Seismic Active Control by a Heuristic-Based Algorithm

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Abstract

A heuristic-based algorithm for seismic active control is generalized to permit consideration of the effects of control-structure interaction (CSI) and actuator dynamics. The control force is computed at one time step ahead before being applied to the structure. Therefore, the proposed control algorithm is free from the problem of time delay. A numerical example is presented to show the effectiveness of the proposed control algorithm. Also, two indices are introduced in the paper to assess the effectiveness and efficiency of control laws.

Introduction

This work is a sequel to Tang (1995) in which a heuristic-based control law was proposed, and the results presented showed that the proposed control law can reduce the structural response by one order of magnitude and has the ability to reduce the peak that occurs during the first few cycles of the response time history. However, in Tang (1995), the effects of control-structure interaction (CSI) and actuator dynamics were not considered. The importance of accounting for the effects of CSI and actuator dynamics in seismic active control has been demonstrated in Dyke et al. (1995a). Also, a recent paper by Dyke et al. (1995b) has indicated that these effects do not result in a pure delay in the system and cannot be accounted for by the time-delay compensation.

Structural System Considered

The structural system considered in this paper is

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basically the same single-degree-of-freedom (SDOF) system presented in Fig. 10 in Dyke et al. (1995a) except that different values of mass and damping coefficient of the structure are used. The structural properties of the SDOF system are: Mass, m: 67.33 N-sec^2/cm; Stiffness, k: 14.06 kN/cm; Damping Coefficient, c: 38.09 N-sec/cm; Mass of the stiff frame and the actuator, m_0: 0.073 N-sec^2/cm; and Stiffness of the four tendons, k_0: 14,879 N/cm.

Equations of Motion

The equations of motion solved in this paper that govern the response of the system are given by

$$m\ddot{x} + c\dot{x} + \left(k + k_0\cos^2\theta\right)x + k_0\cos\theta\, y = -m\ddot{x}_g \tag{1}$$

for the SDOF structure, and

$$m_0\ddot{y} + k_0 y + k_0\cos\theta\, x = -m_0\ddot{x}_g + F \tag{2}$$

for the stiff frame that is used to connect the actuator to the four pretensioned tendons. The notations used in Eqs. (1) and (2) are x = displacement of the building relative to the ground, y = displacement of the actuator, θ = tendon inclination angle relative to base (θ = 36° in this study), and F = force applied by the hydraulic actuator to the rigid frame. F is related to y by the actuator dynamics given by (Dyke et al. 1995a)

$$\dot{F} = \alpha_1(u - y) - \alpha_2 F - \alpha_3\dot{y} \tag{3}$$

in which u = control command, and α_1, α_2, and α_3 = the actuator dependent coefficients. In this study the values of α_i, i=1,2,3 used are those corresponding to a real actuator used in Dyke et al. (1995a) that were determined experimentally. The force developed in the tendons during vibration consists of two parts: $k_0\cos\theta x$ and k_0y. $k_0\cos\theta x$ is a passive force, whereas k_0y is an active force. The horizontal component of k_0y, $k_0y\cos\theta$, is the effective control force acting on the structure. Notation F_a is introduced to denote this effective control force, i.e., $F_a = k_0y\cos\theta$. In Tang (1995), F_a was regarded as an individual control force acting on the structure, and only Eq. (1) was considered in the analysis.

The control algorithm implemented in this paper is an extension of that presented in Tang (1995). Due to space limitations, only the concept is presented in this paper. The control command, u, needed for $t=t_i+ t$ is computed at $t=t_i$, and it is determined such that the structural velocity at $t=t_i+ t$ is zero assuming that $\ddot{x}_g(t_i+ t)=0$.

In this study a control performance index (CPI) is introduced to assess the control performance. CPI is defined by the equation

$$CPI = \frac{p_0 - p_c}{p_0} \tag{4}$$

where p_0 = absolute value of maximum peak of interested response quantity under the condition of zeroed control, and p_c = absolute value of maximum peak of interested response quantity with control. Also, an energy efficiency index (EEI) is introduced to assess the efficiency of the energy consumption of control. EEI is defined by the equation

$$EEI = \text{maximum value of } F_a \text{ / maximum value of } F \tag{5}$$

Numerical Results

The base excitation considered is the first 6.29 sec of the El Centro 1940 N-S accelerogram (scaled to 25% of its magnitude). In the analysis an additional 3-second free vibration response is also computed. The sampling rate is assumed to be 100 Hz. The following strategies are considered in the numerical example. "Zeroed Control" represents the case in which the active bracing is attached, but the control command, u(t), is set equal to zero; "Ideal Control" corresponds to the case in which there are no limitations on the control; and "Limited Control" is the case in which the control is constrained by the cylinder velocity of 63.5 cm/sec, and the maximum value of u(t), u_{max}, is set equal to 0.635 cm. For comparison purposes, the time history of the relative displacement of the SDOF system for the three cases considered are shown in Fig. 1. It can be seen from this figure that with the proposed control law, not only is the system response remarkably reduced, but the first few peaks of time history for the zeroed control condition are also significantly reduced. The value of CPI for x(t) for the case of ideal control is 0.9; however, the value of EEI is about zero due to the excessively large actuator force needed. Therefore, the "ideal control" is not feasible for actual implementation. This unrealistic control, however, would not have been found if the effects of CSI and actuator dynamics were not included in this study. For the case of limited control, the values of CPI for x(t) and EEI are 0.68 and 0.15, respectively, and the corresponding values for the zeroed control case are 0 and 0.19, respectively.

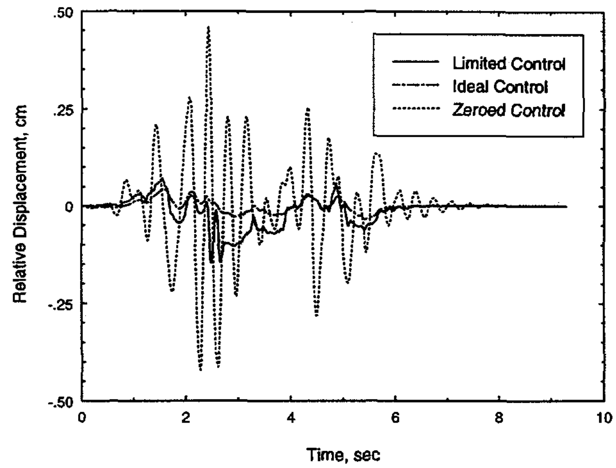

Figure 1. Comparison of Time Histories of Relative Displacement

Concluding Remarks

A preliminary study of seismic active control considering the effects of control-structure interaction and actuator's dynamics is presented. The control law implemented is a heuristic-based control algorithm. The response of a SDOF system is studied. The results obtained indicate that the effectiveness of the proposed control law depends on the capacity of the actuator; also, without considering the capacity limitation of the actuator used, the control results may not be realistic.

Acknowledgments

The author wishes to thank Dr. B. F. Spencer, Jr. and Ms. S. J. Dyrk of the University of Notre Dame for providing the numerical data of the parameters in the equation of the actuator dynamics. This work was performed under the auspices of the U.S. Department of Energy, Contract No. W-31-109-Eng-38.

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