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Dynamic Analytical Modeling of Horizontal Outline Turn of T-Girder Simply Supported Bridge

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ABSTRACT

Layout line of bridge structure is a direction line which is used to define the horizontal and vertical alignment of the bridge structure. The objective of this study is to evaluate and optimize the different designs of bridge horizontal outline turn and compare the results with horizontal layout straight of bridge using dynamic analysis according to finite element analysis method. Dynamic analysis results showed that most models have converging values of dynamic natural frequency except Model No. F. and it explains that the higher rate of natural frequency is 5.10Hz within model No. F. The maximum value of loaded frequency is equal to 6.35 Hz for model No. I (Straight - curve right - straight - curve left - straight). Model No. A appears minimum value of loaded frequency which equal to 3.56Hz. The higher value of loaded frequency indicates that the bridge model has high vibration state which effects on the stiffness and flexibility of bridge structure. Model No. I appears higher value of downward acceleration which is 3.55m/s2. The maximum value of upward and downward deflection is 1.84mm and 4.07mm respectively in model No. G, indicating that this model will easy to deflect under traffic loads. It can be concluded that The bridges models No. F, H, I have values of loaded frequency higher than the values of natural frequency. Therefore, these models have lower stiffness and flexibility and bearing capacity than other. Therefore, this study recommended that the optimum design which has high stiffness and more elasticity.

Keywords: Horizontal outline; T-girder; bridge; finite element; dynamic; loaded frequency

INTRODUCTION

Bridges are significant civil structures which built to span over several obstructions including water, valleys, and roads. These structures provide critical connections between different parts of transportation otherwise un-connectable. Generally, all bridges structure consist of parts as a superstructure and a substructure. The superstructure can be included all members of the bridge higher than the substructure. The essential parts of the superstructure of bridge structure include the pavement surface, the deck, and girders. The task of the superstructure is collecting the different types of loads and transfer them into the substructure of bridge structure. The substructure takes actions as a foundation of the bridge. It is consisted of the abutments, piers, piers cap, bearings, pedestals, and retaining walls. (Terranova 2015), (Jason and Arthur 2009, (Tonias 1995)

A simply supported girder bridges (T and I sections) are a major number of bridges that were built in previous decades and they are two of the most popular bridge types right through the world. This type of bridges can be precast or cast in situ (prestressed or normal concrete). Historically, they became very popular after World War II due to the necessity for fast bridge construction that could fulfill the increased demand for rehabilitation of the damaged transportation networks and while durability. In the following decades simply supported concrete bridges became a common design practice worldwide. (Olga and Ioannis 2013), (Lu et al.. 2015)

Layout line of bridge structure is a orientation lines which is used to define the horizontal and vertical alignment of the bridge structure and the traffic lanes. For both horizontal and vertical alignments, layout line can be straight, bent or curved. (Computers & Structures, Inc. 2009)

The layout line and site of the bridge structure design depends on the vehicles types and volumes. Therefore, the bridge structure can be placed to supply the traffic movement between two sides of bridge structure. In general, different traffic situations and place state will be influenced the selection of bridge location and layout. The most important factor is layout of bridge structure with administration to topographic crossing when the position of bridge is make a decision to select (Troitsky 1994). Analysis of bridge structure can be divided into two methods (static and dynamic analysis). The choice of analysis method depends on objectives of analysis, type of bridge, and soil states. Analysis methods include engineering software models, which are using suitable material properties, boundary situations, and different types of loads. (Bhumika 2020), (Ali and Wang 2011), (Duan 2008)

Determining the dynamic responses of structures which that subjected to moving loads had been an important engineering problem to increase insights into the dynamic responses of railways, different types of bridges structures, pavements and mechanical devices. When a bridges are subjected to vehicular traffic (dynamic loads), the structure will vibrate. A moving vehicle on a bridge will produce vertical deflection and tensile and compressive stresses more than those produced by the same value of vehicle loads applied by using static method, because of the dynamic interaction between the bridge and the vehicle. Curved bridges are important and suitable because of increased demand for curved roadway layout for the soft route sof congested traffic and modern emphasis on aesthetic considerations. (Ali et al. 2019), (Senthilvasan et al. 2002)

Dynamic behaviors of bridge structure due to traffic moving across are one of the most important concerns in the design and rating of bridge. Dynamic responses of bridge depends on many factors. These factors include vehicles types, dynamic properties of bridge which are including span, mass, support types, material, and geometry, roughness of bridge surface which are including approach, roadway, cracks, potholes, and waves, and dynamic properties of vehicles such as mass, suspension, axle configuration, tires, and speed. Dynamic analysis of bridges is made by using number of simplifications. The dynamic effects of traffic loads on bridges can be put a crossed in names of an impact factor. (Trong et al. 2008), (Seung and Nowak 1990), (Ali 2018), (Munirudrappa and Ohruvaraja 1999)

THREE-DIMENSION BRIDGES MODELS

In this study, simply supported T-girder bridge model is used in the dynamic finite element analysis. All models have same span length, width, and depth which is equivalent to 20m, 10m, and 1.8m respectively. Bridges models have six spans and the total length of bridges models is 120m. Each model of bridge is designed according to nine horizontal outline turn (layout bend). The bridge models have one pier in transverse direction with dimensions equal to 2m*2m*8m. The thickness for concrete deck is 30cm and pavement layer is 10cm. Table 1 gives the types of bends. Figure 1 shows the models of T-girder bridge models.

MATERIALS PROPERTIES AND MOVING LIVE LOAD MODEL

For concrete material, The mass per unit volume is 24 kN/m^3 and the poison ratio is 0.2. The strength grade of concrete is C40 and the elasticity modulus is 24855MPa. The shear modulus is 10357MPa. For pre-stressing tendons, the types of tendon is A416 Gr270 and the modulus of elasticity is 196500MPA. The mass per unit volume is 78.4 kN/m^3. The minimum yield stress is 1690MPa and the minimum tensile stress is 1861.5MPa. The passing of live loads on the bridge structure representing by vehicle type is HSn-44L-1which has scale factor is 20 with design speed equal to 80km/hr. The number of loaded lanes are two.

DYNAMIC ANALYSIS RESULTS

The dynamic analysis of bridges models is done by adopting finite element method. SAP2000 is used. The dynamic analysis is adopted to find the dynamic natural frequency, dynamic loaded frequency, dynamic acceleration, and dynamic vertical deflection.

DYNAMIC NATURAL FREQUENCY

Natural frequency is one of the essential dynamic features. The natural frequency of the bridge is used to away from the 1.5 to 4.5 Hz range, which is the ordinary variety of the natural frequency for trucks, based on the theory of resonance, in order to effectively reduce the vibration of bridges subjected to moving vehicles.

TABLE 1. Horizontal outline turn models: numbers and names

Horizontal Outline Turn Model No.	Horizontal Outline Turn Name
A	Straight
B	Straight –turn left
C	Straight – turn left– turn left
D	Curve turn left
E	Straight –curve turn left
F	Curve turn left-straight
G	Straight –curve turn left-straight
H	Straight –curve turn left- Straight –curve turn left- Straight
I	Straight –curve turn right- Straight –curve turn left- Straight

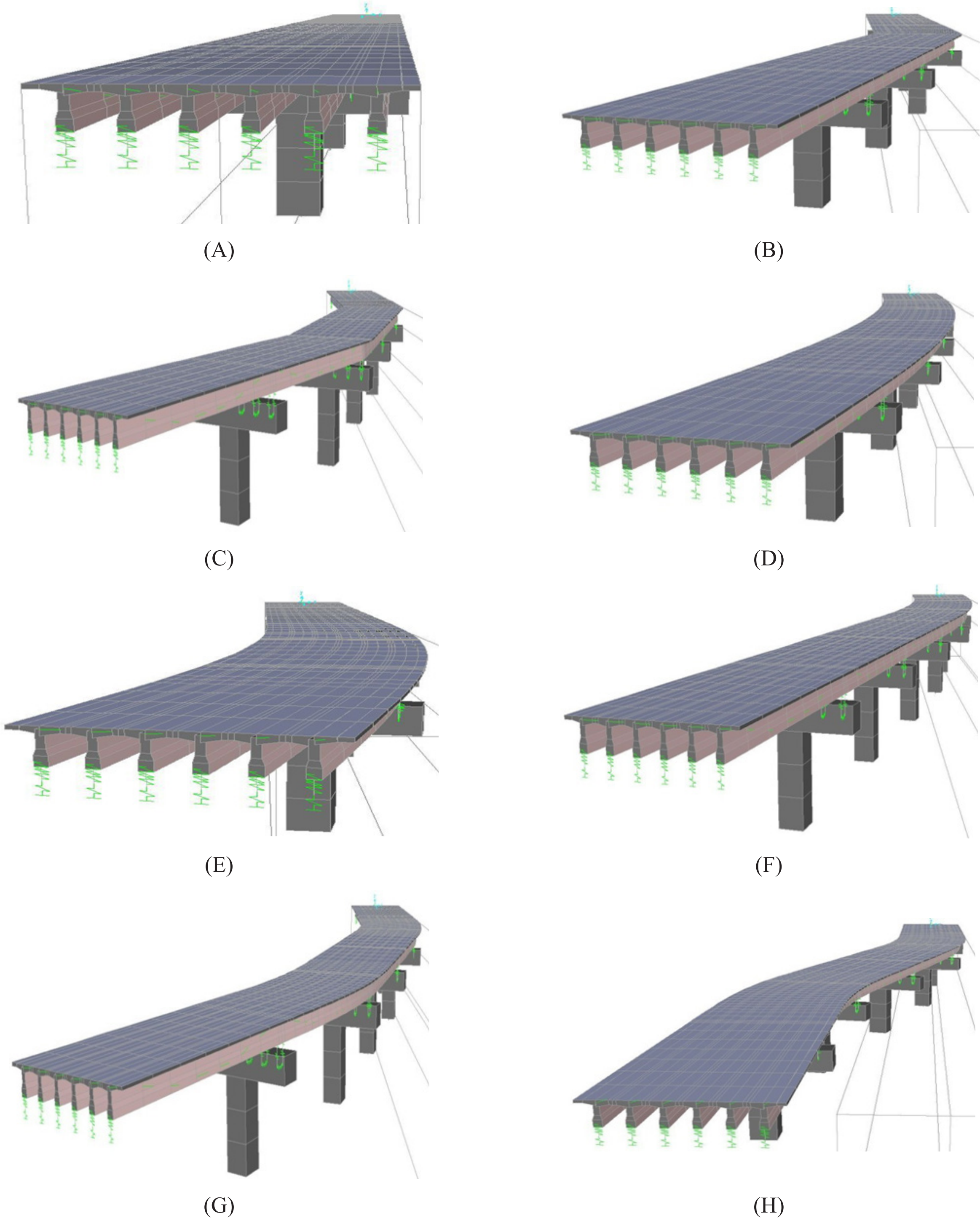


FIGURE 1. Models of T-girder bridge (Ali and Hussam 2020): (a) straight, (b) straight–bend left, (c) straight–bend left–bend left, (d) curve left, (e) straight–curve left, (f) curve left-straight, (g) straight–curve left-straight, (h) straight–curve left- straight–curve left-straight, (i) straight –curve right- straight–curve left- straight

(Qing et al. 2015). In dynamic analysis of bridges, modal analysis illustrates the dynamic response of the structural system through modal factors results such as dynamic natural frequencies, mode shapes and damping ratios. Efficiently estimating these modal factors for bridges permits for better structural integrity evaluations and structural health monitoring of these structures. (Arden 2009)

Figure 2 shows the results of dynamic natural frequency according to modal analysis of moving live load for nine adopted bridges structures models. This figure it can be seen that most models have converging values of dynamic natural frequency except Model No. F. and it explains that the higher value of natural frequency is 5.10Hz within model No. F (curve left-straight). The lower value of natural frequency is 4.93Hz within model No. H (straight–curve left- straight–

curve left- straight). it can be seen that most models have converging values of dynamic natural frequency except Model No. F.

DYNAMIC LOADED FREQUENCY

The loaded frequency is the frequency of free vibration of a bridge structure when the traffic volumes passing on the bridge surface. When the mass of the loading vehicle is included in the system, this type of frequency is a function of the location of the vehicle (Don 1960).

The dynamic analysis results of loaded frequency can be shown that in Figure 3 and Figure 4. From these figures, the maximum value of loaded frequency is equal to 6.35 Hz within model No. I (Straight - curve right - straight - curve left –straight). Model No. A appears minimum value of loaded frequency which equal to 3.56Hz. The higher value of loaded frequency indicates that the bridge model has high vibration state which effects on the stiffness and electricity of bridge structure.

Figure 5 explains the comparative curves between natural and loaded frequency for bridges models. Bridges models No. F, H, I have values of loaded frequency higher than the natural frequency values. Therefore, these models have lower stiffness and elasticity and bearing capacity than others models.

DYNAMIC ACCELERATION

Dynamic acceleration is an unlimited reaction that can be simply captured on a structure without having a fixed reference. In theory, dynamic acceleration can be changed into displacement by double integration in the time domain, while the numerical integration generally brings a significant signal drift (Soojin and Sung 2015).

Figure 6 and Figure 7 show the results of dynamic acceleration. These figures illustrate that model No. D and model No. F appeared higher value of dynamic acceleration in upward direction which is equal to 3.99 mm/s^2. Whereas, model No. I appeared higher value of downward acceleration which is 3.34mm/s^2.

DYNAMIC VERTICAL DEFLECTION

Dynamic deflection of bridge structure due to operational loads of different types of vehicles are a significant support for the determination of dynamic structural performance, but exact measurement of structural displacement remainder as a challenging assignment (Yan et al. 2016).

Figure 8 and Figure 9 show the results of dynamic vertical deflection. These figures show that the maximum value of upward and downward deflection is 1.84mm and 4.07mm in model No. G, indicating that this model will easy to deflect under traffic loads.

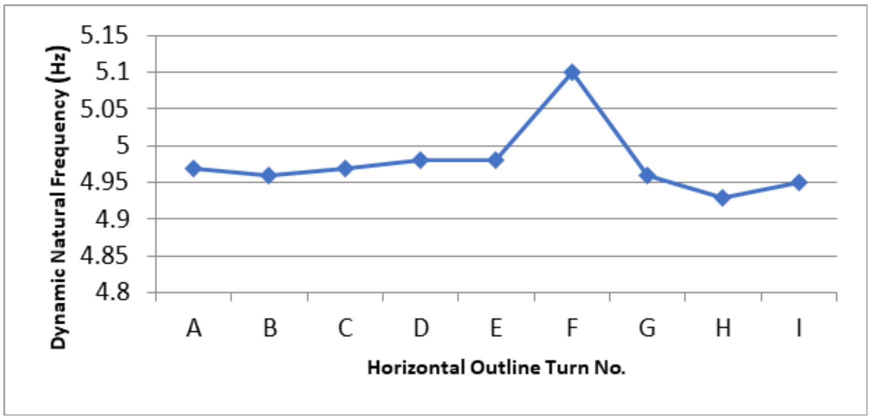


FIGURE 2. The results of dynamic natural frequency

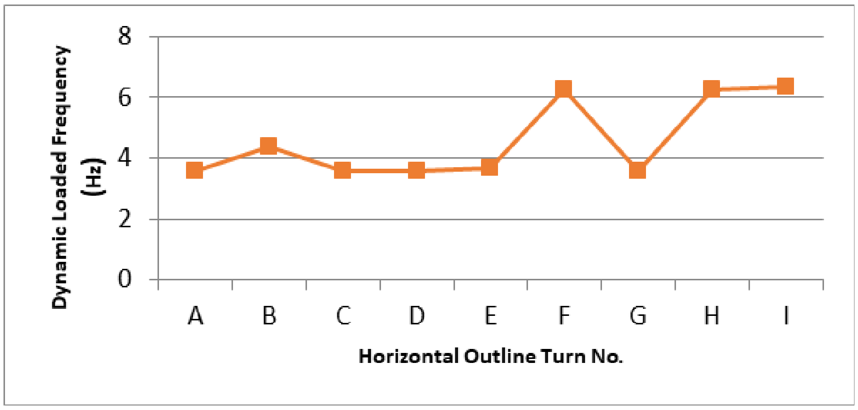
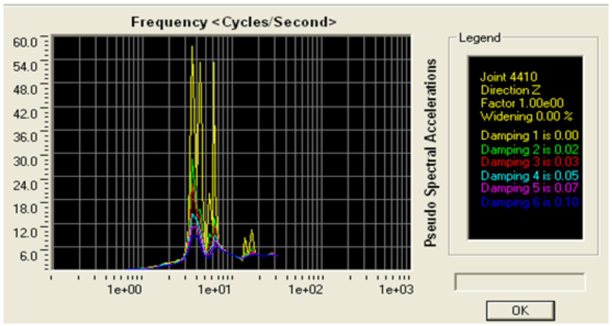


FIGURE 3. The results of dynamic loaded frequency



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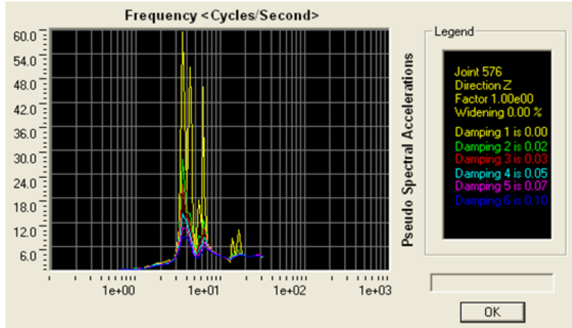
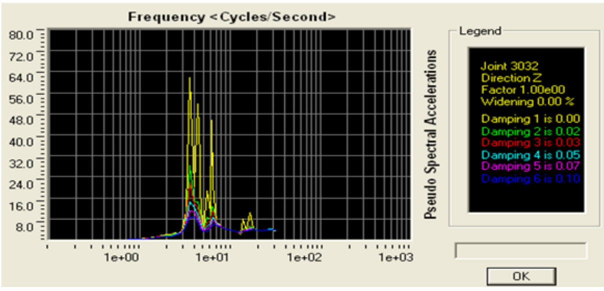
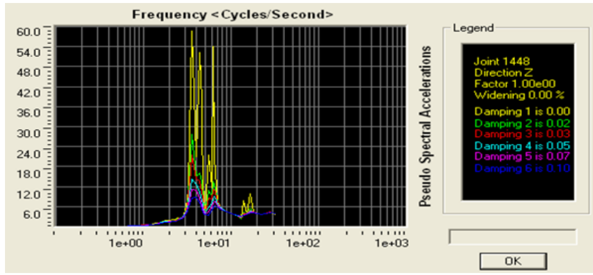


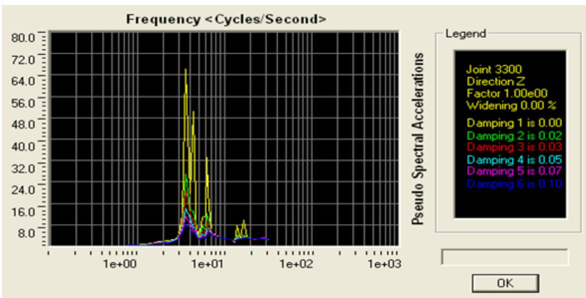
(B)



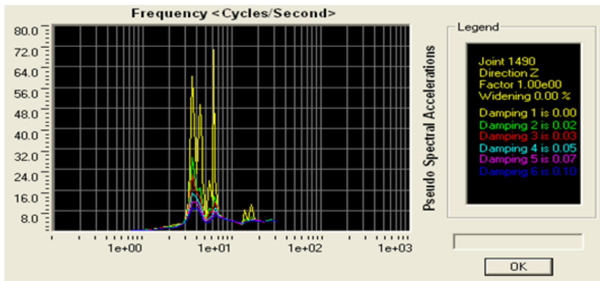
(C)



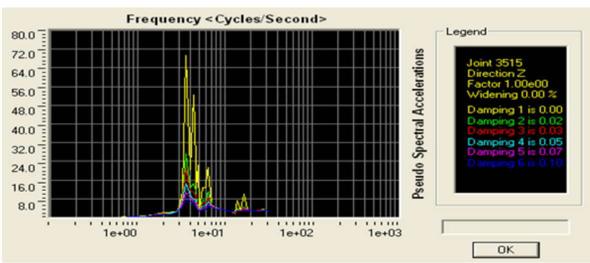
(D)



(E)



(F)



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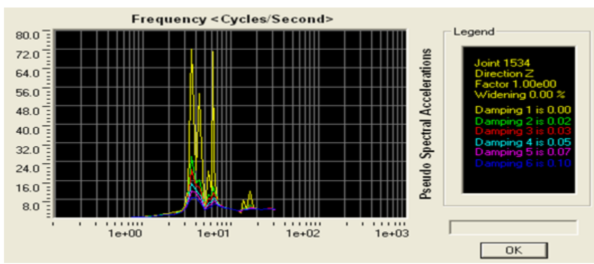

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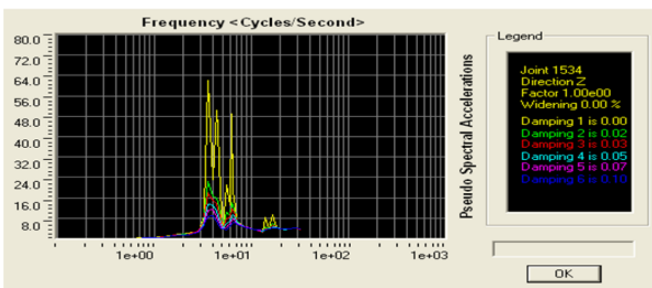


(I)

FIGURE 4. The results of dynamic loaded frequency: (a) Straight, (b) Straight–bend left, (c) Straight–bend left–bend left, (d) Curve left, (e) Straight–curve left, (f) Curve left-straight, (g) Straight–curve left-straight, (h) Straight–curve left- straight–curve left- straight, (i) Straight –curve right- straight–curve left- straight

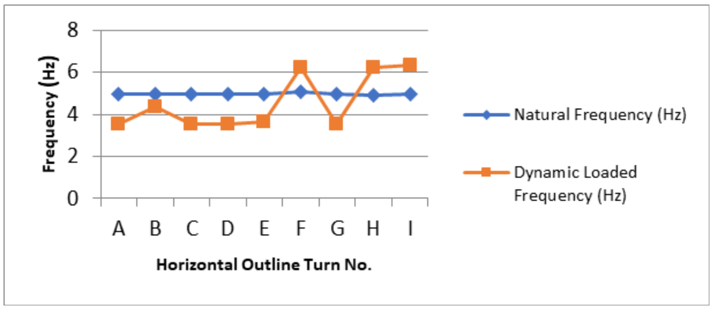


FIGURE 5. The comparative curves between natural and loaded frequency

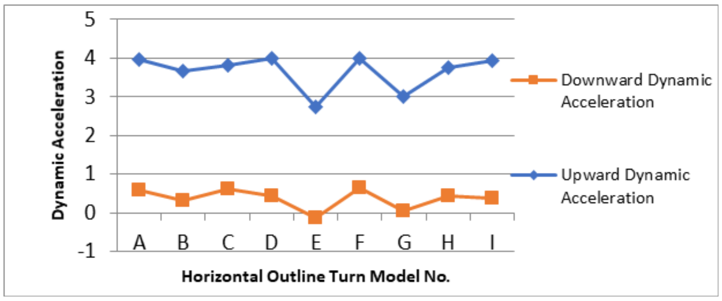
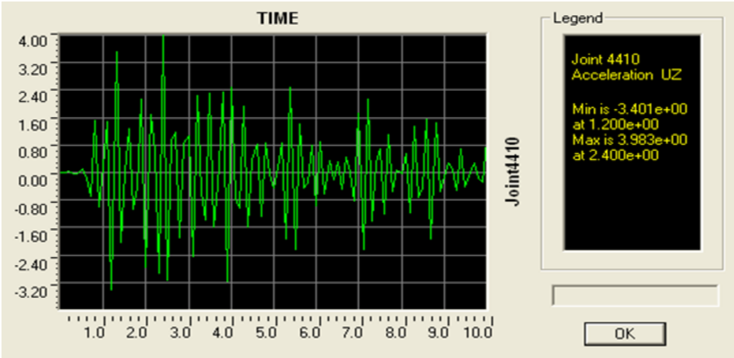


FIGURE 6. The results of dynamic acceleration



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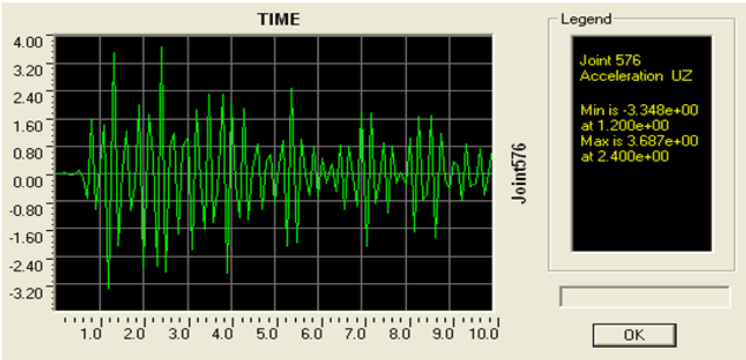
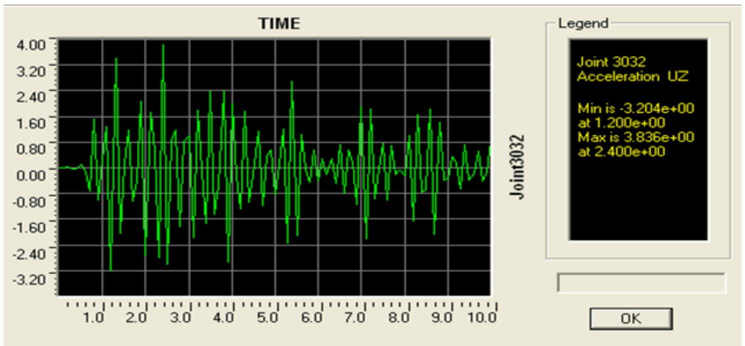


(B)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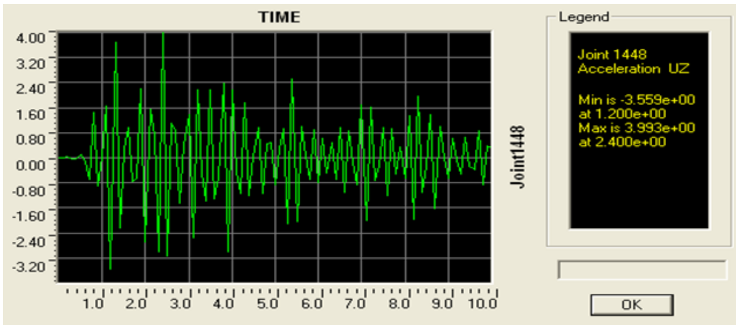
4.00
3.20
2.40
1.60
0.80
0.00
-0.80
-1.60
-2.40
-3.20
1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0
Joint3032
Legend
Joint 3032
Acceleration UZ
Min is -3.204e+00
at 1.200e+00
Max is 3.836e+00
at 2.400e+00
OK

(C)


TIME
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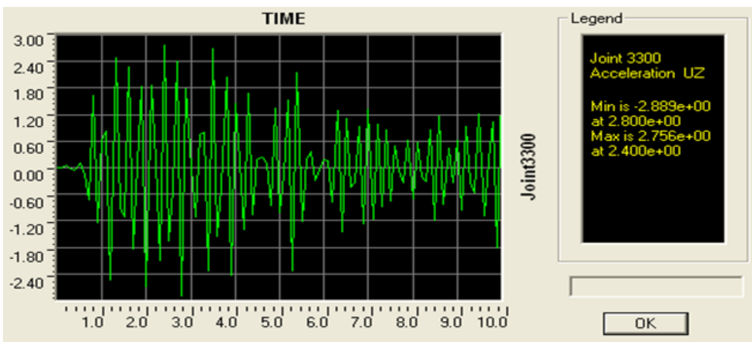
3.20
2.40
1.60
0.80
0.00
-0.80
-1.60
-2.40
-3.20
1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0
Joint1448
Legend
Joint 1448
Acceleration UZ
Min is -3.559e+00
at 1.200e+00
Max is 3.993e+00
at 2.400e+00
OK

(D)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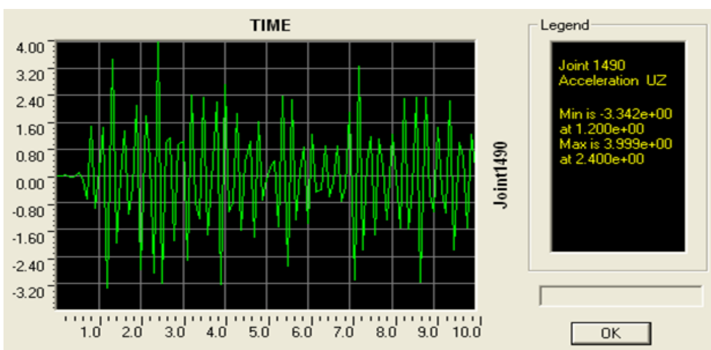
1.80
1.20
0.60
0.00
-0.60
-1.20
-1.80
-2.40
1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0
Joint3300
Legend
Joint 3300
Acceleration UZ
Min is -2.889e+00
at 2.800e+00
Max is 2.756e+00
at 2.400e+00
OK

(E)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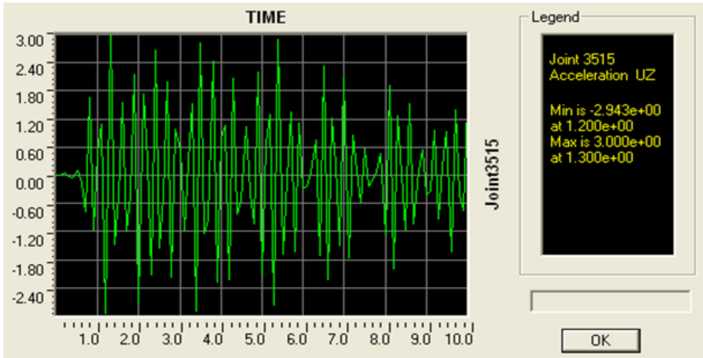
1.60
0.80
0.00
-0.80
-1.60
-2.40
-3.20
1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0
Joint1490
Legend
Joint 1490
Acceleration UZ
Min is -3.342e+00
at 1.200e+00
Max is 3.999e+00
at 2.400e+00
OK

(F)



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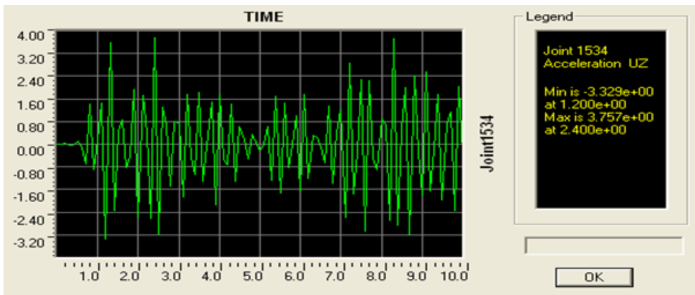

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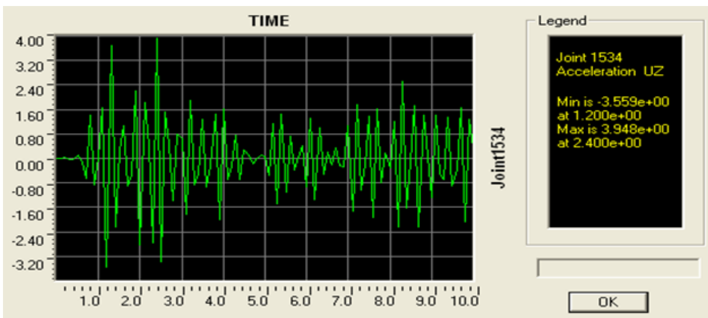


(I)

FIGURE 7. The results of dynamic acceleration: (a) Straight, (b) Straight–bend left, (c) Straight–bend left–bend left, (d) Curve left, (e) Straight–curve left, (f) Curve left-straight, (g) Straight–curve left-straight, (h) Straight–curve left- straight–curve left- straight, (i) Straight –curve right- straight–curve left- straight

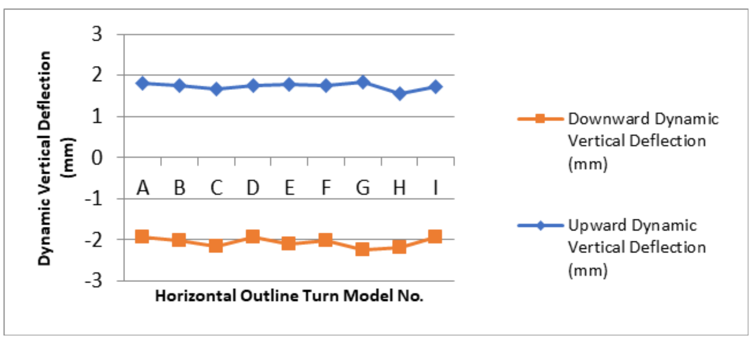
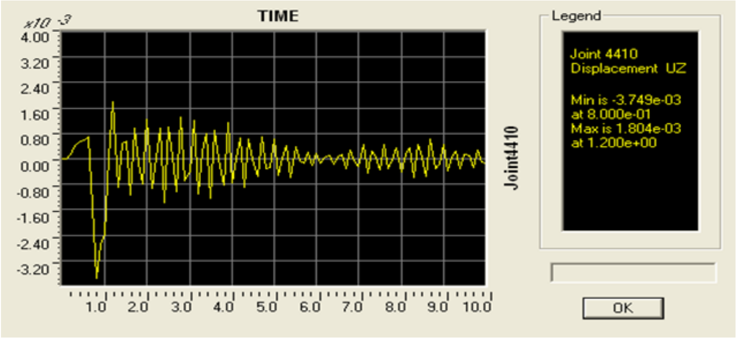


FIGURE 8. The dynamic up and downward vertical deflection


TIME
x10 -3
Joint4410
Legend
Joint 4410
Displacement UZ
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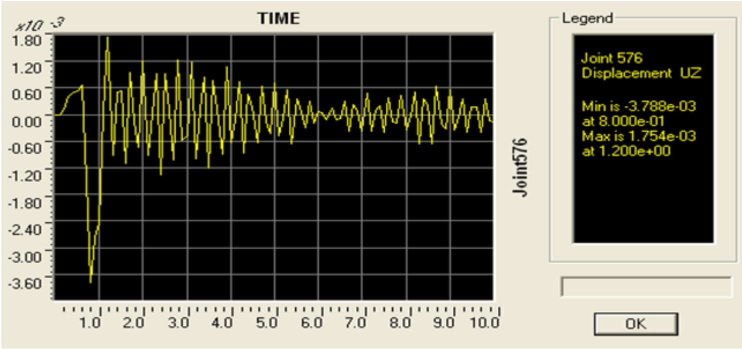
Max is 1.804e-03
at 1.200e+00
OK

(A)


TIME
x10 -3
Joint576
Legend
Joint 576
Displacement UZ
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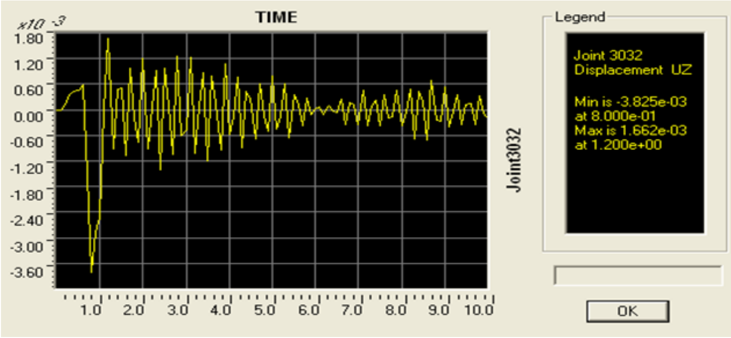
Max is 1.754e-03
at 1.200e+00
OK

(B)


TIME
x10 -3
Joint3032
Legend
Joint 3032
Displacement UZ
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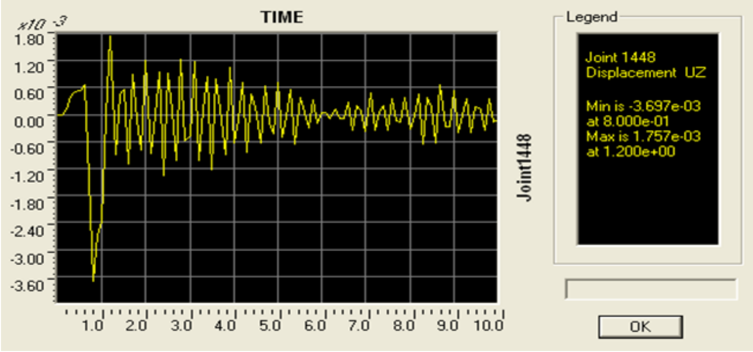
at 8.000e-01
Max is 1.662e-03
at 1.200e+00
OK

(C)


TIME
x10 -3
Joint1448
Legend
Joint 1448
Displacement UZ
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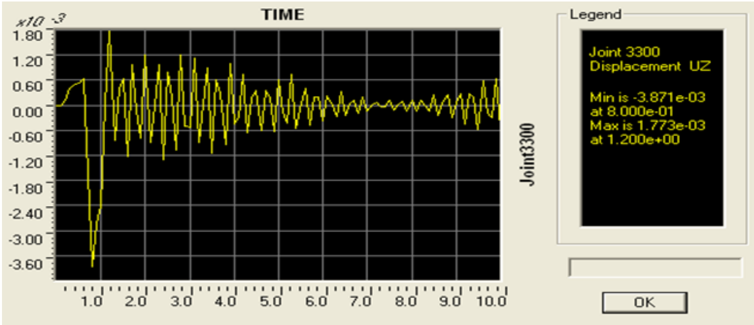
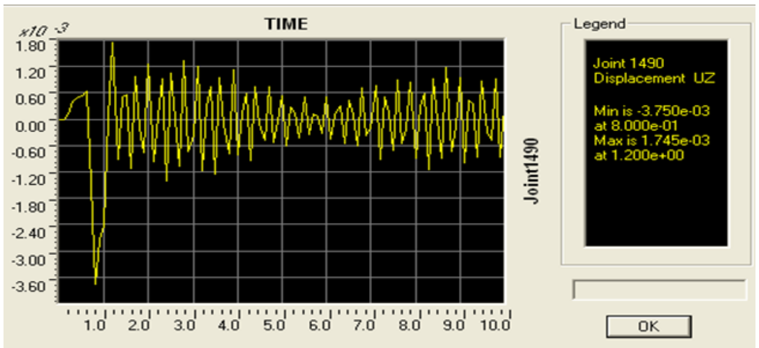
at 8.000e-01
Max is 1.757e-03
at 1.200e+00
OK

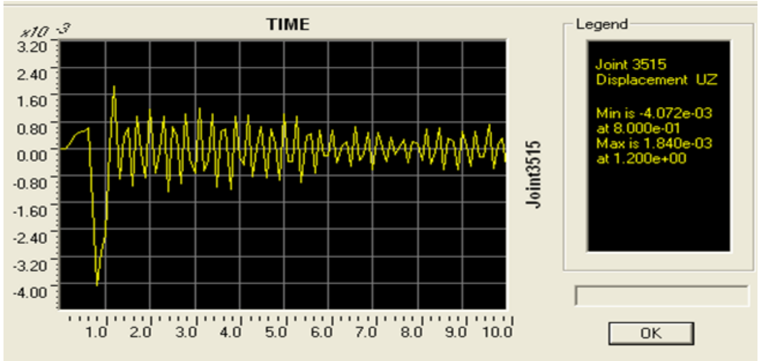
(D)


TIME
Legend
Joint 3300
Displacement UZ
Min is -3.871e-03
at 8.000e-01
Max is 1.773e-03
at 1.200e+00
Joint3300
OK

(E)


TIME
Legend
Joint 1490
Displacement UZ
Min is -3.750e-03
at 8.000e-01
Max is 1.745e-03
at 1.200e+00
Joint1490
OK

(F)


TIME
Legend
Joint 3515
Displacement UZ
Min is -4.072e-03
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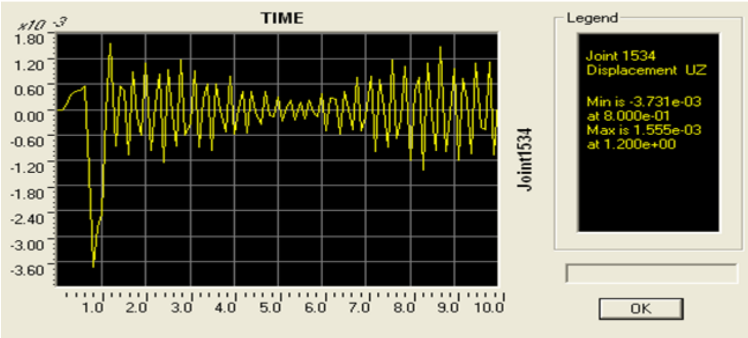
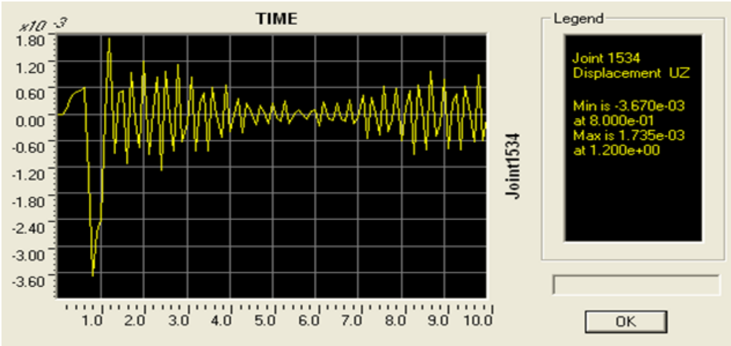
Max is 1.840e-03
at 1.200e+00
Joint3515
OK

(G)


TIME
Legend
Joint 1534
Displacement UZ
Min is -3.731e-03
at 8.000e-01
Max is 1.555e-03
at 1.200e+00
Joint1534
OK

(H)



(I)

FIGURE 9. The results of dynamic upward and downward vertical deflection: (a) Straight, (b) Straight–bend left, (c) Straight–bend left–bend left, (d) Curve left, (e) Straight–curve left, (f) Curve left-straight, (g) Straight–curve left-straight, (h) Straight–curve left-straight–curve left- straight, (i) Straight –curve right- straight–curve left- straight

CONCLUSION

The results of dynamic analysis explained that the higher value of natural frequency is 5.10Hz within model No. F (curve left-straight) which is less than maximum value of dynamic forced frequency that is 6.35Hz with in model No. I (straight–curve right-straight–curve left- straight), indicating that the T-girder bridge model has not enough stiffness and resistance to different types of loads.

Model No. F appeared higher value of dynamic acceleration in upward direction. Whereas, model No. I appeared higher value of downward acceleration which is 3.55m/s^2.

The results of dynamic vertical deflection show that maximum value of upward and downward deflection is 1.84mm and 4.07mm in model No. G, indicating that this model will easy to deflect under traffic loads.

DECLARATION OF COMPETING INTEREST

None.

REFERENCES

Ali, F. N. & Wang, Z. L. 2011. Theoretical analysis of designed internal forces of jiamusi highway prestressed concrete bridge before strengthening in China. *Advanced Materials Research* 189 (193): 2353-2361.

Ali, F. N. 2018. Dynamic evaluation of girder cross-sectional shapes of bridges, Conference Proceeding, 2018 1st International Scientific Conference of Engineering Sciences - 3rd Scientific Conference of Engineering Science (ISCES), 978-1-5386-1498-3/ 18/31.00$©2018 IEEE, Iraq.

Ali, F. N & Hussam, A.M. 2020. Horizontal layout bend of bridges structure effects on the static design internal forces: evaluation and optimization study. *ARPN Journal of Engineering and Applied Sciences* 15(2): 186-191.

Ali, N., Soheil, A., Shabnam, S., Iman, H., & Hossein, K. 2019. A low computational cost method for vibration analysis of rectangular plates subjected to moving sprung masses. *Advances in Computational Design* 4 (3): 307-326.

Arden, R. P. 2009. Field investigation of fundamental frequency of bridges using ambient vibration measurements, Master Thesis of Engineering, Canada.

Bhumika, B. 2020. Basic methods of analysis for bridges, https://www.sefindia.org/?q=system/files/BRIDGES-2.

Computers & Structures, Inc. 2009. Introduction to SAP2000/ Bridge, University Avenue Berkeley, California, USA.

Don, A. L. 1960. Forced vibration of continuous highway bridges, Ph. D Thesis, Iowa State University of Science and Technology, Michigan, USA.

Duan, L. 2008. Highway bridge, in AccessScience@McGraw-Hill, http://www.accessscience.com, DOI 10.1036/1097-8542.800420.

Jason, C. & Arthur, G. 2009. Rt. 122 Highway bridge design and construction, Bachelor Degree, A project submitted to Worcester Polytechnic Institute, Project No. LDA: 1003.

Lu, D., Wei, H., & Yi, S. 2015. Dynamic impact factors for shear and bending moment of simply supported and continuous concrete girder bridges. *Journal of Bridge Engineering* 20(11): 1-9.

Munirudrappa, N. & Ohruvaraja, I. 1999. Dynamic analysis of continuous span highway bridge. *ISET Journal of Earthquake Technology* 36(1): 73-84.

Olga, M. & Ioannis, T. 2013. Retrofit of Old Simply Supported Concrete Bridges, 2013 International Van Earthquake Symposium, Van, Turkey.

Qing, F. G., Zong, L. W., Xiao, H. L., Wei, Z., & Li, H. Y. 2015. Estimation formulas for natural frequencies of girder bridge and continuous rigid frame bridge. *The IES Journal Part A: Civil & Structural Engineering* 8(3): 155-164.

Senthilvasan, J., Thambiratnam, D. P., & Brameld, G.H. 2002. Dynamic response of a curved bridge under moving truck load. *Engineering Structures* 24: 1283–1293.

Seung, H., & Nowak, S. 1990. Dynamic analysis of girder bridges, Transportation Research Record 1223 (TRR), Department of Civil Engineering, The University of Michigan, USA, 85-92.

Soojin, C., Chung, B. Y., & Sung, H. S. 2015. Displacement estimation of bridge structures using data fusion of acceleration and strain measurement incorporating finite element model. *Smart Structures and Systems* 15 (3): 645-663.

Terranova, B. 2015. Analytical fragility assessment of an isolated multi-span simply supported concrete girder bridge in moderate seismic zones, Master Thesis, Department of Civil, Structural and Environmental Engineering, University of Buffalo, New York, United States.

Tonias, D. 1995. *Bridge Engineering*. New York: McGraw-Hill, Inc.

Troitsky, M. S. 1994. Planning and design of bridges. Canada: John Wiley & Sons, Inc.

Trong, L., Toshiro, H., & Takashi M. 2008. Three-dimensional bridge-vehicle interaction analysis of simply supported twin I-girder bridge. *Journal of Structural Engineering* 54 (A): 181-188.

Yan, X., James, M., David, H., & Ki. Y. 2016. Dynamic displacement measurement of a long-span bridge using vision-based system, 8th European Workshop On Structural Health Monitoring (EWSHM 2016), Spain,