

State-of-the-art report of active and hybrid control research in Japan

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1. INTRODUCTION

As for the control of dynamic responses of structures such as buildings and bridges, three types of controlling technology have been rapidly developed in Japan recently. The first type is an attempt to decrease dynamic responses of high-rise buildings, towers of long span bridges and sightseeing towers mainly subjected to strong wind forces. Tuned mass dampers (mass-spring systems, pendulum systems, liquid-container systems and so on) and energy absorbing dampers (viscous dampers, friction dampers, elasto-plastic dampers etc.) are used in this type for consumption of vibration energy. We have now more than twenty actual examples.

The second type is a base isolation system for mitigation of earthquake excitations to building structures. Most structures are made of reinforced concrete and a few structures are made of steel or wood. The largest one is a ten-story building but almost buildings are lower than five-story. About sixty base-isolated buildings have been built now using multi-layered natural rubber bearings with elasto-plastic steel dampers or friction dampers or viscous dampers, so-called lead rubber bearings, high-damping rubber bearings using synthetically-made rubber or sliding bearings.

These two types are called as passive ones of structural response control. The last one is active response control systems for building structures and bridges. This paper presents a general view of active response control researches currently being conducted in Japan.

2. CONCEPT OF ACTIVE CONTROL OF STRUCTURAL RESPONSE

i) Objectives of Structural Response Control

Dynamic excitations to a structural system are roughly classified into three kinds: (1) Environmental vibrations (machinery vibration, traffic noise, etc.), (2) Wind forces and (3) Earthquake ground motions. These excitations are very different each other in a frequency range, spectral character, an amplitude, a duration time, stationality etc.

On the other hand, the purpose of structural response control may stand on several view points: (1) Living Comfort (to decrease discomfort or uneasiness of peoples in buildings or a civil engineering structures). (2) To maintain the function of buildings and civil engineering structures for users. (3) Structural safety (to keep up human lives and properties in buildings and civil engineering structures). To satisfy these various needs for structural responses to various excitations, structural response control of a passive type has the inevitable limitations. Active type strategy of structural response control should be considered the most important one to improve the structural safety and the structural design method.

The procedures of structural response control are as follows [2]: (1) Cutting off the input energy from the disturbance, (2) Isolating the natural frequencies of the structure from the predominant power components of the disturbance, (3) Providing nonlinear structural characteristics and establishing a nonstationary state and a nonresonant system, (4) Supplying a control force to suppress the structural response induced by disturbances, and (5) Utilizing an energy absorption mechanism.

ii) Background

Corresponding to the social demand for active control of structural response research in Japan, the Japan Panel on Structural Response Control Research (Chairperson is Prof. Kobori) was established in the Liaison Committee of Earthquake Engineering Research, the Science Council of Japan in September 1989.

The Japan National Symposium/Workshop on Structural Response Control was held on March 23-25, 1992 under the auspices of the Japan Panel. Forty-five research papers were presented in the symposium. And the workshop was comprised of three discussion groups to the proposed different topics: (1) Control theory, (2) Control devices and control systems, and (3) Structural design based on response control technique and discussed on the research, the development and the future direction. This state-of-the-art report is mainly composed of a summary of symposium papers.

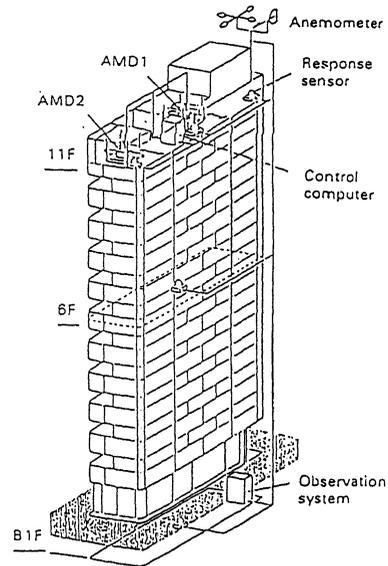


Fig.3.1 Active Mass Driver System [3]

3. ACTIVE RESPONSE CONTROL SYSTEM

i) Control force type system

The response controlled structure of the control force type system provides a control force to the structure by operating the auxiliary mass installed in the structure by means of an actuator, thus reducing the response of the structure to earthquakes and strong winds. There are various systems proposed and some of them have already been applied to actual buildings.

Kyobashi Seiwa Building is built in 1989 and is the first building of the world that has the active control system which was designed by Kobori et al.[3] An active mass driver system was installed to suppress dynamic responses caused by earthquakes and strong winds(Fig.3.1). It was reported that the building had experienced several moderate earthquakes and strong winds during which ground acceleration, wind velocities and structural responses had been measured.[4] The measured responses during the earthquakes are compared with the simulated responses by numerical analyses for an uncontrolled structure. Wind response observations were performed every 30 minutes with and without control. From these comparison, a remarkable decrease in amplitude due to the active mass driver system has been confirmed(Fig. 3.2).

An active mass damper system which could operate in

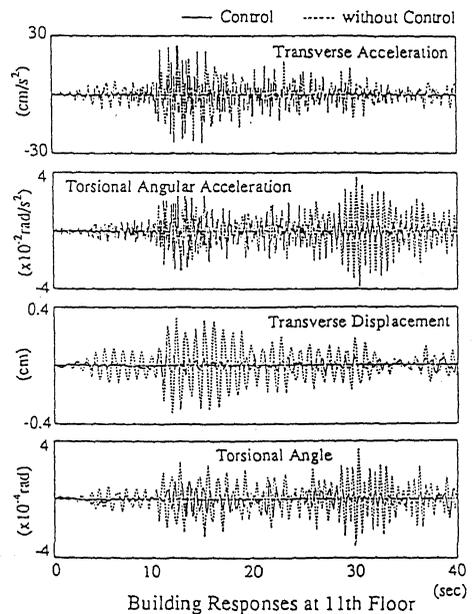


Fig.3.2 Control Effect under Earthquake [4]

two horizontal directions had been installed in a 6-story experimental building.[5] Two actuators set at right angle operate the 6-tons mass (Fig. 3.3). Though this system does not operate at present, the active bracing system is installed at the first story of this building and observation of earthquakes is continued.

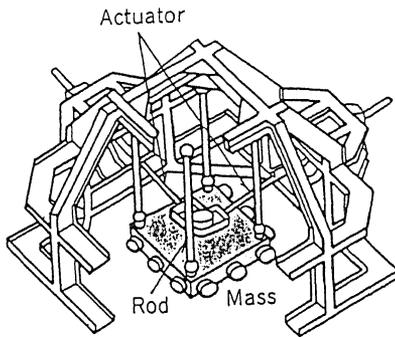


Fig.3.3 Active Mass Damper System [5]

Fig. 3.4 shows a general view of an experimental version of an active vibration control system using dynamic dampers.[6] An auxiliary mass installed on the top floor of a building model is driven by an actuator. An active dynamic damper has a ball-screw driving system equipped with an AC servo-motor.

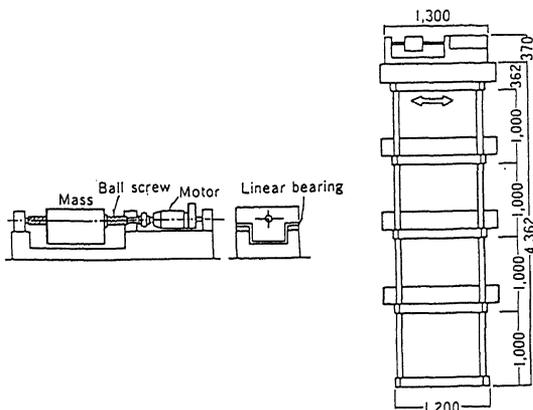


Fig.3.4 Active Dynamic Damper System [6]

In the non-building structures, an active tendon system was applied on a viaduct on the Metropolitan Express way (Fig. 3.5).[7]

INTES building is an eleven-story structure constructed by steel encased reinforced concrete and steel frame with a two-story roof appendage which has been built at the end of 1991(Fig. 3.6). Ice storage tanks of about 36 tons supported multi-stage rubber bearing are driven by hydraulic actuators. The free vibration tests have been done.[8]

Iemura presented an experimental and analytical research on AMD system using a 3-story structural

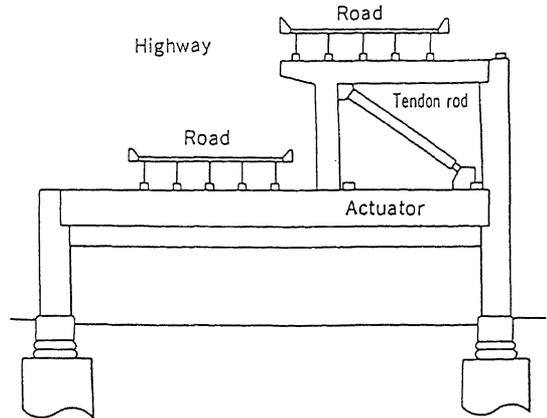
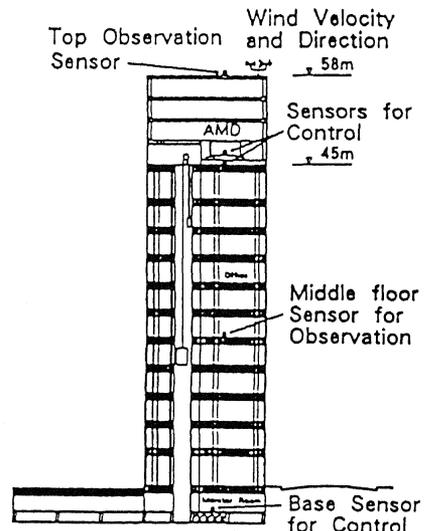


Fig.3.5 Active Tendon System [7]

model.[9] Shimogo examined realization of control technique using pulsive forces of air jet type for suppressing response of structural models within a threshold.[10]

ii) Nonresonant Type System

In the nonresonant type controlled structure, the system actively controls the vibration characteristics of a structure so that resonance with input motion can be avoided and the response can be suppressed. To achieve this objective, the active variable stiffness system has been developed and applied at 3-story steel building.[11] Braces have been placed in the transverse



The Cross Section of Building

Fig.3.6 Active Mass Damper System [8]

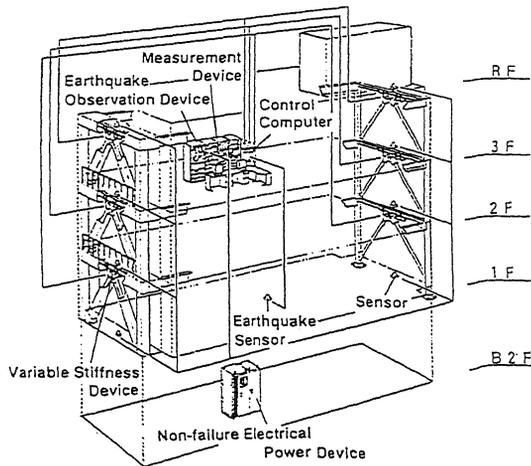


Fig.3.7 Active Variable Stiffness System [11]

direction of the building, and the variable stiffness device has been installed between the brace top and the upper beam (Fig. 3.7). The earthquake motion analysis type of feed forward control scheme has been adopted.

4. HYBRID CONTROL SYSTEM

Response control systems of passive type function effectively only after the structure begins to move, which means it has a short coming of slow start-up in the effect. To supplement this deficiency, trials to combine a passive control system with an active one are made. Up to the present, researches for the active tuned mass damper, which combines a tuned mass damper with actuators, and the active base isolation system have been made.

A pendulum-type tuned active mass damper has been developed (Fig. 3.8).[12] The system has a multi-stage suspended damper mass which can be housed on a single story of a high-rise building. When sensors detect sway vibration, the computer controls servo-motors driving ball-screws to position the damper mass. It will be installed on the top floor of 70-story building (296 meter high).

A two-axis hybrid mass damper has been developed to reduce the vibration of tall bridge towers and high-rise building structures (Fig. 3.9).[13] A sliding mass shaped in an arc segment is combined with active control by the AC servo-motor. After full scale experiments were made with the tower structure model, it has been applied to actual bridge tower. Also it is

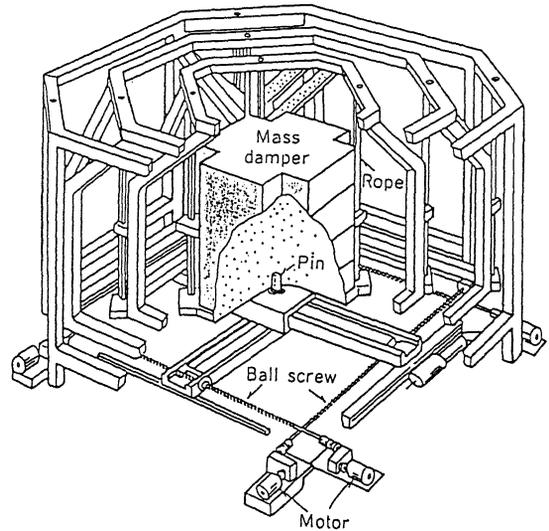


Fig.3.8 Powered Passive Mass Damper [12]

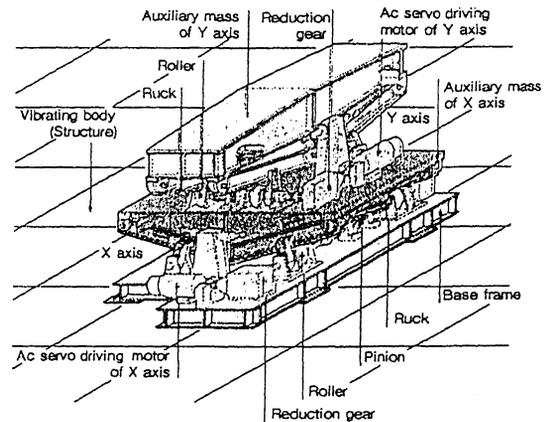


Fig.3.9 Hybrid-type Mass Damper [13]

planned to set in a high-rise residential building.

A hybrid mass damper using the tuned mass damper supported on multi-stage high damping rubber bearing and an actuator has been developed (Fig. 3.10).[14] The actuator is composed of AC servo-motors and ball screws. At present, the system has been mounted on the tower-type 7-story steel frame building and verification tests are being carried out. This system is planned to apply to a 40-story building.

Fujita et al [15] have developed a new mass damper system. It is an active-passive changeable mass damper in controlling the bypass valve of an actuator. It has been applied large scale structural model (18.9 m high).

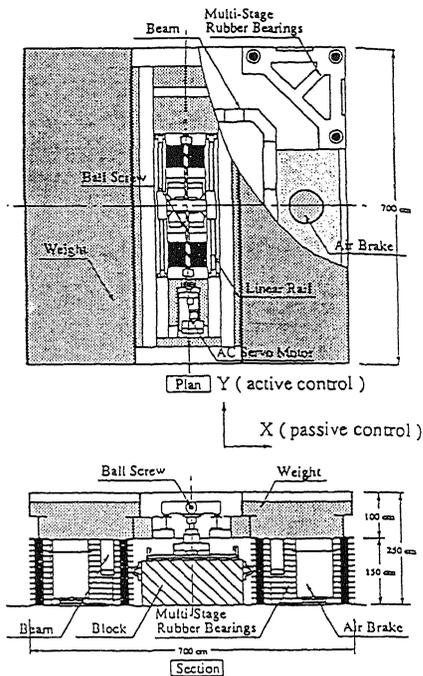


Fig.3.10 Passive-Hybrid Mass Damper [14]

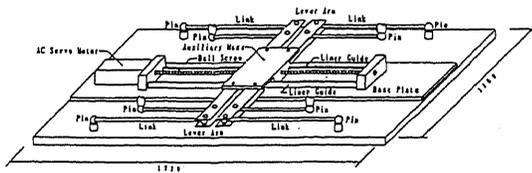


Fig.3.11 Hybrid-type Multi-Mass Damper [16]

Ishimaru presented an experimental study on hybrid tuned multi-mass damper system (Fig. 3.11).[16] It is composed of a main structure, tuned mass damper, which is a pendulum of several stories hung from the uppermost story of the main structure, and a lever mechanism with an auxiliary mass. The results of shaking table tests show that the proposed algorithm is effective in giving robustness, as well as in suppressing structural response.

A tower-like model with two actively controlled gyrostabilizers (Fig.3.12) on its top has been tested.[17] Principle of the active control of this system is that flywheels of two gyrostabilizers are rotating around the vertical axis in the opposite direction, and each gimbal is controlled to rotate around the horizontal axis as the precession of motion.

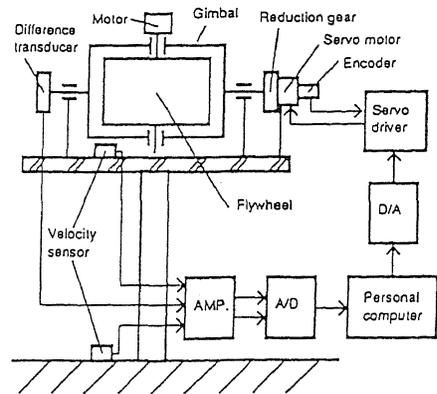


Fig.3.12 Hybrid-type Control System [17]

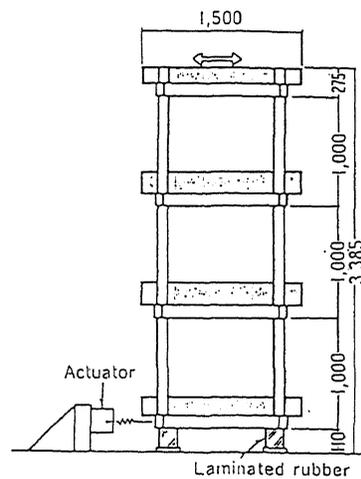


Fig.3.13 Absolute Vibration Control System [18]

An active vibration control system intended to maintain a building absolutely still was tested (Fig. 3.13).[18]

Earthquake input power is reduced by a base isolation structure consisting of rubber bearings. Upper structure model is actively controlled by electro-hydraulic actuators.

Shinozuka, Fujita et al have developed the hybrid isolation system using friction-controllable sliding bearings (Fig. 3.14).[19] By controlling the friction force, the sliding displacement can be confined within an acceptable range, while keeping the overall isolation performance optimal under the circumstances. A model hybrid system has been tested on a shaking table.

As the other hybrid control systems, the following examples are proposed and tested: A modulated tuned mass damper provided with an initial stroke has been

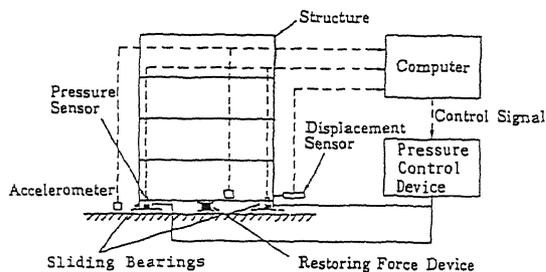


Fig.3.14 Hybrid Base Isolation System [19]

proposed.[20] It consists of an auxiliary mass on linear guides, coil springs, rack-and-pinion system with a clutch and a motor and magnetic dampers. There is no need of continuous power supplier. Shaking table tests are carried out and the control algorithm is investigated as an alternative approach to the pulse control method.

A variable damper is being developed at Public Works Research Institute (Fig. 3.15).[21] The Viscous damping force of this damper is variable depending on the response of highway bridges. Damping coefficient of the damper is taken large for a small amplitude as a damper stopper. Amplitude becomes larger by earthquake excitations, the damping coefficient decreases so that energy dissipation be optimum and inertia force be adjusted appropriate. For the excessive amplitude, the damping coefficient increase to suppress the response.

5. CONTROL ALGORITHM

Depending on the utilization of measured information, the control algorithms are classified as follows; (1) Feedback control, (2) Feedforward control, and (3) Feedback and feedforward control. With regard to

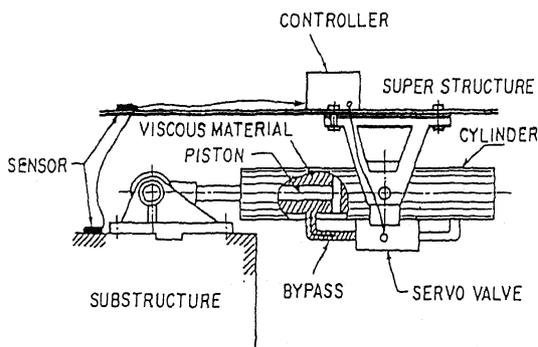


Fig.3.15 Variable Damper System [21]

feedback control algorithm, the following topics or items are researched currently in Japan. For the active mass driver or damper system, weighting coefficients of all state variables, evaluation of time delay and time interval for the control, saturation or constraint of the control system, performance evaluation of the control system etc.

Regards as another control algorithm, for examples, H^∞ control by Nishitani et al [22], neural network by Toki et al [23], Fuzzy control by Inoue et al [24] are proposed. Toki and Sato presented a control algorithm using the concept of neural network. It consists of two parts, one is an identification mode to determine structural parameters, and the other is controller mode in which a closed-open loop optimal control scheme is derived.

6. CONCLUDING REMARKS

Development of the technology required to realize response controlled structures has progressed steadily, and a few actual buildings and civil engineering structures have been come out in Japan. These structures have given us the opportunity to make many observations of earthquake or wind response effects and to verify the effectiveness of control from actual experiences. The final purpose of the system can be said as realization of a structure that will not suffer a large damage, and will be able to maintain its function. To attain this, it may be necessary for us to pass through some more hurdles.

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