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SURVEY OF ACTUAL EFFECTIVENESS OF MASS DAMPER SYSTEMS INSTALLED IN BUILDINGS

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ABSTRACT

Through surveying the real state of the implementation of mass damper systems in building, the effects of these systems were clarified based on various recorded values in actual buildings against both winds and earthquakes. The effects are discussed in relations with the natural periods of buildings equipped with mass damper systems, the mass weight ratios to building weight, wind force levels and earthquake ground motions levels.

KEYWORDS

TMD systems, AMD systems, wind force, earthquake ground motion, damping ratios, vibration control, natural periods of buildings, weight ratios, effectiveness ratios, measured data.

INTRODUCTION

In Japan a number of buildings equipped with mass damper system has been constructed in last decade. The objective of this paper is to survey the real state of the use of mass damper system such as TMD (Tuned Mass Damper), TLD (Tuned Liquid Damper), AMD (Active Mass Damper) and HMD (Hybrid Mass Damper) installed in buildings and to investigate the effects of the mass damper systems based on various recorded values in actual buildings.

In the following, the trends of the use of mass damper systems installed in buildings, several examples of the actual effectiveness of these systems as well as overall examinations of the actual effectiveness of these systems are presented.

TRENDS OF UTILIZING THE MASS DAMPER SYSTEMS IN HIGH-RISE BUILDINGS

In 1968, a 36-story Kasumi-gaseki building was constructed as the first high-rise building in Japan. Since then it took a quarter of century for high-rise buildings to be twice taller as shown in Fig. 1 (Yamazaki, S., May 1995).

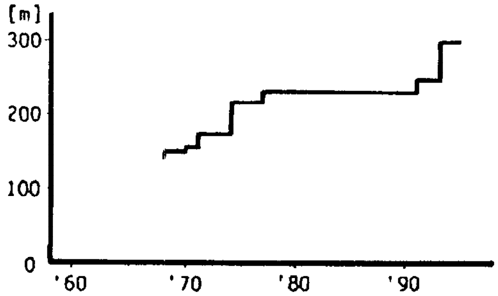

Fig.1 The Height of the High Building

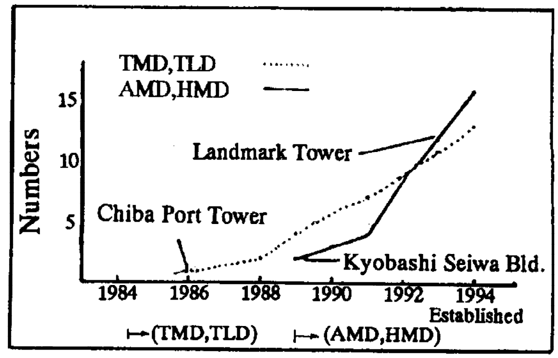

Fig.2 History of Vibration Control Occupation

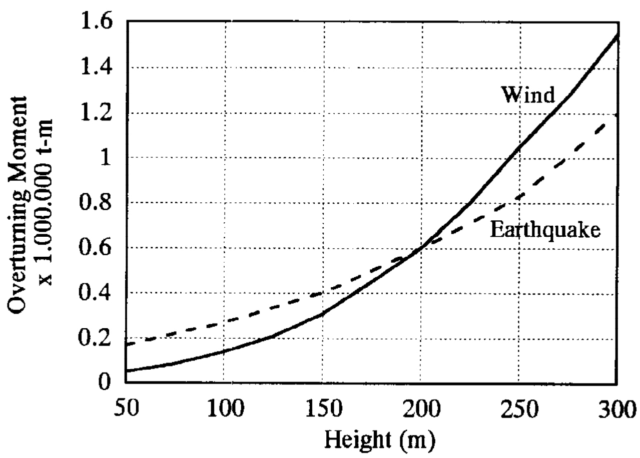

Fig. 3 Comparison of Wind and Earthquake Forces vs Building Height

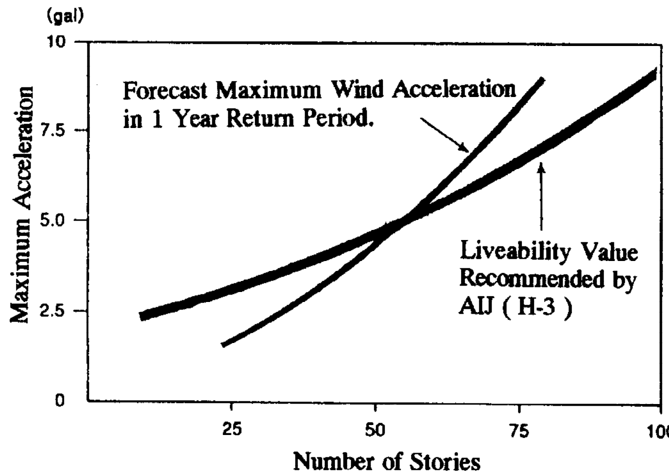

Fig.4 Wind Vibration of Super High Rise Building vs Liveability

Fig. 2 (Wakabayashi, T., *et al.*, Aug. 1995) shows accumulated number of vibration-control-installed buildings in the last decade where TMD or TLD began to be used in Japan. The total number of the use gradually increases up to about fifteen now, while AMD or HMD began to be used only five years ago, but the total number of the use is remarkably increasing up to about twenty now.

Wind design load becomes higher than seismic load for more than 200 m high buildings as shown in Fig. 3 (Nikken Sekkei). TMD systems were developed to install in high-rise buildings in order to give more comfortability to the occupants of buildings against strong winds, while AMDs were developed to control the vibration not only against strong winds but also against moderate earthquakes.

The taller the building, the higher the wind speed acting on its walls, consequently, for high-rise buildings, it is necessary to take measures against the effects of the wind. As shown in Fig. 4 (Maeda Construction Co. Ltd.), during exceptionally strong wind conditions which occur about once a year, the occupants of buildings that are taller than 50 stories (approximately 200 m) tend to feel uncomfortable. Since swaying caused by such strong winds often continues over a long period, the occupants may experience symptoms similar to those of seasickness, even if the magnitude of sway is relatively small.

It should be added that the cost of mass damper systems is usually 1% and 2% up of the total construction cost of the buildings for TMD and AMD respectively.

Photo 1. Gold tower

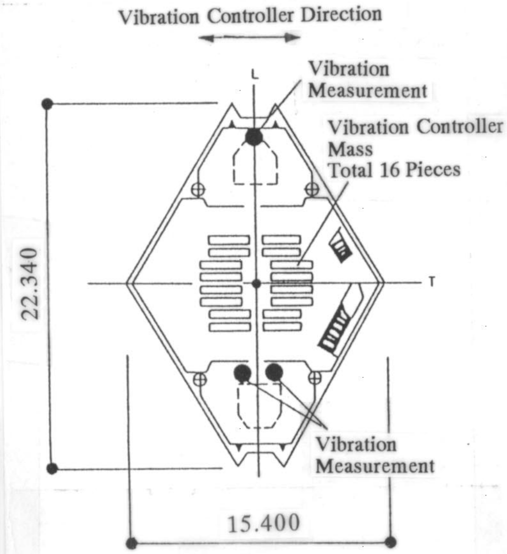

Fig.5 Sixth Floor Plan of the Top Observatory

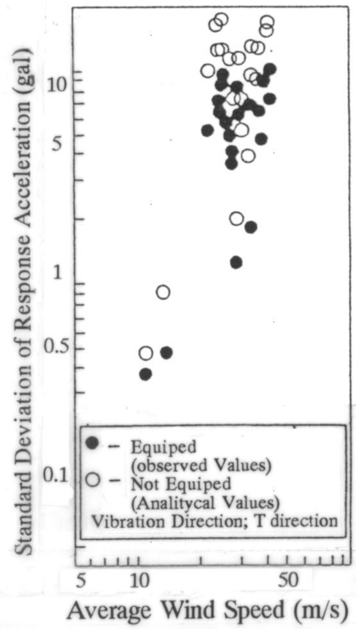

Fig.6 Wind Speed vs Response Acceleration Relationship (During Typhoon No.9119)

ACTUAL EXAMPLES OF THE MOBILIZED BUILDINGS TO MASS DAMPER SYSTEMS

The first case (Toji, T., *et al.*, 1991) is the high observatory tower (Gold Tower), of 150 m height, located in Shikoku island facing the Inland sea, southern Japan (Photo 1, Fig. 5). This tower was constructed in 1988 equipped with sloshing dampers at the top. The measured data on vibration were obtained during the passage of typhoon 9119 in September 1991, which caused the strongest winds of 50 meter per second. It is found as shown in Fig. 6 that the dampers reduced the amplitude of vibration to around a half of what it would have been without the dampers, that is calculated values. It is also seen that maximum acceleration response reaches to 10 gal even with dampers, which is more than the tolerance level given by Fig. 4.

The second case is the Chiba Port Tower, a steel structure of 125 m in height. This building is the first tower equipped with a tuned mass damper in Japan. The details on this tower and the effectiveness of mass damper were reported in proceeding of 9th WCEE (Kitamura, H. *et al.*, Aug. 1988). One of the previous results obtained by measurements during major earthquake is again shown here (Figs. 7 and 8).

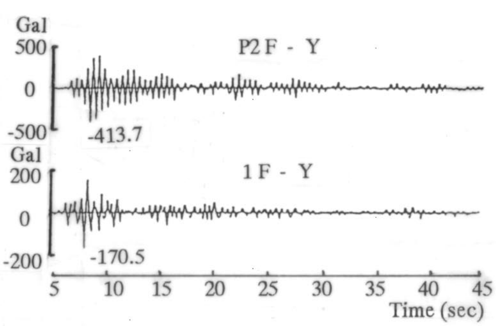

Fig.7 Time History of Acceleration Measured

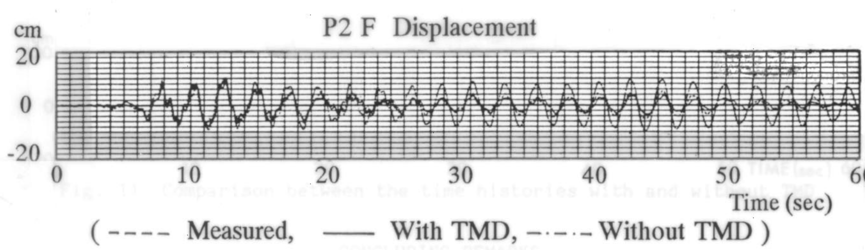

Fig.8 Comparison Between the Time Histories With and Without TMD

Table 1. Record of Wind Observation

Date	Type of Wind	Max Speed (m/s)	Direction	Remark
1992.4.22	Seasonal Wind	23.4		Controlled
5.4	Seasonal Wind	22.8		Controlled
12.8	Seasonal Wind	24.4		Controlled
1993.3.29	Seasonal Wind	25.6		Controlled
4.25	Seasonal Wind	19.9		Controlled
8.27	Typhoon No. 11	21.8	NNW	controlled + Uncon
9.4	Typhoon No.13	21.1		Controlled
9.30	Seasonal Wind	20.3		Controlled
1994.2.10	Seasonal Wind	20.8	SW	Controlled
2.21	Low Pressure Wind	25.0	NW	Controlled

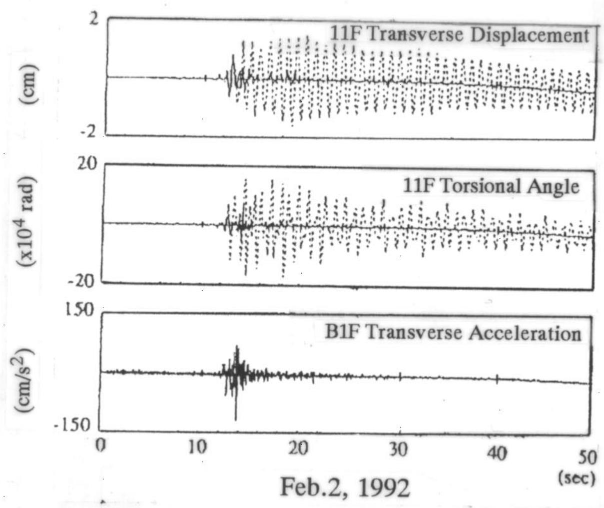

Fig.9 Control Effect During Earthquake
(— Controlled, ----- Uncontrolled)

Table 2. Record of Earthquake Observation

Date	Hypocenter	Magnitude	Depth (km)	Intensity Value	Acceleration (Gal)
1992.2.3	Tokyo Bay	5.9	92	V	114
4.10	East Tokyo	4.6	80	III	15
5.11	North Ibaraki	5.6	56	II	9
8.30	Tokaido Haruka offshore	6.6	325	III	8
11.19	Kanagawa	3.9	40	II	4
1993.1.1	Kusiro offshore	7.8	107	III	6
5.21	South West Ibaraki	5.4	61	IV	22
10.12	Tokaido Haruka offshore	7.1	390	IV	19

The third case (Koshika, N., Sept. 1994) is regarding the 11-story office building completed in Tokyo with active mass driver (AMD) system, in 1989, which is recognized as a first building equipped with AMD system. It should be noted that the mass weight is suspended by steel cable in order to eliminating the friction effect. The measured data of this system under strong winds were reported in 10th WCEE up to 1991. After that it has also experienced many excitations regarding both strong winds and earthquakes (Table 1 and 2). In particular the examined data of February 2, 1992 earthquake with Tokyo bay epicenter indicates its importance because of relatively high ground acceleration level, 114 gal as shown in Table 2. Fig. 9shows the measured response waves including the recorded base acceleration waves. It is seen that the AMD could be able to reduce the vibration remarkably to less than half values of what it would have occurred without damper, which the later was predicted by calculation.

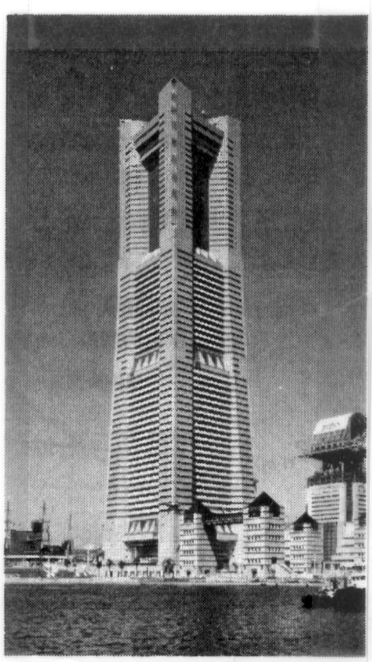

Photo 2. Landmark Tower

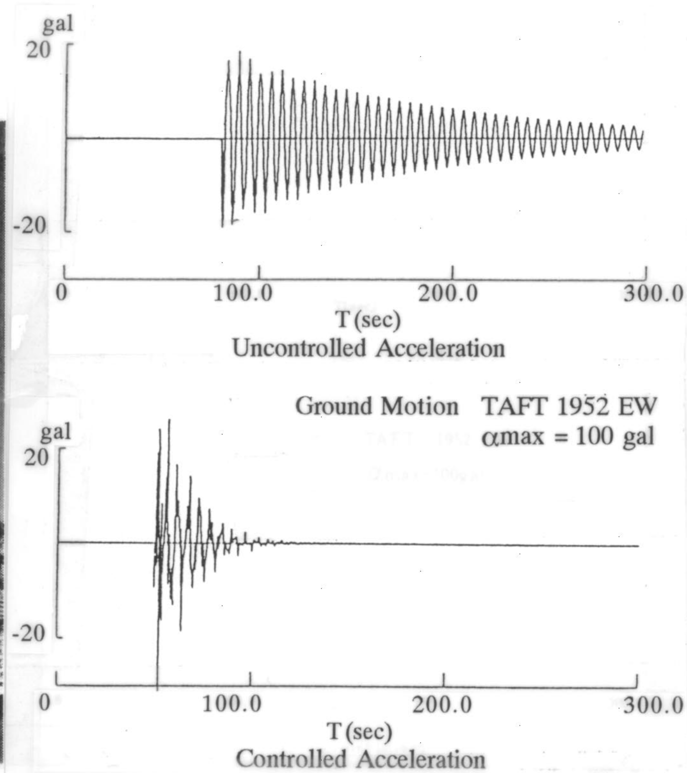

Fig.10. Comparison of acceleration responses
With and Without controlling

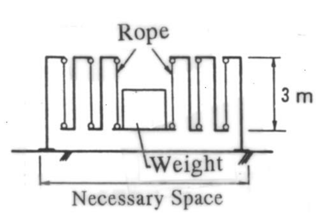

Fig.11. In Case of Multiple
Pendulum

The fourth case (Yamazaki, S., May 1995) is the Yokohama Landmark tower with AMD system. This building is about 300 m high (76 stories in total). The tallest of buildings equipped with TMD or AMD systems, 73 stories above the ground including 3-storied penthouse at top, and basement of 3 stories. It is being used as a office up to 48th story and as a hotel from 49th story to the top, whose vertical view is displayed in Photo 2. The installed AMD system in this building is multi-layer cable/mass which can be freely move in biaxial directions, as shown in Fig. 11. The measured data have not been frequently reported, however its brief report, indicates that it responded effectively in controlling the response acceleration during strong wind to a half of one without being mobilized to the AMD system. On the other hand, the effectiveness of controlling capability of earthquake response acceleration only in respect to oscillation after maximum amplitudes was reported to be remarkable as shown in Fig. 10.

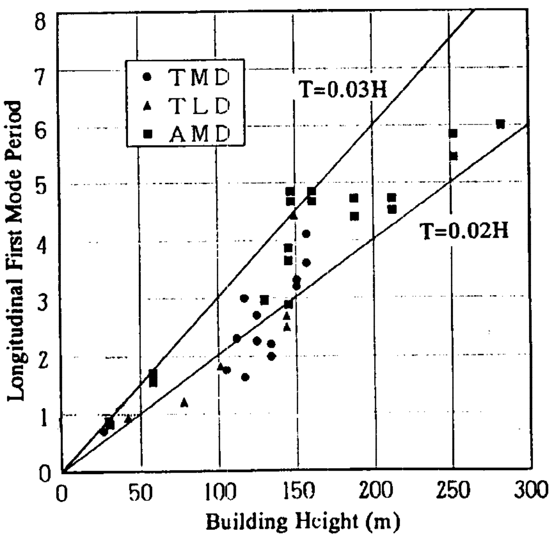

Fig.12 Building Height vs Longitudinal First Mode Vibration Relationship

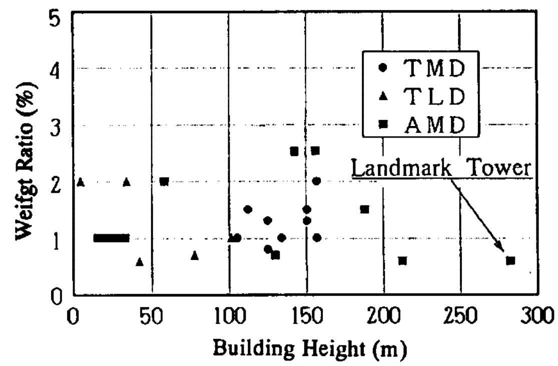

Fig.13 Building Height vs Additional Mass Weight Ratio Relationship

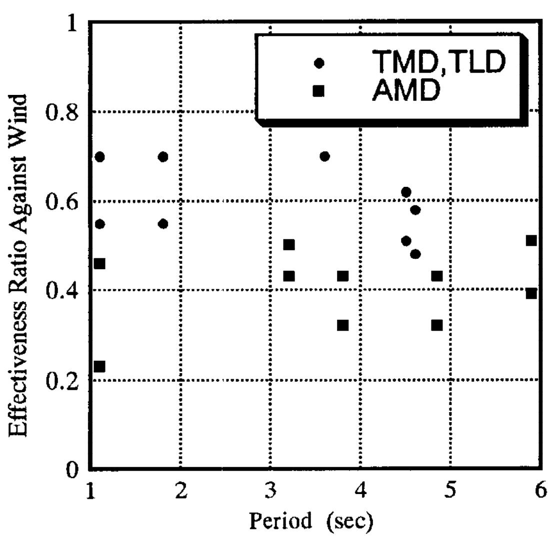

Fig.14 Vibration Control Effectiveness vs Period of Buildings (Against Wind)

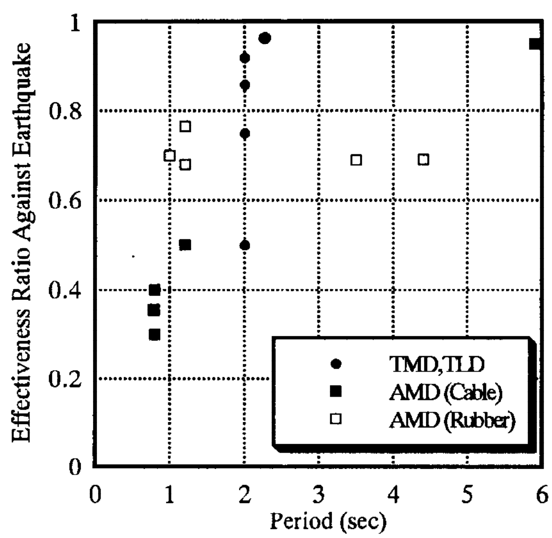

Fig.15 Vibration Control Effectiveness vs Period of Buildings (Against Earthquake)

OVERALL EXAMINATION OF THE ACTUAL EFFECTIVENESS IN MASS DAMPER SYSTEMS

In the following, the overall discussions using about 30 actual examples will be presented. Fig. 12 (Wakabayashi, T., *et al.*, Aug. 1995) shows the relations between the fundamental natural periods of the buildings equipped with TMD or AMD systems and their height. It is observed that the periods of the buildings lie between the lines of T=0.02H (Code recommendation for RC or SRC structures) and T=0.03H (for steel structures) though almost the buildings are steel structures. It is also found that the TMD systems are used up to 150 m high buildings while AMD systems also used in higher buildings, even 300 m in height. Fig. 13 shows the used mass weight ratios to the total weight versus height of buildings. It is found that the ratio lies among 0.3% and 2.5%, around 1% as an average value.

Fig. 14 presents the effectiveness ratios (ratio of controlling to non-controlling corresponded response acceleration R.M.S. values) of the measured data regarding strong winds along with the period of buildings. It can be recognized that the values of effectiveness lie among 20% through 50% for AMD systems while those of 40% through 70% for TMD systems regardless of the period values. Fig. 15 shows the measured data regarding earthquake responses. It is found that only the suspended-cable AMD systems are effective in controlling the response acceleration amplitude within short periods. In longer periods, even suspended-cable AMD systems behave in less effectiveness due to coupling higher mode influences in response of buildings. Figs. 16 and 17 show the relations between the measured effectiveness ratios and the TMD or AMD weight ratio against strong winds or earthquakes respectively. It is concluded that the trends of both the figures are similar to those of Figs. 14 and 15, unaffected by AMD mass ratios as well as the period of buildings. Figs. 18 and 19 present the relation between examined effectiveness ratios and recorded wind level or recorded ground motion level respectively. The trends are similar to Figs. 14 and 15 with maximum values measured on strong wind or ground excitation due to earthquakes, being 50 m/sec and 170 gal respectively.

Finally Fig. 20 shows the relations between the measured damping ratios and TMD or AMD mass ratios. These values were concluded from the free vibration tests for buildings, be able to predicting the measured oscillation of the acceleration after maximum amplitude taking place. AMD systems are on the whole more effective than TMD systems in carrying their duties.

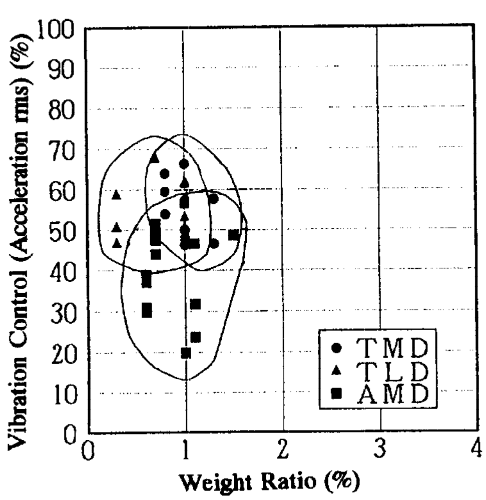

Fig.16. Vibration Control vs Weight Ratio Relationship (During Wind Force)

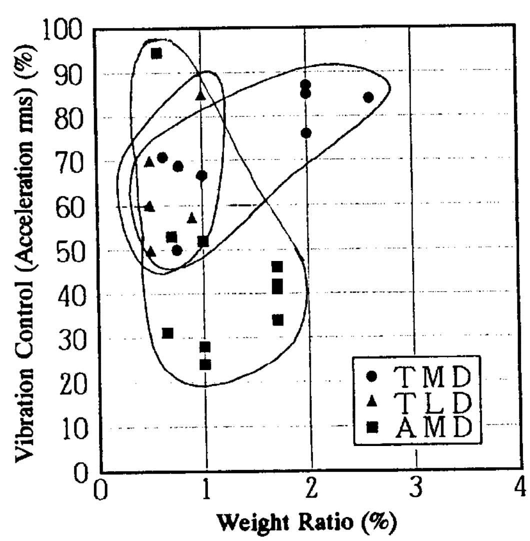

Fig.17. Vibration Control vs Weight Ratio Relationship (During Earthquake)

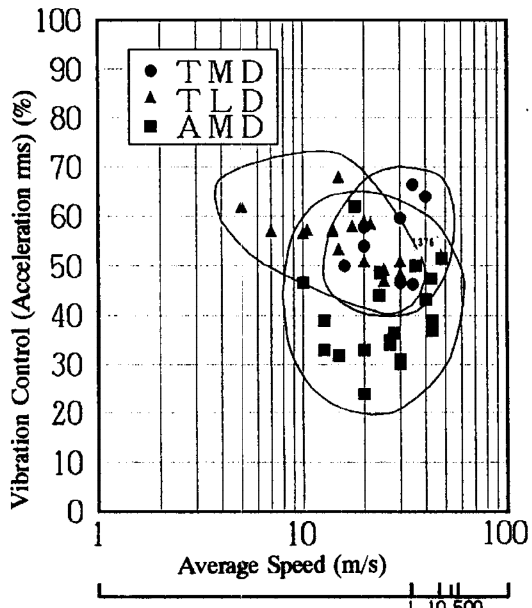

Fig.18 Wind Force vs Vibration Control Relationship

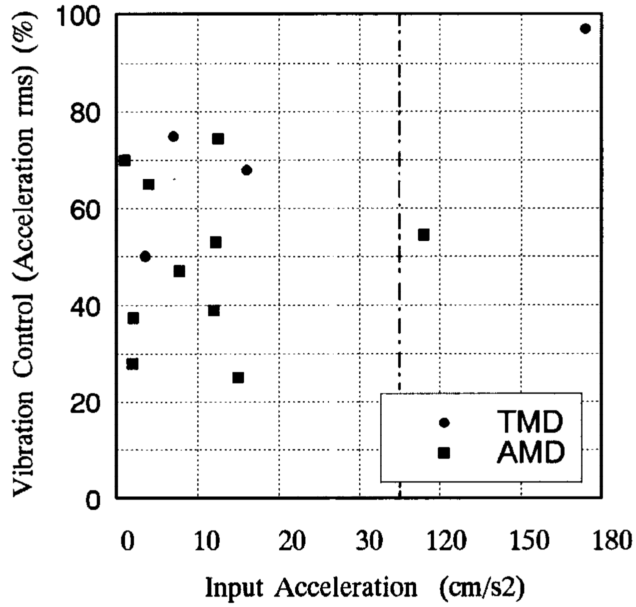

Fig.19 Ground Motion Input Acceleration vs Vibration Control Relationship

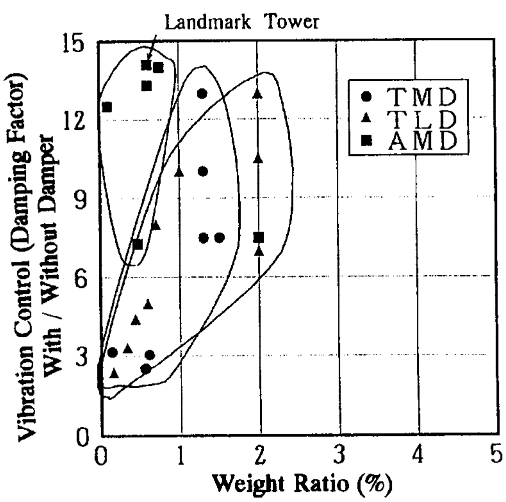

Fig.20 Increment of Damping Factor vs Weight Ratio Relationship

CONCLUSIONS

Based on the study of survey on the actual effectiveness of mass damper index vibrations, the following results can be drawn:

1. TMD systems were used for natural period of the buildings (H<150 m) within mass damper ratios of 1% through 2%, while AMD systems also used in higher range with same mass damper ratios as TMD systems.

2. Effectiveness ratios of mass dampers that is, ratios of controlling to non-controlling corresponded R.M.S. of acceleration response values, against strong winds lie between 20% and 50% for AMD systems while those between 40% and 70% for TMD systems regardless of the period of buildings as well as mass weight ratios.

3. Against the earthquakes, only the suspended-cable AMD systems are effective in controlling response acceleration amplitude within short period of buildings. On longer periods, even suspended-cable AMD systems behave in less effectiveness due to coupling higher mode influences in response of buildings. TMD systems are not effective in controlling the response acceleration amplitude even within short period of buildings.

4. Effectiveness ratios of mass dampers against strong winds do not vary with the recorded wind level maximum values ever measured on the buildings equipped with mass damper systems during strong winds, 50 m/sec was obtained when the fierce typhoon 9119 on September 1, 1991 passed the gold tower located at Shikoku, southern Japan.

5. Effectiveness ratios of mass dampers against earthquakes vary with the type of mass dampers as well as period of buildings not affected by the ground motion level. Maximum acceleration values of ground motion, ever measured during such earthquake of 170 gal in PGA which obtained for TMD system under the offshore earthquake, east of Chiba prefecture attacked Chiba pert tower located at Kanto district on December 17, 1987 and 114 gal obtained for AMD system when Tokyo bay earthquake attacked Kyobashiseiwa office building on February 2, 1992.

6. Measured damping ratios obtained from the free vibration tests for buildings, able to predict the measured oscillation of the acceleration/\after maximum amplitude takes place are on the whole higher for AMD systems than for TMD systems.

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