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RETROFITTING OF STEEL ARCH BRIDGE WITH TMD METHOD IN BABOLSAR (IRAN)

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ABSTRACT

This paper presents analytical modal analysis of a steel-girder arch bridge as a part of its retrofitting process. This bridge has encountered structural problem, mostly because of increase of traffic in recent decades, increase of minimum allowable load of heavy trucks and corrosion of steel due to humid weather at the site. A three-dimensional finite element model is constructed and an analytical modal analysis is performed to generate natural frequencies and mode shapes in the three-orthogonal directions. With regard to vulnerability of this bridge, Tuned Mass Damper method (TMD) is used for retrofitting of the bridge. By changing the place and characteristics of TMD system, optimum specifications for the best behavior is found. Using this method serviceability of bridge can be improved. This method and the positioning of TMD can be used to retrofit bridges with the same structural system.

Introduction

Many seismic design methods and construction technologies have been developed and investigated over the years to reduce the seismic responses of buildings, bridges and other potentially vulnerable structures. The inclusion of mechanical damper can be identified as a method of vibration control. Tuned mass damper (TMD) has been found to be effective in reducing the response of structures subjected to dynamic loads (Federal Emergency Management Agency, 2000).

Low natural frequencies and low system damping are typical characteristics of wide span damaged bridges; therefore, they are often sensitive to dynamic loads, especially when excited in their resonance proximity. The resulting bridge motion not only will reduce the passing comfort

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but also, in the worst case, may even cause the collapse of the whole bridge. With tuned mass dampers (TMD) it is possible to increase system damping of the bridge and to reduce the amplification of resonance-excited bridge motion in a major way, mainly in the frequency range below 3 Hz.

A TMD approach consists of a vibrating mass, with a certain percentage of the total bridge mass, and in its simplest case supported by helical springs with parallel viscous dampers. (Kareem, A., and S. Kline. ,1995), The natural frequency of the TMD is tuned to the natural frequency of the bridge for which system damping has to be increased. The principle of a TMD is simple. If vibration modes are excited in the bridge, the TMD will vibrate too, but with a certain phase shift relative to the bridge motion. This phase shift of motions will lead to inertia loads resulting in a decrease of bridge motion (Kwok, K.C.S., and B. Samali. ,1995). Figs. 1, 2 show the concept of TMD usage.

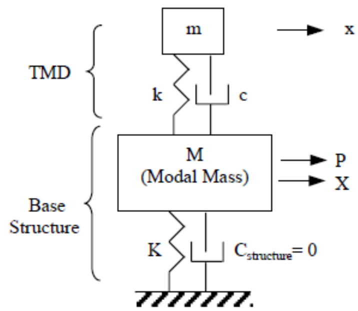


Figure 1. Operating Principle of a TMD

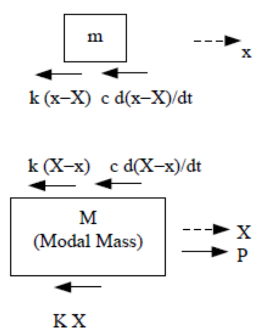


Figure 2. Free-body Diagram of the TMD and Structure

From Free-body diagram of the TMD one can obtain Eq.1 and Free-body diagram of the base structure would lead to Eq.2 which are the main equations of motion.

$$m\frac{d^2x}{dt^2}+c\frac{dx}{dt}+kx-kX-c\frac{dX}{dt}=0 \tag{1}$$

$$M\frac{d^2X}{dt^2}+c\frac{dX}{dt}+(K+k)X-c\frac{dx}{dt}-kx=Fe^{i\omega t} \tag{2}$$

The following paper will provide the results of a TMD application to the "Babolsar Steel Arch Bridge" in Iran as a part of its retrofitting process. A theoretical analysis will be performed to determine the best TMD placement.

Structure of the Bridge

Babolsar Steel Arch Bridge in Iran, crossing the Babolrood River in Babolsar, was constructed over 70 years ago. The Bridge is a 90-meter long span steel-girder arch with an approximately 6000 tons mass. Figs. 3 and 4 show the geometry and a picture of the bridge.

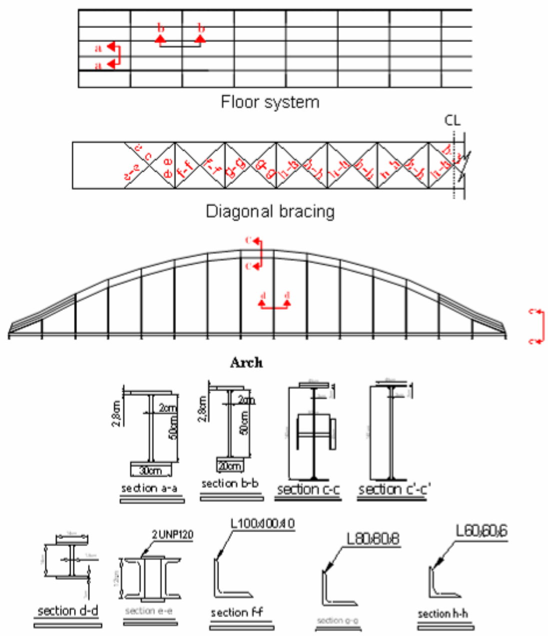
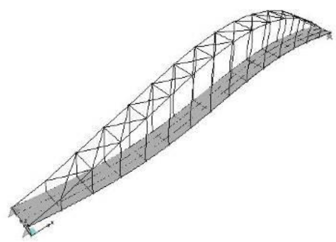


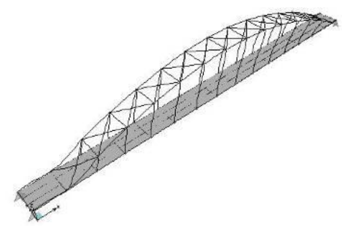
Figure 3. Geometry of the bridge

Figure 4. Side view showing arch of Babolrood Bridge

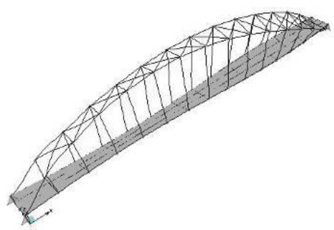
Because of various problems in this bridge, such as low quality of deck concrete, non-composite behavior of deck, dislocation of bearings, permanent deformation of cables due to vehicle impact and terrible corrosion of connections, this bridge without TMD, was extremely sensitive to ambient vibration. In normal condition, because of very low system damping, peak displacement of the bridge may reach amplitudes up to ± 130 mm. By modeling, the first and the second natural frequencies were about 0.9935 Hz and 1.1653 Hz respectively. Fig. 5 shows the results of modal analysis for the first eight modes of vibration based on modeling using realistic material properties and defects in the bridge.



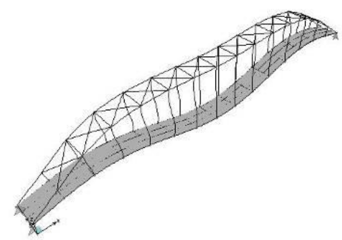
f_1=0.99352 Hz



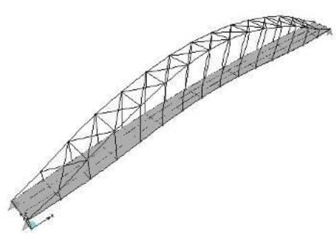
f_2=1.165297 Hz



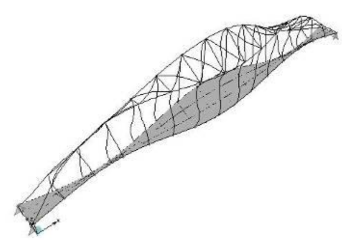
f_3=1.64398 Hz



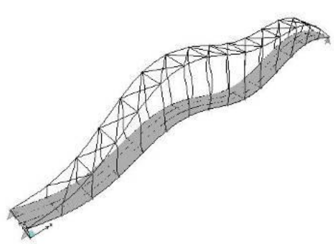
f_4=2.235186 Hz



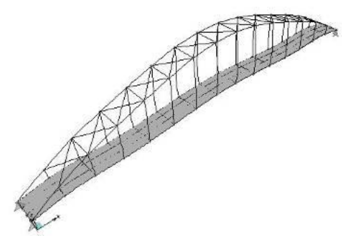
f_5=2.77739 Hz



f_6=3.18755 Hz



f_7=3.87461 Hz



f_8=4.359007 Hz

Figure 5. First eight vibration modes of Babolrood Bridge

Bridge retrofitting strategy and numerical results

TMD was proposed to minimize the peak bridge displacements (Nishimura I et al, 1992) and to control the bridge vibration. Three different TMD arrangements were investigated to select the best strategy for their placement: at the middle of the bridge, at its quarter points and finally, at quarter points of one arch and the middle of the other bridge arch. A sensitivity analysis was performed to select the most effective mass and the tuning frequencies of different TMDs. The mass of the TMD, tuned frequency and other specification can be calculated as follows:

$$m_1 = 12\% M \Rightarrow 12\% \times 6000000 = 72000 \ Kg$$

$$M_R = 0.1\% m_1 \Rightarrow 0.1\% \times 720000 = 720 \, Kg$$

$$\xi = 1\%$$

$$T = 1.072 \text{ sec}$$

$$k = m\omega^2 = 720 \times (\frac{2 \times \pi}{1.072})^2 = 24709.4$$

Where M is the total mass of the bridge, M_R is the mass of TMD, ζ is damping ratio of the TMD, and T is period of TMD. Nonlinear time history analyses were conducted on the bridge using seven ground motion records in order to evaluate the efficiency of each variation of TMD placement. Fig. 6 shows acceleration response spectrum of used time histories for the TMD evaluation. Time histories were all scaled to have PGA=0.35g.

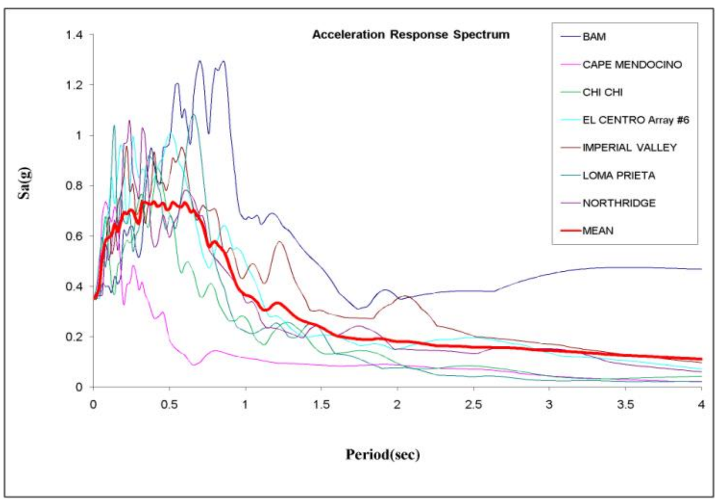
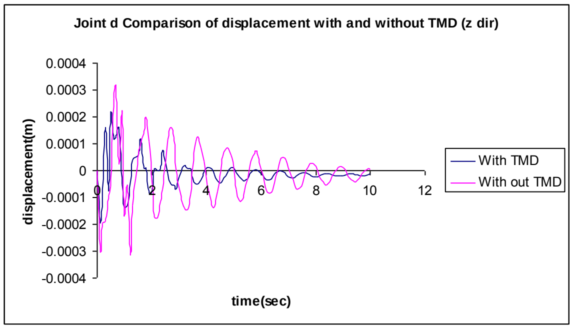


Figure 6. Acceleration response spectrum of selected ground motions

First variation: TMD at the middle

Placing the TMDs at the middle of each arc was the first variation considered but regarding to the results of the analyses this arrangement is inefficient in significant reduction of the bridge response. Fig.7 demonstrates displacement response history of the bridge (for z, y and x directions) with TMD and without TMD usage. Joint d and e represent the apexes of the bridge arches (Practical application TMD, MAURER SOHNE).



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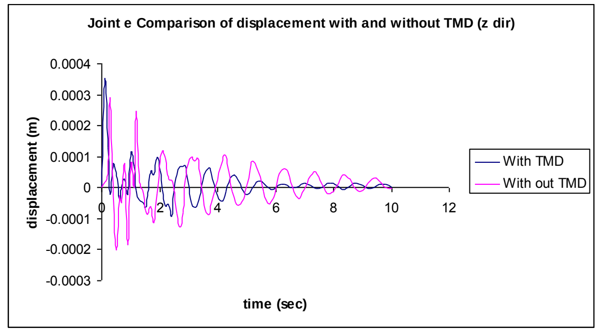

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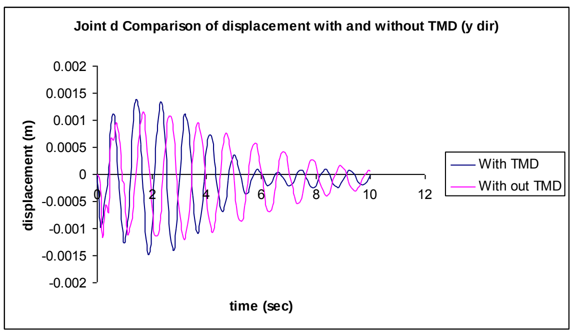

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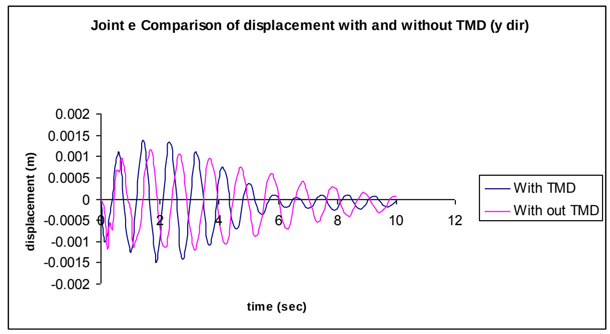

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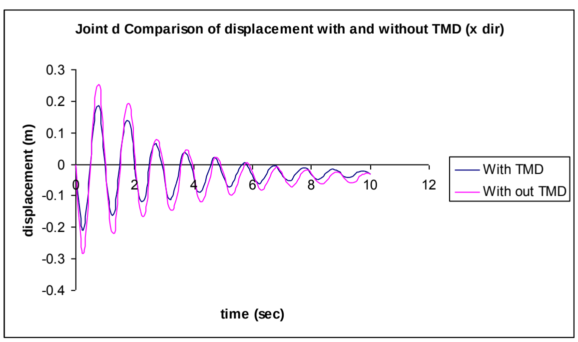

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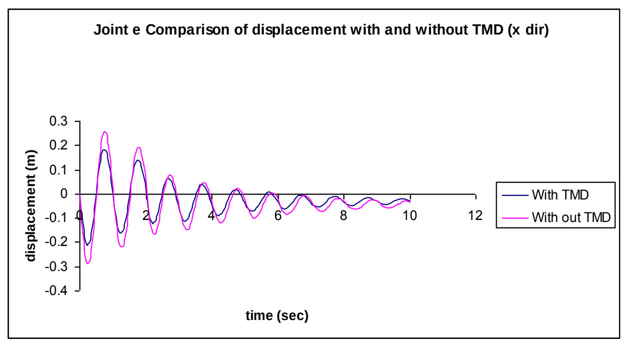

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Figure 7 (a to f). Comparison of displacement for the case with TMD and without TMD (variation1)

Second variation: TMD at quarter points

Second variation proposed in this study was placing of the TMDs at the quarter points of bridge length. Considering the obtained response histories, as the first variation studied here, this arrangement was not able to reduce overall displacement response of the bridge significantly. Fig.8 shows place of A, B, C and D points on the bridge and fig.9 displays comparison of joint A and joint D displacements (in z, y and x directions) before and after TMD usage.

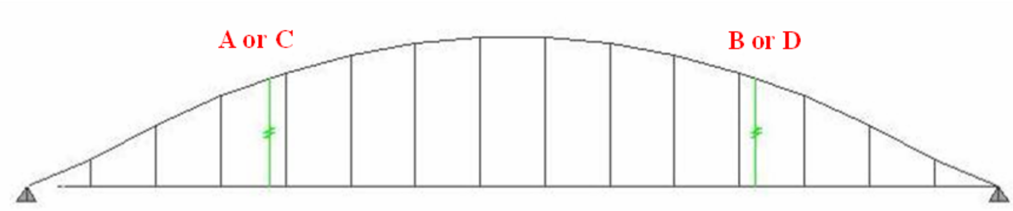
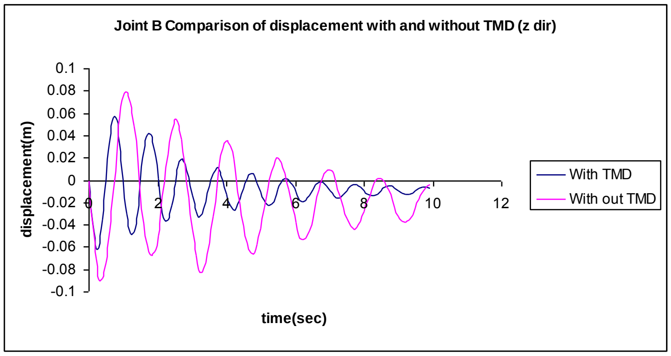
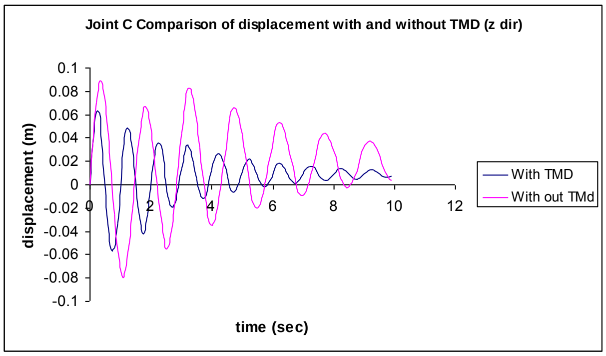


Figure 8. Placement of TMDs at quarter points



(a)



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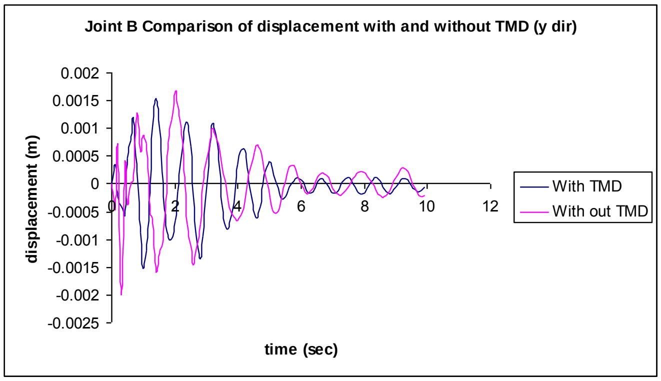

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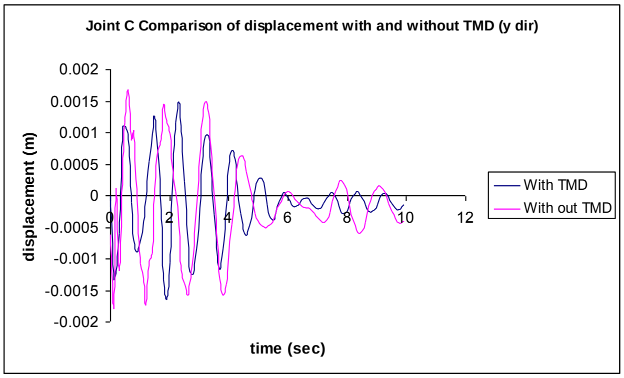

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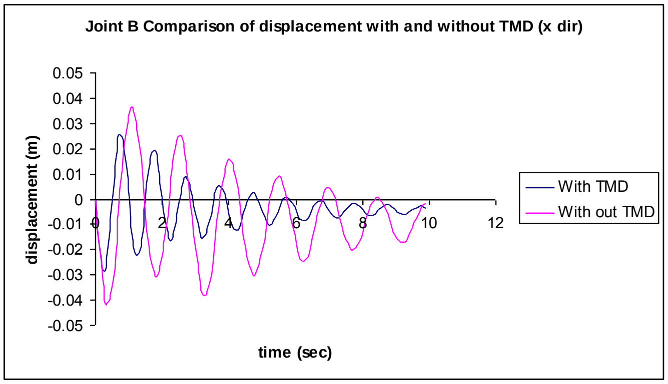

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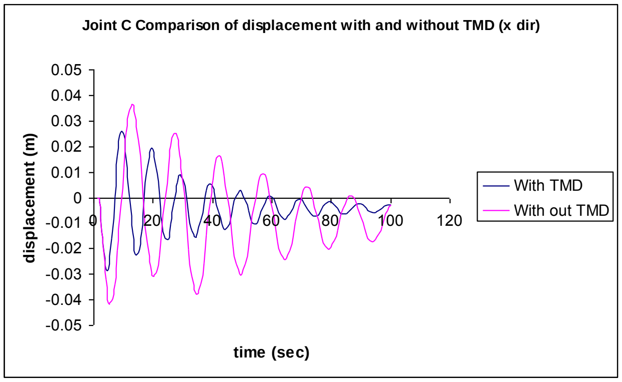


(f)

Figure 9 (a to f). Comparison of displacement for the case with TMD and without TMD (variation 2) Joints B & C

Third variation: TMD at quarter point of one arch and middle point of the other

Regarding the result of the analyses, this arrangement is more effective in reducing bridge displacement responses in comparison with two other arrangements. Mass sensitivity of TMD was also controlled by conducting different analyses using different TMD mass percentages; results of these analyses are shown in Table 1. Figure 10. Shows deformed shape of the bridge and location of point A and fig. 11 shows obtained results from the analyses.

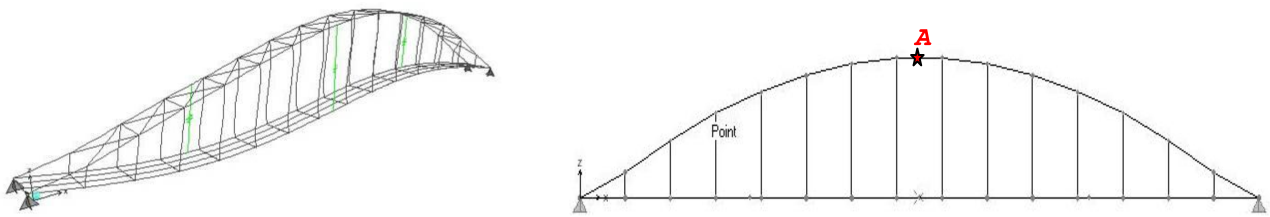
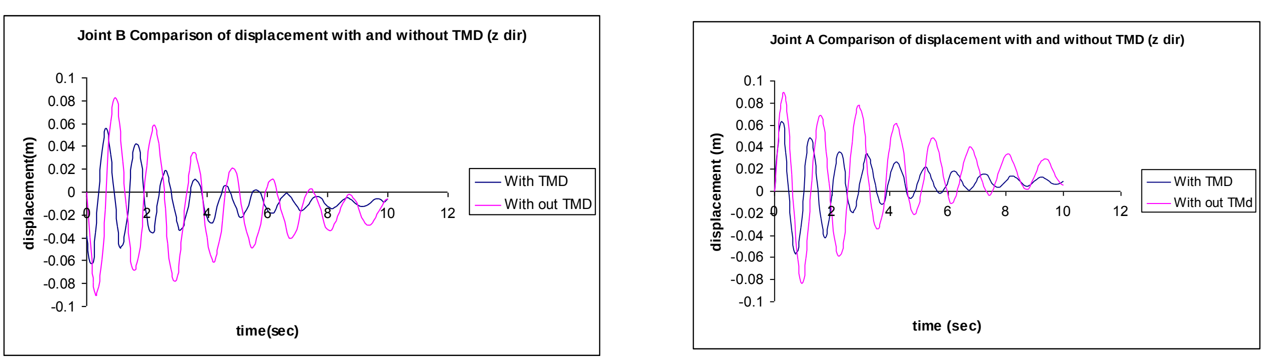


Figure 10. Placement of TMD at the quarter points of one arch and at the middle of the other arch

Table 1. TMD mass sensitivity analysis

M_R	K	$MAXD_Z$		
		POINT A	POINT B	POINT C
0.1M	3217.63	0.000694	0.000465	0.00047
0.5M	163007.16	0.00091	0.000758	0.00092
1M	326014.31	0.000683	0.000558	0.00086
5M	1630071.6	0.000588	0.000455	0.00094

unit: Kg,m,s



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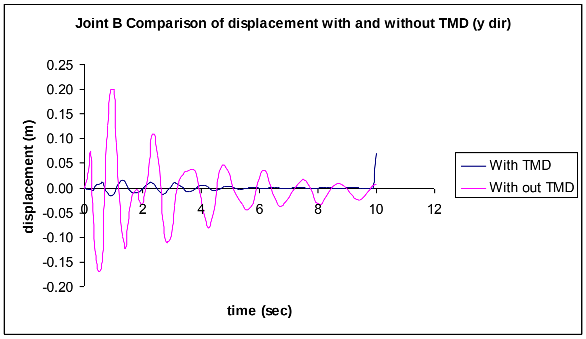

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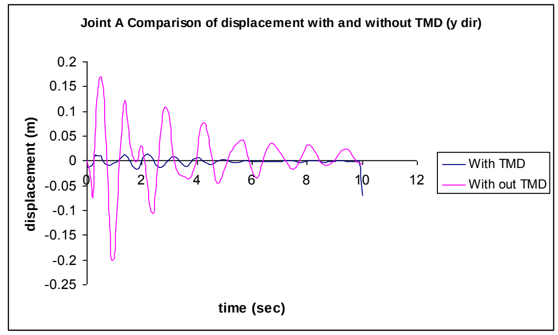

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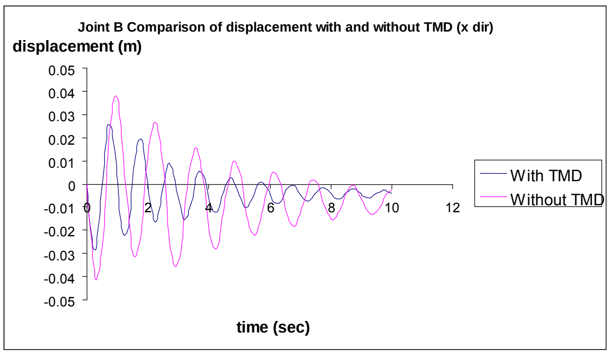

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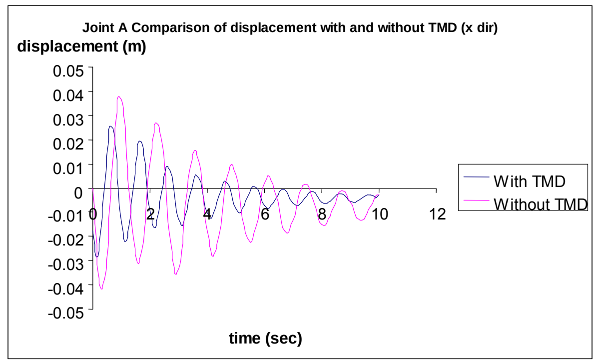

(f)

Figure 10 (a to f). Comparison of displacement in the case with TMD and without TMD (variation3)

Conclusion

TMD usage as a means of reducing bridge displacement response has been investigated. One of the advantages of this method is easy installation of this system without daily traffic interruption for a long time. The Other advantage is the ability to change the specifications of TMD due to future needs of the bridge. Limiting fatigue damage is another advantage of TMD systems which encourages using this system as an option for retrofitting and upgrading the existing bridges. Following observations can be made regarding TMD usage in this study:

- Using TMD, overall displacement response and its sensitivity to vibration excitation has been greatly reduced such that the displacement response reached ±10 mm (from ±130 mm without TMD).
- Excitation of the bridge by crossing cars or people will be reduced and would not cause human discomfort any longer.
- From three variation of TMD placement studied, third variation (TMDs at quarter points of one arch and at the middle of the other arch) was the most effective one in reducing displacement response of the bridge.

- A sensitivity analysis should be performed on the TMD mass to further improve the efficiency of this method. For this study, best result obtained for M_R equals one tenth of the total mass of the bridge.

References

Federal Emergency Management Agency (2000), NEHRP ,*Pre-Standard and Commentary for the Seismic Rehabilitation of Buildings*, FEMA 356, Washington, D.C

Kareem, A., and S. Kline. (1995), *Performance of Multiple Mass Dampers Under Random Loading*, Journal of Structural Engineering, 121(2), 348-361.

Kwok, K.C.S., and B. Samali. (1995), *Performance of Tuned Mass Dampers Under Wind Loads*, Engineering Structures, 17(9): 655-667.

MAURER SOHNE, *Practical application TMD-Abandoibarra Bridge, Bilbao – Spain*, Innovations in steel, since 1876

MAURER SOHNE, *Practical application of TMD-Bridge Forchheim – Germany*, Innovations in steel, since 1876

Nishimura I et al, 1992, *Control performance of active–passive composite tuned mass damper,* Smart Mater. Struct. 1, 306–11

Nishimura I et al, 1994, *Acceleration feedback method applied to active–passive composite tuned mass damper* , J. Struct. Control. 1 103–16.

Tabrizian, Z., H.A.Beygi, M., and Kazemi M.T,2005, *seismic assessmemt of arch steel bridge in Babolsar,* M.Sc. Thesis, College of Civil Engineering, Babol Noshirvani University of Technology, Babol, Iran.