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OPTIMIZATION OF TUNED MASS DAMPERS FOR MINIMIZING STORY DRIFT OF STRUCTURES

Gebrail BEKDAŞ[1] and Sinan Melih NİGDELİ[2]

ABSTRACT

The tuning of tuned mass dampers (TMDs) is an important design in damping structural vibrations resulting from earthquakes. Due to random characteristics of earthquakes and uncertain properties of structures, exact and general solutions can be never found. Thus, optimization methods such as several numerical algorithms are used in the tuning design. In this study, a metaheuristic method called harmony search algorithm is employed to find optimum TMD parameters. These parameters are mass, period and damping ratio. The optimization objective is to reduce maximum story drift of MDOF shear structure under earthquake excitation. The proposed method is effective on finding optimum TMD reducing the maximum story drift of structures.

INTRODUCTION

As we know, tuned mass dampers are vibration absorber devices which use their mechanical components in reduction of responses of mechanical systems. The initial form of TMDs are the invention of Frahm (1911) in which no inherent damping is employed. Without damping, it is not possible to damp random vibrations. In order to use these absorbers in seismic structures, damping is needed for earthquake excitations with random characteristics. Ormondroyd and Den Hartog (1928) added inherent damping to the invention of Frahm (1911) in order to damp vibrations resulting from excitations with random frequency.

For tuning of TMDs, several expressions have been proposed (Den Hartog 1947, Warburton 1982, Sadek *et al.* 1997, Leung and Zhang 2009), but these expressions are for a TMD on a single degree of freedom (SDOF) system. In order to use these expressions, multiple degree of freedom (MDOF) systems must be idealized as SDOF systems. For a better optimization, numerical algorithms have been used (Sadek *et al.* 1997 and Chang 1999). Also, metaheuristic algorithms are effective on optimization of TMDs (Hadi and Arfiadi, 1998; Leung *et al.,* 2008; Leung and Zhang, 2009; Marano *et al.,* 2010; Steinbuch, 2011). The employed metaheuristic method in this study; harmony search has been used in optimization of TMD for different purposes (Bekdaş and Nigdeli, 2011a; Bekdaş and Nigdeli, 2011b; Nigdeli and Bekdaş, 2011; Bekdaş and Nigdeli, 2012a; Bekdaş and Nigdeli, 2012b; Bekdaş and Nigdeli, 2013; Nigdeli and Bekdaş, 2013).

In this study, harmony search algorithm is employed to find optimum TMD parameters such as mass, period and damping ratio in order to reduce maximum story drift of MDOF shear structure under earthquake excitation. For a general optimum result, the responses of six different earthquake excitations are considered in the optimization process.

[1] Dr, Istanbul University, Istanbul, bekdas@istanbul.edu.tr
[2] Dr, Istanbul University, Istanbul, melihnig@istanbul.edu.tr

OPTIMIZATION EMPLOYING HARMONY SEARCH

Harmony search (HS) algorithm is a music inspired metaheuristic algorithm developed by Geem et al. (2001). The optimization process used in this study can be explained in five steps (Figure 1). The names of these steps are data entering step, pre-analyses step, initial optimization step, essential optimization step and termination step. The details of these steps are summarized below.

Data entering step: In this step, ranges of TMD parameters, harmony search parameters, properties of structure, earthquake excitations and the value used in termination criterion are defined.

Pre-analyses step: The structure without TMD is analysed for verification of termination criterion in the following steps.

Initial optimization step: The initial harmony memory matrix is generated by harmony vectors as many as harmony memory size (HMS). Randomly assigned TMD parameters are stored in these vectors.

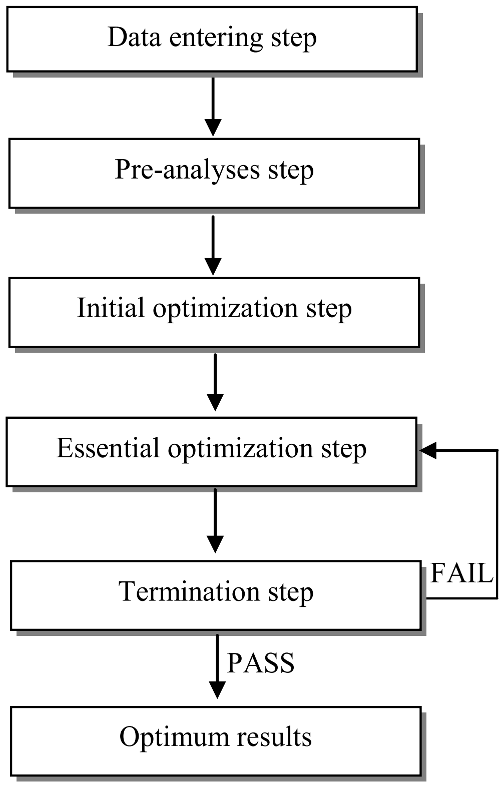

Figure 1. The steps of optimization process

Essential optimization step: A new vector is generated by two ways. With the probability defined with Harmony Memory Considering Rate (HMCR), TMD parameters are assigned around the existing vectors in Harmony Memory Matrix. Otherwise, the parameters are assigned from the whole range. The ratio of ranges when the randomization is done by using an existing vector and whole range is defined as Pitch Adjusting Rate (PAR). If TMD parameters are more effective on reduction of maximum story drift than the existing worst vector in Harmony Memory Matrix, it is replaced with the worst one.

Termination step: The optimization process continue until the stopping criterion is satisfied. The stopping criterion or the objective function is to reduce the ratio of maximum story drift of the uncontrolled and TMD-controlled structure below the value defined by user in the first step. If the value defined by user is very low for a physical solution, it is modified after 200 steps (iterations).

NUMERICAL EXAMPLE

A ten story building is used as a numerical example. A story of the structure has 360 t mass, 6.2 MN s/m damping coefficient and 650 MN/m stiffness coefficient (Singh et al. 1997). The earthquake excitations used in the optimization are given in Table 1.

The TMD parameters are searched between 1%-5%, 0.8-1.2 times of the critical period of main structure and 5%-20% for mass ratio, period and damping ratio of TMD, respectively. Optimum TMD parameter are found as 179.8 t mass, 0.9483 s period, 5.8% damping ratio. The maximum story drifts for the uncontrolled structure are given in Table 2.

The maximum one is 0.097 m which is occurred under Northridge Rinaldi excitation. The maximum story drifts for the TMD controlled structure are given in Table 3.

The maximum story drift is reduced to 0.075 m. Time history displacement plots are given in Figure 2 and 3 for first and top story, respectively. The optimum TMD is effective on the maximum displacements seen at the top of the structure, although the drift of the top story increases with the implementation of optimum TMD.

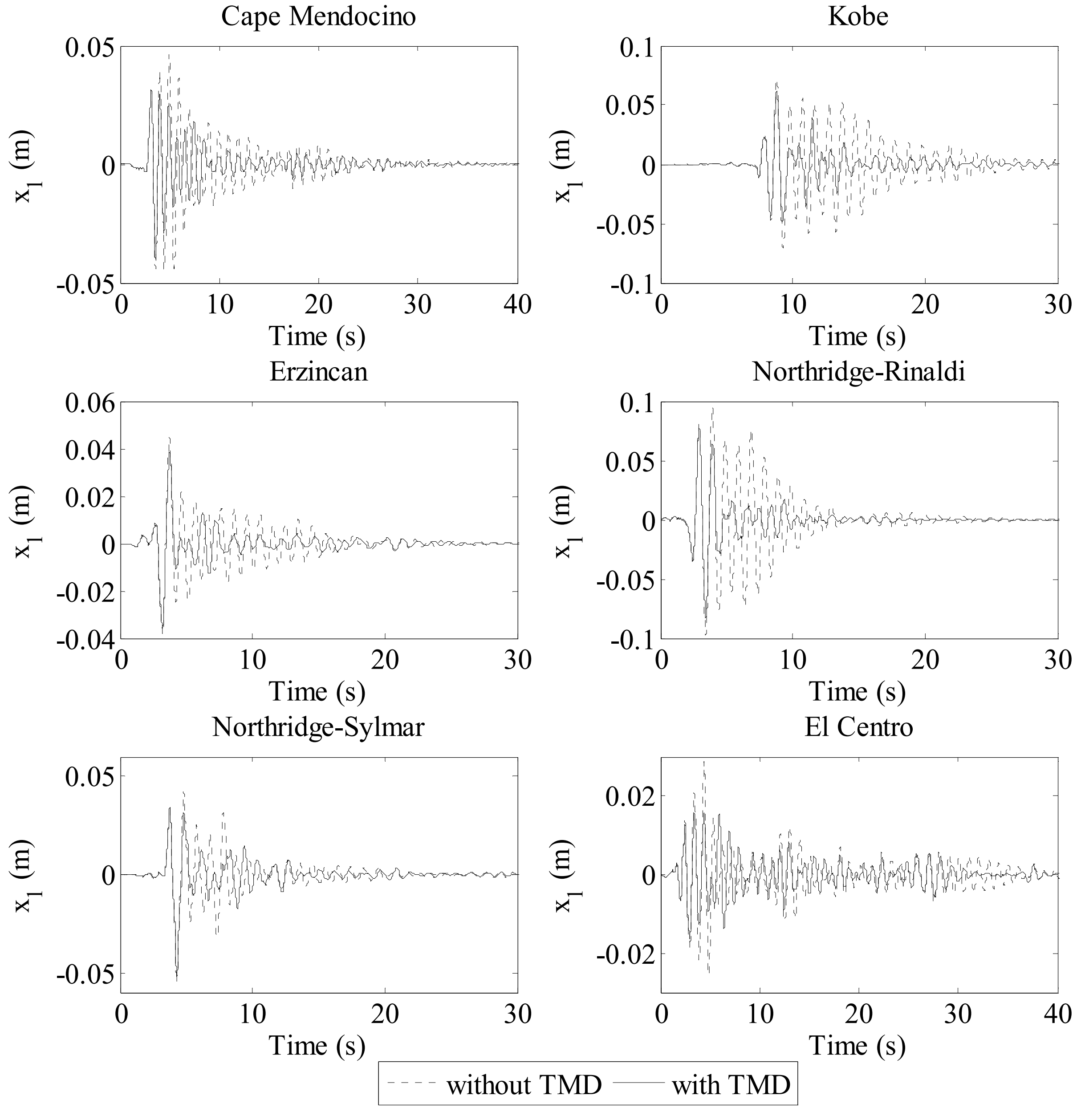

Figure 2. Time history displacement plots for the first story

Table 1. Earthquake records used in the HS optimization (PEER)

Earthquake	Date	Station	Component	PGA (g)	PGV (cm/s)	PGD (cm)
Cape Mendocino	1992	Petrolia	PET090	0.662	89.7	29.55
Kobe	1995	0 KJMA	KJM000	0.821	81.3	17.68
Erzincan	1992	95 Erzincan	ERZ-NS	0.515	83.9	27.35
Northridge	1994	Rinaldi	RRS228	0.838	166.1	28.78
Northridge	1994	24514 Sylmar	SYL360	0.843	129.6	32.68
Imperial Valley	1940	El Centro	I-ELC180	8.3	0.313	29.8

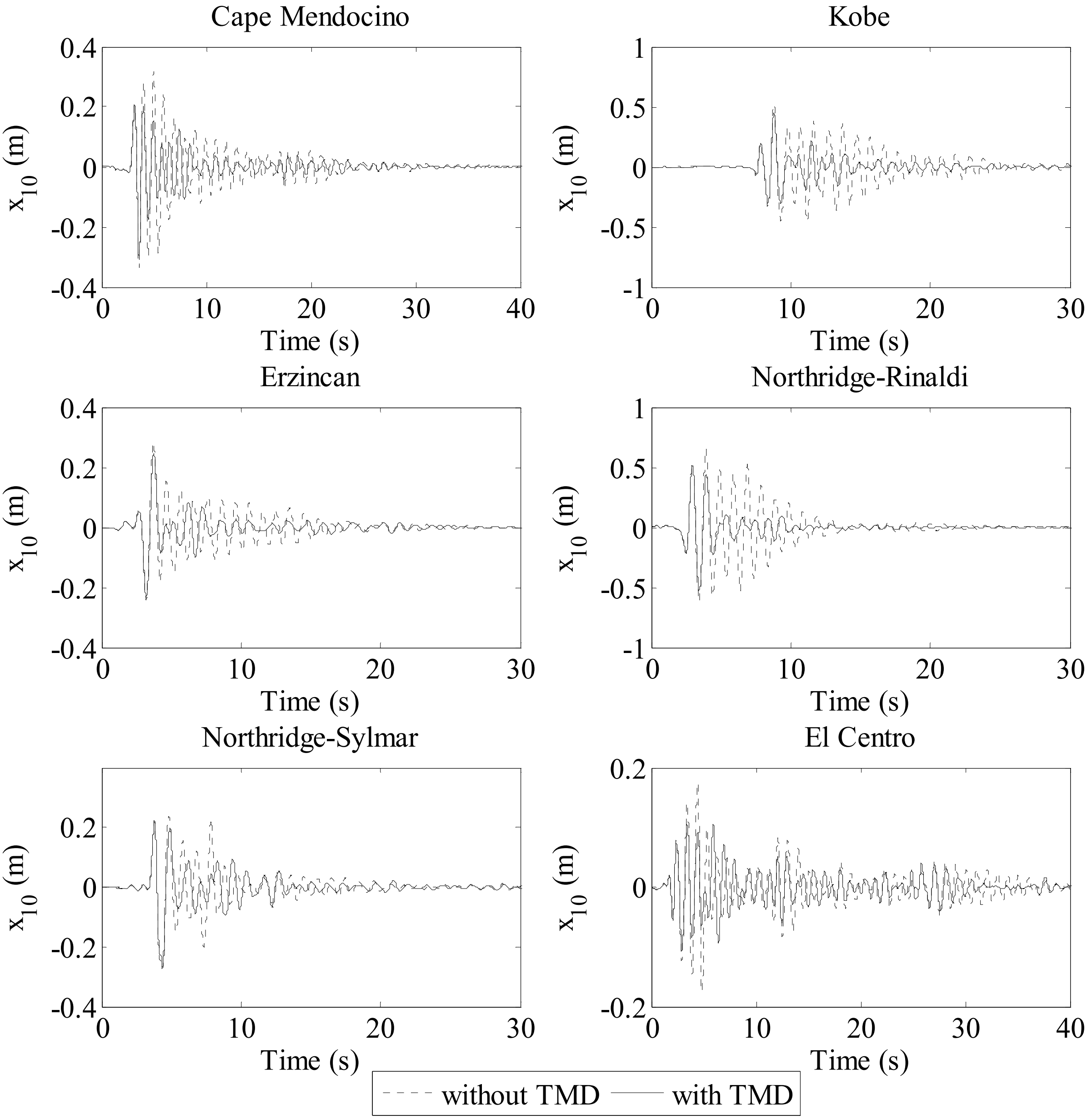

Figure 3. Time history displacement plots for the top story

Table 2. Maximum story drifts for the uncontrolled structure (m)

Story	Cape Mendocino	Kobe	Erzincan	Northridge (Rinaldi)	Northridge (Sylmar)	Imperial Valley
1	0.046	0.072	0.045	0.097	0.055	0.029
2	0.046	0.072	0.043	0.093	0.050	0.028
3	0.045	0.070	0.040	0.090	0.043	0.026
4	0.044	0.067	0.036	0.084	0.036	0.023
5	0.041	0.062	0.032	0.076	0.031	0.021
6	0.037	0.055	0.028	0.067	0.029	0.018
7	0.031	0.047	0.024	0.056	0.026	0.015
8	0.025	0.037	0.018	0.043	0.022	0.012
9	0.017	0.025	0.013	0.030	0.016	0.009
10	0.009	0.013	0.006	0.015	0.008	0.004

Table 3. Maximum story drifts for the TMD controlled structure (m)

Story	Cape Mendocino	Kobe	Erzincan	Northridge (Rinaldi)	Northridge (Sylmar)	Imperial Valley
1	0.038	0.054	0.036	0.075	0.049	0.021
2	0.039	0.054	0.034	0.073	0.044	0.020
3	0.039	0.053	0.032	0.070	0.038	0.019
4	0.038	0.051	0.030	0.065	0.033	0.018
5	0.036	0.047	0.027	0.059	0.032	0.016
6	0.033	0.043	0.023	0.051	0.031	0.014
7	0.028	0.037	0.020	0.043	0.029	0.012
8	0.022	0.030	0.016	0.034	0.026	0.009
9	0.016	0.022	0.013	0.027	0.020	0.007
10	0.010	0.015	0.010	0.021	0.014	0.005

CONCLUSIONS

The proposed method is effective on finding TMD parameters which reduces the maximum story drift of the numerical example with 22.43%. Also, the reduction percentages of the story drifts are presented in Table 4. Up to 27.60%, the maximum story drifts were reduced. Story drifts are critical at the first stories of the structure. At the top stories in which story drifts are very low, optimum TMD is not effective.

Table 4. The ratio of story drifts

Story	Cape Mendocino	Kobe	Erzincan	Northridge (Rinaldi)	Northridge (Sylmar)	Imperial Valley
1	19.32	25.19	20.34	22.43	11.61	27.60
2	15.34	24.77	19.85	21.39	12.08	26.08
3	13.51	24.33	19.20	21.61	12.09	24.09
4	12.99	23.83	18.50	21.72	8.89	21.58
5	12.43	23.23	18.00	22.22	-1.71	20.29
6	11.75	22.49	18.09	22.89	-7.31	20.06
7	10.79	21.41	17.15	22.75	-11.96	22.36
8	9.12	19.55	10.84	20.43	-18.32	24.22
9	4.94	15.34	-5.64	9.36	-30.54	19.98
10	-14.26	-11.96	-57.15	-38.67	-67.57	-20.45

The proposed method is effective on finding optimum TMDs for reducing the maximum story drift of structure. Generally, the maximum drift is equal to the first storey displacement of the structure. By the reduction of the story drifts, shear forces resulting from earthquakes are reduced.

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