IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Seismic Vibration Control of Building using Viscous Wall Damper

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Abstract

Buildings subjected to seismic excitations experience significant lateral vibrations and structural responses, which can lead to damage and loss of structural integrity. This study investigates the application of viscous wall dampers (VWDs) as a passive vibration control technique for improving the seismic performance of buildings. The viscous wall damper dissipates earthquake-induced energy through the viscous resistance generated within the damping mechanism, thereby reducing structural vibrations and inter-storey drift. A building model with and without viscous wall dampers is considered and evaluated under suitable seismic loading conditions. Key response parameters such as displacement, inter-storey drift, acceleration, base shear, and storey response are compared. The study aims to assess the effectiveness of viscous wall dampers in reducing seismic responses and enhancing the safety, stability, and serviceability of building structures.

Keywords; Seismic Vibration Control; Viscous Wall Damper; Seismic Response; Structural Damping; Earthquake Engineering; Building Structures

1. Introduction

Earthquake is the most challenging task which causes severe casualties to the structure, it is also overwhelming in recent decades. The seismic waves created by earthquake leads to sever damages due to the effects of ground shaking, ground rupture, landslides etc. to mitigate theses causalities earthquake resistant design of buildings is the basic principle to prevent seismic forces. It is difficult to predict the amplitude, duration and also frequency of earthquake motion because earthquake load is uncertain. Normally the structures are designed for gravity loading and lateral loading but the earthquake ground motion causes hard destructive forces unless specified arrangements are prepared to decline them. Earthquake loads are cyclic in nature and the stress induced are difficult such that the elements which are axially loaded must encounter both tension and compression.

Structures must be designed such that it must protest any damage admitting any major and minor earthquakes occurs, even though the buildings are designed safe to avoid earthquake loads, the structures may collapse. To alleviate these circumstances researches investigated an alternative, effective and improved techniques such as base isolation and energy dissipation devices to advance the seismic performance of the structures.

Damping is the phenomenon that decline the amplitude of vibration of structures by means of energy dissipation throughout the system, damping characteristics the ratio between dissipated energy and energy unconsumed in the structure for each material during each cycle. Damping is crucial for prohibitive vibrations and gives comfort and security to buildings and substructures. By accumulating supplementary damping devices at organized location of the structure enhanced features of damping might be expected, which also leads to disintegrated earthquake forces. Damping effectively transfers vibrational energy appear in the structure to thermal energy such that main structural system discourages from earthquake energy.

In the present study a 7-story framed RC building is analysed by assuming the building is located in zone II and zone III in SAP2000 an equivalent-static analysis and response spectrum analysis were performed.

1.1 Viscous Wall Damper

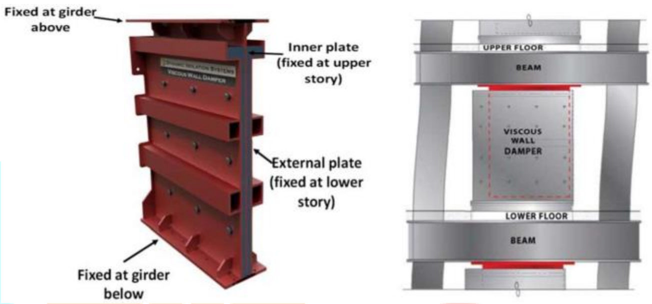

Figure 1.1 Viscous wall damper

A viscous wall damper is a passive energy dissipation used in buildings to reduce structural vibrations caused by earthquake, wind or other dynamic loads. It consists mainly of a piston moving inside a cylinder filled with highly viscous fluid. When the building undergoes lateral movement. The relative motion between floors causes the piston to move through the fluid, generating resistance that dissipates the vibration energy as heat. Viscous wall damper reduces inter – story drift, floor acceleration, base shear, structural damage, improve occupant comfort, dissipate earthquake energy without relying on yielding of the main structural members.

1.2 Components and mechanism of viscous wall damper

Viscous wall dampers consist a steel vane and hallow rectangular tank filed with high viscous fluid, the glutinous fluid consumption in the tank is non-toxic, odorless, colourless fluid with viscosity of 90,000 poises. The vane is linked to the top beam and the tank is linked to bottom beam. When the building is subjected to seismic loads, each story experiences displacements. The vane shear through the high viscous fluid filled between the steel plates when the interstorey drifts occurs and give rise to viscous damping and reinstitute forces due to this interstorey drifts and deformation reduces, damping force can be increased by double vane systems.

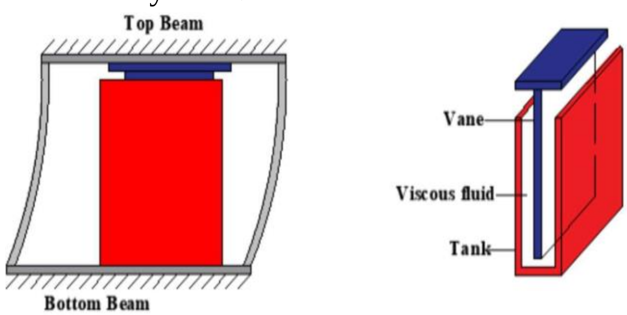

Image (1) **Image (2)**

Figure 1.2 Components of viscous wall damper

Figure 1.2 represents VWD in which the vane is attached to top beam and tank to the bottom beam the viscous fluid is filled between the steel tank, image (1) represents the movement of vane when the building subjects to dynamic loads, image (2) presents the closed view of components of VWD.

Figure 1.3 Viscous fluid filled between the steel plates

Figure 1.3 shows clear representation of viscous fluid filled between the steel plates and the vane, the viscous fluid used in the tank is innocuous, unpressured and translucent fluid with high viscosity of 90,000 poise. During the seismic events, the relative level of interchange pretends the vane to travel along the viscous fluid.

1.3 Objectives

- To model rectangular framed RC building using SAP2000.
- To assign seismic loads by assuming building is located in zone II and zone III.
- To provide viscous wall dampers at corners and interior frames
- To perform equivalent-static analysis and response spectrum analysis for 7 story framed RC building.
- To study the seismic responses of the building such as time period, base shear, story displacement and story drift of different models analyzed and compare the results obtained in individual analysis.

2. Methodology

Seismic performance is the predicted capacity of the building to resist its functions in both current and later action of earthquake and it is related with interstorey drift limits, the unpleasant behavior of the structure is a recurring process under the applications of loads, this also counts other factors such as materials quality, section properties, zone area of the building, analysis performed etc. the results of different seismic parameters considered will be related to method of analysis performed.

In this dissertation work 7 story framed RC building is modelled and equivalent static analysis and response spectrum analysis are performed using SAP2000, seismic parameters such as time period, base shear, story displacement and story drift are considered and compared for different models.

2.1 Methods used for analysis

1. Equivalent static analysis (linear static analysis)
2. Response spectrum analysis (linear dynamic analysis)

1. Equivalent static analysis

This is the basic analysis to be performed for the buildings; this is the simple method to understand effects of loads that damages the structure. The loads are applied both in transvers and longitudinal directions due to the loading causes the member to turn and bounce from its original position, with internal tensile and compressive strains.

2. Response spectrum analysis

Response spectrum analysis is a method to assess the essential reactions of short, predetermined, provisional dynamic measures such as earthquakes and shocks. It accomplishes the impact after every proposal of vibration to depute the regulated seismic response of flexible building. Response spectrum analysis be accounted for intuition into progressive performance by evaluating pseudo-spectral acceleration, velocity/displacement as a purpose of elementary interval pointed at particular time history and damping level. Response spectrum analysis is advantageous for design conclusion characteristics because it relates to dynamic performance.

According to IS 1893(Part-1):2002 response spectrum is the rendering of maximum responses of a spectrum of idealized SDFS of different natural periods but having the same damping, under the action of same earthquake ground motion at their bases.

3. MODELLING AND ANALYSIS OF STRUCTURE

The modelling and analyzing the structure is performed in SAP2000, here 7 story rectangular building has been modelled and analyzed. The structure is designed and evaluated for gravity loads and seismic loads. Equivalent-static analysis and response spectrum analysis were performed and results are tabulated. Analysis is done by assuming the building is located in zone II and zone III. Viscous wall damper and shear wall are included in models and they act as seismic resisting devices.

3.1. Illustration of structure

In this dissertation work 7 storied building is the composite building, it includes restaurant and lodging. Among 7 stories it included parking area at basement, restaurant at ground floor, 1st and 2nd floor, bedrooms at 3rd and 4th floor and conventional hall at 5th floor, bar attached with restaurant at 6th floor.

Table 1 Data used for modelling

Grade of concrete	M30
Grade of steel	Fe500
Floor height	3.6m
Height of foundation	3.2m
Beam	300 X 450 (mm)
Columns	300 X 750, 300 X 300, 450 X 450, 600 X 450 (mm)
Slab thickness	150 mm
Wall thickness	200 mm
Live load on restaurant area	4 kN/m^2
Live load on rest rooms	2 kN/m^2
Live load on kitchen	3 kN/m^2
Live load on bed rooms	2 kN/m^2
Live load on store rooms	5 kN/m^2
Live load on passage and staircase	3 kN/m^2
Live load on balconies	4 kN/m^2
Wall load on beams at basement	12.162 kN/m^2
Wall loads on beams	13.93 kN/m^2
Parapet wall load	3.643 kN/m^2
Floor finish	1 kN/m^2
Shear wall thickness	200 mm

Table 2 Properties of viscous wall dampers

Dimension of VWD	7ft X 11ft
Stiffness value	809.6 Kip/in
Damping co-efficient	257.6 {k-(sec/in) $^{\alpha}$}
Damping exponent	0.5

Table 3 Seismic data required for analysis

Zone factor of zone II	0.10
Zone factor of zone III	0.16
Impotence factor	1.5
Response reduction factor	4
Soil type for zone II	Hard
Soil type for zone III	Medium

VWD is an exponential Maxwell damper model as shown in figure 3.1, which consists of a liner spring K, in series with an exponential damper characteristic by C and α, so that the force in the damper is related to the velocity across the damper through the force-velocity relationship, $F = CV^{\alpha}$

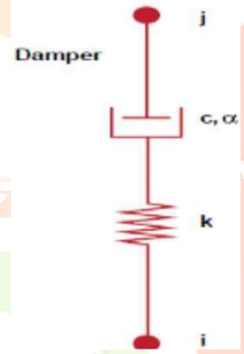

Figure 3.1 Exponential Maxwell damper model

3.2 Modelling

A 7-story building is modelled in SAP2000 software. Basement area 300 sq.m., ground floor 300 sq.m., first floor to sixth floor area 329 sq.m., shear wall is included in lift area. Viscous wall dampers are implemented at different locations to resist the seismic vibrations. seismic parameters such as time period, base shear, story displacement and story drift are considered and compared for different models. Equivalent static and response spectrum analysis were carried out and results are compared with different models for zone 2 and 3.

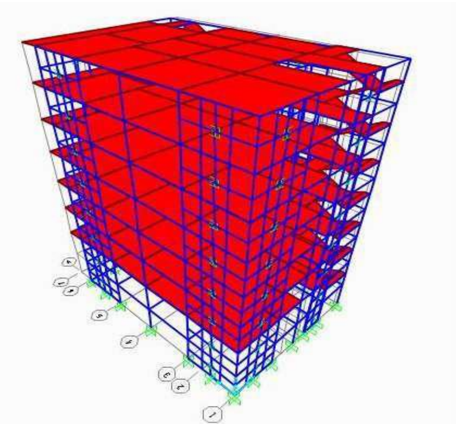

Figure 3.2 Model with dampers at corners and without shear wall (SAP2000)

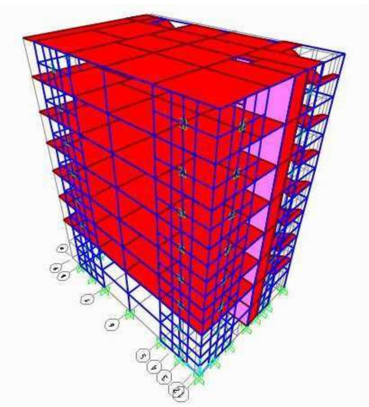

Figure 3.3 Model with shear wall and with dampers at corners (SAP2000)

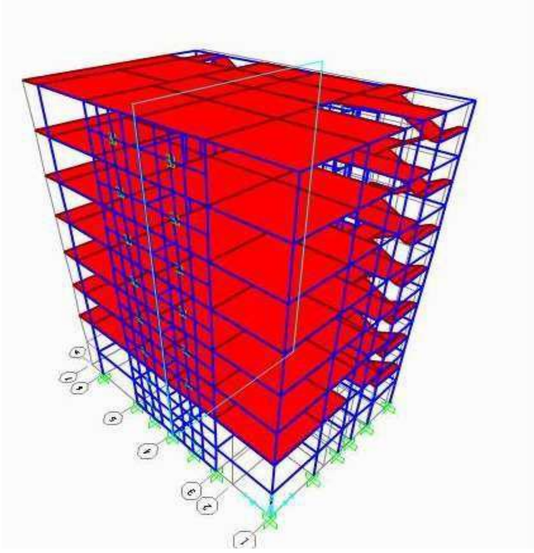

Figure 3.4 Model with dampers at interiors and without shear wall (SAP2000)

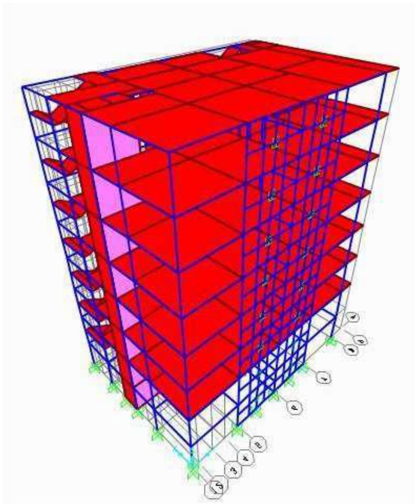

Figure 3.5 Model with dampers at interiors and with shear wall (SAP2000)

4. RESULTS AND DISCUSSIONS

The results of different seismic parameters such as time period, base shear, story displacement and story drift values are discussed, equivalent-static analysis and response spectrum analysis are performed and the results of different models are compared for each individual analysis. The models include viscous wall dampers and shear walls to resist the wind and seismic forces, the models are assumed as located in zone II and zone III, loads are assigned as per IS 875 (part 1 and part 2): 1987 and seismic parameters are assigned as per IS 1893 (part 1): 2002.

4.1. Time Period

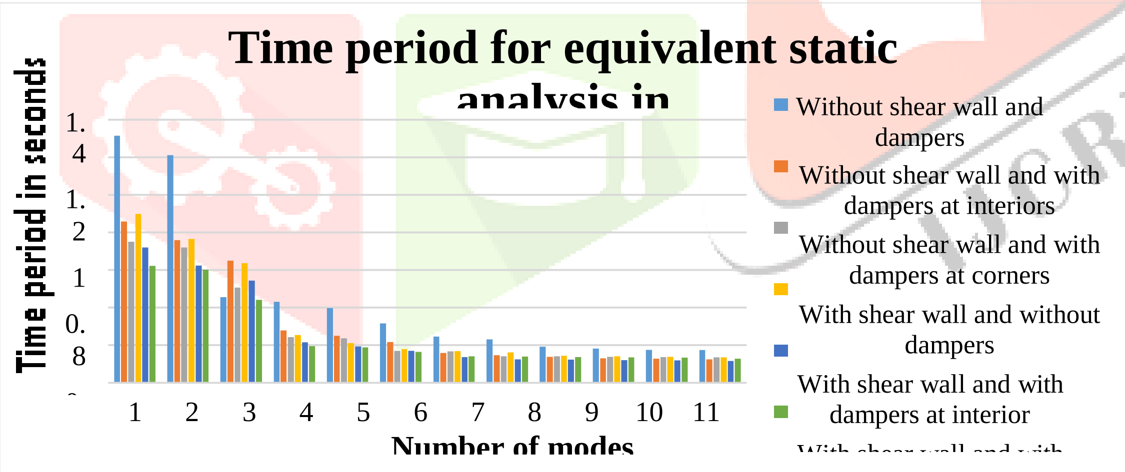

Chart no.4.1.1 Bar graph of time period results for equivalent static analysis in zone 2

From the table no. 6.2.1 and chart no. 6.2.1., the bar graph decreases by implementing shear wall and viscous wall dampers to the structure. The time period is 1.3145 seconds for bare frame, it decreases to 0.7497 seconds for model without shear wall and with dampers at interior, reduces to 0.8975 seconds for the model without shear wall and with dampers at corners, it again decreases to 0.8574 seconds for model with shear wall and without damper, then reduces to 0.7191 seconds for the model with shear wall and with dampers at interior, and finally reduces to 0.6222 seconds for the model with shear wall and with dampers at corners.

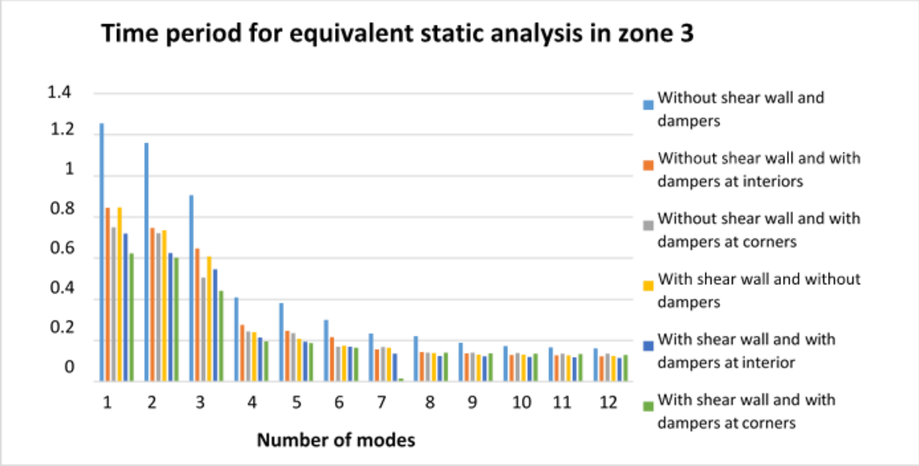

Chart no. 4.1.2 Graphical representation of time period results of equivalent static analysis in zone 3

From the above table and chart it can be concluded that, the time period results for equivalent static analysis for zone 2 decreases with implementation of seismic excitation controlling devices such as shear wall and viscous wall dampers, the time period is 0.1253 seconds for the model without shear wall and dampers, it is 0.7595 seconds without shear wall and with dampers at interior model, it reduces to 0.8455 seconds for model without shear wall and with dampers at corners, it is 0.8441 seconds reduced for model with shear wall and without damper, it decreased to 0.7182 seconds for model with shear wall and with dampers at interior and it is reduced to 0.6222 seconds with model with shear wall and with dampers at corners.

Table no. 4.1.1.1 Percentage prediction of time periods by equivalent static analysis in both zones

Axis	**Without shear wall and with dampers at interior frames**	**Without shear wall and with dampers at corners**	**With shear wall and without damper**	**With shear wall and with dampers at interior**	**With shear wall and with dampers at corners**
Zone 2	57.03%	68.27%	65.22%	54.70%	47.33%
Zone 3	60.63%	67.48%	67.37%	57.332%	49.66%

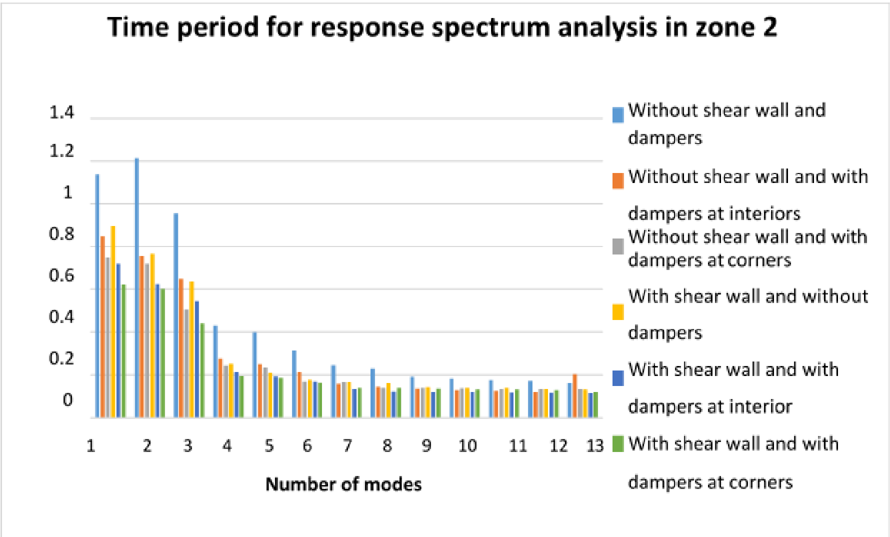

Chart no. 4.1.3. Bar graph representing results of time period of response spectrum analysis in zone 2

The above table and chart represents the results of time period obtained for response spectrum analysis in zone 2, the time period valve is 1.3145 seconds for model without any seismic excitation control devices, it is 0.8484 seconds for the model without shear wall and with dampers at interior, it is 0.7497 seconds for the model without shear wall and with dampers at corners, it is valued as 0.8975 seconds for the model with shear wall and without any dampers, it is reduced to 0.7191 seconds for the model with shear wall and with dampers at interior frames and it is decreased to 0.62227 seconds for the model with shear wall and with dampers at corner frames

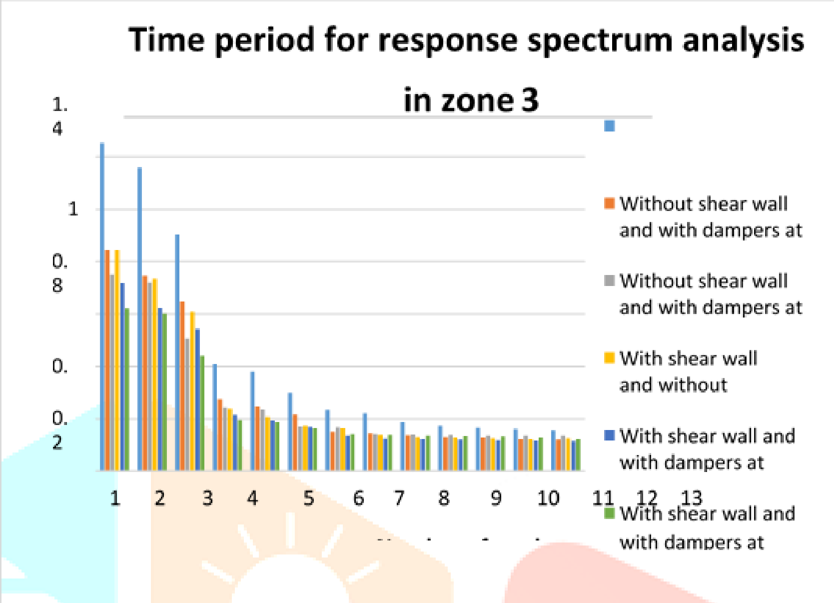

Chart no. 4.1.4 Bar graph representing results of time periods for response spectrum analysis in zone 3

The exceeding table and chart presents the results of time period for response spectrum analysis in zone 3, chart represents the results of different models in different colors, the valve is 1.2530 seconds for model without shear wall and damper, it is 0.8441 seconds for model without shear wall and with dampers at interior, it is 0.7495 seconds for the model without shear wall and with dampers at corners, it is declined to 0.8455 seconds for model with shear wall and without dampers, it is 0.71827 seconds for the model with shear wall and with dampers at interior and it is 0.6222 seconds for model with shear wall and with dampers at corners.

4.2 Base Shear

Base shear is an approximation of the maximum predictable lateral forces that occurs due to seismic excitations at the ground level of the structure.

Table no. 4.2.1 Base shear results obtained for different models in zone 2 for both analyses

Base shear of both analysis in zone 2						
Type of analysis	**Without shear wall and damper (KN)**	**Without shear wall and with dampers at interior(KN)**	**Without shear wall and with dampers at corners(KN)**	**With shear wall and without damper (KN)**	**With shear wall and with dampers at interior (KN)**	**With shear wall and with dampers at corners(KN)**
ESA	726.787	1356.282	1604.489	893.67	1674.194	2006.85
RSA	720.417	1241.603	1486.837	818.249	1497.360	1786.307

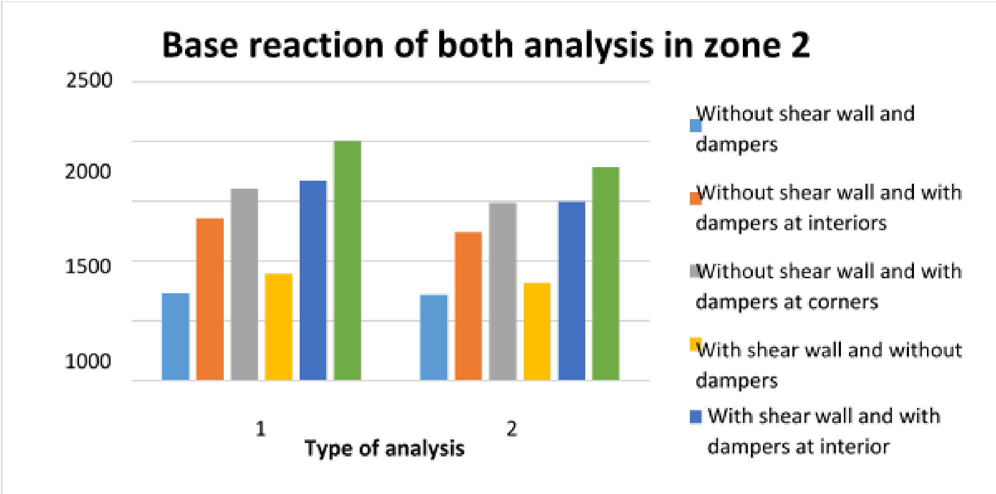

Chart no. 4.2.1 Bar graph for different model with both analyses in zone 2

The above table and graph represent the results of both equivalent static method and response spectrum method performed for different models, it is observed that the base reaction increases with implementing shear wall and viscous wall dampers to the structure from the results it is concluded that the maximum base shear is obtained for the model with shear wall and with dampers at corners.

Table no. 4.2.2 Base shear results of both analyses in zone 3

Base shear of both analysis in zone 3						
Type of analysis	**Without shear wall and damper (KN)**	**Without shear wall and with dampers at interior(KN)**	**Without shear wall and with dampers at corners(KN)**	**With shear wall and without damper (KN)**	**With shear wall and with dampers at interior (KN)**	**With shear wall and with dampers at corners(KN)**
ESA	1713.976	2981.172	3491.369	2228.227	3652.117	4365.894
RSA	1624.795	2678.01	3213.723	1931.013	3233.852	3929.114

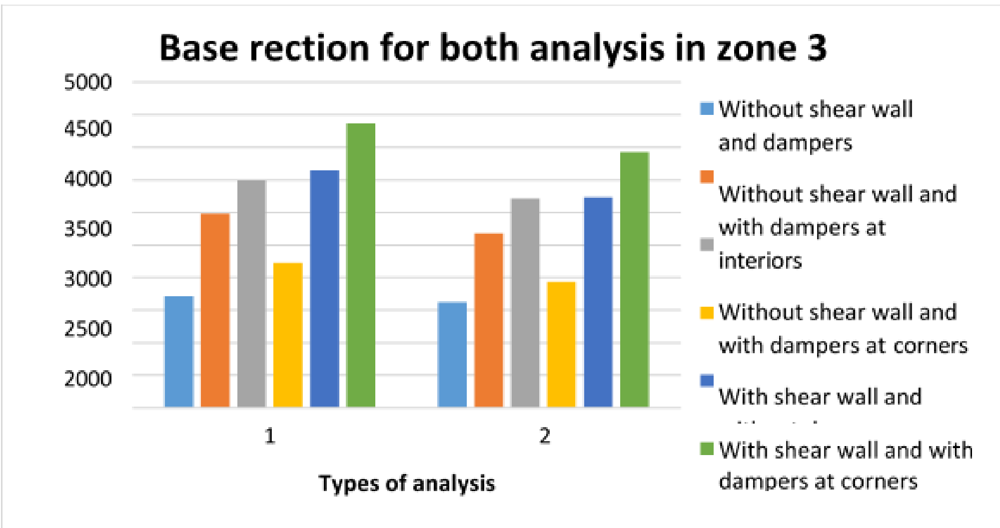

Chart no. 4.2.2 Graphical representation of base shear values for both analyses in zone 3

The above table and graph presents the results of base shear of both analyses in zone 3, the graph presents the clear view of results of different models in different colors which is easy to understand even without the values of base shear, the maximum results are obtained for model with shear wall and with dampers at corners i.e., 4365.894 KN for equivalent static analysis in zone 3 and it is 3929.114 KN for response spectrum analysis in zone 3.

4.3 Story Displacement

Story displacement is the sideway displacement of every story which is associated to the base of the structure, displacement increases along the story height of the structure for the fixed base. In this dissertation work the maximum story displacement results are obtained and tabulated for the load combination (1.5DL + 1.5EQx).

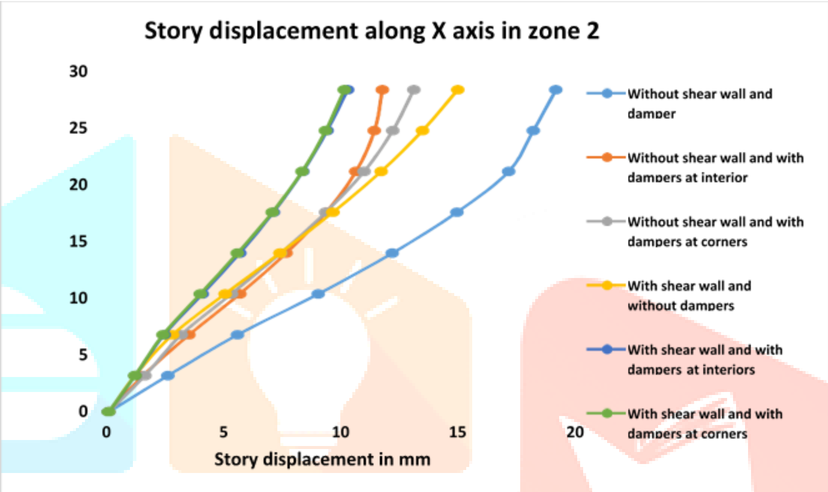

Chart no. 4.3.1 Graphical representation of story displacement along X axis in zone 2 by equivalent static method

The above table and chart represents the results of story displacement along X axis in zone 2 by equivalent static analysis, the displacement 1.99mm for bare frame, it is reduced to 1.152mm for the model without shear wall and with dampers at interior frames, it is decreased to 1.217mm for model without shear wall and with dampers at corners, it declines to 0.878mm with shear wall and without damper model, it further reduced to 0.885mm for the model with shear wall and with dampers at interior frames and it further declined to 0.88mm for the model with shear wall and with dampers at corners.

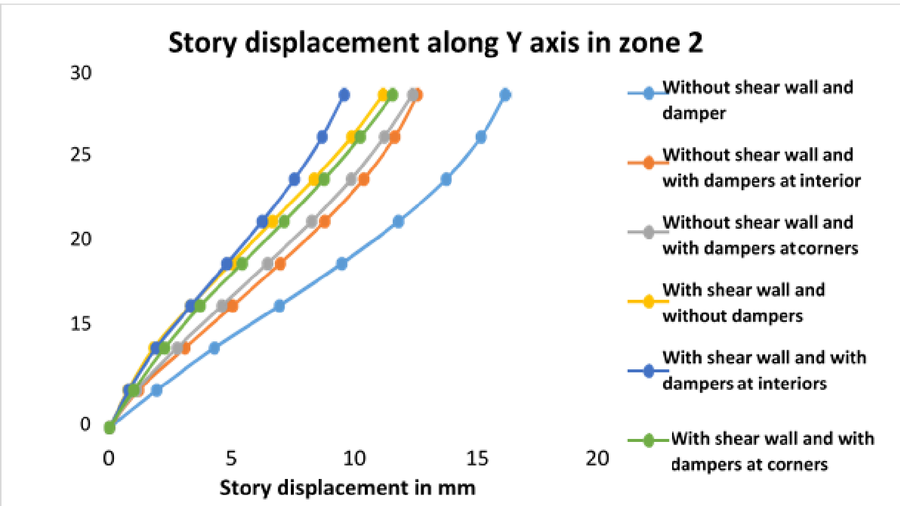

Chart no. 6.4.2 Graph representing story displacement along Y axis in zone 2 by equivalent static method

From table no 6.4.2 it can be concluded that the story displacement results of model without shear wall and dampers declines from 16.184 mm to 1.947 mm, for the model without shear wall and with dampers at interior id decreases from 12.599 mm to 1.195mm, for the model without shear wall and with dampers at corners it reduced from 12.39 mm to 1.11mm, it further reduced from 11.189 mm to 0.772 mm for the model with shear wall and without damper, for the model with shear wall and with dampers at interior frames the story displacement reduces from 9.596 mm to 0.809 mm and for the model with shear wall and with dampers at corners the displacement reduces from 11.59 mm to 0.99 mm. The graph represents the line graph of story displacement results by equivalent static method in X axis in zone 2.

Table no. 4.3.1.1 Percentage reduction of different models compared with conventional building of equivalent static analysis for zone 2

Axis	Without shear wall and with dampers at interior frames	Without shear wall and with dampers at corners	With shear wall and without damper	With shear wall and with dampers at interior	With shear wall and with dampers at corners
X axis	38.08%	31.78%	21.99%	46.53%	47.32%
Y axis	22.15%	23.44%	30.86%	40.70%	28.38%

Table no. 4.3.1.2 Percentage reduction in story displacement of different models compared with bare frame model of equivalent static analysis for zone 3

Axis	Without shear wall and with dampers at interior frames	Without shear wall and with dampers at corners	With shear wall and without damper	With shear wall and with dampers at interior	With shear wall and with dampers at corners
X axis	27.44%	29.48%	26.198%	32.130%	42.23%
Y axis	24.83%	25%	29%	40.66%	34.06%

Similarly the percentage of story displacement of response spectrum analysis in zone 2 and zone 3 in both X and Y axis are tabulated below

Table No 4.3.1.3 Percentage reduction of story displacement by response spectrum analysis in zone 2

Axis	Without shear wall and with dampers at interior frames	Without shear wall and with dampers at corners	With shear wall and without damper	With shear wall and with dampers at interior	With shear wall and with dampers at corners
X axis	31.07%	59%	24.52%	36.16%	62.23%

Y axis	32.80%	23.53%	32.44%	44.24%	30.07%

Table no. 4.3.1.4 Percentage reduction of story displacement by response spectrum analysis in zone 3

Axis	Without shear wall and with dampers at interior frames	Without shear wall and with dampers at corners	With shear wall and without damper	With shear wall and with dampers at interior	With shear wall and with dampers at corners
X axis	32.25%	54.55%	24.97%	37.06%	59.69%
Y axis	39.14%	28.84%	33.54%	44.04%	36.53%

4.3 Story Drift

Story drift is related to displacement of the structure; it is defined as the ratio of displacement upper story comparable to displacement of lower story of the building to that of height of the story.

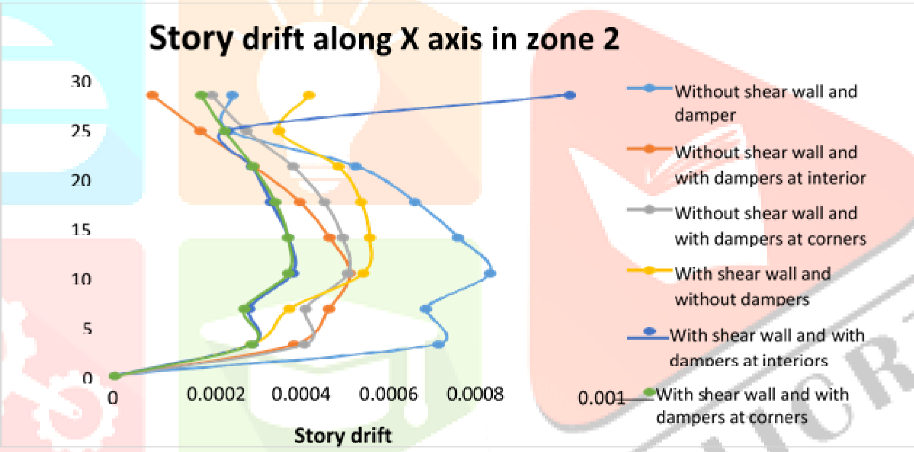

Chart no. 4.3.1 Graphical representation of story drift results by equivalent static analysis in zone 2 along X axis

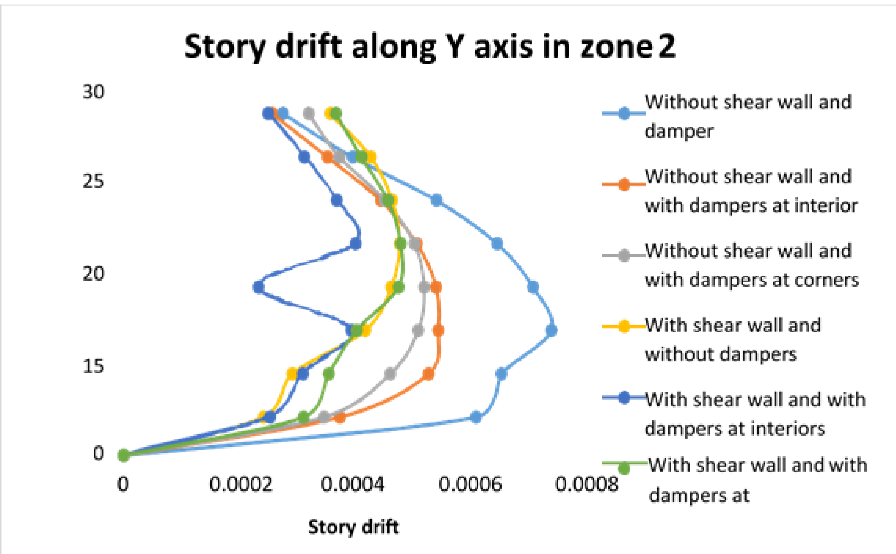

Chart no. 4.3.2 Graphical representation of story drift along Y axis in zone 2 by equivalent static analysis

Story drift values are compared with different models for both analysis graphical representation of , these results are tabulated as per the formula mentioned for the (1.5DL+1.5EQx) load combination. Maximum story drift value is obtained for model with shear wall and dampers at corners.

5. Conclusion

In this dissertation work 7 story framed structure with and without viscous wall damper and with and without shear wall, viscous wall dampers are located at interior frames and at corners whereas shear wall is located at lift well portion of the structure are modelled and analyzed by equivalent static and response spectrum analysis. The seismic parameters considered are time period, base shear, story displacement and story drift each parameter is compared with different models for individual analysis i.e., equivalent static analysis and response spectrum analysis, the results of each parameter is discussed below.

1. The time period for the 7 story framed structure changes from 1.253 seconds to 0.759 seconds for the model without shear wall and with dampers at interiors, 0.845 seconds for the model without shear wall and with dampers at corners, 0.844 seconds for the model with shear wall and without dampers, 0.718 seconds for the model with shear wall and with dampers at interior and 0.622 seconds for the model with shear wall and with dampers at corners are observed for equivalent static analysis in zone III, similar results are obtained for equivalent static analysis in zone II and response spectrum analysis in zone II and zone III.
2. The base shear results of the structure changes from 1713.976 KN to 2981.172 KN for the model without shear wall and with dampers at interior, 3491.369 KN for the model without shear wall and with dampers at corners, 2228.227 KN for the model with shear wall and without damper, 3652.117 KN for the model with shear wall and with dampers at interior, 4365.894 KN for the model with shear wall and with dampers at corners are the results of equivalent static analysis in zone III and similar results are obtained for equivalent static analysis in zone II and response spectrum analysis in zone II and zone III.
3. Story displacement increases from the base of the structure to the top story, for the 7 story framed structure the story displacement decreases from 32.365 mm to 23.481 mm for the model without shear wall and with dampers at interior, 22.824 mm for the model with dampers at corners and without shear wall, 23.886 mm for the model with shear wall and without dampers, 21.966 mm for the model with shear wall and with dampers at interior, 18.66 mm for the model with shear wall and with dampers at corners along X axis and similar decrement of results observed along Y axis these are the results by equivalent static analysis in zone III and by equivalent static analysis in zone II and in response spectrum analysis of both zones, finally by implementing shear wall and viscous wall dampers in the structure the story displacement declines from 26% to 62%.
4. Story drift results are calculated on the bases of story displacement results; story drift is 0.00049 for conventional model, it is 0.00038 for the model without shear wall and with dampers at interior, 0.00048 for the model without shear wall and with damper at corners, 0.00087 for the model with shear wall and without dampers, 0.00085 for the model with shear wall and with dampers at interior, 0.00046 for the model with shear wall and with dampers at corners are the results along X axis and similar results are observed along Y axis by equivalent static analysis in zone III and by response spectrum analysis in zone II and zone III.

According to IS 1983 (part 1): 2022 the story drift results must be within 0.004 times the story height, the story drift results of present work are within the permissible limit.

By observing the results of seismic response parameters, it can be concluded that the implementation of shear walls at lift well portion of the structure and locating viscous wall dampers at interior and corner are controlling the seismic vibrations, thereby reducing the seismic vulnerabilities of the structure.

5.2. Scope of future work

1. Time history analysis can be performed for the structure.
2. Further analysis can be performed by considering the structure is located in seismic zone V.
3. Further studies can be manipulated by implementing other dampers, base isolation technique and also by implementing bracings to resist the wind and seismic forces.
4. The dimensions of viscous wall dampers can be considered by designing instead by considering the dimensions by DIS guidelines.
5. Structure can be analyzed by considering soil structure interaction.

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3. **IS 875 (Part 5): 1987** code of practice for design loads for building and structures part 5 special loads and load combinations.
4. **IS 456-200**: Plain and reinforced concrete.
5. **IS 1893 (Part 1): 2002** criteria for earthquake resistant design of structure.