Earthquake resistance of structures using dampers - a review

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Abstract: During the last decade more and more attention has been put to vibration mitigation of structures subjected to environmental (i.e. seismic and wind loads) and manmade (i.e. traffic or heavy machinery) loads. In this paper an overall control system is explained in brief and also various applications of control system. Now a day a Sevier Earthquake occurs over globally, it is necessary that structure build across the seismic zone built under considerations of seismic resistance. The seismic resistance can be done by using control devices. The control devices are damper. The damper can be classified into various categories based on its functions or control system. The control system classifications are Active, Passive, Hybrid and Semi active control system. Passive control system is internally energy develops, Active requires external power, Semi active requires partially power consumptions. Numerical applications of control system are explained. The overall conclusions say that Semi active control system is more suitable compare to other control system.

Keywords: Active control, Semi active Control, Passive Control, Dampers, MR Dampers

1. Introduction
For a decade, many strong earthquakes have occurred one after another in many countries. These earthquakes have caused severe damages to large-scale infrastructures. To protect structures from significant damage and response reduction of structures under such severe earthquakes has become an important topic in structural engineering. Conventionally, structures are designed to resist dynamic forces through a combination of strength, deformability and energy absorption. These structures may deform well beyond the elastic limit, for example, in a severe earthquake. It indicates that structures designed with these methods are sometimes vulnerable to strong earthquake motions. In order to avoid such critical damages, structural engineers are working to figure out different types of structural systems that are robust and can withstand strong motions. Alternatively, some types of structural protective systems may be implemented to mitigate the damaging effects of these dynamic forces. These systems work by absorbing or reflecting a portion of the input energy that would otherwise be transmitted to the structure itself.

In such a scenario, structural control techniques are believed to be one of the promising technologies for earthquake resistance design. The concept of structural control is to absorb vibration energy of the structure by introducing supplemental devices. Various types of structural control theories and devices have been recently developed and introduced to large-scale civil engineering structures.

2. Control Systems
During the last decade more and more attention has been put to vibration mitigation of structures subjected to environmental (i.e. seismic and wind loads) and manmade (i.e. traffic or heavy machinery) loads. Such a structures needs to be protected against vibrations in order to improve the safety and durability.

Different types of structural control devices have been developed and a possible classification is done by their dissipative nature. Structural control systems can be classified as passive, active, semi-active and hybrid. (Datta T.K. 2003 and Housner et al 1997)

2.1 Passive Control Devices
A passive control device is a device that develops forces at the location of the device by utilizing the motion of the structure. Through the forces developed, a passive control device reduces the energy dissipation demand on the structure by absorbing some of the input energy (Soong and Dargush 1997) [As Shown in Figure 1(b)]. Thus, a passive control device cannot add energy to the structural system. Furthermore, a passive control device does not require an external power supply. Examples of passive devices include base isolation, tuned mass dampers (TMD), tuned liquid dampers (TLD), metallic yield dampers, viscous fluid dampers and friction dampers.

2.2 Active Control Devices
The active control systems are the opposite side of passive systems, because they can provide additional energy to the controlled structure and opposite to that delivered by the dynamic loading (Soong 1990) [As shown in Figure 1(c)]. Active control devices require considerable amount of external power to operate actuators that supply a control force to the structure. An active control strategy can measure and estimate the response over the entire structure to determine appropriate control forces. As a result, active control strategies are more complex than passive strategies, requiring sensors and evaluator / controller equipments. Cost and maintenance of such systems are also significantly higher than that of passive devices (Soong and Spencer 2002). Examples among active control devices include active tuned mass damper, active tuned liquid column damper and active variable stiffness damper.
2.3 Semi-Active Control Devices
Semi-active control devices combine the positive aspects of passive and active control devices. Like passive control devices, semi-active control devices generate forces as a result of the motion of the structure and cannot add energy to the structural system. However, like an active control device, feedback measurements of the excitation and/or structural system are used by a controller to generate an appropriate signal for the semi-active device (Symans and Constanti nou 1999, Spencer and Nagarajaiah 2003) [As shown in Figure 1 (e)]. In addition, only a small external power source is required for operation of a semi-active control device. Examples of semi-active devices include variable orifice dampers, variable friction dampers, variable stiffness damper, and controllable fluid dampers.

2.4 Hybrid Control Devices
A hybrid control system typically consists of a combination of passive and active or semi-active devices (Soong and Spencer 2002) [As shown in Figure 1 (d)]. Because multiple control devices are operating, hybrid control systems can alleviate some of the restrictions and limitations that exist when each system is acting alone. Thus, higher levels of performance may be achieved. Since a portion of the control objective is accomplished by the passive system, less active control effort, implying less power resource, is required. A side benefit of hybrid systems is that, in the case of a power failure, the passive components of the control still offer some degree of protection, unlike a fully active control system. Examples of hybrid control devices include hybrid mass damper and hybrid base isolation.

3. Control Theories
Active and semi-active damper systems are typically highly non-linear. One of the main challenges in control is the development of an appropriate control theory that can take advantage of the features of the control device to produce an effective control system. These control theories are described in this section.

3.1 Active Control Devices
The different control theories are based on control system with both time varying and lumped parameters control operations. Some of the control methods (algorithms) are shown below.

The mathematical equation of motion for all control methods has the following structure:

\[ M\ddot{x} + C\dot{x} + Kx + AF = -M\Gamma\ddot{x}_g \]  

Where, \( M \) is the mass matrix, \( C \) is the damping matrix, \( K \) is the stiffness matrix, \( x \) is the vector of floor displacements, \( \dot{x} \) and \( \ddot{x} \) are floor velocity and acceleration vectors, respectively, \( A \) is a matrix of zeros and ones, where one will indicate where the MR damper force is being applied.

\[ F = [f_{d1}, f_{d2}, \ldots, f_{dn}]^T \]  

is the vector of control force produced by the dampers, \( \Gamma \) is the influence coefficient vector of ones and \( \ddot{x}_g \) is the acceleration due to an earthquake. Different control algorithms developed for the active control include: (i) Linear Optimal Control, (ii) Pole Assignment Technique, (iii) Independent Modal Space Control, (iv) Instantaneous Optimal Control, (v) Bounded State Control, (vi) Non-linear Control, (vii) Generalized Feed-Back Control, (viii) Sliding Mode Control (SMC), (ix) Time Delay Compensation, (x) Neural Network and Fuzzy Logic.

3.2 Semi-Active Control Devices
Most of the algorithms and control for semi-active control are studied for the variable damping. Different control algorithms developed for the variable dampers include: (i) Lyapunov stability approach, (ii) Decentralized bang-bang control, (iii) Clipped optimal control, (iv) Modulated homogeneous friction control, and (v) Riccati matrix solution technique. Recently, neural network and fuzzy control has also been used for the semi-active variable devices.

4. Applications of Passive Control
Over 200 bridges have been seismically isolated with about one half of the applications being in new bridges. In Japan, USA and New Zealand the lead-rubber bearing is the favored device while in Italy viscous and steel hysteretic dampers are used. In Japan seismically isolation has been applied to new buildings the largest being the C-1 building (an office building in Tokyo (LRB)), the T-l building (a computer centre in Tokyo (LRB)), and the Matumura Research Institute (a small laboratory (HDRB)).

In the USA, the applications have been mainly with the retrofit of seismic isolation to existing buildings including the city halls of Oakland (LRB), Los Angeles (HDRB), San Francisco (LRB), US Court of Appeals in San Francisco (Friction Pendulum). In New Zealand there are two large seismic isolation projects that have been completed. These were the retrofitting of isolation to the NZ Parliament Building and the associated Assembly Library and the new Museum of NZ. Both of these use LRB systems.

Three isolated buildings performed extremely well in earthquakes: the USC Teaching Hospital in Los Angeles (LRB) in 1994, the Computer Centre of the Ministry of Post and Telecommunications (LRB) in 1995, and in 1995 the Matumura Research Institute building in Kobe. The performance of these three buildings in real earthquakes illustrates the huge advantages of seismically isolation with these structures being able to continue to operate during and immediately after an earthquake with no break in utilization.
The application of viscoelastic materials to vibration control of civil engineering structures appears to begin in 1969 when approximately 10,000 viscoelastic dampers were installed in each of the twin towers of the World Trade Center in New York to reduce wind-induced vibrations.

In addition to World Trade Center in New York viscoelastic dampers have been utilized in other buildings. In the 1980s, the Columbia Sea First and Two Union Square buildings in Seattle utilized the dampers to reduce wind-induced vibrations. In 1994, the Chien-Tan railroad station roof in Taipei, Taiwan, utilized the dampers to reduce wind-induced vibrations. In addition, seismic retrofit projects using viscoelastic dampers have been completed for the 13-story steel-frame Santa Clara County building in San Jose, Calif and a Navy-owned three-story lightly reinforced concrete building in San Diego. The applications of friction dampers to the McConnel Library of the Concordia University in Montreal, Canada, a total of 143 dampers were employed in this case.

Viscous fluid dampers have in recent years been incorporated into a large number of civil engineering structures. In several applications, they were used in combination with seismic isolation systems. In 1995, VF dampers were incorporated into base isolation systems for five buildings of the San Bernardino County Medical Center, located close to two major fault lines. The five buildings required a total of 233 dampers.

5. Applications of Active Control

Some actual applications of active control schemes for the reduction of wind-induced vibrations of tall buildings have been reported. These control schemes have also been found to control the seismic response of buildings to moderate earthquakes. Salient features of three such applications on tall buildings are presented below:

AMD on Kyobashi Seiwa Building is located at Chuo-Ku, Tokyo, with a frontage of 4 m and a total height of 33 m. The building has 11 floors, and is made of rigid steel frames. Two AMDs are located at the top floor, spaced apart. First AMD has a mass of 4 ton, and second one has a mass of 1 ton. The idea of providing two AMDs was to control the torsional response of the structure also. A hydraulic pump of 22 kW is used to actuate the masses. Sensors are placed at the basement, 6th floor, and at the 11th floor. The computer is provided on the top floor itself. This is the world’s first AMD installed on a building.

Duox on ANDO Nighikicho is located in Chiyoda–Ku, Tokyo. It has 14 storeys and two basement levels, and is made of rigid steel frames. Above the ground, weight of the building is 2600 t-f. Two-directional simultaneous AMD is placed on the top of a TMD which is placed on the top floor. The damping system of the TMD consists of oil dampers. The TMD weight is 18 t-f, while the AMDs have 2 t-f weight each. The Duox system operates on the principle that if the active control system fails, the TMD will provide at least the minimum control of response.

Trigon on Shinjuku Tower is located in Shinjuku–Ku, Tokyo, with a floor area of 264,100 m². The structure is made of steel and partially reinforced concrete frames. It is a 52-storeyed plus 5- basement structure, with a above-ground weight of 130,000 t-f. Three control devices are installed in the form of roller pendulum mass on the 36th floor. The control masses are 110 t each. Maximum stroke of the pendulum is 110 cm. Period adjusted is 3.7258 s, and the motor capacity to drive the pendulum is 75 kW.

6. Practical Application of Semi-Active Control

As theoretical research on semi-active control devices has shown significant promise in vibration control of structure researchers have progressed to apply semi-active control in actual civil engineering applications. Most of the practical applications of semi-active control devices to civil structures are found in Japan and to a greater extent in their building structures.

The first semi-active controlled 5-storey, Kajima Shizuoka Building was constructed in Shizuoka, Japan, in 1998. Here, semi-active hydraulic dampers are installed inside the walls on both sides of the building to enable it to be used as a disaster relief base in post earthquake situations. Each damper contains a flow control valve, a check valve and an accumulator, and can develop a maximum damping force of 1000 kN.

In the United States, the first full-scale implementation of semi-active variable stiffness damper was conducted on the Walnut Creek Bridge in Oklahoma, on interstate highway I-35 to demonstrate variable-damper technology.

The 27-storey Laxa Osaka building was constructed in Osaka, Japan in 1999 and employed semi-active TMD. The 11-storey building CEPCO Gifu constructed in Gifu, Japan, in 2000 used semi-active dampers. Here, for both the buildings actuation mechanism of variable-orifice hydraulic damper was used.

In 2000, the world’s first smart base isolated 9-storey building was constructed at the Keio University School of Science and Technology, Tokyo in Japan. This building employs variable-orifice dampers in parallel with traditional damping mechanisms. In this scheme, large deformations of the isolators are prevented by variable-orifice damper by controlling the damping coefficient of oil dampers.

In 2001, the first full-scale implementation of MR dampers for civil engineering applications was achieved. The Nihon-Kagaku- Miraikan, the Tokyo National Museum of Emerging Science and Innovation, has two 30-tons, MR fluid dampers installed between the third and fifth floors.
The use of the variable-orifice damper has blossomed in Japan. The Siodome Tower, of a 38-storey hotel and office complex was installed with 88 semi-active dampers. In the Roppongi area of Tokyo, the Mori Tower, a 54-storey building uses 356 variable-orifice dampers. Altogether, in Japan, the Kajima Corporation has recently finished nine buildings that employed a total of nearly 800 variable-orifice dampers for their buildings as structural control systems.

The Dongting Lake Bridge in Hunan, China retrofitted with stay-cable dampers, was the first full-scale implementation of MR dampers for bridge structures. Two Lord SD-1005 MR dampers are mounted on each cable to mitigate cable vibration. A total of 312 MR dampers are installed on 156 stayed cables. In 2003, MR dampers have been opted for implementation on the Binzhou Yellow River Bridge in China to reduce cable vibration.

7. Application of Hybrid Control

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. An example of such an application is the HMD system installed in the Sendagaya INTES building in Tokyo in 1991. 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.

8. Conclusions

Finally we are conclude that control systems are classified as passive control, active control, semi-active control, and a combination of passive and active or semi-active control. The passive control system are vary low cost compare to other control system and also works (absorbs vibrations) without external power consumptions. Active control systems use computer controlled actuators to produce the best performance. Active mass dampers are very effective in controlling oscillations in high winds and in medium sized earthquakes. Semi-active devices combine the best features of both passive and active control systems and offer some adaptability, similar to active control systems, but without the requirement of large power sources for their control action. The hybrid control uses active control with a passive control to supplement and improve the performance of the passive control system and to decrease the energy requirement of the active control system. Structural control systems will allow seismic resistance and safer design of building of civil engineering structures.

REFERENCES


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Figure 1a: Conventional Structure

Figure 1b: Structure with Passive Energy Dissipation (PED)

Figure 1c: Structure with Active Control

Figure 1d: Structure with Hybrid Control