COUPLED OPTIMAL DESIGN OF BUILDING WITH TMD

Anupam S. Ahlawat*, Ananth Ramaswamy*
*Department of Civil Engineering, Indian Institute of Science, Bangalore-560 012, India

Summary A genetic algorithm based integrated approach to optimize the total cost of building and the associated control device has been proposed. Constraints for performance of the design include peak inter-story drift and peak absolute acceleration of the floors. Two examples, a three- and a nine-story building subjected to design seismic excitations have been studied. The control device considered is a tuned mass damper (TMD) installed at the roof of the building. The study concludes that for 3-story example problem, building alone without any TMD is an optimal solution while for 9-story, a building with a TMD is the best design.

INTRODUCTION

Stringent performance requirements to mitigate structural damage in the event of large environmental loads such as strong earthquake or wind gusts and occupant comfort during normal service of the structure have gained increased significance in recent years. These performance requirements can be met through the use of optimal design of the structure with constraints for dynamic response [1]. Alternatively, performance of the structures can be improved through the application of a passive, active or hybrid control system [2].

A substantial amount of research has been carried-out on structural optimization as well as on optimal control system design. However, deployment of an optimal control system in an optimal structure may not lead to an optimal design of combined structure-control system. Very little effort has been made in the direction of integrated structural-control system optimization and these were primarily focused on small aerospace structural components.

In the present paper, a coupled approach for an integrated optimization of seismically excited building structure with associated tuned mass damper (TMD) has been presented and demonstrated through example problems. Results indicate that proposed approach is robust and leads to superior designs not previously envisaged.

STRUCTURAL AND CONTROL SYSTEM

For the present study, idealized plane frame equivalent models of the 3-story and 9-story steel buildings have been considered. Building structure has been assumed to be linear elastic with Rayleigh damping. Mass of the building is lumped at floor levels. A TMD installed at roof of the building has been used as a passive vibration control device. Four actual earthquake records that are listed below have been used as design excitations.

- El Centro, May, 18, 1940: North-South (N-S) component recorded in El Centro, California, at the Imperial Valley Irrigation District substation with an absolute peak acceleration of 3.417 m/s^2.
- Hachinohe, May, 16, 1968: N-S component of the Tokachi-oki earthquake recorded in Hachinohe city, Japan with an absolute peak acceleration of 2.250 m/s^2.
- Northridge, January, 17, 1994: N-S component recorded in Sylmar, California, at the parking lot of the Sylmar County Hospital with an absolute peak acceleration of 8.2676 m/s^2.
- Kobe, January 17, 1995: N-S component recorded during the Hyogo-ken Nanbu earthquake at the Kobe Japanese Meteorological Agency (JMA) with an absolute peak acceleration of 8.1782 m/s^2.

FORMULATION OF OPTIMIZATION PROBLEM

The building consists of 3 or 9 storys of equal eights. For simplicity, all the columns for a story are considered to be of the same size and equi-spaced, however, the column size for different storys may be different. Cost associated with the mass of the floors do not change in the optimization process. Hence, the only variable component of the cost of the building depends on the column sizes. Cost of the TMD has been assumed to be directly proportional to its mass. Thus, the optimization problem can be defined as:

Design variables

Stiffness of the column K^i_{col} for all the storys, i.e., for $i = 1$ to N, (where N is total number of storys in the building), mass (m_{tmd}), stiffness (k_{tmd}) and damping (d_{tmd}) of the TMD have been considered as design variables. Here it should be noted that the column stiffness is a secondary design variable and is linked to the area of the column (A^i_{col} for standard column sections.

Objective function

$$f_{obj} = c_{col} N_{col} \sum_{i=1}^{N} A_{col}^{i} + c_{tmd}\, m_{tmd} \tag{1}$$

Where c_{col} is the unit cost of the column per unit area, N_{col} is the number of columns in each story, A_{col}^{i} is the area of a column of the i^{th} story, c_{tmd} and m_{tmd} are unit cost and mass of the TMD, respectively.

Constraints

Design constraints include structural strength related constraints (permissible stress, etc.), dynamic performance related constraints (peak inter-story drift, peak absolute acceleration at floor level) and control device related constraints (maximum limit on mass, stiffness and damping of TMD and maximum allowable displacement of the TMD relative to the roof).

Constant parameters

Material properties, mass of the floors, boundary conditions, modal damping coefficient for two predefined modes are the constant parameters and kept unchanged in the optimization process.

SOLUTION PROCEDURE

Idealized plane frame equivalent model of the building, and control device (TMD) have been simulated using SIMULINK [3] and MATLAB [4]. Genetic algorithm (GA) has been used to solve the optimization problem. Optimal design of the building with an optimal TMD has been introduced as a member in the randomly generated initial population. Boxed constraints for the design variables have been incorporated in coding of the chromosomes [2]. All the design variables have been represented by 8 bit long string. Thus total length of chromosome is $8\times$ Number of design variables.

ILLUSTRATIVE EXAMPLES

Two example problems namely, a 3-story and a 9-story building structures with TMD installed at the roof, have been considered to demonstrate the proposed coupled optimization approach. These example problems have been taken from the 3rd generation benchmarks on structural control [5]. These benchmark problems are for nonlinear analysis but for the present study, linear analysis has been carried-out. Story height for these buildings is 3.96m. Dimensions in plan are $36.58m \times 54.87m$ and $45.75m \times 45.75m$ for 3-story and 9-story building, respectively. Total mass is 2.95×10^6kg for 3-story and 9.00×10^6kg for 9-story building. The modal damping coefficients have been taken as 0.02 for first and third mode. Constraints for maximum mass of the TMD has been taken as 5% of the total mass of the structure. Constraint for maximum stiffness and damping of the TMD have been taken as 4000 kN/m and 1000 kN-s/m, respectively [6].

RESULTS

For 3-story building example problem optimal design is one without any TMD, i.e., the optimum mass of the TMD is zero. For the 9-story building, the best design is one with a TMD of 3.96×10^5kg. Constraint for maximum mass of the TMD is not active at the solution.

CONCLUSIONS

The proposed approach for coupled optimization of structural and control system leads to a superior design than the corresponding one obtained by plugging an optimal TMD in the optimal design of the building. It is clear from the design obtained for two example problems that the proposed method is robust and results in an optimal solution for both cases, one when the building alone is an optimal design and does not require any TMD and the other when building with a TMD is the optimal solution.

References

[1] Pantelides C.P., Tzan S.R.: Optimal Design of Dynamically Constrained Structures. *Computers & Structures* **62**:141–149, 1997.
[2] Ahlawat A.S., Ramaswamy A.: Multi-objective Optimal Design of FLC driven Hybrid Mass Damper for Seeismically Excited Structures. *Earthquake Engrg. and Struct. Dyn.* **31**:1459–1479, 2002.
[3] SIMULINK: version 4.0, The MathWorks, Inc.: Natick (USA), 2001.
[4] MATLAB: Version 6.1.0.450, The MathWorks, Inc.: Natick (USA), 2001.
[5] Ohtori Y., Christenson R.E., Spencer Jr. B.F., Dyke S.J.: “Benchmark control problems for seismically excited nonlinear buildings. web site http://www.nd.edu/~quake/benchmarks/bench3def, 2003
[6] Hadi M.N.S., Arfiadi Y.: Optimum design of absorber for MDOF structures. *J. Struct. Engrg.*, ASCE, **124**:1272–1280, 1998.