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# Seismic Performance of Low to Medium Rise Reinforced Concrete Buildings using Passive Energy Dissipation Devices

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## Abstract

*One of the major concerns in structural engineering is the development of new design concepts to improve structural performance and safety from the damaging effects of destructive earthquakes and winds. With the intent to achieve cost-effective seismic-resistant constructions the structures must be constructed to dissipate a large amount of seismic energy. Supplemental damping strategies are useful for improving the seismic response of structures to natural and manmade hazards. Passive energy dissipation devices, when integrated into a structure, dissipate a part of the input energy, thereby reducing energy dissipation requirement on primary structural members and reducing probable structural damage. The purpose of this research is to study the performance of building structure by using passive energy dissipation devices. Different types of devices used in this study are hysteretic dampers, friction dampers viscous and visco-elastic dampers. The finite element modeling technique is used to observe the behavior of structure with dampers. Three prototype concrete buildings (3, 5 and 10 Story) with same configuration are analyzed with damper using time history analysis. The buildings are analyzed with different types of dampers and by using different variation of their properties along the height of the building and the responses of buildings are observed in terms of, displacements, base shear and floor accelerations. It is found that the viscous and visco-elastic dampers are more effective for 3 & 5 storey buildings while friction and hysteresis dampers are effective for 10 storeys.*

**Key Words:** Seismic performance, Energy dissipation devices, Buildings, Dampers, Base shear

## 1. Introduction

Earthquake has always adverse effects on mankind. Building structures are susceptible to severe damage and/or collapse during moderate to strong ground motion. This has been illustrated after study of recent and past earthquake damages. Residential buildings, bridges, industrial and port facilities can adversely damage with an earthquake resulting in great financial and economic loss. Several destructive earthquakes have hit Pakistan over the times (October 08, 2005 earthquake being the one in renown recently). Major area of Pakistan has always under the danger of this natural hazard (earthquake) [8].

A large amount of energy is transmitted to the structure during seismic event. Current design practice is to prevent collapse by permitting structural members to absorb and dissipate the transmitted earthquake energy by inelastic cyclic deformations. These strategies represent that some damage may occur, possibly to the extent that the structure is no longer repairable. Figure 1(a) shows the conventional building behavior during a seismic event.

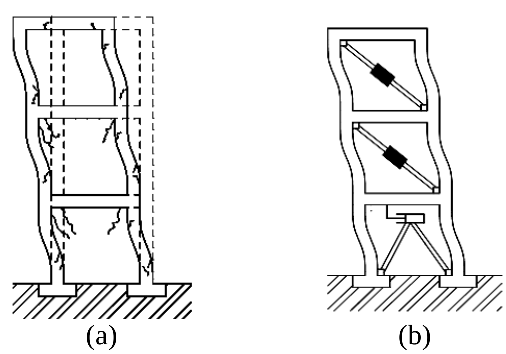



**Fig.1** (a) Conventional design of seismic resistant structure (b) Structure with passive dissipation devices

Nowadays, more innovative means to enhance structural performance and safety against earthquake and wind loads have been in different phases of research. These unconventional techniques enhance the energy dissipation capacity of the system. Mainly, they can be categorized into three broad areas. i.e., passive energy dissipation and active and semi-active control systems. Base isolation (passive control) can now be considered a more full-grown technique with large use as compared with the other two [6]. Passive energy dissipation systems encompass a range of materials and devices for enhancing damping, stiffness and strength, and can be used both for seismic vulnerability improvement and for retrofitting of deficient structures [9]. Figure 1 (b) shows the deformed shape of the structure with passive energy dissipation devices. These passive energy dissipation devices reduce demand on primary structural members as seismic energy is absorbed by the passive energy. Therefore, significant reduction of structural and non-structural damage could be achieved through a good design which reduces the inelastic demand on primary structural members. Generally, these devices are introduced in the form of bracing. While the conventional bracing members dissipate the input energy by means of axial plastic deformations, this energy can be dissipated by shear or flexural yielding of these devices according to some arrangement.

Passive energy dissipation devices are used widely in other areas of vibration control such as shock absorber for vehicles, vibration isolators for equipment, pipe restraints, and shock isolation devices for mitigation of blast effects. In the last two decades, much effort has been directed towards applying passive energy dissipation techniques to seismic applications. Several passive damping devices have been suggested and used for wind and earthquake loads. The devices are categorized according to how they operate. Passive energy systems include a wide range of devices for enhancing damping, stiffness, and strength. In general, they are characterized by their capability to dissipate energy either by transfer of energy among different modes of vibration or by translation of kinetic energy to heat.

In Pakistan, owing to the lack of new research conventional types of retrofitting techniques are used comprising of providing shear wall and column jacketing. The proposed study is based on latest development and outcome of this will be helpful for the structural engineers in the following respect.

- Use of different passive energy dampers that not only provide adequate energy dissipation under earthquake excitation, but also are easy to install and inspect.
- Use of different bracing strategies with passive energy dampers.
- Use of different passive energy dampers to reduce the damages of structures and hence preventing loss of lives.

The objective of the presented work is to analyze the seismic response of three, five & ten storey buildings using different types of Passive Energy dissipation devices which include Hysteretic, Friction, Viscous and Visco-elastic damper. Dampers properties were studied by varying them in uniform, triangular and reverse triangular mode and finally a comparison among the different types of passive energy dampers is presented. The scope of this research is limited to medium to low-rise buildings in low to moderated seismic zone.

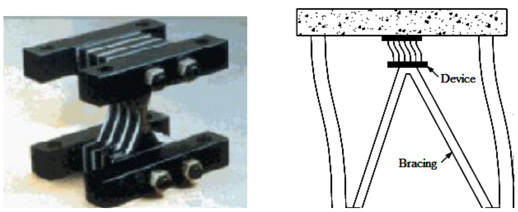
## 2. Types of Passive Energy Dissipation Devices

Several passive energy dissipation devices have been suggested and used for wind and earthquake loads. The devices are categorized according to how they operate. Following is a brief discussion of the application of each device:

### 2.1 Hysteretic Damper

Hysteretic Dampers dissipate the energy through the inelastic deformation of metals. Several devices which function as an integral part of seismic isolation system have been researched and developed in New-Zealand [7]. Different types of hysteretic dampers include Added Damping and Stiffness (ADAS) dampers, Bell-shaped Steel Dampers and Honeycomb Dampers System (HDS) and Lead joint dampers.

The most commonly used hysteretic dampers are Added Damping and stiffness (ADAS) and they consists of multiple X-shaped steel plates as shown in the figure 2(a). The device can sustain repeated inelastic deformation by avoiding concentrations of yielding and premature failure. Extensive experimental research has been carried out to observe the performance of ADAS elements in energy dissipation system. The test showed stable hysteretic behavior without any sign of pinching or stiffness degradation for the displacement up to 13.6 times the yield displacement of device. It should be noted that the ADAS elements and their braces on which it is supported primarily resist shear forces. The ADAS elements are designed in such a way that it yield in a predetermined manner and ease the main frame from excessive ductility demand. The basic construction and idealized hysteretic behavior of ADAS of damper is shown in the figure 3.




(a) (b)

**Fig.2** (a) Added Damping and stiffness (ADAS) Damper (b) Idealized building structure with supplemental yielding Hysteretic element. [7]

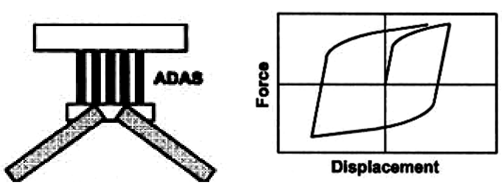



**Fig.3** Basic construction and idealized hysteresis behavior of Hysteretic damper

## 2.2 Friction Damper

Friction dampers dissipate energy by sliding of the plates against each other. A wide range of friction devices has been proposed and developed for energy dissipation in structure. Most of these devices generate rectangular hysteresis loop, which shows that the performance and behavior of friction damper is comparable to Coulombs friction. Generally, these devices have good performance characteristics, and their behavior is relatively less affected by load frequency, number of load cycles, or variations in temperature. The friction devices differ in the material used for the sliding surface and in their mechanical complexity. Different types of friction dampers include Pall Friction Dampers (Figure 4), Wall Friction Dampers, Sumitomo Friction Dampers and Energy Dissipation Restraint (EDR).

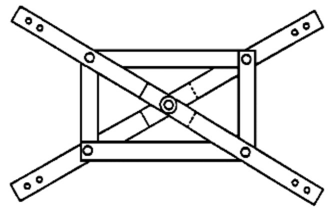


**Fig.4** Pall Friction Damper [10]

The basic construction and idealized hysteretic behavior of friction dampers is shown in the figure 5.

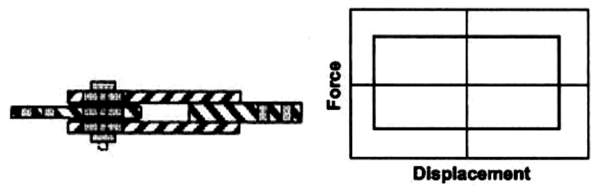



**Fig.5** Basic construction and idealized hysteresis behavior of friction damper

## 2.3 Viscous Dampers

Dampers which utilize the viscous properties of fluids have been developed and used in structural applications. A viscous-damping (VD) wall system was developed by Sumitomo Construction Company, Japan. The device consists of an outer steel casing attached to the lower floor and filled with a highly viscous fluid. An inner moving steel plate hanging from the upper floor is contained within the steel casing. The viscous damping force is induced by relative velocity between the two floors. The principle of fluid viscous dampers on which they operate is of fluid flow through orifices, which have been used since many years in automotive, aerospace, and defense industries. They are beginning to emerge in structural applications. These dampers possess piecewise linear viscous behavior and are relatively insensitive to temperature changes. Experimental and analytical studies of building and bridges with fluid viscous dampers manufactured by the Taylor Devices have been carried out by Constatinou and Symans [5]. The typical viscous fluid damper is shown in the figure 6.

The basic construction and idealized hysteretic behavior of viscous dampers is shown in the figure 7.

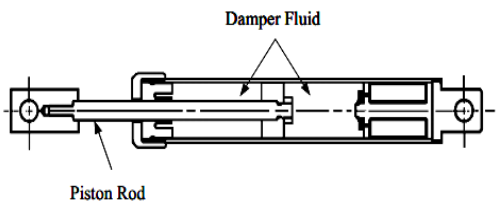



**Fig.6** Viscous fluid damper [14]

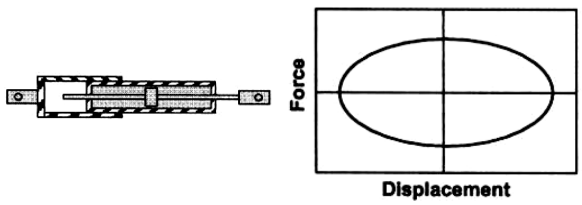



**Fig.7** Basic construction and idealized hysteresis behavior of viscous damper

### 2.4 Visco-elastic Dampers

Visco-elastic (VE) damper is one of important kind of passive energy devices these have been used as energy dissipation devices in many structures where the damper undergoes shear deformations. Visco-elastic materials exhibit combined features of viscous liquid and elastic solid when deformed. In other words they dissipate a certain amount of energy as heat and return to their original shape after every cycle of deformation. The characteristic of constrained double layer Visco-elastic shear damper is described by Mahmoodi [11] and he also mentioned that it can be efficient in decreasing the dynamic response of buildings. Visco-elastic dampers made of bonded acrylic polymers (Visco-elastic) layers. The extension of Visco-elastic shear damper to seismic applications is more recent. For seismic applications, more effective use of Visco-elastic materials is required since large damping ratios than those for wind are usually required. Figure 8 shows a typical visco-elastic shear damper consists of visco elastic layers bonded to steel plate. When these dampers are mounted to a building structure shear deformations occur, as a result energy dissipation take place when relative motion occurs between the outer steel flanges and central plate.

The basic construction and idealized hysteretic behavior of visco-elastic dampers is shown in the figure 9.

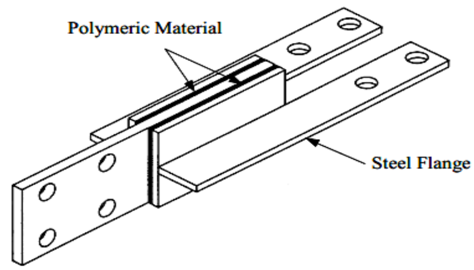



**Fig.8** Visco-elastic damper [7]

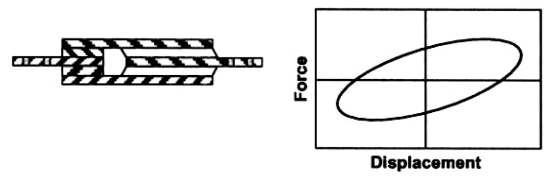



**Fig.9** Basic construction and idealized hysteresis behavior of visco-elastic damper

## 3. Buildings Description

Three different prototype buildings have been used in this research; the buildings are of concrete frame with varying heights of 3, 5 & 10 stories respectively. These buildings are designed for moderate seismic zone and the performance of these buildings is evaluated for seismic records corresponding to a high seismic zone with different passive energy devices.

Building-1 is a three storey frame and following are the parameters of the concrete frame:

| | | |
|---|---|---|
| No. of bays in X-direction | = | 3 |
| No. of bays in Y-direction | = | 1 |
| Width of bay in X-direction | = | 7.5 m |
| No. of stories | = | 3 |
| Height of first storey | = | 4.570 m |
| Height of other storey | = | 3.650 m |
| Column size | = | 500×500 mm |
| Beam size | = | 400×600 mm |
| Time Period in fundamental mode | = | 0.468 sec |

Building-2 is a five storey frame and following are the parameters of the concrete frame:

| | | |
|---|---|---|
| No. of bays in X-direction | = | 3 |
| No. of bays in Y-direction | = | 1 |
| Width of bay in X-direction | = | 7.5 m |
| No. of stories | = | 5 |

| | | |
|---|---|---|
| Height of first storey | = | 4.570 m |
| Height of other storey | = | 3.650 m |
| Column size | = | 600x600 mm |
| Beam size | = | 400x600 mm |
| Time Period in fundamental mode | = | 0.67 sec |

Building-3 is a ten storey frame and following are the parameters of the concrete frame:

| | | |
|---|---|---|
| No. of bays in X-direction | = | 3 |
| No. of bays in Y-direction | = | 1 |
| Width of bay in X-direction | = | 7.5 m |
| No. of stories | = | 10 |
| Height of first storey | = | 4.570 m |
| Height of other storey | = | 3.650 m |
| Column size | = | 700x700 mm |
| Beam size | = | 500x600 mm |
| Time Period in fundamental mode | = | 1.1 sec |

Following table describes the material properties which are used in analysis of above described building frames.

**Table 1** Material Properties

| Properties | Units (metric) |
|---|---|
| $f_c'$ | 21 MPa |
| $E_c$ | 21538 MPa |
| $F_y$ | 420 MPa |
| $f_y$ (for structural steel) | 250 MPa |

## 4.0 Loading

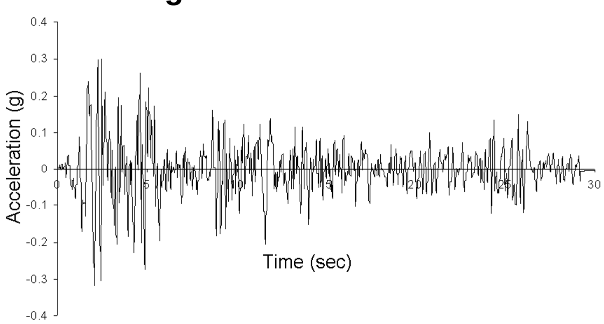



**Fig.10** E-W Direction Time Acceleration Graph of El-Centro Earthquake

The building frames are subjected to gravity and dynamic loadings. Gravity loading includes dead and l v ive load on building, while dynamic loading consists of time history loading. The E-W component of EL-Centro earthquake 1940 time history data is applied in X- direction of all the buildings. The time acceleration graph for the E-W component is shown in Figure 10. The peak ground acceleration (PGA) is 0.318g.

## 5. Damper Characteristics

In order to observe the performance of buildings under earthquake loading four different types of damper variations are used in this research namely, Hysteretic, Friction, Viscous and Visco-elastic damper. These dampers are installed in the middle bay of frames. Dampers types and properties are defined in Table 2.

1. ‘H’ is Hysteretic steel damper, modeled as Plastic-Wen element. The values listed in Table 2 are the yield force, Py, applied in kN. Maximum force is 1000 kN.
2. ‘F’ is a Friction damper, which is also modeled as Plastic-Wen element. The values listed is the friction force, Fy in kN same as the ‘H’ type damper. The stiffness, by a factor of 10 is increased for the friction damper as compared to Hysteretic damper [10].
3. ‘V’ is Viscous damper, which link the adjacent floors and slope in diagonal. The values of damping coefficient are listed in Table 2. The units of damping coefficient, ‘C’, are kN-sec/m. and the value of exponent, a, is assumed to be 1.0 for all types of analysis.
4. Visco-elastic or ‘VE’ damper, which also link the adjoining floors and therefore oriented in diagonal. The values of damping coefficient are listed in Table 2. The units of damping coefficient, ‘C’, are of kN-sec/m, which are the same as for viscous dampers. $K_{EFF}$, is the corresponding effective stiffness of Visco-elastic dampers, in units of kN/m, with a value numerically equal to 2 times of damping coefficient, ‘C’. Effective stiffness is the reasonable ratio of modulus loss to the storage modulus for smaller frequency responses.

## 6. Damper Variations

The property variation of each damper type is modeled with three different types of distributions as shown in the Figure 11 and the damper property variations for a typical 500KN damper is shown in the Figure 12.

1. ‘U’ represents Uniform distribution. The properties of dampers for uniform distribution are listed in Table 3, which are used for analyzing dampers at each storey level.

2. 'T' represents Triangular distribution. The properties of dampers for triangular distribution are listed in Table 3, which are used to define the dampers at uppermost floor. The damper at bottom floor is defined by using a value of ¼ of the value which is used at the top floor. For damper values at intermediate storeys, linear interpolation method is used.

3. 'R' represents Reverse triangular distribution. The properties of dampers are listed in Table 2, which are used to define the dampers at bottom floors. The damper at top floor is defined by using a value of ¼ of the value used at the bottom floor. For damper values at intermediate storeys, linear interpolation method is used.

**Table 2** Damper Properties

| Case No. | H & F | H & F | H & F | V & VE |
|---|---|---|---|---|
| | 10 Story | 5 Story | 3 Story | ALL |
| | Yield Strength (kN) | | | Damping (kN-sec/m) |
| 1 | 0 | 0 | 0 | 0 |
| 2 | 100 | 50 | 30 | 1000 |
| 3 | 200 | 100 | 60 | 2000 |
| 4 | 300 | 150 | 90 | 3000 |
| 5 | 400 | 200 | 120 | 4000 |
| 6 | 500 | 250 | 150 | 5000 |
| 7 | 600 | 300 | 180 | 6000 |
| 8 | 700 | 350 | 210 | 7000 |
| 9 | 800 | 400 | 240 | 8000 |
| 10 | 900 | 450 | 270 | 9000 |
| 11 | 1000 | 500 | 300 | 10000 |

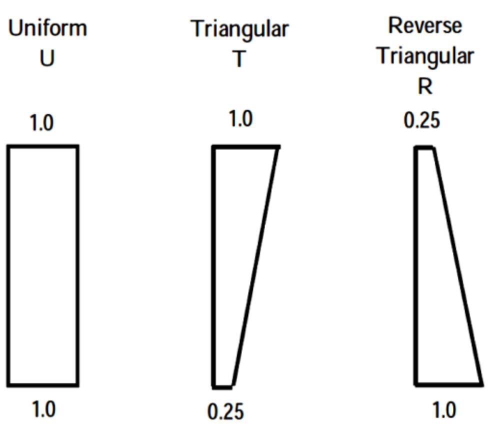



**Fig.11** Damper Variation

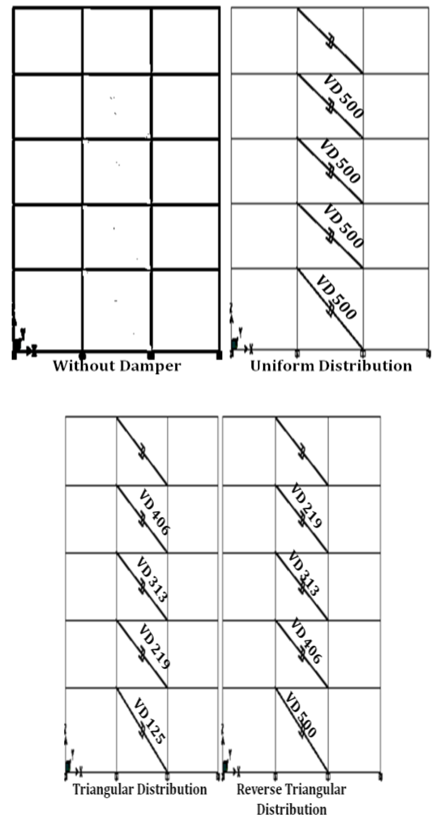



**Fig.12** Damper Distribution with Height

**Table 3** Damper Variation

<table>
<tr><th rowspan="3">No. of Storey's</th><th colspan="2">Without Dampers</th><th colspan="4">With Dampers</th></tr>
<tr><th rowspan="2">Analysis</th><th rowspan="2">Drift, Disp. & Base Shear</th><th>Hysteretic</th><th>Frict.</th><th>Visc.</th><th>Visco-Elas.</th></tr>
<tr><th>U<br>T<br>R</th><th>U<br>T<br>R</th><th>U<br>T<br>R</th><th>U<br>T<br>R</th></tr>
<tr><td>3</td><td>1</td><td>5</td><td rowspan="3">10<br>10<br>10</td><td rowspan="3">10<br>10<br>10</td><td rowspan="3">10<br>10<br>10</td><td rowspan="3">10<br>10<br>10</td></tr>
<tr><td>5</td><td>1</td><td>5</td></tr>
<tr><td>10</td><td>1</td><td>5</td></tr>
</table>

Using the above mentioned damper properties described in Table 2, and damper variation described in Table 3 a total number of 379 analysis have been performed for observing behavior of Hysteretic, Friction, Viscous and Visco-elastic dampers. ETABS 9.7.2 is used for analysis purpose, which is a product of Computer & Structures Inc. Buildings. A detailed analysis of each type of damper system is conducted by varying its properties.

# 7. Results and Discussion

## 7.1 Response of Buildings without Dampers

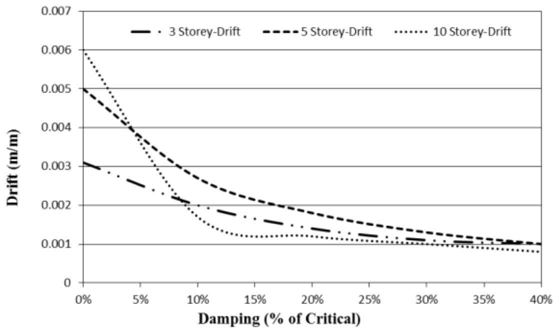



**Fig.13** Relation b/w Drift & Increasing Damping Ratio

The purpose of all passive energy dissipation devices is generally same, they convert the kinetic energy from external sources or loads into heat energy. It is necessary to mention that the prototype buildings are modeled with and without different types of dampers, and then, the response of structure is compared within the different models. The seismic behavior of the building, free vibration and time history analyses have been considered to be performed. In order to determine the behavior of buildings, response of as-designed buildings was analyzed for increasing level of viscous damping from 0% to 40% and effect of increasing damping value is studied on drift, displacement and base shear.

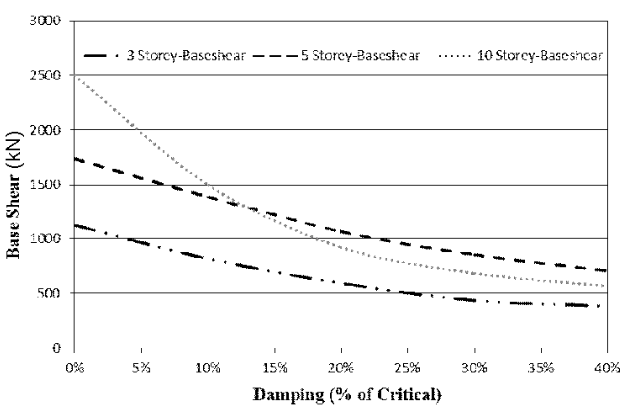



**Fig.14** Relation b/w Base Shear & Increasing Damping Ratio

Maximum drift in all three prototype buildings as viscous damping is increased from 0% to 40% is shown in Figure 13. The figure shows the drift behavior tends to decrease with the increasing damping value. The effect of viscous damping on the base shear is shown in Figure 14. For base shear in structures there is much less variation than the case of drifts. It may be because of the fact that beam hinging mechanism is formed in each building and the base shear is limited by the strength of this mechanism.

Furthermore, the effect of roof displacements is evaluated by increasing the damping, from 5 to 25%. It was seen that the roof displacement more significantly reduces the permanent set occurring in 3 and 10 storey buildings. Now since the main purpose of installation of the dampers is to reduce the displacements & corresponding deformations so the efficiency of these dampers is mainly calculated by the degree to which these deformations are reduced.

## 7.2 Effects of Damping Parameter on Displacement

### *7.2.1* Hysteretic Damper

The hysteretic damper reduces displacement for all types of building and all types of displacements as shown in Figures 15, 16 & 17. Some hysteretic dampers are indistinguishable from a structural member, such as the yielding brace, they act as a structural member. The purpose of installing hysteretic dampers in buildings is to dissipate energy more dominantly than the strength and/or added stiffness.

Hysteretic dampers are usually designed in such a way that they yield before the existing structure. For 3-storey building displacement reduces 15.9% for uniform distribution, 6.94% for triangular distribution and 12.61% for reverse triangular distribution.

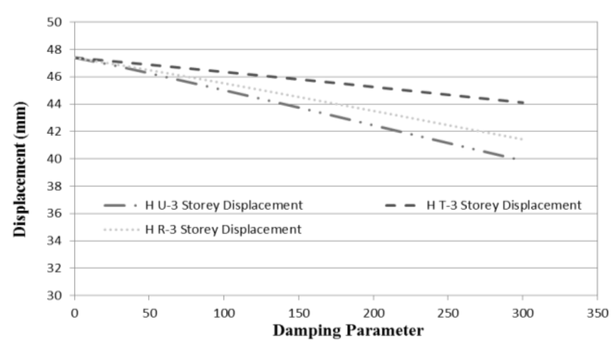



**Fig.15** Relation b/w Displacement & Damping Parameter (3-Storey Building)

Similarly for 5-storey building displacement reduces 17.73% for uniform distribution, 8.68% for triangular distribution and 14.29% for reverse triangular distribution. Hysteretic dampers are most effective for 10-storey building which reduces displacement 38.36% for uniform distribution, 22.95% for triangular distribution and 32.20% for reverse triangular distribution. For all types of buildings triangular distribution is more effective than uniform and reverse-triangular distributions.

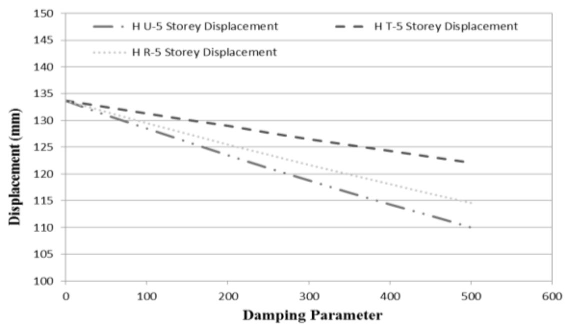



**Fig.16** Relation b/w Displacement & Damping Parameter (5-Storey Building)

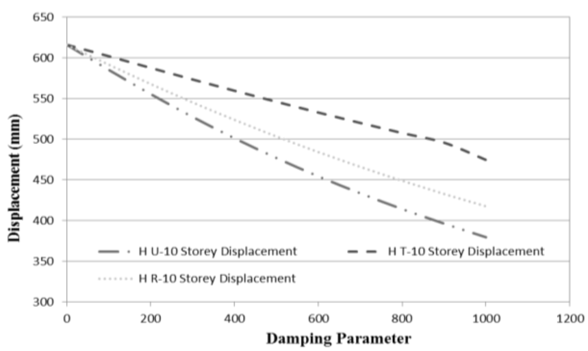



**Fig.17** Relation b/w Displacement & Damping Parameter (10-Storey Building)

### *7.2.2 Friction Damper*

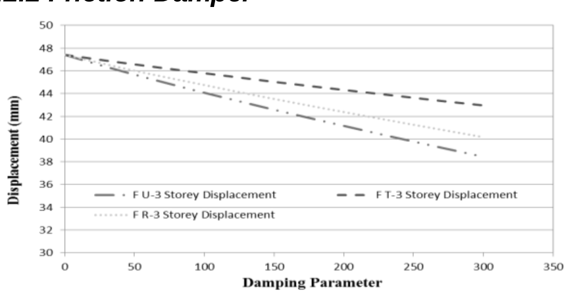



**Fig.18** Relation b/w Displacement & Damping Parameter (3-Storey Building)

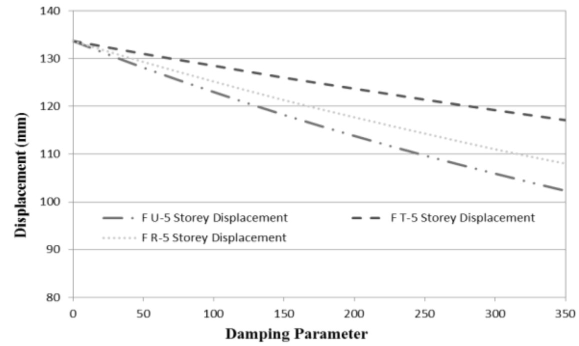



**Fig.19** Relation b/w Displacement & Damping Parameter (5-Storey Building)

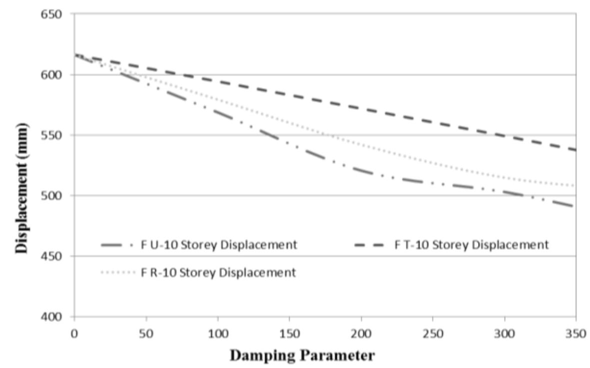



**Fig.20** Relation b/w Displacement & Damping Parameter (10-Storey Building)

Figure 18, 19 & 20 show that the friction damper reduces displacement for all types of building and all types of displacements. Friction dampers are also most likely to be placed in diagonal braces of building. Some friction devices are configured such that they generate stable rectangular hysteresis while some friction devices are configured such that they produce self-centering force and generate non-rectangular hysteresis loops.

For 3-storey building displacement reduces 18.92% for uniform distribution, 9.39% for triangular distribution and 15.27% for reverse triangular distribution. Unlike Hysteretic dampers, friction dampers are more effective for 5-storey & 10-storey buildings, for 5-storey buildings displacement reduces 30.41% for uniform distribution, 16.83% for triangular distribution and 25.35% for reverse triangular distribution. Similarly for 10-storey building displacement reduces 43.88% for uniform distribution, 27.78% for triangular distribution and 38.30% for reverse triangular distribution.

For all types of buildings triangular distribution is more effective than uniform and reverse-triangular distributions.

### *7.2.3* Viscous Damper

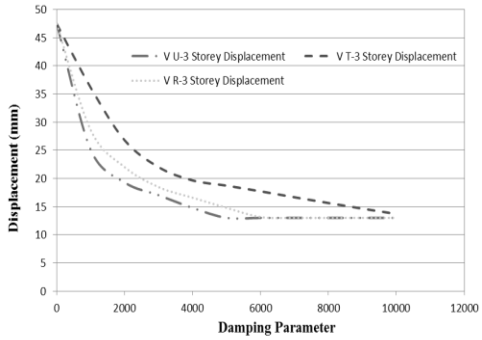



**Fig.21** Relation b/w Displacement & Damping Parameter (3-Storey Building)

Figure 21, 22 & 23 shows that the viscous dampers are effective for all types of distributions and all types of buildings. Viscous dampers normally provide an opposing force that is proportional to applied velocity than applied displacement.

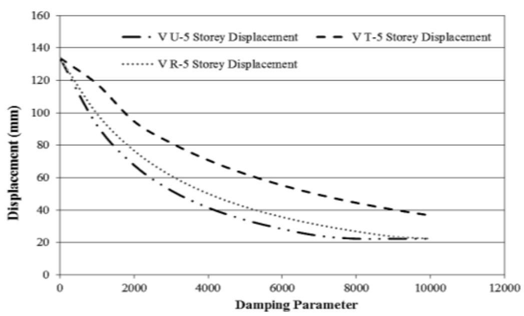



**Fig.22** Relation b/w Displacement & Damping Parameter (5-Storey Building)

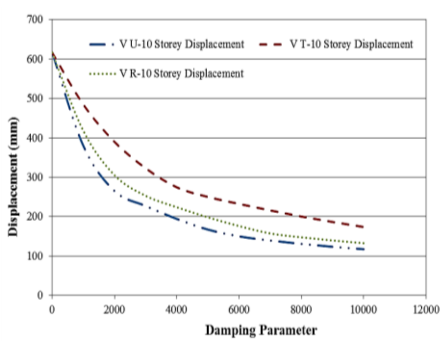



**Fig.23** Relation b/w Displacement & Damping Parameter (10-Storey Building)

Low deformation resistance occurs in viscous dampers when loads are applied gradually but this resistance increases as the speed at which the deformations is applied increases. As velocity is out of phase with the displacement, therefore such dampers are attractive from theoretical point of view. For 3-storey building displacement reduces 75.58% for uniform distribution, 71.12% for triangular distribution and 72.58% for reverse triangular distribution. For 5-storey buildings displacement reduces 83.34% for uniform distribution, 72.62% for triangular distribution and 83.34% for reverse-triangular distribution. Similarly for 10-storey building displacement reduces 80.94% for uniform distribution, 71.79% for triangular distribution and 78.45% for reverse triangular distribution.

For all types of buildings triangular distribution is more effective than uniform and reverse-triangular distributions.

### *7.2.4* Visco-elastic Damper

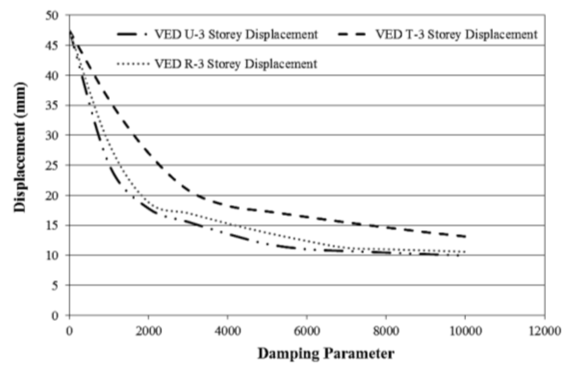



**Fig.24** Relation b/w Displacement & Damping Parameter (3-Storey Building)

Figure 24, 25 & 26 show that the like viscous dampers, visco-elastic dampers are effective for all types of distributions and all types of buildings. For 3-storey building displacement reduces 79.01% for uniform distribution, 72.31% for triangular distribution and 77.66% for reverse triangular distribution. For 5-storey buildings displacement reduces 85.31% for uniform distribution, 70.78% for triangular distribution and 82.16% for reverse triangular distribution.

Similarly for 10-storey building displacement reduces 81.59% for uniform distribution, 70.13% for triangular distribution and 78.51% for reverse triangular distribution. For all types of buildings triangular distribution is more effective than uniform and reverse-triangular distributions.

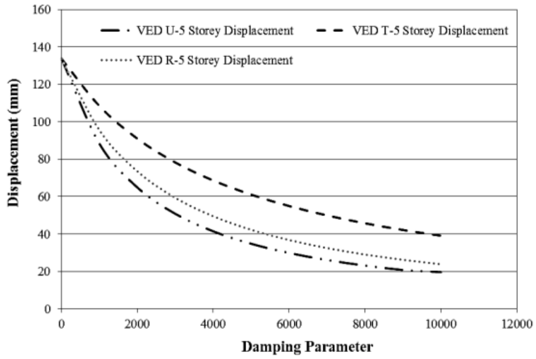



**Fig.25** Relation b/w Displacement & Damping Parameter (5-Storey Building)

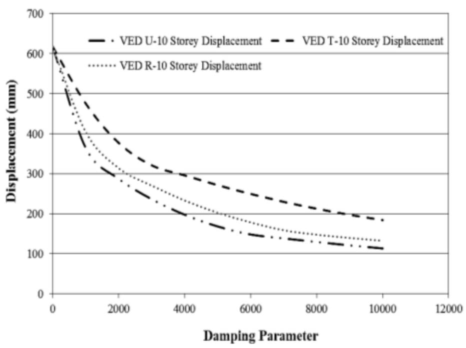



**Fig.26** Relation b/w Displacement & Damping Parameter (10-Storey Building)

## 7.3 Effect of Damping Parameter on Base Shear

The proportion of the shear resisted and the total shear by structural system might be significant depending on the deficiencies in structure. Some type of dampers, will add force to the existing structural system, especially those installed in diagonal braces of buildings, such dampers must oppose the vertical component of the force (axial force) in the column, and hence they reduce the base shear. The structural system may be overloaded by increased shear, for such type of systems, the total force is important.

### *7.3.1 Hysteretic Damper*

Figure 27, 28 & 29 show that the hysteretic damper reduces base shear for all types of building and all types of variations. For 3-storey building base shear reduces 15.97% for uniform distribution, 8.69% for triangular distribution and 13.81% for reverse triangular distribution. Similarly for 5-storey building base shear reduces 25.25% for uniform distribution, 14.23% for triangular distribution and 20.49% for reverse triangular distribution. Hysteretic dampers are most effective for 10-storey building which reduces base shear 42.33% for uniform distribution, 28.91% for triangular distribution and 36.61% for reverse triangular distribution.

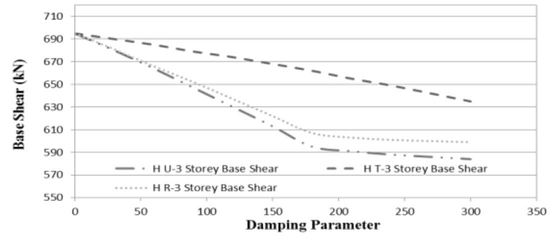



**Fig.27** Relation b/w Base Shear & Damping Parameter (3-Storey Building)

For all types of buildings triangular distribution is more effective than uniform and reverse-triangular distributions. The stiffness and yield force are two main parameters of hysteretic dampers, these parameters are normalized to the structure elastic force level and stiffness, which are somewhat difficult to define for any except the simplest single storey structure.

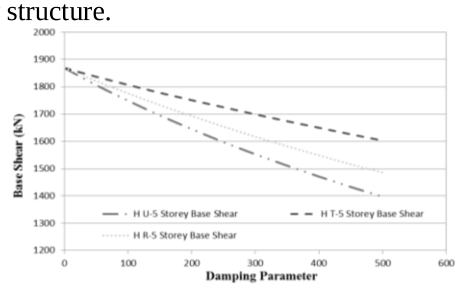



**Fig.28** Relation b/w Base Shear & Damping Parameter (5-Storey Building)

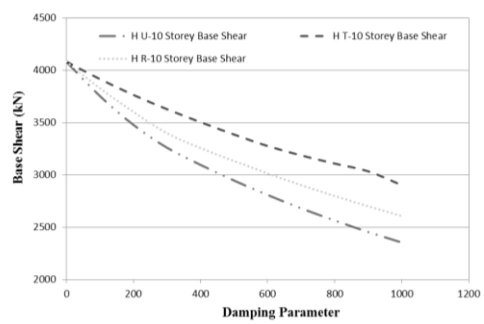



**Fig.29** Relation b/w Base Shear & Damping Parameter (10-Storey Building)

### *7.3.2 Friction Damper*

Figure 30, 31 & 32 show that the friction dampers reduces base shear for all types of building and all types of variations. For 3-storey building base shear reduces 15.97% for uniform distribution, 15.4% for triangular distribution and 14.53% for reverse triangular distribution. Similarly for 5-storey building base shear reduces 25.85% for uniform distribution, 12.09% for triangular distribution and 19.21% for reverse triangular distribution. Hysteretic dampers are most effective for 10-storey building which reduces base shear 33.46% for uniform distribution, 18.23% for triangular distribution and 32.58% for reverse triangular distribution.

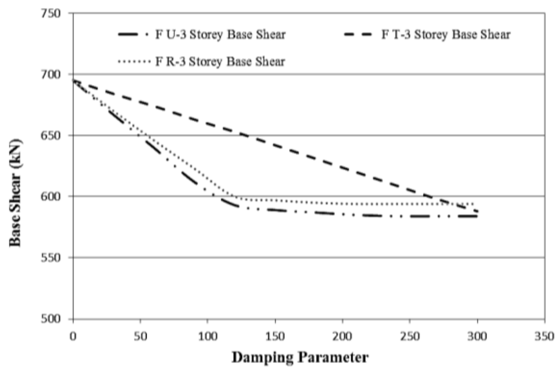



**Fig.30** Relation b/w Base Shear & Damping Parameter (3-Storey Building)

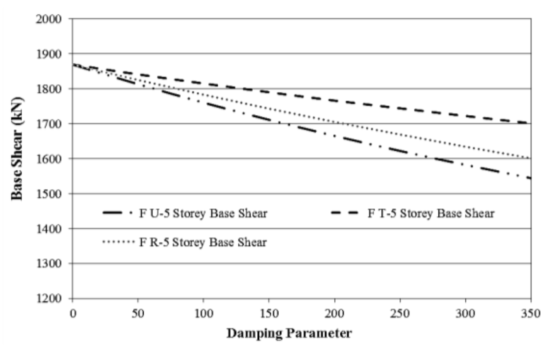



**Fig.31** Relation b/w Base Shear & Damping Parameter (5-Storey Building)

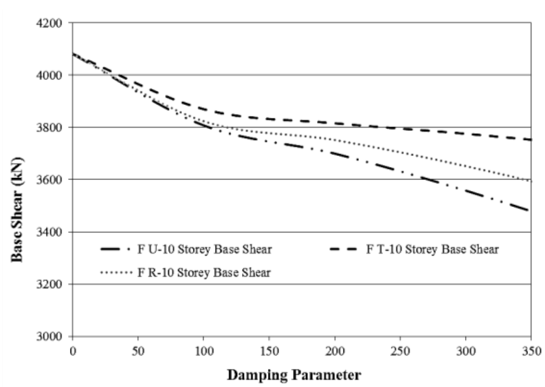



**Fig.32** Relation b/w Base Shear & Damping Parameter (10-Storey Building)

For all types of buildings triangular distribution is more effective than uniform and reverse-triangular distributions. Friction dampers provide high damping in the initial cycles but this reduces in the subsequent cycles. Hysteretic cycling is caused by the initial cycle decay but the damper is linear elastic for successive cycles and hence damping reverts to that for the elastic structure.

### *7.3.3 Viscous Damper*

Figure 33, 34 & 35 show that the viscous dampers reduces base shear for all types of building and all types of variations. For 3-storey building base shear reduces 28.49% for uniform distribution, 27.8% for triangular distribution and 26.04% for reverse triangular distribution. Hysteretic dampers are most effective for 5 & 10-storey building, for 5-storey building base shear reduces 40.9% for uniform distribution, 40.58% for triangular distribution and 37.15% for reverse triangular distribution. Similarly for 10-storey buildings base shear reduces 48.69% for uniform distribution, 53.45% for triangular distribution and 48.55% for reverse triangular distribution.

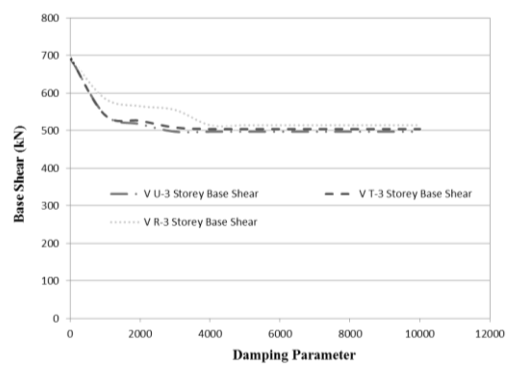



**Fig.33** Relation b/w Base Shear & Damping Parameter (3-Storey Building)

For all kind of distributions and buildings it is clear that base shear values reduces up to damping coefficient values of 5000 to 6000 kN/cm after that it become constant, this is because of the fact that total force in the structure is increased due to damper forces but the additional shears are resisted by dampers as a result they usually don't result in an increase in the shear forces in the structural system. For all types of buildings triangular distribution is more effective than uniform and reverse-triangular distributions.

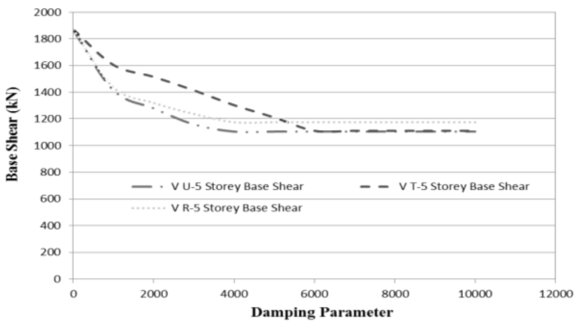



**Fig.34** Relation b/w Base Shear & Damping Parameter (5-Storey Building)

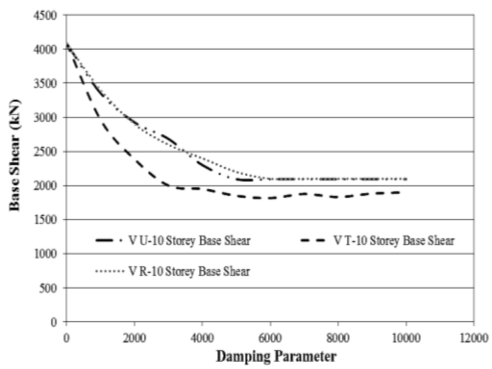



**Fig.35** Relation b/w Base Shear & Damping Parameter (10-Storey Building)

### *7.3.4 Visco-elastic Damper*

Figure 36, 37 & 38 show that the visco-elastic dampers reduce base shear for all types of building and all types of variations. For 3-storey building base shear reduces 29.50% for uniform distribution, 25.18% for triangular distribution and 28.78% for reverse triangular distribution. Visco-elastic dampers are most effective for 5 & 10-storey building, for 5-storey building base shear reduces 40.88% for uniform distribution, 45.69% for triangular distribution and 42.48% for reverse triangular distribution. Similarly for 10-storey buildings base shear reduces 56.45% for uniform distribution, 57.29% for triangular distribution and 55.72% for reverse triangular distribution. For all kind of distributions and buildings it is clear that base shear values reduces up to damping coefficient values of 5000 to 6000 kN/cm after that it become constant, this is because of the fact that damper forces increase the total force in the structure but the additional shears are resisted by devices themselves and don't usually result in an increase in the shear forces in the structural system. For all types of buildings triangular distribution is more effective than uniform and reverse-triangular distributions

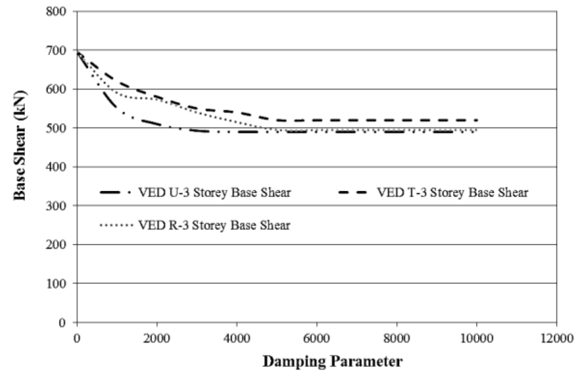



**Fig.36** Relation b/w Base Shear & Damping Parameter (3-Storey Building)

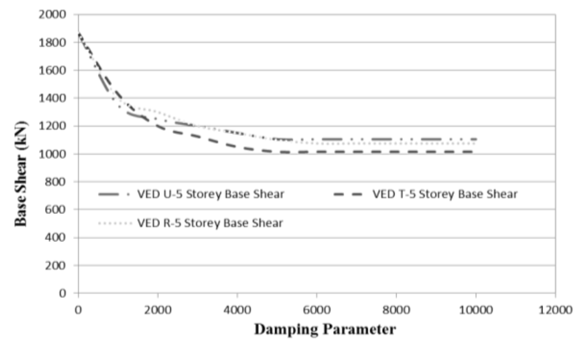



**Fig.37** Relation b/w Base Shear & Damping Parameter (5-Storey Building)

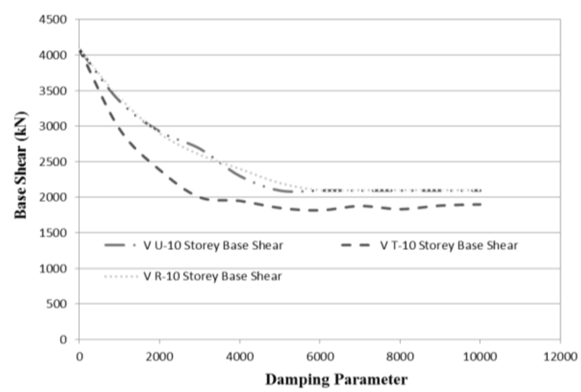



**Fig.38** Relation b/w Base Shear & Damping Parameter (10-Storey Building)

## 7.4 Effect of Damping Parameter on Floor Acceleration

In conventional construction floor accelerations generally increase with the level/height of building. The ability to provide effective isolation under a range of earthquake-motion intensities is a main feature of passive energy dampers. The passive energy devices have low stiffness and strength particularly where traditional isolation systems exhibit high initial stiffness and strength, which is defined by its geometry and may therefore be specified by the engineer. Floor accelerations are much significant in assessment of existing buildings and structures as they define the forces acting on equipment's, contents and components of building. Floor accelerations may be able to cause damage to the architectural facades, building contents, ductwork and partitions, piping, ceiling and elevators. Acceleration transfer functions are computed by installing passive energy dampers diagonally at each floor this is to investigate the effectiveness of the dampers specimens to filter high-frequency acceleration. Dampers are installed diagonally in each type of buildings and the following results show the influence of floor accelerations on different dampers type and for all types of variations.

### *7.4.1 Hysteretic Damper*

Figure 39, 40 & 41 show that the hysteretic damper reduces floor accelerations for all types of building and all types of variations. For 3-storey building floor accelerations reduces 21.77% for uniform distribution, 14.31% for triangular distribution and 16.08% for reverse triangular distribution. Similarly for 5-storey building floor accelerations reduces 20.78% for uniform distribution, 9.95% for triangular distribution and 16.87% for reverse triangular distribution. For 10-storey building floor accelerations reduces 8.7% for uniform distribution, 6.04% for triangular distribution and 7.28% for reverse triangular distribution. Hysteretic dampers are more effective for 3 & 5-storey building. For all types of buildings Reverse-triangular distribution is more effective than uniform and triangular distributions.

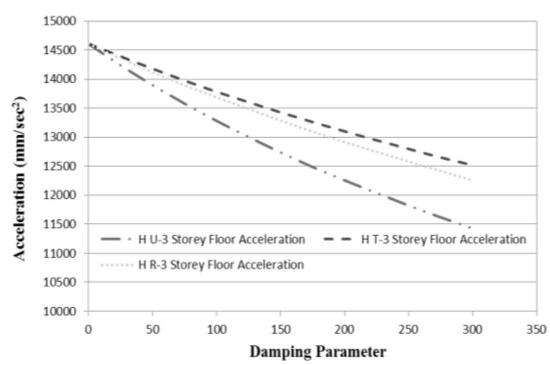



**Fig.39** Relation b/w Floor Acceleration & Damping Parameter (3-Storey Building)

### *7.4.2 Friction Damper*

Floor accelerations are significant in assessment of building and structures as they describe the forces on different equipments, contents and components.

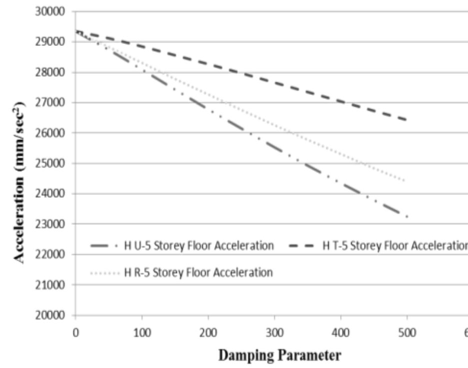



**Fig.40** Relation b/w Floor Acceleration & Damping Parameter (5-Storey Building)

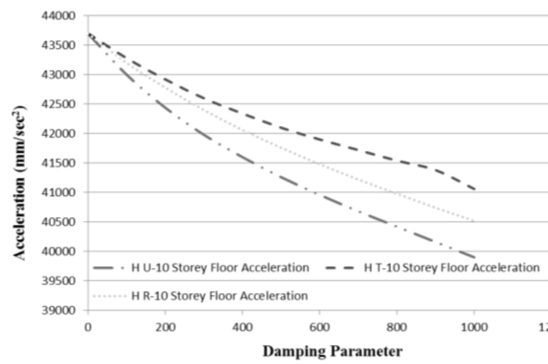



**Fig.41** Relation between Floor Acceleration and Damping Parameter (10-Storey Building)

As for shears, the accelerations are the maximum value from the earthquake normalized by the maximum acceleration in the structure without dampers. Figure 42, 43 & 44 show that the friction damper reduces floor accelerations for all types of building and all types of variations. For 3-storey building floor accelerations reduces 9.31% for uniform distribution, 8.97% for triangular distribution and 5.41% for reverse triangular distribution. Similarly for 5-storey building floor accelerations reduces 19.83% for uniform distribution, 9.68% for triangular distribution and 15.78% for reverse triangular distribution. For 10-storey building floor accelerations reduces 7.68% for uniform distribution, 5.68% for triangular distribution and 6.77% for reverse triangular distribution. Hysteretic dampers are more effective for 5-storey building. For all types of buildings Reverse-triangular distribution is more effective than uniform and triangular distributions.

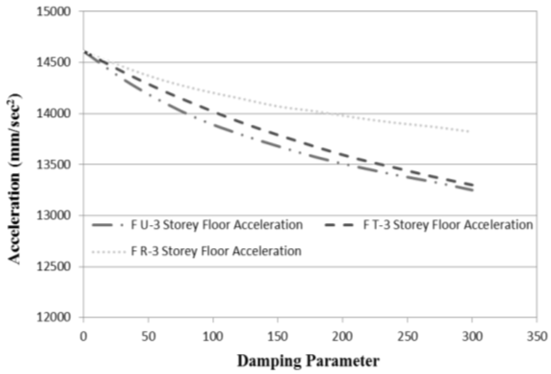



**Fig.42** Relation b/w Floor Acceleration & Damping Parameter (3-Storey Building)

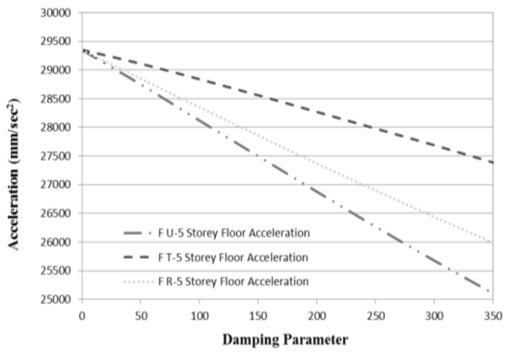



**Fig.43** Relation b/w Floor Acceleration & Damping Parameter (5-Storey Building)

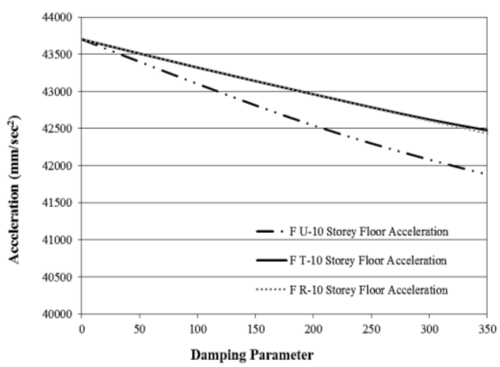



**Fig.44** Relation b/w Floor Acceleration & Damping Parameter (10-Storey Building)

### *7.4.3 Viscous Damper*

Figure 45, 46 & 47 show that the viscous dampers reduce floor accelerations for all types of building and all types of variations. For 3-storey building floor accelerations reduces 54.85% for uniform distribution, 54.41% for triangular distribution and 54.85% for reverse triangular distribution.

Hysteretic dampers are most effective for 5-storey building, for 5-storey building floor accelerations reduces 75.61% for uniform distribution, 73.47% for triangular distribution and 75.61% for reverse triangular distribution. Similarly for 10-storey buildings floor accelerations reduces 45.77% for uniform distribution, 28.92% for triangular distribution and 40.05% for reverse triangular distribution. For 3-storey buildings it is clear that floor accelerations values become constant after damping coefficient values of 5000 to 6000 kN-sec/cm, therefore if floor accelerations are important and we have to use viscous dampers in building than we should use damping constant value less than 6000 kN-sec/cm. For all types of buildings triangular distribution is more effective than uniform and triangular distributions.

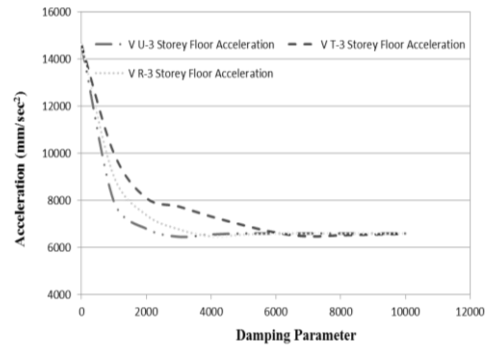



**Fig.45** Relation b/w Floor Acceleration & Damping Parameter (3-Storey Building)

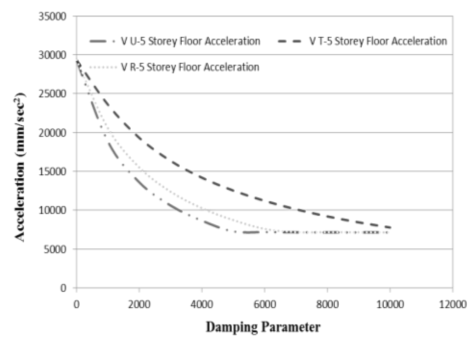



**Fig.46** Relation b/w Floor Acceleration & Damping Parameter (5-Storey Building)

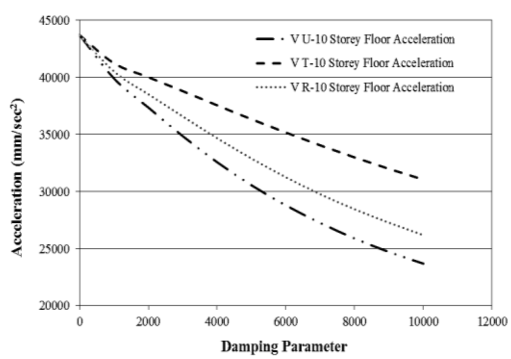



**Fig.47** Relation b/w Floor Acceleration & Damping Parameter (10-Storey Building)

#### *7.4.4 Visco-elastic Damper*

Figure 48, 49 & 50 show that the viscous dampers reduce floor accelerations for all types of building and all types of variations. For 3-storey building floor accelerations reduces 55.55% for uniform distribution, 55.41% for triangular distribution and 55.57% for reverse triangular distribution. Hysteretic dampers are most effective for 5-storey building, for 5-storey building floor accelerations reduces 77.10% for uniform distribution, 70.03% for triangular distribution and 77.08% for reverse triangular distribution. Similarly for 10-storey buildings floor accelerations reduces 44.16% for uniform distribution, 26.36% for triangular distribution and 38.72% for reverse triangular distribution. For 3-storey buildings it is clear that floor accelerations value s become constant after damping coefficient values of 5000 to 6000 kN-sec/cm, therefore if floor accelerations are important and we have to use viscous dampers in building than we should use damping constant value less than 6000 kN-sec/cm. For all types of buildings triangular distribution is more effective than uniform and reverse-triangular distributions.

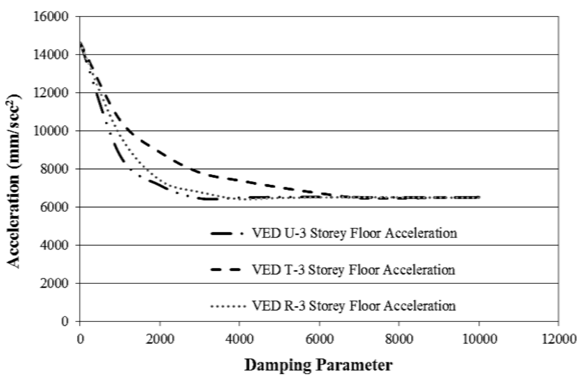



**Fig.48** Relation b/w Floor Acceleration & Damping Parameter (3-Storey Building)

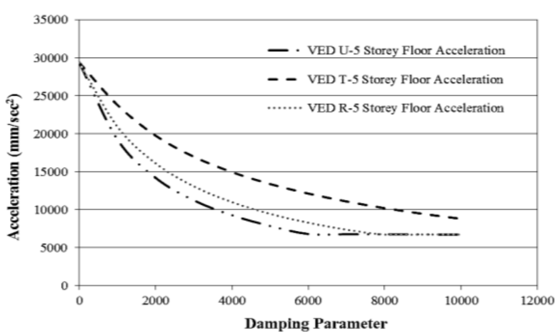



**Fig.49** Relation b/w Floor Acceleration & Damping Parameter (5-Storey Building)

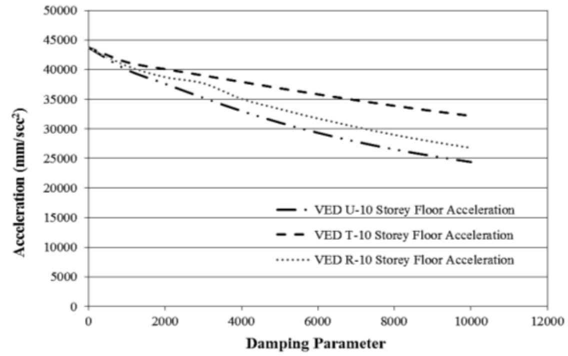



**Fig.50** Relation b/w Floor Acceleration & Damping Parameter (10-Storey Building)

## 8. Conclusions

The outcomes and observations made from the study are as follows:

1. The optimum dampers for the 3 storey building are either Visco-elastic or Viscous dampers in any of reverse-triangular or uniform distribution having damping coefficient of 5000 kN-sec/m or higher. This will minimize the base shear and the displacement. The damping coefficient value must be reduced to 4000 kN-sec/m or less, if floor accelerations are important, but keeping low value of damping coefficient will cause effectiveness in reducing displacements as a result shears will also be much less.
2. Passive energy dissipation devices which are primarily effective for the 3-storey buildings are also optimal for the 5-storey buildings. If less effectiveness in decreasing shears and displacements is acceptable than the damper which are very effective in controlling the floor accelerations are friction dampers with a low slip-forces.
3. For the 10-storey building friction dampers are the most effective. High slip-force friction dampers are mainly effective in decreasing shears and displacements but at the same time floor accelerations will increase. Therefore, at the cost of effectiveness in decreasing shears and displacements using low slip-forces for friction dampers will reduce floor accelerations.
4. Generally for all types of dampers, reverse-triangular distributions are best for controlling base shears, uniform distributions were best for controlling displacements, and the triangular distributions are most effective in reducing floor accelerations.

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