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# Effect Of Switch Probability In Flower Pollination Algorithm On Optimization Of Tuned Mass Dampers

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## Abstract.

Metaheuristic algorithms are the numerical algorithm processes which inspired from natural happenings involving life, species, processes and evolution. These algorithms are perfectly effective on engineering optimization including structural engineering. The advantage of the algorithms is the capability to solve optimization problems which are non-linear due to design constraints. Also, some problems cannot be mathematically derived. Because of damping, optimum tuning of tuned mass dampers (TMDs) are done via numerical algorithms including metaheuristic ones. In the present study, the optimum design of TMDs was done via flower pollination algorithm (FPA). FPA inspired from pollination process of flowering plants and several types of pollinations are used in the generation of two optimization phases; namely global and local optimization. To choose one of these phases in an iteration, a switch probability is used. The novelty of the study is the investigation of different values of switch probability on optimum TMD parameters and objective function of the optimization which is minimization of structural responses under seismic excitations. Thus, the best switch probability values in the optimization of TMDs are presented.

**Keywords:** Structural control; tuned mass damper; optimization; metaheuristic algorithms; flower pollination algorithm.

## 1. Introduction

Metaheuristic methods are the algorithms which are generally used in optimization variables of a function or multiple functions. The minimization and maximization of analysis results of an engineering structure are also in the scope of metaheuristics. The applications include structural engineering problems using structural dynamics topic. One of the basic application areas of metaheuristics is to optimize tuned mass dampers (TMDs) for structures subjected to unsteady vibration resulting from strong winds and earthquakes.

TMDs are vibration absorber devices, which are the combination of a mass, stiffness elements and dampers. For an effective performance on damping and reduction of vibrations, the parameters about the components of TMDs must be tuned according to the characteristic of applied structure. Although several basic form formulations have been proposed [1-3], numerical optimization techniques were also studied [4-7] to overcome the assumptions done in the optimization. Especially in the last decade, metaheuristic algorithms were highly used in optimum tuning of TMDs. The employed metaheuristic algorithms are genetic algorithm [8-12], particle swarm optimization [13-14], bionic optimization [15], harmony search [16-19], ant colony optimization [20], artificial bee optimization [22], teaching-learning-based optimization [23] and flower pollination algorithm [24].

Metaheuristic algorithms include special parameters in the design. One of these parameters which is generally exist in all metaheuristic algorithms, is a probability used for controlling the type of optimization. Generally, metaheuristic methods include two types of optimization; namely global and local optimization.

Flower pollination algorithm (FPA) developed by Yang [25] uses switch probability (sp) to control global and local optimization stages. In the present study, the optimum TMD properties are presented for different values of sp and the performance of the optimization are evaluated.

## 2. Optimization of TMDs via FPA

FPA is a metaheuristic algorithm inspired by the process of pollination of flowering plants. By the modelling of several pollination types, two types of optimization are proposed, and these stages are controlled by a switch probability value called switch probability (sp).

The first stage to mention is global pollination (optimization) process. This process involves the inspiration of biotic and cross-pollination. In biotic pollination, pollinators carry the pollens of flower. Cross pollination is the reproduction process of different species of flowers. Biotic pollination involves the transfer of pollens in long distances since pollens are carried by pollinators such as insects, bees and animals. Also, cross-pollination involves a high range of species of flowers. Since these properties show similarities of global pollination, these types are used as global optimization.

$$x_i^{t+1} = x_i^t + L(x_i^t - g_*) \quad (1)$$

In the Eq. (1), $x_i^{t+1}$ represent the candidate solution results of $i^{th}$ flower (population) at $t^{th}$ iteration. The updated solution of next iteration ($x_i^{t+1}$) is found according to best existing solution (g*) with best value of objective function and a Lévy distribution (L) representing the random flight of pollinators.

Local optimization is generated via biotic and self-pollination. Self-pollination is done between flowers of the same species. During abiotic pollination, the pollen transfer is done without the help of pollinators. Self-fertilization (like peach) or natural factors (wind, diffusion in the water) play an important role in reproduction. The pollen transfer distance is shorter in abiotic pollination and a single type of flower involves in self-pollination. As seen in Eq. (2), a linear distribution (ε) is used by using two randomly chosen existing ($x_j^t$ and $x_k^t$) in local pollination.

$$x_i^{t+1} = x_i^t + \varepsilon(x_j^t - x_k^t) \quad (2)$$

The optimization process of TMD optimization are listed as follows:

i. Enter structural properties, ranges of design variables, population (number of flowers), algorithm parameter (switch probability, sp), earthquake records used in the optimization.

ii. Randomly assign design variables to generate and initial solution matrix for all flowers and analyze the structure to find objective function value for all set of candidate solutions.

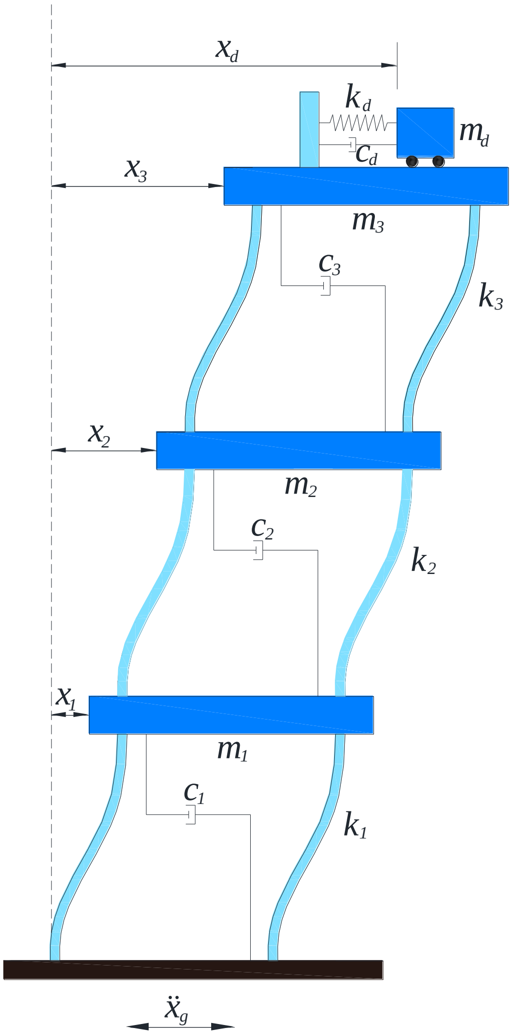
iii. Update the solution via global or local pollination by controlling a random number with sp, and also update value of objective function.

iv. Compare new and existing solutions and update the new ones if value of the objective function is better than the existing one.

v. Iteratively continue the steps iii and iv until several maximum number of iterations.

The objective function of the optimization problem is to minimize the maximum top story displacement of the structure under ground acceleration ($\ddot{x}_g(t)$). The design variables are mass ($m_d$), period ($T_d$) and damping ratio ($\xi_d$) of TMD positioned on the top of the structure as seen in Fig. 1. In the study, a three-story structure was investigated.

*Figure 1: Three story structure with a TMD on the top*




The matrices such as mass (M), stiffness (K) and (C) are as follows:

$$M=\text{diag}\,[m_1\; m_2\; m_3\; m_d] \tag{3}$$

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

$$C=\begin{bmatrix} (c_1+c_2) & -c_2 & & \\ -c_2 & (c_2+c_3) & -c_3 & \\ & -c_3 & (c_3+c_d) & -c_d \\ & & -c_d & c_d \end{bmatrix} \tag{5}$$

The equation of the motion of the structure is given as Eq. (6). x(t) is the displacement vector as shown as Eq. (7).

$$M\ddot{x}(t)+C\dot{x}(t)+Kx(t)=-M\{1\}\ddot{x}_g(t) \tag{6}$$

$$x(t)=[x_1\; x_2\; x_3\; x_d]^T \tag{7}$$

$m_d$, $k_d$ and $c_d$ are mass, stiffness and damping coefficient of TMD, respectively. The period of TMD ($T_d$) and damping ratio of TMD ($\xi_d$) are formulated as Eqs. (8) and (9), respectively.

$$T_d=2\pi\sqrt{\frac{m_d}{k_d}} \tag{8}$$

$$\xi_d=2c_d m_d\sqrt{\frac{k_d}{m_d}} \tag{9}$$

The optimized value of TMD must provide the following condition for the limitation of the stroke of TMD.

$$\frac{\max[|x_d-x_3|]_{\text{with TMD}}}{\max[|x_3|]_{\text{without TMD}}}\le st\_max \tag{10}$$

## 3. Numerical example

The structural properties are 360t, 6.2MNs/m and 650MN/m for mass, stiffness and damping coefficient of a story, respectively. The st_max limit used in stroke limitation is 1. The optimization is done for different earthquake excitations and the critical one was considered for optimization. The records are presented in FEMA P-695 [26] as far-fault ground motions. These records are given as Table I.

The optimization of TMD was done for different sp values as seen in Table 2. Also, the design variable ranges are presented.

*Table 1: FEMA P-695 Far-fault ground motions.*

| Earthquake Number | Component |
|---|---|
| Northridge | NORTHR/MUL009 |
| | NORTHR/MUL279 |
| Northridge | NORTHR/LOS000 |
| | NORTHR/LOS270 |
| Duzce, Turkey | DUZCE/BOL000 |
| | DUZCE/BOL090 |
| Hector Mine | HECTOR/HEC000 |
| | HECTOR/HEC090 |
| Imperial Valley | IMPVALL/H-DLT262 |
| | IMPVALL/H-DLT352 |
| Imperial Valley | IMPVALL/H-E11140 |
| | IMPVALL/H-E11230 |
| Kobe, Japan | KOBE/NIS000 |
| | KOBE/NIS090 |
| Kobe, Japan | KOBE/SHI000 |
| | KOBE/SHI090 |
| Kocaeli, Turkey | KOCAELI/DZC180 |
| | KOCAELI/DZC270 |
| Kocaeli, Turkey | KOCAELI/ARC000 |
| | KOCAELI/ARC090 |
| Landers | LANDERS/YER270 |
| | LANDERS/YER360 |
| Landers | LANDERS/CLW-LN |
| | LANDERS/CLW-TR |
| Loma Prieta | LOMAP/CAP000 |
| | LOMAP/CAP090 |
| Loma Prieta | LOMAP/G03000 |
| | LOMAP/G03090 |
| Manjil, Iran | MANJIL/ABBAR--L |
| | MANJIL/ABBAR--T |
| Superstition Hills | SUPERST/B-ICC000 |
| | SUPERST/B-ICC090 |
| Superstition Hills | SUPERST/B-POE270 |
| | SUPERST/B-POE360 |
| Cape Mendocino | CAPEMEND/RIO270 |
| | CAPEMEND/RIO360 |
| Chi-Chi, Taiwan | CHICHI/CHY101-E |
| | CHICHI/CHY101-N |
| Chi-Chi, Taiwan | CHICHI/TCU045-E |
| | CHICHI/TCU045-N |
| San Fernando | SFERN/PEL090 |
| | SFERN/PEL180 |
| Friuli, Italy | FRIULI/A-TMZ000 |
| | FRIULI/A-TMZ270 |

*Table 2: The optimum results*

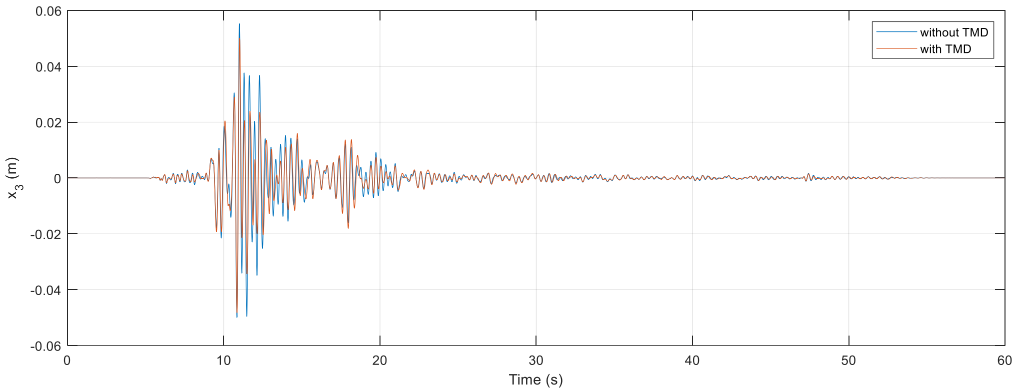
| sp | | Mass (t) | Period (s) | Damping ratio (%) |
|---|---|---|---|---|
| | Range | between 1% and 5% total mass of structure | between 0.5 and 1.5 times of the critical period of structure | between 0.1% and 30% |
| 0 | | 54000 | 0.2881 | 0.3 |
| 0.1 | | 54000 | 0.2881 | 0.3 |
| 0.3 | | 54000 | 0.2795 | 0.3 |
| 0.5 | | 54000 | 0.2875 | 0.2979 |
| 0.7 | | 54000 | 0.2881 | 0.2999 |
| 0.9 | | 54000 | 0.253 | 0.162 |
| 1 | | 54000 | 0.2881 | 0.3 |

## 4. Conclusion

As seen in the results of optimum design variables, the FPA based methodology is effective to find similar optimum values except sp=0.9. This reason is resulting from trapping to local optimum solutions which have a close value to best objective function value.

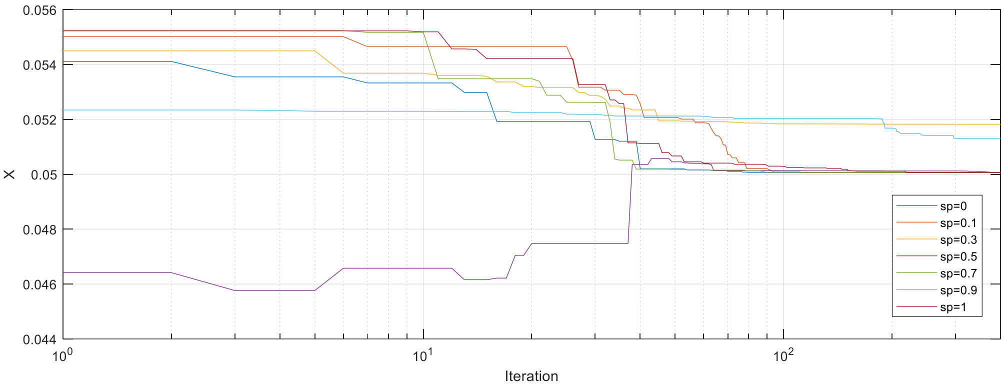
Generally, the optimized TMD is effective to reduce the maximum displacement under critical excitation (DUZCE/BOL0000) by 10% for all sp cases. The top-story time history displacement for that excitation and sp=0.5 is shown as Fig.2.

*Figure 2: Time history plot for critical excitation*




Since all results are close to each others, the essential evaluation of usage of different sp values can be done via convergence plot for 400 iterations. These plots are given as Fig. 3.

*Figure 3: Time convergence of objective function for sp cases*




For sp=0.9 and sp=0.3, the methodology is effective to find results close to the best results. For all other cases, the best results are nearly found. For sp=0.5, the initial value starts form a low value, but this value violates the stroke capacity criterion. The value of objective function without violation is found. Then, it reduces to the best optimum value.

When sp is equal to 0, only local pollination is used, and it has a good convergence ability since the results assigned as initial values were quickly reduced after 40 iterations. Finding an effective value in the initial values helps the convergence for sp=0. Whereas, sp=0.1 has the worst convergence ability except sp=0.3 and sp=0.9, because the initial value is high. Similar situations can be also said for sp=0.9 case. It is clearly seen that sp=0.7 is the best option. The initial value is the highest one, but only a minor difference is seen between the best result and the result of 30$^{th}$ iteration. As a conclusion, global optimization with 70% is effective with 30% usage to local optimization.

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