Passive and active response control of buildings

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Passive and Active Response Control of Buildings

Dispositifs de réponse active et passive des bâtiments

Passive und Aktive Erdbebeuisolation von Gebäuden

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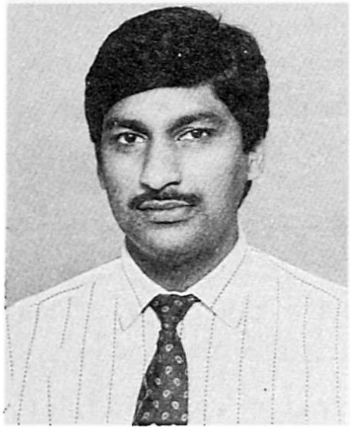

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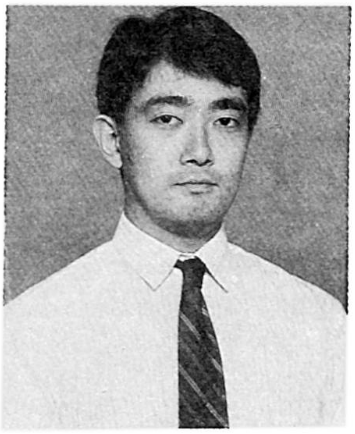


Ichiro Nagashima, born 1960, obtained his M.Tech at Kyoto University, Japan. For six years he was mainly involved in research and development of base isolation systems for Taisei Corporation. Since 1990 he is working on active structural control problems.

SUMMARY

A strategy is proposed to control the response of buildings to wind and earthquake loads. The strategy covers low to high rise buildings and identifies a variety of control devices and the range for their application. The control devices are divided broadly into passive and active types. Research activities are reviewed on actually used isolation type passive devices and mass damper type active devices.

RÉSUMÉ

L'article présente une stratégie poursuivie pour contrôler la réponse des bâtiments aux charges du vent et des tremblements de terre. Cette stratégie couvre les bâtiments bas et élevés et identifie une foule de dispositifs de contrôle et leurs possibilités d'application. Les dispositifs de contrôle sont divisés en types actif et passif. La présentation porte sur quelques dispositifs passifs du type à isolation actuellement utilisés et sur la recherche d'un dispositif actif du type amortissement de masse.

ZUSAMMENFASSUNG

Zur Kontrolle der Reaktion von Gebäuden auf Wind und Erdbeben gelangen unterschiedliche Strategien zur Anwendung. Diese Strategien umfassen sowohl hohe als auch niedrige Gebäude und eine Vielfalt von Kontrollgeräten und einen weiten Anwendungsbereich. Allgemein betrachtet sind die Kontrollgeräte in passive und aktive Typen eingeteilt. Wir erläutern einige gängige passive Ausstattungen des Isolationstyps und unsere Forschungsanstrengungen im Bereich der Massendämpfung des Type der aktiven Ausstattung.

1. OBJECT AND STRATEGY FOR RESPONSE CONTROL OF BUILDINGS

In recent years, a lot of work has been done on response control of civil engineering structures, such as buildings, towers, bridges and so on in Japan and the U.S. The purposes of response control are as follows.

1) To improve the safety of the building against severe natural hazard, such as strong earthquakes (maximum ground acceleration in the range of 300 gal to 400 gal), which the building may experience once in its lifetime.
2) To maintain the functions inside the building against medium level natural hazard, such as moderate earthquakes (maximum ground acceleration of 80-100 gal), which the building will experience several times in its lifetime.
3) To realize an enhanced comfort level for internal environment of the building subjected to wind or small earthquakes which will occur frequently in its daily life.

Research and development of several types of response control systems for buildings have been carried out as listed in Table 1. They can be classified into two types; passive type and active type. These control systems are applied according to the type of building and the control purposes mentioned above.

Here we introduce base isolation as an example of passive control systems and active mass damper as an example of active control systems.

2. BASE ISOLATION

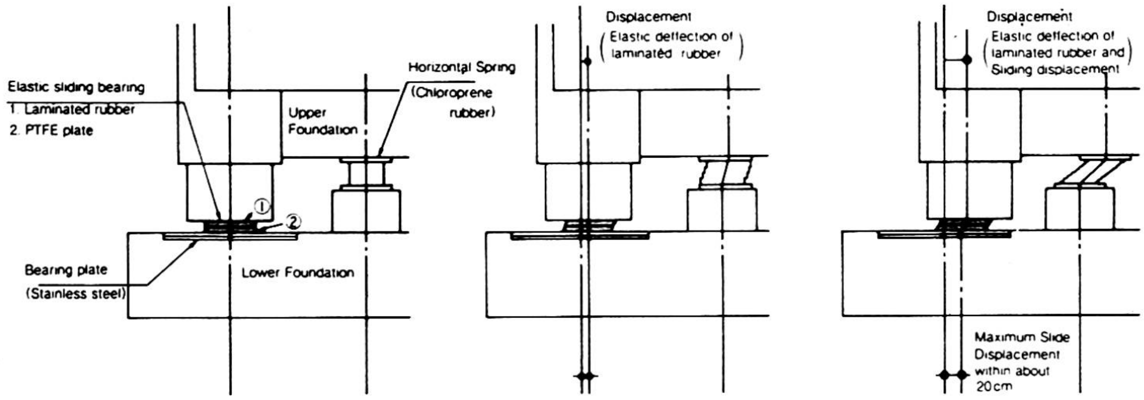
2.1 Introduction

Base isolation is now a well-known anti-seismic strategy to improve the safety of buildings against strong earthquakes. In recent years more than 40 base isolated buildings have been built in Japan. It can be applied mainly for low to medium rise buildings. Period-lengthening type base isolation systems using elastomeric bearings are the most popular at present. However, since they have their own natural periods, they may cause resonance to earthquake motions with longer predominant periods.

A sliding-type base isolation system to reduce horizontal acceleration, which never resonates to any type of earthquake motion, has been developed at Technology Research Center. It has been named "TASS system" which stands for "TAisei Shake Suppression system"[1].

Table 1 Response Control Systems for Buildings by TAISEI CORPORARION

Building Height		Low	Middle	High
Period		Short	Medium	Long
		< 1sec	1 ~ 2sec	2sec <
Control Systems	Passive type	◀ Base isolation (TASS system) ▶		
		◀ Floor isolation (TASS floor) ─	─	─ ▶
			◀ Damping System (DREAMY) ─	─ ▶
	Active type		◀ Active Mass Damper (AMD) ─	─ ▶
		◀ Active Base isolation (VFB) ▶		
			◀ Active Gyro - stabilizer (STREAM) ─	─ ▶



(a) At Rest (b) During Moderate Earthquake (c) During Severe Earthquake

Fig.1 Composition and Isolation Mechanism of TASS System

2.2 Sliding-type base isolation system

2.2.1 System Composition and its Superiority

The TASS system is essentially composed of sliding bearings, bearing plates and horizontal springs as shown in Fig.1(a). The sliding bearings and bearing plates support the vertical load of a superstructure and reduce the horizontal seismic force by sliding against severe earthquake motions. The horizontal springs restrain slide displacement with weak lateral stiffness. They sustain no long-term vertical load.

Two types of sliding bearings are prepared according to the required performance; one is a rigid type and the other one is an elastic type. Rigid sliding bearing is composed of a PTFE (Poly-Tetra Fluoro Ethrene) plate encased in a steel frame. The elastic sliding bearing is a laminated chloroprene rubber bearing with a PTFE plate attached to its bottom. This type of bearing deforms in shear at the rubber section even before sliding occurs. Accordingly an isolation effect can be expected under weak or moderate earthquakes as well as under severe earthquake motions. Behavior of the isolation devices under earthquake motions is schematically shown in Fig.1(b),(c).

The sliding-type base isolation system is supposed to have the following superiorities,

1) It never resonates to any type of excitation because the sliding mechanism has no natural period by itself unless an extremely strong restoring force overwhelming the friction is applied.
2) It stably supports superstructure because bearing devices do not deform excessively due to sliding. It is needless to say that the bearing plate should be wide enough.
3) It cripples the horizontal seismic force because no more than friction force is transmitted to the superstructure.

2.2.2 Implementation

Three buildings, utilizing this sliding-type base isolation system, have already been built in Japan. The first implementation is a laboratory building in the Technology Research Center, Taisei Corporation, in Yokohama Japan. It is a reinforced concrete building with four stories. Its isolation devices set in the underground pit are shown in Photo 1. Elastic sliding bearings with diameters of 85 cm (maximum loading capacity 400 ton) and 75 cm (Maximum 300 ton) and with heights of 10 cm are placed at the bottom of the columns. Eight horinzontal springs of 35 cm in diameter and 15 cm height are placed at four corners.

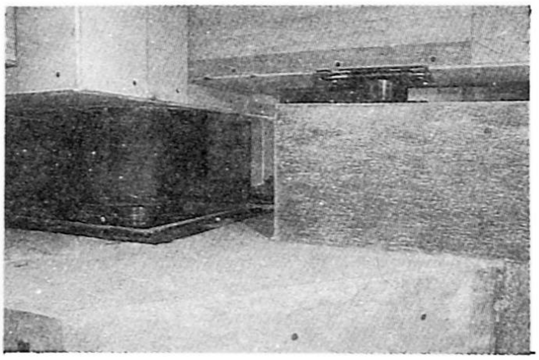


Photo 1 TASS System Actually Set

2.2.3 Earthquake Observation

Up to July 1991, since the completion of the building in July 1988, more than 100 earthquakes have been observed with the acceleration over 0.5 gal at GL-75m. The maximum ground acceleration was 55 gal observed in M5.7 earthquake Oct.14. 1989. No sliding has occurred yet. The amplification factors, which are the ratio of maximum acceleration at the roof to that of ground surface, are in the range 0.4 ~ 0.8 and mostly lie under 1.0, see Fig.2. The amplification factor of the isolated building is reduced to 1/2 ~ 1/9 that of the non-isolated building even in the stage without sliding.

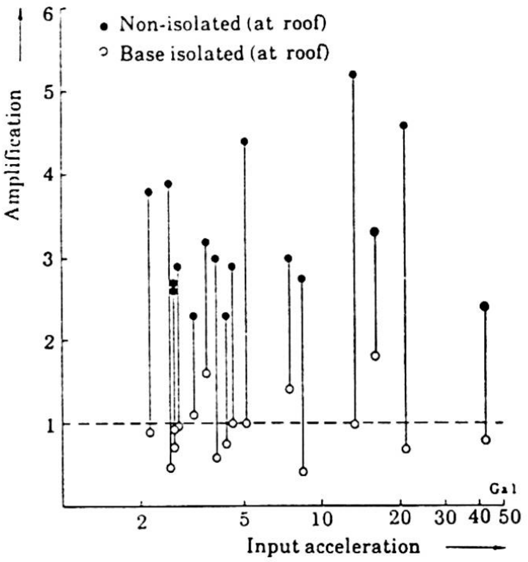


Fig.2 Ovserved Amplification of Acceleration Response.

3. Active Control Systems

3.1 Introduction

There are at least two main reasons why active structural control is a promising concept. One is that many passive control systems when augmented with even a small active control force perform much better; such systems are called hybrid systems. Another one is that active control provides the designer hitherto unavailable flexibility (and possibility) in designing buildings with enhanced comfort and safety; also, as buildings evolve with time because of structural degradations or changed performance requirements, the control system can be readjusted easily. Over the last 5-6 years a concerted effort has been made mainly in Japan and the US to active control for buildings. However, a control theory which is tailored to account for random, intermittent and transient load processes, and which can characterize the control performance more physically yet remains to emerge.

3.2 Active Mass Damper

Research activities at Technology Research Center on active mass dampers(AMD) are described, see Fig.4 for a schematic diagram of the control system. The additional mass at the top, usually 0.5-1.0% of the building mass,

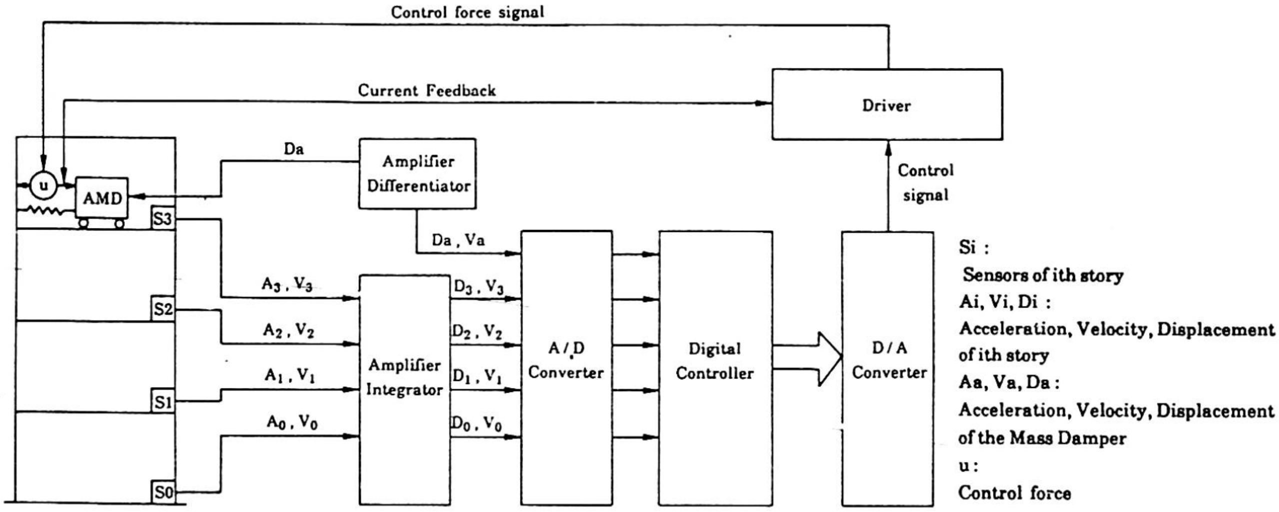


Fig.3 Active Mass Damper System

if tuned to one of the lower structural mode is called ATMD(and TMD when passive), otherwise simply AMD. The control force, u, which acts on the mass, thereby generating a reaction force on the building, is computed according to a control algorithm, pole allocation for example.

3.2.1 AMD vs ATMD

A lot of simulations were performed on the four story building model shown in Fig.4, with El Centro(NS), 1940, record of 50 gal peak acceleration as the input. With no control the first mode contributes almost 95% to the top story (peak) displacement. Assuming an additional mass of 1% of the effective first modal mass, with 6% damping, we studied if there exists a response reduction that separates the ranges of effective performances for ATMD and AMD. These simulations reveal that for small reduction, up to 25%, ATMD requires much smaller control force than AMD does, whereas for higher reductions AMD performs better[2].

In Figs.5(a)-(c) we show time hisotries of the earthquake input and the top story displacements with no control and with TMD; the TMD causes a slight reduction in the peak value 0.65 cm to 0.62 cm. We then used both ATMD and AMD to reduce the peak response value further to 0.47 cm(by 25%) and 0.31 cm(by 52%). For 25% reduction, ATMD required a peak control force of 14N, whereas AMD required 42N. In contrast, for 52% reduction, ATMD required a peak control force of 215N, whereas AMD required only 150N. Fig.5(d) shows the top story displacement for the case of 25% reduction with ATMD, and Fig.5(e) shows the same for the case of 52% reduction with AMD.

Through these simulations the following two conclusions are confirmed. The first is that a passive TMD supplied with even a small active control force may give much enhanced performance. The second is that for tall buildings if the first mode alone does not dominate the response, then an ATMD tuned to the first structural mode would be effective against wind and earthquake loads because then the same ATMD acts as an AMD for higher modes.

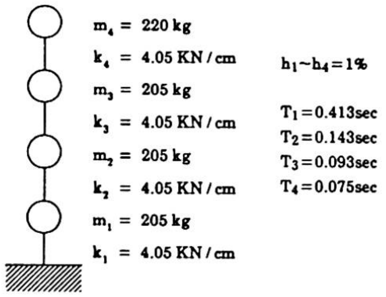


Fig.4 A Four Story Building Model

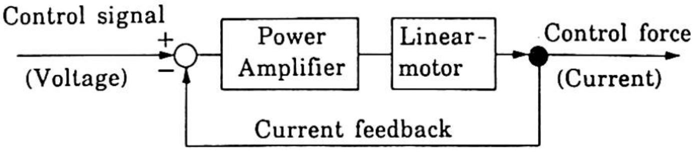
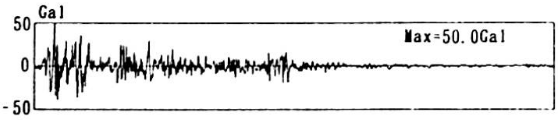
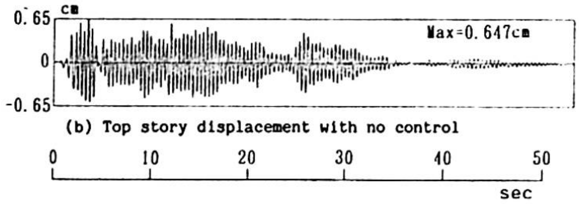


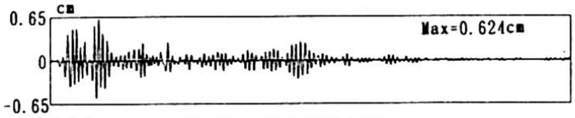
Fig.6 Block Diagram of the Driver



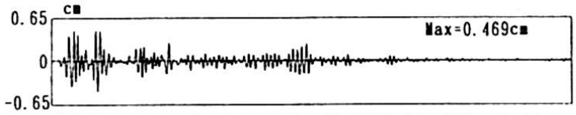
(a) Input Earthquake



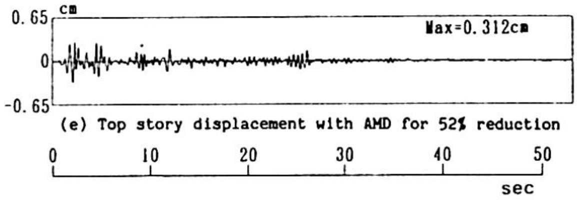
(b) Top story displacement with no control



(c) Top story displacement with TMD



(d) Top story displacement with ATMD for 25% reduction



(e) Top story displacement with AMD for 52% reduction

Fig.5 Active Control of the 4 Story Building Model

3.2.2 Experimental study on AMD system

A series of experiments has been performed on the four story building model with both ATMD and AMD for the cases of full state feedback, output feedback, small reduction, large reduction, etc. The matching between the simulation and experimental results was very good(see [3]). A unique feature of our experiment was the use of a linear motor as an actuator, where the current feedback driver was used to generate the control force according to the control signal from the digital controller. The block diagram of the driver is shown in Fig.6. With high gain of the power amplifier, the time lag between the control signal and the control force tends to be zero; the measured time lag for this system is 0.9 msec. Thus, the continuous time control algorithm can be directly applied.

4. FUTURE SCOPE

As for the active mass damper we have established the feasibility through the model experiment. Our effort now forcuses on (a) development of poweful, high quality active control systems for highrise buildings, (b) studying robust output feedback control, and (c) assessing the reliability and the maintenance aspects of the control system.

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