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Vibration Control of Elevated Water Tank Using Different Seismic Control Techniques – A Review

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Abstract: A review is presented for vibration suppression of elevated water tank. 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. Water tanks are important components of lifeline and industrial facilities. During the earthquakes that more number of tank damages has been observed, this shows that it is necessary to choose new methods to improve the seismic resistance of elevated water tank (EWT). A supplemental device is one of the effective methods to improve the energy dissipation and vibration control of Elevated Water Tank. Seismic dampers are special supplemental devices introduced in the building to absorb the energy provided by the ground motion to the building. The damper can be classified into various categories based on its functions or control system; such as Passive, Active and Semi active control system. This paper first presents basics about seismic control systems and the reviews of work done on elevated water tank.. Then this paper reviews introduction into the application of piezoelectric friction damper in various civil structures such as beams, trusses, steel frames and cable-stayed bridges.

Keywords: Elevated Water Tank, Seismic Control Systems, Piezoelctric Friction Damper.

1.1. Introduction

Structural active vibration control has always received considerable research attention by the civil engineering community among the control approaches. 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. Most of the structures are subjected to vibrations. These vibrations may arise from wind forces, earthquake excitation, machine vibrations or many other sources. In some cases, especially under strong earthquake excitations, these vibrations can cause structural damage or even structural collapse.

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 motion. 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 the construction of concrete structure for the storage of water and other liquids the imperviousness of concrete is most essential. The Elevated Water Tank consists of tank supported by staging system composed of columns, braces and foundations. Large number of tank collapses has been observed during earthquakes from, as early as the 1906 San Francisco Earthquake to the 2001 Bhuj earthquake. The observed damages in recent earthquakes show that it is necessary to choose new methods to improve the designing of structures. In many earthquake prone countries, buildings are continuously being retrofitted or constructed with control devices to reduce stresses, displacements and base shear during seismic activity [2].

Intelligent or smart or adaptive structures are a subset of active structures that have highly distributed actuator and senor systems with structural functionality and in addition distributed control function and computing architecture. By the modern development of civil engineering, the vibration of structures is being introduced. Real-time structural health monitoring and vibration control systems can provide instantaneous information on a condition of a specified structure such as huge bridges and towers that will result in a significant increase of safety margin and reductions in maintenance cost. Also recent advances in smart sensor technologies have provided various tools for structural vibration control of civil engineering structures and introduced a concept of smart structures. 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. The higher the inherent or natural damping in structures, lower will be the likelihood of damage. However, for structures subjected to strong vibrations, the inherent damping in the structure is not sufficient to mitigate the structural response. In many situations, supplemental damping may be used to control the response of these structures. In this regard, many researchers were studied, developed and tested different supplemental damping techniques. These dampers used widely in many retrofitting projects all over the world, because of their low cost and good performance.

1.2. Seismic control Systems

Conventional seismic design attempts to make structures that do not collapse under strong earthquake shaking, but may sustain damage to nonstructural elements (like glass facades) and to some structural members in the building. This may render the structure non-functional after the earthquake, which may be problematic in some structures, like hospitals, water tanks, which need to remain functional in the aftermath of the earthquake. Special techniques are required to design buildings such that they remain practically undamaged even in a severe earthquake. Structures with such improved seismic performance usually cost more than normal structures do. However, this cost is justified through improved earthquake performance.

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. Seismic damage in buildings could be controlled by installing dampers in the form of diagonal bracing. These dampers act like the hydraulic shock absorbers in cars - much of the sudden jerks are absorbed in the hydraulic fluids and only little is transmitted above to the chassis of the car. When seismic energy is transmitted through them, dampers absorb part of it, and thus damp the motion of the building. Different types of structural control systems have been developed to increase structural resistance against lateral loads. A possible classification is done by their dissipative nature. Structural control systems can be classified as passive, active, semi-active and hybrid.

Conventional Systems	Isolation Systems	Supplemental Damping Systems	
		Passive Damper	Active/Semi-Active Dampers
Flexural Plastic Hinges	Elastromeric Lead Rubber	Metallic Friction	Braces Tuned mass
Shear Plastic Hinges	High- Damping Rubber	Viscoelastic	Tuned- Liquid
	Metallic	Viscous	Variable Damping
Yielding Braces	Lead- Extrusion	Tuned- Liquid	Piezoelectric
	Friction Pendulum	Self centering	Rheological

Table 1.2.1: Seismic control Systems

1.2.1 Conventional Systems

These systems are based on traditional concepts and use stable inelastic hysteresis to dissipate energy. This mechanism can be reached by plastic hinging of columns, beams or walls, during axial behavior of brace elements by yielding in tension or buckling in compression or through shear hinging of steel members. Passive devices work without any type of sensing equipment or computation. These are the least expensive and most widely used devices.Figure1.1 shows the conventional system.

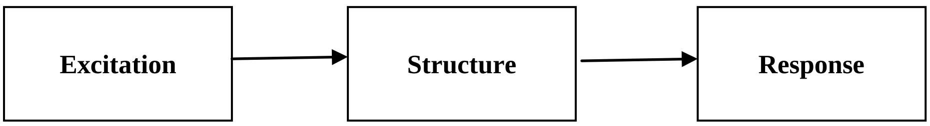

Figure1.1: Conventional System

1.2.2 Isolation Systems

Isolation systems are usually employed between the foundation and base elements of the structures also between the deck and the piers of bridges. These systems are designed to have less amount of lateral stiffness relative to the main structure in order to absorb more of the earthquake energy. A supplemental damping system could be attached to the isolation system to reduce the displacement of the isolated structure as a whole.

1.2.3 Supplemental Damping Systems

Supplemental damping system can be categorized in three groups as passive, active and semi-active systems. These dampers are activated by the movement of structure and control structural displacements by dissipating energy via different mechanisms.

Active systems monitor the structural behavior, and after processing the information, in a short time, generate a set of forces to modify the current state of the structure. Generally, an active control system is made of three components: a monitoring system that is able to perceive the state of the structure and record the data using an electronic data acquisition system; a control system that decides the reaction forces to be applied to the structure based on the output data from monitoring system and; an actuating system that applies the physical forces to the structure. To accomplish all these, an active control system needs continuous external power source. The loss of power that might be experienced during a catastrophic event may render these systems ineffective.

Semi-active systems are similar to active systems except that compared to active ones they need less amount of external power. Instead of exerting additional forces to the structural systems, semi-active systems control the vibrations by modifying structural properties (for example damping modification by controlling the geometry of orifices in a fluid damper). The need for external power source has also limited the application of semi-active systems.

Passive systems dissipate part of the structural seismic input energy without any need for external power source. Their properties are constant during the seismic motion of the structure and cannot be modified. Passive control devices have been shown to work efficiently; they are robust and costeffective. As such, they are widely used in civil engineering structures. The main categories of the passive energy dissipation systems are listed in table.

Displacement- Activated	Velocity Activated	Motion Activated
Metallic dampers Friction dampers Self-Centering dampers	Viscous Dampers	Tuned Mass Damper Tuned Liquid Damper

Table 1.2: Types of Passive Dampers

1.3. Literature Review

Asari Falguni P and Prof.M.G.Vanza [1]. analyzed the results of an analytical investigation of the seismic response of elevated water tanks using fiction damper. They studied behavior of RCC elevated water tank with using friction damper (FD). Non-linear time-history dynamic analysis were carried out using the computer program SAP2000. These values were compared with original structure. Results of the elevated tank with FD are compared to the corresponding fixed-base tank design and indicate that friction damper is effective in reducing the tower drift, base shear, time period, and roof acceleration for the full range of tank capacities. From this analysis, he concluded that friction damper significantly reduces the dynamic response of structure in terms of acceleration, base shear and time period. And also proved that the performance of friction damper used in water tank is better than without FD. And finally concluded that Friction Damper also improve ductility in structure.

Dr. Suchita Hirde & Dr.Manoj Hedaoo [2].studied seismic performance of the elevated water tank for various seismic zones of India, for various heights and capacity of elevated water tanks for different soil conditions. The effect of height of water tank, earthquake zones and soil conditions, earthquake forces has been presented in this paper with the help of analysis of 240 models of various parameters. In this paper, the study was carried out on RCC circular elevated water tank with M-20 grade of concrete and Fe-415 grade of steel are considered for analysis. Elevated water tank having 50,000 liters and 100,000 liters capacity with staging height 12 m, 16 m, 20 m, 24 m, 28 m considering 4 m height of each panels are considered for the study. Author has given following conclusions from his analysis – (1)

Seismic forces are directly proportional to the Seismic Zones. (2) Seismic forces are inversely proportional to the height of supporting system. (3) Seismic forces are directly proportional to the capacity of water tank. (4) Seismic forces are higher in soft soil than medium soil, higher in medium soil than hard soil. Earthquake forces for soft soil is about 40-41% greater than that of hard soil for all earthquake zones and tank full and tank empty condition.

K. Krishne Gowda and K. K. Kiran[3]. explained an overall control system and also various applications of control system. 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 develops energy internally, Active requires external power, Semi active requires partially power consumptions. They conclude that semi-active control systems are very low cost compare to other control system and also works (absorbs vibrations) with less external power consumptions.

H. Metwally, B. El-Souhily and A. Aly [4]. studied vibration control of buildings due to earthquake effect. The model was subjected to the horizontal component of the earthquake, which has a larger effect than the vertical component. Newton's second law of motion is applied to obtain the mathematical model of the structures. Magneto- Rheological (MR) dampers are placed between the stories. The MR damper (depending on the control algorithm used) gives a better reduction in the maximum absolute acceleration, also an excellent reduction in the maximum inter-story displacement; also the maximum displacement of the top story is reduced. The effect of changing the frequency of excitation on the responses of the building model was studied. Effect of changing building's stiffness on the responses with the MR damper is also considered. Two major earthquake motion records were used as inputs in the analyses. This study addresses the use of semi-active dampers for the seismic response reduction of buildings under seismic loads. It was seen that the control system is more effective for flexible structures.

Nikil N. Pujari and S.V. Bakre[5] investigated the seismic effectiveness of the X-plate damper (XPD) for square shaped building. The seismic responses of a square shaped building are then studied under important parametric variation of the damper properties under real earthquake ground motions to obtain the optimum properties of the XPD. Damper properties considered were height, width and thickness of the XPD. The seismic responses of a square shaped building were then studied under important parametric variation of damper properties under real earthquake ground motions to obtain the optimum properties of XPD. They found XPDs are very effective in reducing the seismic response of square shaped building. The building considered for their study was a G+3 square shaped building with fixed XPDs. Damper were placed in the form of diagonal braces with connecting lugs. All the numerical analysis was performed in SAP2000. The seismic response of building system with an XPD was investigated under uni-directional (X-direction) excitation of four components of real earthquake ground motions. They concluded that XPDs are very effective in reducing the seismic response of square shaped building. The effectiveness of the XPD increases as the percentage energy dissipated by the XPD increases implying that the dissipated energy controls the effectiveness of the XPD in the controlled square shaped building .The energy dissipated in the square shaped building is dependent on the thickness of the XPD and input ground motion. As thickness increase the amount of energy dissipated by XPD increases.

N. N. Pujari and S. V. Bakre[6] studied that, an X- plate damper (XPD) is one device that is capable of sustaining many cycles of stable yielding deformation resulting in a high level of energy dissipation or damping. They focus on effect of placement of X-Plate damper on square shaped buildings. The most optimal damper placement location is selected from some fixed location formats. To highlight the effect of optimal location of XPD on the response reduction, five different location configurations of the XPDs are considered. In these study, one building frame without XPD and one with XPDs in all bays. The response and optimal locations of XPDs are checked for three different heights of buildings namely G+3, G+5 and G+8. All these buildings are investigated under four real earthquake ground motions. Nonlinear Time History analysis is performed using structural analysis software SAP2000. The optimal placement of XPDs provides more reduction in response compared with other schemes of placement of XPD considered in the study. Furthermore, the optimal placement of dampers is sensitive to the nature of excitation force, number of XPDs used and the modeling of XPD.

Research has been carried out by Emili Bhattacharjee, LipikaHalder and Richi Prasad Sharma[7] to find the application of TLD in reducing the seismic vibration of the structure. They studied to reduce structural response by installing to sinusoidal external excitation. To study the effect of various parameters, which affects the structural response These parameters include the ratio of water depth to tank length, called water depth ratio, the ratio of sloshing frequency to structural natural frequency, called tuning ratio, and the ratio of excitation frequency to natural frequency of the structure, called excitation frequency ratio. A series of experimental tests were conducted on a scaled model of structure tuned liquid damper systems to evaluate their performance under harmonic excitation. One rectangular and one square TLD with various water depth ratios were examined over different frequency ratios and time histories of accelerations are measured by precisely controlled shaking table tests. The present study focused on the implementation of a tuned liquid damper for mitigation of structural response. A set of experiments were carried out for studying the sloshing phenomenon in a rectangular and a square tank under harmonic loading condition. They found the square TLD is less effective in comparison with the rectangular TLD for the controlling response of the structure and also found that TLD can be successfully used to control the response of the structure.

Uma Chaduvula, Deepam Patel and N Gopalakrishnan's[8] investigation aims at study of hydrodynamic behavior of elevated water tanks during multiple degree earthquake excitations experimentally. The values for studied parameters i.e. sloshing frequency, hydrodynamic pressure, base shear and tank acceleration and sloshing height are calculated for the same tank analytically the standard codes. They analysis the multiple base motion effect on hydrodynamic pressure, acceleration of tank and fluid surface elevation problem in Elevated water tank is understood as a Fluid-Structure-Soil Interaction problem. The aim of the experiment was to study the behavior of elevated steel water tank model during horizontal and vertical along with rocking earthquake motions. An experimental investigation for a 1:4 scale model of cylindrical steel elevated water tank has been carried out on shake table facility at CSIR-SERC, Chennai. The impulsive base shear and impulsive base moment values increase with increase in earthquake acceleration. The Non-linearity in structure is observed, when the impulsive pressure of tank decreases with increase in tank acceleration. The pressure variation along tank height due to vertical excitation increased with increasing acceleration, and increased furthermore with added rocking. Using various codes available on water tanks, the recorded experimental results were used to calculate and compare the base shear, base moment, pressure variation in the tank. The pressure variation along tank height due to vertical excitation increased with increasing acceleration, and increased furthermore with added rocking. Moreover, the stiffness of staging plays an important role in tank acceleration in magnifying the acceleration at the tank level.

Chirag N. Patel, Shashi N. Vaghela and H. S. Patel[9]. Investigation's main aim of this study was to understand the seismic behavior of the elevated water tank under alternate column proportionality under different time history records using finite element software SAP2000. It considered water as two mass idealizations suggested by Gujarat State Disaster Management Authority (GSDMA) guideline. Their work shows aims at checking the adequacy of water tank for the seismic excitations. The result shows that the structure responses are exceedingly influenced by different column proportionality and earthquake characteristics. The responses include sloshing displacement under the four different time-history have been compared and contrasted. They concluded that (1) the critical response depends on the earthquake characteristics and particularly frequency content of earthquake records. (2) Sloshing displacement is increase in the panel number and increase against high frequency earthquake.

1.4. Basics About Piezoelectic Dampers

The piezoelectric material converts mechanical energy into electric energy when the material is strained. This phenomenon is called the piezoelectric effect. A piezoelectric material can be applied as a strain sensor to detect the electric current or voltage caused by the piezoelectric effect. By shunting an appropriate circuit to the piezoelectric material, electric energy caused by the mechanical energy will be consumed as heat energy. As a result, mechanical energy inputted into a building structure in which piezoelectric dampers are installed is dissipated, resulting in a damping effect. The piezoelectric damper considered here consists of piezoelectric material and a shunted circuit (resistor, inductor and capacitor). Figure 1 shows a schematic of a piezoelectric damper.

The mechanism of a piezoelectric damper can simply be described by use of complex stiffness. In general, a piezoelectric material with complex stiffness can be evaluated by using the energy consumption ratio and damping factor from a phase angle diagram corresponding to its real and imaginary parts. The phase angle varies depending on frequency, electrical impedance of the shunted circuit, and the properties of the piezoelectric material. Thus, the damping factor and effective stiffness of the damper are controllable by adjusting the frequency and electrical impedance.

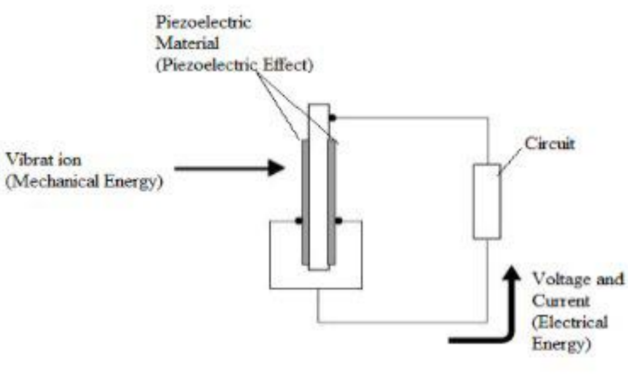

Fig1.schematic of a piezoelectric damper.

1.5. Summary & Conclusion

The available literature review show that performance of elevated water tank with friction dampers, tune liquid dampers and tune mass dampers is better than without damper. We observe that SAP2000v15 is suitable software for analysis Damper devices. Many of the researchers have worked on dampers in structures but, no work is reported on piezoelectric damper installed in Elevated Water Tank at different floor levels. Hence, further study will be carried out on of behavior of Elevated Water Tank using piezoelectric damper for seismic control, using structural software SAP2000v15 and validating it experimentally using shake table. Response quantities such as joint displacement and base shear will be obtained after non-linear time history analysis.

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