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Behavior of Connected Tall Buildings Installed with Dampers

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Abstract: Tall structures are now a days very popular because of land acquisition problems. A connected tall building generally refers to a skyscraper or high-rise building that is physically connected to one or more adjacent buildings, either through bridges or other structural elements. It gives enhancement of structural performance under lateral loads and also gives horizontal connectivity for users. To control the lateral displacement of a tall structure, various lateral load resisting system and vibration control system need to be adopted. In this paper, tall building with Shear Wall system, and Linear Viscous Damper are compared. Models of 25-storied connected tall buildings is studied with different location of sky bridges and dampers. The buildings are analysed by linear time history analysis, response spectrum analysis and wind analysis and the optimum solution have been derived for better performance of building. It has been observed that the structures connected with Sky Bridge and dampers are found to be more effective in reducing various responses like displacement, acceleration, storey drift etc.

Keywords - Connected Tall Building, Shear Wall, Bracing, Damper, Earthquake, Wind

I.INTRODUCTION

There is no precise definition of how tall a building needs to be to be considered "tall," but according to IS 16700: 2017 a building of height greater than 50 m but less than or equal to 250 m is termed as Tall Building. A building of height greater than 250 m is known as Super Tall Building. [3] Skyscrapers are tall buildings typically located in densely populated cities where land is limited and costly. To withstand lateral forces, such as wind and seismic forces, lateral load-resisting systems are used in construction. Examples of these systems include moment frames, braced frames, shear wall structures, framed tube structures, diagrid structures, etc. Vibration control systems, such as dampers and base isolation systems, are also utilized to reduce the impact of oscillations on these buildings.

A shear wall structure is a building construction method that utilizes walls to provide lateral stability and resist seismic and wind forces. These walls are commonly used in both tall and low-rise buildings and are responsible for carrying vertical loads in together with columns. [1]

Structural control systems are used to reduce the response of structures to dynamic loads such as earthquakes, and wind. There are several types of structural control systems, including: Passive, Active, Hybrid, and Semi-Active control. Here, Passive control system is used, i.e. Linear Viscous Damper. The diagram and mathematical model of Viscous Damper is shown in Figure 1(a) and 1(b). LVDs are passive vibration control systems that utilize the structure's motion to produce reactive forces. Linear viscous dampers are velocity dependent dampers that offer further damping to the structure without additional stiffness. They operate on the principle of fluid flowing through an orifice which provides the force that resists the motion of structure during a seismic event. The damper is made of a cylinder filled with a viscous fluid, such as oil or silicone, which is connected to the structure using a piston rod, which strokes through a fluid-filled chamber. Differential pressure generated across the piston head results in damper force. The force in the viscous damper is proportional to the relative velocity between the ends of a damper. [11]

The force in the viscous damper is proportional to the relative velocity between the ends of a damper. It is given by,
$F_{di} = C_{di}\ (\dot{u}_{di})^{\alpha}$

Where, F_{di} = damping force of ith damper, α = damper exponent and $\dot{u}_{di}$ = Relative Velocity between two ends of the damper, which is to be considered. When α=1 damper behaves as a linear viscous damper, and when α is less than unity, it will behave as a non-linear viscous damper.

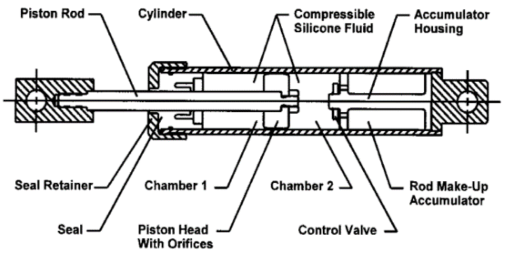

Figure 1(a): Schematic diagram of fluid viscous damper

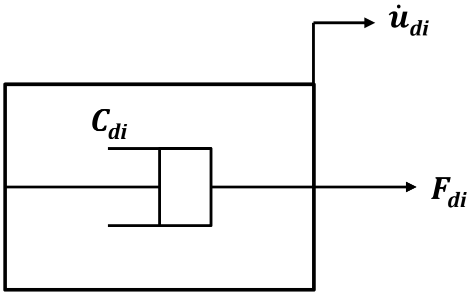

Figure 1(b): Mathematical model of fluid viscous damper

Penumatcha et al. (2020) have studied for perfect positioning of Connecting Beams (CB) in between twin tower structure subjected to lateral loads (i.e. Wind and Earthquake). The study reveals that the 'lateral sway' at the top of structure against wind was within the allowable limit only in case of all floors joined with CB and the 'story drift' was also fulfilled the code requirements against earthquake. [13] Khan et al. (2020) have studied the seismic response of two adjacent buildings of fifteen and ten-story which was connected by a viscous damper. Also compares the responses of the building by using under damped and critically damped dampers. Study reveals that critically damped dampers give better results than considered under damped dampers. [7] Huang-sheng et al. (2013) have performed a simplified 3-DOF model of twin-tower structure linked by a sky-bridge. It was showed that the optimal connecting parameters derived from the simplified 3-DOF model were applicable for two multi-story structures linked by a sky-bridge with dampers.[2] Tubaldi (2015) have analyzed the properties of the dynamic behaviour of two adjacent buildings of different height connected by viscous/viscoelastic dampers positioned at the top of the shortest building. It was shown that the preliminary design of the damper properties ensuring the optimal control against seismic loadings. [15] Yang and Lam (2013) have studied dynamic responses of two buildings connected by viscoelastic dampers under bidirectional excitations. For asymmetric buildings, the effectiveness of the connecting dampers was affected by building eccentricities. For adjacent symmetric buildings, the maximum displacement and the maximum base shear responses can be notably reduced by the connecting viscoelastic dampers. [16] Patel and Jangid (2013) have investigating the dynamic behavior of two identical adjacent structures (symmetric) connected with viscous dampers under base acceleration. It was observed the viscous dampers were found to be effective in reducing the dynamic responses of adjacent identical structures under harmonic as well as real earthquake excitation. Moreover, the optimum damping coefficient of damper calculated for connected undamped system can also be used for connected damped system. [12] Zhou et al. (2016) have evaluated structural behaviors of Shanghai International Design Center (SHIDC) under earthquakes. Analyses have shown that the maximum interstory drift can satisfy the limits specified in Chinese code and the failure sequence of structural members was reasonable. Natural periods from numerical analyses were little different from those of shake table testing. [17] Lee et al. (2010) have done the evaluation of coupling–control effect of a sky-bridge for adjacent tall buildings. Numerical results proven that the sky-bridge could effectively increase the damping ratio of the coupled tall buildings, resulting in decreased dynamic responses. It was also revealed that the coupling–control effect of the sky-bridge could be significantly improved by using additional viscous dampers. [9] Mahmoud et al. (2015) have studied numerical modeling of the seismic behavior of two super-tall buildings with a connecting sky bridge – the Petronas Twin Towers in Malaysia. The results reveal that the location of the linking bridge has an insignificant effect on the overall dynamic response of the connected towers in both longitudinal and transverse directions. The inter-story drift in the transverse direction (y-direction) showed sensitivity to variations in bridge location, while the corresponding storeys in the longitudinal direction (x-direction) were insensitive to the location of the connecting bridge. [10] Kim et al. (2005) have investigates the effect of installing viscoelastic dampers (VEDs) in places such as seismic joints or building–sky-bridge connections to reduce earthquake-induced structural responses. The use of VEDs in seismic joints or in sky-bridges can be effective in reducing earthquake-induced responses. The optimum size of VED reduced the relative as well as the absolute displacements of connected structures and also the hysteretic energy and the plastic deformation were reduced. [8]

This paper studies the Shear Wall system and Linear Viscous Dampers. Further, the Shear Wall system has been provided at outer periphery of building. And also the study has been carried out on a shear wall system having dampers at outer periphery.

Based on the literature review carried out herein, the following are the major objectives:

- To study the performance of connected tall buildings with Shear Wall system
- To study the performance of connected tall buildings with Passive Viscous Damper
- To study various parameters like base shear, displacement, acceleration, story drift for the connected buildings under consideration.

- To study the behaviour and performance of connected building with various locations of Sky Bridge.

II.NUMERICAL STUDY

Two 25-storied building having a plan dimension of 35m x 35m are selected for the study. Distance between two buildings is considered as 36 m and Sky Bridge is provided between 12th & 13th floor and 24th & 25th floor. The ETABS software is used to analyze and design four different systems with shear walls as lateral load-resisting systems for dead load, live load, earthquake load, and wind load. Static Earthquake analysis, Response spectrum analysis, Wind analysis, and Earthquake time history analyses are performed. The Gust factor approach is used to calculate wind load. Properties of building and loading details are mentioned in Table-I. Hot rolled I-sections are used to model beams. Columns and bracings are modelled as built-up box sections. Section details of all models are given in Table-III. For Model-1, the beam and column size in the Sky Bridge is B-350X55. For Models 2-4, the beam and column size for those directly connected to buildings are B-800X65 for storey 12&13, and B-550X55 and B-500X55 for storey 24&25 respectively in the Sky bridge. Remaining are of sizes B-350X55. The section details mentioned are based on critical design checks.

Following are the cases considered in the present study.

A. Conventional frame system with Shear Wall (SW)

SW is modelled as a shell-thin wall element. Plan, elevation, and 3D view of the conventional model having SW are shown in Figure-2.

B. Conventional frame system with SW and Linear Viscous Damper (LVD) in Sky Bridge only

Linear Viscous Dampers are provided at Sky Bridge only, as shown in Figure-3. LVDs are modelled using link properties.

C. Conventional frame system with SW and LVD at all storey

LVDs are provided at Sky Bridge and also at the outer periphery, as shown in Figure-4.

D. Conventional frame system with SW and LVD at alternate storey

LVDs are provided at Sky Bridge and also at the outer periphery at alternate storey, as shown in Figure-5.

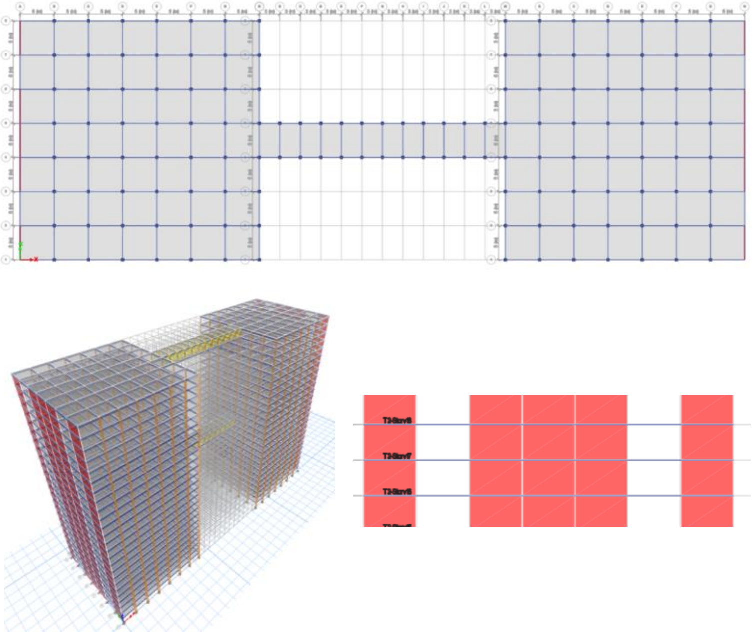

Figure 2: Plan and 3D view of Model-1

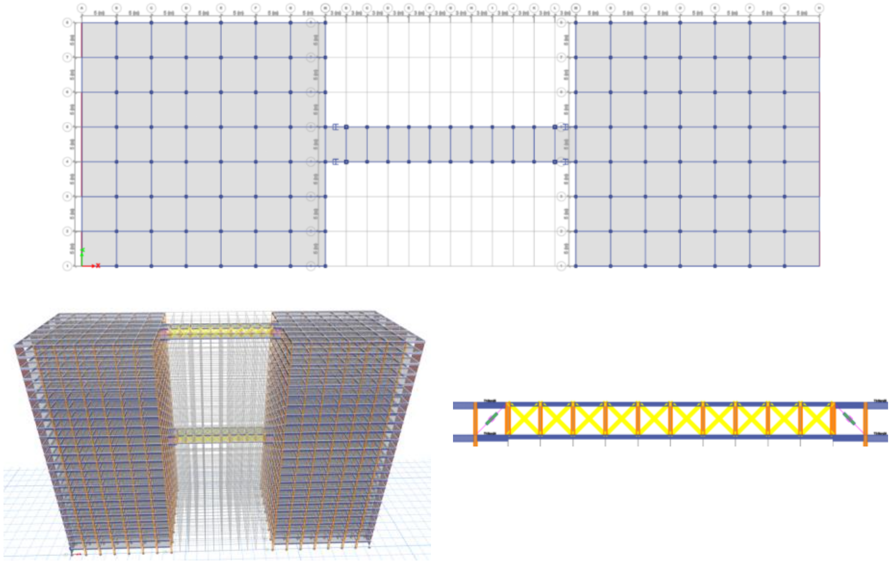

Figure 3: Plan and 3D view of Model-2

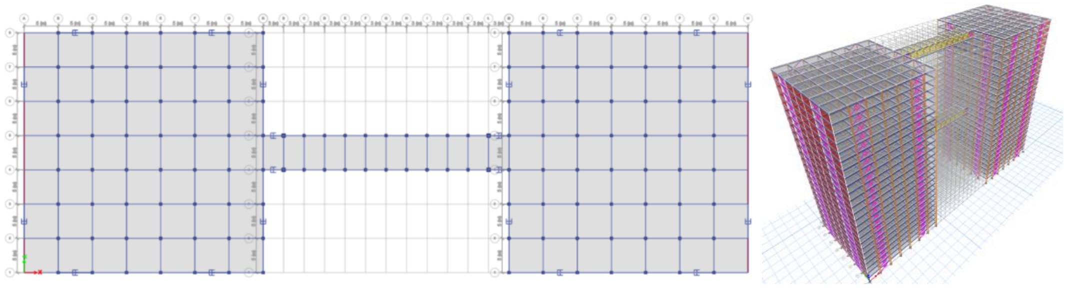

Figure 4: Plan and 3D view of Model-3

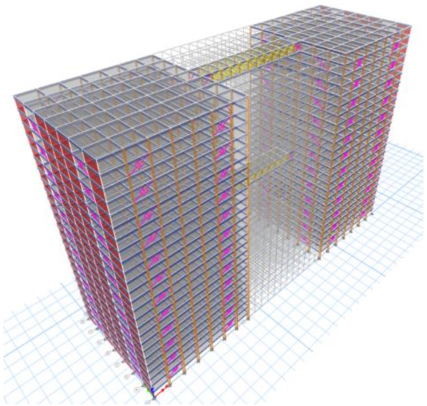

Figure 5: Plan and 3D view of Model-4

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Table I: Properties and data

Parameters	**Value**
Number of stories	25
Height of each story	3 m
Total height of building	75 m
Plan dimension (one building)	35 m X 35 m
Grid dimension	5 m X 5 m
Distance between two building	36 m
Slenderness ratio (H_t/B_t)	2.14
Plan aspect ratio (L_t/B_t)	1
Grade of steel for steel section	Fe250
Concrete grade (Slab)	M25
Slab (Thickness)	125 mm
Density of brick masonry	20 kN/m^3
Seismic Zone	V
Importance Factor	1.2
Response Reduction Factor	5
Wind Speed	55 m/s
Floor finish load	1.5 kN/m^2
Wall load (230 mm thick)	13.8 kN/m
Wall load (115 mm thick)	6.9 kN/m
Live load	2.5 kN/m^2

Table II: Details of Earthquake considered in the study

Earthquake	**Duration in seconds**	**PGA (g)**
Imperial Valley, 1940	40	0.31

Table III: Section Details

Model	**Element**	**Number of storey**				
		1 to 5	**6 to 10**	**11 to 15**	**16 to 20**	**21 to 25**
Model 1	**Beam**	ISWB550 + PLATE40	ISWB550 + PLATE40	ISWB500 + PLATE40	ISWB500 + PLATE25	ISWB600-1
	Beams connected to SW	ISWB600-2 + PLATE40	ISWB600-2 + PLATE40	ISWB600-2 + PLATE40	ISWB550 + PLATE20	ISWB450 + PLATE40
	Column	B-600X75	B-450X65	B-400X65	B-400X55	B-350X45
	Bracing (SB)	B-350X55				
Model 2	**Beam**	ISWB550 + PLATE40	ISWB550 + PLATE40	ISWB500 + PLATE40	ISWB500 + PLATE25	ISWB600-1
	Beams connected to SW	ISWB600-2 + PLATE40	ISWB600-2 + PLATE40	ISWB600-2 + PLATE40	ISWB550 + PLATE20	ISWB450 + PLATE40
	Column	B-600X75	B-500X55	B-450X55	B-400X55	B-350X45
	Bracing (SB)	B-350X55				
Model 3	**Beam**	ISWB550 + PLATE40	ISWB550 + PLATE40	ISWB500 + PLATE40	ISWB500 + PLATE25	ISWB600-1
	Beams connected to SW	ISWB600-2 + PLATE40	ISWB600-2 + PLATE40	ISWB600-2 + PLATE40	ISWB550 + PLATE20	ISWB450 + PLATE40
	Column	B-600X75	B-500X55	B-450X55	B-400X55	B-350X45
	Bracing (SB)	B-350X55				
Model 4	**Beam**	ISWB550 + PLATE40	ISWB550 + PLATE40	ISWB500 + PLATE40	ISWB500 + PLATE25	ISWB600-1

	Beams connected to SW	ISWB600-2 + PLATE40	ISWB600-2 + PLATE40	ISWB600-2 + PLATE40	ISWB550 + PLATE20	ISWB450 + PLATE40
	Column	B-600X75	B-500X55	B-450X55	B-400X55	B-350X45
	Bracing (SB)	B-350X55				

III.RESULTS and DISCUSSION

A. *Effect of C_d*

The value of the damping coefficient is decided by optimizing it for nearly constant displacement and acceleration. The impact of C_d on the response parameters of Model 3 and Model 4 under Imperial Valley Earthquake is shown in Figure 6(a) and 6(b), respectively. Here, the top storey displacement and acceleration are considered. It is observed that, value of C_d increases, response parameters decreases. Optimum value of the damping coefficient is considered as 200000 kNs/m for Model 3, and Model 4.

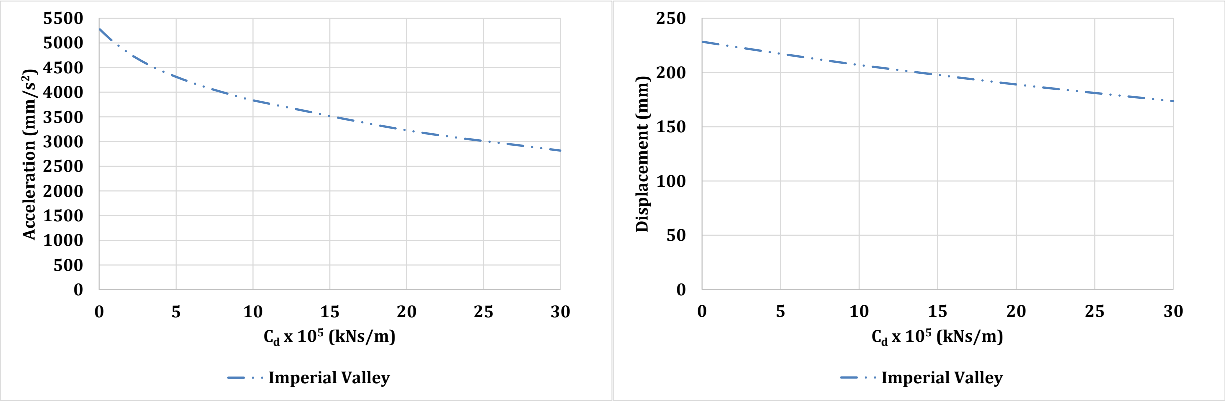

Figure 6(a): Effect C_d on various response parameters for Model-3

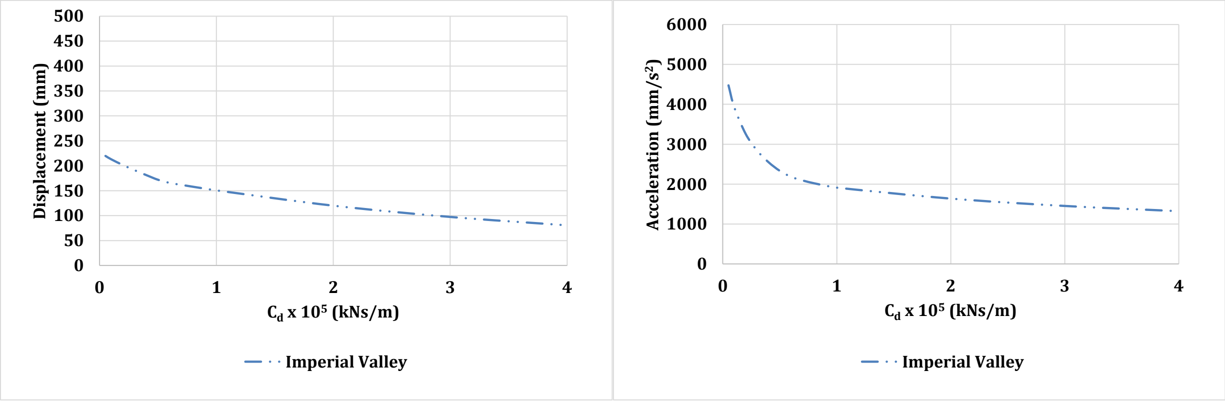

Figure 6(b): Effect C_d on various response parameters for Model-4

B. *Hysteresis loop*

Figure 7(a) and 7(b) shows the hysteresis loop for damper at Storey-25 in Model 3 and Model 4 under Imperial Valley Earthquake, respectively. From the loop of damper force vs. displacement, it is observed that energy is getting dissipated. Hysteresis loop of damper force vs. velocity reflects the characteristic of the damper.

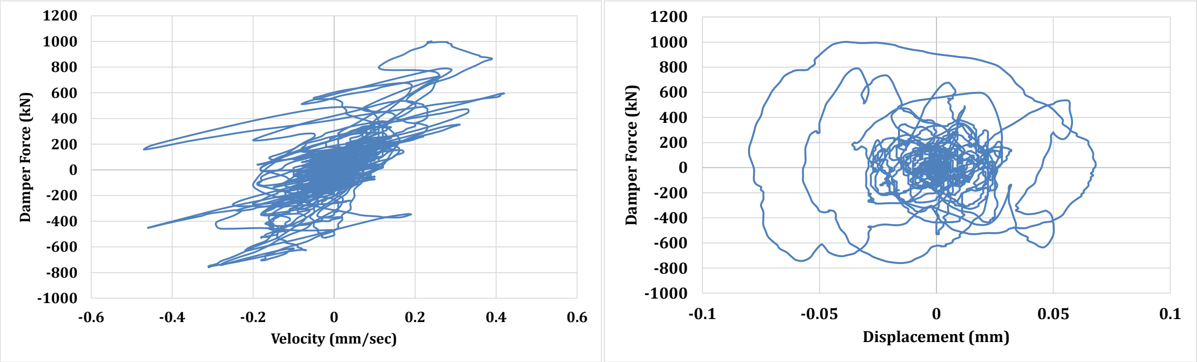

Figure 7(a): Hysteresis loop of Force v/s Displacement and Force v/s Velocity under Imperial Valley Earthquake for Model-3

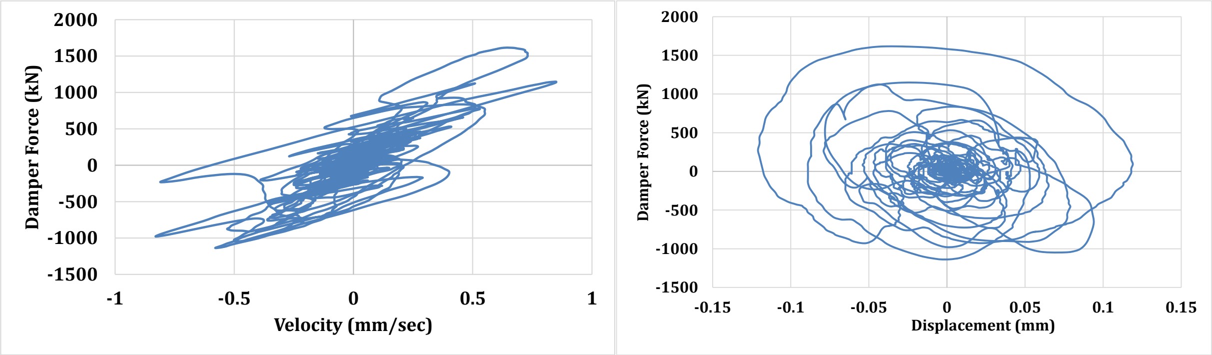

Figure 7(b): Hysteresis loop of Force v/s Displacement and Force v/s Velocity under Imperial Valley Earthquake for Model-4

C. Base Shear

Figure 8 and Table-IV show base shear by different analyses for all the systems. Minimum base shear is found for model 3 in all the analyses. A significant reduction in base shear is observed for models having LVDs. In comparison to Model 1, average percentage reduction in base shear for model 3, and model 4 is found to be 54.98%, and 50.13%, respectively, for the time history analysis.

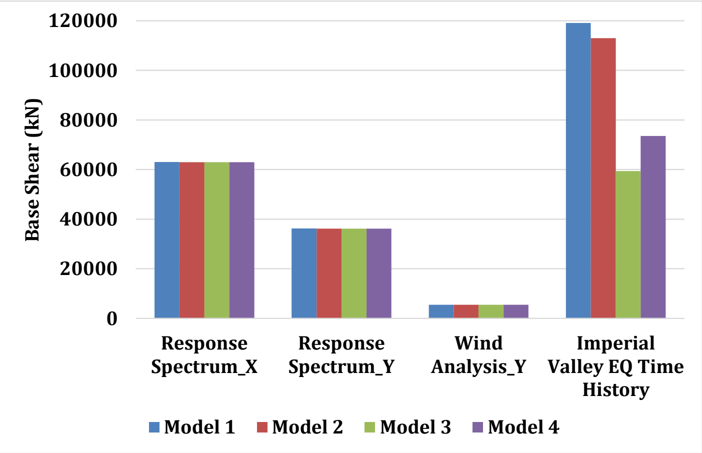

Figure 8: Comparison of Base Shear

Table IV: Base Shear of different Earthquake Time Histories

Model	**Base Shear (kN)**			
	Response Spectrum_X	**Response Spectrum_Y**	**Wind Analysis**	**Imperial Valley EQ Time History**
Model 1	63061.42	36237.24	5494.33	119105.79
Model 2	63007.76	36206.40	5494.33	112984.00
Model 3	63007.76	36206.40	5494.33	59408.36
Model 4	63007.76	36206.40	5494.33	73583.01

D. Max Storey Displacement

Figure 9 show a comparison of maximum storey displacement by serviceability load combination. Minimum storey displacement is found for Model 3, which is a SW system with LVDs at all storey.

Figure 10 and 11 show the maximum storey displacement under Imperial Valley EQ Time History. Compared to Model 1, a maximum reduction in storey displacement is observed for model 3. i.e., 49.23%.

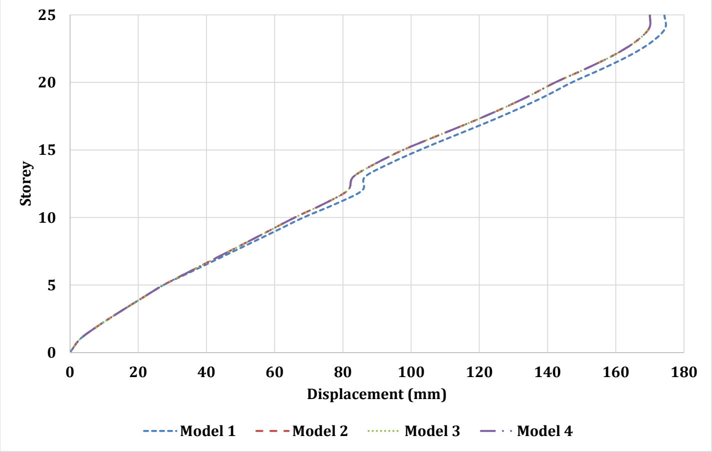

Figure 9: Maximum Displacement

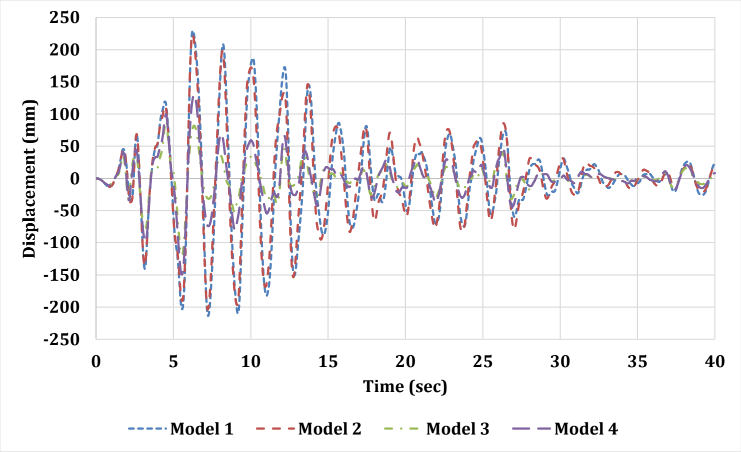

Figure 10: Displacement Response for different systems under Imperial Valley Earthquake Time History

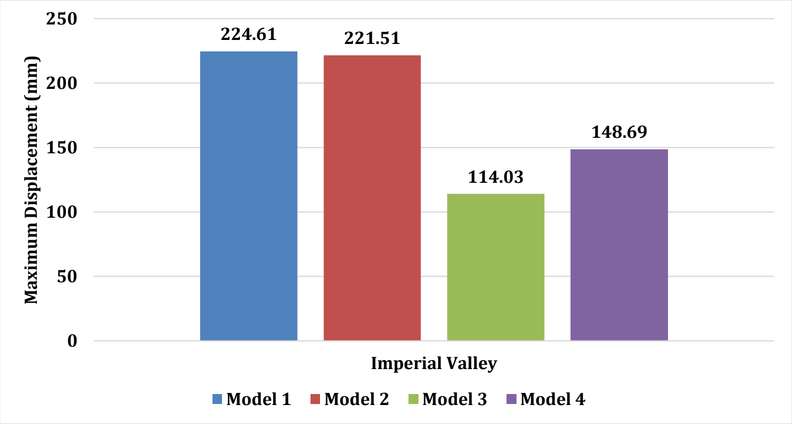

Figure 11: Max Storey Displacement based on Earthquake Time History analysis

E. Drift Ratio

Figure 12 presents the drift ratio for serviceability load combination. Minimum drift ratio is observed for model 4 in serviceability load combination.

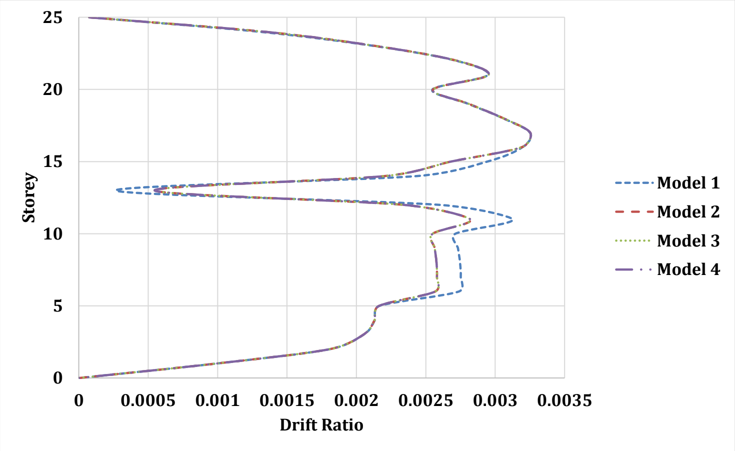

Figure 12: Drift Ratio based on Serviceability load combination

F. Time Period

Figure 13 shows a comparison of the time for different systems. Model 4 is a stiffer system compared to other systems. As LVDs are not providing additional stiffness to the structure, no variation in the time period is observed.

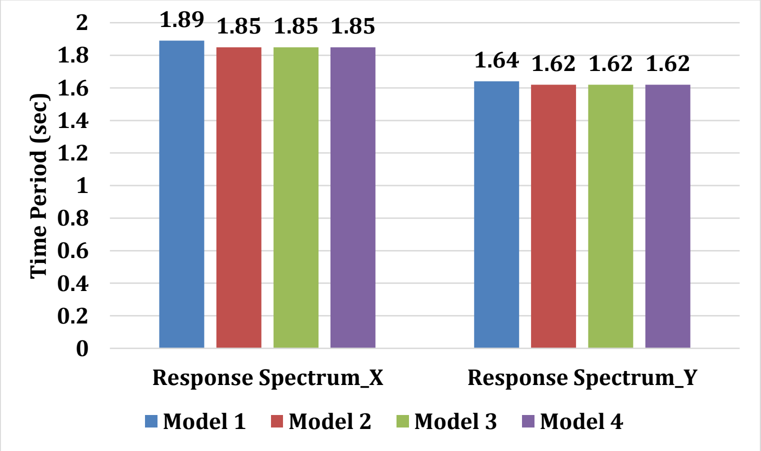

Figure 13: Comparison of Time Period

G. Acceleration

Figure 14 shows the acceleration response at the top storey of different systems under Imperial Valley Earthquake Time History. Figure 15 shows the comparison of max acceleration for Imperial Valley Earthquake time history analysis at the top storey. Model 1, SW system is a stiffer systems as they have high acceleration values compared to other systems. It is noted that acceleration for systems with LVD is less than in other systems.

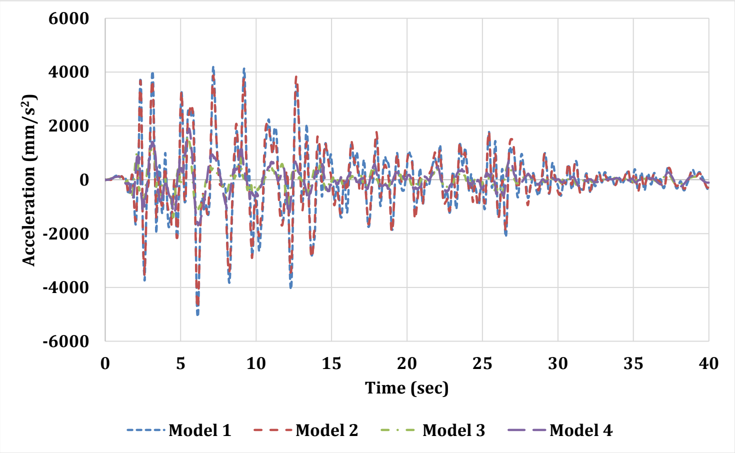

Figure 14: Acceleration Response for different systems under Imperial Valley EQ Time History

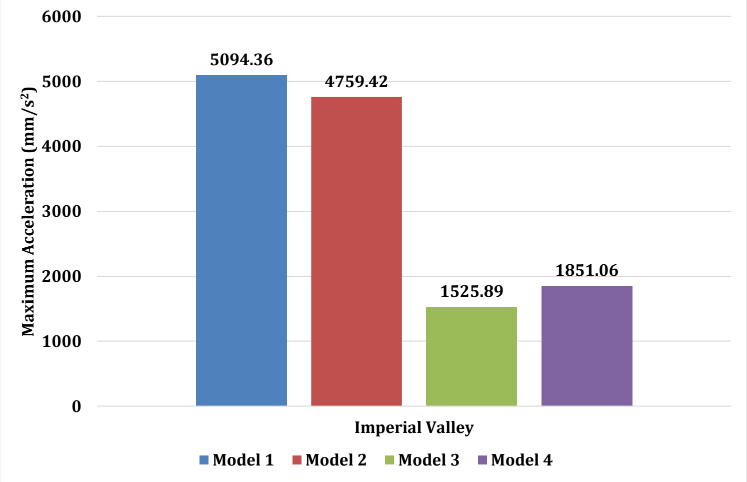

Fig. 15 Comparison of Maximum Acceleration due to Imperial Valley EQ Time History

IV.CONCLUSION

In this research work, the response of shear wall and linear viscous damper are studied for earthquake load and wind load for connected tall building. Based on the study carried out, following major conclusions can be drawn.

- It is necessary to provide lateral load resisting system in connected tall building to make them perform better in earthquake and wind forces.
- The building's displacement and acceleration response can be capably controlled by providing LVDs.
- Minimum displacement is observed for Model 3 (i.e.) conventional frame system SW with LVD at all storey installed with dampers. The reduction in max storey displacement at top storey is 50.95% for Model 3 compared to Model 1 in time history analysis.
- Minimum acceleration is observed for Model 3 (i.e.) conventional frame system with SW and LVD at all storey. The reduction in acceleration at the top storey is 70% for Model 3 compared to Model 1 in time history analysis.
- Minimum base shear is observed for Model 3 (i.e.) conventional frame system having SW and LVD at all storey for both, response spectrum and time history analysis. The base shear reduction is 50.12% for Model 3 compared to Model 1 in time history analysis.

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