Application of Damping Devices for Tall Steel Structure

[1]Pratik S. Khadatare, [2]Shriganedsh S. Kadam
[1]MTech Student, [2]Assistant Professor,
[1]SKN Sinhgad College of Engineering, Korti,
[1]SKN Sinhgad College of Engineering, Korti,, Pandharpur, INDIA.

Abstract: Tall buildings have become a trend and, moreover, they have paved the way to world competition in constructing tall buildings to exhibit the symbol of power and technology possessed by its population. The building in earthquake prone area is frequently subjected to serious ground motion, the result of which is collapse of structure. The various effects of earthquake are landslide, tsunami, rock fall, etc. such that in this area tall building is not allowed to construct unless properly analyzed for seismic behaviour. However, tall building is constructed necessarily due to increase in demand. The design of building in earthquake zone should be such that they must resist moderate earthquake. The main the objective is to control the major part of energy that is getting into the structure and to avoid the collapse of structure, thus analysis of building is done in nonlinear domain. To take care of response viscous damper and friction damper is used in the building. The analysis and design of viscous damper and friction damper is discussed in this report. The analysis is carried out using ETABs software. The storey response in terms of displacement and inter storey drift have been compared, time history plots for displacement, drift and base shear have been also plotted. The results represent the effectiveness of damper in controlling the structure response of structure.

***IndexTerms* - nonlinear dynamic analysis, viscous damper, friction damper, ETABS.**

1. Introduction

The world population is growing so rapidly in recent years that there has been a resurgence of high-rise constructions in the major cities. High rise buildings have become a trend and, moreover, they have paved the way to world competition in constructing tall buildings to exhibit the symbol of power and technology possessed by its population. Also, a competition around the whole world to construct high rise buildings is occurring to indicate the symbol of power and technology owned by its population. However, high rise buildings are subjected to vibrations. These vibrations can be due to wind loads, earthquakes, machinery vibrations and other sources of vibration. These vibrations can cause structural damage or even collapse of the structure. Earthquakes are the most serious phenomena that engineers are extremely concerned about. The place and time of occurrence of an earthquake are unpredictable and therefore, this categorizes them as a disaster phenomenon. During an earthquake, a large amount of energy is pumped into the structure. The damage degree of the structure is determined by the way that this energy is consumed. The criteria specified in common building codes is to design structures that can resist to moderate earthquakes without any significant damage and avoid collapse during major earthquakes. The most important emphasis is on life safety. Recent earthquakes have clearly demonstrated that even in developed countries, typical constructions, are not immune to destruction. The main goal is to study and analyse the seismic behaviour of tall steel structure using viscous dampers. Different nonlinear computer programs are now capable of modelling viscous dampers. Some of these programs are SAP2000, ETABS, ANSYS, etc.

2. Structural Damping

Damping is a phenomenon by which mechanical energy is dissipated in dynamic systems; generally, it is converted into thermal energy. Damping reduces the build-up of the strain energy and the system response, especially for near resonance conditions, where damping controls the response. In other words, damping is utilized to characterize the ability of structures to dissipate energy during dynamic.

Types of damping
1) Active Control systems
2) Passive control systems
3) Semi-active control systems
4) Hybrid control systems

A. Active control system

An active structural control system has the basic configurations as shown schematically in Figure. 1. It consists of (i) sensors located about the structure to measure either external excitations, or structural response variables, or both; (ii) devices to process the measured information and to compute necessary control force needed based on a given control algorithm; and (iii) actuators, usually powered by external sources, to produce the required forces. Active control requires a power supply to activate the dampers and hence may be undependable during seismic events where the power supply could be disrupted. For this reason, dampers with active control have been tested on tall buildings subjected to wind induced loading rather the more unpredictable cyclic loading caused by earthquakes.

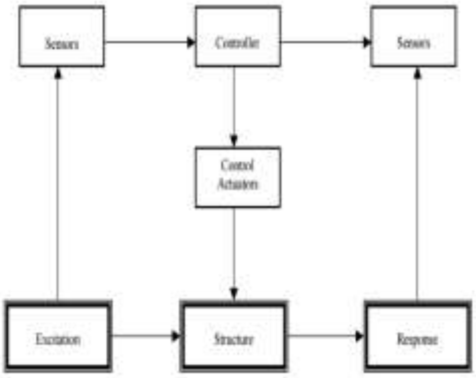

Figure 2.2.1 Active damping system

B. Passive Control Systems

The passive control system does not require an external power source and being utilizes the structural motion to dissipate seismic energy or isolates the vibrations so that response of structure can be controlled.

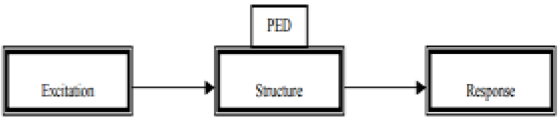

Figure 2.2.2 Passive damping system

3. SEISMIC METHODS OF ANALYSIS

After selecting the structural model, it is possible to perform analysis to determine the seismically induced forces in the structures. The analysis can be performed on the basis of the external action, the behavior of the structure or structural materials, and the type of structural model selected. Based on the type of external action and behavior of structure, the analysis can be further classified as linear static analysis, linear dynamic analysis, non-linear static analysis and non-linear dynamic analysis.

Linear static analysis or equivalent static analysis can be used for regular structures with limited height. Linear dynamic analysis can be performed in two ways, either by the response spectrum method or by the elastic time history method. The significant difference between linear static and linear dynamic analysis is the level of the forces and their distribution along the height of the structure.

Non-linear static analysis is an improvement over linear static or dynamic analysis in the sense that it allows inelastic behavior of the structure. The method is simple to implement and provides information on the strength, deformation and ductility of the structure of the structure, as well as the distribution of demands. But this method is based on many assumptions, which neglect the variation of loading patterns, the influence of higher modes of vibration, and the effect of resonance. In spite of the deficiencies, this method known as push-over analysis provides a reasonable estimation of the global deformation capacity, especially for structures that primarily respond according to the first mode.

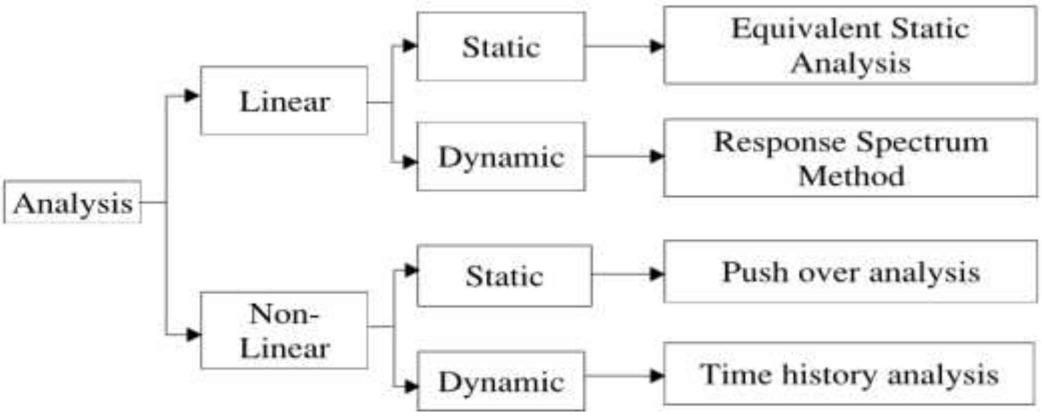

Figure 3.1 Method of seismic analysis

4. NON-LINEAR STATIC ANALYSIS

Pushover analysis is a simplified, static, nonlinear analysis under a predefined pattern of permanent vertical loads and gradually increasing lateral loads. This can be defined as the procedure in which the structure (taking into account the material nonlinearity) is pushed till collapse to generate the pushover curve, which is then used to estimate the target displacement at which the response quantity is extracted from the deformed modal. Load is applied incrementally to frameworks until a collapse mechanism is reached. Thus it enables determination of collapse load and ductility capacity on a building frame. Plastic rotation is monitored, and a lateral inelastic force versus displacement response for the complete structure is analytically computed. This type of analysis enables weakness in the structure to be identified. The decision to retrofit can be taken in such studies. The ATC-40 document has developed modeling procedures, acceptance criteria and analysis procedures for pushover analysis.

5. NON-LINEAR DYNAMIC ANALYSIS

It is a useful technique for the elastic analysis of structures; it is not directly transferable to in elastic analysis because the principle of superposition is no longer applicable. Also, the analysis is subject to uncertainties inherent in the modal superimposition method. The actual process of combining the different modal contributions is a probabilistic technique and, in certain cases, it may lead to results not entirely representative of the actual behavior of the structure. The time history analyses (THA) technique represents the most accurate method of dynamic analysis for buildings.

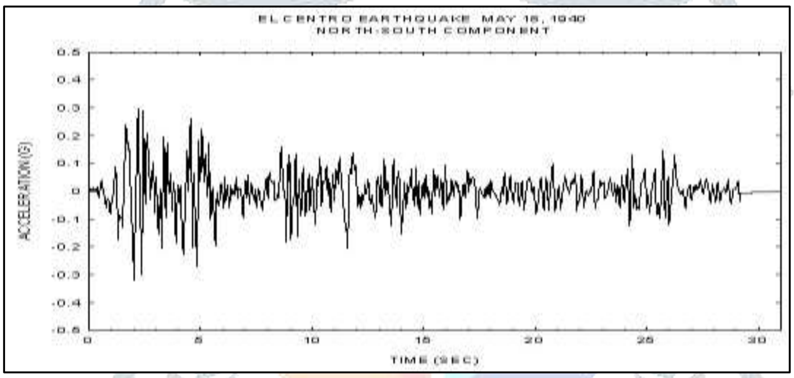

Figure 5.1 Time history data (acceleration vs. time) graph for El Centro earthquake

Various Time History selected for study are:

1) Imperial valley
2) North West California
3) Bhuj
4) Friuli Italy
5) Gazli USSAR
6) Lucerne valley
7) Sylmar country

6. VISCOUS DAMPER

Viscous dampers as shown in fig. is same as the action of shock absorber in automobile but performs better with high force. These dampers are larger than automotive damper and are more durable to serve for long time. The fluid use is of silicone oil which is inert, non-toxic. When the fluid viscous damper strokes in compression, fluid flows from Chamber 2 to Chamber 1. When the fluid viscous damper strokes in tension, fluid flows from Chamber 1 to Chamber 2. The high pressure drop across the annular orifice produces a pressure differential across the piston head, which creates the damping force.

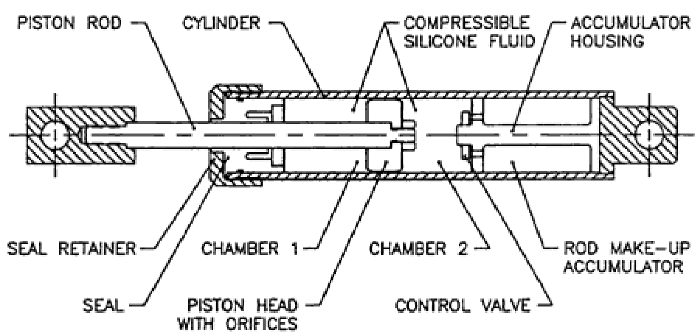

Figure 6.1 Viscous Damper

Design of viscous damper is done by the formula derived by Levy (2008).

$$C_d Total = 2 * \zeta * \omega_n \frac{[\phi^T][M][\phi]}{[\phi^T][\phi]}$$

Where

ζ = Damping in %

ω_n =Natural frequency of the structure (rad/sec)

ϕ = Modal displacement matrix

M= Mass matrix

C_d =Coefficient of Damping

7. FRICTION DAMPER

The friction dampers have advantages such as simple mechanism, low cost, less maintenance and powerful energy dissipation capability as compared to other passive dampers. They were found to be very effective for the seismic design of structures as well as the rehabilitation and strengthening of existing structures. They provide a practical, economical and effective approach for the design of structures to resist excessive vibrations. However, modelling of frictional force in the damper is quite a cumbersome process, as the number of equations of motion varies depending upon the non-slip and slip modes of vibration.

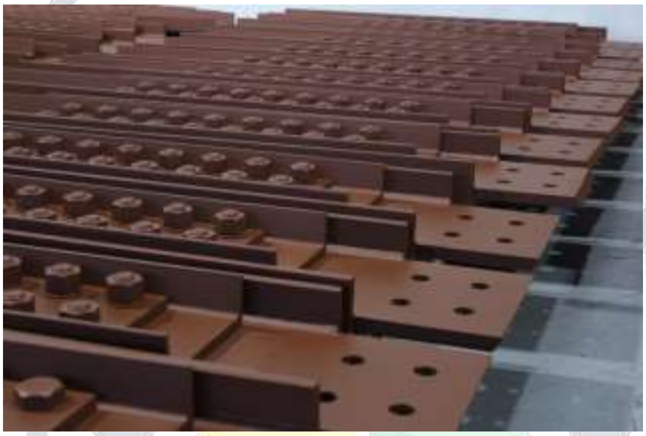

Figure 7.1 friction damper

8. MODELLING OF BUILDING

For this study a 30-story steel frame building is considered. The steel building consists of 5 bays in X-direction and 5 bays in Y-direction. Each bay is of dimension of 4mx4m, having total plan area of 20m X 20m. The building is considered to be located in zone V and designed according to Indian standard code. The structures are considered to be fixed at the base. The structures are modeled using software ETABS 2016. Models are studied for comparing maximum story displacement, maximum story drift and base shear.

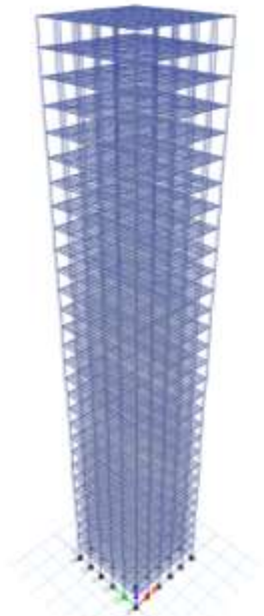

Figure 8.1 3-D View of Building in ETABS 2016

The common data used for modelling of building are as follows:

Table 8.0.1 Details of Building

No. of Storey	30
Storey height	4000 mm
Total height of building	120 m
Thickness of Slab	150 mm
Grade of concrete	M25
Grade of steel	Fe500
Number of bays	5 (X and Y direction)
Column Size	Outer=PISHB450-2-400/40
	Inner= PISWB600-2-400/40
Beam Size	ISWB300
Zone	V
Response reduction factor	5
Soil Type	Medium (Type II)
live load	3 kN/m^2
floor finish load	1 kN/m^2

The loads considered for the modelling of building are given in Table 2.

Table 8.0.2 Loading data

Sr no.	Load type	Value(kN/m^2)
1	Live load	3
2	Floor finished	1

A. Building with viscous damper

The viscous damper is applied as link property in ETABS 2016, the link type is damper exponential. The damper is modelled only along one longitudinal direction and restrained in other two transverse directions, in its local coordinate system. Rotational inertia is zero and rotation is restrained.

Figure 8.2 Building with Viscous Damper

B. Building with friction damper

Tension-compression diagonal brace with Pall FD has been modelled as per suggestions available on manufactures website (Pall Dynamics, Canada). Since the dampers are installed with supportive bracing systems, the combined system is modelled together as a link element. The damper is modelled only along one longitudinal direction and restrained in other two transverse directions, in its local coordinate system. Non-linearity is considered along the active direction U1. Rotational inertia is zero and rotation is restrained.

Table 8.0.3 Friction Damper details

Link type	-	
Weight	(kN)	4.211
Effective Stiffness	(kN/m)	20006.26
Effective damping	(kNs/m)	0
Yield strength	(kN)	353.3
Post yield stiffness ratio	-	0.0001
Yielding exponent		10

Figure 8.3 Building with Friction Damper

9. Result and Discussion

The complete analysis of building is done first linearly and then time history are applied to building to check the performance for different earthquakes taken from ETABS. The result is divided into three forms, first the building is linearly analysed without application of time history, then the building is analysed for seven different time history data. Then the results are shown with use of viscous damper and friction damper to show its effect of change in storey response.

Table 9.1 Response of building for linear static analysis

Model	**30 storey**
Displacement(mm)	215.32
Inter storey drift	0.002273
Base shear(kN)	1060.58
Time period(sec)	4.057

The Table 6.2 shows the response of building for different time history in terms of displacement, drift and base shear. The table shows that the response has increased after the application of time history.

Table 9.2 Response of building for nonlinear analysis

Time history	Displacement(mm)	Drift	Base shear(kN)
Imperial valley	247.54	0.003629	2140.31
NW California	215.55	0.002808	1388.03
Bhuj	279.65	0.003069	1941.41
Friuli Italy	190.32	0.002492	1704.41
USSAR	271.45	0.003439	1268.88
Lucerne	263.53	0.003348	1397.67
Sylmar	256.76	0.003275	1558.49

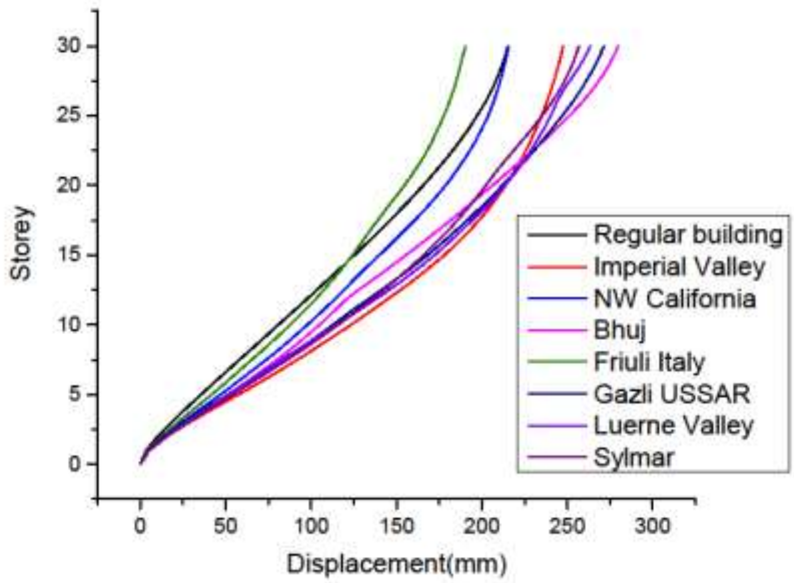

Figure 9.1 Displacement curve for different time history

The above Figure 6.1 shows the displacement curve for different time history, the displacement of regular building is about 215.32 mm which increases after the nonlinear analysis.

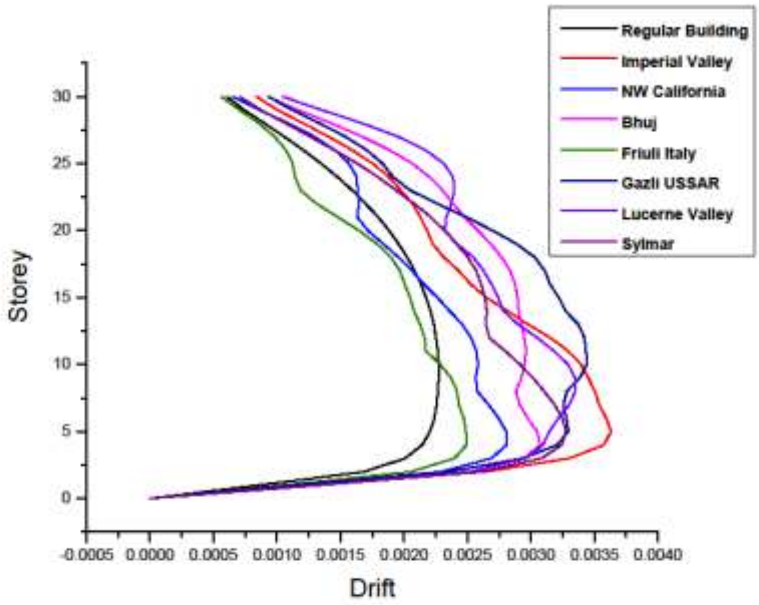

Figure 9.2 Drift curve for different time history

The above Figure 6.2 shows the inter story drift for different time history, the drift of regular building is 0.002273 which increases after the application of time history.

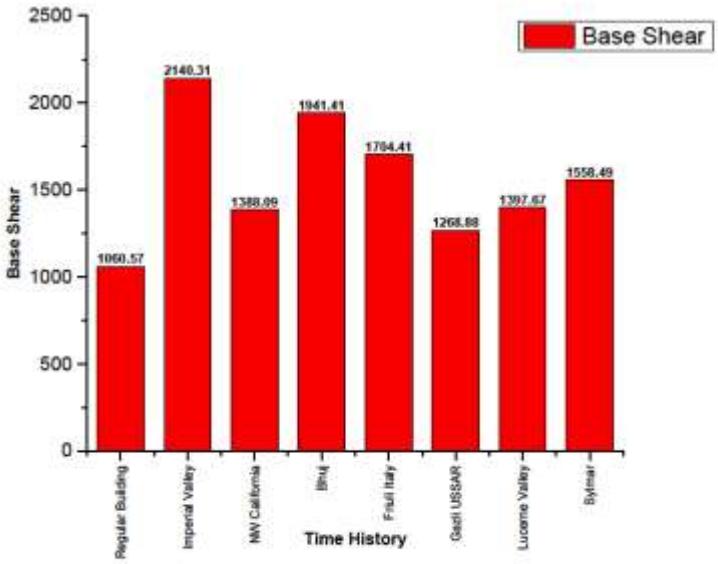

Figure 9.3 Base shear for different time history

The above Figure 6.3 shows the base shear of building for different time history, the base shear for regular building is 1060.57 kN, which increases after the application of time history.

A. Structural response by viscous damper

For the modal analysis carried out for 12 modes following time periods have been noted down (Tables 6.3) in each case for frame with and without supplemental damping. From the table for time period it can be easily seen that the time period of the oscillation of the structure has shifted to lower values on addition of dampers to the system to as much as 26% reduction in time period.

Table 9.3 Time period of structure

Mode No.	Without VD	With VD
1	4.057	3.978
2	4.001	3.125
3	3.185	2.952
4	1.956	1.658
5	1.24	0.985
6	0.819	0.789
7	0.643	0.594
8	0.588	0.476
9	0.402	0.348
10	0.401	0.301
11	0.355	0.298
12	0.288	0.275

a) Nonlinear time history results

After the application of viscous damper in the building the results of displacement and inter storey drift are plotted. For the building with viscous damper the results are checked for various damping effects such as 2%, 5%, 10% and 20%, in this the top displacement of the building and inter storey drift is shown for various time history which are taken from ETABS 2016.

1) For 2% damping

Table 9.4 Displacement and Drift for 2% damping

Time history	Displacement(mm)	Drift
Imperial valley	203.78	0.002526
NW California	189.45	0.002574
Bhuj	215.89	0.002599
Friuli Italy	187.58	0.002274
USSAR	191.85	0.002465
Lucerne	188.26	0.002601
Sylmar	186.48	0.002201

2) 5% damping

Table 9.5 Displacement and Drift for 5% damping

Time history	Displacement(mm)	Drift
Imperial valley	201.59	0.002434
NW California	182.89	0.002426
Bhuj	209.64	0.002596
Friuli Italy	180.36	0.002125
USSAR	184.24	0.002380
Lucerne	184.75	0.002514
Sylmar	180.08	0.002074

3) 10% damping

Table 9.6 Displacement and Drift for 10% damping

Time history	Displacement(mm)	Drift
Imperial valley	200.63	0.002410
NW California	181.45	0.002412
Bhuj	207.45	0.002489
Friuli Italy	179.58	0.002105
USSAR	182.48	0.002289
Lucerne	182.15	0.002459
Sylmar	178.15	0.002014

4) 20% damping

Table 9.7 Displacement and Drift for 20% damping

Time history	Displacement(mm)	Drift
Imperial valley	199.54	0.002345
NW California	180.95	0.002389
Bhuj	205.15	0.002410
Friuli Italy	177.15	0.002101
USSAR	181.54	0.002278
Lucerne	180.66	0.002459
Sylmar	179.10	0.002001

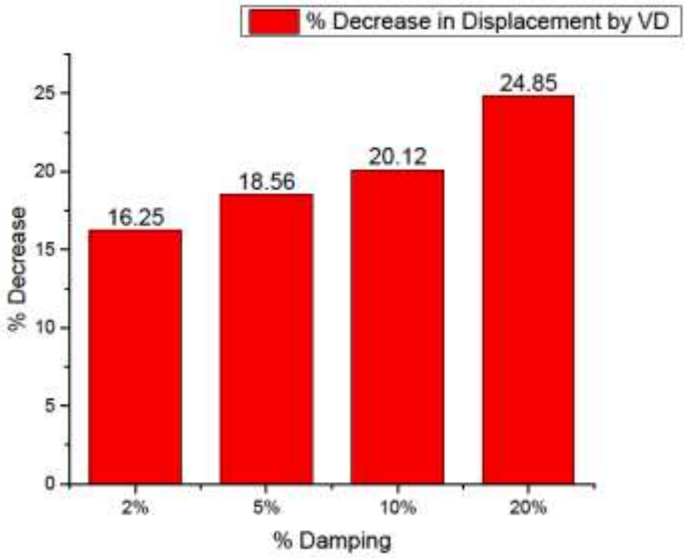

Figure 9.4 Percent decrease in Displacement due to Viscous Damper

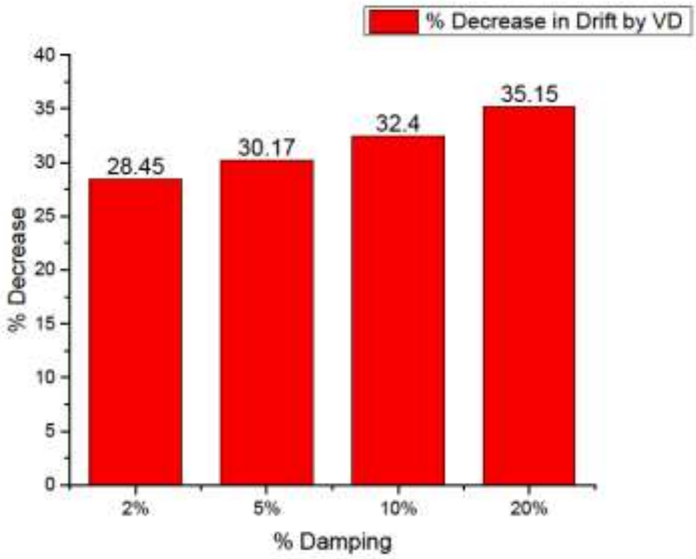

Figure 9.5 Percent decrease in Drift due to Viscous Damper

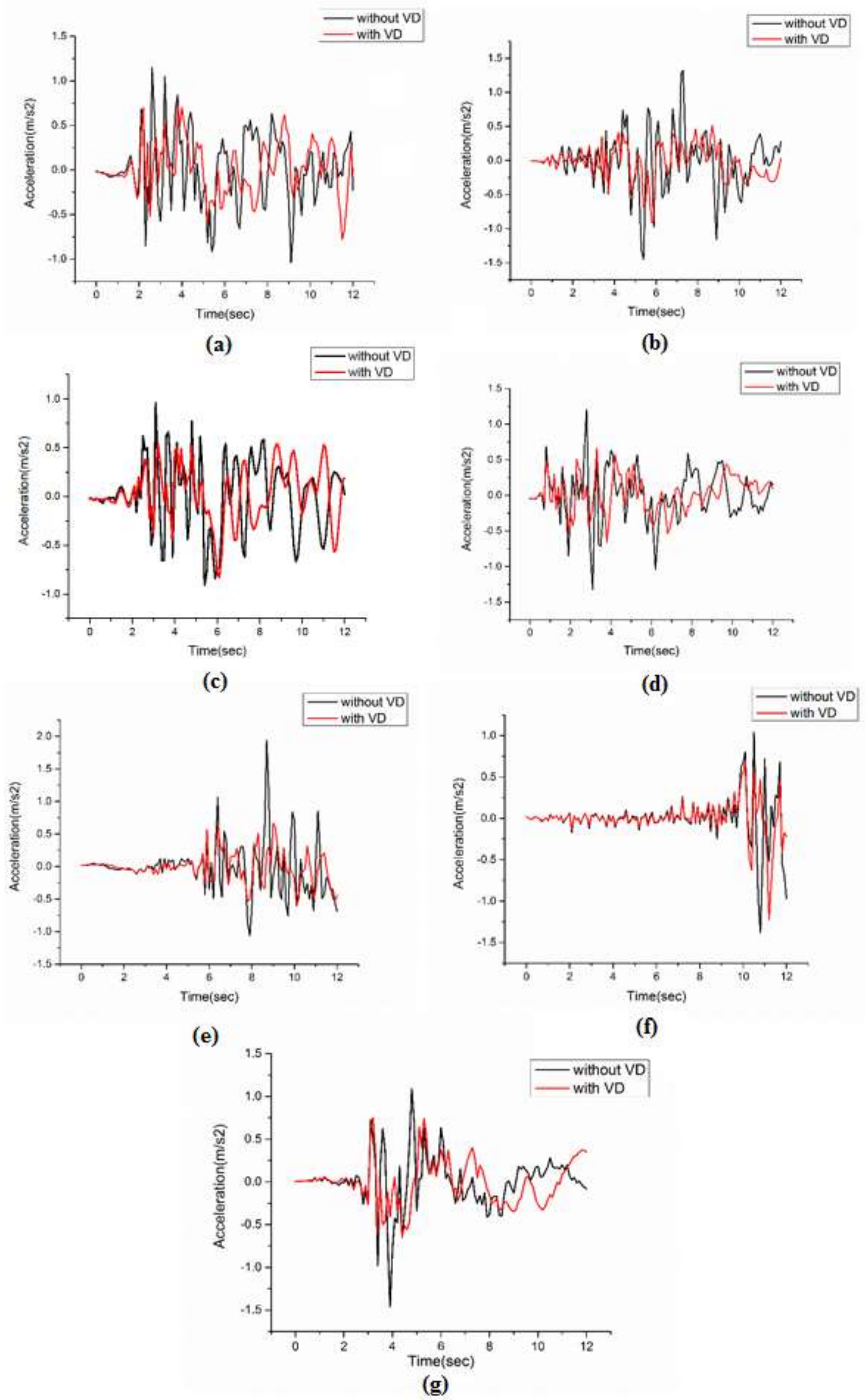

Figure 9.6 Time history graphs (a) Imperial Valley (b) NW California (c) Bhuj (d) Friuli Italy (e) USSAR (f) Lucerne Valley (g) Sylmar Country

b) Discussion

1. The Table 6.4 to Table 6.7 shows the results for different damping percent, it is seen that as damping increases the displacement and drift decreases.
2. After the application of viscous damper it is seen that about 25% decrease in displacement and 30% to 35% decrease in drift occurs.
3. The Figure 6.4 and Figure 6.5 shows the percent decrease in displacement and drift due to application of viscous damper.
4. Figure 6.6 shows the time history graph for different earthquake. The red colour curve shows the decrease in response in terms of acceleration after the application of viscous damper.

B. Structural response by friction damper

For the modal analysis carried out for 12 modes following time periods have been noted down (Tables 6.8) in each case for frame with and without supplemental damping. From the table for time period it can be easily seen that the time period of the oscillation of the structure has shifted to lower values on addition of dampers to the system to as much as 28% reduction in time period.

Table 9.8 Time period of structure

Mode No.	Without FD	With FD
1	4.057	3.975
2	4.001	3.256
3	3.185	2.989
4	1.956	1.748
5	1.24	0.998
6	0.819	0.801
7	0.643	0.596
8	0.588	0.486
9	0.402	0.384
10	0.401	0.342
11	0.355	0.285
12	0.288	0.264

a) Nonlinear time history results

After the application of friction damper in the building the results of displacement and inter storey drift are plotted. For the building with friction damper the results are checked for various damping effects such as 2%, 5%, 10% and 20%, in this the top displacement of the building and inter storey drift is shown for various time history which are taken from ETABS 2016.

1) 2% damping

Table 9.9 Displacement and Drift for 2% damping

Time history	Displacement(mm)	Drift
Imperial valley	204.59	0.002789
NW California	195.47	0.002485
Bhuj	217.56	0.002778
Friuli Italy	189.14	0.002310
USSAR	190.25	0.002425
Lucerne	194.82	0.002575
Sylmar	188.10	0.002302

2) 5% damping

Table 9.10 Displacement and Drift for 5% damping

Time history	Displacement(mm)	Drift
Imperial valley	202.98	0.002709
NW California	191.50	0.002340
Bhuj	212.12	0.002748
Friuli Italy	185.53	0.002261
USSAR	189.47	0.002374
Lucerne	190.18	0.002513
Sylmar	186.00	0.002230

3) 10% damping

Table 9.11 Displacement and Drift for 10% damping

Time history	Displacement(mm)	Drift
Imperial valley	201.15	0.002689
NW California	187.41	0.002310
Bhuj	208.94	0.002702
Friuli Italy	182.51	0.002206
USSAR	185.98	0.002320
Lucerne	188.45	0.002489
Sylmar	184.65	0.002198

4) 20% damping

Table 9.12 Displacement and Drift for 20% damping

Time history	Displacement(mm)	Drift
Imperial valley	199.65	0.002579
NW California	185.54	0.002299
Bhuj	204.72	0.002695
Friuli Italy	180.67	0.002201
USSAR	182.38	0.002315
Lucerne	186.94	0.002468
Sylmar	181.85	0.002136

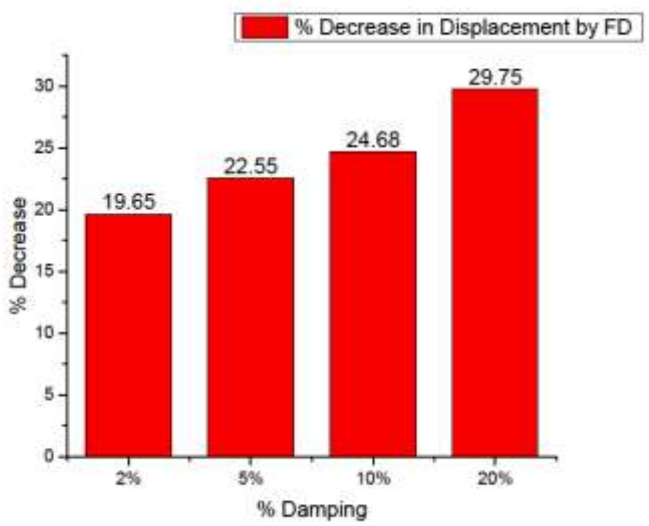

Figure 9.7 Percent decrease in Displacement by Friction damper

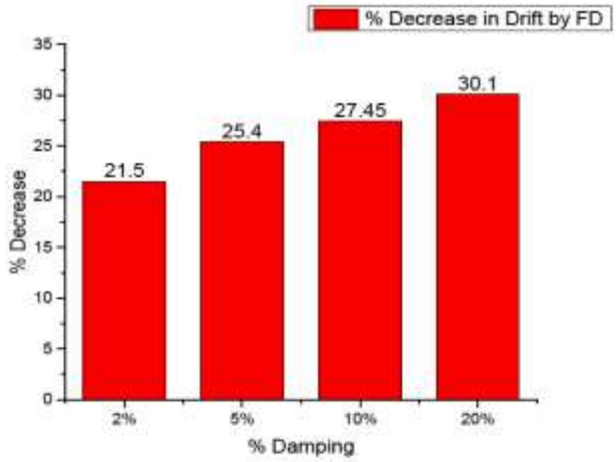

Figure 9.8 Percent decrease in Drift by Friction damper

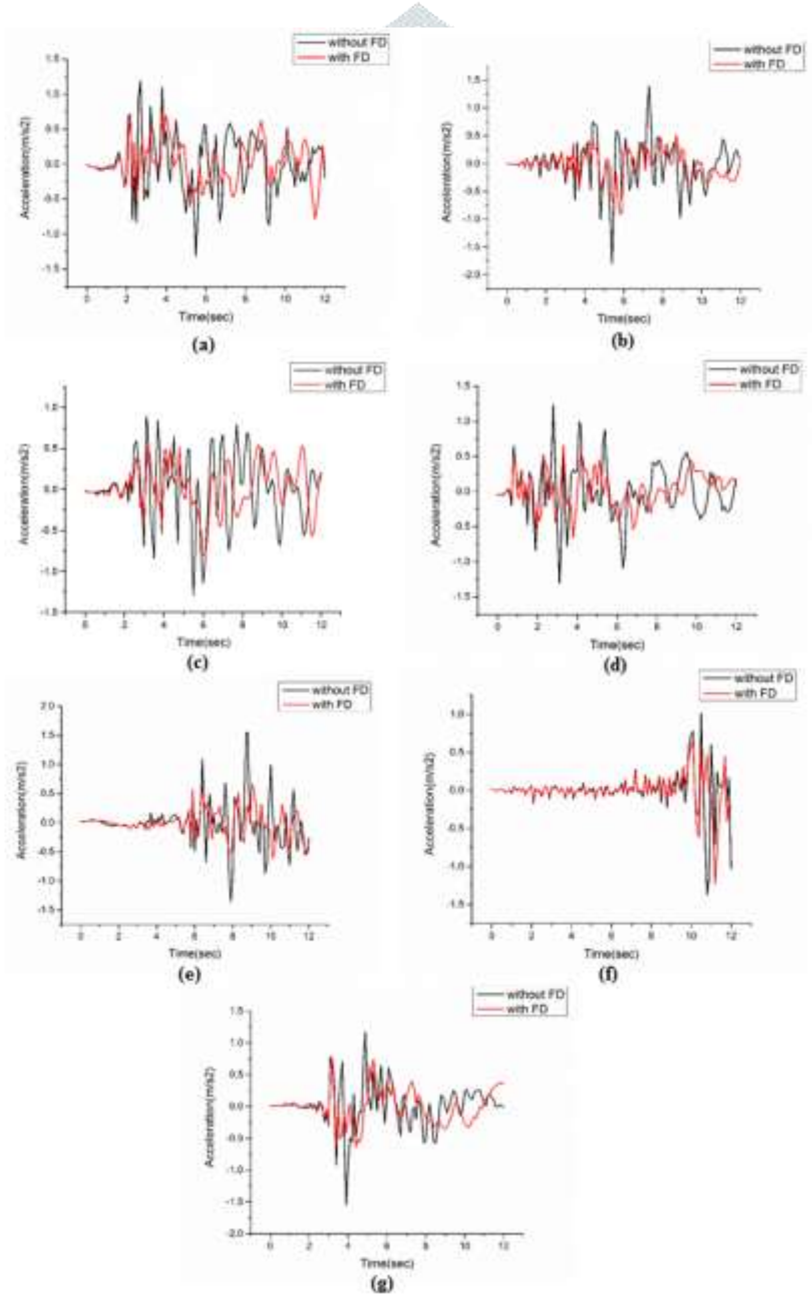

Figure 9.9 Time history graphs (a) Imperial Valley (b) NW California (c) Bhuj (d) Friuli Italy (e) USSAR (f) Lucerne Valley (g) Sylmar Country

a) Discussion

1. The Table 6.9 to Table 6.12 shows the results for different damping percent, it is seen that as damping increases the displacement and drift decreases.
2. After the application of friction damper it is seen that about 30% decrease in displacement and 30% to 35% decrease in drift occurs.
3. The Figure 6.7 and Figure 6.8 shows the percent decrease in displacement and drift due to application of friction damper.
4. Figure 6.9 shows the time history graph for different earthquake. The red colour curve shows the decrease in response in terms of acceleration after the application of friction damper.

C. Comparison of damper

From Table 6.13 the viscous damper reduces displacement to about 25% and drift to about 30% and friction damper reduces the displacement to about 30% and drift to about 35%, thus it is seen that friction damper is more effective than viscous damper, so use of friction damper gives better results after the analysis.

Table 9.13 Comparison of Dampers

	Viscous damper	Friction damper
Displacement	25%	30%
Drift	30%	35%

10. CONCLUSION

The modelling of building is done in ETABS for analysis. The first static analysis shows that there is more deflection in building than required. Thus to reduce the response of the building there is need of energy dissipating device like damper. The design of viscous damper and friction damper is done and it is applied in building to check the performance in terms of deflection, inter storey drift and base shear. The nonlinear time history analysis is also done to check the nonlinearity of the building. Various time history taken from ETABS 2016 are applied to the considered building model. The result for seven different time history is found out.

The time history plot of time vs. acceleration shows considerable reduction of acceleration over the time scale of the event by use of dampers against the building without damper. The analysis results show that there is more deflection of building for different time history. After application of viscous damper and friction damper in the building, it shows great results in terms of reduced response of the structure. The use of viscous damper shows about 25% reduction in the response of structure in terms of deflection, 30% reduction in inter storey drift and the use of friction damper shows about 30% reduction in the response of the structure in terms of displacement, 35% reduction in inter storey drift.. This shows that the use of viscous damper and friction damper helps in reducing the response of the structure, thus ultimately prevent the collapse of the structure.

Comparing both the dampers the use friction gives effective results than viscous damper after the analysis. Thus use of friction damper is more effective.

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