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Analysis of G+35 Storey RCC Building using Viscoelastic Damper on ETABS

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ABSTRACT

High rise building construction is adopted everywhere as we have sophisticated designing softwares, engineers and also due to advancement in the field on engineering and technology. As the structure height increases its response to seismic and wind loading also increases. Codes suggest that the forces and displacements of a structure is directly proportional to its height. A lot of research work is going on for reduction in responses during extreme loading condition due to wind and earthquake. Passive control devices like various types of dampers comes very handy as they can be easily installed, requires no operation cost and are easily replaceable. These devices become active only when loading is applied. This paper discusses the reduction in response of a G+35 RCC building located in Mumbai when Viscoelastic dampers are used considering seismic loading and wind loading (including gust factor). Best type of bracing configuration, its location and comparison of three different type of dampers is studied. The analysis is done on ETABS 2015 and special emphasis is laid on reduction of displacement and storey drift.

Keywords

Deflection, Bracing, Gust, Storey Drift, Seismic analysis, Viscoelastic Damper (V.E.).

1. INTRODUCTION

Earthquakes produce almost instantaneous response leading to destruction of buildings and wind forces are also detrimental to structures if they are not designed for it. The effect of earthquake forces and wind forces goes on increasing with the height of the building and governing factor for design also depends on various factors from location of the building to the geometry of the building and also soil conditions. With increasing population, engineers and architects have opted for high rises and it has become a general practice for going for high rise structure. The ideal aspects of a building form are simplicity, regularity and symmetry in both plan and elevation which is what people normally avoid to do. Also buildings with high ratio of its height to plan area, will generate higher overturning moments while buildings with large plan areas may not act as expected due to differences in ground behaviour (differential ground settlement) which are not always predictable. Torsion can be of great concern because of the eccentricity in the building layout which is not taken into consideration by the architects.

The concept of structural behaviour control in recent years, has taken a central role in the seismic design of structures. The philosophy is that a safer and more economical design of the system can be achieved by adding innovative devices to reduce the forces and deformations in structures. By modifying the dynamic properties of the system, these devices aim to control the response and the energy dissipation demands of the structural members. The operation of these special devices is initiated by the motion of the structure and, guided by the control scheme; they reduce the overall response of the system and thus meet the design goal in mitigating seismic damage. Various response control methods have been implemented in the design procedures and can be generally divided into three groups: passive control, active control, and semi-active control. Among these schemes, passive control devices were developed the earliest and have been used more commonly in practice for seismic design because they require minimum maintenance and need no external power supply to operate.

This paper discusses the use of Viscoelastic dampers (passive control) as they are capable of reducing the building motion or responses by converting a portion of the mechanical energy into heat. The function of passive energy dissipation systems, on the other hand, is to absorb energy generated by the seismic or wind excitation. These are installed strategically in the structure to link various parts of the framing system, and provide supplemental damping to dissipate the energy. Since these added dampers can be designed to consume a major portion of the input energy so that less is available to the main structure, the deformation in the primary members is significantly reduced, hence limiting the structural damage.

Many research work is going on Viscoelastic dampers which shows that the analysis and their working is complex in nature. The feasibility of using viscoelastic dampers to mitigate earthquake-induced structural response has also been studied by various authors. Chang Y.Y. Lin & M.L. Lai compared seismic performance between the viscoelastically damped structure and a conventional special moment resisting frame. The temperature variation formula during an earthquake excitation was introduced. They also studied the change in the natural frequency due to addition of viscoelastic damper. Julius Marko showed that bitumen rubber compound VE damper induces large damping forces to shear deformation and can sustain shear stains of about 300% and can reduce seismic response by 50% and super-plastic silicone rubber VE damper reduces response upto 60%. Different models were cited and dynamic analysis of the frames with viscoelastic damper was carried to derive the formula for energy dissipation by R. Lewandowski et al. B. Samali& K.C.S Kwok showed that amount of energy stored in damper is about 2-4% and thus rest of it is dissipated. Many others have studied the seismic analysis and performance of structures with VE damper and this paper also addresses issue even for wind effects on performance.

1.1 Mechanism of Viscoelastic Damper

Solid VE dampers use a polymeric material that dissipates energy through shear deformation when loaded cyclically, and the most important characteristic is that the mechanical properties are functions of the excitation frequency and the environmental temperature. The damper consists of the plates between which the polymer materials filled in between and kinetic energy is consumed with the shear deformation of the polymer layers, so that viscoelastic material has a polymer molecule structure as their molecules are linked together as chain. As the result of the molecular network, viscoelastic material shows a considerable amount of resistance against the deformation. In fact, stiffness of structural systems will be increased by using this material in the structure which are normally installed on bracing. On the other hand, while deformation is applied to this material, some of the molecular bonds are broken down and the heat is produced, depending on temperature and the loading frequency. So, some energy is spent to break the bonds, and is wasted. Damping of these materials is due to the friction or breakdown of intermolecular bond. After loading over time, the material recovers their initial strength, which the amount of this recovery depends on the temperature of the material, stimulant frequency and strain amplitude. In short, there is an increase in stiffness and damping in the structural system by installation of this material. Installation of the dampers should not be limited only to braces, but they can be used with special arrangements throughout the structure in which shear deformations occur.

2. MODELLING OF G+35 RCC BUILDING ON ETABS 2015

The main aim of the model is to study the change in building responses (mainly deflection and storey drift) due to addition of VE Dampers. The building is analyzed in 2 stages, first is without any dampers and second is using D3 type of damper, best brace configuration and best location of the dampers will be concluded. And using three different dampers, differences in response will be studied. Analysis is done on ETABS 2015. It is a G+35 RCC structure of residential type. Plan is typical throughout all stories with bottom storey height 4.5

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m and at top 3.6 m each. The height of the building is 130.5m (high rise). The building is situated in Mumbai with medium soil condition. Total load (DL+LL) is assumed to be 15 kN/m^2. Seismic Coefficient method as per IS 1893 (Part 1): 2002 is used for seismic load analysis and Gust analysis is used for wind loading as per IS 875 (Part 3): 1987. Load Combination was used as per specified by IS 456: 2000. Various properties of the elements used to model in ETABS are given in the Table 1-5.

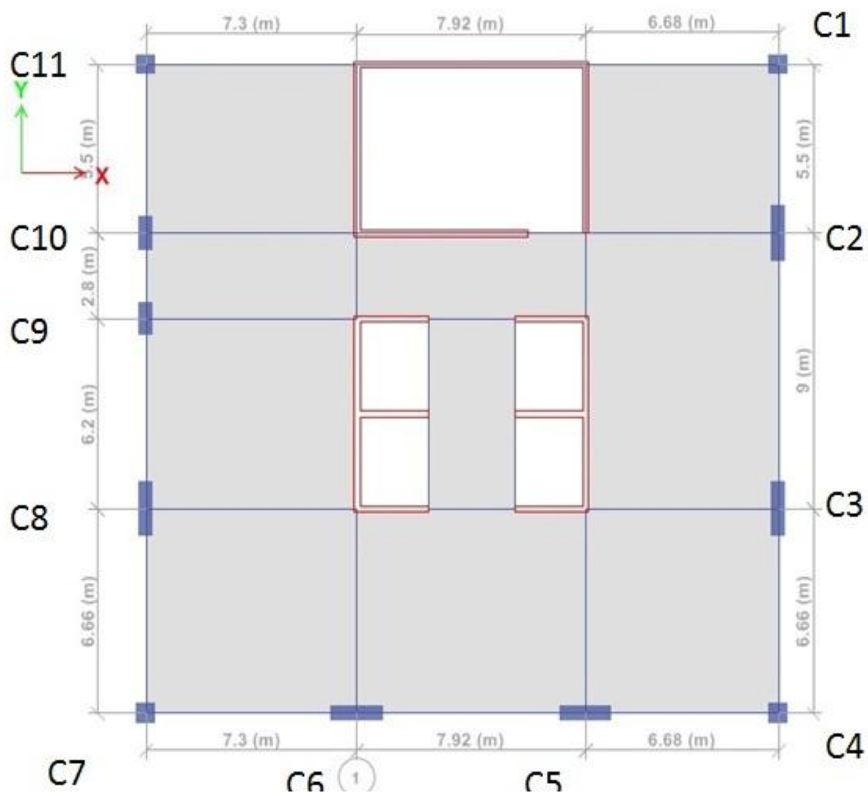

Figure 1: Typical Plan of G+35 RCC Building

Table 1. Concrete grade used for different structural elements in building

Member	Levels	Concrete grade
Footing	-	M50
Columns	Ground floor to 8th floor	M50
	9th floor to 17th floor	M40
	18th floor to terrace (storey 36)	M30
Shear Wall	Ground floor to 8th floor	M50
	9th floor to 17th floor	M40
	18th floor to terrace (storey 36)	M30
Beams / Slabs / Staircase	All slabs	M40
	All beams	M40

Table 2. Grouping of Columns

From Foundation upto 8th Floor (mm) (Grade M50 & Fe 500)								
C1,C4,C7,C11	650	650	C2,C3,C6,C8	1800	500	C9,C10	1100	500
From 9 theupto 17th Floor (mm) (Grade M40 & Fe500)								
C1,C4,C7,C11	600	600	C2,C3,C6,C8	1800	400	C9,C10	1100	450
From 18th upto 35th Floor (mm) (Grade 30 & Fe500)								
C1,C4,C7,C11	500	500	C2,C3,C6,C8	1800	300	C9,C10	1100	300

Table 3. Beams Properties of Structural Elements of the Building

Frame Element	Material	Area of section
External Beam connected to shear wall of staircase and columns &internal beam connected to lift Depth = 600 mm; Width = 400 mm	Concrete	0.24 m2
Internal Beam connected to shear wall Depth = 600 mm; Width = 500 mm	Concrete	0.30 m2
Internal beam connected to shear wall of lift Depth = 1200 mm; Width = 600 mm & Depth = 600 mm; Width = 300 mm	Concrete	0.72 m2 0.18 m2
Other internal beams Depth = 600 mm; Width =650 mm &Depth = 1200 mm; Width =500 mm	Concrete	0.39m2 & 0.6m2

Table 4. Slab Properties

Slab type	Dimension	Thickness
Two way	6.68mx5.5m	225mm
Two way	6.68mx9m	250mm
Two way	6.68mx6.66m	225mm
Two way	7.92mx6.66m	225mm
Two way	7.3mx6.66m	225mm
Two way	7.3mx6.2m	225mm
One way	7.3mx2.8m(Passage)	150mm
One way	7.92mx2.8m(Passage)	150mm
One way	2.8mx6.2m(Passage)	150mm
One way	7.92mx5.5m	225mm
One way	7.3mx5.5m	225mm

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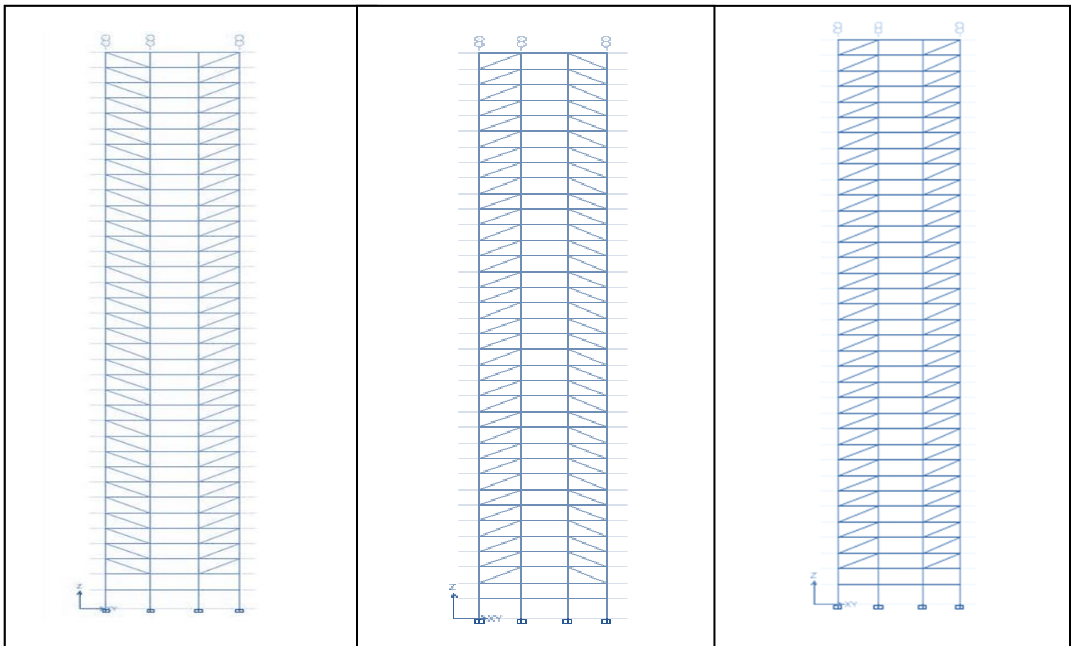
Table 5. Damper Properties[7]

Damper Name (Notation)		3M ISD 110 (D1-30C Temp)	3M ISD 110 (D2-20C Temp)	D3-K57-D12
Type of Damper		Exponential	Exponential	Exponential
Non Linear		Yes	Yes	Yes
Linear Properties	Effective Stiffness (kN/m)	17839.01	62750.13	57000
	Effective Damping (kN-s/m)	19808.12	69676.63	12000
Non Linear Properties	Stiffness (kN/m)	17839.01	62750.13	57000
	Damping (kN-(s/m)^Cexp)	19808.12	69676.63	12000
	Damping Exponteent	1	1	1
Effective temperature (in degree)		30	20	Ignored

3. RESULTS AND DISCUSSION

3.1 Configuration Selection for Bracing for dampers

V.E. Dampers are fixed on Bracings. Hence various configurations of diagonal bracing were studied to decide the best configuration for fixing of dampers. This was based on reduction in critical displacement which is in Y Direction for Wind forces. The amount of bracing material was kept same & the configuration was changed to get configuration with minimum deflection. For this bracing with Damper D3 K57D12 where applied in 8 no's per floor from 36-2^{nd}storey. Displacement(deflection) will be sole criteria for the choice of configuration and the location of the braces.



Configuration 1	Configuration 2	Configuration 3

Figure 2: Various Bracing Configuration used

The building was modelled on ETABS and following results were found out which is summarised in Table 5,6& 7.

Table 6. Average Reduction in Displacement of Stories due to Spec (Seismic) under different Configurations

Configuration	X Direction (%)	Y Direction (%)
Config. 1 With D3	20.43	16.06
Config. 2 With D3	**20.98**	16.60
Config. 3 With D3	20.41	**16.79**

Table 7. Top Storey Displacement due to Spec under different Configurations

Configuration	X Direction (mm)	Y Direction (mm)
Without Dampers	120.6	**142.8**
Config. 1 With D3	98.70	121.00
Config. 2 With D3	**98.20**	120.80
Config. 3 With D3	98.50	**120.10**

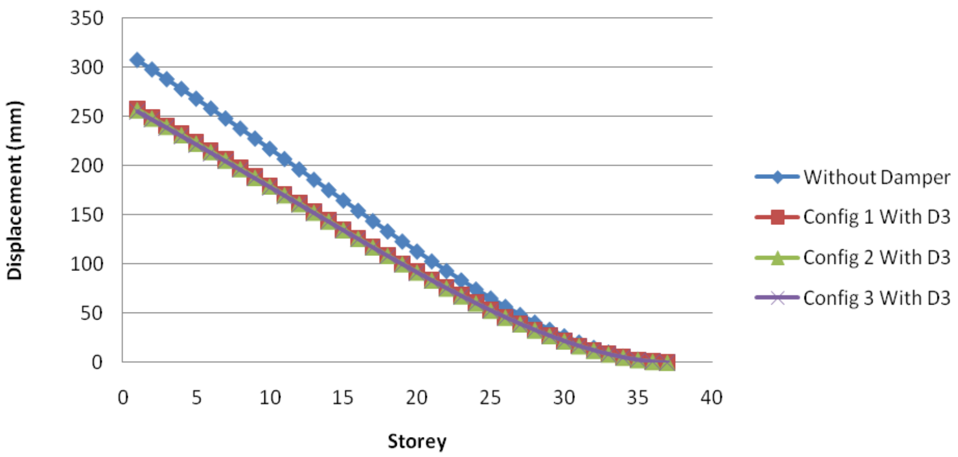


Figure 3: Displacement Due to Wind Y in Y Direction for Various Configurations

Table 8. Top Storey Displacement due to Wind under different Configurations

Config.	X Direction (mm)	Y Direction (mm)
Without Dampers	239.4	**307.5**
Config. 1 With D3	163.60	257.60
Config. 2 With D3	161.50	256.70
Config. 3 With D3	162.70	**255.30**

For G+35 Storey Building with Height 130.5m permissible deflection in Wind is H/500 i.e. 261mm & For Earthquake is H/250 i.e. 522mm. From the above tables it can be seen that there is maximum reduction in storey displacement in Direction Y for Wind Y is by Configuration no. 3 where top storey displacement reduced from 307.5mm (more than permissible 261mm) to 255.3mm (within permissible) hence it is to be used for further analysis.

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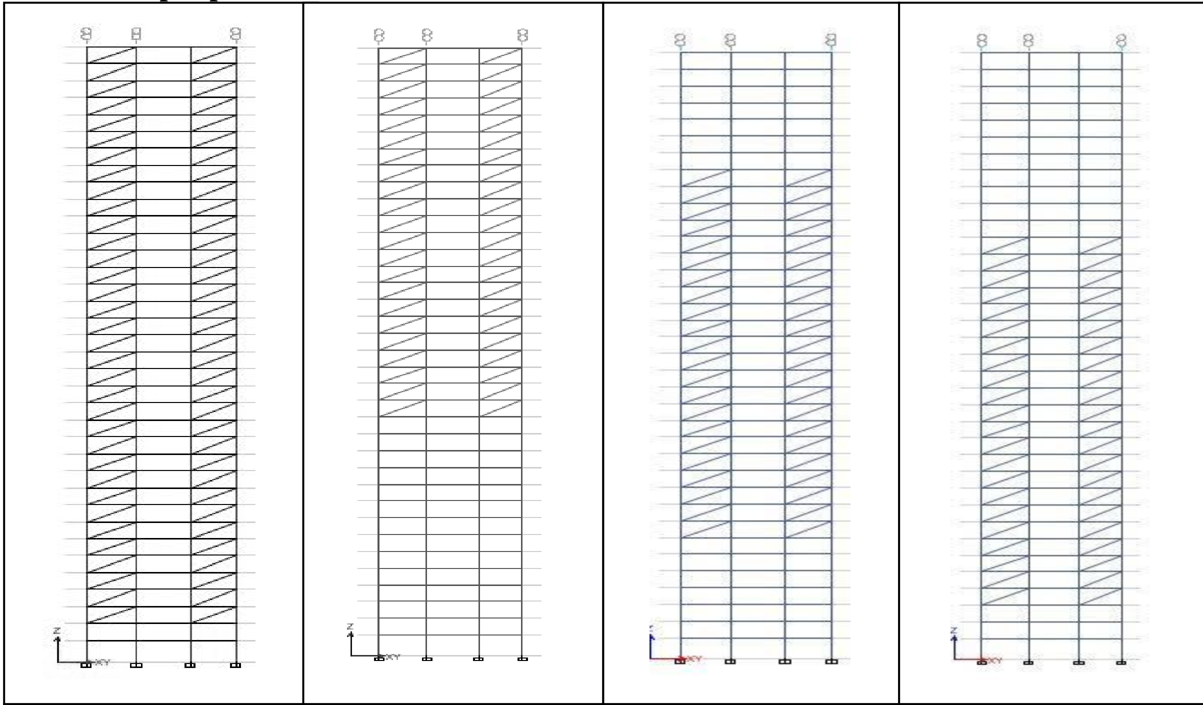
3.2 Damper placement at different locations



36-2 Storey	36-15 Storey	29-8 Storey	24-3 Storey

Figure 4: Various Damper Placement Locations

Here 4 cases of damper placement have been studied & these are shown below. In first case dampers have been placed throughout & in second case at the position of maximum absolute displacement in building while in 3rd case dampers have been placed at position of maximum storey drifts & in 4th in lower stories. At each story 8 dampers have been placed. Main objective of this study is to know the best possible position in building for dampers placements so that damper can be utilized in reducing structure responses in more effective ways.

Table 9. Top Storey Displacement due to Wind under different Configurations

Damper Location	X Direction (mm)	Y Direction (mm)
Without Damper	239.4	**307.5**
36-2 Floor	162.70	255.30
36-15 Floor	190.70	281.50
29-8 Floor	171.00	**259.98**
24-3 Floor	177.8	275.6

Table 10. Top Storey Displacement due to Spec (seismic) under different damper location

Damper Location	X Direction (mm)	Y Direction (mm)
Without Damper	**120.60**	**142.80**
36-2 Floor	98.50	120.10
36-15 Floor	103.80	128.40
29-8 Floor	**101.60**	**121.60**
24-3 Floor	102.2	124

From the above tables it can be seen that there is maximum (economical) reduction in storey displacement in Direction Y for Wind Y is by placing the dampers at 29-8 Storey where the storey drift was maximum. The percentage reduction in displacement is 15-16% for both wind and spectral (seismic) forces. The top storey displacement reduced from 307.5mm (more than permissible 261mm) to 259.98mm (within permissible) hence this location is to be used for further analysis. The main reason for Location 29-8 storey to be best is that placing dampers here help to reduce the storey drift & thus reduce displacement. Placing dampers in top stories is not advantageous. Further placing dampers in lower operation 24-3 storey reduces displacement in lower stories but not top storey displacement. Placing dampers from 36-2 storey (i.e. at all floors) reduces just 1.5mm more deflection then that by 29-8 storey. Thus it is not economical to go for 36-2 storey location i.e. using 112 No.s of extra dampers for 1.5mm displacement reduction.

3.3 Analysis with Best Bracing Configuration & Damper Location

After Successful Deciding Best Configuration of Bracing & Best Location of Dampers we will use Configuration No.3 for 8-29 Storey Damper location & further carry out analysis for studying various characteristics of structure & various types of Dampers.

Table 11. Time period reduction of building due to dampers

Various Mode	D1	D2	D3
Average Time period %reduction	12.35801	13.29817	13.0479

It can be seen from above Table 11 that there is reduction in time period of structure by addition of Viscoelastic dampers due to increase in stiffness of structure. Further D2 K70D63 -20°C being the most stiffness have the lowest time period while followed by D3 K57D12 -30°C which has second highest stiffness has second lowest time period & D1 K18D20 having lowest stiffness &highest time period.

3.3.1 Analysis for Seismic Forces

Table 12. Average Reduction in Acceleration of Stories due to Spec under different VE dampers

Damper	X Direction (%)	Y Direction (%)
D1	9.64	3.26
D2	24.68	15.66
D3	14.89	4.77

It can be seen from above Table 12 that there is reduction in acceleration response of structure due to addition of VE damper. Compare to X-direction, response reduction in Y-direction is less may be because of presense of shear walls in that direction. Dampers having higher damping coefficient + higher stiffness (D1 K70D63) perform well in reducing storey acceleration than dampers with higher stiffness value + less damping value (D3 K57D12). So it can be concluded that damping plays important role in reducing storey acceleration.

Table 13. Average Reduction in Storey Drift under Spec under different dampers

Damper	X Direction (%)	Y Direction (%)
D1	14.37	12.01
D2	21.64	17.93
D3	12.61	13.92

Figure 5 shows the considerable reduction in storey drift in X-direction of the structure with respect to that of the structure without damper. Similarly, it was also found for Y-direction.

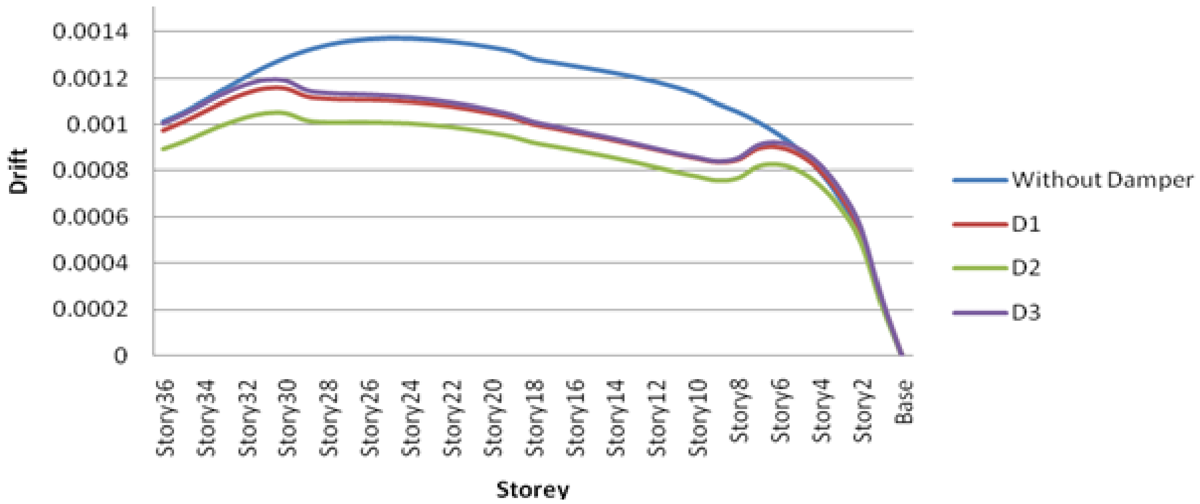


Figure 5:Storey drift response of structure in X-direction (SpecX)

Reduction in drift is because of added stiffness and damping of structure because of addition of dampers. Here also damping component of damper plays important role. This is the sole aim of using dampers.Table 14 shows the percentage reduction in displacement in two directions which is also quite considerable for a high rise structure. Base shear is also important for design of foundations hence its reduction was also analyzed (shown in Table 15).

Table 14. Average Reduction in Displacement of Stories under Spec under different dampers

Damper	**X Direction (%)**	**Y Direction (%)**
D1	14.80	14.50
D2	21.60	18.14
D3	13.17	14.40

Table 15. Reduction in Base shear

Dampers	D1	D2	D3
X-Direction Reduction %	16.32	28.33	2.59
Y direction Reduction %	10.47	22.73	2.61

3.3.2 Analysis for Wind Forces

Following Table 16 shows percentage reduction in displacement of top storey due to damper system.From above table it can be seen that there is a reduction in storey displacement in both directions by addition of viscoelastic damper. Compare to earthquake response, response reduction for wind is less because wind is applied as static load. Table 17 shows that reduction in drift is high as 25% in X-direction.

Table 16. Average Reduction in Displacement of Stories due to Wind under different dampers.

Damper	**X Direction (%)**	**Y Direction (%)**
D1	25.14	14.43
D2	26.77	15.28
D3	26.26	15.00

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Table 17. Average Reduction in Storey Drift due to Wind under different dampers

Damper	X Direction (%)	Y Direction (%)
D1	24.44	13.69
D2	25.92	14.51
D3	25.48	14.26

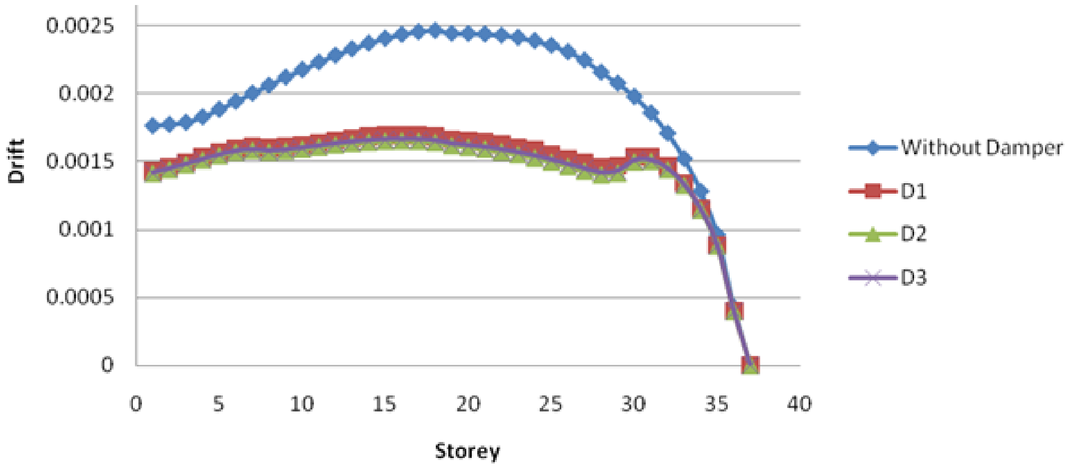

Figure 6: Storey drift response of structure in X-direction due to wind

It seen for Figure 6 that the there is considerable amount of reduction in story drift. Further commenting that it cannot be concluded which type of damper is the best as the difference in results are small. Also in the literature it is seen that many factors affect the performance of damper which has to be modelled and studied and detail. This will require deeper analysis of the responses with varying property of the structure.

4. CONCLUSION

The present study was to analyze tall building without and with viscoelastic dampers and to assess the seismic behavior of structure. The main purpose of this study is to investigate the effectiveness of viscoelastic damper which provides both additional stiffness and damping to structure. From all of results presented above following conclusions have been made:

1) The results of this investigation shows that, response of structure can be reduced to considerable (20-25%) amount by installation of viscoelastic dampers.
2) Properties of dampers i.e. stiffness and damping coefficient are highly sensitive to temperature changes but comparatively less sensitive to frequency change. Bracing plays an important role in reducing difference in efficiency of damper due to changes in temperature. Also properties of dampers are inversely proportional to temperature i.e. lower the temperature higher will be the damper properties.
3) Compare to reduction in displacement, reduction in storey drifts and acceleration is more which indicates that dampers are prominently effective in reducing storey acceleration and storey drift than storey displacement.
4) Most suitable position for damper placement is at the point of maximum interstorey drift than at the point of maximum absolute displacement. If interstorey drift is more, damper material will subject to more shear deformation and hence it will be more effective in reducing storey responses.
5) To reduce Wind Deflection, Stiffness Property of Damper is Important & to reduce Earthquake Deflection, Damping Property of Damper is Important
6) Increase in stiffness of building causes increase in earthquake forces acting on building.

4.1 Scope ofFuture Work

It is recommended that further research be undertaken in following areas:

1) Determining seismic behavior of tall structure by using different viscoelastic damper materials at different temperature ranges and frequency ranges.
2) Determining behavior of structure to dynamically applied wind loading in different software like ANSYS.
3) Determining effect of dampers on design of structural component like beams and column.
4) Determining the seismic behavior of tall building structures by using different arrangements of viscoelastic damper devices in the field of their locations in the building.

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