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PREVENTING THE DISPLACEMENT OF BASE ISOLATED STRUCTURES WITH OPTIMUM TUNED MASS DAMPERS

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Abstract. In base isolated structures, the peak displacement of the isolation system must be limited. Otherwise, the isolation system may fail and also, base isolated structure may collide to other structures if the seismic gap is not enough for the sway of the base isolated structure. In this study, the displacements of structures equipped with linear isolation systems are limited by using optimum tuned mass dampers (TMD). Single degree of freedom base isolated structures with different periods are investigated. A metaheuristic method, harmony search algorithm is employed to find optimum TMD parameters such as mass, period and damping ratio. The optimization is conducted for four different near fault ground excitation in order to find a global optimum solution. The method is effective to find optimum TMD parameters for reducing the displacement of isolation system.

1 INTRODUCTION

Base isolated structures may collide to other structures if the seismic left around the structure is insufficient. This paper investigates optimum tuned mass damper (TMD) design for seismic isolated structures in order to reduce base displacement of the structures. Base isolated structures were assumed as single degree of freedom (SDOF) structure by neglecting the flexibility of the main structure. Kelvin-Voight visco-elastic model was considered for isolation system with linear stiffness and damping. Base isolated system was investigated for different periods and damping ratios.

Pounding is not only a potential risk for base-isolated structures. During strong ground motions, adjacent structure may collide to each other as seen in major earthquakes. Pounding of structures have different types according to the condition of structures. Details about these types can be found in [1]. Several approaches have been proposed for preventing the pounding of adjacent structures. Proposal includes nonlinear hysteric dampers modelled as Bouc-Wen differential model [2], connection of structures with control devices [3], magnetorheological dampers [4, 5], hydraulic actuators [6], bumper-type collision shear walls [7], viscoelastic dampers [8, 9], active control [10], rubber shock absorbers [11], passive dissipation devices [12], hybrid control MR dampers [13], variable damping semi-active control [14] and configuration of passive dampers [15].

In the tuning of the TMD, harmony search (HS) algorithm developed by Geem et al. [16] is employed. Music inspired HS has been successfully employed in several studies including the major areas of civil engineering such as structural engineering [17-29], structural materials [30-32], hydraulics [33-36], cost optimization and management [37-41] and structural dynamics [42-47].

2 OPTIMUM TUNING OF TUNED MASS DAMPERS

Tuned mass dampers (TMD) were invented by implementing inherent damping to the vibration absorber devices of Frahm [48- 49]. Several tuning approaches for TMDs can be found in [50-53]. Also, metaheuristic methods have been employed in several proposal [54-59] including HS [42-45].

The proposed methodology employing HS is summarized in this section. The optimization code was developed by using Matlab with Simulink [60]. Ground accelerations downloaded from the website of Pacific Earthquake Engineering Research Center (PEER) [61] were used in all iterations of optimization process. In time history analyses, Runge-Kutta method with 0.001 s time step was chosen. The methodology can be explained in five steps.

Step 1: Structural properties, HS parameters, stopping criterion, ground acceleration records and solution ranges are defined.

Step 2: Dynamic analyses of structure without TMD is done for future comparisons.

Step 3: Initial harmony memory (HM) matrix is generated by harmony vectors containing randomly generated mass, period and damping coefficient of TMD. Harmony memory size (HMS) is the number of harmony vectors.

Step 4: After an initial HM matrix is constructed, new harmony vectors are generated according to the special rules of HS and the new one is replaced with the worst one in HM if the solution is better than the existing ones. The stopping criterion and measurement in selecting the worst and the best vector is the same. It can be also named as the objective function. If the maximum base displacement under critical earthquake are respectively defined as x and x_d for structure without and with TMD, the criterion is to reduce the x_d/x ratio to a user defined value. If this value is not physically possible within the solution range, it is increased after several iterations.

Step 5: After every generation of a new harmony vector, the stopping criterion is checked. The optimization is repeated from Step 4 in order to satisfy the stopping criterion.

3 NUMERICAL EXAMPLES

The proposed method is applied for eight different single degree of freedom structures (Table 1). The first four structures have low damping (10%) while the others have high damping (40%). The mass of the structures is taken as 1000 tons. Also, the ranges of TMD parameters used in the optimization are given in Table 2. The near-fault earthquake records used in the optimization are shown in Table 3. The optimum results and x_d/x ratios are given in Table 4 for all structures.

Table 1: Properties of base isolated structures

Structure	Period (s)	Damping (%)
1	2	10
2	3	10
3	4	10
4	5	10
5	2	40
6	3	40
7	4	40
8	5	40

Table 2: Solution ranges

Symbol	Definition	Ranges
μ_d	Mass ratio of TMD to structure	1%-10%
T_d	Period of TMD	0.8-1.2 times of the period of structure
ξ_d	Damping ratio of TMD	5%-30%

Table 3: Ground motion acceleration records

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

Table 3: Optimum TMD parameters

	1	2	3	4	5	6	7	8
μ_d	9.81	9.94	9.79	9.82	9.96	9.83	9.95	9.96
T_d	2.33	3.57	3.60	4.01	2.15	3.55	3.87	4.02
ξ_d	6.02	5.19	6.19	7.01	5.33	5.02	5.03	5.96
x_d/x	0.86	0.83	0.78	0.86	0.91	0.94	0.90	0.89

4 CONCLUSIONS

According to the results, TMDs are more effective for the structures with low damping than the others. For the structures with period 2 s and 3 s, the period of the TMD is more than the main structure period, but the period of TMD is less than the main structure period for the other ones. Especially, the optimum TMD period is nearly 4s (lower limit of the range) for structure with 5 s period. A difference between the values of the low and high damped structures is the damping ratios of TMD. Damping of the TMD is lower for the structures with 40% damping than the others. The proposed method is suitable to find the optimum TMD parameters. TMDs can be used as an additional support for base isolated structures if the damping of isolation systems is not enough.

REFERENCES

[1] Jeng V., Tzeng W.L. Assessment of seismic pounding hazard for Taipei City. *Eng. Struct.* (2000) **22**:459–471.

[2] Ni Y.Q., Ko J.M., Ying Z.G. Random Seismic Response Analysis of Adjacent Buildings Coupled with Non-Linear Hysteretic Dampers. *Journal of Sound and Vibration* (2001) **246**(3): 403-417.

[3] Ying Z.G., Ni Y.Q., Ko J.M. Stochastic optimal coupling-control of adjacent building structures. *Comput. Struct*. (2003) **81**:2775–2787.

[4] Bharti S.D., Dumne S.M., Shrimali M.K. Seismic response analysis of adjacent buildings connected with MR dampers. *Eng. Struct*. (2010) **32**:2122-2133.

[5] Sheikh M.N., Xiong J., Li W.H. Reduction of seismic pounding effects of base-isolated RC highway bridges using MR damper. *Structural Engineering and Mechanics* (2012) **41**(6):791-803.

[6] Xu Y.L., Zhang W.S. Closed-form solution for seismic response of adjacent buildings with linear quadratic Gaussian controllers. *Earthquake Engng Struct. Dyn*. (2002) **31**:235–259.

[7] Anagnostopoulos S.A., Karamaneas C.E., Use of collision shear walls to minimize seismic separation and to protect adjacent buildings from collapse due to earthquake-induced pounding. *Earthquake Engng Struct. Dyn.* (2008) **37**:1371–1388.

[8] Matsagar V.A., Jangid R.S. Viscoelastic damper connected to adjacent structures involving seismic isolation. *Journal of Civil Engineering and Management* (2005) **11**(4):309-322.

[9] Tubaldi E., Barbato M., Ghazizadeh S. A probabilistic performance-based risk assessment approach for seismic pounding with efficient application to linear systems. *Structural Safety* (2012) 36–37:14–22.

[10] Park K-S., Ok S.-Y. Optimal design of actively controlled adjacent structures for balancing the mutually conflicting objectives in design preference aspects. *Eng. Struct*. (2012) **45**:213–222.

[11] Polycarpou P.C., Komodromos P., Polycarpou A.C. A nonlinear impact model for simulating the use of rubber shock absorbers for mitigating the effects of structural pounding during earthquakes. *Earthquake Engng Struct. Dyn*. (2013) **42**:81–100.

[12] Cimellaro G.P., Lopez-Garcia D. Algorithm for design of controlled motion of adjacent structures. *Struct. Control Health Monit*. (2011) **18**:140–148.

[13] Kim G.C., Kang J.W. Seismic response control of adjacent building by using hybrid control algorithm of MR. *Procedia Engineering* (2011) **14**:1013-1020.

[14] Cundumi O., Suarez L.E. Numerical Investigation of a Variable Damping Semiactive Device for the Mitigation of the Seismic Response of Adjacent Structures. *Computer-aided civil and infrastructure engineering* (2008) **23**:291-308.

[15] Bigdeli K., Hare W., Tesfamariam S. Configuration optimization of dampers for adjacent buildings under seismic excitations. *Eng Optim* (2012) **44**:1491-1509.

[16] Geem Z.W., Kim J.H., Loganathan G.V. A new heuristic optimization algorithm: harmony search *Simul.* (2001) **76**: 60–68.

[17] Lee K.S., Geem Z.W. A new structural optimization method based on the harmony search algorithm, *Computers and Structures* (2004) **82**: 781–798.

[18] Saka M.P. Optimum geometry design of geodesic domes using harmony search algorithm. *Advance in Structural Engineering* (2007) **10**(6): 595–606.

[19] Degertekin S.O. Harmony search algorithm for optimum design of steel frame structures: A comparative study with other optimization methods. *Structural Engineering and Mechanics* (2008) **29**(4): 391-410.

[20] Saka M.P. Optimum design of steel sway frames to BS5950 using harmony search algorithm. *Journal of Constructional Steel Research* (2009) **65**: 36-43.

[21] Hasancebi O. Performance Evaluation of Metaheuristic Search Techniques in the Optimum Design of Real Size Pin Jointed Structures. *Computers and Structures* (2009) **87**: 284-302.

[22] Degertekin S.O., Hayalioglu M.S., Gorgun H. Optimum Design of Geometrically Non-Linear Steel Frames with Semi-Rigid Connections Using a Harmony Search Algorithm. *Steel and Composite Structures* (2009) **9**(6): 535-555.

[23] Erdal F., Saka M.P. Harmony search based algorithm for the optimum design of grillage systems to LRFD-AISC. *Structural and Multidisciplinary Optimization* (2009) **38**: 25-41.

[24] Togan V., Daloglu A.T., Karadeniz H. Optimization of Trusses under Uncertainties with Harmony Search. *Structural Engineering and Mechanics* (2011) **37**(5): 543-560.

[25] Hasancebi O., Carbas S., Dogan E., Erdal F., Saka M.P. Comparison of Non-Deterministic Search Techniques In The Optimum Design of Real Size Steel Frames. *Computers and Structures* (2010) **88**(17-18): 1033-1048.

[26] Erdal F., Dogan E., Saka M.P. Optimum Design of Cellular Beams Using Harmony Search and Particle Swarm Optimizers. *Journal of Constructional Steel Research* (2011) **67**(2): 237-247.

[27] Bekdaş G., Nigdeli S.M. Optimization of T-shaped RC Flexural Members for Different Compressive Strengths of Concrete. *International Journal of Mechanics* (2013) **7**: 109-119.

[28] Akin A., Saka M.P. Optimum Detailed Design of Reinforced Concrete Continuous Beams using the Harmony Search Algorithm, in B.H.V. Topping, J.M. Adam, F.J. Pallarés, R. Bru, M.L. Romero, (Editors), "Proceedings of the Tenth International Conference on Computational Structures Technology", Civil-Comp Press, Stirlingshire, UK, Paper 131, (2010) doi:10.4203/ccp.93.131.

[29] Toklu Y.C., Bekdaş G., Temur R. Analysis of Trusses by Total Potential Optimization Method Coupled with Harmony Search. *Structural Engineering and Mechanics* (2013) **45**(2):183-199.

[30] Lee J-H., Yoon Y-S. Modified Harmony Search Algorithm and Neural Networks for Concrete Mix Proportion Design. *ASCE International Workshop on Computing in Civil Engineering* (2007) **23**(1): 57-61.

[31] Mun S., Lee S. Identification of Viscoelastic Functions for Hot-Mix Asphalt Mixtures Using a Modified Harmony Search Algorithm. *Journal of Computing In Civil Engineering* (2011) **25**(2): 139-148.

[32] Suh Y., Mun S., Yeo I. Fatigue Life Prediction of Asphalt Concrete Pavement Using a Harmony Search Algorithm. *KSCE Journal of Civil Engineering* (2010) **14**(5): 725-730.

[33] Geem Z.W. Harmony Search Optimisation to the Pump-Included Water Distribution Network Design. *Civil Engineering and Environmental Systems* (2009) **26**(3): 211-221.

[34] Baek C.W., Jun H.D., Kim J.H. Development of a PDA Model for Water Distribution Systems Using Harmony Search Algorithm. *KSCE Journal of Civil Engineering* (2010) **14**(4): 613-625.

[35] Geem Z.W., Cho Y-H. Optimal Design of Water Distribution Networks Using Parameter-Setting-Free Harmony Search for Two Major Parameters. *Journal of Water Resources Planning and Management-ASCE* (2011) **137**(4): 377-380.

[36] Geem Z.W. Parameter Estimation of the Nonlinear Muskingum Model Using Parameter-Setting-Free Harmony Search. *Journal of Hydrologic Engineering* (2011) **16**(8): 684-688.

[37] Kaveh A., Abadi A., Shakouri M. Cost optimization of a composite floor system using an improved harmony search algorithm. *Journal of Constructional Steel Research* (2010); **66**(5): 664-669.

[38] Kaveh A., Abadi A., Shakouri M. Harmony Search Based Algorithms for The Optimum Cost Design of Reinforced Concrete Cantilever Retaining Walls. *International Journal of Civil Engineering* (2011); **9**(1): 1-8.

[39] Kaveh A., Sabzi O. A Comparative Study of Two Meta-Heuristic Algorithms for Optimum Design of Reinforced Concrete Frames. *International Journal of Civil Engineering* (2011); **9**(3): 193-206.

[40] Geem Z.W. Multiobjective Optimization of Time-Cost Trade-Off Using Harmony Search. *Journal of Construction Engineering and Management-ASCE* (2010) **136**(6): 711-716.

[41] Gholizadeh R., Amiri G.G., Mohebi B. An alternative approach to a harmony search algorithm for a construction site layout problem. *Canadian Journal of Civil Engineering* (2010) **37**(12): 1560-1571.

[42] Bekdaş G., Nigdeli S.M. Estimating Optimum Parameters of Tuned Mass Dampers using Harmony Search. *Engineering Structures* (2011) **33**: 2716-2723.

[43] Bekdaş G., Nigdeli S.M. Optimization of Tuned Mass Damper with Harmony Search, In *Metaheuristic Applications in Structures and Infrastructures*, Edited by Amir Hossein Gandomi, Xin-She Yang, Amir Hossein Alavi, Siamak Talatahari. (2013) Elsevier.

[44] Bekdaş G., Nigdeli S.M. Mass Ratio Factor for Optimum Tuned Mass Damper Strategies. *International Journal of Mechanical Sciences* (2013) **71**: 68-84.

[45] Nigdeli S.M., Bekdaş G. Optimum Tuned Mass Damper Design for Preventing Brittle Fracture of RC Buildings. *Smart Structures and Systems* (2013) **12**: 137-155.

[46] Kayhan, A.H. Selection and Scaling of Ground Motion Records Using Harmony Search. *Teknik Dergi* (2012) **23**(1): 5751-5775.

[47] Nigdeli S.M., Bekdaş G. and Alhan C. Optimization of Seismic Isolation Systems via Harmony Search." *Eng. Optimiz.*, DOI:10.1080/0305215X.2013.854352.

[48] Frahm H. Device for damping of bodies. U.S. Patent No: 989,958 (1911).

[49] Ormondroyd J., Den Hartog J.P. The theory of dynamic vibration absorber. *Transactions of the American Society of Mechanical Engineers* (1928) **50**: 9–22.

[50] Den Hartog J.P. *Mechanical Vibrations*. (1947) McGraw-Hill, New York.

[51] Warburton G.B. Optimum absorber parameters for various combinations of response and excitation parameters. *Earthquake Engineering and Structural Dynamics* (1982) **10**: 381–401.

[52] Sadek F., Mohraz B., Taylor A.W., Chung R.M. A method of estimating the parameters of

tuned mass dampers for seismic applications. *Earthquake Engineering and Structural Dynamics* (1997) **26**: 617–635.

[53] Chang C.C. Mass dampers and their optimal designs for building vibration control. *Engineering Structures* (1999) **21**: 454-463.

[54] Hadi M.N.S., Arfiadi Y. Optimum design of absorber for MDOF structures. *Journal of Structural Engineering-ASCE* (1998) **124**: 1272–1280.

[55] Singh M.P., Singh S., Moreschi L.M. Tuned mass dampers for response control of torsional buildings. *Earthquake Engineering and Structural Dynamics* (2002) **31**: 749–769.

[56] Marano G.C., Greco R., Chiaia B. A comparison between different optimization criteria for tuned mass dampers design. *Journal of Sound and Vibration* (2010) **329**: 4880-4890.

[57] Steinbuch R. Bionic optimisation of the earthquake resistance of high buildings by tuned mass dampers. *Journal of Bionic Engineering* (2011) **8**: 335-344.

[58] Leung A.Y.T., Zhang H., Cheng C.C., Lee Y.Y. Particle swarm optimization of TMD by non-stationary base excitation during earthquake. *Earthquake Engineering and Structural Dynamics* (2008) **37**: 1223-1246.

[59] Leung A.Y.T., Zhang H. Particle swarm optimization of tuned mass dampers. *Engineering Structures* (2009) **31**: 715-728.

[60] Mathworks, MATLAB R2010a (2010) The MathWorks Inc., Natick, MA,USA.

[61] Pacific Earthquake Engineering Research Center (PEER NGA DATABASE) http://peer.berkeley.edu/nga.