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

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Abstract: - *Tall constructions are becoming increasingly popular as a result of land acquisition issues. A linked tall building is a skyscraper or Highrise structure that is physically connected to one or more nearby buildings via bridges or other structural features. It improves structural performance under lateral stresses while simultaneously providing users with horizontal connection. To manage the lateral displacement of a tall building, various lateral load resisting systems and vibration control systems must be used. In this thesis, several construction models with Shear Wall systems, bracing systems, and Linear Viscous Dampers are compared. Models of 25-story linked tall structures with various locations of sky bridges and dampers are investigated. The buildings are examined using linear time history analysis, response spectrum analysis, and wind analysis, and the best approach for improved building performance is determined. It has been discovered that buildings coupled with Sky Bridge and dampers are more successful in lowering different reactions such as story shear, displacement, acceleration, and story drift.*
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Key Words*: *Connected Tall Building, Shear Wall, Bracing, Damper, Earthquake & wind load.

1. INTRODUCTION: -

Although no precise height is necessary for a building to be categorized as "tall," IS 16700: 2017 defines a "tall building" as one that is greater than 50 meters in height but less than or equal to 250 meters. A extremely tall skyscraper is one that stands higher than 250 meters. These constructions, known as skyscrapers, are generally found in densely populated urban areas with expensive and restricted land. Tall buildings are often designed with a large amount of floor space contained within a small footprint. Various uses, such as offices, apartments, hotels, or retail establishments, can be achieved by their construction. Usually, steel or concrete are used to make them. Sophisticated engineering and design go into the construction of tall structures to guarantee that they are stable, safe, and able to withstand wind and gravity. Notable skyscrapers across the world include the Empire State Building in New York City, Taipei 101 in Taiwan, the Burj Khalifa in Dubai, and the Shanghai Tower in China.

The COUNCIL ON TALL structures AND URBAN HABITAT (CTBUH) established international guidelines for recognizing and quantifying tall structures. As seen in Fig 1. According to CTBUH standards, tall structures 300 meters (984 feet) or higher are referred to as "supertalls," while those 600 meters (1,968 feet) or more are referred to as "megatalls."

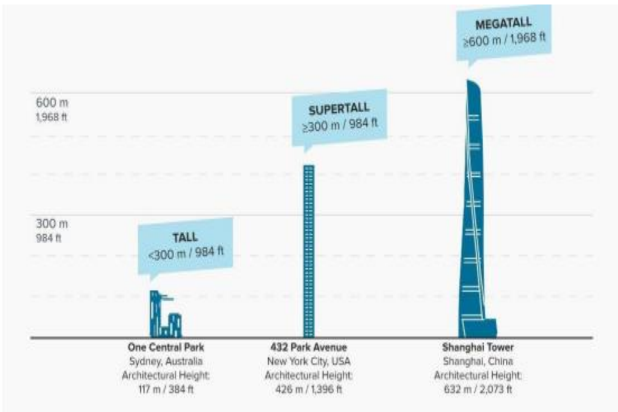

Fig 1: - Tall, Supertall and Mega tall Building [2]

1.1. CONNECTED SKYSCRAPER: - Connected tall structures improve a cityscape's architectural character and visual appeal in addition to their utilitarian advantages. They offer a distinctive skyline that is visually stunning as well as practical. The American Copper buildings in New York City, the Marina Bay Sands and Sky Habitat in Singapore, and the Petronas Towers in Kuala Lumpur, Malaysia, are a few well-known examples of linked tall structures. A skybridge may affect the structural characteristics of the linked structures in addition to its intended use. Nearby tall structures connected by a skybridge will exert control pressures on one another via the skybridge in the case of an earthquake or wind disturbance. A skybridge may affect the structural characteristics of the connected structures in addition to its intended use. Nearby tall structures connected by a skybridge will exert control pressures on one another via the skybridge in the case of an earthquake or wind disturbance.

Fig 2: -Connected Buildings[4]

1.2. FLUID VISCOUS DAMPER: -Using the motion of the structure to produce reactive forces, a Fluid Viscous Damper is a passive vibration control method. Velocity dependency exists in fluid viscous dampers. They function by providing the force necessary to stop structural motion during a seismic event using the idea of fluid passing through an aperture. Without increasing rigidity, they provide the structure more damping. The structure consists of a cylindrical cylinder with a central piston that travels through a chamber filled with fluid. The pressure difference across the piston head generates the damper force. For optimum performance and stability, a silicone-based fluid is typically utilized. One common fluid that guarantees correct operation and stability is silicon-based fluid.

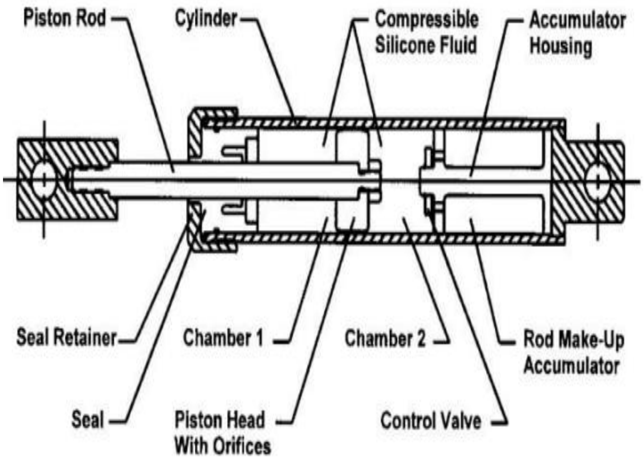

Fig 3: - Schematic model of fluid viscous damper [6]

1.3. OBJECTIVE: -

1. To investigate how various lateral load-resisting systems—such as shear walls and bracing—perform in linked tall structures, both symmetric and asymmetric.
2. To examine the operation of symmetric and asymmetric linked tall structures using a fluid viscous damper model that is represented by a passive viscous schematic.to investigate several factors for the linked structures under consideration, such as natural period, base shear, displacement, acceleration, and storey drift.
3. To research the actions and functionality of linked buildings at different Sky Bridge sites.

2. LITERATURE REVIEW: -

[1] Kim, J., Ryu, J., & Chung, L. (2006). Seismic performance of structures connected by viscoelastic dampers. Engineering Structures, 28(2), 183-195.[1]

__INTRODUCTION__: - Because they maximize relative inter-story drift and velocity, viscoelastic dampers, or VEDs, are often located in a building's inter stories. However, because of the interference that VEDs linked to diagonal or chevron bracing generate, which impedes internal visibility and hinders spatial design, architects and building owners frequently protest to such placements. In the event that this strategy is sufficiently successful, these constraints may be overcome by putting VEDs in skybridge links or across seismic joints. By doing this, it would also be impossible for nearby structures to pound against one another.

OBSERVATION TABLE: -

Table 2.1 Maximum Displacement (shear area) [1]

Viscoelastic Damper		
Story	Maximum Displacement (cm^2)	Shear area (cm^2)
VED (Top story)	(4-16.8) (cm^2)	(4-16.8) (cm^2)
VED (All Story)	(3.9-16.5) (cm^2)	(3.9-16.5) (cm^2)

__CONCLUSION__: - In order to reduce structural reactions brought on by earthquakes, an analysis of the effects of installing viscoelastic dampers at seismic joints and linkages between buildings and sky-bridges has been conducted. The parametric study first concentrated on systems with one degree of freedom that were linked by VEDs and that applied both white noise and ground seismic excitations.

[2] Bharti, S. D., Dumne, S. M., & Shrimali, M. K. (2010). Seismic response analysis of adjacent buildings connected with MR dampers. Engineering Structures, 2122- 2133.[2]

__INTRODUCTION__; -In light of this, installing and maintaining these sensors comes with extra expenses as compared to passive control. Researchers have looked closely at magnetorheological (MR) dampers among semiactive control systems because of its possible use in mitigating seismic reaction. One benefit of using MR dampers is that they are low power consumption and can continue to work as passive devices even if the control algorithm fails. To forecast the dynamic behavior of MR dampers, Spencer et al. have created a model based on the Bouc-Wen hysteresis model.

CONCLUSION: - Previous research have looked at the efficacy of magnetorheological (MR) dampers for reducing seismic response in nearby multistory structures under a linked building control system. The use of passive-off, passive-on, and semi-active control techniques has been investigated in these works. Two reinforced concrete structures, one with 20 levels and the other with 10 floors, were the subject of the study.

[3] Zhu, H. P., Ge, D. D., & Huang, X. (2011). Optimum connecting dampers to reduce the seismic responses of parallel structures. Journal of Sound and Vibration, 1931-1949.[3]

INTRODUCTION; - The ideal connecting damper parameters have always been determined by meticulous parametric analysis in all of the published theoretical studies pertaining to the coupling control technique of 2-mdof neighboring structures. During the preliminary design phase, engineers will find it convenient to pick acceptable damper parameters if the necessary connecting damper parameters can be obtained using generic expressions.

OBSERVATION TABLE: -

Table 3.1 Percentage reduction of (RMS) of seismic response in double [3]

Root Mean Square Of Seismic Response			
Top Floor Displacement	Top Floor Velocity	Top Floor acceleration	Base shear force
11% (11%)	20% (20%)	27% (27%)	26% (26%)
35% (36%)	36% (38%)	38% (38%)	33% (32%)
39% (39%)	42% (43%)	42% (43%)	32% (31%)

CONCLUSION: - Through the use of theoretical analysis, we examined the factors related to the connection of dampers between two neighboring structures and a twin-tower structure with a big podium. The Kelvin model was used to simulate the connecting viscos-elastic damper (VED), and the Maxwell model was used to simulate the connecting viscous fluid damper (VFD).

[4] Lee, D. G., Kim, H. S., & Ko, H. (2012). Evaluation of coupling-control effect of a sky-bridge for adjacent tall buildings. Structural Design of Tall and Special Buildings, 21(5), 311-328.[4]

INTRODUCTION; - Few significant studies have been done on the coupling-control mechanism using a sky-bridge, despite the fact that many have been done on the application of various control techniques, such as passive, active, or semi-active control, in the context of linked building control. Therefore, this paper's goal is to offer research that explores this uncharted territory.

[A] **[B]**

Fig. 4: - Bearings used in this study: (a) lead rubber bearing; (b) linear motion bearing [4]

CONCLUSION: - An assessment of a skybridge's coupling-control impact on nearby tall structures has been completed. A sky-bridge situated at the 34th story connected two buildings, one having 49 floors and the other 42 stories. With the use of wind load data from wind tunnel experiments and seismic excitations, a boundary nonlinear time history analysis was carried out.

[5] Patel, C., & Jangid, R. (2014). Dynamic response of identical adjacent structures connected by viscous damper. Structural Control and Health Monitoring, 21(2), 205-224.[5]

INTRODUCTION; - The main goal of this study is to find out how well a viscous damper works to regulate the dynamic response of identical connected structures that are next to one another. This study includes stationary white-noise random stimulation in addition to harmonic excitation. The research seeks to complete a number of particular goals in order to reach this purpose. Its initial goal is to ascertain the dynamic reaction of nearby buildings with two degrees of freedom that are coupled to viscous dampers.

CONCLUSION: - Analysis of the dynamic behaviour of two similar, symmetrical, neighbouring structures was part of the inquiry. Base acceleration acts on these structures, which are coupled via viscous dampers.

OBSERVATION TABLE: -

Table 5.1 Seismic Responses of the two adjacent structures connected with Viscous Damper [5]

Observed that percentage responses reduction				
Earthquake	Top floor displacement (m)		Top floor acceleration(m/s)	
	Unconnected	connected	Unconnected	connected
Imperial Valley	0.189	0.088	8.409	4.147
Kobe	0.433	0.332	19.557	14.747
Northridge	0.260	0.180	12.407	8.512
Loma Prieta	0.328	0.241	13.254	10.746

[6] Huang-sheng, S., Mo-han, L., & Hong-ping, Z. (2014). Connecting parameters optimization on unsymmetrical twin-tower structure linked by sky-bridge. Journal of Central South University, 21(6), 2460–2468.[6]

INTRODUCTION; - Kim and associates carried out research on the ideal connection parameters—ignoring the sky-bridge's mass—between towers and skyscrapers. The mega-structure reduces to a group of nearby structures linked by seismic dampers in the case when the mass of the sky-bridge is deemed tiny and inconsequential. Viscoelastic dampers (VEDs) were used to link nearby buildings, and Zhang and Xu investigated the seismic response and dynamic properties of these structures.

OBSERVATION GRAPHS: -

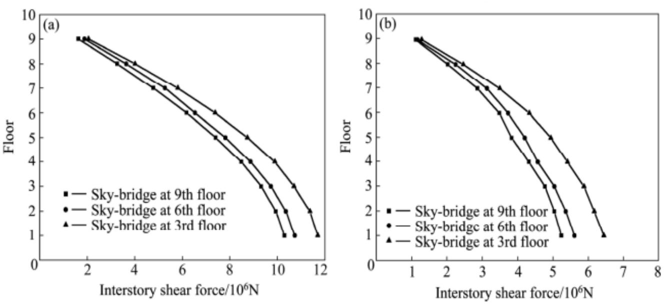

Fig 5: - Inter story shear force distribution of towers excited by E1 Centro wave: P-tower; A-tower [6]

CONCLUSION: - This study used a scaled-down model of a twin-tower construction connected by a skybridge. The system was shown as a single-degree-of-freedom (SDOF) system, and the Voigt model was used to characterize the dampers. A number of characteristics were acquired under the assumption that the earthquake stimulation was white noise, including frequency response functions, displacement power spectral density (PSD) functions, and time-averaged total vibration energy.

[7] Khan, S., Kumar, C. M., & Shwetha, K. (2020). Analytical study on the seismic behaviour of two adjacent buildings connected by viscous dampers. AIP ConferenceProceedings. Bengaluru.[7]

INTRODUCTION; - In this research, we look at two nearby buildings one with 10 stories and the other with fifteen. The purpose of installing dampers between these structures is to lessen their structural reaction to seismic activity. Numerous studies have shown that linking buildings with various fundamental frequencies via dampers significantly reduces the seismic reactions that each structure experiences. Furthermore, it has been shown that a smaller number of strategically placed dampers can still greatly lessen the earthquake reaction, negating the need for dampers to be placed at each floor. Through the use of dampers, the effects of movement, vibration, and friction caused by outside forces on the structure may be lessened.

OBSERVATION TABLE: -

Table 7.1 Comparison Of maximum torsion 10^{-3}Rad

Comparison Of maximum torsion				
Earthquake	Left building		Right building	
	Accidental Eccentricities	Connecting Dampers	Accidental Eccentricities	Connecting Dampers
EL-Centro	6.69	5.90	7.56	4.89
Taft	5.57	4.11	8.76	5.84
Michoacán	6.12	5.99	6.20	6.22
Chichi	7.40	8.04	10.28	8.48

CONCLUSION: - My research focuses on the seismic reaction of two nearby buildings that are connected by a viscous damper. The structures are ten stories and fifteen stories tall, respectively. Furthermore, I used critically damped and underdamped dampers to compare how these structures responded. According to the IS code, the design was completed.

[8] Penumatcha, K. R., Vipparthy, R., & Yadav, A. (2020). A Study on effect of Connecting Beams in a Twin Tower Structure. Journal of The Institution of Engineers (India): Series A, 101(4), 847–856.[8]

INTRODUCTION; - To satisfy the needs of the urban population, emerging countries are progressively moving toward the construction of towering structures. The idea that the developed areas, which presently include low-rise buildings, should be replaced with taller structures that better meet the community's changing demands would be considered bold. By adopting eco-friendly technology and adding modern conveniences, this may be accomplished. The notion of keeping a space between many towers has also emerged from the requirement for sufficient ventilation on all sides of the structures. Meeting serviceability requirements, including lateral sway and storey drift, is the main goal of these buildings, especially when it comes to wind and seismic activity.

CONCLUSION: - It has been extensively researched where to place Connecting Beams (CB) between twin tower constructions in the event of lateral stresses, particularly wind and earthquake. Four residential units were examined in the research; each unit was an eighteen-story reinforced concrete building with plan dimensions of 20 by 40 meters and a height of 54 meters. The IS Code was followed when designing the project.

[9] Avinash, A. R., Padigela, A., Karthik, B., & Kamath, K. (2016). A Study on Seismic Performance of Adjacent Structures Connected with Fluid Viscous Dampers. International Journal of Advances in Mechanical and Civil Engineering, 21-25[9]

INTRODUCTION; - Structures that are located near to one another are more vulnerable to earthquake damage. When two structures have significantly different fundamental periods, there is an increased chance of collision during seismic events, which might cause significant damage and harm to the inhabitants. The International Building Code (IBC) suggests specific rules to guarantee a minimum distance between adjacent structures in order to avoid such accidents. conducted finite element analyses on hard, medium, and soft soils, among other soil types. It is important to note that there isn't research that looks at how SSI affects nearby structures that are connected by finite vertical displacements (FVDs).

CONCLUSION: -An experiment is conducted to understand the behaviour of buildings that are connected by fluid viscous dampers and that are situated close to one another, while accounting for the influence of soil-structure interactions. By comparing the height ratios of the buildings, the behaviour of the structures is investigated. The results show that the linked structure's reaction is very sensitive to the interaction between the soil and the structure.

[10] Anjali Mistry, A., Mevada, S. V., & Agrawal, V. V. (2022). Vibration Control of Tall Structure using Various Lateral Load Resisting Systems and Dampers. International Journal of Civil Engineering, 9(6), 2842.[10]

INTRODUCTION; - As to the IS16700 standard, super tall constructions surpass 250 meters in height, whereas tall buildings are defined as those that are higher than 50 meters. With little land available these days, tall buildings offer a practical solution for meeting the needs of the residential, commercial, and industrial sectors. The presence of wind and seismic stress causes significant problems for tall buildings. Occupant discomfort and structural and non-structural damage are the results of the substantial displacement of the structure caused by these lateral stresses. For the purpose of minimizing this lateral displacement, a vibration control system or lateral load resisting device is needed. A vibration control system or any other device that resists lateral loads is required.

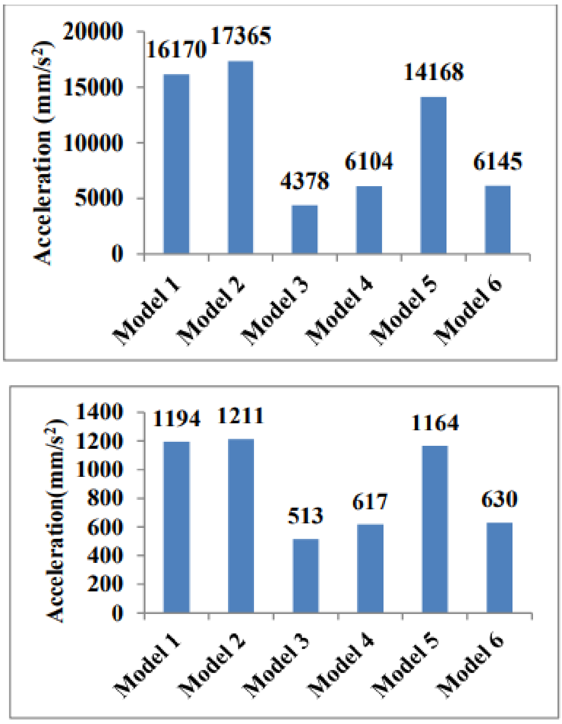

Fig 6: - Comparison of Max top storey Acceleration due to Response Spectrum analysis & Time History analysis [10]

CONCLUSION: - Compared to the other systems, the braced frame and Diagrid systems exhibit more rigidity. The displacement and acceleration response of the structure may be effectively controlled by providing LVDs. The braced frame system fitted with LVDs is found to have an average percentage decrease in base shear, maximum storey displacement, and acceleration at the top storey of 43%, 25%, and 56%, respectively, according to time history analysis.

3. CONCLUSIONS

- The properties (such as PGA and frequency content) of the ground motion define the high values of base shear from time history analysis.
- The top storey lateral acceleration for EQ TH analysis is lowest for SW with LVDs in both the X and Y axes.
- It is found that by considering dampers and devices that resist lateral loads, the drift ratio may be effectively decreased.
- Less lateral top story movement is seen in the X and Y directions in the Bracing and Bracing + Alternate Damper systems.
- The results indicate that the storey shear for bracing systems is the minimum for both wind and dynamic wind investigations.
- Base shear is distributed differently for each tower in an asymmetrical construction than in a symmetrical one, where base shear is divided into two equal parts.
- The SW system is less flexible than the braced frame system.

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[2] Bharti, S. D., Dumne, S. M., & Shrimali, M. K. (2010). Seismic response analysis of adjacent buildings connected with MR dampers. Engineering Structures, 2122- 2133.

[3] Zhu, H. P., Ge, D. D., & Huang, X. (2011). Optimum connecting dampers to reduce the seismic responses of parallel structures. Journal of Sound and Vibration, 1931-1949.

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[7] Khan, S., Kumar, C. M., & Shwetha, K. (2020). Analytical study on the seismic behavior of two adjacent buildings connected by viscous dampers. AIP ConferenceProceedings. Bengaluru

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[5] IS 875 (Part 2): 1987, Code of Practice for Design Loads (Other than Earthquake) For Buildings and Structures, (Imposed Loads). (1987). New Delhi: Bureau of Indian Standards.

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