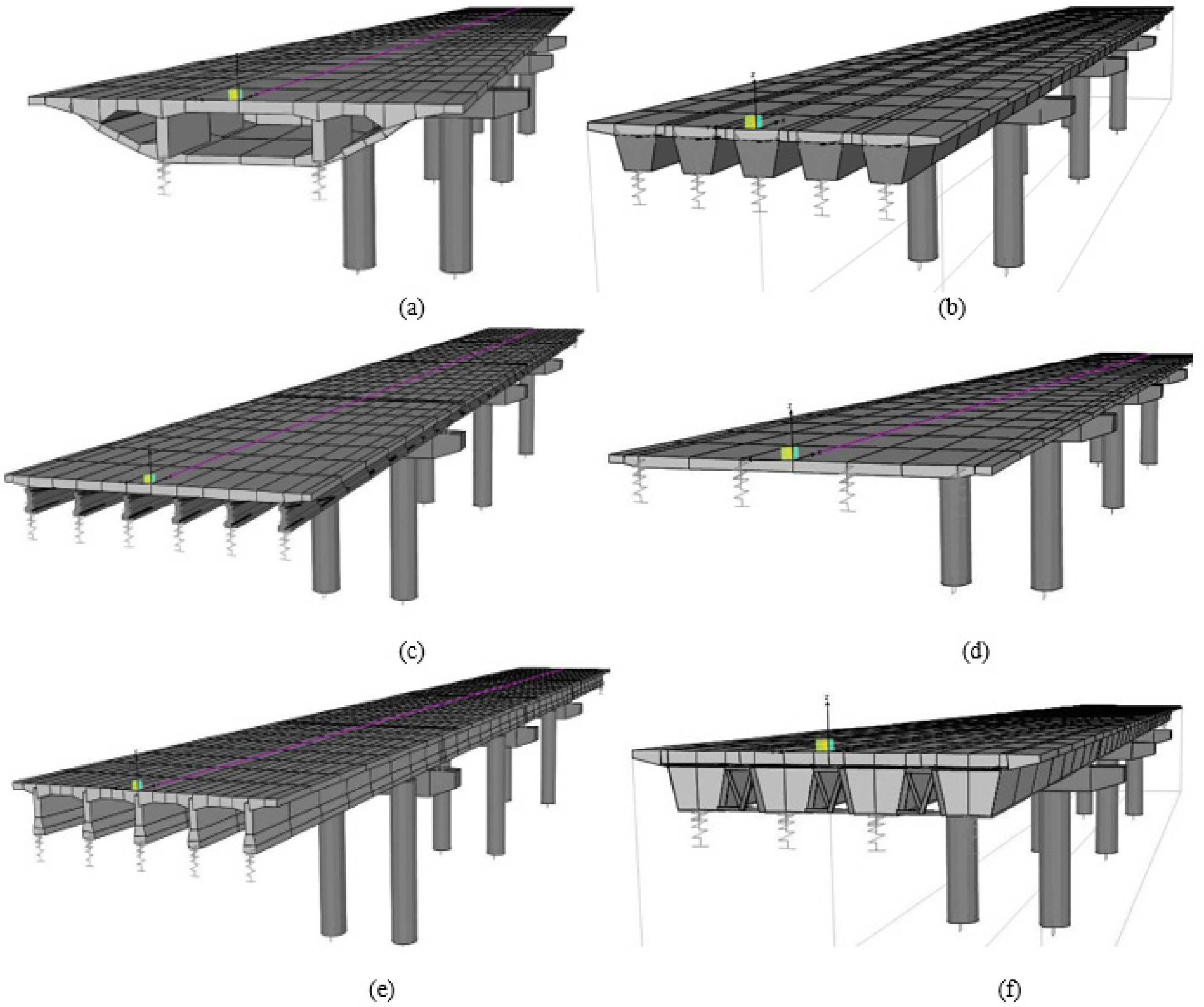


FIGURE 1. Bridges structures models: (a): Box girder bridge model, (b): Solid girder bridge model, (c): Precast I girder bridge model, (d): Slab bridge model, (e): Precast T girder bridge, (f): U steel girder bridge

SEISMIC LOAD CASES

There are nine load cases which are using in the seismic design for each bridge. Seismic design curve is selected for all bridges according type of response spectra function. Figure 2 shows the seismic design curve which is described the ground movement hazard by adopting the time period and displacement. The response spectra function name is AASHTO2007_RS and damping ratio is 0.05. The first load cases is seismic-GRAV which is related to dead load of bridge structure for non-linear static analysis. The second load case is seismic-MODAL that deals with dynamic modal. The third, fourth, fifth, and sixth load cases deal with dynamic response spectra which are used to determine the demand and they include seismic-RS-X, seismic-RS-Y, seismic-RS-Z, seismic-RS-XYZ respectively. The seventh, eighth, and ninth load cases are seismic-PO.TR1, seismic-PO.TR2, and seismic-PO.TR3 respectively which relate with pushover analysis method (non-linear static analysis) to find capacity curves for three bents of bridge in transverse direction. The tenth load case include seismic-LONG which deals with longitudinal direction of bents.

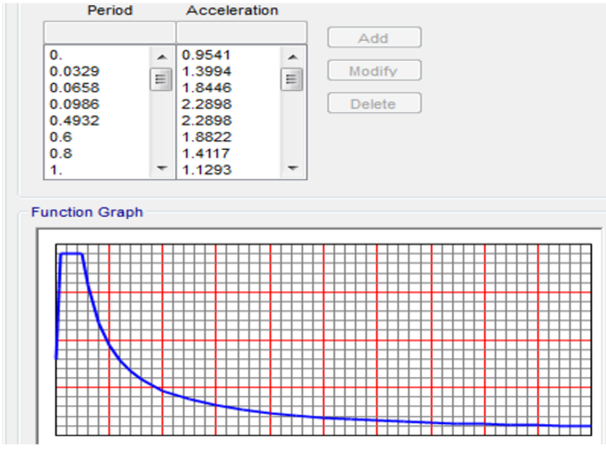


FIGURE. 2 The seismic design curve

SEISMIC MODAL ANALYSIS

Seismic modal analysis is carried out under self-weight of bridges structures which are subjected to seismic load and it is used to find the demand values such as natural frequencies and modes shapes. (Alperen O. 2016). Figure 3 and Figure 4 shows the seismic natural frequency and time for the first six deform modes under seismic load for bridges structures. It can be noted that box girder bridge, precast T girder bridge, and U steel girder bridge have the higher values of natural frequency from others bridges structures.

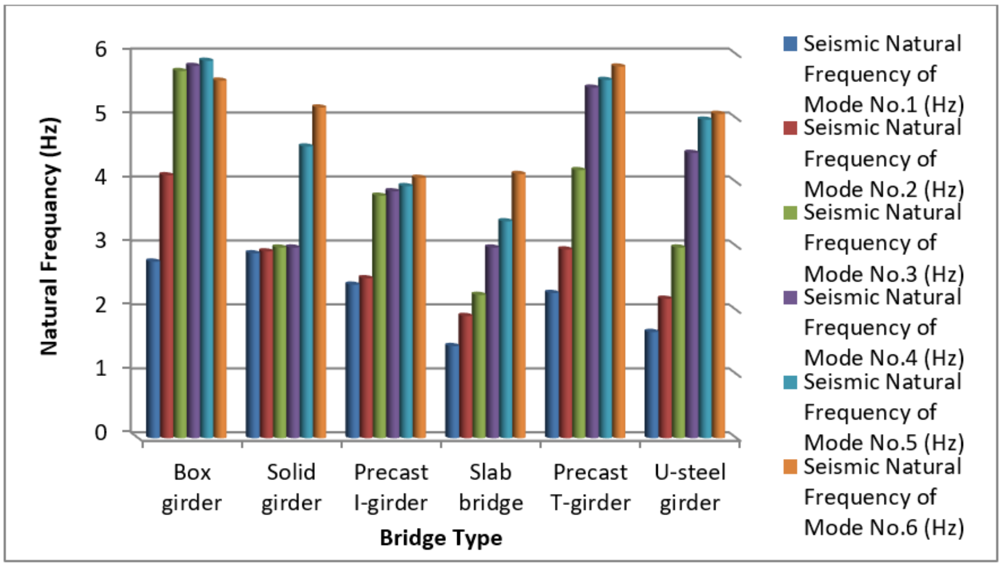


FIGURE 3. Seismic natural frequency for bridges models of first six modes shapes

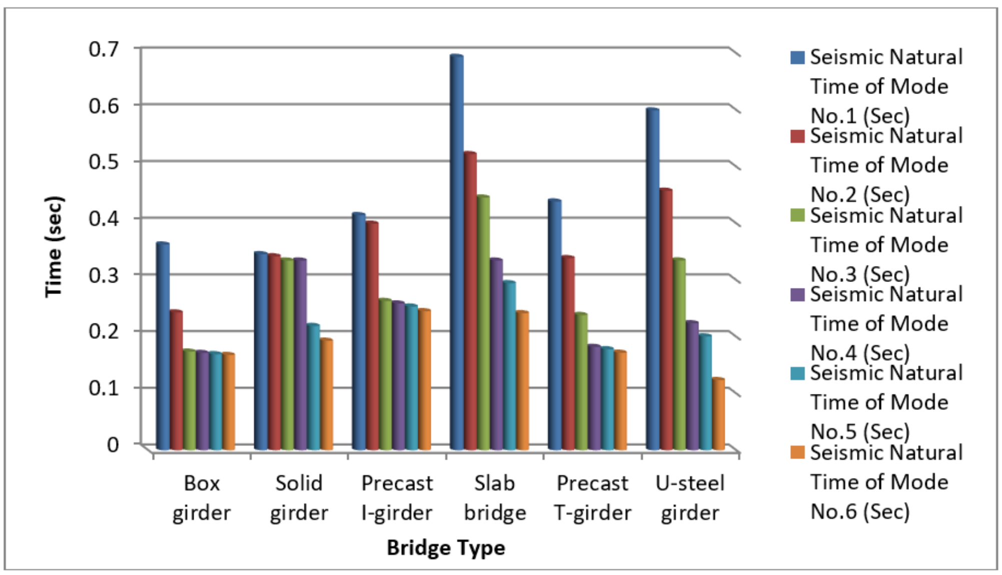


FIGURE 4. Seismic natural time for bridges models of first six modes shapes

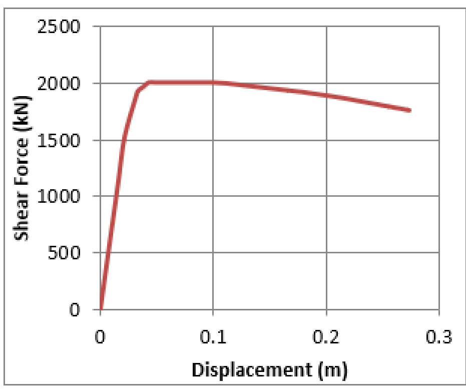
SEISMIC PUSHOVER ANALYSIS FOR BENTS IN TRANSVERS DIRECTION

Seismic pushover analysis (nonlinear static analysis) is become a widespread method during the last decade for the evaluation of seismic design of civil structure such as buildings and bridges. However, comparing to nonlinear time history analysis, pushover analysis is main advantage of lower calculation cost is counter balanced by its characteristic limit to structures in which the fundamental mode controls the response (Paraskeva S. et al. 2006; Hamed and Chung 2021).

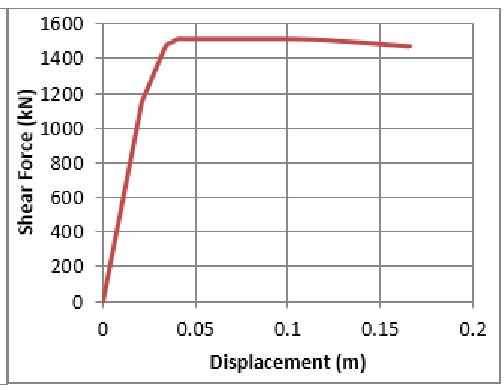
Figure 5, Figure 6, and Figure 7 show the curves of displacement capacity of bridges structures due to pushover analysis in transvers direction for bent No. 1, Bent No.2, and Bent No. 3 respectively. This curve is practically calculated by using a fixed force distribution depending on the first mode shape of the elastic system in modal analysis. (Giuseppe F. 2004). To determine the displacement capacity (control point) for each bent of bridge structure, the displacement capacity value is determined by taking the point (displacement, force) on the curve which located directly after the maximum point on the curve. Therefore, the displacement capacity values of bent No. 1 for box girder bridge, solid girder bridge, precast I girder bridge, slab bridge, precast T girder bridge, and U steel girder bridge are 0.1043 m, 0.0916 m, 0.1066 m, 0.1051 m, 0.1003 m, and 0.0977 m respectively. According to these results, bent No. 1 of precast I girder bridge model has the maximum value of displacement which is equal to 0.1066 m and bent No. 1 of solid girder bridge model has the lower value of displacement which is 0.0916 m, indicating that solid girder bridge has minimum yield point comparing with others bridges.

For bent No. 2, the control values of displacement for box girder bridge is 0.1109 m, for solid girder bridge is 0.0966 m, for precast girder bridge is 0.1096 m, for slab bridge is 0.1071 m, for precast T girder bridge is 0.1043 m, and for U steel girder is 0.1081 m. Bent No. 2 of box girder bridge appears higher value of control displacement from others bridges structures. Whereas, bent No. 2 of solid girder bridge also gives the lower value of control displacement. Approximately, bent No. 3 of bridges structures appears displacement values near the values of bent No. 1. except U steel girder which has displacement value (10.59 m) more than bent No. 1.

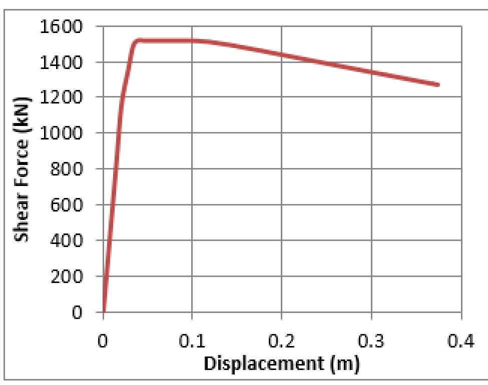
From above notes it can be concluded that bent No. 2 of bridges structures which is located in the middle of bridges superstructure is displaced in transvers direction more than bent No. 1 and bent No. 3.



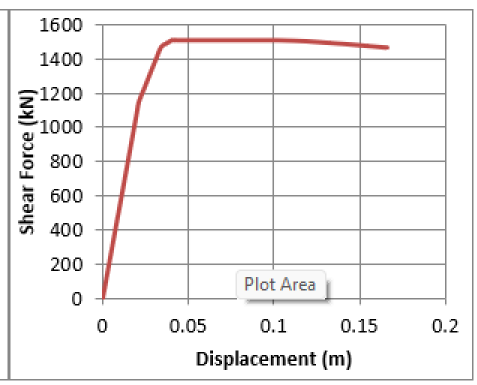
(a)



(b)



(c)



(d)

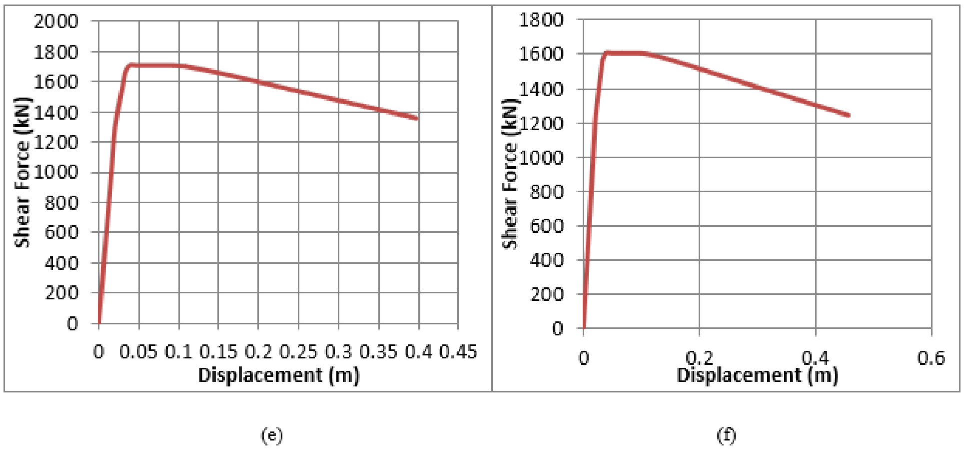


FIGURE 5. Displacement capacity curve of bridges models for bent No. 1 in transvers direction: (a): Box girder bridge model, (b): Solid girder bridge model, (c): Precast I girder bridge model, (d): Slab bridge model, (e): Precast T girder bridge, (f): U steel girder bridge

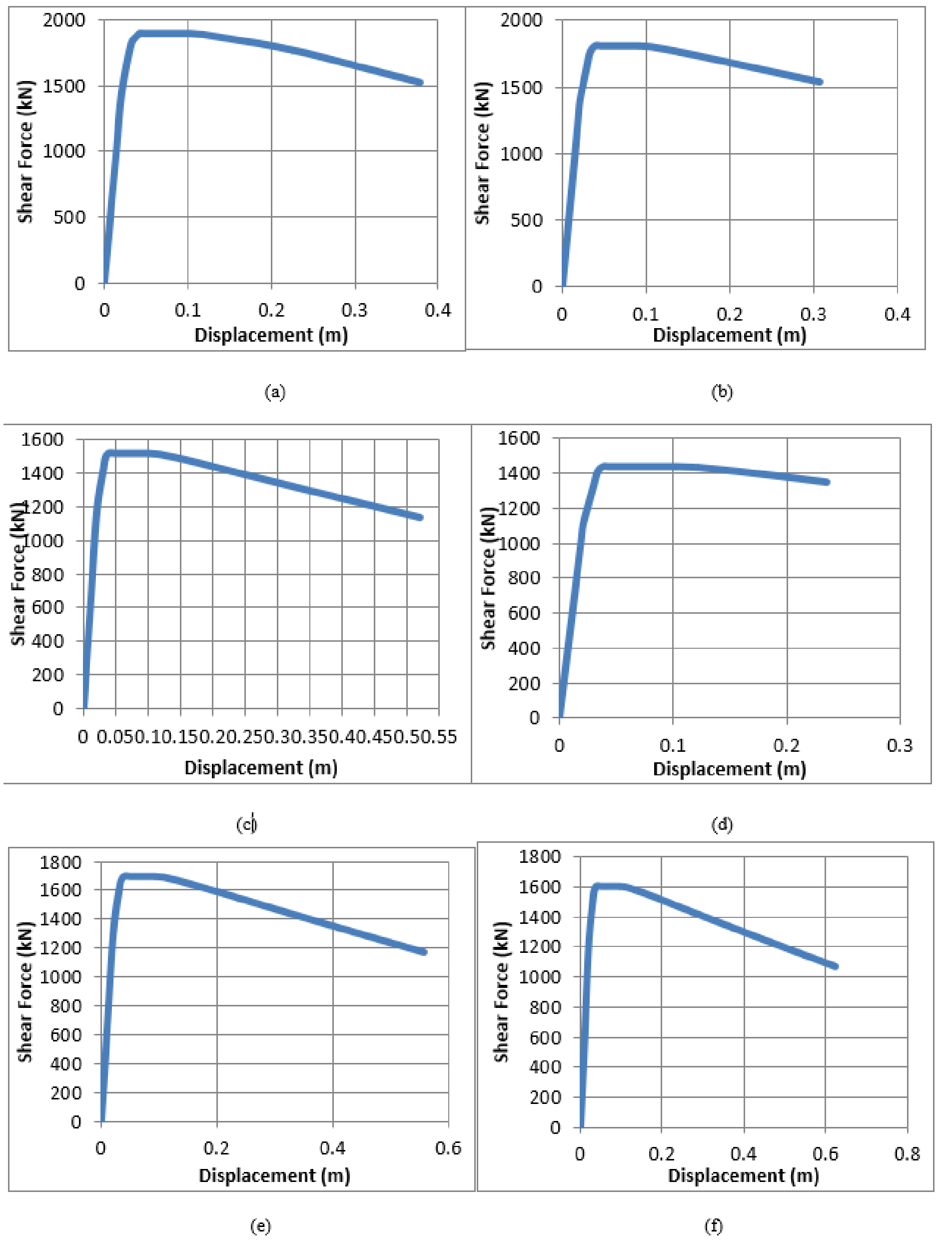


FIGURE 6. Displacement capacity curve of bridges models for bent No. 2 in transvers direction: (a): Box girder bridge model, (b): Solid girder bridge model, (c): Precast I girder bridge model, (d): Slab bridge model, (e): Precast T girder bridge, (f): U steel girder bridge

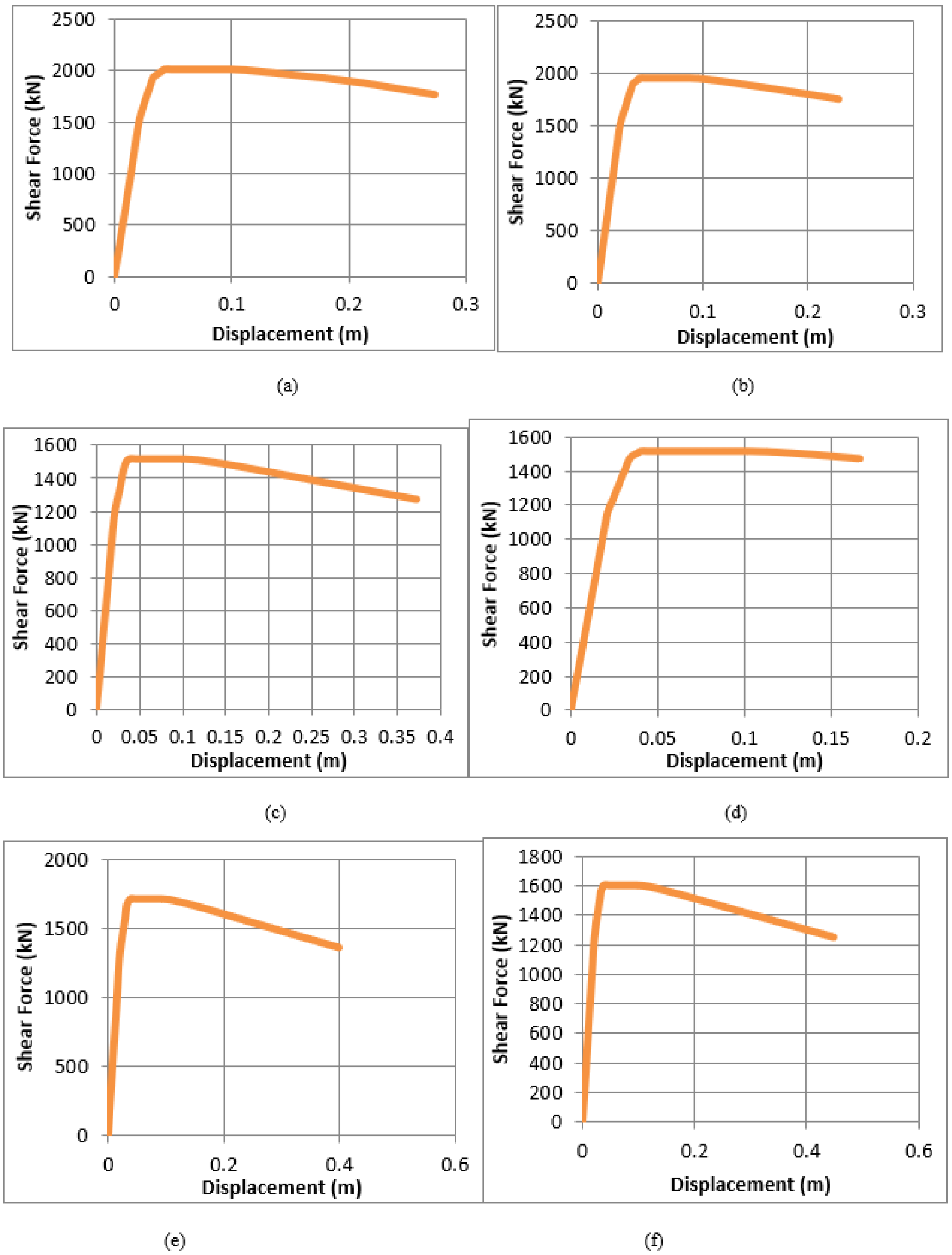
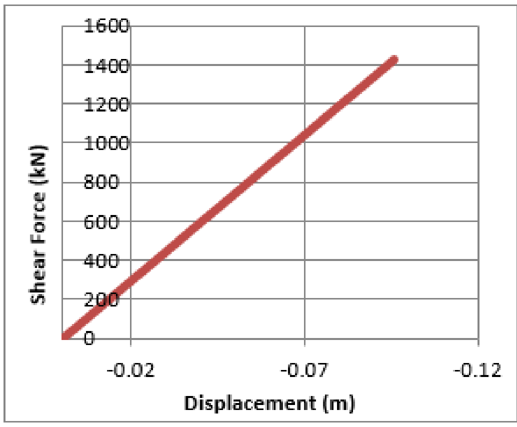


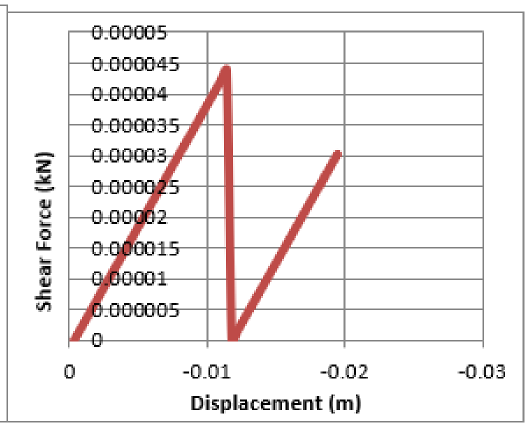
FIGURE 7. Displacement capacity curve of bridges models for bent No. 3 in transvers direction: (a): Box girder bridge model, (b): Solid girder bridge model, (c): Precast I girder bridge model, (d): Slab bridge model, (e): Precast T girder bridge, (f): U steel girder bridge

SEISMIC PUSHOVER ANALYSIS FOR BENTS IN LONGITUDINAL DIRECTION

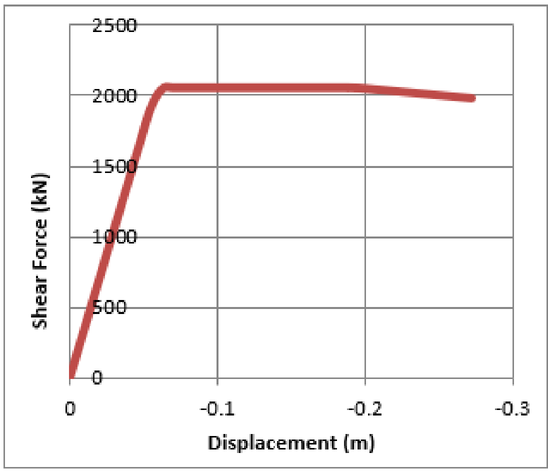
The displacement in longitudinal direction of the bridge superstructure is controlled by the bearing friction. (Mwafy and Elnashai 2007). Figure 8 illustrates the displacement capacity curve according to nonlinear static pushover analysis for bridges structures. From this figure it can be seen that box girder bridge, solid girder bridge, and slab bridge appear un-normal displacement capacity curve (Figure 8, a, b, d) in longitudinal direction but precast I girder bridge, precast T girder, and U steel girder bridge has normal curves. The displacement capacity values in longitudinal direction for box girder bridge is -0.0957 m, for solid girder bridge is -0.0114 m, for precast I girder bridge is -0.1930 m, for slab bridge is -0.000008 m, for T girder bridge is -0.1812 m, and for U steel girder is -0.1873 m. Precast I girder bridge has higher value of longitudinal displacement comparing with others bridges structures, and it is more than the maximum value of transvers displacement.



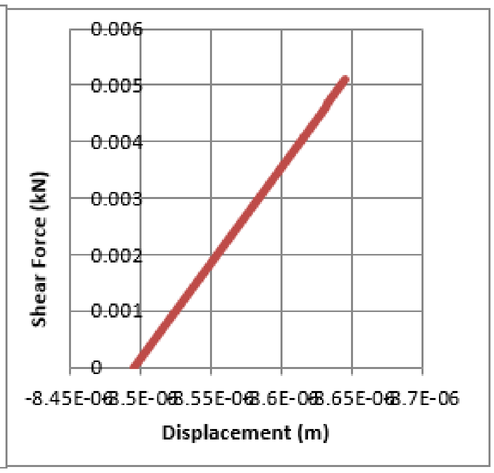
(a)



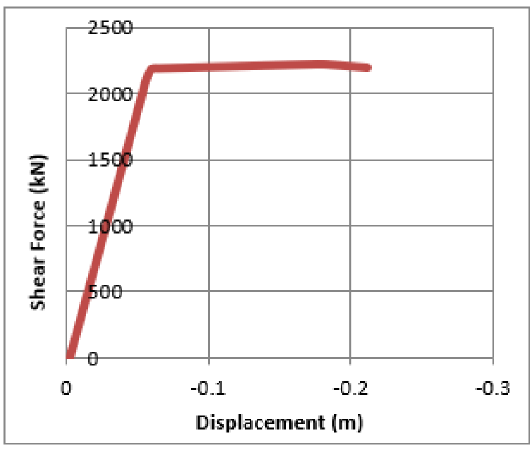
(b)



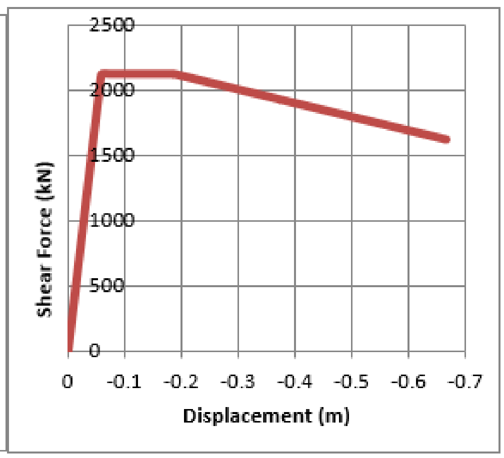
(c)



(d)



(e)



(f)

FIGURE 8. Displacement capacity curve of bridges models for supports in longitudinal direction: (a): Box girder bridge model, (b): Solid girder bridge model, (c): Precast I girder bridge model, (d): Slab bridge model, (e): Precast T girder bridge, (f): U steel girder bridge

DEMAND/CAPACITY RATIO ANALYSIS IN TRANSVERS DIRECTION

To determine demand/capacity ratio, the forces result from elastic analysis (demand) such as moment and shear are compared with strength (capacity) under action for different structural members of bridge structure. When this ratio is more than critical limit which is 1.0, the capacity of structural member is not enough and it will subject to failure. (Priestley M. and Calvi G. 1996).

In this study, bents of bridges structure are selected to determine the demand/capacity ratio because of this structural member is the critical part in the bridges when they are subjected to seismic load. Table 1 lists the values of demand/capacity ratio for bridges structure bents under seismic load. From this table it can be concluded that the values of demand/capacity ratio for bent No.1 of bridges structure are less than 1.0. The maximum value is appeared in U steel bridge model which is 0.908 and the minimum value is existed within slab bridge. For bent No. 2, box girder bridge, solid girder bridge, and slab bridge have values of demand/capacity ratio are less than critical limit 1.0, but precast I girder bridge, precast T girder bridge, and U steel bridge have ratio values more than critical limit 1.0. The all values of demand/capacity ratio for bent No. 3 are less than critical limit 1.0 which they are near the values of bent No. 1. Figure 9 shows the comparative values of demand/capacity ratio for bridges structures models. This figure shows that the models of precast I girder bridge, precast T girder bridge, and U steel bridge have higher values of demand/capacity ratio. Table 2 gives the values of demand/capacity ratio in longitudinal direction, and it shows that all values are less than critical limit 1.0. therefore, there is no structural problems in longitudinal direction. Figure 10 shows the comparative values of demand/capacity ratio for bridges structures models in longitudinal direction.

According to above results, bent No. 2 is the critical structural member which has values of demand/capacity ratio more than 1.0 or near from it especially precast I girder bridge, precast T girder bridge, and U steel bridge, indicating that these types of bridges will be subjected to failure in bent No. 2. Therefore, there is needing to redesign the bents of these types of bridges by increasing the numbers of piers, using high strength materials in construction of bents, and increasing of dimensions of piers and pier caps. Also it can be seen that the models precast I girder bridge, precast T girder bridge, and U steel bridge have the higher values of forces comparing to others models, indicating that these results agree with results of demand/capacity ratio and pushover analysis method.

TABLE 1. Demand, capacity, ratio for bridges structure bents due to response spectra analysis in transverse direction

Bridge Types	Bent No. 1 of span 1 in transverse direction			Bent No. 2 of span 2 in transverse direction			Bent No. 3 of span 3 in transverse direction		
	Demand (D)	Capacity (C)	D/C Ratio	Demand (D)	Capacity (C)	D/C Ratio	Demand (D)	Capacity (C)	D/C Ratio
Box girder	0.0684	0.1228	0.557	0.0943	0.1285	0.726	0.0681	0.1226	0.555
Solid girder	0.0496	0.1097	0.452	0.0768	0.1163	0.660	0.0573	0.1096	0.522
Precast I-girder	0.0936	0.1295	0.722	0.1298	0.1296	1.001	0.0931	0.1295	0.718
Slab bridge	0.0936	0.1295	0.722	0.1298	0.1296	1.001	0.0931	0.1295	0.718
Precast T-girder	0.0990	0.1187	0.834	0.1394	0.1191	1.170	0.0995	0.1186	0.838
U-steel girder	0.1137	0.1252	0.908	0.1559	0.1251	1.246	0.1116	0.1250	0.892

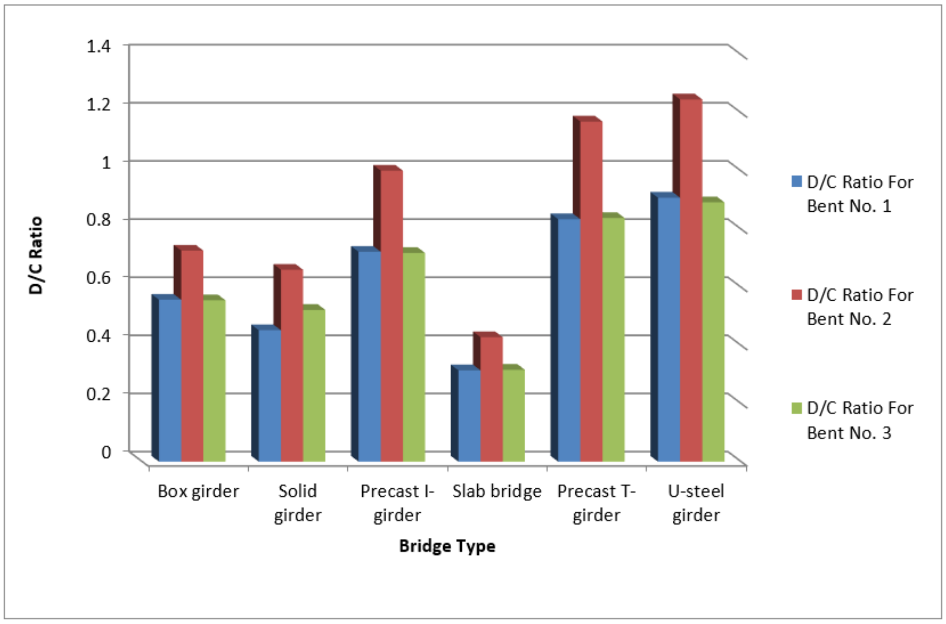


FIGURE 9. Demand/capacity ratio for bridges structure bents due to response spectra analysis in transverse direction

TABLE 2. Demand, capacity, ratio for bridges structure bents due to response spectra analysis in longitudinal direction

Bridge Types	Longitudinal direction of bridge		
	Demand (D)	Capacity (C)	D/C Ratio
Box girder	0.023938	0.095753	0.2500
Solid girder	0.004772	0.011406	0.4184
Precast I-girder	0.067865	0.214496	0.3164
Slab bridge	3.728E-08	0.000008645	0.0043
Precast T-girder	0.052342	0.206874	0.2530
U-steel girder	0.166209	0.205949	0.8070

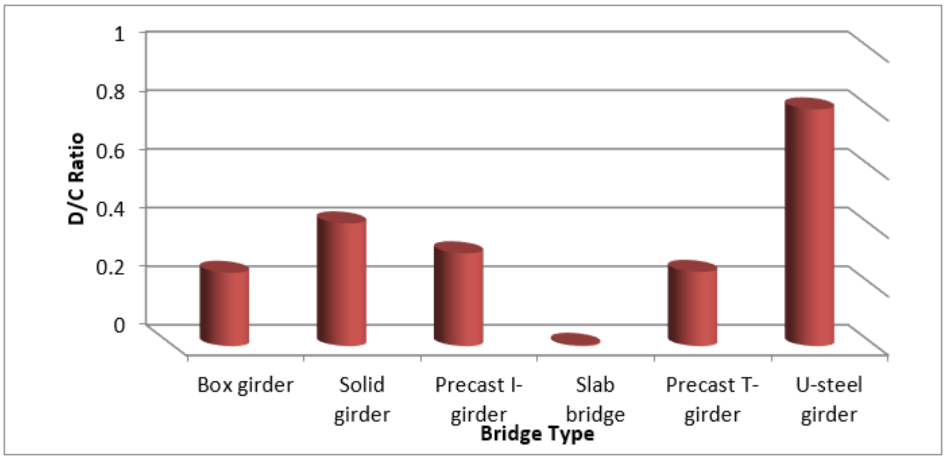


FIGURE 10. Demand/capacity ratio for bridges structure bents due to response spectra analysis in longitudinal direction

BENTS DESIGN INTERNAL FORCES FOR DEMAND UNDER SEISMIC LOADS

To check the demand on bents of bridges structure which is represented by the axial force, horizontal shear, and bending moment, Figure. 11, Figure 12, and Figure 13 are provided under seismic load. These Figures show that bent No. 2 which have two piers are subjected to the maximum values of axial force, horizontal shear, and bending moment for all types of bridges structures.

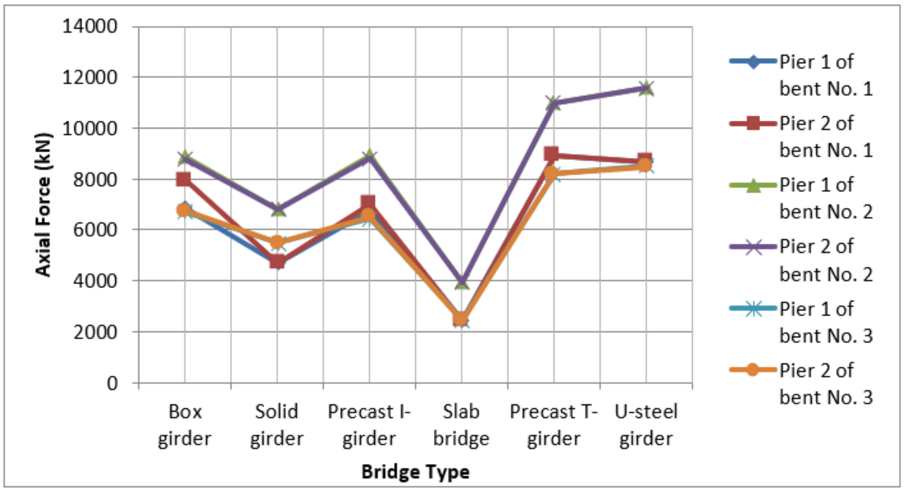


FIGURE 11. Axial force due to seismic load

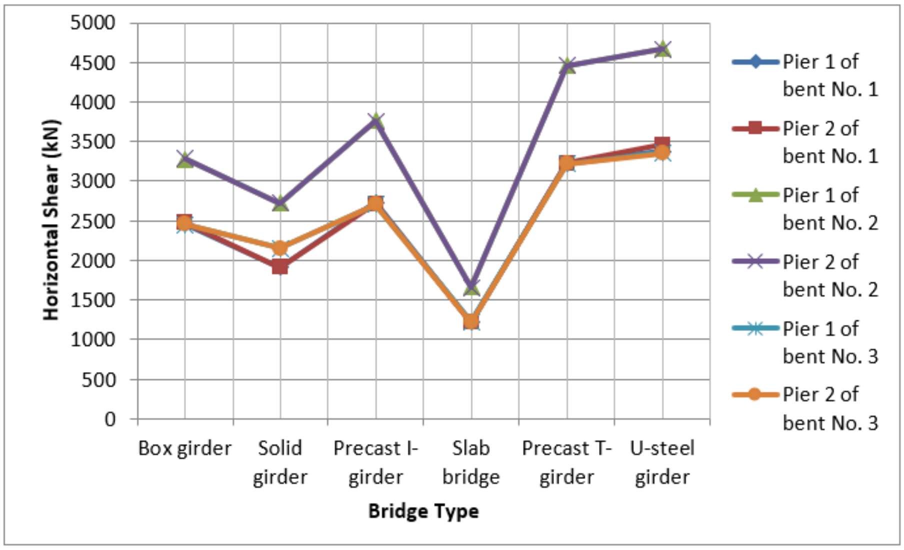


FIGURE 12. Horizontal shear force due to seismic load

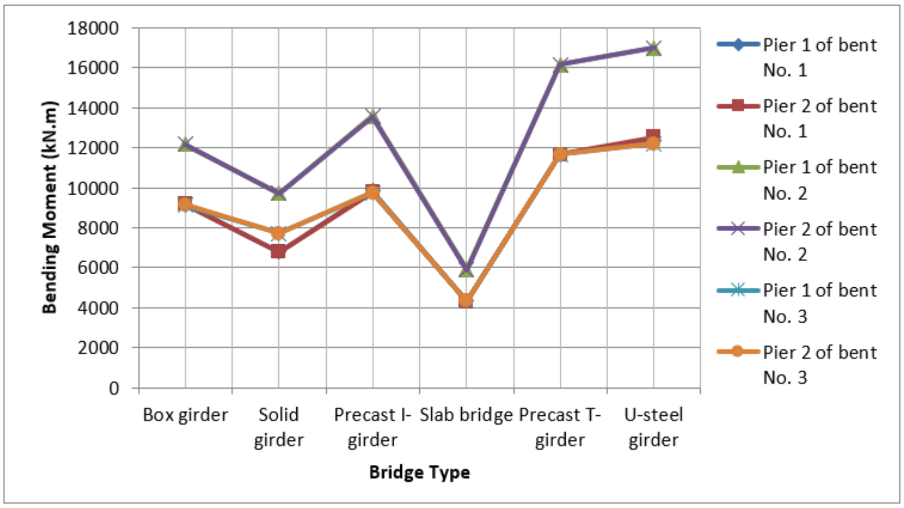


FIGURE 13. Bending moment due to seismic load

CONCLUSION

From this study it can be concluded that:

1. The main objective of this study is to compare the structural members capacity between different types of bridges structures under seismic load. Three-dimension FEM was used by adopting CSI bridge ver. 20. 2. Six different types of bridges structures were selected according to superstructure type (simply supported and continuous) and girders shapes. The bridges models consist of four spans. Each span length was equal to 20m. Therefore, the total length of each bridge was 80m and the total width was 11m. All others boundary conditions and materials properties were same for all bridges' types.

2. There were nine load cases which were using in the seismic design for each bridge. Seismic design curve was selected for all bridges according type of response spectra function. The response spectra function name was AASHTO2007_RS and damping ratio was 0.05.

3. The results of seismic modal analysis showed that the models of box girder bridge, precast T girder bridge, and U steel girder bridge had the higher values of natural frequency comparing with others bridges structures.

4. Seismic pushover analysis (nonlinear static analysis) was used to determine the displacement capacity curve for three bents of bridges models in transvers and longitudinal direction. The results of analysis in transvers direction showed that bent No. 2 of bridges structures which is located in the middle of bridges superstructure is displaced in transvers direction more than bent No. 1 and bent No. 3. In longitudinal direction, Precast I girder bridge had higher value of longitudinal displacement comparing with others bridges structures, and it was more than the maximum value of transvers displacement.

5. The results of demand and capacity showed that bent No. 2 was the critical structural member which had values of demand/capacity ratio more than 1.0 or near from it especially precast I girder bridge, precast T girder bridge, and U steel bridge, indicating that these types of bridges will be subjected to failure in bent No. 2. Therefore, there was needing to redesign the bents of these types of bridges by increasing the numbers of piers, using high strength materials in construction of bents, and increasing of dimensions of piers and pier caps.

6. The results of internal forces showed that bent No. 2 was subjected to the maximum values of axial force, horizontal shear, and bending moment for all types of bridges structures. Also it can be seen that the models precast I girder bridge, precast T girder bridge, and U steel bridge had the higher values of forces comparing to others models, indicating that these results agree with results of demand/capacity ratio and pushover analysis method.

ACKNOWLEDGEMENT

The authors are highly thankful to Al-Furat Al-Awsat Technical University on its excellent help and support to conduct this research.

DECLARATION OF COMPETING INTEREST

None

REFERENCES

Al Ayed, H. & Fu, C. Using pushover analysis method in seismic analysis of bridges. https://research.iugaza.edu.ps/files/2259.PDF.

Ali, F. 2018. Dynamic evaluation of girder cross-sectional shapes of bridges. Conference Proceeding of IEEE, 2018 1st International Scientific Conference of Engineering Sciences-3rd Scientific Conference of Engineering Science (ISCES), Dayla City, Iraq.

Ali, F. 2018. Optimum design of vertical steel tendons profile layout of post-tensioning concrete bridges: fem static analysis. *ARPN Journal of Engineering and Applied Sciences* 13(23): 9244- 9256.

Buckle, I. 1991. Seismic design criteria for highway bridges. Transportation Research Record, 1/1290 (038): 80-94.

Caltrans. 1999. Guidelines for generation of response-spectrum-compatible rock motion time history for application to Caltrans toll bridge Seismic retrofit projects, Caltrans Seismic Advisory Board, California Department of Transportation, Sacramento, CA.

Chopra, A. & Goel R. 2002. A modal pushover analysis procedure for estimating seismic demands for buildings. *Earthquake Engineering & Structural Dynamics* 31 (3): 561-582.

Dexu, L. 2014. Application of Pushover seismic analysis method to bridge structure. *Theoretical Research on Urban Construction* 20: 828-829.

Duan, L., & Reno, M. 1999. *Performance-based seismic design criteria for bridges.* Structural Engineering Handbook Ed., Chapter 16, Chen Wai-Fah Boca Raton: CRC Press LLC.

Faella, G., Giordano, A. & Mezz, M. 2004. Definition of suitable bilinear pushover curves in nonlinear static analyses. In Proceeding of 13th World Conference on Earthquake Engineering Vancouver, B.C., Canada.

Godse, P. 2013. Seismic performance study of urban bridges using non-linear static analysis. *International Journal of Innovative Research in Science, Engineering and Technology* 2(6): 2440-2447.

Huafeng, H., Shanyong, Z. & Guangzu, S. 2021. Study of high pier of Bridge Seismic demand based on the modal Pushover analysis. *Journal of China & Foreign* 32(1): 152-159.

Hussam, M., & Ali, F. 2020. Mathematical assessment of vehicles types and loads influences on the structural performance parameters of concrete and steel bridges. *Journal of Engineering Science and Technology* 15(2): 1254 – 1266.

Jie, H. 2008. Bridge seismic static elastic-plastic analytical method. *Journal of Xuzhou Institute of Technology* 23(4): 19-23.

Li, H. 2020. The seismic design suggestions of girder bridge. Proceeding of E3S Web of Conferences 165, 04034.

Moehle, J. & Eberhard, M. 2003. Earthquake damage to bridges. https://www.researchgate.net/publication/329683038_Earthquake_damage_to_bridges.

Mohan, A. 2017. The structural behavior of horizontally curved pre-stressed concrete box girder bridges. A Thesis of ph. D degree, School of Computing, Science and Engineering, University of Salford, United Kingdom.

Mwafy, A. & Elnashai, A. 2007. Assessment of seismic integrity of multi-span curved bridges in mid-America, Final Report, Mid-America Earthquake Center Civil and Environmental Engineering Department University of Illinois at Urbana-Champaign, IL, USA.

Ozel, A. 2016. Seismic design of a prestressed concrete bridge. Thesis of Master Degree, University of New Orleans.

Paraskeva T., Kappos A. & Sextos, A. 2006. Extension of modal pushover analysis to seismic assessment of bridges. *Earthquake Engineering Structural Dynamics* 35(10): 1269-1293.

Pinho, R. 2005. Using pushover analysis for assessment of buildings and bridges. Advanced Earthquake Engineering Analysis, Courses and Lectures, Italy.

Priestley, M. & Calvi, G. 1996. Seismic design and retrofit of bridges. *Engineering Handbook.* John Wiley & Sons, Inc.

Ramirez, J., Frosch, R., Sozen, M. & Turk, M. 2000. Post-earthquake safety evaluation of bridges and roads, Handbook for Indiana Department of Transportation, INDOT, USA.

Wilson, T. 2013. Seismic performance of skewed and curved RC bridges. A Thesis of Master Degree, Colorado State University, Fort Collins, Colorado.

Wood, J. 2015. Earthquake design of bridges with integral abutments. In Proceeding of 6th International Conference on Earthquake Geotechnical Engineering, Christchurch, New Zealand.

Yang, F., Zhang, Y., Zheng, T. & Li, B. 2016. Application of Pushover Analysis in Bridge Piers, The 2016 International Forum on Energy, Environment and Sustainable Development, Shenzhen, China.

Zhang, W., Vinayagamoorth, M. & Duan, L. 2014. Dynamic analysis. *Bridge Engineering Handbook.* 2nd edition. Seismic Design.