Review Paper on Seismic Performance of Steel Buildings with Viscous Fluid Dampers

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Abstract*- Design of earthquake resistant structures requires both ductility & stiffness. Lateral force resisting systems such as moment resisting frames & braced frames are conventional and have unexceptional performance. Structures subjected to earthquake forces are vulnerable to collapse and large lateral displacement. This leads us to focus on limiting this displacement. Energy Dissipating Devices(EDD) provided at appropriate locations in a building are an effective solution in reducing the seismic energy.*

Keywords*-* Moment Resisting Frames, Energy Dissipating Devices, Viscous Fluid Dampers, Etabs

I. INTRODUCTION

Earthquakes have accompanied man though ages While some may cause no harm others tend to cause large scale disruption of life & property. Seismic events are by energy in form of ground acceleration which is transformed into potential (strain energy) & kinetic energy which needs to be either absorbed or dissipated through heat.

Conventional approach in India is to increase stiffness of members by increasing their sizes. Though this makes the members strong, the energy dissipation takes place through the joint which remains weak. This approach proves futile in cases the structure allows for resonance & magnification of seismic forces.

This inadequacy is tackled through the advances in earthquake engineering augmented by computational techniques and advanced state of the art testing facilities. This has led to emergence of Energy Dissipating Devices (EDD’s) (Ras & Bou-mechra 2016)

A. Energy Dissipating Devices.

Certain structures have immediate effect of increasing the critical damping ratio to the tune of 20–30% (as against 5% value usually used for metal structures) along with reducing the stresses and strains generated by earthquakes. This approach is conventionally known as the ‘‘energy dissipation”. Ithas the ability to absorb significant energy without causing damageto the structure meanwhile ensuring the protection of human lives and property (Ouali 2009). This approach of seismic energy dissipation is illustrated clearly by considering the following time dependent conservation of energy relationship as shown in Equation (1) (Uang and Bertero 1990).

$$E(t) = E_k(t) + E_s(t) + E_h(t) + E_d(t) \qquad (1)$$

$E$is the total energy input from the seismic event;
E_k is the total kinetic energy;
E_s is the elastic (recoverable) strain energy;
$E_h$is the irrecoverable energy dissipated by the structural ***system through inelastic deformations;***
E_d is the energy dissipated by any energy dissipating device and *t* represents time.

The absolute input energy E represents the work done by the total base shear force at the foundation on the ground displacement and thus accounts for the effect of the inertia forces on the structure. In the conventional design approach, the term E_d in Equation (1) is considered as zero. In such a case acceptable structural performance is achieved by the occurrence of inelastic deformations, which have a direct effect on increasing E_h. Finally, the increased flexibility accounts for a portion of seismic energy.

Introduction of supplemental damping devices in the structure involves increasing the term E_d in Equation (1) and is responsible for the major seismic energy that is absorbed during the earthquake (Syman and Constantinou 1998).

In the recent years’ engineers have been able to develop several approaches to modify dynamic response for the purpose of limiting damage to buildings subjected to earthquake ground motions. Such approaches include active control, passive control, and hybrid control. An active control system works by exerting a force on the structure from an external source. In this system, energy can be dissipated, and it can also be added to the structure. Passive control systems impart forces that develop in response to the motion of a structure. The passive control devices dissipate energy in the structure but cannot increase the energy. A hybrid control system is one that incorporates both passive and active devices (Hanson and Soong, 2001).

The current study focuses on Viscous Fluid Dampers (VFD) which are classified as passive control systems

B. Viscous Fluid Dampers

The initial development of fluid dampers began during the late 1800's. In the field of artillery, a high-performance device was required to realize attenuation of the recoil of huge cannons. After extensive research & evaluation, the French Army incorporated a unique fluid damper in the design of their 75mm gun, Model M1897. The fluid damper design incorporated use of inertial flows, where oil was forced through small orifices at speeds fare more than 200 m/s, which successively produced high damping forces. This allowed to create dampers with relatively high operating pressures in 20 N/mm^2 range. The output of this device remained unaffected by changes in viscosity of the fluid but varied with the specific mass of the fluid which had a very low sensitivity to temperature. So, an enormously compact fluid inertial damper, which remained virtually unaffected by temperature was developed. Initial productions how cased a further important feature. The damper's output could be controlled to a very high degree during production with the employment of conventional machining techniques. Thus, the employment of technology of fluid inertial dampers was widely adopted by the armies and navies of most nations within the 1900-1945 period. Also due to its secretive nature, this information was not widely publicized.

With World War II, the emergence of technologies of radar and similar electronic systems necessitated the rise of specialized shock isolation techniques. These techniques would ensure equipment were able to withstand the a "weapons' grade" shock. As the Cold War ensued, the guided missile evolved as the preferred weapon, and the inertial fluid damper was again considered by the military as the most cost-effective way of protecting missiles against weapons detonation, both conventional & nuclear. The transient shock from a near miss weapon detonation would contain free field velocities starting from 3 m/s to 12 m/s, displacements of up to 2000 mm, and accelerations that go up to 1000 times gravity. Extremely high damping forces were needed for the attenuation of such transient pulses on large structures. Fluid inertial dampers again evolved as a preferred solution to these problems. As the Cold War came to an end in the late 1980's, much of this fully developed defense technology was made available to the overall public through sale.

Taylor Devices, since 1955, a supplier of dampers and shock absorbers to 1-ton output teamed with the U.S. Government, teamed with the State University of recent York at Buffalo (SUNYAB) to use these devices to buildings and bridges to boost seismic performance. SUNYAB is the site of the U.S. National Center for Earthquake Engineering Research (NCEER). Experiments commenced in 1991 using scaled structures and testing on an enormous seismic shake table (Taylor and Constantinou 2000).

II. STATE OF DEVELOPMENT

Fractional-Derivative Maxwell Model for Viscous Dampers-

Nicos Makris and M. C. Constantinou (1993)

This paper examines a viscous damper based on fractional-derivative Maxwell model, which can be utilized for isolating vibrations in piping systems, forging hammers, and other industrial equipment. It can be used for isolation of building structures from vibration and seismic forces also. The development and calibration of the model is guided by experimental data of dynamic characteristics. The mode thus proposed is validated through dynamic testing and predicted data is fairly in conformance with experimental outputs obtained. Study presents numerical solution based on algorithms of the relation constituting the time or frequency domain. Some analytical results for a single-degree-of-freedom viscous damper system are presented. These results are useful to design vibration-isolation systems. Furthermore, an equivalent viscous oscillator is defined whose response is essentially the same as that of the viscous damper isolator. Also, a base-isolated model structure was analyzed using this model that is tested on a shake table.

Seismic performance of chevron braced steel frames with and without viscous fluid dampers as a function of ground motion and damper characteristics-

Murat Dicleli, Anshu Mehta (2007)

The seismic performance of steel chevron braced frames (CBFs) with and without viscous fluid dampers (VFDs) compared as a function of VFD parameters and the intensity and frequency characteristics of the ground motion. For this purpose, nonlinear time history (NLTH) analysis of single and multiple story CBFs were compared including & excluding VFDs.The analysis are conducted using ground motions with various frequency characteristics scaled to represent small, moderate and large intensity earthquakes.

Further, NLTH analysis of both single and multiple story CBFs including VFDs are conducted to study the effect of the damping ratio and velocity exponent of the VFD on the seismic performance of the frames. The analysis outputs exhibited that the seismic performance of the CBFs excluding VFDs is extremely poor and remains sensitive to the frequency characteristics as well as intensity of the ground motion due to brace buckling effects.Further, installing VFDs into the CBFs remarkably improved their seismic performance by allowing to maintain their elastic behavior. In addition, VFDs having smaller velocity exponents and larger damping ratio are seen to be more effective in enhancing the seismic performance of the CBFs. However, it was observed that VFDs with damping ratios larger than 50% do not produce any remarkable enhanced improvement in the seismic performance of the CBFs.

Seismic energy dissipation study of linear fluid viscous dampers in steel structure design-
A. Ras, N. Boumechra (2016)

This paper presents the efficiency of linear Viscous Fluid Dampers (VFD) in SMRF to produce dissipation. A 3D numerical investigation is applied considering the seismic response of a twelve-story steel building moment frame with diagonal (VFD) that have linear force versus velocity behavior. Nonlinear time history, using Boumerdes earthquake (Algeria, May 2003) is considered for the analysis and applied using the SAP2000 software. Responses of unbraced, braced and damped structure are shown in an exceedingly tabulated and graphical format. The results of the varied systems are studied to match the structural response with and without this device of the energy dissipation thus obtained. The conclusions showed the formidable potential of the VFD to enhance the dissipative capacities of the structure without increasing its rigidity. it's contributing significantly to scale back the number of steel necessary for its general stability.

Study of the Effect of Viscous Damper for RCC Frame Structure-
Puneeth Sajjan , Praveen Biradar (2016)

Structures are mainly subjected to varied varieties of loading conditions like earthquake, wind loads etc. For earthquake zone areas, the structures are designed considering seismic forces. The structure which are present in higher earthquake zone area are vulnerable to get damaged or collapsed, hence, to extend the protection of those structure few retrofitting techniques or addition of materials to stabilize the structures against the earthquake forces are done. And if the retrofitting techniques are adopted then cost plays a significant role and possibly few spaces are compromised depend on the kind of methods adopted. Later the structure could even be strengthened by adding materials externally to transfer the lateral loads i.e. some protective devices are developed. In modern seismic design, damping devices are accustomed reduce the seismic energy and enable the control of the structural response of the structure thereto earthquake excitation. For this study, an 8-story structure which is symmetrical in plan is modelled and analyzed using the ETABs 2015 software. The earthquake loads are defined as per IS1893-2002 (Part 1). to research the structure, the static and dynamic analysis method is adopted. The response spectrum function is defined to hold out dynamic analysis. To manage the seismic response and to extend the stiffness of the structure, viscous dampers are provided to the structure. The structure with viscous damper is modelled and analyzed with same parameters. The mechanical properties of viscous damper employed during this study are as damping coefficient Cd= 810 kN-s/m and exponent as 0.3. The results obtained and compared within the kind of displacement, story drift and story shear are compared.

Seismic performance assessment of steel moment-resisting frames equipped with linear and nonlinear fluid viscous dampers with the same damping ratio-
Mehdi Banarzadeh, Ali Ghanbari (2017)

This paper presents a comparative study between the seismic collapse performances of steel moment-resisting frames (MRFs) with the identical additional damping ratio while equipped with linear and nonlinear viscous dampers. Three steel moment-resisting frames of 6, 8 and 12 stories were designed supported ASCE 7–10 with and without dampers. The characteristics of the linear (α = 1) and nonlinear (α = 0.5) dampers were then assigned while assuming equal damping ratios (20% for the models of 6 and eight stories, and 25% for the model of 12 stories). the subtle nonlinear model of the structures was then developed in Opensees considering both cyclic strength and stiffness deterioration with lumped plasticity likewise because the linear and nonlinear dashpot for dampers while nonlinear geometry was included altogether the models. The collapse probability was calculated using well-known incremental dynamic analysis (IDA) under far-field records. The paper demonstrates that the use of damper improves the performance of the steel MRFs and reduces the collapse probability compared with the quality steel MRFs. Moreover, it had been observed that steel MRFs with linear dampers have better collapse performance than steel MRFs with nonlinear dampers for the identical damping ratio.

Effectiveness of fluid-viscous dampers for improved seismic performance of inter-story isolated buildings- Yanhui Liu, Jinbiao Wu, Marco Dona (2018)

The use of fluid viscous dampers (FVDs) along with isolators, frequent in near-fault buildings, is effective in reducing displacements of the isolation layer. Such a hybrid system is additionally beneficial within the case of inter-story isolation with the aim of limiting P-Δ effects. However, previous research aboard isolation shows that this extra damping can also be detrimental, as inter-story drifts and floor accelerations may increase. This paper analyses the effectiveness of FVDs for enhanced seismic performance of systems with inter-story isolation. A seven-floor building, with natural and lead rubber bearings between the second and third levels, was used as a case study, and a multi-objective optimal design was performed to spot the simplest damper parameters. specifically, time-history analyses with various natural records were administered and two competing objectives were examined: minimization of the deflection of the isolation layer and minimization of the whole drift of the superstructure. The results show not only the effectiveness of optimal FVDs but also the very fact that their optimal linearity degree depends to an excellent extent on the non-linear seismic response of the structure, i.e., on the sort of earthquake. The only design approach, consisting of applying an optimization algorithm for every design accelerogram, didn't seem, during this case, to be sufficient to spot the simplest overall design solution. the look consequences of those findings are discussed..

III. CONCLUSION

This paper focuses only on the literature review of previously published studies. The findings of this study are as follows

a) Fractional Derivative Maxwell Model can be used in viscous dampers for base isolation in seismic response.
b) An equivalent viscous oscillator can be defined using Fractional Derivative Maxwell Model whose response is essentially the same as that of the viscous damper isolator a base-isolated model structure.
c) VFD's allow for increasing the dissipating capacity of the structure without increasing rigidity.
d) To study the effect of viscous dampers, parameters in results obtainedin the form of displacement, story drift and story shear can be compared.
e) Steel Moment Resisting Frames aided with Viscous dampers have less collapse probability.
f) Linear dampers are more effective than non-linear dampers with same damping ratio in steel MRF's.

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