SECTION 8

COMPARISON OF PERFORMANCES OF ABS AND AMD

As a active control devise, an Active Mass Damper system (AMD) has been installed on the top floor of the same test building with ABS (Fig. 2.1) to compare their performances. The top view of the AMD system is shown in Fig. 8.1. A complete description of the AMD system and some observed results are given by Aizawa, S., et al. (1990). In the AMD system, a six-ton moving mass is suspended (T=3.1secs) so that it can respond instantaneously. The structural response can be controlled in two directions by the two electrohydraulic servo actuators, which are installed along orthogonal directions.

While both systems were installed in the same building, the structural control is performed by only one at a time. The control effect of the AMD system was examined during the Izu-Oshima earthquake on October 14, 1989 and on February 20, 1990. The observation results are shown in Fig. 8.2. The structural response in the frequency domain is shown in Fig. 8.3.

Summarizing the observation results for both control systems, a rough performance comparison of AMD and ABS is shown in Table 8.1.

Table 8.1 - Comparison of AMD and ABS

		AMD	ABS
Average Reduction of Peak	Displacement	56%	29%
Structural Response	Acceleration	22%	26%
Maximum Actuator Movement (cm)		10.51	0.194

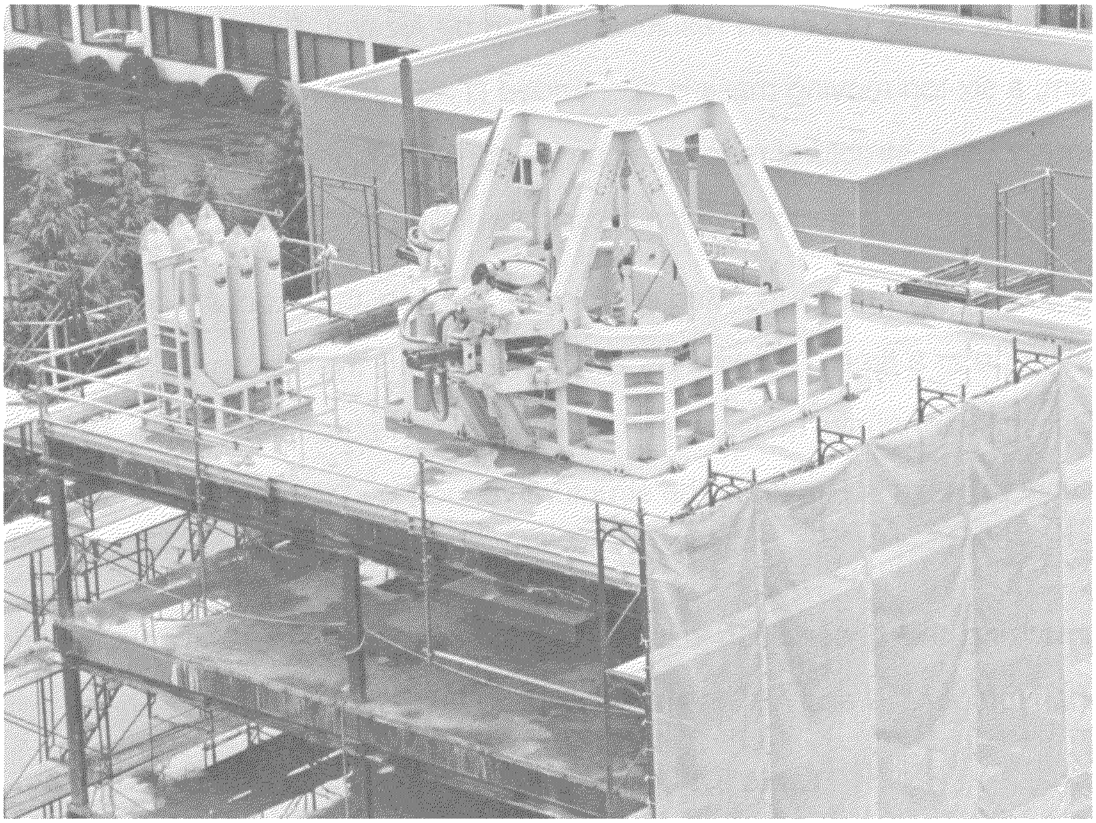

Fig. 8.1 Full-Scale AMD

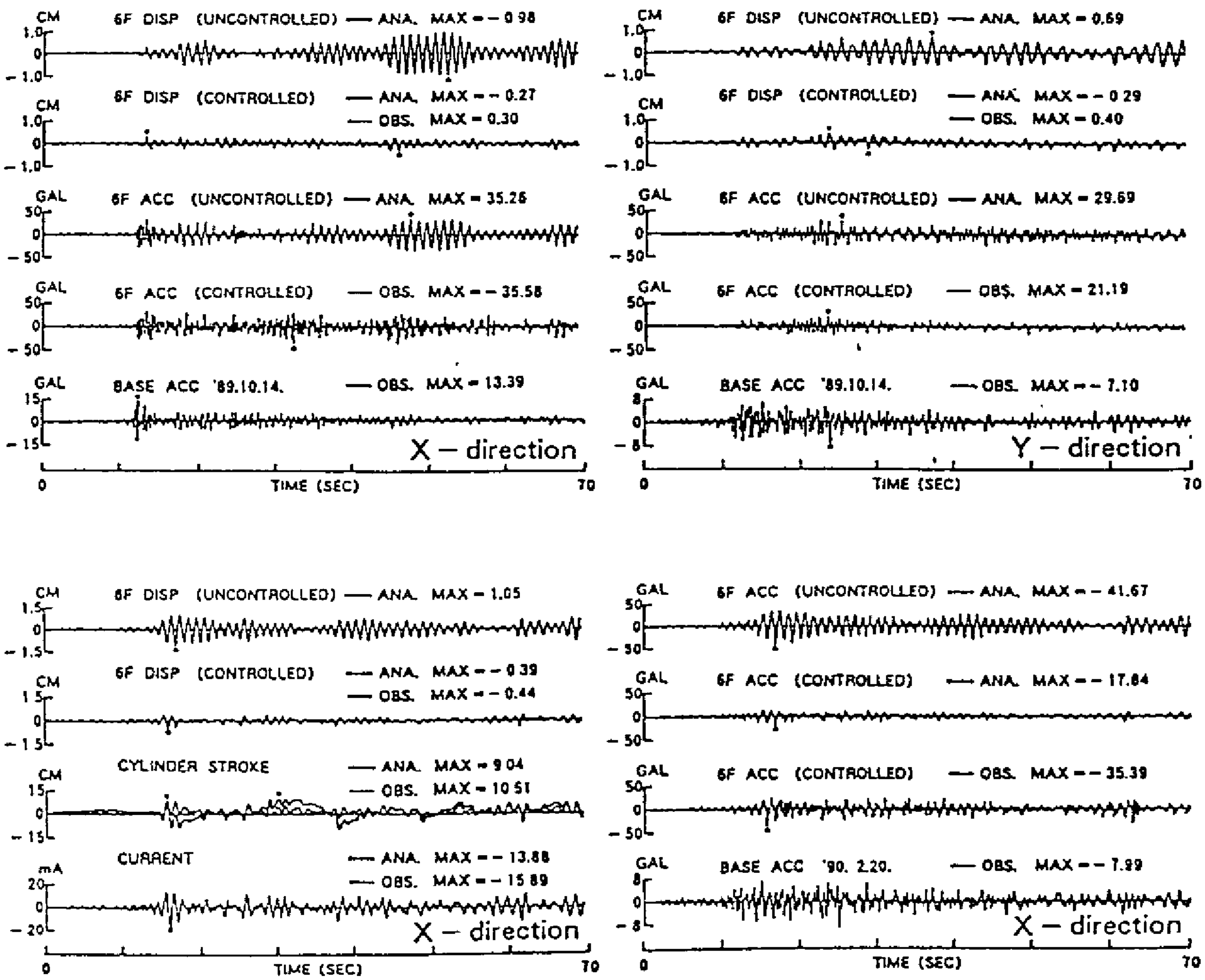

Fig. 8.2 Observation Results of AMD

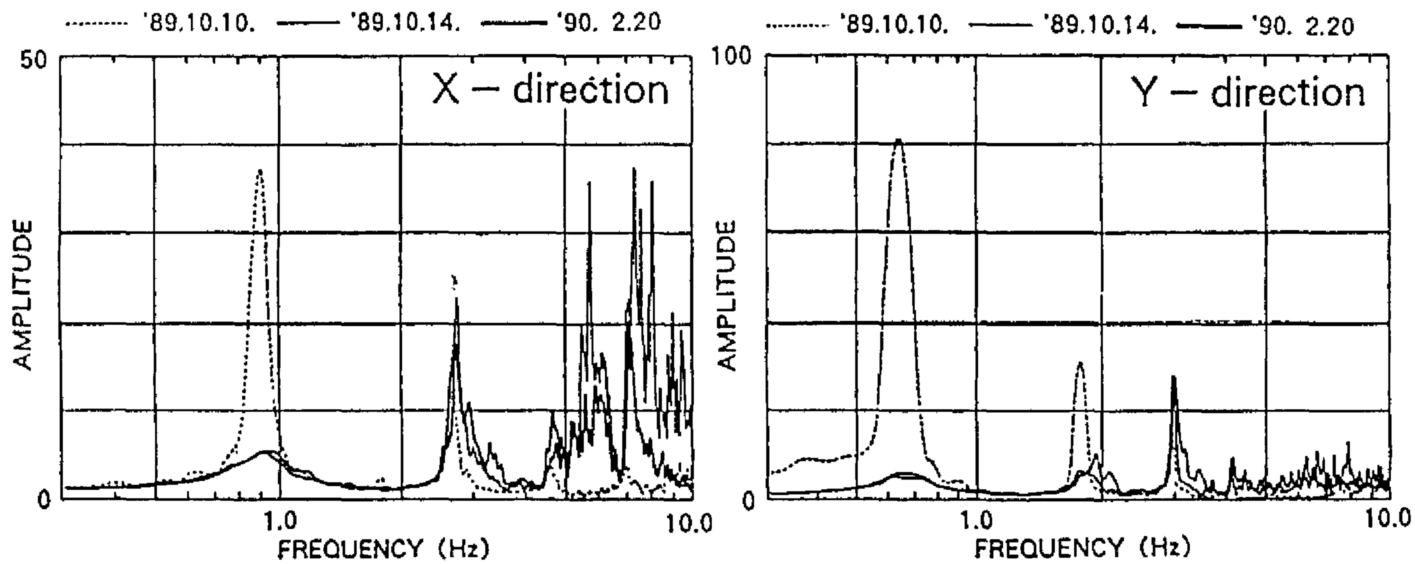

Fig. 8.3 Acceleration Transfer Functions With and Without Active Mass Damper (From Aizawa et al, 1990)

Note that the AMD system has a better reduction of displacement response and a lesser reduction of accelerations. This implies a more comfortable response using the ABS and lesser base shear

using the AMD. The maximum actuator movement is an indicator of the required input energy. It is very large for the AMD system and is quite small for the ABS indicating substantially less energy needed by the ABS. Comparing the response transfer functions shown in Fig. 6.5 and Fig. 8.3, it is noted that the AMD reduces the structural response substantially in the first and second modes in the y-direction and only in the first mode in the x-direction (Fig. 8.3). The ABS system reduces the structural response in all modes, as can be observed in Fig. 6.5. The main reasons of this behavior are (i) the ABS has better ability to redistribute earthquake energy in higher modes and suppress their influence, as noted also by Yang (1982) and (ii) the AMD constructed in this building was designed to suppress only the lower modes. A change in the control algorithm can produce even better performance in the higher modes for the ABS.

SECTION 9

CONCLUDING REMARKS

The design, installation, and operational characteristics of a full-scale ABS for earthquake resistance of a building have been presented in this report. The control algorithms were developed based on the classic optimal closed-loop control theory. As required by sensor limitations, two modified control algorithms were used. They are (1) velocity feedback with observer, and (2) three-velocity feedback. Both alternatives have been proven to be effective through numerical verification.

Based on the recognition that it is more efficient to control a structure by applying a force rather than a moment, (Yang et al. 1978, Reinhorn et al. 1989), horizontal control forces were applied to the first floor through the action of diagonal active braces. While it is conceivable that extra column axial forces are introduced by the vertical component of the bracing forces when the control system is activated, the $P - \Delta$ effect, which is a problem in structures with large deformations, be less pronounced since the braces are connected to the first floor where the displacement is relatively small.

While several active mass dampers have been implemented in full-scale structures over the last few years, the active bracing system reported here represents the *first* full-scale active system of this type developed and tested under actual ground motions. The results presented in this report demonstrate that:

(a) The concept of an active tendon or bracing system, originated almost 20 years ago, has led to the successful development of the device for civil engineering structural control.

(b) The success of the full-scale ABS performance is the culmination of numerous analytical studies and carefully planned laboratory experiments involving model structures.

(c) The ABS can be implemented with existing technology under practical constraints such as power requirements and under stringent demand of reliability.

(d) The use of ABS in existing structures can be a practical solution for retrofit as demonstrated by this full-scale experiment. Note that the active braces were added only after the structure was completed.

(e) The full-scale ABS performs, by and large, as expected, and its performance can be adequately predicted through simplified analytical and simulation procedures.

(f) The experience gained through the development of this system can serve as an invaluable resource for the development of active structural control systems in the future.

SECTION 10

REFERENCES

Aizawa, S., Hayamizu, Y., Higashino, M., Soga, Y., Yamamoto, M., and Haniuda, N. (1990). "Experimental Study of Dual Axis Active Mass Damper." Proceedings of the U.S. National Workshop on Structural Control Research, (Housner, G.W. and Masri, S.F., eds), University of Southern California, Los Angeles, 68-72.

Chen, C.T. (1984) *Linear System Theory and Design*, Holt, Rinehart and Winston, NY.

Chung, L.L., Lin, R.C., Soong, T.T. and Reinhorn, A.M. (1988), "Experimental Study of Active Control of MDOF Structures Under Seismic Excitations," Report NCEER-88-0025, National Center for Earthquake Engineering Research, Buffalo, NY.

Chung, L.L., Lin, R.C., Soong, T.T. and Reinhorn, A.M. (1989), "Experimental Study of Active Control for MDOF Seismic Structures," ASCE J. Engr. Mech. Div., Vol. 115, No. 8, pp. 1609-1627.

Chung, L.L., Reinhorn, A.M. and Soong, T.T.(1988), "Experiments on Active Control of Seismic Structures," ASCE J. Engr. Mech. Div., Vol. 114, No. 2, pp. 241-256.

Clough, R.W. and Penzien, J. (1975), Dynamics of Structures, McGraw-Hill, NY.

McGreevy, S., Soong, T.T. and Reinhorn, A.M. (1988), "An Experimental Study of Time Delay Compensation in Active Structural Control," Proceedings of 6th International Modal Analysis Conference and Exhibits, Vol. I, pp. 733-739, Orlando, FL.

Reinhorn, A.M. and Soong T.T., et al. (1989), "1:4 Scale Model Studies of Active Tendon Systems and Active Mass Dampers for Aseismic Protection," Report NCEER-89-0026, National Center for Earthquake Engineering Research, Buffalo, NY.

Reinhorn, A.M., Soong, T.T., Riley, M.A., Lin, R.C., Aizawa, S., and Higashino, M., (1992). "Full Scale Implementation of Active Control - Part II: Installation and Performance," ASCE/J. of Structural Engineering, (in print).

Roorda, J. (1980), "Experiments in Feedback Control of Structures, in *Structural Control*, H.H.E. Leipholz (ed.), North Holland, Amsterdam, pp. 629-661.

Soong, T.T. (1990), *Active Structural Control: Theory and Practice*, Longman, London and Wiley, NY.

Soong, T.T., Reinhorn, A.M., Wang, Y.P. and Lin, R.C. (1991). "Full Scale Implementation of Active Control - Part I: Design and Simulation," ASCE/Journal of Structural Engineering, ASCE, Vol. 117, No.11, 3516-3536.

Wang, Y.P., Reinhorn, A.M. and Soong, T.T. (1992). "Development of Design Spectra for Actively Controlled Wall Frame Buildings," ASCE/Journal of Engineering Mechanics, ASCE, Vol. 118 No. 6, 1201-1220.

Yang, J.N. (1982). "Control of Tall Buildings Under Earthquake Excitations," ASCE/Journal of Engineering Mechanics Division, 18 No.1, 50-68.

Yang, J.N. and Giannopoulos, F (1978), "Active Tendon Control of Structures," ASCE/Journal of Engineering Mechanics Division., Vol. 104, No. EM3, pp. 551-568.