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A Research on Behavior of Connected Tall Buildings with Lateral Load Resisting Systems and Dampers Under Seismic Load

Vishvesh Jayswal[1], Aakash Suthar[2],

[1]*M. Tech Student, L.J. University, Ahmedabad*
[2]*Aakash Suthar, Head of Department, Structural Engineering Department, L.J. University, Ahmedabad, India.*

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Abstract: -In addition to issues with land acquisition, tall buildings are becoming increasingly common. In general, a linked tall building is a skyscraper or high-rise that is physically joined to one or more neighboring structures by bridges or other structural components. It provides customers with horizontal connection in addition to improving structural performance under lateral stresses. Various lateral load resisting systems and vibration control systems must be implemented in order to regulate the lateral displacement of a tall building. This study compares linear viscous dampers and shear wall systems in tall buildings. The study examines models of interconnected, (25-story) tall structures with varying skybridge and damper locations. Reduction of several reactions such as displacement, acceleration, storey drift, etc. has been proven to be more successful in the constructions associated with Sky Bridge and dampers.

Key Words*: (*Connected Tall Building), (Shear Wall), (Bracing), (Damper), (Seismic load) & (wind load).

1. INTRODUCTION: -

A building is classified as a "tall building" by (IS:6700: 2017) if its height is more than 50 meters but less than or equal to 250 meters. There is no set standard for what constitutes a "tall" structure. "Super Tall Building" refers to a structure taller than 250 meters. [3] Towering structures known as skyscrapers are usually found in crowded urban areas with expensive land. In the construction industry, lateral load-resisting devices are utilized to withstand lateral forces including wind and seismic forces. Shear wall structures, moment frames, braced frames, framed tube structures, diagrid structures, and so on are a few examples of these systems. These buildings are additionally protected from the effects of oscillations by vibration control devices, such as base isolation systems and dampers.

A shear wall structure is a kind of building construction where walls are used to resist wind and seismic stresses and to offer lateral stability. These walls, which are frequently seen in both tall and low-rise structures, are in charge of supporting columns and vertical loads.[1]

The reactivity of structures to dynamic loads, such wind and earthquakes, is lessened by the employment of structural control systems. Structural control systems can be of numerous sorts, such as hybrid, semi-active, active, and passive. In this instance, a linear viscous damper a passive control system is employed. The Viscous Damper diagram and mathematical model are displayed in (Figures 1(a) and 1(b). Passive vibration control systems, or LVDs, use the motion of the structure to generate reactive forces. Velocity-dependent linear viscous dampers provide more dampening to the structure without adding more rigidity. They function according to the idea that fluid passing through an opening creates the force needed to stop a building from moving during a seismic event. The damper is composed of a cylinder that is filled with a viscous fluid, such silicone or oil, and is attached to the structure by a piston rod that passes through a chamber that is filled with fluid. Damper force is produced by the differential pressure that is created across the piston head. The relative velocity between a damper's ends determines the force inside the viscous damper.[11]

The relative velocity between a damper's ends determines the force inside the viscous damper.
The formula for it is: -

$$\underline{Fdi=Cdi(u_{di})^{a}}.$$

Where α = damper exponent, Fdi = damping force of the it damper, and udi = relative velocity between the two ends of the damper, which is what has to be taken into account. The damper exhibits linear viscous damping behavior when α=1, and non-linear viscous damping behavior when α is less than unity.[1]

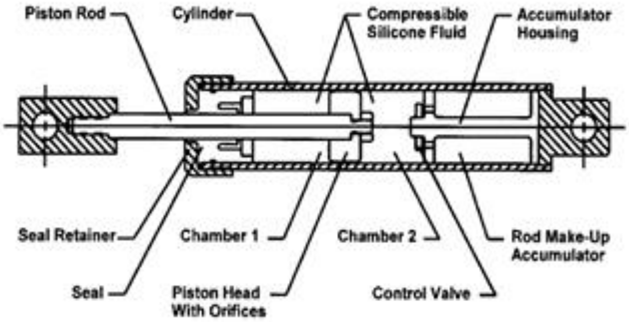

Figure 1(a): Schematic diagram of fluid viscous damper [1]

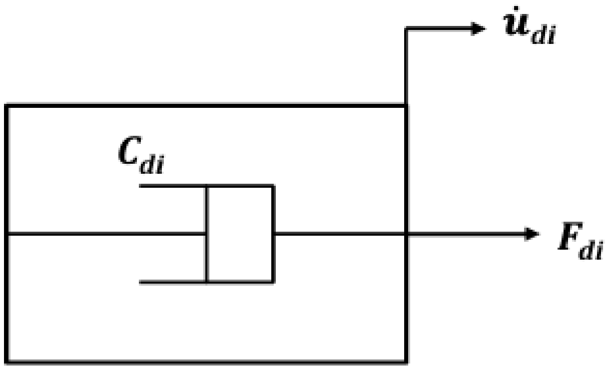

Figure 1(b): Mathematical model of fluid viscous damper [1]

The ideal location of Connecting Beams (CB) between twin tower structures susceptible to lateral loads—such as wind and earthquakes—has been researched by Penumatcha et al. (2020). According to the analysis, the "lateral sway" at the top of the structure against wind was only permitted if all floors were connected with CB, and the "story drift" also complied with the code's criteria on earthquake resistance. **[13]** The seismic response of two nearby fifteen- and ten-story buildings linked by a viscous damper was investigated by Khan et al. (2020). further compares the building's reactions when under- and critically-damped dampers are used. According to research, critically damped dampers perform better than under damped dampers.

[7] A simplified 3-DOF model of a twin-tower building connected by a sky-bridge was created by Huang-sheng et al. (2013). It was demonstrated that two multi-story buildings connected by a sky-bridge equipped with dampers might use the ideal connection parameters that were obtained from the reduced 3-DOF model.**[2]** Tubaldi (2015) examined the characteristics of the dynamic behavior of two nearby structures that range in height and are joined by viscous/viscoelastic dampers that are placed at the top of the building that is the shortest. It was demonstrated that the damper properties' early design ensured the best possible control against seismic loadings. **[15]** Yang and Lam (2013) investigated the bidirectional excitations and dynamic responses of two buildings linked by viscoelastic dampers. Building eccentricity have an impact on the connecting dampers' efficacy for asymmetric structures. The linking viscoelastic dampers have the potential to significantly lower the maximum displacement and the maximum base shear responses for nearby symmetric buildings. **[16]** Under base acceleration, Patel and Jangid (2013) are examining the dynamic behavior of two symmetrically similar nearby structures linked by viscous dampers. The dynamic reactions of nearby similar structures were shown to be lessened by the viscous dampers during both actual and harmonic earthquake stimulation. Furthermore, a connected damped system can employ the optimal damping coefficient of a damper that was determined for a linked undamped system. **[12]** Shanghai International Design Center's (SHIDC) structural characteristics during earthquakes were assessed by Zhou et al. (2016). Studies have demonstrated that the failure sequence of the structural elements was plausible and that the maximum interstory drift may meet the restrictions stipulated in the Chinese code. The natural periods found in numerical analysis and shaking table tests showed little differences. **[17]** An assessment of the coupling-control impact of a skybridge for nearby tall buildings was conducted by Lee et al. (2010). Based on numerical studies, it was demonstrated that the sky-bridge may reduce the dynamic reactions of the paired tall structures by efficiently increasing their damping ratio. It was also discovered that adding more viscous dampers might greatly enhance the coupling-control effect of the sky-bridge. **[9]** Mahmoud et al. (2015) investigated the seismic behavior of the Petronas Twin Towers in Malaysia, which are two extremely tall structures connected by a sky bridge. The findings show that the total dynamic response of the connected towers in both longitudinal and transverse directions is not significantly impacted by the position of the linking bridge. While the comparable storeys in the longitudinal direction (x-direction) were insensitive to the placement of the connecting bridge, the inter-story drift in the transverse direction (y-direction) demonstrated sensitivity to changes in bridge location.

[10] In order to lessen earthquake-induced structural reactions, Kim et al. (2005) looked at the impact of placing viscoelastic dampers (VEDs) in locations such seismic joints or building–sky-bridge connections. Reduction of earthquake-induced reactions can be achieved by using VEDs in seismic joints or sky-bridges. The ideal dimensions of VED resulted in a decrease in both the absolute and relative displacements of linked structures, along with a reduction in hysteretic energy and plastic deformation. **[8]**

This work examines linear viscous dampers and the shear wall system. Moreover, the building's outside has a shear wall system installed. Additionally, a shear wall system with dampers at the outside periphery was studied.

These are the main goals, which are based on the literature research that was done: -

- To evaluate the effectiveness of linked tall structures equipped with shear walls.
- To investigate how linked tall structures with passive viscous dampers operate.
- To investigate several factors for the linked structures, such as foundation shear, displacement, acceleration, and story drift under consideration.
- To research how linked buildings behave and function at different Sky Bridge sites.

2.NUMERICAL STUDY: -

Two (25-story) buildings with (35×35) m plan dimensions have been chosen for the investigation. The Sky Bridge is located between the (12th &13th) floor and the (24th &25th) level. The distance between two buildings is measured in meters. Four distinct systems with shear walls serving as lateral load-resisting systems for dead load, live load, earthquake load, and wind load are analyzed and designed using the ETABS program. Analysis of wind, earthquake time history, response spectrum, and static earthquakes are all carried out. The wind load is computed using the Gust factor method. Table I lists the building's attributes as well as loading information. To simulate beams, hot-rolled I-sections are utilized. The model for columns and bracings looks like pieces of a built-up box. All model section details are provided in Table III. The Sky Bridge's beam and column sizes for Model-1 are (B-350X55). For Models 2-4, storeys (12&13) have beam and column sizes of (B-800X65), whereas storeys (24 & 25) in the Sky bridge have beam and column sizes of (B-550X55) & (B-500X55), respectively. The rest come in sizes (B-350X55). The sectional information is predicated on a rigorous design review.

Following are the cases considered in the present study: -

(A) standard frame structure with a shear wall (SW) The SW wall element is modeled as being shell-thin. (Figure-2) displays the plan, elevation, and three-dimensional perspective of the traditional model with SW.

(B) Standard frame system exclusively in Sky Bridge with Linear Viscous Damper (LVD) and SW As seen in (Figure-3), only at Sky Bridge are linear viscous dampers available. Link characteristics are used in the modeling of LVDs.

(C) Standard frame system with LVD and SW at every story as seen in (Figure-4), LVDs are available at Sky Bridge as well as at the outer periphery.

(D) Standard frame structure with LVD and SW at different story levels as seen in (Figure-5), LVDs are available at the Sky Bridge as well as at alternative storeys around the outer periphery.

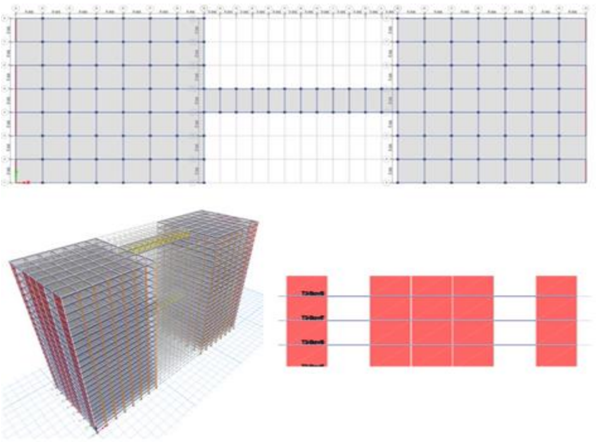

Figure 2: Plan and 3D view of Model-1

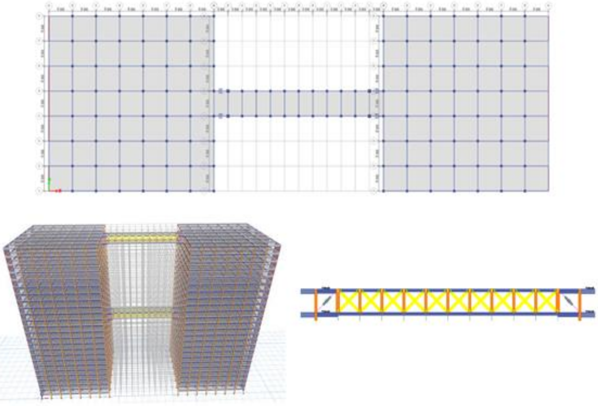

Figure 3: Plan and 3D view of Model-2

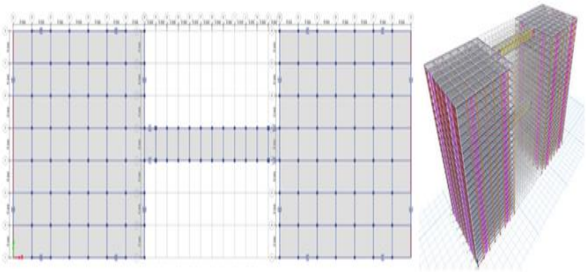

Figure 4: Plan and 3D view of Model-3

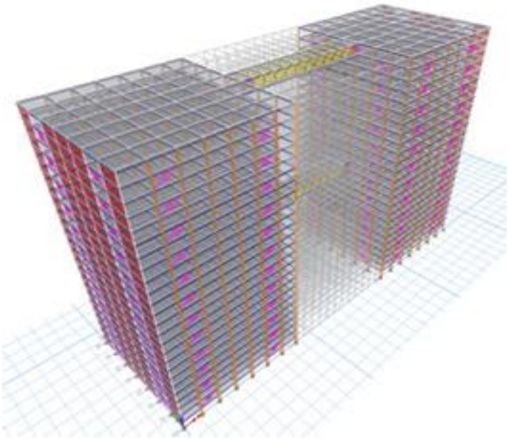

Figure 5: Plan and 3D view of Model-4

Table I: Properties and data: -

Parameters	Value
Number of stories	25
Height of each storey	3 m
Total height of building	75 m
Plan dimension (one building)	35 x 35 m
Grid dimension	5 x 5 m
Distance between two building	36 m

Slenderness ratio (Ht/Bt)	2.14
Plan aspect ratio (Lt/Bt)	1
Grade of steel for steel section	Fe 250
Concrete grade (Slab)	M-25
Slab (Thickness)	125 mm
Density of brick masonry	20 kN/m³
Seismic Zone	V
Importance Factor	1.2
Response Reduction Factor	5
Wind Speed	55 m/s
Floor finish load	1.5 kN/m²
Wall load (230 mm thick)	13.8 kN/m
Wall load (115 mm thick)	6.9 kN/m
Live load	2.5 kN/m²

Table II: Details of Earthquake considered in the study: -

Earthquake	Duration in seconds	PGA (g)
Imperial Valley,1940	40	0.312

Table III (1): Section Details: -

Model	Element	Number of Storey	
		16-20	21-25
Model-(1)	Beam	ISWB500 +PLATE25	ISWB600-1
	Beam co-SW	ISWB550 2+(PE)40	ISWB450 +(PE)40
	Column	B-400x55	B-350X65
	Bracing (SB)	B-350X55	
Model-(2)	Beam	ISWB500+ (PE)25	ISWB600-1
	Beam co-SW	ISWB550+ (PE)20	ISWB450+ (PE)40
	Column	B-400X55	B-350X45
	Bracing (SB)	B-350X55	
Model-(3)	Beam	ISWB500+ (PE)25	ISWB600-1
	Beam co-SW	ISWB550+ (PE)20	ISWB450+ (PE)40
	Column	B-400X55	B-350X45
	Bracing (SB)	B-350X55	
Model-(4)	Beam	ISWB500+ (PE)25	ISWB600-1
	Beam co-SW	ISWB550+ (PE)20	ISWB450+ (PE)40
	Column	B-400X55	B-350X45
	Bracing (SB)	B-350X55	

Table III (2): Section Details: -

Model	Element	Number of storeys		
		1- 5	6-10	11-15
Model-(1)	Beam	ISWB550 +PLATE40	ISWB550 +PLATE40	ISWB550 +PLATE40
	Beam co-SW	ISWB600-2+(PE)40	ISWB600-2+(PE)40	ISWB600-2+(PE)40
	Column	B-600x75	B-450X65	B-400X55
	Bracing (SB)	B-350X55		
Model-(2)	Beam	ISWB550+ (PE)40	ISWB550+ (PE)40	ISWB550+ (PE)40
	Beam co-SW	ISWB600-2+(PE)40	ISWB600-2+(PE)40	ISWB600-2+(PE)40
	Column	B-600X75	B-500X55	B-450X55
	Bracing (SB)	B-350X55		
Model-(3)	Beam	ISWB550+ (PE)40	ISWB550+ (PE)40	ISWB550+ (PE)40
	Beam co-SW	ISWB600-2+(PE)40	2+(PE)40	ISWB600-2+(PE)40
	Column	B-600X75	B-500X55	B-450X55
	Bracing (SB)	B-350X55		
Model-(4)	Beam	ISWB550+ (PE)40	ISWB550+ (PE)40	ISWB550+ (PE)40
	Beam co-SW	ISWB600-2+(PE)40	ISWB600-2+(PE)40	ISWB600-2+(PE)40
	Column	B-600X75	B-500X55	B-450X55
	Bracing (SB)	B-350X55		

3.RESULTS & DISCUSSION: -

A. Effect of C_d: -

The damping coefficient's value is determined by optimizing it for almost constant acceleration and displacement. (Figures: -6(a)&6(b)) respectively illustrate the effect of Cd on the reaction characteristics of (Model 3 & Model 4) under the Imperial Valley Earthquake. The displacement and acceleration of the upper level are taken into account here. It has been noted that when the value of Cd rises, response parameters fall. Regarding (Models 3 & 4), the damping coefficient's optimal value is 200000 kNs/m.

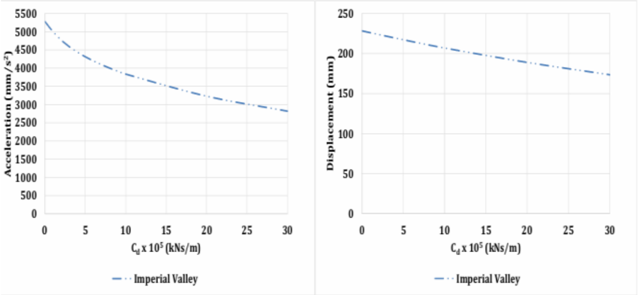

Figure 6(a): Effect Cd on various response parameters for Model-3

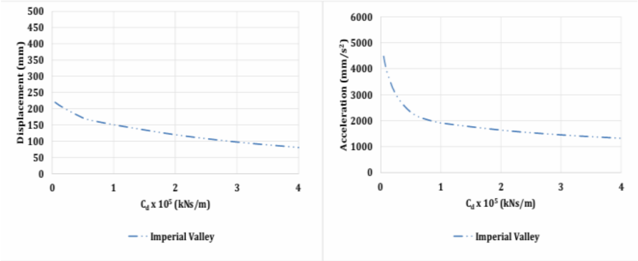

Figure 6(b): Effect Cd on various response parameters for Model-4

B. Hysteresis loop: -

Figures 7(a) and 7(b) depict the hysteresis loop for the damper at storey-25 in Models 3 and 4, respectively, under the conditions of the Imperial Valley Earthquake. It can be seen that energy is being lost from the damper force vs. displacement loop. The damper's characteristics are shown in the damper force vs. velocity hysteresis loop.

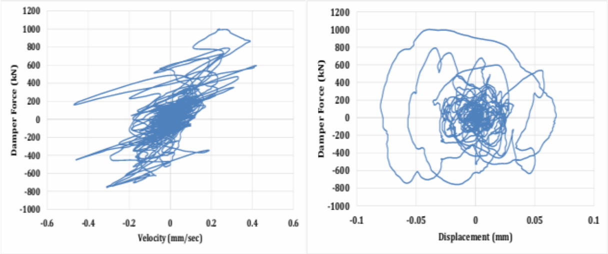

Figure 7(a): Hysteresis loop of Force v/s Displacement and Force v/s Velocity under Imperial Valley Earthquake for Model-3

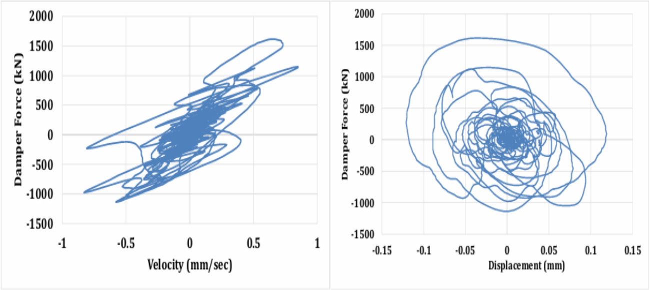

Figure 7(b): Hysteresis loop of Force v/s Displacement and Force v/s Velocity under Imperial Valley Earthquake for Model-4

C. Base Shear: -

Base shear for each system is shown by various investigations in Figure 8 and Table IV. For model 3, the minimum base shear is determined in each analysis. There is a notable decrease in base shear in the models using LVDs. Based on the time history study, the average percentage reduction in base shear for Models 3 and 4 is determined to be 54.98% and 50.13%, respectively, compared to Model 1.

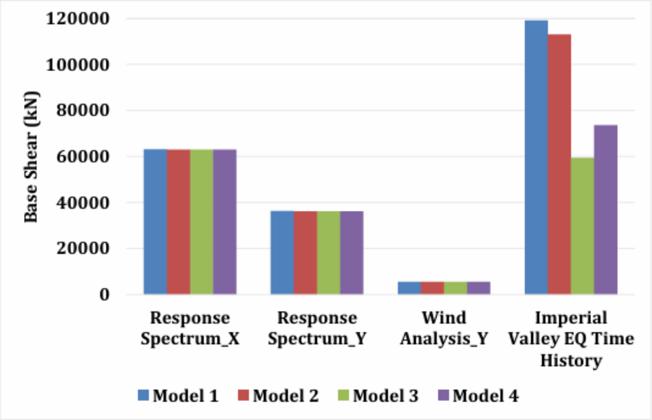

Figure 8: Comparison of Base Shear

Table IV: Base Shear of different Earthquake Time Histories: -

Mode l	Base Shear (kN)			
	RS-X	RS-X	Wind	Imperial(V)Time History EQ
Mode l-1	63062.42	36237.23	5494.34	119105.80
Mode l-1	63007.48	36206.39	5494.34	112984.01
Mode l-1	63007.48	36206.39	5494.34	59408.37
Mode l-1	63007.48	36206.39	5494.34	73583.02

D. Max Storey Displacement: -

A comparison of the maximum storey displacement by serviceability load combination is shown in Figure 9. A SW system with LVDs at every level, Model 3, has the lowest storey displacement. The maximum storey displacement under the Imperial Valley EQ Time History is displayed in (Figures 10 & 11). Model 3 has a greatest reduction in storey displacement, or 49.23%, when compared to Model 1.

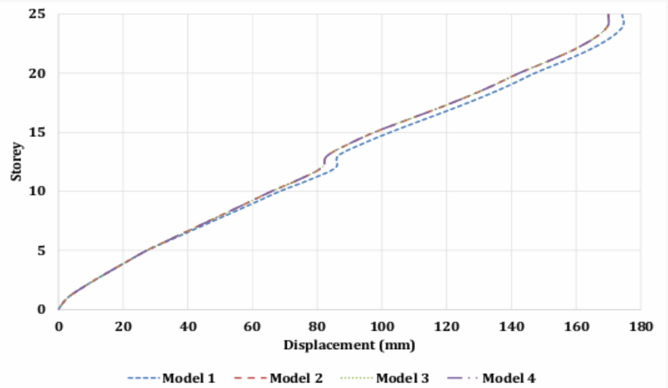

Figure 9: Maximum Displacement: -

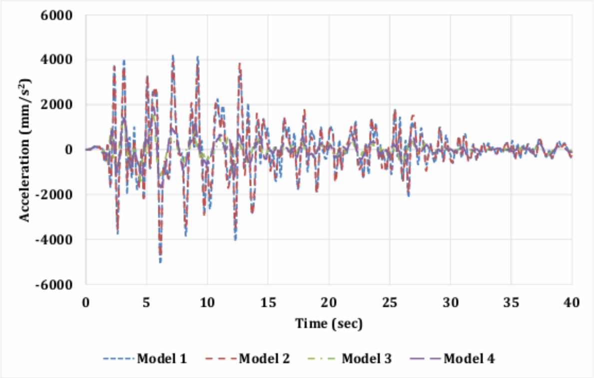

Figure 10: Displacement Response for different systems under Imperial Valley Earthquake Time History

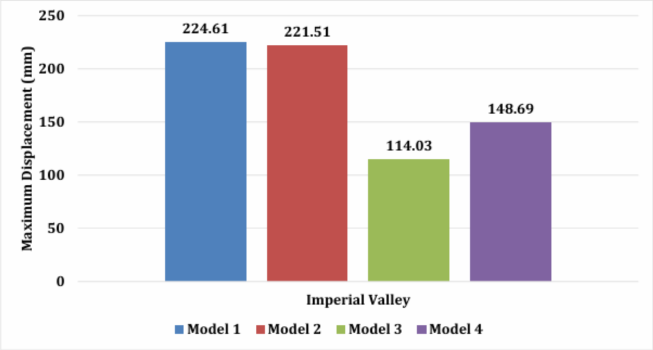

Figure 11: Max Storey Displacement based on Earthquake Time History analysis

E. Drift Ratio: -

The drift ratio for a combination of serviceability loads is shown in Figure 12. For model 4 in the serviceability load combination, the minimum drift ratio is noted.

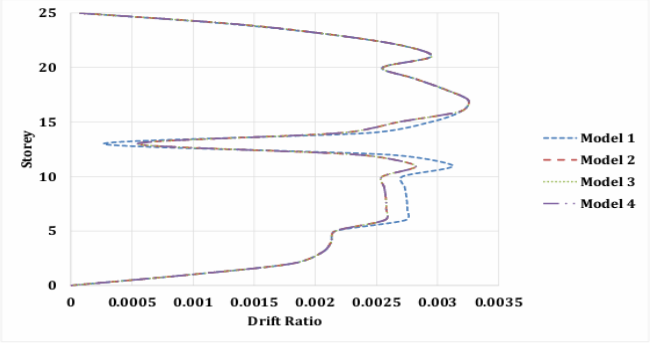

Figure 12: Drift Ratio based on Serviceability load combination

F. Time Period: -

A comparison of the times for various systems is shown in Figure 13. In comparison to previous systems, Model 4 is a stiffer system. Since LVDs don't provide the structure any more rigidity, there isn't a change in the time period.

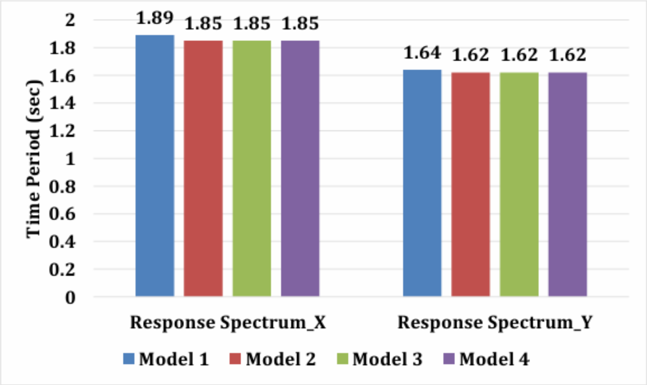

Figure 13: Comparison of Time Period

G. Acceleration: -

Figure 14 shows the acceleration response at the top level of different systems under the Imperial Valley Earthquake Time History. Figure 15 shows the top story comparison of the greatest acceleration for the time history analysis of the Imperial Valley Earthquake. The Model 1 SW system is stiffer than other systems because of its greater acceleration values. It has been noted that compared to other systems, LVD systems accelerate more slowly.

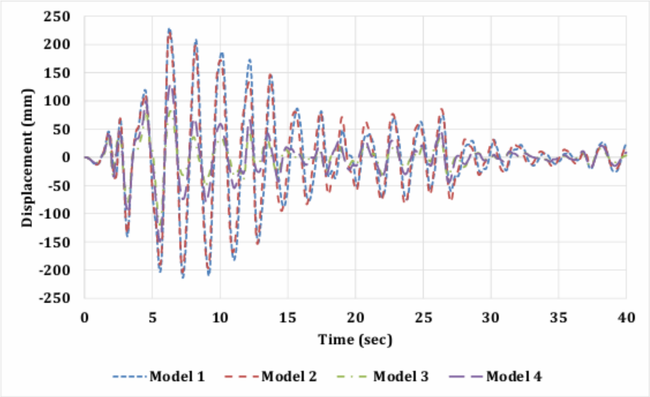

Figure 14: Acceleration Response for different systems under Imperial Valley EQ Time History

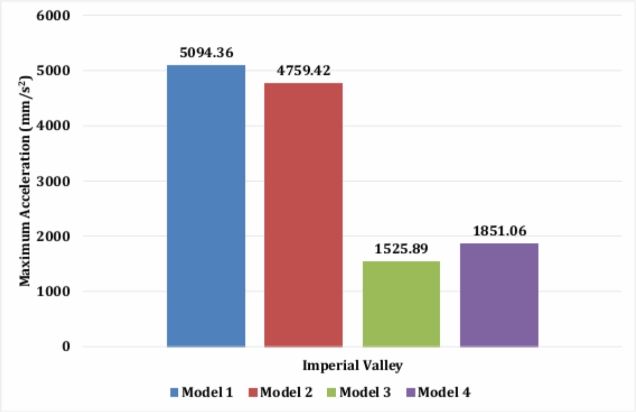

Figure. 15 Comparison of Maximum Acceleration due to Imperial Valley EQ Time History

4.CONCLUSION: -

This study examines how a linked tall building's shear wall and linear viscous damper respond to wind and seismic loads. The investigation conducted allows for the following key findings to be made.

- To improve their performance in the event of an earthquake or wind force, connected tall buildings must include lateral load resisting systems.
- Giving LVDs allows for competent control over the building's displacement and acceleration response.
- The Model 3 conventional frame system SW with LVD fitted at every story with dampers exhibits the minimum displacement. Time history study shows that for Model 3 compared to Model 1, the maximum storey displacement at the top storey is reduced by 50.95%.
- Model 3, or the traditional frame system with SW and LVD, exhibits the least acceleration over all storeys. According to time history study, Model 3's acceleration at the top story is 70% less than Model 1's.
- The Model 3 conventional frame system, which has both SW and LVD at every storey for response spectrum and time history study, exhibits the least amount of base shear. By comparing Model 3 to Model 1, the base shear reduction in time history analysis is 50.12%.

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