Structures 43 (2022) 1084–1090

Contents lists available at ScienceDirect

Structures

journal homepage: www.elsevier.com/locate/structures

Optimal design of elastic and elastoplastic tuned mass dampers using the Mouth Brooding Fish algorithm for linear and nonlinear structures

Mostafa Roozbahan [a,*], Ehsan Jahani [b]

[a] Department of Civil Engineering, Izmir Institute of Technology, Urla, Izmir, Turkey
[b] Department of Civil Engineering, University of Mazandaran, Babolsar, Mazandaran, Iran

ARTICLE INFO

Keywords:
Tuned Mass Damper
Nonlinear Structure
Elastoplastic
Optimization
Mouth Brooding Fish Algorithm

ABSTRACT

A tuned mass damper (TMD) is a vibration control system used to reduce the structural responses to earthquakes and extreme wind loads. The performance of a TMD depends on its parameters, such as mass, damping coefficient, and stiffness. Therefore, several methods have been proposed to optimize the parameters of TMDs. This paper proposes a new method for optimizing TMDs' parameters using the Mouth Brooding Fish (MBF) algorithm based on white noise excitations. The effectiveness of TMDs optimized using the proposed method and other methods in reducing the maximum displacement of a ten-story linear structure was compared. The results indicated that the proposed method could effectively find the optimum parameters of the TMD. The efficacy of elastic and elastoplastic TMDs optimized using the proposed method in the responses of linear and nonlinear 10-story structures was also investigated. According to the results, the optimal elastic TMD more effectively reduced the maximum displacement of linear and nonlinear structures than the optimal elastoplastic TMD. Besides, elastic and elastoplastic TMDs exhibited higher efficiency in reducing the maximum displacement of the linear structure than the nonlinear structure.

1. Introduction

Tuned mass dampers (TMDs) are among the earliest and most used structural control systems installed on various structures to reduce structural vibrations caused by natural disasters such as earthquakes and extreme winds [1,2]. The primary type of a tuned mass damper, made up of a mass, a dashpot, and a spring, was designed by Den Hartog by attaching dampers to the device invented by Frahm [3]. The performance of a TMD depends on its properties, such as mass, stiffness, and damping coefficient; thus, they need to be tuned according to the properties of the main system [4]. Brock discussed the procedure of determining optimal parameters of TMDs utilized in a linear structure subjected to external harmonic excitation [5]. Den Hartog proposed formulas to calculate the optimized frequency and damping ratio of TMDs for single-degree-of-freedom (SDOF) structures [6]. Warburton developed a simple tuning equation to identify the optimal parameters of linear SDOF systems subjected to random excitations, including harmonic and white noise excitations [7]. Based on frequency domain analyses, Sadek et al. proposed formulas to optimize the parameters of TMDs for linear SDOF and multi-degree-of-freedom (MDOF) structures [8].

In the last decades, various optimization techniques have been used to optimize the parameters of tuned mass dampers [9–12]. Hadi and Arfiadi proposed an optimum tuned mass damper design for seismically excited buildings using the genetic algorithm (GA). By comparing their method with the approaches of Den Hartog and Warburton, they found that it led to greater reductions in the responses of the structures [13]. Lee et al. developed a numerical optimization algorithm for buildings with TMD to decrease the performance index value [14]. Harmony search (HS), a metaheuristic optimization method, was used by Bekdaş and Nigdeli to find the optimum parameters of TMDs [15]. Farshidianfar and Soheili employed the ant colony optimization (ACO) method to obtain the best parameters of TMDs for high-rise structures considering the soil-structure interaction [16]. Özsarıyıldız and Bozer utilized the differential evolution (DE) algorithm to find optimal parameters of TMDs. According to their study, the DE algorithm worked as effectively as GA while its execution time was seven times shorter than that of GA [17]. Kaveh et al. revised and applied the charged system search (CSS) to minimize the dynamic response of MDOF structures. According to their numerical studies, the TMD optimized using CSS outperformed those of previous works in displacement reduction of structures [18]. Using an improved harmony search (IHS) algorithm, Yazdi et al. optimized the

* Corresponding author.
E-mail address: mroozbahan@iyte.edu.tr (M. Roozbahan).

https://doi.org/10.1016/j.istruc.2022.07.037
Received 2 May 2022; Received in revised form 10 July 2022; Accepted 14 July 2022
Available online 18 July 2022

parameters of TMDs. Their study showed that the IHS was superior to GA [19]. Using the HS algorithm, Nigdeli and Bekdaş compared frequency domain-based and time domain-based optimization of TMDs and reported that both methods effectively found optimum parameters of TMDs [20]. Nigdeli et al. hybridized HS and flower pollination algorithm (FPA) for optimum tuning of mass dampers [21]. Etedali and Rakhshani evaluated the performance of the multi-objective cuckoo search (MOCS) for the optimal design of TMDs. They showed that the MOCS performed better than other methods in reducing the maximum responses of the structures subjected to different earthquakes [22]. Chang et al. used the active control algorithm (ACA) for the seismic design of parameters of tuned mass dampers [23]. Fahimi and Kaveh used colliding bodies optimization (CBO) algorithm to find the optimum parameters of the TMD for a ten-story shear building in the frequency domain [24]. Kaveh et al. optimized the parameters of TMDs using the chaotic optimization algorithm (COA). According to their numerical studies, the TMDs optimized using COA were well capable of attenuating the responses of structures under different earthquakes [25]. Through a metaheuristic optimization based on the differential evolution method, Caicedo et al. optimized TMDs to minimize the seismic response of high-rise buildings [26]. Kayabekir et al. combined HS, FPA, teaching learning-based optimization (TLBO) algorithm, and Jaya algorithm (JA) to generate a hybrid algorithm for the optimal design of active TMDs [27].

In addition to extensive and comprehensive studies performed on the effect of elastic dampers on linear structures and different methods proposed for their optimization, several researchers also focused on the effectiveness of elastoplastic and elastic TMDs in the response of linear and nonlinear structures, respectively. Pinkaew et al. evaluated the effects of a TMD on a nonlinear structure. They modeled a 20-story building based on an equivalent inelastic SDOF building. The results indicated a gradual reduction in the effectiveness of the TMD by increasing the inelasticity of the building [28]. Sgobba and Marano analyzed the effects of a linear TMD on a simple SDOF Bouc-Wen system, which indicated the possibility of tuning loss. Due to the detuning effect, the tuning loss may reduce the efficiency of the TMD in reducing the vibration of structures in nonlinear ranges [29]. Mohebbi and Joghataie used a distributed genetic algorithm for the optimal design of a linear TMD to reduce the structural response of an eight-story nonlinear shear building. According to the results, the method successfully determined the TMD parameters [30]. Mate et al. evaluated the seismic pounding response of inelastic and elastic SDOF structures with and without a TMD. They found that using a TMD was more effective in increasing the consistency and regularity of the force–deformation hysteresis plot of the main system in inelastic structures than in elastic structures [31]. Gerges and Vickery designed a wind tunnel test to evaluate the effectiveness of a group of nonlinear TMDs in reducing the oscillations of an across-wind structure. They found that the damping of a nonlinear system must be less pronounced than that of its equivalent linear system. Based on their results, the optimal frequency ratio of a TMD with a nonlinear stiffness occurs only within a certain range of amplitudes [32]. Alexander and Schilder examined the performance of a nonlinear TMD, designed based on a two-degree-of-freedom system with cubic nonlinearity. The results indicated that any configuration of the proposed nonlinear TMD would not result in any improvement compared to an optimal linear TMD [33]. Guo et al. introduced a simplified optimization method for nonlinear TMDs in an SDOF system. They argued that excitation could affect the effectiveness of the nonlinear TMD. Therefore, the performance sensitivity of the optimal nonlinear TMD was examined using various structural damping ratios and excitation intensities. According to the results, the engineering applications of the nonlinear TMD may be limited by sensitivity. They concluded that a nonlinear TMD is more practical for determinate excitations, such as the wind [34]. Bagheri and Rahmani utilized an elastoplastic spring in a TMD to develop a new seismic response control system. They studied the responses shown by several main structures in the form of SDOF systems

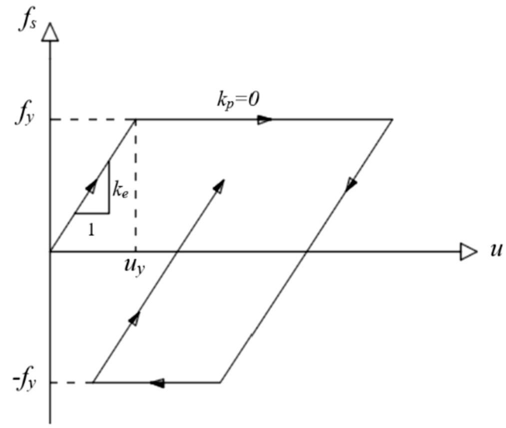

Fig. 1. Elastoplastic stiffness model.

using the proposed TMD under various seismic excitations. Their device reduced seismic responses efficiently [35]. Li and Du compared the effectiveness of TMD and nonlinear tuned mass damper (NTMD) optimized using the harmonic balance method (HBM) in the reduction of the steady-state displacement amplitude of an SDOF structure. They concluded that TMD developed using the typical design method, which ignores TMD's nonlinearity, cannot produce the best control effect when stiffness nonlinearity is considered [36].

The present study proposes a new optimization method using the Mouth Brooding Fish (MBF) algorithm, considering a set of white noise excitations for the optimal design of the parameters of TMDs. Additionally, the efficiency of the proposed method is evaluated and compared with several other methods in reducing the maximum displacement of a linear structure under a set of earthquakes. Moreover, the effectiveness of elastic and elastoplastic TMDs optimized using this method in reducing the maximum displacement of linear and nonlinear MDOF structures is compared.

2. Equation of motion of structures with TMD

The equation of motion of an N-story shear building equipped with a TMD on top of it, subjected to an earthquake, can be defined as follows:

$$M\ddot{x}(t) + C\dot{x}(t) + Kx(t) = -Me\ddot{x}_g(t) \tag{1}$$

where M, C, and K are the matrices of mass, damping coefficient, and stiffness of the system, defined by Eqs. (2), (3), and (4), respectively. Moreover, x, $\dot{x}$, and $\ddot{x}$ are $(N+1)\times 1$ vectors of displacement, velocity, and acceleration of the system, respectively, and $\ddot{x}_g$ donates the $(N+1)\times 1$ acceleration vector of the earthquake [37]. Furthermore, $e^T = [1,\ 1,\ \cdots,\ 1]_{1\times(N+1)}$ is the ground acceleration mass transformation vector [22]. The properties of TMD are donated with m_d, c_d, and k_d for mass, damping coefficient, and stiffness of TMD, respectively.

$$M = \begin{bmatrix} m_1 & & & & & \\ & m_2 & & & & \\ & & \ddots & & & \\ & & & m_{N-1} & & \\ & & & & m_N & \\ & & & & & m_d \end{bmatrix} \tag{2}$$

$$C = \begin{bmatrix} c_1+c_2 & -c_2 & & & & \\ -c_2 & c_2+c_3 & -c_3 & & & \\ & -c_3 & \ddots & \ddots & & \\ & & \ddots & \ddots & -c_N & \\ & & & -c_N & c_N+c_d & -c_d \\ & & & & -c_d & c_d \end{bmatrix} \tag{3}$$

$$K = \begin{bmatrix} k_1+k_2 & -k_2 & & & & & \\ -k_2 & k_2+k_3 & -k_3 & & & & \\ & -k_3 & \cdot & \cdot & & & \\ & & \cdot & \cdot & \cdot & & \\ & & & \cdot & \cdot & -k_N & \\ & & & & -k_N & k_N+k_d & -k_d \\ & & & & & -k_d & k_d \end{bmatrix} \quad (4)$$

In an elastoplastic system, the stiffness of each degree of freedom (DOF) is not constant and depends on the value of the resisting force of the system at each time step. An elastoplastic stiffness model is illustrated in Fig. 1. Here, f_s is the resisting force, and f_y and u_y are yield strength and deformation, respectively. The value of stiffness at each time step is straightly dependent on the ratio of the resisting force of each DOF of the system to its yield strength (f_s/f_y); $f_s/f_y < 1$ means the DOF behavior is elastic, and k_e should be used as the stiffness value in calculations; while $f_s/f_y = 1$ indicates that the behavior is within the elastoplastic range, and k_p should be considered as the stiffness value.

3. Mouth brooding fish algorithm

Highly complex optimization problems have arisen with the advancement of technology. Most newly-developed optimization problems have many variables with a wide range of variations. Consequently, numerous optimization algorithms have been proposed to solve problems. Most of these algorithms are nature-inspired and widely used in engineering applications, thanks to their ability to obtain global optima and fast convergence [38–42]. Inspired by the lifecycle of the mouth-brooding fish, an algorithm called the Mouth Brooding Fish was developed by Jahani and Chizari in 2018 [43]. This algorithm mimics the movements of the Cichlid family as a foundation to solve optimization problems. Considering the effects of various factors on the movements of this fish family, including the main movements of each fish, the movements of left-out fish, shark attacks, or various dangers, and integrating the roulette wheel selection, the algorithm seeks to find the optimal solution for a selected problem [44].

The MBF algorithm consists of several control parameters, which increase the convergence speed to find the best possible solution [45]. In this algorithm, the size of the fish population (nFish), as one of the most important control factors, indicates how many fish will go through the procedure of solving a problem. While it can be any positive number more than two, choosing *nFish* values of less than five is not logical. In this study, *nFish* was considered equal to 50. Another determining factor is the influence of a mother's power or source point (SP) on the cichlid movement. This factor only affects the measure of movements, not their direction. The displacement between motions grows when *SP* is increased. It should be emphasized that increasing the value of *SP* merely makes it simpler for the MBF algorithm to tackle local optima problems. In the present research, the value of *SP*, which can range from 0 to 1, was taken to be equal to 0.6. In nature, as time passes, the mother's strength diminishes, affecting the movements of herself and her children. Damping of the source point of the mother (SPdamp) plays a similar role in each iteration of the MBF algorithm. In this study, *SPdamp* was set equal to 0.95, although it can be considered any value between 0.85 and 0.95. The cichlid's best position, discovered in previous iterations, is another movement factor. Every cichlid tends to move to their best position in previous iterations, which is distinct from its present position. The other regulating parameter in the MBF algorithm, the dispersion (Dis), which varies between 1 and 2 and was set to 1.8, allows the user to regulate this movement effect. It is worth noting that this movement becomes more effective as the value of *Dis* grows. The mouthbrooding fish keeps and protects some of the cichlids. The mother may care for as many cichlids as her mouth can hold, and the others, known as left-out cichlids, must contend with nature's obstacles. These left-out cichlids must deviate from the basic movement to avoid harm. Like in nature, the MBF algorithm employs a regulating parameter called *Pdis*, which is between 0 and 1 and was assumed equal to 0.2 in this study for tuning the second phase of movement of the left-out cichlids. The control parameter settings made based on the MBF algorithm's optimal performance for various problem types may be found in [43]. The authors of [43] regarded four different kinds of problems using these functions to identify the values of the control parameters: unimodal functions, simple multi-modal functions, hybrid functions, and composition functions. While one of the controlling parameters varies between the minimum and maximum limits, the others remain constant at their average values. The settings of the governing parameters that result in the best potential solutions for any type of problem were ultimately selected based on a successful examination of the MBF algorithm.

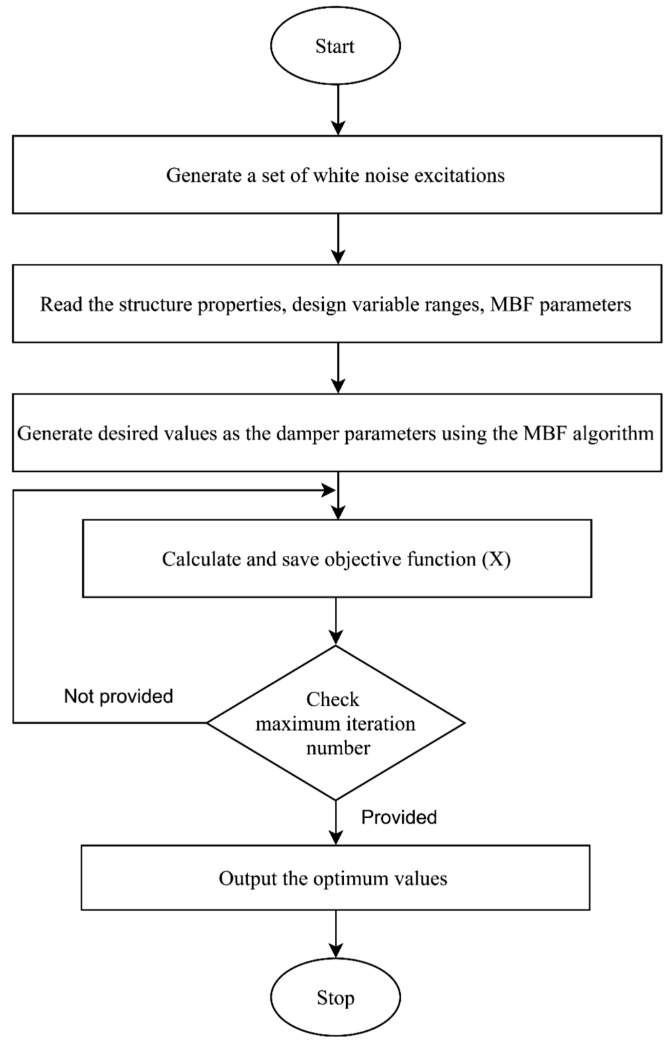

Fig. 2. The flowchart of the proposed method.

4. Optimal design of TMDs using the MBF algorithm

For optimal design of the parameters of TMDs and NTMDs, an optimization problem is defined, and using the MBF algorithm, the optimum values of dampers are found. The optimization problem has two design variables for optimization of TMDs, including the damping coefficient and stiffness of TMD, and three design variables for optimization of NTMDs, including the damping coefficient, elastic stiffness (k_{ed}), and yielding displacement (u_{yd}) of NTMD.

In the optimization procedure, instead of using a specific seismic motion record, a set of white noise excitation records is used, and an

Table 1
A comparison between the proposed method and the other methods.

Optimization method	c_d (kN.s/m)	k_d (kN/m)	Max. displacement (m)	Percentage reduction
GA [13]	151.50	3750.00	0.1216	35.2
Lee et al. [14]	271.79	4126.93	0.1260	32.9
DE [17]	151.20	3752.60	0.1216	35.2
CSS [18]	88.70	4207.74	0.1219	35.0
IHS [19]	210.90	3727.88	0.1231	34.4
MOCS [22]	160.50	4428.70	0.1218	35.1
COA [25]	144.60	3586.60	0.1215	35.2
The proposed method	122.55	3667.04	0.1208	35.6

objective function is considered to minimize the sum of the ratios of the maximum displacement of the controlled structure to the corresponding value of the uncontrolled structure under all white noise excitations. The design variables and objective functions are defined as follows:

For elastic TMDs:

$$\text{Find}: \ c_d, k_d \tag{5}$$

$$\text{Minimize}: \ X = \sum_{i=1}^{N} \left(\frac{\max\left|x_{structure}^{TMD}\right|}{\max\ \left|x_{structure}\right|}\right)_i \tag{6}$$

and for elastoplastic TMDs:

$$\text{Find}: \ c_d, k_{ed}, u_{yd} \tag{7}$$

$$\text{Minimize}: \ X = \sum_{i=1}^{N} \left(\frac{\max\left|x_{structure}^{NTMD}\right|}{\max\ \left|x_{structure}\right|}\right)_i \tag{8}$$

where N is the number of white noise excitations used in the optimization problem, which is considered equal to 20 in this study, and $x_{structure}$, $x_{structure}^{TMD}$, and $x_{structure}^{NTMD}$ are the maximum displacements of the structure without TMD, with TMD, and with NTMD, respectively.

In the optimization methodology, as shown in Fig. 2, a set of random white noise excitations are generated. Then, the properties of the structure, design variable ranges, and MBF parameters are read. In the next step, the MBF algorithm generates desired values as the parameters of the tuned mass dampers. Then, the ratios of the maximum displacement of the controlled structure to the maximum displacement of the corresponding uncontrolled structure under all white noise excitations are summed. In the same way, the next cycles start, the sum of the ratios of the maximum displacement of the controlled structure equipped with TMD with newly generated parameters to the maximum displacement of the corresponding uncontrolled structure under all white noise excitations is calculated. This cycle continues until the stop condition is met, which herein occurs when the number of function evaluations (NFE) reaches 100. Finally, the most effective parameters of TMD are presented.

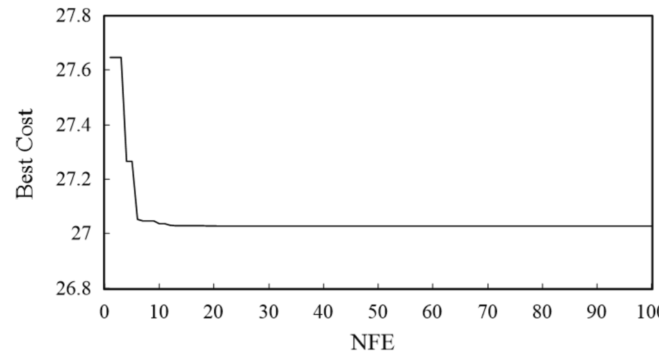

Fig. 4. The convergence curves of the proposed method.

5. Numerical examples

5.1. Example 1

In the first numerical study, the effectiveness of the TMD which was optimized using the proposed method in reducing the maximum displacement of a ten-story linear shear building from [46] subjected to the El Centro 1940 NS earthquake is investigated and compared to the effectiveness of TMDs optimized using other methods presented in Table 1. The mass, damping coefficient, and stiffness of each story are 360 tons, 6200 kNs/m, and 650,000 kN/m, respectively. For optimal design of the parameters of the TMD, the mass was considered equal to 108 tons, and the damping coefficient and stiffness were explored up to 300 kNs/m and 5000 kN/m, respectively.

As presented in Table 1, the proposed method, which optimizes TMD based on white noise excitations using the MBF algorithm, more effectively reduced the maximum displacement of the building under the El Centro earthquake than other methods. The displacement of the top story of the structure, without TMD and with TMD optimized using the proposed method under the El Centro earthquake, is shown in Fig. 3. Furthermore, the convergence curves of the methods are depicted in Fig. 4. As can be seen, using the proposed method, the optimum variables are found in 21 function evaluations (NFE = 21).

As shown in Fig. 4, the cost function starts at 27.65 and approaches 27. In other words, the difference between the 1st best cost and 100th best cost is approximately equal to 2%, which means the MBF algorithm could almost find the optimum values as the parameters of TMD in the first NFE based on the fifty cichlids' best positions after their movements considering the control parameters including *SP*, *Dis*, *Pdis*, and *SPdamp*. It indicates the high performance and the adjustment of the control parameters of the MBF algorithm.

For a comprehensive comparison between the proposed method (P. M.) and the other methods, the efficiency of the elastic TMDs optimized using the methods in reducing the maximum displacement of the ten-

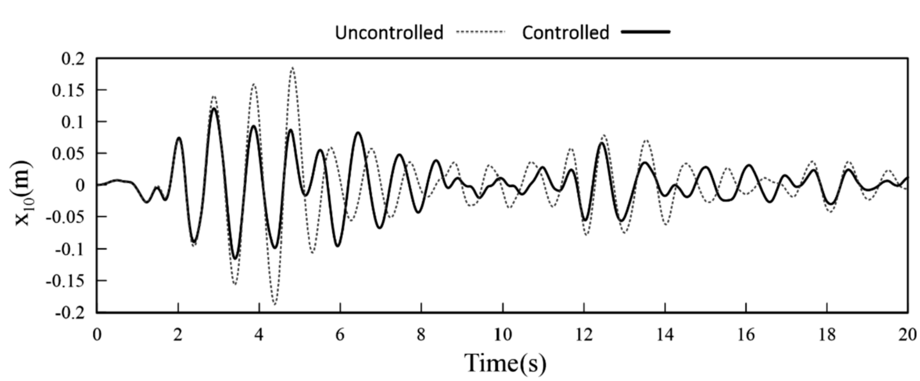

Fig. 3. Displacement of the top story of the uncontrolled and controlled structures under the EI Centro earthquake.

Table 2
Percentage reduction of maximum displacement of the structure with TMD optimized using different methods under near-field earthquakes.

Name	Component	GA	Lee	DE	CSS	IHS	MOCS	COA	P.M.
Imperial Valley-06	E06140	27.6	25.1	27.7	34.6	25.4	31.2	26.4	27.9
Imperial Valley-06	E07140	18.1	12.7	18.1	18.0	15.8	14.6	19.0	19.8
Irpinia, Italy-01	STU000	15.3	19.3	15.3	11.1	18.4	16.4	15.2	13.5
Superstition Hills-02	PTS225	38.1	27.6	38.1	29.7	32.3	33.2	38.3	41.5
Loma Prieta	STG000	21.0	16.2	21.1	18.9	18.6	14.2	20.4	21.8
Erzican, Turkey	ERZ-NS	4.4	2.7	4.4	5.2	3.6	3.8	4.5	4.9
Cape Mendocino	PET000	5.9	7.0	5.9	6.8	6.2	7.5	5.5	5.5
Landers	LCN260	−17.7	−19.1	−17.7	−25.7	−16.9	−24.3	−15.7	−16.9
Northridge-01	RRS228	17.3	15.1	17.3	18.6	16.2	16.9	17.4	17.9
Northridge-01	SYL090	−1.9	9.0	−1.9	−0.7	2.4	8.6	−4.5	−6.0
Kocaeli, Turkey	IZT180	51.1	41.4	51.1	53.4	46.1	46.4	47.8	51.1
Chi-Chi, Taiwan	TCU065-E	22.4	6.7	22.4	13.3	16.5	4.5	26.5	28.5
Chi-Chi, Taiwan	TCU102-E	10.5	4.0	10.5	4.6	9.2	1.1	13.2	12.5
Duzce, Turkey	DZC180	17.4	17.1	17.4	20.9	16.5	20.0	16.6	17.3
Average		**16.4**	**13.2**	**16.4**	**14.9**	**15.0**	**13.9**	**16.5**	**17.1**

Table 3
Design variable ranges and the optimum values.

	Maximum	TMD	NTMD
m_d (tons)	108	108.00	108.00
c_d (kNs/m)	300	122.55	82.67
k_{ed} (kN/m)	5000	3667.04	3987.00
u_{yd} (m)	1.0	–	0.29

story structure under a set of near-field earthquake excitations, presented in FEMA P-695 [47], are evaluated and presented in Table 2.

According to Table 2, the average percentage reduction of the maximum displacement of the ten-story structure equipped with a TMD optimized using the proposed method is approximately 17.1%, indicating its higher efficiency in reducing the maximum displacement of the structure than the TMDs optimized using other methods.

5.2. Example 2

In the second numerical study, the effectiveness of elastic and

Table 4
The maximum displacements of the structures with and without TMD and NTMD (m).

Name	Component	Linear structure W/O	Linear structure with TMD	Linear structure with NTMD	Nonlinear structure W/O	Nonlinear structure with TMD	Nonlinear structure with NTMD
Imperial Valley-06	H-E06140	0.217	0.156	0.152	0.171	0.144	0.158
Imperial Valley-06	H-E07140	0.226	0.181	0.188	0.245	0.218	0.221
Irpinia, Italy-01	A-STU000	0.095	0.082	0.085	0.080	0.082	0.084
Superstition Hills-02	B-PTS225	0.365	0.213	0.265	0.328	0.309	0.328
Loma Prieta	STG000	0.154	0.121	0.114	0.158	0.139	0.144
Erzican, Turkey	ERZ-NS	0.282	0.268	0.266	0.300	0.311	0.314
Cape Mendocino	PET000	0.214	0.202	0.200	0.145	0.139	0.138
Landers	LCN260	0.137	0.160	0.168	0.226	0.245	0.260
Northridge-01	RRS228	0.657	0.539	0.575	0.488	0.479	0.480
Northridge-01	SYL090	0.214	0.225	0.221	0.253	0.275	0.280
Kocaeli, Turkey	IZT180	0.118	0.058	0.054	0.097	0.058	0.054
Chi-Chi, Taiwan	TCU065-E	0.437	0.313	0.383	0.390	0.333	0.346
Chi-Chi, Taiwan	TCU102-E	0.188	0.165	0.164	0.354	0.395	0.417
Duzce, Turkey	DZC180	0.183	0.151	0.148	0.157	0.132	0.144

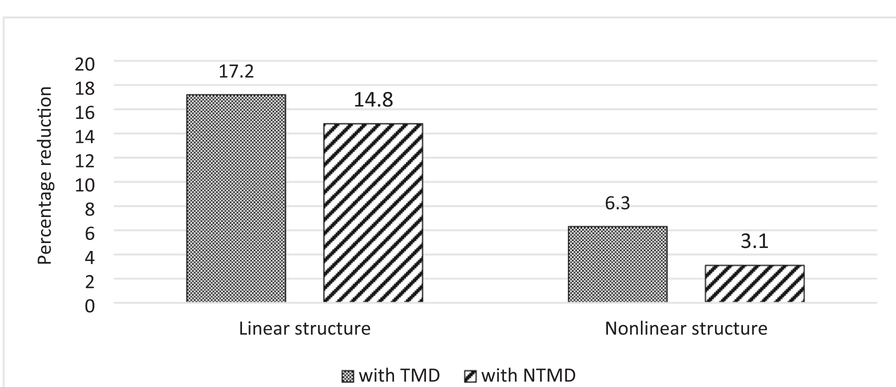

Fig. 5. The average percentage reduction of the maximum displacements of the controlled linear and nonlinear structures under the near-field earthquakes.

elastoplastic TMDs optimized based on a set of white noise excitations using the MBF algorithm, in the response of linear and nonlinear ten-story shear buildings subjected to a set of near-field earthquakes presented in [47] is investigated and compared. The properties of both linear and nonlinear structures are the same as the structures used in the first example. However, for the nonlinear structure, the yielding displacement of each story is assumed to be equal to 0.01 m. The design variable ranges and the optimum values are presented in Table 3. Table 4 lists the maximum displacements of the linear and nonlinear structures with and without TMDs.

According to Table 4 and Fig. 5, the average percentage reductions of the maximum displacements of the 10-story structures equipped with the elastic and elastoplastic TMDs under near-field earthquakes are 11.75% and 8.95%, respectively. Moreover, using the dampers on the top story of the linear and nonlinear structures led to a 16% and 4.7% reduction in the maximum displacement of the structures under the earthquakes, respectively. In other words, in nonlinear structures, once over yield strength, plastic deformation-mediated stiffness variations may result in modified mechanical properties, which causes TMDs to lose their efficiency. Furthermore, the vibration reduction efficiency of the elastoplastic TMD is reduced because of detuning effects, as suggested by the results.

6. Conclusion

This study proposed a new optimization method for the optimal design of tuned mass dampers using the Mouth Brooding Fish algorithm based on a set of white noise excitations. The proposed method was evaluated using a ten-story linear structure subjected to fourteen near-field earthquakes. The results indicated higher efficiency of the proposed method in the optimal tuning of TMDs compared to several other methods, e.g., the genetic algorithm, multi-objective cuckoo search algorithm, charged system search algorithm, and chaotic optimization algorithm. Afterward, the effectiveness of the elastic and elastoplastic TMDs optimized using the proposed method in reducing the maximum displacement of the linear and nonlinear 10-story structures under the near-field earthquakes was assessed. According to the results, the elastic TMD was more efficient in reducing the maximum displacement of the structures than elastoplastic TMD. Additionally, the elastic and elastoplastic TMDs were more effective in reducing the maximum displacement of linear structure than nonlinear structure.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] Ghaffarzadeh H, Younespour A, Cheng S. Design of a tuned mass damper for damped structures using an orthogonal-function-based equivalent linearization method. Structures 2020;28:2605–16.

[2] Huang H, Chang W. Re-tuning an off-tuned tuned mass damper by adjusting temperature of shape memory alloy: Exposed to wind action. Structures 2020;25: 180–9.

[3] Prakash S, Jangid R. Optimum parameters of tuned mass damper-inerter for damped structure under seismic excitation. Int J Dyn Control 2022:1–15.

[4] Kavyashree B, Patil S, Rao V. Review on vibration control in tall buildings: from the perspective of devices and applications. Int J Dyn Control 2020;9(3):1316–31.

[5] Brock JE. A note on the damped vibration absorber. J Appl Mech- Trans ASME 1946;13(4):A284–.

[6] Den Hartog JP. Mechanical vibrations. New York: McGraw-Hill; 1947.

[7] Warburton G. Optimum absorber parameters for various combinations of response and excitation parameters. Earthquake Eng Struct Dyn 1982;10(3):381–401.

[8] Sadek F, Mohraz B, Taylor A, Chung R. A method of estimating the parameters of tuned mass dampers for seismic applications. Earthquake Eng Struct Dyn 1997;26 (6):617–35.

[9] Zuo L, Nayfeh S. Minimax optimization of multi-degree-of-freedom tuned-mass dampers. J Sound Vib 2004;272(3–5):893–908.

[10] Hoang N, Warnitchai P. Design of multiple tuned mass dampers by using a numerical optimizer. Earthquake Eng Struct Dyn 2005;34(2):125–44.

[11] Leung A, Zhang H, Cheng C, Lee Y. Particle swarm optimization of TMD by non-stationary base excitation during earthquake. Earthquake Eng Struct Dyn 2008;37 (9):1223–46.

[12] Leung A, Zhang H. Particle swarm optimization of tuned mass dampers. Eng Struct 2009;31(3):715–28.

[13] Hadi M, Arfiadi Y. Optimum design of absorber for MDOF structures. J Struct Eng 1998;124(11):1272–80.

[14] Lee C, Chen Y, Chung L, Wang Y. Optimal design theories and applications of tuned mass dampers. Eng Struct 2006;28(1):43–53.

[15] Bekdaş G, Nigdeli S. Estimating optimum parameters of tuned mass dampers using harmony search. Eng Struct 2011;33(9):2716–23.

[16] Farshidianfar A, Soheili S. Ant colony optimization of tuned mass dampers for earthquake oscillations of high-rise structures including soil–structure interaction. Soil Dyn Earthquake Eng 2013;51:14–22.

[17] Özsarıyıldız Ş, Bozer A. Finding optimal parameters of tuned mass dampers. Struct Design Tall Spec Build 2014;24(6):461–75.

[18] Kaveh A, Mohammadi S, Hosseini OK, Keyhani A, Kalatjari VR. Optimum parameters of tuned mass dampers for seismic applications using charged system search. Iran J Sci Technol Trans Civ Eng 2015;39(C1):21.

[19] Yazdi H, Saberi H, Saberi H, Hatami F. Designing optimal tuned mass dampers using improved harmony search algorithm. Adv Struct Eng 2016;19(10):1620–36.

[20] Nigdeli S, Bekdaş G. Optimum tuned mass damper design in frequency domain for structures. KSCE J Civ Eng 2016;21(3):912–22.

[21] Nigdeli S, Bekdaş G, Yang XS. Optimum tuning of mass dampers by using a hybrid method using harmony search and flower pollination algorithm. International Conference on Harmony Search Algorithm. 2017 Feb 22 (pp. 222-231). Springer, Singapore.

[22] Etedali S, Rakhshani H. Optimum design of tuned mass dampers using multi-objective cuckoo search for buildings under seismic excitations. Alexandria Eng J 2018;57(4):3205–18.

[23] Chang C, Shia S, Lai Y. Seismic design of passive tuned mass damper parameters using active control algorithm. J Sound Vib 2018;426:150–65.

[24] Fahimi Farzam M, Kaveh A. Optimum design of tuned mass dampers using colliding bodies optimization in frequency domain. Iran J Sci Technol Trans Civ Eng 2019;44(3):787–802.

[25] Kaveh A, Javadi S, Mahdipour MR. Optimal structural control of tall buildings using tuned mass dampers via chaotic optimization algorithm. Structures 2020;28: 2704–13.

[26] Caicedo D, Lara-Valencia L, Blandon J, Graciano C. Seismic response of high-rise buildings through metaheuristic-based optimization using tuned mass dampers and tuned mass dampers inerter. J Build Eng 2021;34:101927.

[27] Kayabekir A, Nigdeli S, Bekdaş G. A hybrid metaheuristic method for optimization of active tuned mass dampers. Comput-Aided Civ Infrastruct Eng 2021;37(8): 1027–43.

[28] Pinkaew T, Lukkunaprasit P, Chatupote P. Seismic effectiveness of tuned mass dampers for damage reduction of structures. Eng Struct 2003;25(1):39–46.

[29] Sgobba S, Marano G. Optimum design of linear tuned mass dampers for structures with nonlinear behavior. Mech Syst Signal Process 2010;24(6):1739–55.

[30] Mohebbi M, Joghataie A. Designing optimal tuned mass dampers for nonlinear frames by distributed genetic algorithms. Struct Design Tall Spec Build 2011;21(1): 57–76.

[31] Mate N, Bakre S, Jaiswal O. Seismic pounding response of singled-degree-of-freedom elastic and inelastic structures using passive tuned mass damper. Int J Civ Eng 2017;15(7):991–1005.

[32] Gerges R, Vickery B. Wind tunnel study of the across-wind response of a slender tower with a nonlinear tuned mass damper. J Wind Eng Ind Aerodyn 2003;91(8): 1069–92.

[33] Alexander N, Schilder F. Exploring the performance of a nonlinear tuned mass damper. J Sound Vib 2009;319(1–2):445–62.

[34] Guo W, Li H, Liu G, Yu Z. A simplified optimization strategy for nonlinear tuned mass damper in structural vibration control. Asian J Control 2011;14(4):1059–69.

[35] Bagheri S, Rahmani-Dabbagh V. Seismic response control with inelastic tuned mass dampers. Eng Struct 2018;172:712–22.

[36] Li L, Du Y. Design of nonlinear tuned mass damper by using the harmonic balance method. J Eng Mech 2020;146(6).

[37] Bekdaş G, Nigdeli S, Yang X. A novel bat algorithm based optimum tuning of mass dampers for improving the seismic safety of structures. Eng Struct 2018;159: 89–98.

[38] Wang B, Jin X, Cheng B. Lion pride optimizer: An optimization algorithm inspired by lion pride behavior. Sci China Inf Sci 2012;55(10):2369–89.

[39] Li X, Zhang J, Yin M. Animal migration optimization: an optimization algorithm inspired by animal migration behavior. Neural Comput Appl 2013;24(7–8): 1867–77.

[40] Fausto F, Cuevas E, Valdivia A, González A. A global optimization algorithm inspired in the behavior of selfish herds. Biosystems 2017;160:39–55.

[41] Abualigah L. Group search optimizer: a nature-inspired meta-heuristic optimization algorithm with its results, variants, and applications. Neural Comput Appl 2020;33(7):2949–72.

[42] Dehghani M, Hubalovsky S, Trojovsky P. Tasmanian devil optimization: A New bio-inspired optimization algorithm for solving optimization algorithm. IEEE Access 2022;10:19599–620.

[43] Jahani E, Chizari M. Tackling global optimization problems with a novel algorithm – Mouth Brooding Fish algorithm. Appl Soft Comput 2018;62:987–1002.

[44] Sedaghat Shayegan D, Lork A, Hashemi S. Optimum cost design of reinforced concrete slabs using mouth brooding fish algorithm. J Appl Eng Sci 2020;10(1): 95–100.
[45] Ebrahimi E, Abdollahzadeh G, Jahani E. Developing the seismic fragility analysis with fuzzy random variables using Mouth Brooding Fish algorithm. Appl Soft Comput 2020;91:106190.
[46] Yucel M, Bekdaş G, Nigdeli SM, Sevgen S. Estimation of optimum tuned mass damper parameters via machine learning. J Build Eng 2019;26:100847.
[47] Quantification of building seismic performance factors. [Washington, DC]: US Dept. of Homeland Security, FEMA; 2009.