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A Comparative Study on the Performance of Viscous and Friction Dampers under Seismic Excitation

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Abstract**—**Earthquakes over the years have been known to cause devastating damage on buildings and induced huge loss on human life and properties. It is for this reason that engineers have devised means of protecting buildings and thus protecting human life. Since the invention of devices such as the viscous and friction dampers, scientists/researchers have been able to incorporate these devices into buildings and other engineering structures. The viscous damper is a hydraulic device which dissipates the seismic forces by pushing fluid through an orifice, producing a damping pressure which creates a force. In the friction damper, the force is mainly resisted by converting the kinetic energy into heat by friction. Devices such as viscous and friction dampers are able to absorb almost all the earthquake energy, allowing the structure to remain undamaged (or with some amount of damage) and ready for immediate reuse (with some repair works). Comparing these two devices presents the engineer with adequate information on the merits and demerits of these devices and in which circumstances their use would be highly favorable. This paper examines the performance of both viscous and friction dampers under different ground motions. A two-storey frame installed with both devices under investigation are modeled in commercial computer software and analyzed under different ground motions. The results of the performance of the structure are then tabulated and compared. Also included in this study is the ease of installation and maintenance of these devices.

Keywords**—**Friction damper, seismic, slip load, viscous damper.

I. Introduction

EARTHQUAKES have been known to cause a lot of damage to buildings. Past records of the effects of earthquakes show that the destructive effect results in a lot of lives lost, loss of infrastructure running into millions and sometimes affects the growth of a country immensely. The invention of devices such as viscous dampers, friction dampers, tuned mass dampers, etc. helps to reduce the total amount of damage experienced by a structure during an earthquake.

A known method of improving structural seismic response is by using supplemental energy dissipation systems [1]. Examples of these methods include the use of base isolators, viscous dampers, friction dampers, etc. These devices have been proven over time to enhance the performance of buildings during an earthquake. A great amount of work has been carried out on friction and viscous dampers.

Using viscous dampers strategically installed throughout a building can help to protect the structure in the event of an earthquake. Viscous dampers working on the principle of fluid flow through orifices have been applied in real buildings. The main advantage is that the output of a fluid viscous damper is out of phase with primary bending and shearing stresses in a structure [1].

Friction dampers as the name suggests, dissipate energy through friction. This energy dissipation is achieved by the relative sliding of two surfaces in contact. Friction dampers were first introduced by Avtar S. Pall in 1984 and since then a great deal of modifications and improvements have been made on the device. Studies carried out by Zahraei et al. showed that the installation of friction dampers in buildings provides a practical, economical and effective way to design and retrofit buildings to resist earthquakes [2]. These devices can be easily incorporated into a building to improve its performance. Friction dampers possess a great deal of advantages and thus they are an easy choice for seismic protection of buildings.

Viscous dampers are passive devices which help to protect buildings against wind, blast and earthquakes [3]. They are hydraulic devices that dissipate the kinetic energy of seismic events and cushion the impact between structures. Viscous dampers can be found in a wide array of applications. Some of these include installations in bridges, towers and even sometimes connecting two buildings together. Mcnamara and Taylor verified the benefits of using fluid viscous dampers for high rise buildings [4].Constantinou and Symans carried out an experimental study which showed that the use of fluid damping devices results in reduced inter storey drifts, floor accelerations and story shear [5]. Pall and Marsh showed the effectiveness of friction damped braced frames as compared to moment resisting frame and braced moment resisting frame [6].

In this paper, a thorough comparison of both viscous dampers and friction dampers are studied, and their ease of installation is also compared. Finally, the ease of maintenance of devices before and after an earthquake is studied.

II. Description of the Viscous Damper

Over the years, viscous dampers have been the most preferred form of protection of buildings against seismic action. The viscous damper as shown in Fig 1 consists of a fluid (low viscosity) filled chamber and a central piston. As the piston moves through the chamber, it pushes the fluid through the orifices around the piston head. Within this region, the fluid velocity is very high so the upstream energy almost entirely converts to kinetic energy [3]. As the fluid then expands into the next chamber, the piston head gradually slows down and loses its kinetic energy into turbulence and thus there is a

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smaller pressure on the downstream end of the piston head. This difference in pressure results in a large force that resists the motion of the damper.

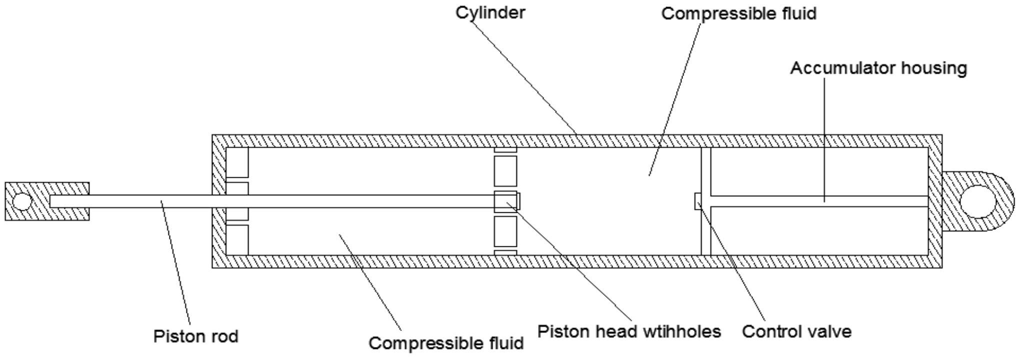

Fig. 1 Typical viscous damper

The response of a structure with added viscous dampers is described by the following dynamic equation of equilibrium:

$$[M]\{\ddot{u}\}+[C]\{\dot{u}\}+[K]\{u\}+\{F_{vd}\}=-[M]\{\ddot{u}_g\} \qquad (1)$$

where ***M*, *C*, *K*** are the mass, damping and stiffness matrices respectively; $\ddot{u}$, $\dot{u}$ and u are the acceleration, velocity and displacement vectors respectively. $\ddot{u}_g$ is a vector representing the seismic excitation, i.e. the base acceleration. F_{vd} represents the damping force of the viscous damper. This force is directly proportional to the relative velocity between the ends of the damper and can be stated mathematically as follows:

$$F_{vd} = C_D\,|\dot{u}|^{\alpha}\,sign(\dot{u}) \qquad (2)$$

where F_{vd} is the damper force, C_D is the damping coefficient, $\dot{u}$ is the velocity, α is an exponent that ranges from 0.3 to 1 for seismic applications and *sign()* is the signum function.

For α equal to 1, the damper may be described as a linear damper, and the total energy dissipated per cycle is obtained by integrating (2) over the displacement leading to the following expression [7]:

$$E_D = 4P_0u_0 2^{\alpha}\left(\frac{\Gamma^2(1+\alpha/2)}{\Gamma(2+\alpha)}\right)=\lambda P_0 u_0 \qquad (3)$$

where P_0 is the peak force developed by the damper; u_0 is the peak displacement across the damper; Γ is the gamma function and λ is a parameter whose value depends exclusively on the velocity exponent α. In the case of the non-linear viscous damper, the energy dissipated per cycle is larger by a factor of λ/π than that for the linear viscous damper and increases monotonically with reducing velocity exponent [7]. This can be clearly seen in Fig. 2 below; for a given value of velocity, there is an exponential increase in the force of the damping device for increasing values of α.

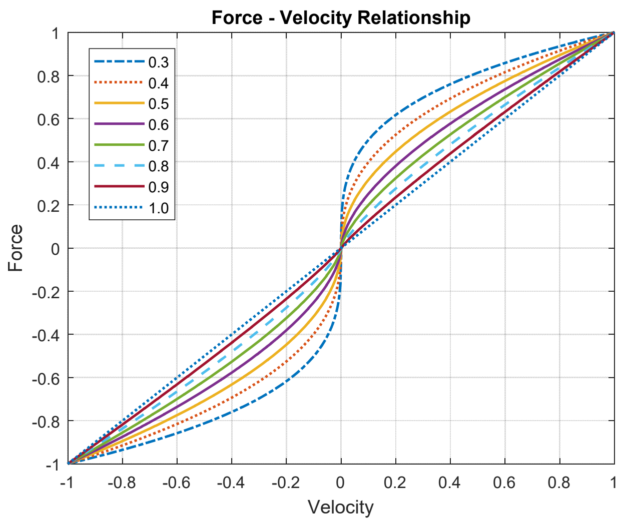

Fig. 2 Force-velocity relationship for various values of α

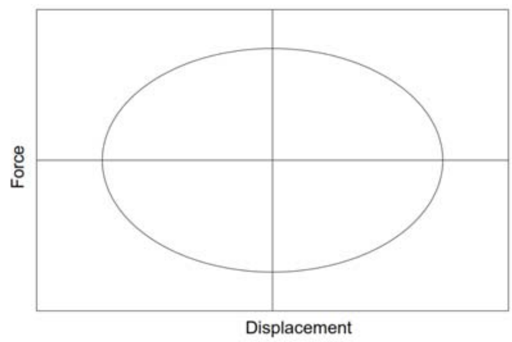

Fig. 3 Idealized force displacement relationship of viscous damper

III. Description of the Friction Damper

As the name suggests, friction dampers dissipate energy following the principle of friction. The friction damper usually consists of a series of steel plates with a special surface treatment which allows them to develop very reliable friction. Installation procedure of the friction damper is quite simple since it involves bolting of steel sections and steel plates together. Thus, this makes it quite easy to inspect and repair the friction damper if the need arises.

Fig. 4 Friction Damper

The response of a structure with added friction dampers is described by the following dynamic equation of equilibrium:

$$[M]\{\ddot{u}\}+[C]\{\dot{u}\}+[K]\{u\}+\{F_{fd}\}=-[M]\{\ddot{u}_g\} \tag{4}$$

where in this case F_{fd} is the Coulomb friction force which is defined by:

$$F_{fd}=F_{fn}sgn(\dot{u}) \tag{5}$$

where $F_{fn}=\mu N$, where μ is the friction coefficient assumed to be constant and N is the normal force. From (5), we can clearly see that the velocity direction changes frequently, and would cause many discontinuities in the friction force thus complicating the process of determining the structural response [8]. For this reason, [9] derived four different continuous functions to represent the discontinuous Coulomb friction force. The four continuous functions are shown in (6) below:

$$\begin{aligned} f_1(\alpha_1,\dot{u}) &= Erf(\alpha_1\dot{u}) \\ f_2(\alpha_2,\dot{u}) &= \mathrm{Tanh}(\alpha_2\dot{u}) \\ f_3(\alpha_3,\dot{u}) &= \left(2/\pi\right)\mathrm{Arc\,Tan}(\alpha_3\dot{u}) \\ f_4(\alpha_4,\dot{u}) &= \alpha_4\dot{u}/(1+\alpha_4\,|\,\dot{u}\,|) \end{aligned} \tag{6}$$

The force-velocity relationship and the idealized force-displacement of the friction damper are shown in Fig. 5 below. The friction damper has large energy dissipation per cycle as shown by the rectangular shape of the hysteresis plot.

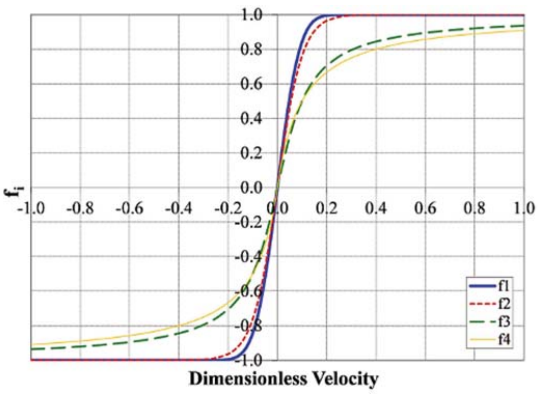

Fig. 5 Force velocity relationships according to Mostaghel and Davis [9]

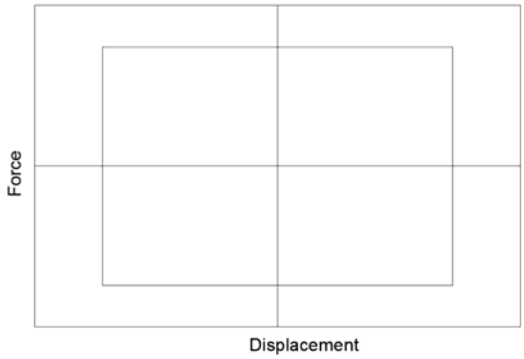

Fig. 6 Idealized force-displacement relationship of friction damper

IV. Benefits of Friction Damper and Viscous Damper

The use of viscous and friction dampers comes with their very own advantages and disadvantages. Friction dampers introduce high damping and thus results in the reduction of forces and deflections in the structure. Friction dampers are relatively inexpensive devices that can be easily installed in a structure. Friction dampers are designed not to slip during wind and thus are not suitable for protection of buildings against wind.

Friction dampers are easily hidden in partitions or walls of buildings and do not change the aesthetics of a building since they are usually installed in the form of a diagonal brace in buildings. The use of friction dampers increases the overall stiffness of a structure.

Viscous dampers are the most widely known and preferred form of damping devices with a proven track record of performance in military applications. Viscous dampers are usually activated at low displacements and are usually used to protect buildings under frequent earthquakes (earthquakes of magnitude x and lower). The construction and installation of viscous dampers requires skilled personnel to carry it out. Viscous dampers protect buildings against wind and earthquake.

V. Numerical Example

In this paper, we set out to make a comparison between two energy dissipating devices, namely the friction damper and viscous damper. The test setup consists of a two-storey steel frame with 6 m bay and 4 m height subjected to the El Centro ground motion record (N.S. component) with a dead and live load of 12 kN/m and 10 kN/m, respectively. Four different cases were considered, namely:

Case 1. (no damping device)
Case 2. (viscous damper)
Case 3. (friction damper)
Case 4. (viscous damper and friction damper)

The optimal parameters used to model the friction and viscous damper are given below:

Friction damper: stiffness = 25627.514 kN/m, yield exponent = 10, yield force = 1000 N and yield stiffness ratio = 0.0001.

Viscous damper: damping = 4000 N*s/m, damping exponent

= 0.3.

The frame is analysed using commercial structural analysis software and to save computational cost, the analyses were conducted for a duration of only the first fifteen seconds.

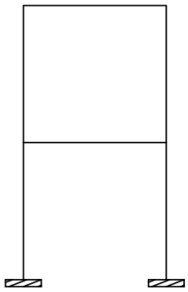

Fig. 7 Case 1

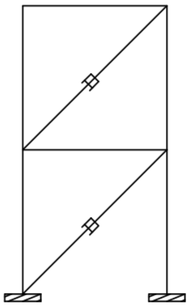

Fig. 8 Case 2

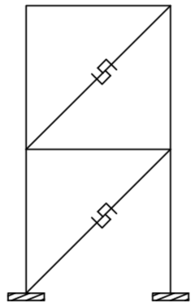

Fig. 9 Case 3

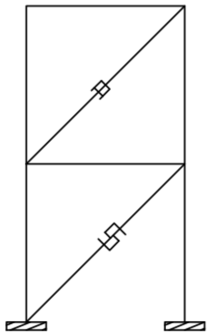

Fig. 10 Case 4

The following ground motion data (El Centro) were used in the given numerical example:

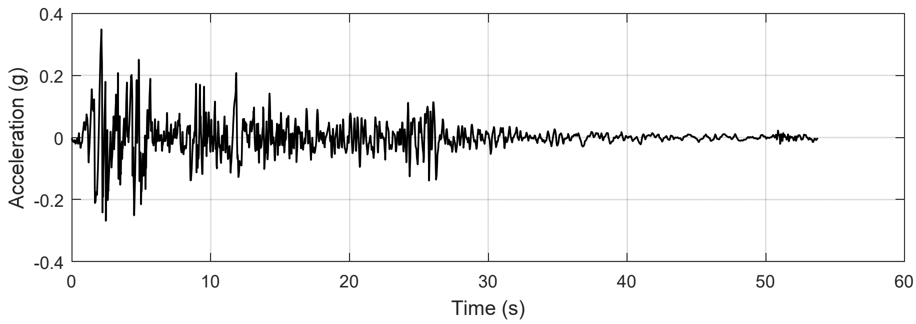

Fig. 11 El Centro (N. S. component)

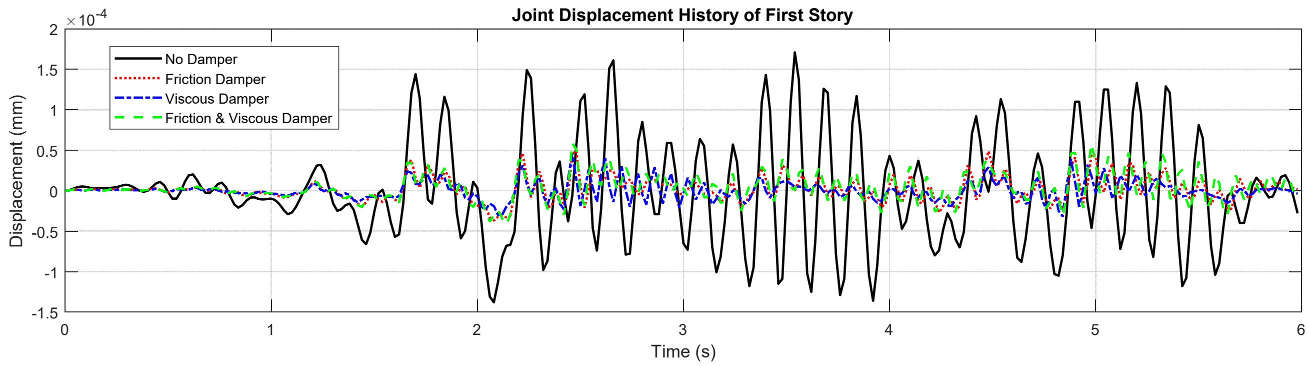

Fig. 12 Joint Displacement History of First Story

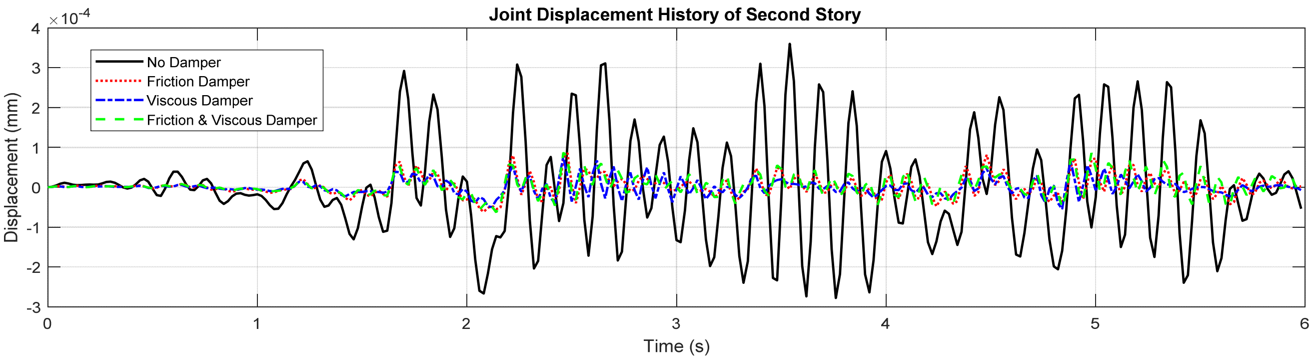

Fig. 13 Joint Displacement History of Second Story

Since both devices are nonlinear, their installation in the frame would cause it to behave in a nonlinear manner and thus a nonlinear time history analysis would be needed to determine the response of the frame under the given seismic loads. The analysis procedure was carried out using commercial structural analysis software and the results are shown below.

TABLE I
PEAK RESPONSE OF FRAME UNDER EL CENTRO EARTHQUAKE

Peak Responses under El Centro earthquake				
	Displacement (mm)			
Floor	Case 1	Case 2	Case 3	Case 4
1	0.000171	0.000046	0.00005	0.000059
2	0.00036	0.000076	0.000086	0.000087

A plot of the top storey displacement history of the various cases studied shows a great reduction in the response of the frame with viscous and friction dampers as compared to the bare frame with no devices. The results given in Table I show the peak displacements of the roof level. There is a reduction of an average of 70% in displacement response between case 1 and the other three cases studied. The use of friction and viscous dampers induces added stiffness and damping respectively to the frame. The added damping provided by the viscous damper provides an alternative means for the building to dissipate energy rather than by the frame elements yielding themselves to dissipate the energy. Similarly applies to the friction damper as well which improves the stiffness of the overall frame. Incorporating both friction and viscous dampers in the frame provides a rather interesting way for dissipating the input energy to the frame. As discussed earlier, both friction and viscous dampers are activated under different frequency intensity of earthquake with the friction device designed not to slip during wind loads.

VI. CONCLUSION

This study presented a comparison of the performance of two widely known devices namely; the friction damper and the viscous damper. The use of friction and viscous dampers in buildings proves to be advantageous in controlling the seismic response of buildings. The use of both friction and viscous damping components induce added stiffness and damping to the system respectively. Conventionally, a system with added viscous dampers primarily gains additional damping under low frequency movement, whereas the frame with added friction dampers gains both stiffness and damping under high frequency excitations.

For energy dissipation, viscously damped systems have a higher efficiency than friction damped devices under low frequency excitation. This is due to the fact that viscous dampers are easily activated under low frequency excitations. Under high frequency excitations, the friction damper records a better performance due to the added stiffness and the fact that friction dampers are activated under high frequency excitations.

As can be seen from Table I, the use of the viscous and friction damper has significant effect in reducing the total joint displacement and there is a lower response in the frame fitted with friction and viscous dampers and would be very suitable in areas of high seismicity. The friction damper gives a lower displacement of the frame with an increase in the total stiffness of the frame. There is an average of 6% difference in the displacement values between the friction and viscous damper. With adequate design, the use of both friction and viscous dampers installed in a structure can result in a great reduction in overall building displacements and storey drifts.

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