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State-of-Art in Active, Semi-Active and Hybrid Control Systems for Tall Buildings

[1]Aditya Tiwary, [2]Ashish Tiwari, [3]Anil Kumar
[1, 2, 3] (Department of Civil Engineering, Jaypee University of Information Technology
Waknaghat, Solan (H.P.) – 173234
(Email: [1]adadtiwary15@gmail.com, [2]shshkmr52@gmail.com, [3]anil.juit@gmail.com)

ABSTRACT
This paper focuses on the state-of-the-art developments in active, semi-active and hybrid structural control systems. Control systems are force actuation devices integrated with sensors, controllers and real-time information processing. This paper includes a brief historical outline of their development and the current and still evolving technologies in this field. Various criteria were proposed to examine the efficiency of the control. Active system which are reviewed include Active mass damper, Active tendon damper and active tuned mass dampers and Semi active system which include stiffness control devices, electro-rheological dampers, magneto-rheological dampers, friction control devices, fluid viscous dampers, tuned mass dampers and tuned liquid dampers. It is imperative that active and semi active control devices have the potential for improving the seismic behavior of civil structures.
***Keywords* -** Active control, Hybrid control, Semi active control, Seismic protection, tuned mass damper.

I. INTRODUCTION

In the recent years many techniques has been developed to reduce the vibration response in civil structure, such as a tall building and long bridges. Attention of this paper is focused on Active and semi-active control systems. The purpose of this paper is to provide an assessment of the state of the art and state of the practice of this exciting, and still evolving, technology. Also included in the discussion are some basic concepts, the type of Active control and Semi active control systems being used and deployed. A wide variety of systems have been proposed for controlling structures subjected to earthquakes induced ground motion. However, these systems may be categorized according to one of the followings definitions.

II. ACTIVE CONTROL SYSTEMS

These systems require a power source for operation since electro-hydraulic actuators are used to provide control forces. The magnitude and direction of the control forces depends on the structural response and ground excitation. An active structural control system has the basic configuration as shown schematically in Fig 1. It consists of (a) Sensors located in the structure to measure either external excitations, or structural response variables, or both; (b) Devices to process the measured information and to compute necessary control force needed based on a given control algorithm; and, (c) Actuators, usually powered by external sources, to produce the required forces.

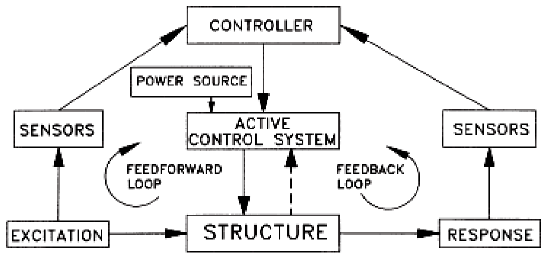


Fig 1: Schematic diagram of Active Control System

III. TYPES OF ACTIVE CONTROL SYSTEMS

The Active control systems are distinguished between the active controls; this is designed to reduce structural motion and that which generates structural motion. Different types of active control devices include:

3.1 Active Tendons. The active tendon system comes into action when roof sensor indentifies that building is moving. Then, the computer activates devices to shift a large weight to counteract the movement. The cables stretched between diagonal joints are pulled or released by a motor guided by a computer. Fig 2 illustrates tendon control system.

3.2 Active mass dampers. The active mass damper (AMD) system have been designed and Installed in the Kyobashi Seiwa Building in Tokyo and the Nanjing Communication Tower in Nanjing, China.

The Kyobashi Seiwa Building, the first full-scale implementation of active control technology is an 11-story building with a total floor area of 423 m^2.

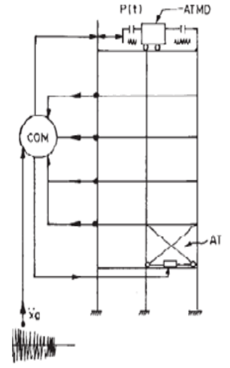


Fig 2: Tendon Control System

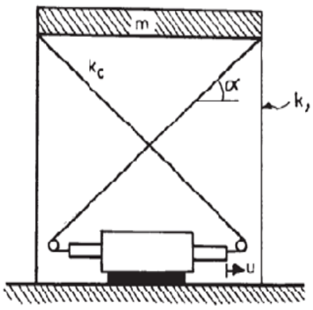


Fig 3: Cross-sectional View

As shown in Fig 4, the Control system consists of two AMDs where the primary AMD is used for transverse motion and has a weight of 4 tons, while the secondary AMD has a weight of 1 ton and is employed to reduce torsional motion. The role of the active system is to reduce building vibration under strong winds and moderate earthquake excitations and consequently to increase comfort of occupants in the building.

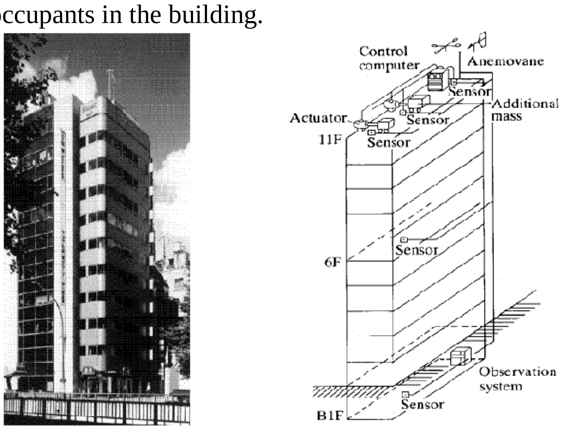


Fig 4: Kyobashi Seiwa Building in Tokyo with AMD

IV. SEMI-ACTIVE CONTROL SYSTEMS

Systems which offer a combination of features associated with passive and active control systems. Semi active control systems utilized the energy associated with the motion of the structure to developed control forces. The magnitude of the control force is usually adjusted using a small power source and may be based on the structural response, and the ground excitation. The direction of the control force is usually dependent upon the response of the structure. Semi active system can produce a large control force with significantly low power-source like a battery. Therefore, it is known as a more promising technology for vibration control. Fig 5 shows the schematic diagram of semi-active control system.

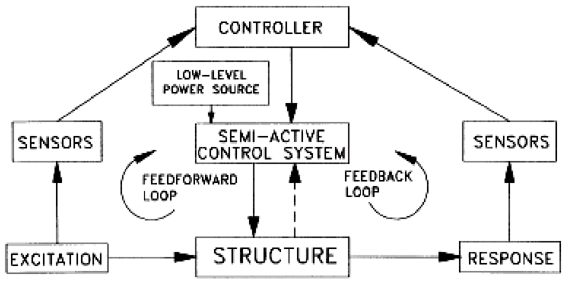
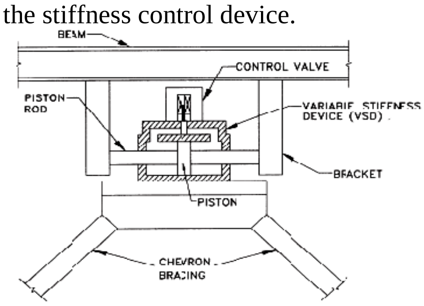


Fig 5: Schematic Diagram of Semi-Active Control System

V. TYPES OF SEMI-ACTIVE CONTROL SYSTEMS

As an active control system, it monitors the feedback measurement, and generates appropriate force signal. In a passive control system, control forces are developed as a result of the motion of the structure. Control forces primarily act to oppose the motion, and are developed through appropriate control algorithms. Different types of semi-active control devices include the following.

5.1 Stiffness control devices. These devices modify the stiffness and hence the natural frequency of the system. Example is stiffness bracings, which are engaged or released so as to include or not to include the additional stiffness in the system [1] [6]. Fig 6 shows the stiffness control device.



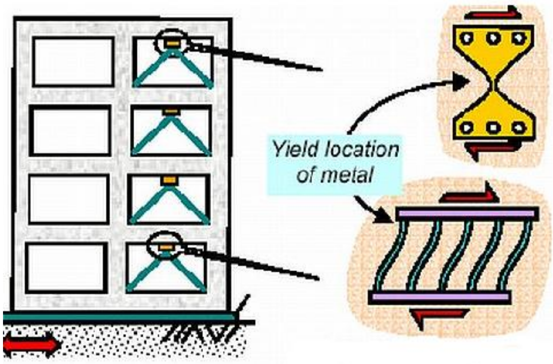


Fig 6: Stiffness control Device

5.2 Tuned Mass Dampers and Liquid Dampers. TMDs apparently modify dynamic properties of the structure. In the TLDs, the sloshing frequencies of the fluid contained in U-shaped tanks are used for damping.

5.3 Electro or Magneto Rheological dampers. Micron-size dielectric particles suspended in a fluid polarize when current passes through and thus develop an increased resistance to flow [2] [3]. Fig 7 shows the MR damper with its working.

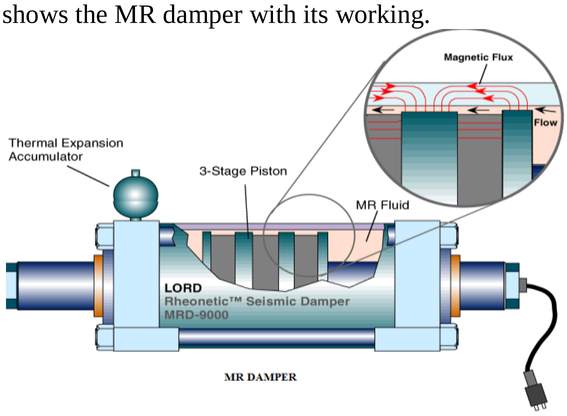


Fig 7: MR damper

5.4 Friction control devices. They are energy dissipaters in the diagonal bracing of a structure or in the sliding isolation systems. Sometimes, the coefficient of friction of sliding is controlled by fluid pressure in a pneumatic pressure vessel [4], as shown in Fig 8.

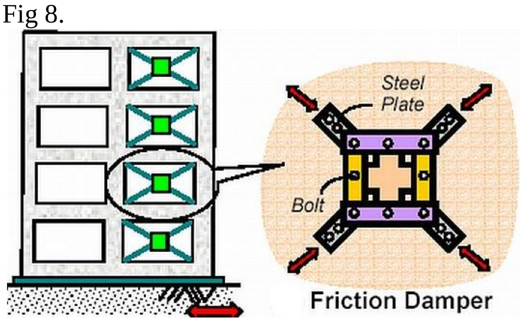


Fig 8: Friction damper.

5.5 Fluid viscous devices. This is like a dashpot system. Pushing oil through an orifice dissipates energy. The force is controlled by a valve connecting two sides of the cylinder as shown in Fig 9 [5].

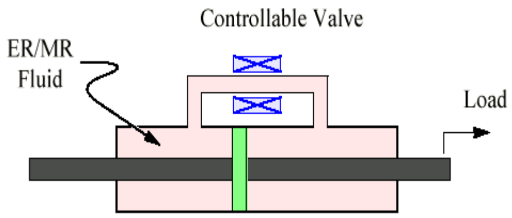
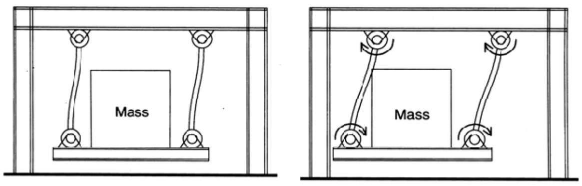


Fig 9: Viscous fluid device

VI. CONTROL SYSTEMS FOR STRONG WINDS

Strong winds cause vibrations in high-rise buildings which are not only unsafe for the structure, but also make the residents in the building uncomfortable. To reduce such vibrations, structural control is adopted on some occasions. In ordinary cases, displacements induced by strong winds are significantly smaller than those induced by large earthquakes. Accelerations need to be controlled. Thus, a control device for reducing wind effects must be effective for small displacements, and at the same time should be robust enough to withstand large displacements during large earthquakes. One of the effective devices for such purpose is a tuned mass damper (TMD) system as shown in Fig 10.



During Small Vibration During Large Vibration

Fig 10: A View of TMD

VII. APPLICATION OF STRUCTURAL CONTROL SYSTEM WITH TMDS

Applications of TMD systems to high-rise buildings began with an office building named Crystal Tower in Osaka, which was completed in 1990. Further, a new type of tuned mass damper was developed and applied in an office building in Osaka as shown in Fig 11. As shown by the vertical section of the building in this building is seismically isolated below the third floor level. The isolating system of this building uses newly developed mechanical bearings called a linear slider, each of which supports 30,000 kN of the building weight. Properties of the building are given in the table beside.

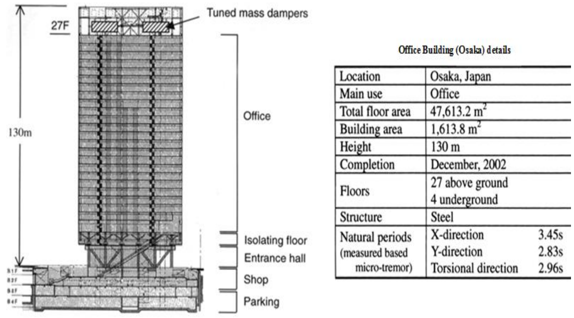


Fig 11: Office building with TMD on top with details

Such isolation is quite effective against earthquakes, but not necessarily good for winds. Especially for high-rise buildings, the application of a seismic isolation system sometimes causes adverse effects under wind loading. This building is designed so that the friction of the linear sliders prevents the isolation floor from moving and disturbing residential comfort during winds. Furthermore, when wind load is large enough to move the isolation floor, a locking system consisting of multifunction oil dampers installed in the isolation floor would automatically lock the isolation floor. Hence, this building is essentially identical to conventional (non-isolated) high-rise buildings during strong winds.

VIII. HYBRID MASS DAMPER SYSTEMS

Fig 12 shows the hybrid mass damper (HMD) is the most common control device employed in full-scale civil engineering applications. An HMD is a combination of a passive tuned mass damper (TMD) and an active control actuator. The ability of this device to reduce structural responses relies mainly on the natural motion of the TMD. The forces from the control actuator are employed to increase the efficiency of the HMD and to increase its robustness to changes in the dynamic characteristics of the structure.

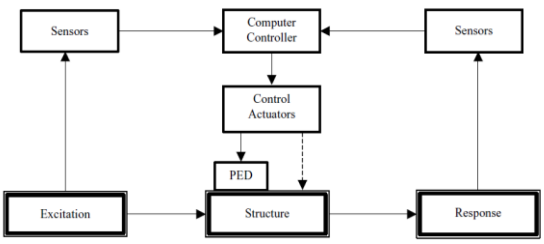


Fig 12: Schematic diagram of HMD System

An example of such an application is the HMD system installed in the Sendagaya INTES building in Tokyo in 1991. As shown in Fig 13, the HMD was installed atop the 11th floor and consists of two masses to control transverse and torsional motions of the structure, while hydraulic actuators provide the active control capabilities. The top view of the control system is shown in Fig 14 where ice thermal storage tanks are used as mass blocks so that no extra mass must be introduced. The masses are supported by multi-stage rubber bearings intended for reducing the control energy consumed in the HMD and for ensuring smooth mass movements.

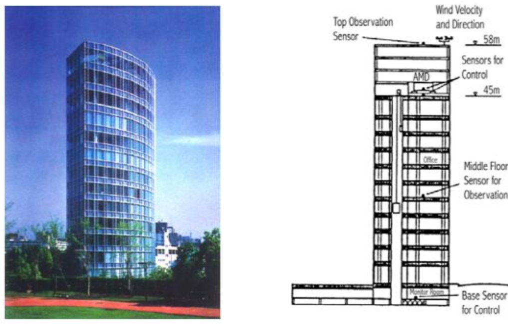


Fig 13: Sendagaya INTES Building.

The response of this building at the fundamental mode has been reduced by 18% and 28% for translation and torsion, respectively. Similar performance characteristics were observed during another series of earthquakes in 1990s.

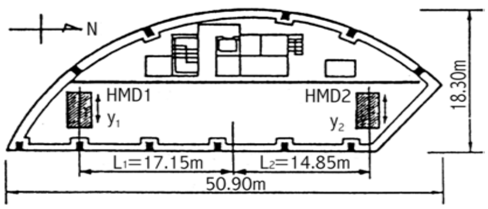


Fig 14: Top view of HMD

Some of the actual applications of these systems worldwide are given in Table 1.

Table 1: Application

Location	**Building**	**Year**	**No. of stories**	**Type of control**
Japan	Kyobashi Bldg, Tokyo	1989	11	AMD
Japan	Kansai Int'l Airport, Osaka	1992	(88m)	HMD
Japan	Century Park Tower, Tokyo	1999	54	HMD
Japan	Osaka Resort City 200, Osaka	1993	50	AMD
USA	Highway Bridge, OK	1997		SAHD
Taiwan	TC Tower, Kaohsiung	1999	85	HMD
China	Nanjing Communication Tower	1999	(310 m)	AMD

IX. CONCLUSION

In spite of enough research in active structural control systems, there is a gap between the latest active control technology and some intended purposes. Some of these include mitigating higher level hazards, economical and ease of construction, etc. One of the goals of active control research is to protect structures against unlikely to occur but highly damaging earthquakes. However, the active control devices are currently deployed in many cases, are used for occupants' comfort. Also, active control systems remain to be one of only a few mechanisms for structural protection against near-field and high-consequence earthquakes. Second goal is to add economy and flexibility to structural design and construction.

An active structure [6] is defined as one consisting of two types of load resisting members- the traditional members that are designed to support design loads, and dynamic members whose function is to help the structure in resisting dynamic loads. An active structure is conceptually and physically different from a structure that is actively controlled in that, the latter is a conventional structure supplemented by an active control device. The structure and control system are designed and optimized individually. Whereas, an active structure has active and passive components integrated and simultaneously optimized. For example [7], the Kurusima Bridge in Shikoku area, Japan, was designed with the application of active vibration control as integrated structural components. Several modes of the bridge-tower were protected by suitable controllers during the construction phase. This facilitated lighter and more slender construction of the tower than the one with traditional design. Therefore, control systems can be effectively used if designed with extensive analysis and optimized.

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