Study of Seismic Performance of Reinforced Cement Concrete Structures with and Without Viscous Damper

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Abstract: Tremendous energy from earthquake is induced on civil engineering structure, which leads to major devastation and heavy toll to life. In this paper, passive energy dissipating devices are studied so as to dissipate the unwanted energy due to heavy seismic and wind actions. Fluid viscous dampers which work on the principle of flow of fluid through orifice and require no external source of energy so as to dissipate the energy during seismic action are proved to be best energy dissipating by many researchers. In this paper, in depth study is done so as to understand the working of dampers and its impact on the dynamic properties of building structures.

Keywords: Fluid Viscous dampers, Earthquake, Dynamic properties of structure.

I. INTRODUCTION

Man has always lived with earthquakes. Some of them are so small that they are not even felt; others are so strong that they can destroy the entire city, cause major damage to infrastructure (bridges, buildings) and kills thousands of people. During a seismic event, the tremendous amount of energy emitted is transformed into kinetic and potential energy which must be either absorbed or dissipated through heat. In addition to the loads due to the effect of gravity, earthquake loading must be considered while designing structures in seismically active areas.

Tremendous research and advancement in the field of earthquake engineering has minimized the computational efforts of complex problems by using software packages and coding. From the previous records of catastrophic earthquakes such the 1985 Mexico City earthquake and 1989 Loma Prieta earthquake, which resulted in heavy toll of life and property, it is clear that inherent damping of the material alone cannot dissipate the unwanted energy due to earthquake and heavy wind actions. Hence there was an emerging need of structural vibration control devices which can reduce the severe responses of structure without altering the dynamic characteristics of structure; they are also known as supplemental damping devices. Structural passive control systems have been developed with the design philosophy different than the conventional design seismic design method, which have immediate effect of increasing the critical damping ratio right up 25-30%.(against 5% value usually used for metal structures) and at the same time reducing the response of the structure during seismic event.

The study will focus on the seismic analysis and design of structures with supplemental ‘viscous dampers’. The effect of the supplemental damper can be easily explained from the energy consideration. The event of a structure responding to earthquake ground motion is explained with the help of energy consideration which is as follows. The absolute energy is given below in Eq. 1.1

$$E_I = E_k + E_s + E_h + E_d \qquad (1.1)$$

Where E_I is Earthquake input energy, E_k is kinetic energy, E_S is recoverable strain energy, $E_h$is irrecoverable hysteretic energy and E_d is the energy dissipated by the supplemental viscous damper.

The right-hand side of the equation is basically the energy capacity of the structure and left-hand side is the energy demand by the earthquake ground motion on the structure. For a structure to survive energy capacity or supply must be greater than energy demand. In conventional seismic design, the supply energy mostly depends on the hysteretic energy term, E_H, which results in inelastic behavior of the structure. For a structure with viscous damper, the energy dissipation capacity will increase due to addition of E_d and the complete system will be designed to allow early engagement of the viscous damper in dissipating the earthquake energy prior to the inelastic deformation of the primary structure. In simple words the primary frame will be better protected and the performance of the structure subjected to ground motion can be improved effectively.

Dampers are classified as follows:

1) Viscous Dampers
2) Visco-Elastic Dampers
3) Friction Dampers
4) Mass Dampers
5) Metallic Dampers

These are passive dampers which do not require external power or energy to actuate during seismic event. Depending upon the intensity of lateral forces acting on a structure it dissipates seismic energy thus reducing inter-storey drift and bending moment induced in the structure.

II. WORKING PRINCIPLE

Viscous damper consist of a cylinder and a stainless steel piston. The cylinder is filled with silicone fluid. The damper is activated by the flow of silicone fluid between the chambers at the opposite ends of the unit through small orifice. Figure 1 shows the longitudinal cross section of viscous damper.

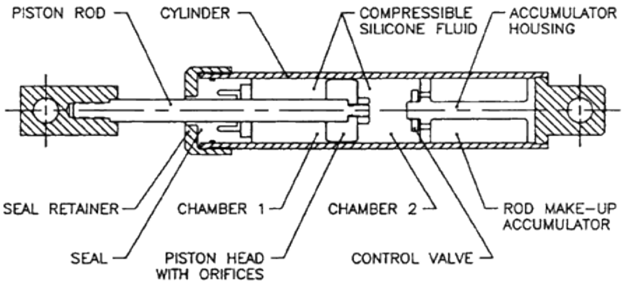

Figure 1 Longitudinal Cross-section of a fluid damper

It consists of piston rod which moves to and fro depending upon the lateral force induced during an earthquake. High strength seal is used to avoid leakage of the fluid.Now to understand the mechanism how damper works. Let us assume that the piston rod is moving from left to right as seen in figure 1 (device subjected to compressive force). Fluid flows from chamber 1 to chamber 2. Accordingly, the force developed will be the pressure differential in these two chambers. However, the fluid volume is reduced by the product of travel and piston rod area. Since the fluid is compressible the amount of volume reduced is accompanied by the development of the restoring (spring like) force. This phenomenon can be prevented by either using an accumulator. This restoring force helps in reducing the response of the structure during an earthquake.The viscous dampers can be attached to existing or new structure as a bracing element as shown in figure 2.

Figure 2 Fluid Dampers as bracing element

III. LITERATURE REVIEW

The requirement of seismic analysis and design of structures using supplemental viscous dampers was felt all over the world. Various types of control systems were explored. Energy dissipation using fluid viscous dampers was found to be one of the effective concepts. Engineers all over the world retrofitted and designed structures using FVD. Some of the prominent literature available on the supplemental viscous dampers has been reviewed in brief in the subsequent paragraphs.

Constantinou and Symans (1993) conducted an experimental as well as analytical study of the response of the structure using viscous damper. One and three storey steel frames were modelled over shake table with and without damper. The test was conducted at different temperature and frequency range. A comparison of the analytical and experimental study of various parameters such as force displacement relation, story shear and drift relation were made. Final conclusion made from the tested results was 30-70% reduction in storey drift, 40 – 70 % reduction in the storey shear. The tested damper showed linear viscous behaviour for frequencies of motion below cut off frequency. The cut off frequency was 4 Hz and beyond this frequency, damper showed visco-elastic behaviour.

Xu, et al. (1999) experimentally investigated the response of two buildings connected by linear fluid viscous dampers. Two steel building models of three storey with different frequencies were considered adjacent to each other. Two buildings were tested individually to obtain the dynamic response. The main objective of the study was to check to the modal damping ratio and the natural frequency of the two buildings connected by FVD. Typical force-displacement loops were obtained at the temperature of 25^{o}C and frequency of 1, 2 and 10 Hz. Damper exhibits negligible storage stiffness at the frequency less than 4 Hz and the behaviour is essentially linear viscous. When the frequency is above 4 Hz, the damper exhibits storage stiffness and shows visco-elastic behaviour.

Hwang (2002) studied the mechanical properties of the viscous damper. The amount of the work done by linear and non-linear viscous damper was derived for single degree of freedom system. By using modal strain energy method, work done by the dampers for considered three storey steel frame was evaluated and the effective damping ratio of the complete system with viscous damper was determined.

Garcia and Soong (2002) gave a simplified procedure for the design of optimal damper configuration. The method is known as simplified sequential search algorithm (SSSA), which is mainly used for linear viscous damper and is found to be efficient for regular building configuration, ranging from low to medium rise building. In the study, building structures were modelled as two-dimensional, lumped mass system. For a considered 12 storey steel building, a relation between maximum inter-storey drift and number of damper required were established. From the graph drawn optimum number of dampers required for the chosen structure was determined.

Matsagar and Jangid (2006) studied the seismic response of the two adjacent building including base isolation and fluid viscous damper. It has been shown that the damage caused due to large bearing displacements of isolator can be reduced to a great extent by linking two base isolated buildings with fluid viscous dampers.

Patel and Jangid (2009)studied the seismic performance of two adjacent dynamically similar buildings coupled with fluid viscous dampers. The analysis is carried by formulating the equations of motions using Newmark beta method. Thorough study is conducted in order to arrive at optimum damping coefficient by choosing top storey displacement, acceleration and base shear as principal damaging measure by placing dampers of same and different damping coefficient at each storey. Beyond optimum damping the responses were found to increase. Finally, in order to minimize the cost, dampers were placed at location of maximum relative velocity and responses were checked. Thus, it is finally concluded, minimum dampers at suitable locations minimize the severe responses of two adjacent buildings connected with fluid dampers.

Narkhede and Sinha (2013) conducted an experimental investigation on non-linear fluid viscous dampers by subjecting it to half-cycle sine shock loading of varying amplitude. Total 36 number of tests were performed on Type A and B dampers. Standard charts have been prepared for the tested models which can be used for preliminary design of non-linear viscous dampers. Moreover, non-linear dampers produce less damping force as compare to linear viscous dampers, due to which less force is transmitted to supporting system. Hence, weight of non-linear dampers is less as compare to linear viscous dampers for same effectiveness.

Ras and Boumechra (2014)analysed a twelve storey steel building by performing nonlinear time history analyses with and without using viscous damper in SAP 2000. In order to maximize the performance, various optimization study on the location of the steel bracing element was conducted, effect of variation of damping constant on the axial forces, shear force and the bending moment in the members were studied. Jankowski and Mahmoud (2016)carried out analytical study on pounding of structures by linking two shear type buildings with various elements such as link, dashpot and visco-elastic element. It has been concluded that the use of link elements proved to control the responses of flexible building and responses remain unchanged in case of stiffer building even for high stiffness and damping of link elements. Thus, pounding of two structures in case of seismic action can be avoided with the help of such gap elements.

IV. CONCLUSION

From the study of past literature conducted on structures equipped with viscous dampers, it has been concluded that damper is quite effective in reducing the critical response of the structure subjected to wind or seismic loading. Many of the companies are manufacturing such dampers on large scale as they are economical and do not require any external source of energy to operate during seismic event. Most of the structures which are located in earthquake prone areas may be retrofitted by using such passive energy dissipation devices. In the present work fluid viscous dampers will be used as supplemental energy dissipating device on a 3D building of suitable plan and elevation to dissipated earthquake energy.

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