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EXPERIMENTAL STUDY ON APPLICATION OF LINEAR-SATURATION CONTROL TO ACTIVE MASS DAMPER WITH ADDED MASS STROKE REDUCTION

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1. INTRODUCTION

Active mass damper(AMD) is widely used as an active control system to suppress vibrations in civil engineering structures. Since the mass of the structure is much larger than the auxiliary mass, the limitations of AMD both in control force capacity and auxiliary mass stroke length must be take into account in the design of controller.

In this paper, we proposed the linear-saturation control method[1] which deals with the control force limitation explicitly and uses the full capacity of the actuator for effectiveness in suppressing the vibration of structures. Furthermore, the constraint on stroke of AMD is also included as the self-protection of AMD in order to increase the applicability of the control system for strong earthquake excitation. Finally, the experimental study is conducted to verify the proposed control algorithm.

2. CONTROL ALGORITHM

Linear-saturation (LS) control is the combination of the linear and saturation control. The saturation control is used to achieve the best performance as the control force capacity is limited. The control switch to linear control when the response is small to save the control energy and shutdown the control system smoothly later after excitation. To implement saturation control for the multi-degree-of-freedom (MDOF) structure, the concept of modal control is introduced. First, the state equations are decomposed into the modal state equations:

$$\dot{\mathbf{w}}_j(t) = \mathbf{\Lambda}_j \mathbf{w}_j(t) + \mathbf{Z}_j(t) \qquad (1)$$

where the subscript j stands for mode number, $\mathbf{w}_j(t)$ is the modal state vector, and $\mathbf{Z}_j(t) = \mathbf{W}_j u_j(t)$ is the modal control vector. The control force for each mode can be obtained independently from:

$$u_j(t) = -u_{cj}\, swsrf(\mathbf{w}_j(t)) \qquad (2)$$

where u_{cj} is the modal control capacity and $swsrf$ is the switching function which indicates the control sign. Then the control in the physical coordinate is synthesized from the modal control force. To keep the control capacity within the limit, the modal control capacities are specified according to the modal energy as

$$u_{cj} = u_c E_j \Big/ \sum_{i=1}^{n} c_i E_i \qquad (3)$$

where E_j is the modal energy and c_i is modal control influence coefficient. The modal saturation control scheme is shown in Fig. 1.

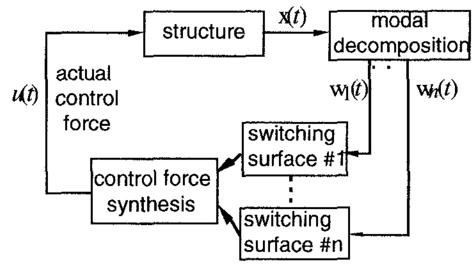

Fig. 1 Modal Saturation Control Scheme

To switch between saturation control and LQ control, the vibration energy of the system is monitored on-line. When the energy is lower than the specified level, the control will switch to LQ control. It is noted that the gain of LQ control must be choosed carefully according to the switching energy level such that the maximum control force will never exceed the limit.

Since the concept of AMD is to extract the vibration energy from the structure to the added mass , it is unavoidable for added mass which have a size only 1-5% of the first modal mass of the structure to have a large stroke. The AMD control system have to be turned off during the strong earthquake when the AMD stroke length exceed the limit. This situation is more severe when LS control algorithm is applied to AMD system. To extend the LS control applicability for strong earthquake, the additional AMD stroke length algorithm is constructed. The idea is to create a self-protection system for the AMD by seperating the total control force capacity(u_c) into control capacity for structure(u_{cs}) and AMD(u_{ca}). The choice of proportion of capacity can be decided by using a simple fuzzy logic as,

$$\alpha_{uca} = \alpha_{Ea}^n \Big/ \left(\alpha_{Ea}^n + (1-\alpha_{Ea})^n\right) \qquad (4)$$

where $\alpha_{uca} = u_{ca}/u_c$ is the control capacity coefficient, $\alpha_{Ea} = E_a/E_{total}$ is the energy coefficient between the added mass energy(E_a) and the total energy(E_{total}), and n is the flexibility index (n=2 in this study).

3. EXPERIMENT

A 2-story building model with fundamental frequencies 4.3360Hz. and 11.9838Hz. is used as the controlled structure. The AMD control system which is composed of the linear motor actuator, the mass with linear ball slider, and the spring is installed on the top of the model. The laser displacement sensors are placed on the fixed observation truss and on the top of the model in order to measure the displacement of each floor and the added mass. On-line control is implemented using the digital signal processor (DSP) to compute the control signal from the measured displacements. Both model and observation truss are erected on the shaking table which generates the earthquake ground excitation.

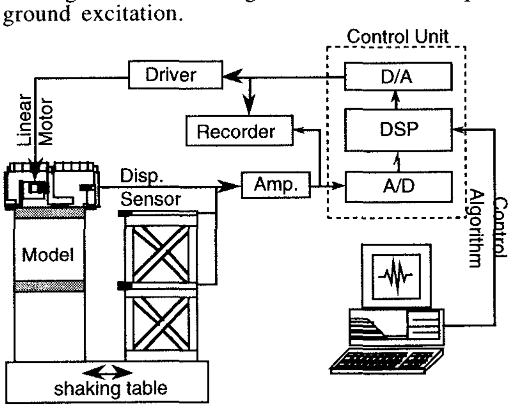

Fig. 2 Experimental setup

The Hyogo-Ken Nanbu earthquake record with scaled intensities is used as the excitation. Three control method are employed: Linear Quadratic (LQ) control, Linear-Saturation(LS) control, and LS control with stroke reduction (LS+STRK). The results are shown in Fig. 3 to 6. In Fig. 3, which shows the maximum AMD stroke length, LS+STRK can greatly reduces the stroke compared with LQ and LS control where the AMD stroke already exceed the limit of 14 mm and have to be shutdown at 27 gal. With stroke reduction, performance is also improved as shown in Fig. 4: reduction in RMS displacement of the top floor as well as in reduction in the first (Fig. 5) and second (Fig. 6) modal energy of the building model. Since AMD stroke is well controlled, AMD can have more capability to suppress response of the structure.

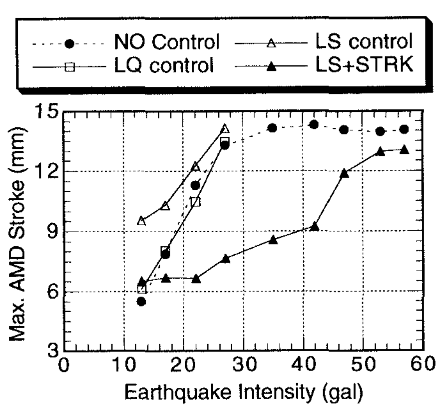

Fig. 3 Maximum AMD Stroke

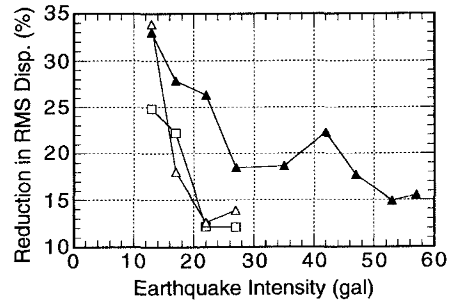

Fig. 4 RMS Disp. of the Top Floor

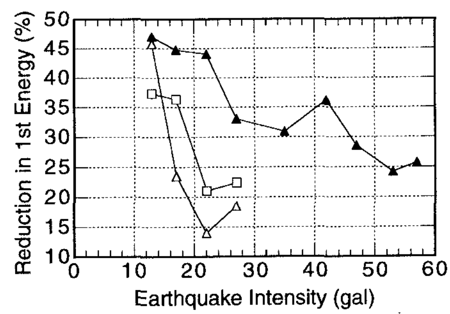

Fig. 5 Reduction in 1st Mode Energy

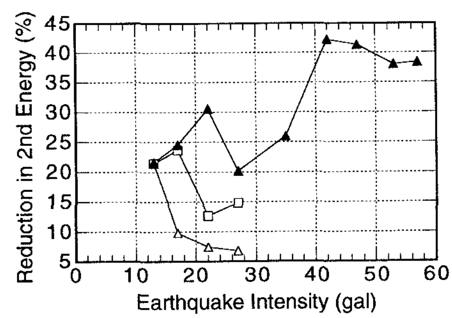

Fig. 6 Reduction in 2nd Mode Energy

4. CONCLUSIONS

A new control method is proposed, in which the limitations of AMD control system are considered both in control capacity and stroke length in order to obtain a suitable control methodology for civil engineering structure. From experiment, the combination of linear and saturation control enables the control to work smoothly under small disturbance and effectively under strong excitation. The additional stroke reduction algorithm even increases the applicability of control (almost two times from the experiment) to strong ground motion.

REFERENCES

1) J. Mongkol, B. Bhartia, and Y. Fujino, Optimal Linear-Saturation Control of Structure, *Proceeding of the Fifth East Asia-Pacific Conference of Structural Engineering and Construction*, Gold Coast, Australia, July 1995.