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Determination of Tuned Mass Damper Parameters and its performance in a Four-Span Integral Bridge

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ABSTRACT: In this paper, the performance of the Tuned Mass Damper (TMD) control system in seismic response reduction of a four-span integral bridge is investigated. Two classic analytical methods and one optimization method are then employed to calculate TMD parameters. Then, the effect of selecting each of the three methods for calculating TMD parameters on the seismic response of the bridge is studied. Three objective functions are considered for the optimization procedure in MATLAB. After calculating TMD parameters, nonlinear dynamic analysis of the bridge in a transverse direction is carried out in OpenSees. The purpose of this study is to compare different methods for obtaining damper parameters and to introduce a method that calculates damper parameters in such a way that the damper has a better performance on the bridge. Numerical results indicate the performance of the damper is affected by its parameters and selecting the objective function. It is recommended to use the optimization method to calculate the damper parameters with maximum lateral displacement of the deck midpoint objective function. Also, the results show that the reduction of the response is related to the response corresponding to the objective function. For the studied bridge, the maximum values of reduction of displacement and acceleration of the middle deck are equal to 22.4 and 17.7%, respectively, and for the base, shear is 4.3%. Therefore, the lateral displacement of the deck midpoint objective function is introduced as the best cost function.

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1- Introduction

Bridges are critical structures in highways and their failure under seismic excitation disrupts the transportation system. One effective method to avoid seismic failure is to apply passive control systems. Tuned mass damper (TMD) is one of the passive systems for controlling seismic forces on structures. It was first designed to reduce the ship's lateral rotation and movement fluctuations, developed by Farham in 1909 [1]. Yin et al. [2], Bathaee et al. [3], and Bayat and Daneshjoo [4], among other researchers, recently published papers on using TMDs for decreasing the bridge's seismic response.

In this paper, the influence of TMD on decreasing responses of a four-span integral bridge under several severe earthquakes is investigated. Researchers have developed a variety of methods to estimate TMD parameters. Here, three methods are employed to calculate TMD's parameters. Nonlinear time history analyses are then performed to study the effect of method selection on the efficiency of the TMD in reducing the seismic response of the bridge.

2- Methods for calculating TMD parameters

An ordinary TMD consists of mass M connected to the main structure via a spring with stiffness K, and a viscous damper with damping C. TMD parameters can be determined using dynamic equations, first introduced by Den Hartog [6] for single-degree-of-freedom systems. Afterward, Sadek et al. [7] extended this method to the multi-degree of freedom structures. Another method for calculating TMD parameters is the optimization method. In this study, Passive Congregation-based Particle Swarm Optimization (PSOPC) is selected due to its popularity and simplicity. To calculate TMD parameters using the PSOPC optimization algorithm, single cost functions, including minimization of the deck maximum displacement, the deck midpoint acceleration and the maximum base shear are considered. This paper uses both classic methods (dynamic equations and Sadek et al. equations) and optimization methods to calculate these parameters.

3- Numerical analysis and results

To perform seismic analysis on the bridge with TMD, seven earthquakes are selected from major earthquakes in the world. In this study, the PGA of the records is scaled to 0.4g [8]. The characteristics of the selected ground motions are summarized in Table 1. Earthquakes are applied in the

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Table 1. List of the selected input ground motions

Earthquake	Year	Station—component	PGA(g)
Iwate,Japan	2008	IWT010	0.223
Kobe,Japan	1995	Nishi-Akashi	0.503
LomaPrieta,USA	1989	13- BRAN	0.501
Northridge,USA	1994	24087	0.344
Shizuoka,Japan	2009	SZO014	0.314
Shizuoka,Japan	2011	SZO011	0.511
Tabas,Iran	1979	9101-Tabas	0.852

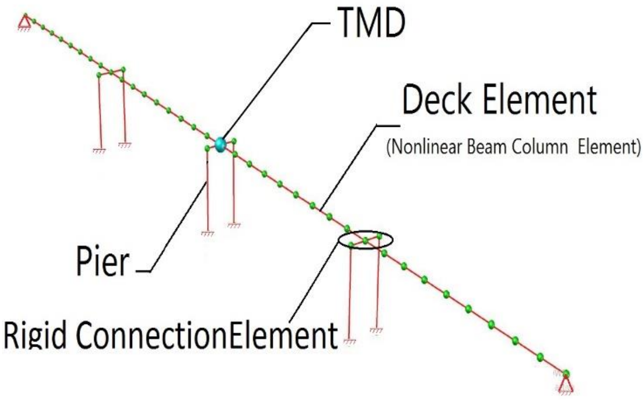

Fig. 1. Schematic geometry of the bridge with TMD

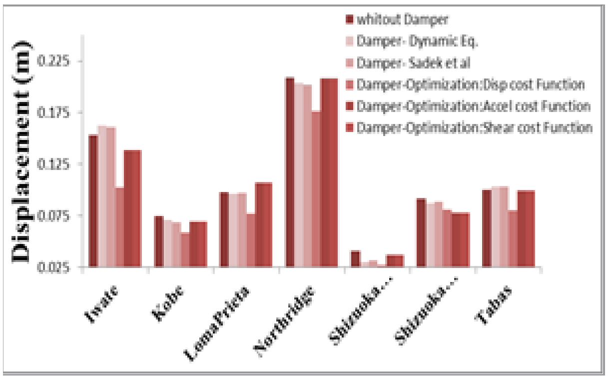

Fig. 2. Displacement of the deck midpoint in the controlled and uncontrolled bridge under the selected earthquakes, in classic and optimization methods

transverse direction. [9]

In the finite element model of the bridge in OpenSees [10], as shown in Figure 1, the TMD is located at the midpoint of the deck, with a maximum weight of 5% of the total bridge weight. A total number of 35 nonlinear time history analyses are performed on the bridge and average value responses are compared. The average displacements of the deck midpoint in different methods are presented in Figure 2.

A summary of the average reduction of the deck midpoint displacement and acceleration, and the base shear of the bridge with TMD in different methods, are presented in Table 2.

Table 2. The average reduction of displacement, acceleration, and base shear of the bridge with TMD in different methods

Method	Reduction (%)		
	Displacement	Acceleration	Base Shear
Dynamic Eq.	4.7	12.2	1.3
Sadek et al.	4.2	9.1	0.6
Optimization (cost Function is Displacement)	22.4	13.3	2.4
Optimization (cost Function is Acceleration)	1.0	17.7	0.2
Optimization (cost Function is Base Shear)	4.7	7.0	4.3

4- Conclusions

This research studied the TMD performance on a four-span integral bridge. OpenSees software was employed for bridge modeling, and MATLAB was used for programming the optimization method. Analysis results are as below:

- TMD is effective in reducing seismic responses of the bridge according to numerical results. The maximum observed reduction value was 23% in the deck midpoint displacement in the optimization method.
- In classic methods, the maximum reduction value of the response occurs in acceleration. Therefore, TMDs designed based on the classic method perform better in reducing the deck midpoint acceleration. It is by the code's purpose that the prominent role of dampers is to decrease the acceleration caused by dynamic actions.
- Among the three provided methods to estimate damper's parameters, the optimization method calculates more suitable parameters for TMD to reduce seismic responses of the bridge. Therefore, the optimization algorithm showed better overall performance due to the calculation of TMD parameters based on each earthquake separately, while the two classic methods consider a constant value for mass, damping, and stiffness for all earthquakes.

- In the PSOPC optimization algorithm with 3 costs function (displacement and acceleration of middle point of deck and base shear), the reduction of each response of the bridge is based on the selected cost function. Also, if the displacement of the middle point of the deck is selected as a cost function, TMD reduces every three values of displacement, acceleration, and base shear in the bridge.

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