APPLICABILITY OF DAMPERS ON STRUCTURES – A BRIEF REVIEW

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Abstract : Dampers absorb seismic forces and dissipate the energy and reduce the horizontal vibrations, in the present review Tuned Mass Dampers (TMD), Friction damper, Fluid Viscous Damper are studied, based on the review TMD works effectively in broad spectrum of central frequencies. In the case of narrow band central frequency if the structural frequency is similar to that of central frequency. When we go for a lightly damped structure tuned mass damper serves its best. The energy dissipated by the friction damper increases up to optimal slip load if the force exceeds optimal slip load then there may not be increase in the energy dissipation. Fluid viscous damper is relatively cheap and easy to maintain as fluid viscous damper various it's resisting force with velocity it has a unique ability of reducing both stresses and deflections simultaneously when it is subjected to transient forces. When we need to connect adjacent buildings with dampers then we can go for friction dampers as this technique does not need additional space for installation of dampers.

Index Terms - **Dampers, Tuned Mass Dampers, Frictional Dampers, Fluid Viscous Dampers**

I. INTRODUCTION & REVIEW

A tuned mass damper shown in figure 1 (Chakraborty and Roy, 2011 [1]) is a passive damping system when attached to the main structure reduces the structural responses. It acts like a secondary vibrating system when attached to the main system (structure). Its frequency is set too close to that of structural frequency, so that when the structure gets excited the damper resonates out of phase with the structural frequency and reduces the structural vibrations.

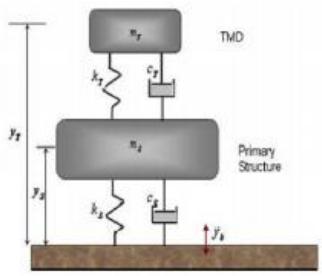


Fig.1 The primary structure with TMD system (Chakraborty and Roy, 2011[1])

A tuned mass damper consists of mass, spring and a dashpot when attached to the main structure reduces the structural responses caused by wind and seismic loads. The natural frequency of the TMD is tuned closely to the dominant mode of the vibration-prone structure. Kinetic energy will be transferred to Tuned Mass Damper from vibrating main structure then it is later dissipated by viscous element. The seismic response of a tuned mass damper when subjected to seismic excitation is studied by Dr. MohanM. Murdi and Mr.Sarath Chandra M. Manne[2]. Their main focus of study is to study effect of ground motion with the parameters that include intensity, central frequency, band width, duration on effectiveness of Tuned Mass Damper and their optimization

The joint system of Tuned Mass damper with spring attached to a Single Degree of Freedom System acts as two degree of freedom configuration. They have stated that as the central frequency of the ground motion is similar to that of structural frequency the effectiveness of tuned mass damper increases. Even in the vicinity of the central frequency the effectiveness increases with an increase in the central frequency, see table 1. The effect of frequency bandwidth of ground motion is also studied. The TMD is effective over a broad spectrum of structural frequencies, whereas for narrow-banded ground motion the TMD is only proved effective if the structural frequency and ground motion are in vicinity of each other. The reason for the above behaviour can be traced to the fact that the narrow-banded ground motion tends towards a harmonic ground motion, Tuned Mass Damper can be effective only if the structure and excitation frequency and damper are in close area to one other.

Table 1

Structural Properties		Central frequency of ground motion		
		$\omega_g=1.5\pi$	$\omega_g=2.0\pi$	$\omega_g=3.0\pi$
Tn (s)	φ_s (%)	% Reduction in a_{max}	% Reduction in a_{max}	% Reduction in a_{max}
0.67	2	22.77	24.10	29.61
	5	15.13	18.17	25.07
1.00	2	23.14	25.88	26.41
	5	17.41	22.02	22.96
1.50	2	25.83	23.98	23.55
	5	24.40	21.27	21.03

Table 2

Structural Properties		Bandwidth of ground motion		
Tn (s)	φ_s (%)	φ_g=0.2	φ_g=0.4	φ_g=0.6
		% Reduction in a_{max}	% Reduction in a_{max}	% Reduction in a_{max}
0.50	2	15.12	21.66	24.49
	5	8.30	13.91	17.70
1.00	2	31.10	25.88	27.84
	5	26.66	22.02	23.80
2.00	2	16.90	18.74	18.05
	5	14.50	17.40	16.43

According to the tests conducted by Christopher Adam and Thomas Furtmuller[4], tuned mass dampers are effective for mass ratios in between 2% to 8% for controlling seismic excitation. For their study a set of real earthquake ground motions are applied to the structure. This set consists of 40 ground motions recorded in California of moment magnitude 6.5 to 7. The effectiveness of an optimally tuned mass damper decreases with an increasing structural damping. Reviewing their results obtained in their study reveals that optimal tuning of the TMD parameters under the assumption of white noise base acceleration is sufficiently accurate. However the accurate tuning of TMD natural frequency is necessary for effectiveness.

A study by Mr. Ashish A. Mohite and Prof. G.R. Patil[5] states that placing of tuned mass damper at the top floor gives the best result .for proving this they have taken moment resisting frames of 10, 12, 14, 16, 18, 21 storeys. To find out the seismic response (storey drift, storey displacement, and acceleration) of a symmetrical MRF building with and without any damping device using ETABS. With difference in mass ration of 5% Tuned mass dampers are applied. For Bhuj Earthquake (2001 – India) intensity with specified dimensions time history analysis is carried out Graph below shows the maximum displacement time histories of structures with and without TMD under the Bhuj earthquake. It demonstrates that the maximum displacement of the top storey without TMD is 35.4 mm and that of with TMD is 21.9 mm in an 10th storey structure. In comparison with an 10th storey structure, in a 12th storey structure, the maximum displacement of the top storey without TMD is 42.9 mm and that of with TMD is 27.3 mm. Whereas, in a 21 storey structure the maximum displacement of the top storey without TMD 76.8 mm and that of with TMD is 53.4 mm.

Then, from base shear table 4 plots that were obtained after analysis for MRF symmetrical building frame, buildings without TMD & with TMD.

Table 4 showing the variation of base shear with and without TMD

Time History	Storey No.	Base shear (KN)	
		Building without TMD	Building with TMD
X,Y	10	2612.15	2670.07
X,Y	12	2511.07	2577.49
X,Y	14	2417.66	2489.56
X,Y	16	2355.58	2412.62
X,Y	18	2299.15	2365.02
X,Y	21	2234.38	2288.77

From analysis it can be seen that it is necessary to properly implement and construct a damper in any high rise building situated in earthquake prone areas.The TMD should be placed at top floor for best control.

Now-a-days several techniques are available to reduce wind and earthquake induced structural vibration. Shear wall is an already existing technique and commonly used. Passive tuned mass damper (TMD) is widely used to control structural vibration under wind load but its effectiveness to reduce earthquake induced vibration is an emerging technique.The paper given by Mohammed Murrad and Lavanya[6] is to study the comparison of shear wall and TMD for reducing vibration of tall buildings due to wind and earthquake loading by using SAP2000 software. Shear walls and Tuned Mass Dampers are assigned in the structure alternatively. Various arrangements of Tuned Mass Dampers in this 30 storey building are studied. A 30 storey building model has been created and shear wall is provided in it to make it safe under lateral loading conditions. The various characteristics of the structure has analyzed and studied. TMDs are located at various positions. A total of 7 models have been created with TMDs at various positions.The models created are as follows: Model 1: 30 storey building with shear wall. Model 2: 30 storey building with 4 TMDs located at four exterior corner joints of all the floors. Model 3: 30 storey building with 4 TMDs located at interior corner joints of all the floors. Model 4: 30 storey building with 8 TMDs located at exterior and interior corner joints of all the floors. Model 5: 30 storey building with 8 TMDs located at joints in a plus shape of all the floors. Model 6: 30 storey building with 12 TMDs located at all exterior joints of all the floors. Model 7: 30 storey building with 12 TMDs located at joints in a plus shape of all the floors. Model 8: 30 storey building with 16 TMDs located at all joints of all the floors. Table 5 and 6 shows their comparison.

Table 5 & 6

Model		1	2	3	4
Base shear (kN)	X	23670	3404	3404	3404
	Y	10512	2595	2753	2034
	Z	161399	177834	132216	132216
Storey displacement(m)		0.088	0.043	0.046	0.046
Joint acceleration (m/s^2)		24.391	4.073	3.189	3.81
Frequency (rad/sec)		38.949	12.975	15.457	13.55

Model		5	6	7	8
Base shear (kN)	X	3404	3404	3404	3404
	Y	750	1947	1925	2174
	Z	132216	132821	132216	132183
Storey displacement (m)		0.046	0.037	0.037	0.046
Joint acceleration (m/s^2)		2.49	2.89	4.18	3.47
Frequency (rad/sec)		13.55	12.237	13.952	13.589

They have concluded that the base shear, storey displacements and frequency of 30 storey buildings with Tuned Mass Dampers in all the directions are very less when compared to building with shear wall. The cost of TMDs is almost similar to that of shear wall in 30 storey's structure. Tuned mass Damper are more applicable comparable to shear wall due to less base shear, storey displacement, Joint acceleration and frequency

Friction damper is a passive energy dissipating device which dissipates energy by means of solid friction developed between the surfaces. This type of a device was pioneered by Pall in 1979. Mualla and Borislav[7], 2002 have investigated the performance of a friction damper installed in a single storey steel frame subjected to seismic loading. Based on the Experimental and Numerical results as compared to conventional design of dampers friction damper can improve the dynamic response

When the force acting on the friction damper reaches a predetermined value(slip load), the sliding surfaces starts slipping, thus dissipates the seismic energy. The energy dissipating property depends on the slip load. For a installed friction damper device their exists an optimal slip load for which there exists minimum displacement and maximum energy dissipation. There are basically two phases in the operation of a friction damper they are sliding phase and non sliding phase. The component parts of a friction damper are as shown in the figure 2.

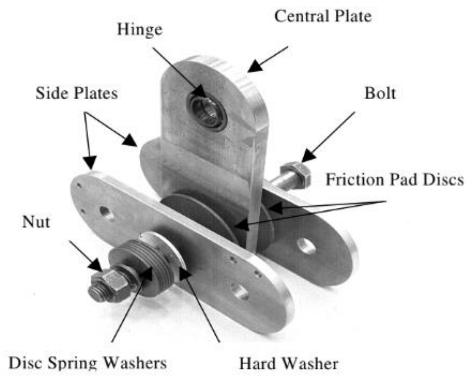
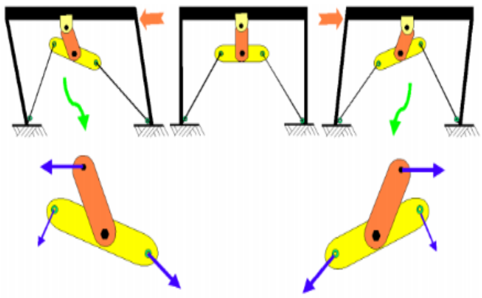


Figure 2 showing the components of friction damper

The mechanism of friction damper was explained by Imad H Mualla[7]. Due to force girder stats to displace horizontally when the excitation is due to horizontal external force in case of framed structure. Hinge connection transfer the forces to corresponding damper parts as the damper follows the horizontal motion of frame for hinge connection. The horizontal motion due to bracing system and the frictional forces will be resisted by friction pad materials and frictional surfaces of steel. Central plate will rotate around the hinge by moving horizontally. The damper parts stick to each other due to clamping force in the bolt and due to this action the frictional forces are introduced. As the frictional forces are higher than applied forces the side plates will rotate as same as central plate.

In anticipation of the applied forces to exceed frictional forces the damper will continue in non sliding phase at this point phase starts and central plate starts rotating relative to friction pad discs around the bolt. Due to tensile forces acting in the bracing the side plates start to rotate and slip in another direction. This is the sliding phase, in this phase the energy starts to dissipate from the dampers by means of friction, this sliding phase will later be changed to non-sliding phase when the load reverses its direction



From their tests one can conclude that, the use of supplemental damping provided by this friction damper dissipates a big amount of kinetic energy in a structure, and, thereby eliminates the utilization of structural ductility while the structure remains elastic without damage.

According to Amir Shirkhani, NaserShabakhty, Seyed Roohollah Mousaviit[8] is concluded that by adding dampers, the reduction percentage of roof displacement of frames will be decreased by increasing the number of stories. In their study they have taken steel moment frames with 3, 7 and 12 stories equipped with the friction damper. The frames are subjected to nonlinear time history analysis. The energy dissipated by friction damper device and its behaviour (the hysteresis curve of moment-rotation) are investigated in their study.

According to the results of their study, it is obvious that, by increasing the number of stories and free vibration period of structure, reduction percentage of roof displacement will be decreased by adding dampers to the structure. The energy dissipated by damper in 7 stories frame is more than other frames. It reveals that 7 stories frame equipped with dampers has a better performance. For lessening the displacement and base shear friction damper plays a vital role

A study was carried out to find out the optimal slip load of a friction damper by Adithya G. S. , H. Narendra[9]. For this the optimal slip load of the friction dampers provided in a nine storey reinforced concrete frame model was evaluated analytically using nonlinear time history analysis. The structure was evaluated for the effect of frictional dampers on the displacements and forces. In the present study, the safety of the structure, maximum displacement of the roof, maximum base shear, percentage of input energy dissipated by the friction dampers and the maximum column axial loads due to earthquake were considered as the criteria to select the optimal slip load. These response quantities were first obtained for the bare frame using the nonlinear time history analysis. The friction damper element is then introduced and a series of nonlinear time history analyses were carried for various slip loads and above mentioned response quantities were obtained for each slip load. The optimal slip load is then selected as 350kN for the Indian seismic zone IV, at which all the elements are within their stress capacity, with minimum response and higher energy dissipation by the friction dampers. Table 7 shows the variation of physical quantities for a change in slip load

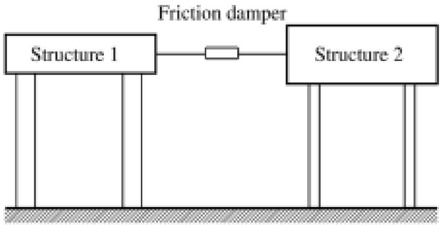
Table 7

Slip Load of the Friction Damper in kN	Total Input Energy in kN-m	Total Energy Dissipated by the Dampers in kN-m	Percentage of Total Input Energy Dissipated by the Dampers (%)	Maximum Base Shear in kN	Maximum Displacement of the Top Storey in mm	Maximum Axial Force in the Members in kN*	No of Members Failed
0	6725	0	0.00	16120	192.1	2179	56
50	7569	3096	40.90	14120	168.7	1915	18
100	8384	4805	57.31	14680	154.6	1756	24
150	8971	5880	65.54	14400	144.5	1638	22
200	9362	6512	69.56	13770	135.4	1533	12
250	9545	6811	71.36	12930	124.6	1409	2
300	9788	7035	71.87	12410	118.8	1343	0
350	**10100**	**7254**	**71.82**	**11780**	**118.5**	**1337**	**0**
400	10420	7440	71.40	11620	119.2	1344	0
450	10720	7588	70.78	11890	119.9	1352	0
500	11010	7703	69.96	12070	120.5	1357	0
550	11270	7780	69.03	12160	120.7	1359	0
600	11500	7813	67.94	12120	120.2	1353	0
650	11690	7802	66.74	12000	119.0	1340	0

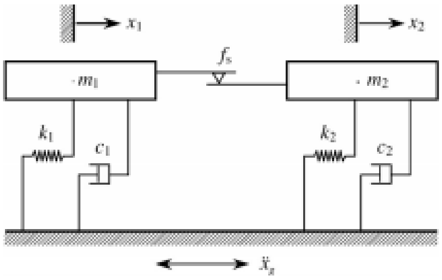
Once the optimal slip load of the friction damper was obtained, the response quantities were found out for both the bare frame and the friction damped frame and the results were compared. The response quantities considered in the present study includes, maximum storey displacements, inter storey drifts, maximum storey accelerations, maximum storey shear, maximum base shear, maximum beam moments at each storey level due to earthquake and maximum column axial loads and maximum column moments due to earthquake at each storey level.

The slip load of the friction damper is the primary variable in the analysis of friction damped structure and it controls the response of the damped frame. Hence it is possible to optimize the response of the structure by proper selection of optimal slip load.

The optimal placement of dampers, rather than providing dampers at all floor levels is studied by A.V. Bhaskararao, R.S. Jangid[10] to minimize the cost of dampers. Connecting the adjacent structures with passive energy dissipation devices has attracted the attention of many researchers due to its ability in mitigating the dynamic responses as well as to reduce the chances of pounding. The space between the two closest structures can be utilized for placing the control devices and the installation does not oblige any additional space

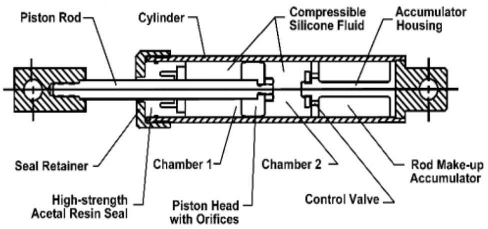


(a) Adjacent structures with friction damper.



They have also conducted tests on the optimal placing of dampers in the connected structures. They have carried out various possible outcomes in the placing of dampers. Results have been proved that It is not necessary to connect two adjacent structures by dampers at all floors but lesser dampers at appropriate locations can significantly reduce the earthquake responses of the combined system. The neighbouring floors having more relative displacement should be chosen for optimal damper locations. The friction dampers are found to be very effective in reducing the earthquake responses of the adjacent connected structures

Fluid viscous dampers woks mainly by fluid flow through orifices. They are similar to those of shock absorbers used in vehicles. These are widely used in aerospace industry and military for many years. Usage of fluid viscous dampers to structures is developing now days. Fluid viscous dampers have the unique capability of reducing the stresses and deflections simultaneously. The components of fluid viscous dampers are stainless steel piston rod with a bronze orifice head and a self-contained piston displacement accumulator. When the FVD is subjected to external excitations, the piston rod with piston will make reciprocating motion in the cylinder to force the damping medium move back and forth between the two chambers separated by the piston.



SaiChethan K. ,Srinivas K.S. , Ranjitha K.P[11] have studied the effectiveness of fluid viscous dampers in reducing the responses of a structure under seismic excitations. It is evaluated analytically using non-linear time history analysis. A 5 bay 20 story reinforced concrete space frame made up of M30 grade concrete and Fe 500 grade steel is considered in their study. It is important to determine the optimal properties of fluid viscous dampers in order to reduce the response of the structure by a considerable amount. The optimal damper properties are nothing but the values of damping coefficient (C) and damping exponent (α) corresponding to minimum response of the structure and maximum seismic energy dissipation.

In their study, maximum displacement of top story, maximum base shear, maximum axial load on the columns and percentage of input energy dissipated by the dampers are considered as the criteria to determine the optimal values of damping coefficient and damping exponent. These response quantities are first determined for bare frame using non-linear time history analysis. The FVDs are then introduced and a series of non-linear time history analysis are carried out by varying the values of damping co-efficient and damping exponent and the above mentioned response quantities are noted. The optimum values of damping coefficient and damping exponent are obtained as 1082kN-s/m and 0.2. The average reduction in the response quantities is shown below table 8

Table 8

Average reduction (%) in	Seismic Zone	
	Zone IV	Zone V
Base shear	38.79	33.53
Displacement	28.15	28.37
Acceleration	30.05	31.60
Story drifts	42.57	40.49
Story Shear	31.76	33.50
Column axial loads	52.47	46.59
Column moments	45.06	42.36

From the study conducted by liyamathew& c. Prabha [12] on finding the optimum properties of fluid viscous dampers they have stated that for maximum effectiveness in reducing the dynamic responses, a structure with FVD should be designed for damping ratio of 20% and the velocity exponent, α of the FVD as 0.5. They have conducted non linear time history analysis on symmetrical square building. They have also stated the effect of FVD along width and height.

Effectiveness of FVD along the Width: From the dynamic floor responses of the buildings, it can be concluded that, placing FVD at the external corners on all four sides of the building is effective for square plans

Effectiveness of FVD along the Height:The peak displacements and interstorey drifts are minimized most effectively by placing the FVD along the first three floors alone. But while considering the other dynamic responses such as the floor velocity and floor acceleration, placement of FVD all throughout the height is found to be effective.

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