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DYNAMIC RESPONSE MITIGATION ADOPTING MULTI-DAMPING TECHNOLOGICAL STRATEGY

MOHAMMAD S. MIAH*, **WERNER LIENHART**†

*Institute of Engineering Geodesy and Measurement Systems
Graz University of Technology
8010 Graz, Austria
e-mail: miah@tugraz.at, web page: www.igms.tugraz.at

† Institute of Engineering Geodesy and Measurement Systems
Graz University of Technology
8010 Graz, Austria
e-mail: werner.lienhart@tugraz.at, web page:www.igms.tugraz.at

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Abstract. Troublesome disturbance into the dynamical system is unavoidable not only due to extreme exogenous dynamic excitation but also for operational loading conditions. Hence, it is essential to employ appropriate vibration mitigation strategy to keep them safe during any unexpected incident. There are many available alternatives in the real world, however, still there is no fool-proof technology among them due to individual inherent technological drawbacks. For instant, the cheapest alternative would be a passive system that doesn't require alternating/direct current like its competitors e.g. active, semi-active system. Therefore, many recent studies have focused to develop hybrid type systems that might be operable during normal operational time and also at an extreme scenario when alternating current might not be available. In this study, to achieve the utmost technological benefit a passive and a semi-active system have been combined to mitigate excessive vibration of the investigated dynamical system. The findings of this study show that the investigated approach is capable of reducing vibration better than having a single damping technology (passive or semi-active). Further, there are more benefits of the studied approach as it can be operable in any condition such as with alternate or direct current and without any current as passive device has been considered in different level than other device. Finally, the studied approach (e.g., due to vibration reduction) has an added advantage in case of structural health monitoring.

1 INTRODUCTION

Vibration mitigation under operational and dynamic loads are well-known problem in the area of structural dynamics. More elaborately, vibration reduction under dynamic loads are critical for all type of structures such as civil, mechanical, and aerospace structures. To tackle vibration,

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there are many vibration reduction technologies (i.e., dampers, isolators) are available for those early mentioned structural applications. Different types of vibration control alternatives such as passive systems, active systems, semi-active, hybrid systems can be found in [1, 2, 5, 6, 7]. Also, from those articles the drawbacks linked to each alternative along with their listed advantages can be obtained. In addition to their advantages, it can be found from those technologies that none of the system is fool-proof. And the aforementioned point has encouraged to study a hybrid-type control approach that can be optimal in terms of vibration minimization.

In this context, due to the simple structure of the passive type mitigation technologies are well developed and also they have been implemented in many structures around the globe [1]. For instance, tuned mass damper (TMD) is adopted in [2] to reduce the vibration of buildings. Further, in order to achieve better control, in [3, 4] have optimized and design the TMD and both studies show quite good performance for their specific problem. While in [5] has studied the behaviour of a bearing type passive system made of elastomer. The main drawback of the passive system is that it is not able to adjust due to real-time changes. In other words, it can function nicely as long as it is within the design frequency range. To overcome the early mentioned issue designers can adopt active, semi-active or hybrid type system. However, for all those aforesaid systems electric or battery power supply is needed. Due to the power supply reason, it might be impossible to keep an active system functional during an extreme earthquake or gale. While for the preceding problem semi-active or hybrid system might an suitable alternative as they can be operable with both battery power and electricity supply.

Regardless the minor drawbacks and due to many underlying advantages there are different types of active, semi-active and their hybrid types are getting popular in the recent decades. For example,[8] has investigated the performance of an active control system to reduce sound transmission of a double panel partition. In [9] adopted active control system to reduce the noise of duets. And a modified active or hybrid active system has been studied for various applications such as multi-storied building [7], a control performance comparison [10], experimental verification under seismic excitation [11], mixed control for output-feedback control [12]. When it comes to semi-active control systems it has gained quite a lot attention in terms of diverse applications and technological developments. Similar to active control system there are many available alternatives of semi-active control systems and they also been modified to have hybrid system. Among many the magnetorheological damper (MR) is gaining attention by the research community and their superior performances have been verified through experimental verification [13, 14, 15]. While the hybrid type semi-active control system's application can be found in [16].

This study investigates the possibility of a hybrid situation which is achieved by adopting both semi-active and a TMD type control system to achieve optimal performance and keeping the operational goal that can be attained via power supply and without power supply. The outcome shows such approach might be beneficial for control applications as well as for structural health monitoring.

2 CONTROL PROBLEM FORMULATION

In order to evaluate the control performances a 14 degree-of-freedom system has been combined with both tuned-mass damper (TMD) and a semi-active damper (SAD). For the investigations, the TMD is assumed to be placed on the top floor while the SAD is assumed to be placed in the top floor. This study has investigated the controlled and uncontrolled performances numerically by employing MATLAB and SIMULINK. To perform the numerical investigations, the problem has been formulated by adopting state-space formulation. And two different problems have been formulated namely; (i) uncontrolled structure, and (ii) controlled structure. In context of the uncontrolled structure the dynamical system in state-space form has been defined via equations 1 and 2 as presented below. The Equation 1 describes the system and the Equation 2 contains the measurement information.

$$X_{k+1} = Ax_k + Bu_k \tag{1}$$

where A and B are the system and input control matrices, respectively, x is the state of the system, u is the control input vector.

$$Y_k = Cx_k + Du_k \tag{2}$$

where C and D are the measurement and feed-through matrices, respectively.

Similarly, the controlled problem has been formulated where the applied control force is accommodated in the input vector u^c. The aforementioned uncontrolled state-space equations are rearranged as described in 3 and 4. It needs to be noted that superscript ^{c} has been used to separate the controlled quantities from uncontrolled information. Also it needs to be mentioned that all the matrices and vectors in the controlled problem needs to be adjusted. For instance, in the control problem the variable ζ that control the location of the TMD and SAD.

$$X^c_{k+1} = A^c x^c_k + \zeta B^c u^c_k \tag{3}$$

$$Y^c_k = C^c x^c_k + \zeta D^c u^c_k \tag{4}$$

The control vector has more than one input, in other words, it has both the input excitation $\ddot{x}_g$ and control force f^c as given by equation 5. While in case of uncontrolled problem, the input vector u does not have the control force component.

$$u^c = \begin{bmatrix} \ddot{x}_g \\ f^c \end{bmatrix}^T \tag{5}$$

Herein, the control force is provided by employing a combination of the TMD and SAD force. In short, the control force can be assumed by the given expression below:

$$f^c_k = \gamma[-K^{lqr} x^c_k] + \lambda[K^c_{tmd} x^{tmd}_k] \tag{6}$$

Where the first part of the equation 6 refers to the control force of SAD and the parameter γ indicates the location of the damper. And the second part of the above equation is the control force contributed via the adopted TMD and the variable λ controls the location of the TMD.

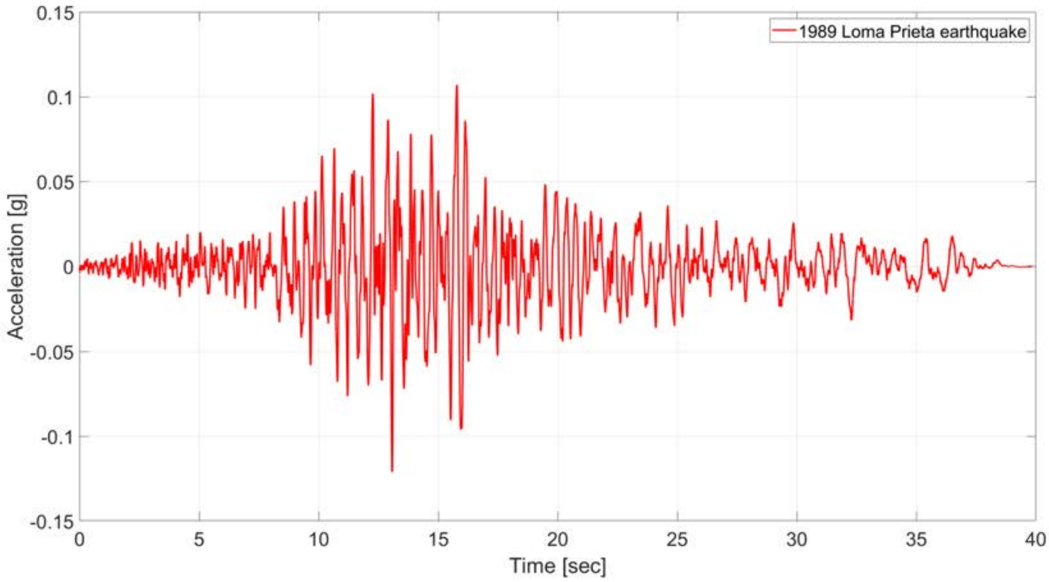

Figure 1: Input excitation

3 RESULTS AND DISCUSSION

The study has investigated the controlled and uncontrolled performances of a 14 degree-of-freedom system. Both controlled and uncontrolled structures have been excited by the 1989 Loma Prieta earthquake (see Figure 1). It can be seen from the prior mentioned figure that the excitation period between 10-20 sec have dominating excitation frequencies. And this is the reason of employing such devastating input excitation to get a wide-rage of frequencies those may help to excite most of the resonant frequencies (both lower and higher) of the structure. The structural model is assumed to be lumped-mass model that is having a floor mass of 50000 Kg and floor stiffness component is about 70000000 N/m. The damping coefficient of the structure has been estimated based on the first two resonant frequencies of the structure.

In this context, initially, the uncontrolled responses of the dynamical system has been evaluated. The displacements, velocities, and acceleration responses are depicted in Figures 2, 3, and 4, accordingly. Note that due to the similarity of the outcome all of the degree of freedoms responses are not provided here. Hence, the responses of the 1st, 5th, 10th, and 14th degree of freedoms output are shown in those figures.

Later, the controlled responses are estimated and compared with the uncontrolled output. In order to compare the performance, the states (displacements and velocities) are compared. The comparison of the displacements are presented inn Figures 5. While the velocities of the dynamical system has been shown in Figure 6. In both the aforementioned figures the 1st, 5th, 10th, and 14th DOFs responses are compared. And for both of the figures, the blue line indicates the uncontrolled time-history while the green line represents the controlled signals. In a nutshell, it can be summarized from those figures that the applied control strategy worked

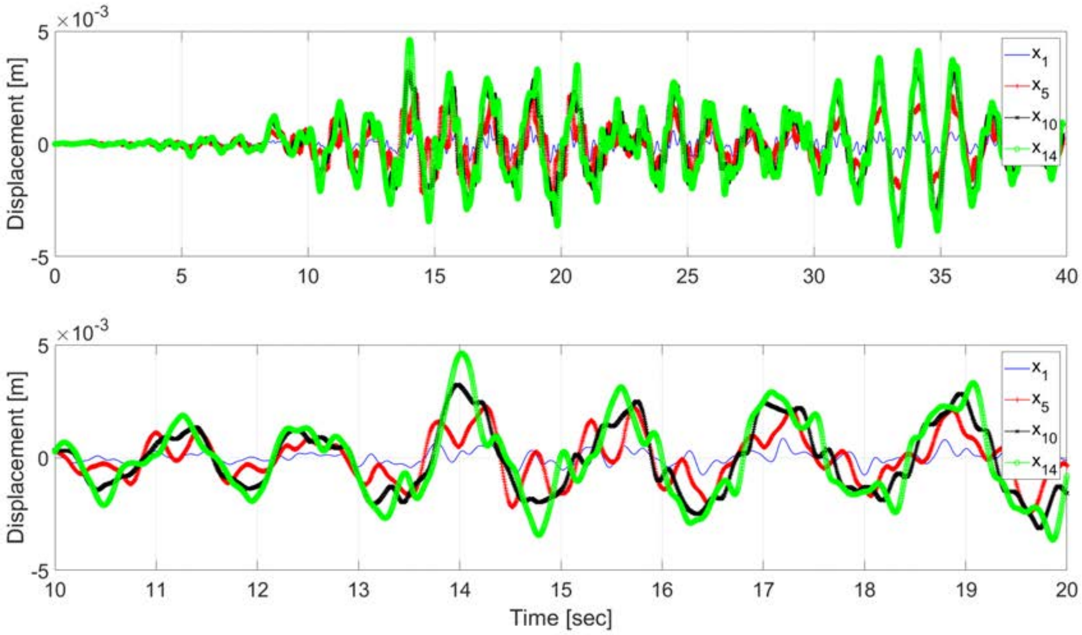

Figure 2: Displacements of the uncontrolled structure

quite efficiently.

In addition to those figures, a summary of the peak values of the controlled and uncontrolled signals have give in Table 1. The percentage of the reduction of displacements and velocities are estimated and provided in the table for better understanding. Last but not least, as the states (displacement and velocity) are known hence the acceleration can be easily estimated, if needed.

Table 1: Summary of the peak displacements and velocities for uncontrolled and controlled cases

DOFs	Uncont. Peak Disp.	Cont. Peak Disp.	Uncont. Peak Velo.	Cont. Peak Velo.
01	0.0010	0.0002 (76.94%)	0.0138	0.0019 (86.30%)
05	0.0043	0.0002 (94.84%)	0.0289	0.0114 (60.52%)
10	0.0065	0.0002 (96.57%)	0.0336	0.0114 (66.07%)
14	0.0068	0.0023 (66.38%)	0.0437	0.0211 (51.72%)

4 CONCLUSIONS

The reduction of vibration has been achieved by adopting so-called hybrid system as passive and semi-active systems have been adopted to achieve goals. In a nutshell, it has been observed like other studies that semi-active control technology is very efficient tool to reduce unwanted vibration. To achieve a hybrid system herein in addition semi-active a TMD is also considered

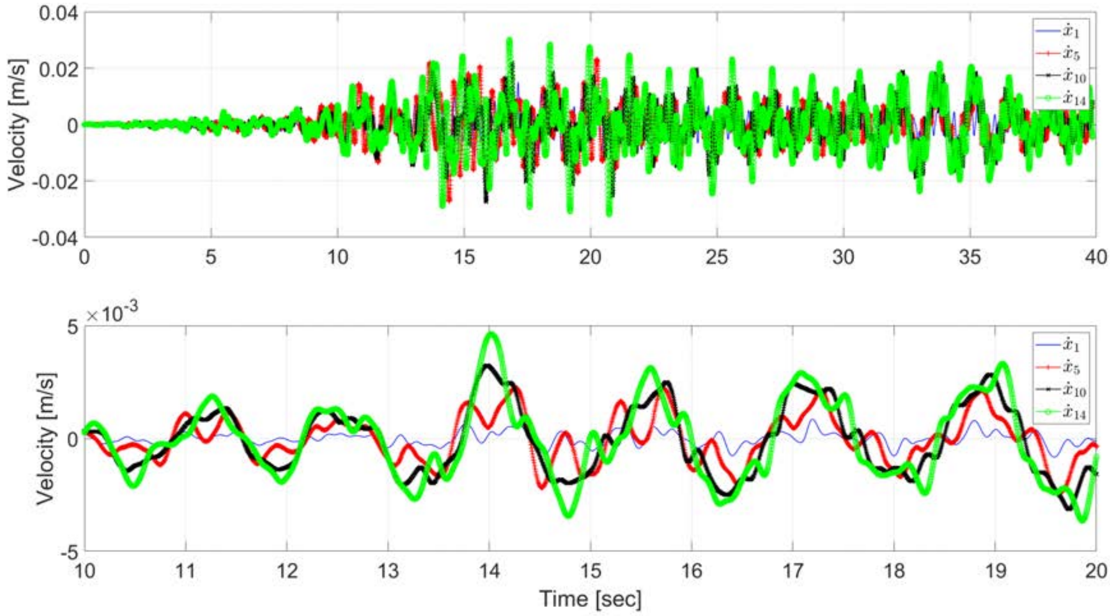

Figure 3: Velocities of the uncontrolled structure

at the top floor of the investigated structure. The results evident that besides the vibration reduction the system such concept can be used during an extreme incident such as earthquake even when there will be no power supply at all. Though semi-active system can be operated via the used of the battery power but still having a TMD with it would add more advantages for controlling dynamical responses. Further study is planned to verify the performance of the studied control approach by changing the location of the dampers.

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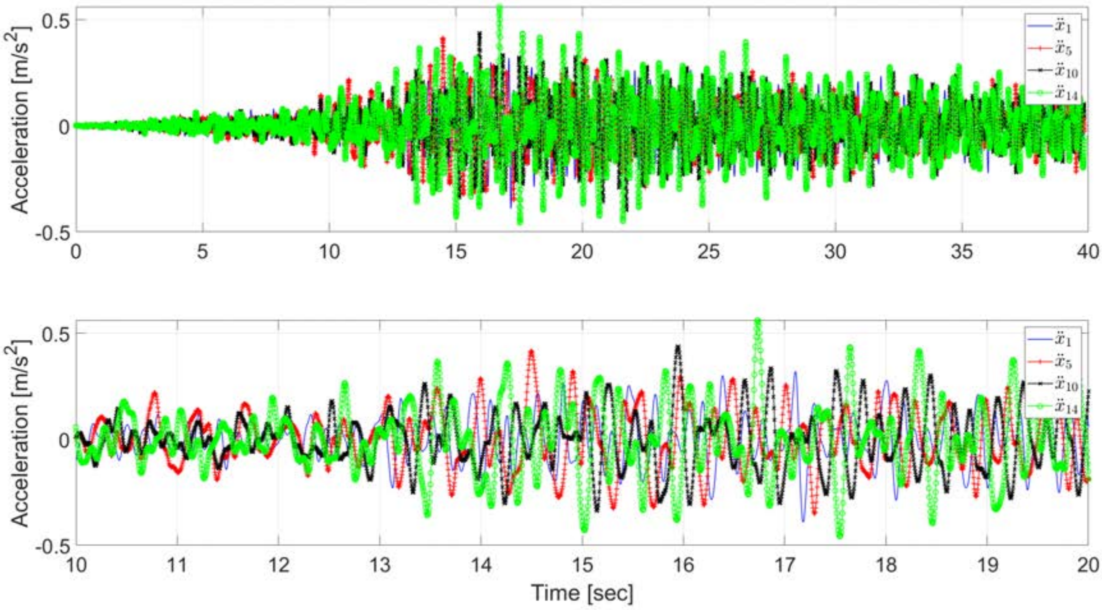

Figure 4: Accelerations of the uncontrolled structure

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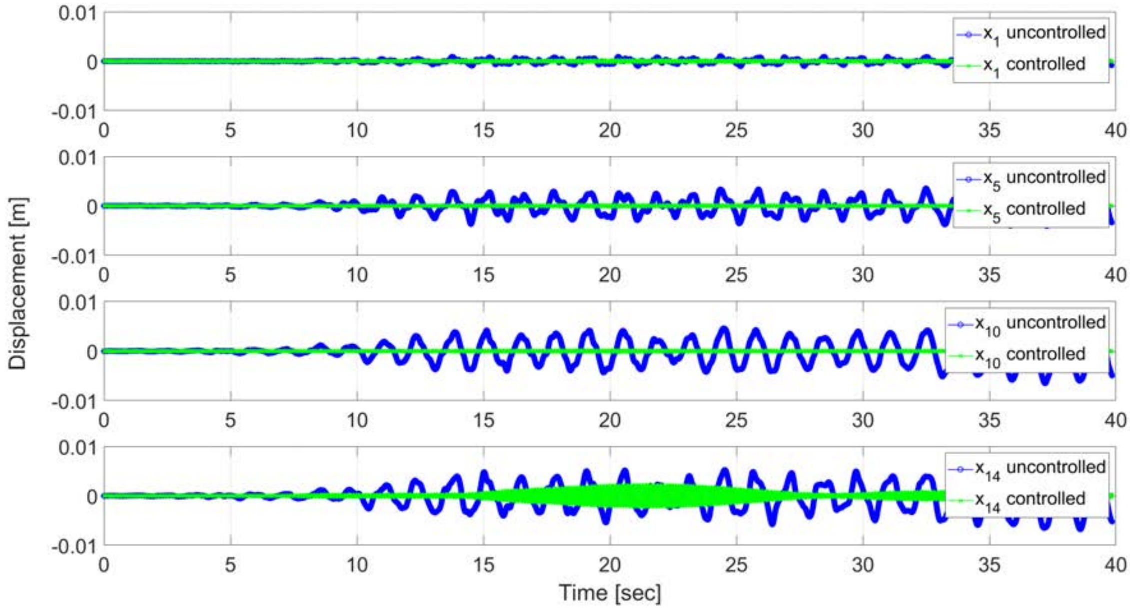

Figure 5: Comparison of uncontrolled and controlled displacements

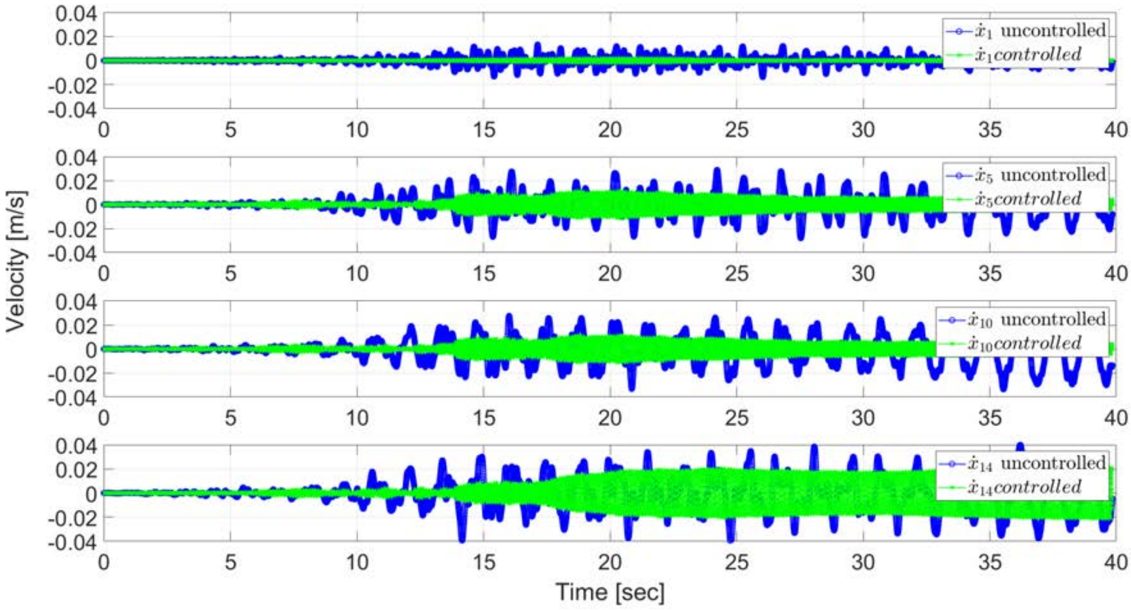

Figure 6: Comparison of uncontrolled and controlled velocities

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