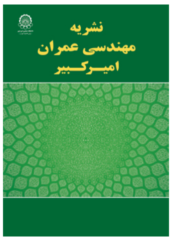

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Designing Variable Stiffness Semi-Active Tuned Mass Damper for Nonlinear Structures

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ABSTRACT: In this paper, designing variable stiffness semi-active tuned mass damper (SATMD) for mitigating the responses of nonlinear structures under earthquake excitation has been studied. Two semi-active control algorithms based on instantaneous optimal control and clipping control concept as well as modified balance control have been developed to determine the optimal stiffness of SATMD for nonlinear structures in each time step. For determining optimal parameters of semi-active control system including the weighting matrices in performance index of control algorithm as well as the maximum and minimum values of SATMD stiffness, an optimization problem for minimization of structure maximum response has been defined where genetic algorithm (GA) has been used for optimization. For numerical simulations, an eight-story nonlinear shear building with bilinear hysteresis behavior has been subjected to a white noise excitation and optimal SATMDs have been designed. The results showed that optimal variable stiffness SATMD using both control algorithms has been effective in suppressing the seismic responses of nonlinear structure. Also, variable stiffness SATMD shows better performance than TMD and variable damping SATMD in structural response controlling. Comparing the performance of the variable stiffness SATMD under testing earthquakes which were different from design record, showed that the efficiency of SATMD depends on the characteristics of excitation, hence design record needs to be chosen properly.

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Clipped optimal control algorithm
Modified balance control algorithm.

1- Introduction

Since decades ago a variety of structural control techniques have been introduced to suppress structural vibration under external dynamic forces such as earthquake loading, wind or impact. Among the control systems, semi-active control strategies can offer adaptability of active systems without requiring the associated large power sources, which is critical during natural hazards, when the main power source of the structure may fail. Also, in contrast to active control systems, semi-active control systems do not have the potential to destabilize the structure due to inappropriate operation. Moreover, semi-active systems can perform significantly better than passive systems and have the ability to achieve the majority of the efficiency of active and hybrid systems [1].

Tuned mass dampers (TMD) have drown many researchers' attention and different kinds of design technics have been proposed to determine theirs optimum parameters. Due to the fact that TMD should be tuned to a fixed frequency, it may have no benefits during some earthquakes which vibrates the structure in other frequency bands [2]. Furthermore, under severe earthquakes, the structure shows non-linear behavior which may detune the TMD and consequently will leads to inefficiency. Recently, the semi-active tuned mass damper (SATMD) with variable stiffness [3-9] or variable damping [10, 11] has been proposed to overcome the disadvantageous of conventional TMDs.

n this paper, a method to design variable stiffness SATMD for non-linear frame structures has been presented and its effectiveness in reducing the structural response under earthquake excitations has been investigated.

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2- Methodology

In the semi-active independently variable stiffness (SAIVS) devices modify the stiffness of SATMD in each time step according to control algorithm [12]. Two control algorithms including instantaneous optimal control using clipped optimal control concept [13] and modified balance control [14] have been developed to determine the appropriate command signals. For optimal design of variable stiffness SATMD, a method based on defining an optimization problem to minimize the maximum response of the structure has been proposed where the genetic algorithm (GA) has been used to find optimal solution.

In this method, the weighting matrices in performance index of instantaneous optimal control algorithm and the upper and lower limit of semi-active control device stiffness have been considered as design variables and the optimal vector of these parameters have been determined through solving the optimization problem. Based on the design criteria, different combination of structural response could be included in the objective function. In this research, minimizing the maximum inter-story drift which is a safety criterion has been considered as objective function.

3- Conclusions

To illustrate the design procedure of the proposed method, an eight-story nonlinear shear frame with bilinear hysteresis behavior equipped with a variable stiffness SATMD, attached to the top floor, has been considered. For different values of SATMD mass ratio and both semi-active control strategies, the structure has been subjected to a white noise excitation and optimal SATMDs have been designed to minimize the maximum inter-story drift of the structure. Time history of inter-story drift and hysteresis loops of first story of controlled and un-controlled structures have been compared respectively in Figure 1 and 2. It is clear that by installation of SATMD, the non-linearity observed at first story of un-controlled structure, has been disappeared.

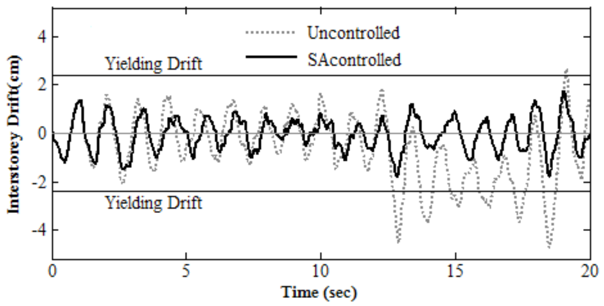

Figure 1: Time history of un-controlled and controlled structures inter-story drift for first story.

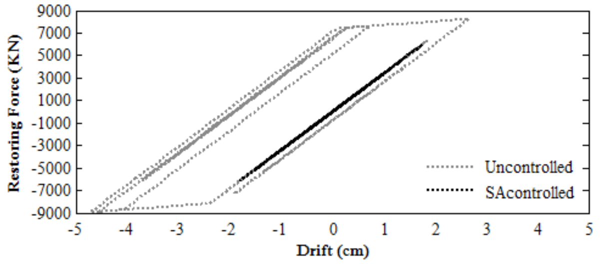

Figure 2: Hysteresis loops of un-controlled and controlled structures for first story.

In order to assess the effectiveness of the variable stiffness SATMD in improving the seismic behavior of the non-linear frames, the performance of TMD and variable damping SATMD have also been investigated. The maximum responses including inter-story drift, displacement and acceleration of un-controlled and controlled structures using different mechanisms under white noise excitation has been reported in Table 1. Results show that variable stiffness SATMD is more effective in structural response control under design record.

Table 1: Maximum responses of un-controlled and controlled by TMD and variable stiffness and damping SATMD

Mechanism	Max. drift (mm)	Max. disp. (mm)	Max. acc. (mm/s^2)
Uncontrolled	47.3	172.1	8567
TMD	28.8	128.5	7711
SATMD-VD(CO)	21.8	111.2	7217
SATMD-VS(CO)	18.0	92.2	6421
SATMD-VS(MB)	17.5	108.2	7116

Max. (Maximum); disp. (Displacement); acc. (Acceleration); VD. (Variable Damping); VS. (Variable Stiffness); CO. (Clipped Optimal); MB. (Modified Balance).

To evaluate the performance of designed variable stiffness SATMD under real earthquakes, optimal SATMD has been subjected to some real earthquakes which are different from design record in frequency content and peak ground acceleration (PGA). According to the results, it has been found that the efficiency of SATMD depends on the characteristics of excitation. In addition, it can be concluded that the semi-active control system parameters need to be chosen by considering site condition and a proper design record.

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