A LITERARY REVIEW OF STRUCTURAL CONTROL: EARTHQUAKE FORCES

TECHNICAL RESEARCH PAPER

BY

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INTRODUCTION

Any structure that is built must be designed with certain forces in mind. Some of the forces that buildings must withstand are live and dead loads. Dead loads refer to loads that are permanent and do not move. Live loads refer to loads that move. Other forces that play a big role in the overall strength of a building are: wind, snow, earthquakes, and waves. Many buildings have been built as passive structures. Passive structures use their mass and solidity to resist forces. As passive structures, they can not adapt to a changing environment. With the passing years, structural safety is of great importance. Many factors have surfaced as keys to building better buildings. These factors are: flexibility, safety, material, and lower costs. Thus, structural control takes on a new technology that permits the design of lighter structures with control. The new concepts of structural protection are: damping, passive control, and active control. [5]

Passive control systems include base isolation systems, bracing systems, friction dampers, and viscoelastic dampers. Active control systems encompass active mass dampers, active mass drivers, active tendon systems, pulse thrusters and active variable stiffness systems. Active structural control is now an area of heavy research for its means of controlling systems through an external energy supply. Active control works well with the use of new materials and new construction methods. It also safeguards against structures with excessive vibrations. Both active and passive control can be used to protect buildings that exceed 500 stories. This control system is known as hybrid active-passive control. Hybrid active-passive control can be used in the support of existing buildings. Active control can be a means to protect such buildings and extend their life.

Active control acts as a means of extra protection for structures that are at high risk for seismic activity. Passive control devices are also used to protect some existing structures, or buildings in areas of low seismic activity. The overall idea of active control is a revolutionary one. It has the capability to elevate structural concepts from a static and passive level to a dynamic and adaptable level. [6,7] However, active control may not be the most cost affective measure in protecting buildings that are in areas of low risk for earthquakes.

This paper will cover some of the different active control systems that are in current use today. It will act as a brief literary review of active structural control with a comparison to a passive control system that is the basis for the design of the General Motors Vehicle Engineering Center (VEC), currently under construction in Warren, Michigan. The VEC is part of the General Motors Southeast Michigan Project, with PB Automotive Division as the program manager. Different ideas and concepts have helped with the performance of structures. The use of active control is just one of the control measures being used and planned to be used to protect structures against earthquakes and vibrational forces. Passive control improves the performance of structures through the use of materials or devices with lower cost impacts

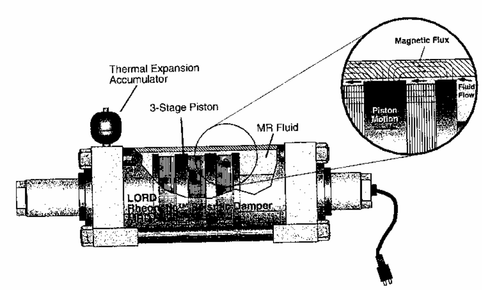
DAMPING

Damping is the dissipation of energy from an oscillating system, primarily through friction. The kinetic energy is transformed into heat. Dampers (mechanical systems) can be installed to increase the damping rate. Attention has been devoted to active control of engineering structures for earthquake hazard mitigation. These type of control systems are often referred to as protective systems and have the advantage of being able to dynamically modify the response of a structure in order to increase the safety and reliability.

MAGNETO-RHEOLOGICAL (MR) FLUID DAMPER

One of the most promising classes of semi-active control devices is the magneto-rheological (MR) damper. It overcomes the expenses and technical difficulties associated with other types of semi-active devices. The development of MR fluids and devices can be credited to Jacob Rabinow at the US National Bureau of Standards in the late 1940s. The fluids are materials that respond to an applied magnetic field with a dramatic change in rheological behavior. The outstanding characteristic of these fluids is their ability to reversibly change from free- flowing, linear viscous liquids to semi-solids having controllable yield strength in milliseconds when exposed to a magnetic field. Through simulations and laboratory model experiments, it has been shown that a MR damper, used in connection with the proposed acceleration feedback strategies, outperforms passive damping configurations. Figure 1 shows a schematic of a 20-ton MR fluid damper.

Fig. 1. Schematic of 20-ton MR fluid damper.[1]



[1] Picture taken from "Smart Dampers-Full Scale Model" by Billie F. Spencer.

MR fluid dampers have provided technology that has enabled effective semi-active control in a number of real world applications. The simplicity of the low input power allows for more engineering application.

VARIABLE-ORFICE DAMPERS

A variable damping device can be achieved by using an electromechanical, variable-orfice valve to alter the resistance to flow of a conventional hydraulic fluid damper. Figure 2.1 shows a schematic of a variable-orfice damper. Feng and Shinozuka, Kawashima and Unjoh discovered this concept. The effectiveness of variable-orfice dampers in controlling seismically excited buildings has been demonstrated through both simulation and small-scale experimental models. The results of the studies showed that the device was effective in reducing structural responses. [4]

Fig. 2.1. Schematic of a variable-orfice damper[2]

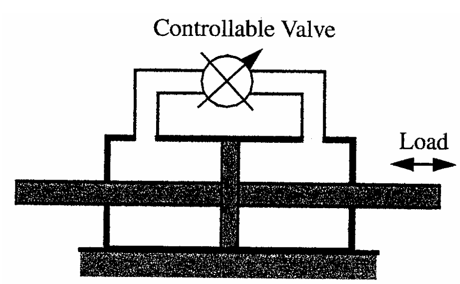
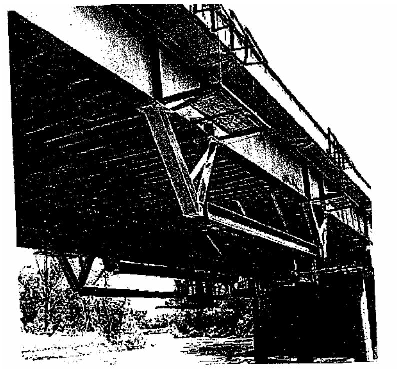


Figure 2.2 shows an actual full-scale model of a hydraulic actuator with a controllable orifice implemented in a single-lane model bridge to dissipate the energy induced by vehicle traffic.

[2] Taken from " Smart Dampers" by Billie F. Spencer

Fig.2.2. Full-Scale Experiment on Interstate 35 in Oklahoma[3]

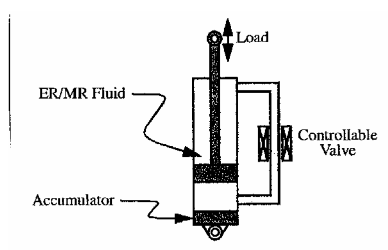


Variable semi-active devices have been used to utilize forces generated by surface friction to dissipate vibratory energy in a structural system. The ability of semi-active devices to reduce drifts within a high story building that is seismically excited has been investigated. With much success, the friction controllable system has been employed in conjunction with a seismic isolation system.

CONTROLLABLE TUNED LIQUID DAMPERS

Another type of semi-active control device is a controllable tuned liquid damper. It utilizes a sloshing fluid or a column of fluid to reduce the responses of a structure. In a tuned mass damper, the liquid in a sloshing tank is used to add damping to the structural system. The passive system has a fixed design, which is shown in figure 2.3. It is not very effective for a wide variety of loading conditions. [4]

Fig. 2.3. Schematic of controllable fluid damper[4]



[3] Taken from " Smart Dampers" by Billie F. Spencer
[4] Taken from " Smart Dampers" by Billie F. Spencer

HYBRID MASS DAMPER

The hybrid mass damper (HMD) is a common device used in full-scale civil engineering buildings. The HMD is actually a combination of the tuned mass damper and an active control actuator. The efficiency of the HMD relies on the forces from the control actuator. A typical HMD requires less energy to operate than a fully active mass damper system.

ACTIVE MASS DAMPER

An active mass damper (AMD) is a small-auxiliary mass that is installed on one of the upper floors of a building. An actuator is connected between the auxiliary mass and the structure. Response and loads are measured at key locations on the building and sent to a control computer. The computer then processed the information according to an algorithm and sends the appropriate signal to the AMD actuator. The actuator then reacts by applying inertial control forces to the structure to reduce the structural responses in a desired manner.

PASSIVE CONTROL SYSTEMS

Passive control systems relate to uncontrolled dampers, which require no input power to operate. They are simple and generally low in cost, but are unable to adapt to changing needs. Passive control systems are most commonly used in new and existing buildings that are in low seismic areas. Passive systems include base isolation systems, friction dampers, viscoelastic dampers, and bracing systems.

Base Isolation systems are used to isolate the dynamic force transfer from the structure to the base. Friction dampers consist of a steel plate and two plates holding the steel plate from both sides. All plates work together to absorb energy by friction as the building deforms due to seismic activity. Viscoelastic dampers attenuate the force due to external and seismic loads. Bracing systems are used to permanently stabilize buildings from external forces such as wind loads and earthquakes.

GENERAL MOTORS VEHICLE ENGINEERING CENTER

Under General Motors Southeast Michigan Project, the Vehicle Engineering Center (VEC) is currently under the guided construction and program management by Parsons Brinckerhoff Automotive Division. The VEC was designed as a passive control system that utilizes a brace frame system to resist external forces such as wind and seismic activity. The VEC once completed will stand approximately 160 feet high, 600 feet long, and 185 feet wide. Pinned columns are used to support the building vertically. Thirteen (13) permanent brace frame systems were designed to stabilize the building's lateral forces. All forces and loads acting on the building will be transferred through the beams through the "K" braces to base resistance. A small lake will surround the building causing uplift forces to also be a consideration. The design wind load for the VEC is 80 mph and the seismic hazard exposure group is two. Thus the most cost affective design favored a passive control system. Figure 3 shows a current view of the building under steel erection.

[5]**Figure 3. VEC Steel Erection**

[5] Photo taken from web-site: www.warrentechcenter.com

CONCLUSION

The overall objective of this paper was to briefly review the literary works of structural control. Structural control is being researched and currently being employed on existing and new buildings to protect against seismic activity. The structural control systems that were discussed were based on passive control, active control, and a combination of passive and active control. The passive control system absorbs the vibrations automatically without the need of an electrical control system. Passive control systems are generally low in cost and affective for support of buildings in low structural risk areas. The General Motors Vehicle Engineering Center gave an example of a braced frame system that is designed to stabilize the building against wind loads and any seismic activity while operating within a fixed budget. Active control systems use computer controlled actuators to produce the best performance. Active mass dampers are used to suppress the oscillation of a building by actuating a weight to control axial forces. Active mass dampers are very effective in controlling oscillations in high winds and in medium-sized earthquakes. Researching each control system is necessary to determine which will produce the required performance. Structural control systems have and will allow for new designs that produce safer, comfortable, and earthquake protected civil engineering structures.

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