

## Seismic Behaviour Of A Soft Storey Building With & Without Viscous Dampers

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### ABSTRACT

During January 2001 Bhuj Earthquake in India, many multi-storeyed buildings in urban areas collapsed and suffered wide spread damages. Post earthquake observations revealed many deficiencies in these structures including non-adoption of seismic engineering practices and lack of seismic resistant features. The seismic performance of a building can be improved by using energy absorbing devices, which may be active or passive in nature. Active control techniques have not found much appreciation due to its high cost and large instrumentation set up. Whereas, passive control systems such as base isolation, dampers, bracing systems etc are found to be easy to install and cost effective as compared to previous one. Use of dampers is now becoming cost effective solution to improve seismic performance of existing as well as new buildings. This paper deals with use of viscous dampers in the building. A five storey building with a open ground storey is analysed with and without braced type viscous dampers placed at soft storey. Non-linear time history analysis is carried out using SAP2000 software and comparisons are shown in a tabular and graphical format.

**Keywords** - Energy dissipation, Seismic retrofitting, Soft storey, time history analysis, Viscous dampers.

### I. INTRODUCTION

Over the past few decades world has experienced numerous devastating earthquakes, resulting in increased loss of human life due to collapse of buildings and severe structural damages. In recent years, much attention has been paid to the research and development of structural control techniques such as passive control system, active control system, and semi active control system giving special importance on improvement of wind and seismic responses of buildings. Passive control systems do not require any power supply. In conventional construction Earth quake-induced energy is dissipated in Components of the gravity resisting system. The action of dissipating energy in framing, such as beam and column in a moment-resisting frame produces damage in those components. Repair of such damage after an earth quake is typically expensive and often requires evacuation of the building. The objective of adding damping hardware to new and existing construction is to dissipate much of the earth quake-induced energy. The philosophy is limiting the damage to the gravity-load-resisting system. Although testing and Perhaps replacement of all supplemental damping devices in a building should be anticipated after a design earth quake, evacuation of the building for repair might not be necessary and hence the total cost

of repair will likely be less as compared with the cost associated with repair in a conventional building.

### II. VARIOUS PASSIVE ENERGY DEVICES

The main reason to use passive energy dissipation devices in a structure is to limit damaging deformations in structural components. The degree to which a certain device is able to accomplish this goal depends on the inherent properties of the basic structure, the properties of the device and its connecting elements, the characteristics of the ground motion. Device that have most commonly been used for seismic protection of structures include viscous fluid dampers, viscoelastic solid dampers, friction dampers and metallic dampers. Semi-active dampers have also been used for seismic response control in other countries, notably Japan, but not within the United States (Soong and Spencer, 2002) [1].

#### 2.1 Viscous Fluid Damper

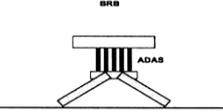
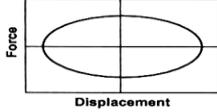
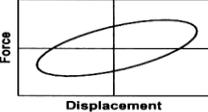
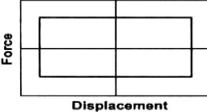
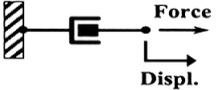
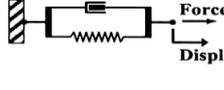
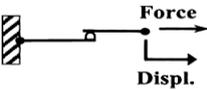
Viscous fluid dampers are commonly used as passive energy dissipation devices for seismic protection of structures. Such dampers consist of a hollow cylinder filled with fluid as shown in Fig 1, the fluid typically being silicone based. As the damper piston rod and piston head are stroked, fluid

is forced to flow through orifices either around or through the piston head. The resulting differential in pressure across the piston head (very high pressure on the upstream side and very low pressure on the downstream side) can produce very large forces that resist the relative motion of the damper (Lee and Taylor 2001)[2]. The fluid flows at high velocities, resulting in the development of friction between fluid particles and the piston head. The friction forces give rise to energy dissipation in the form of heat. The fluid typically has a relatively low viscosity (e.g., silicone oil with a kinematic viscosity on the order of  $0.001 \text{ m}^2/\text{s}$  at  $20^\circ\text{C}$ ). Note that the fluid damper - shown in Fig 2 includes a double-ended piston rod. Such configurations are useful for minimizing the

development of restoring forces due to fluid compression.

### 2.2 Viscous Elastic Damper

Viscoelastic solid dampers generally consist of solid elastomeric pads viscoelastic material bonded to steel plates as shown in Fig 1. The steel plates are attached to the structure within chevron or diagonal bracing. As one end of the damper displaces with respect to the other, the viscoelastic material is sheared resulting in the development of heat which is dissipated to the environment. By their very nature, viscoelastic solids exhibit both elasticity and viscosity. For viscoelastic materials, the mechanical behavior is typically presented in terms of shear stresses and strains rather than forces and

	Viscous Fluid Damper	Viscoelastic Solid Damper	Metallic Damper	Friction Damper
<b>Basic Construction</b>				
<b>Idealized Hysteretic Behavior</b>				
<b>Idealized Physical Model</b>			Idealized Model Not Available	
<b>Advantages</b>	<ul style="list-style-type: none"> <li>- Activated at low displacements</li> <li>- Minimal restoring force</li> <li>- For linear damper, modeling of damper is simplified.</li> <li>- Properties largely frequency and temperature-independent</li> <li>- Proven record of performance in military applications</li> </ul>	<ul style="list-style-type: none"> <li>- Activated at low displacements</li> <li>- Provides restoring force</li> <li>- Linear behavior, therefore simplified modeling of damper</li> </ul>	<ul style="list-style-type: none"> <li>- Stable hysteretic behavior</li> <li>- Long-term reliability</li> <li>- Insensitivity to ambient temperature</li> <li>- Materials and behavior familiar to practicing engineers</li> </ul>	<ul style="list-style-type: none"> <li>- Large energy dissipation per cycle</li> <li>- Insensitivity to ambient temperature</li> </ul>
<b>Disadvantages</b>	<ul style="list-style-type: none"> <li>- Possible fluid seal leakage (reliability concern)</li> </ul>	<ul style="list-style-type: none"> <li>- Limited deformation capacity</li> <li>- Properties are frequency and temperature-dependent</li> <li>- Possible debonding and tearing of VE material (reliability concern)</li> </ul>	<ul style="list-style-type: none"> <li>- Device damaged after earthquake; may require replacement</li> <li>- Nonlinear behavior; may require nonlinear analysis</li> </ul>	<ul style="list-style-type: none"> <li>- Sliding interface conditions may change with time (reliability concern)</li> <li>- Strongly nonlinear behavior; may excite higher modes and require nonlinear analysis</li> <li>- Permanent displacements if no restoring force mechanism provided</li> </ul>

**Fig 1:** Summary of construction, models, advantages, and disadvantages of Dampers [8]

displacements. The mechanical properties then become the storage and loss moduli that define the properties of the viscoelastic material rather than properties of the damper. In general, the storage and loss moduli are dependent on frequency of motion, strain amplitude, and temperature.

### 2.3 Metallic Damper

Two major types of metallic dampers are buckling-restrained brace dampers and added damping and stiffness dampers. A BRB damper consists of a steel brace with a cruciform cross section that is surrounded by a stiff steel tube. The region between the tube and brace is filled with a concrete-like material and a special coating is applied to the brace to prevent it from bonding to the concrete. Thus, the brace can slide with respect to the concrete-filled tube. The confinement provided by the concrete-filled tube allows the brace to be subjected to compressive loads without buckling. Under compressive loads, the damper behavior is essentially identical to its behavior in tension. Since buckling is prevented, significant energy dissipation can occur over a cycle of motion. Additional details on the behavior of BRB dampers are provided [3].

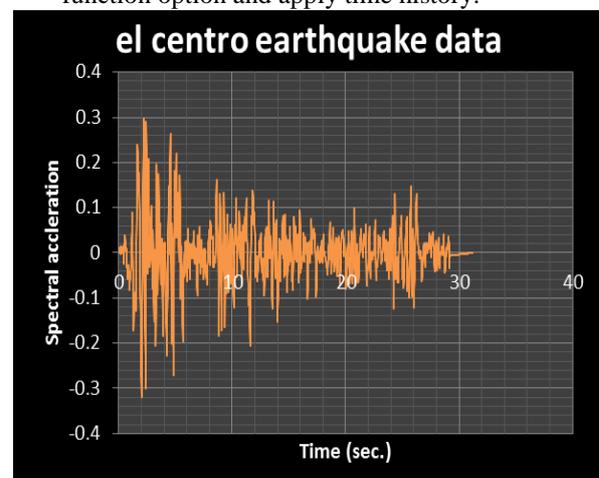
### 2.4 Friction Damper

Friction dampers dissipate energy via sliding friction across the interface between two solid bodies. Examples of such dampers include slotted-bolted dampers are available wherein a series of steel plates are bolted together with a specified clamping force as shown in Fig 1. The clamping force is such that slip occurs at a pre-specified friction force. At the sliding interface between the steel plates, special materials may be utilized to promote stable coefficients of friction. An alternate configuration, known as the Pall cross-bracing friction damper, consists of cross-bracing that connects in the center to a rectangular damper [4]. Other configurations include a cylindrical friction damper in which the damper dissipates energy via sliding friction between copper friction pads and a steel cylinder [5]. The idealized hysteretic response of a friction damper for cyclic loading reveals that the force output is bounded and has the same value for each direction of sliding as shown in Fig 1. The hysteresis loops are rectangular, indicating that significant energy can be dissipated per cycle of motion. However, the rectangular shape of the hysteresis loops indicates that the cyclic behavior of friction dampers is strongly nonlinear. The deformations of the structural framing are largely restricted.

## III. MODELLING OF BUILDING FRAME WITH VISCOUS DAMPERS

A five storey reinforced concrete building frame with open ground storey is modeled. Sudden reduction in lateral strength and stiffness of ground storey due to absence of masonry wall at ground storey results in excessive inelastic deformation on the ground storey columns leading to the soft-storey collapse of the building under the seismic loading conditions. Here, viscous dampers are provided to check the seismic performance of the structure. In this example, non-linear time history analysis is carried out using SAP 2000 version 14 software. Modelling procedure is summarized in following steps.

1. Create a five storey model using file menu.
2. Define materials to be used, here we will define concrete, steel and strut material using define section properties menu.
3. Assign properties to all the framed sections and struts which are used to incorporate the masonry wall effect.
4. Dampers are added into the model by defining link/support properties in the SAP. Input appropriate value of stiffness, damping coefficient and damping exponent in the data sheet.
5. Assign the joint masses/forces using Assign menu.
6. Define and apply time history analysis using past earthquake data. A time history data of 31.2 seconds 'el centro earth-quake' at 0 degree is considered for the analysis. This is given in the form of text file having 1560 points of acceleration data equally spaced at .020 second as is shown in Fig 2. Define menu select the function option and apply time history.

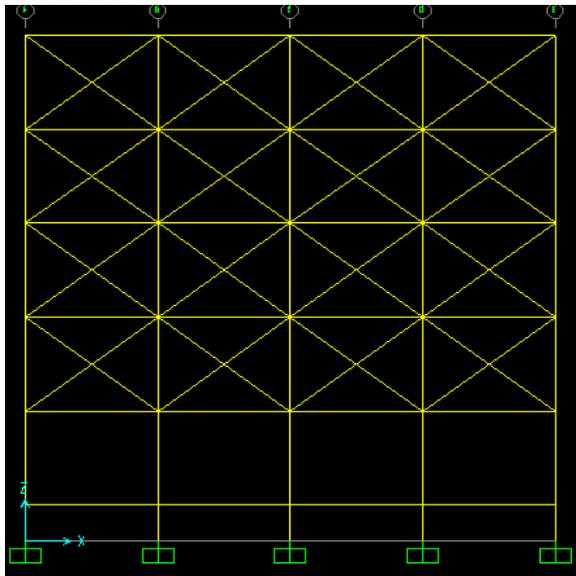


**Fig 2:** El centro earthquake data

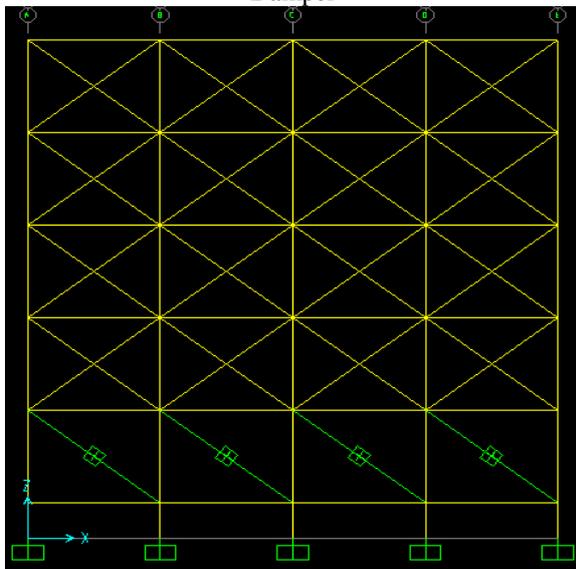
7. Assign the load cases using assign menu. Non-linear time history cases are considered for analysing the given model.
8. At last Analyze menu activates analysis of the frame. SAP is capable of doing different types of analysis. In this problem, nonlinear time history analysis is carried out to compare the response of building with or without dampers.

#### IV. MODEL DETAILS & SPECIFICATIONS

The model represents a five storey building with open ground storey considerations. Fig 3 shows the building model without Dampers while Fig 4 shows the building model with viscous Damper considerations.

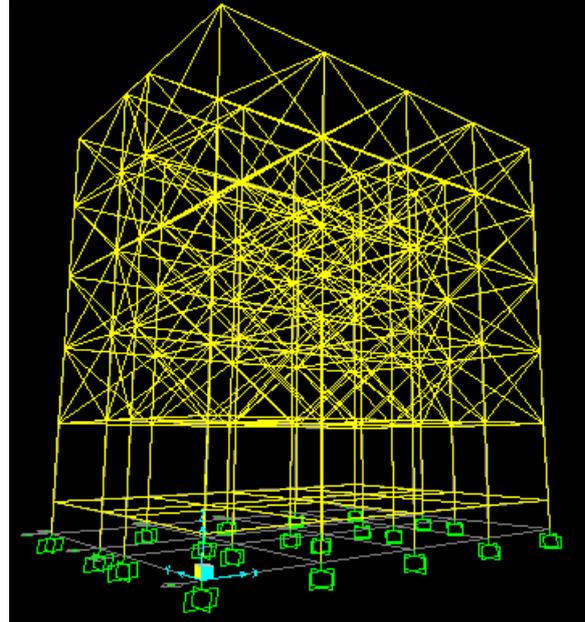


**Figure 3:** Five storey building Model without Damper



**Figure 4:** Five storey building Model with Dampers

Fig 5 shows the complete three dimensional model structure of the analyzed frame. Open ground storey at the ground level is also clearly highlighted.



**Figure 5:** 3-Dimensional Model of building frame

Effects of masonry provided in the structures are considered in the form of struts provided which take compression forces only with the help of SAP 2000. Specifications of Dampers and Struts have been provided in Table.1 . A constant Damping coefficient is considered for analyzing given model. Struts are provided of three different types depending upon dimensions of Bays , a uniform width equal to wall width of 230 mm is considered and accordingly strut width are calculated using equivalent strut width formula and there values are tabulated in Table.1. Here, strut2, strut4, strut5 refers to struts provided in Bays with length of 2m, 4m and 5m respectively.

**Table 1:** Properties of Dampers

<b>PROPERTIES OF DAMPERS</b>	
Damping coefficient	40000
Damping exponent	1
Stiffness	0
Strut 2 width	0.795m
Strut 4 width	0.767m
Strut 5 width	1.07m

Following Table 2 shows the various specifications and properties of member, materials used in the given model. Three values of bays width are provided for three different bay lengths.

**Table 2:** Specifications of Building

SPECIFICATIONS OF BUILDING	
Items	Properties
Density of concrete	25 KN/m <sup>3</sup>
Height of the floor	3.1 m
Bay width	2m, 4m, 5m
Poisson's ratio (concrete)	0.2
Elasticity of concrete	25000 N/mm <sup>2</sup>
Density of Masonary	20000 N/mm <sup>2</sup>
Live load	3 KN/m <sup>2</sup>
Beam size	450 x 300
Column size	450 x 300

Table 3 shows the calculations and values of various types of loads considered in the given building model. All results and conclusions are obtained with respect to these load value and all loads are applied as line loads, floors loads are converted to line loads format using trapezoidal and triangular load distribution patterns.

**Table 3:** Load Calculations

Load Calculations		
Load Type	Calculations	Magnitudes
External Wall	0.23x(3.1-.45) x20	12.19 KN/m
Internal Wall	0.15x (3.1-.45) x20	7.95 KN/m
Parapet Wall	0.23 x 1.5 x 20	6.9 KN/m
Slab	0.15 x 1 x 1 x 25	3.75KN/m
Floor finish	1 x 1	1 KN/m
Roof treatment	1.5 x 1	1.5 KN/m
Live	3 x 1	3 KN/m
Live roof	1.5x 1	1.5 KN/m

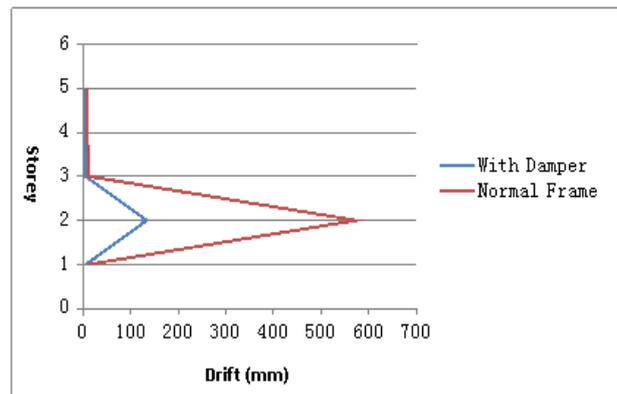
## V. ANALYSIS AND RESULTS

A viscous damper provides a damping force of  $F = C Vu$ , where  $C$  is the damping coefficient,  $V$  is the velocity and  $u$  is the damping exponent. Damping exponent is generally in the range of 0.4 to 1.0 and in this paper it is taken as 1.0 for all cases. The value of damping coefficient  $C$  is taken as 40000(KN.s/m). The response of structure is determined for five storey building with open ground storey (without damper) and same soft storey building frame with dampers provided up to specific storey and the results are given in the various tables below.

**Table 4:** Drift of different storey

Drift of different storey (mm)		
	Normal Frame	With Damper
Storey 1	10.98	6.21
Storey 2	573.50	133.3
Storey 3	10.94	3.981
Storey 4	8.92	3.542
Storey 5	8.314	3.325

In Fig 6, the analysis results show that there is a sudden rise in drift and displacements at storey 2 due to loss of stiffness at the ground storey. Thus, the building can undergo soft storey failure if exposed to seismic conditions. Also, it can be interpreted from the results that the use of Viscous Dampers has improved the performance of the building to great extent.



**Fig 6:** Plot of Drift vs Storey

Sudden change in red plot at storey 2 indicates sharp change in stiffness due to soft storey. Blue plot represents the drift behavior of soft storey with viscous Damper and shows considerable reduction in this soft storey problem of excessive drift. Also the maximum drift of building is checked within the maximum permissible limits.

**Table 5:** Displacements of different storey

Displacements of different storey (mm)		
	Normal Frame	With Damper
Storey 1	10.98	6.12
Storey 2	584.48	139.42
Storey 3	595.42	143.40
Storey 4	604.34	146.94
Storey 5	612.66	150.27

## VI. CONCLUSIONS

- With the deployment of viscous damper in the structure maximum response and drift reduces in structure during seismic loading.
- The performance of building structure in seismic loading is improved to great extent. By the provision of viscous dampers up to five stories, maximum drift is reduced from 3.7 % to 0.86 %.
- Main factors for reduction of response of the structure are parameters associated with Dampers and the dissipation of energy produced during earthquake by the mean of viscous Dampers.
- The maximum acceleration decreases from 2.2% to 0.4% and base shear increased from 0.8% to 1.67% by providing dampers.

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