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Investigation of Seismic Pounding Effect on Symmetric 10 Story Reinforced Concrete Buildings Using SAP2000

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Abstract

Earthquakes have historically been responsible for significant structural failures, often resulting in substantial economic losses and endangering human lives. One notable failure mechanism observed during seismic activity is seismic pounding, which occurs when adjacent buildings collide due to insufficient separation gaps. This phenomenon is particularly concerning in densely populated urban areas where space constraints often prevent the provision of adequate clearances between structures. Such impacts can lead to severe damage or even progressive collapse, especially when the adjacent buildings have different dynamic properties. This study focuses on analyzing the potential of Fluid Viscous Dampers (FVDs) to mitigate the effects of seismic pounding between two closely spaced G+10 story symmetric reinforced concrete buildings. The structural behavior of the buildings was modeled and evaluated using SAP2000, a comprehensive software for seismic analysis and design. To determine the effectiveness of the dampers, critical structural response parameters, such as base shear, lateral displacement, inter-story drift, and fundamental time, were assessed under seismic loading. These parameters were compared for cases with and without FVDs to understand their influence on seismic performance. The findings from this research reveal that the incorporation of FVDs significantly improves the dynamic response of adjacent buildings by absorbing seismic energy and reducing structural vibrations. Consequently, the risk of pounding is minimized, which enhances the overall safety and durability of buildings during earthquakes. This study highlights the value of implementing supplemental damping devices in earthquake-prone zones and provides practical insights for engineers and urban planners involved in the seismic design of adjacent structures.

Keywords: Symmetric reinforced concrete buildings, story drift, story shear, SAP2000, seismic

INTRODUCTION

In areas exposed to frequent seismic activity, the spacing between buildings plays a vital role in determining their safety during an earthquake. When two structures are constructed too closely without providing adequate separation, they may collide during ground shaking – a scenario referred to as seismic pounding. This situation mainly arises from insufficient distance between buildings and is often observed in older urban development's where seismic design guidelines were either lacking or not enforced.

The consequences of such collisions can be significant. Apart from the immediate damage at the point of impact, the energy transferred between buildings can cause further structural distress. The overall damage depends on how each building responds dynamically during the shake. In many city centers, where land use is dense and plot sizes are limited, buildings are frequently constructed right up to the boundary line, leaving no room for

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lateral movement during seismic events [1]. This issue becomes even more critical when there is a mismatch in floor levels or building heights. In such cases, the collision is uneven, and one building may transfer forces directly into the columns or slabs of the other, potentially leading to severe structural damage. Shorter buildings are often subjected to higher lateral forces, while taller buildings may experience irregular motion due to stiff variations. Although recent building codes recommend a minimum separation to avoid pounding, these provisions are not always feasible, especially for existing structures in compact urban zones. Therefore, alternative approaches are necessary. These include controlling inter-story drift, aligning floor levels between neighboring buildings, and using devices that can reduce or absorb seismic energy. In some situations, connecting adjacent structures through damping systems helps in distributing seismic loads, thereby reducing the possibility of damaging impacts.

LITERATURE REVIEW

The current literature on seismic gaps between two adjacent RCC buildings. It also discusses various methods employed to mitigate the pounding effects between these structures. Elements, each measuring 1 m, is incorporated in contact zone of the lower height building to account for all possible deformation modes that occur under earthquake. Double pounding is considered, occurring at certain upper points of the superstructure within the contact zone, as well as at the foundation level [2].

Seismic pounding between buildings located closely together is a significant contributor to damage in earthquake-prone regions. During earthquakes, adjacent buildings with different dynamic properties may move out of sync, resulting in collisions due to the absence of an energy removal. To mitigate seismic pounding, passive structural control systems, like dampers, can be utilized to dissipate the energy generated during such interactions. This study practices FVDs for decreasing the effects of adjacent structures [3]. The seismic interaction among torsionally linked multi-story moment frame structures. Five pairs of adjacent structures, with separation distances and building heights varying between 4 and 10 stories, are analyzed. Although the lateral stiffness distribution is kept symmetric, mass eccentricity is introduced ranging from 0% to 30% of the floor plan dimensions. Using three-dimensional nonlinear models with aligned floor levels, the results show that pounding due to seismic activity can occur at various points along the perimeter of the adjacent buildings [4].

Nonlinear time-history analysis is performed on base-isolated structures to assess their susceptibility to pounding with neighboring fixed-base buildings and surrounding moat walls. The objective is to identify the conditions that lead to such interactions and evaluate the impact of key parameters on peak seismic responses. A specific focus is placed on how the orientation of seismic ground motions relative to the main structural axes of the base-isolated buildings influences their dynamic performance [5]. The consequences of structural pounding – collisions between neighboring buildings caused by insufficient separation – under the influence of recurring seismic activity. IDA assesses the seismic response for adjacent buildings exposed to reasonable, frequent ground shaking. Breakability curves are established for various performance levels to demonstrate the buildings' structural capacity and vulnerability to damage. The analysis includes nine unique pounding configurations, combining different arrangements of two four-story and two ten-story frames. Each configuration is subjected to three synthetic seismic sequences. To evaluate the impact of separation distance, three gap widths are examined: 1 mm (indicating immediate contact), 10 cm, and 1 m [6]. The effects of localized inelastic demands in a multi-story reinforced concrete (RC) frame structure into a probabilistic assessment of seismic pounding risk. Two types of structural impact are analyzed: (a) floor-to-floor interaction (Type A) and (b) collisions between a floor and a column at differing story levels (Type B). The study evaluates three initial gap distances between the neighboring buildings. Additionally, the seismic performance of the RC frame is assessed, serving as a benchmark. Fragility curves are constructed to represent the probabilistic risk, incorporating both global and localized EDPs in relation to PGA. The initial stage of the research emphasizes developing probabilistic seismic demand models (PSDMs) that characterize structural behavior under various pounding scenarios [7]. The seismic behavior of a real-life reinforced concrete (RC) frame structure under different seismic intensity levels, with a focus on situations where the gap between structures is too narrow to prevent contact with a neighboring, shorter, and stiffer building. A total of 882 nonlinear incremental dynamic analyses are performed to evaluate the effects. The study initially concentrates on inter-story collisions – where a building's floor impacts the column of an adjacent structure – across nine varying seismic load conditions. For each scenario, 14 ground motion records, scaled appropriately, are utilized. The analysis considers a 8-story RC frame experiencing pounding against either a 3-story RC frame-wall or a 3-story rigid structure, representing a high-stiffness configuration. In all simulation cases, the buildings are assumed to remain in direct contact throughout the analysis [8].

Various configurations of adjacent buildings, based on their relative heights and floor alignments, are being studied. The study considers two scenarios: (1) buildings of equal height with aligned floor levels, and (2) buildings of unequal height but with matching floor elevations. These adjacent structures are modeled using ETABS software, and the seismic response is evaluated by connecting corresponding floor levels of the two buildings using a "Gap Element Model". The analysis is conducted under different ground motion records to assess the interaction effects [9].

The review and comparison of previous and recent research – both incorporating and excluding SSI conducted for highlighting the impact of SSI proceeding structural pounding. Findings emphasize the critical role that SSI plays in influencing seismic response of end-to-end buildings, particularly in close proximity. This underscores the necessity for a revised seismic design approach that explicitly accounts for the adverse effects of SSI on structural performance during earthquakes [10]. The structural pounding can occur either between adjacent buildings or within different segments of the same structure during seismic events. This phenomenon has been frequently documented in past earthquakes, contributing to a wide range of structural damage – from minor cracks to complete collapse [11].

Investigation has been carried out to examine the collision response of two 3-story structures when subjected to seismic forces buildings with identical story heights under harmonic ground excitations, using dimensional analysis. To capture the nonlinear structural behavior, bilinear approximation is employed for the relationship between story shear force and lateral drift. The impact between the buildings is modeled through a viscoelastic contact element, which activates only when the masses of the adjacent structures come into contact [12].

METHODOLOGY

To prevent pounding between adjacent symmetric reinforced concrete (R.C.C.) buildings that differ in height, geometry, and floor-to-floor dimensions, it is essential to conduct a non-linear ground motion analysis. This analysis helps determine an approximate inter-story height that ensures a safe separation distance between the structures, assuming rigid floor diaphragms. A FVD is added to represent interaction space among buildings, incorporating a predefined gap and a spring element with appropriate stiffness properties.

BUILDING SPECIFICATION

In this study, two symmetric G+10 story building models are chosen. As per Table 1, all structural components, including beams, columns, and slabs, are modeled using M30 grade concrete and reinforced with Fe 500 grade steel.

Table 1. Building specification.

S.N.	Symmetric Building	Elevation of Story	Column	Beam	Slab
1.	(Left Structure) G+10	3 m	350 x 350 mm 400 x 400 mm	230 x 450 mm	150 mm
2.	(Right Structure) G+10	3 m 3.2 m, 3.4 m, 3.6 m	350 x 350 mm 400 x 400 mm	230 x 450 mm	150 mm

The designed models for the research are shown in Figures 1 to 9. The figures illustrate the models of varying floor to floor height between two symmetric structures that were studied for understanding the effect of pounding.

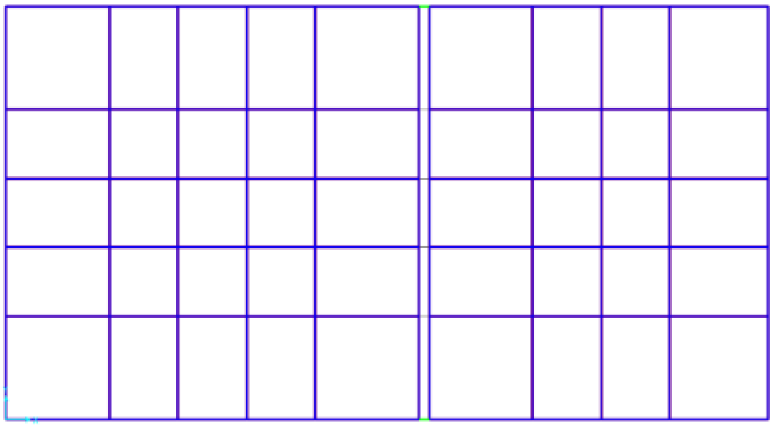

Figure 1. Plan of structure – G+10 symmetric structure.

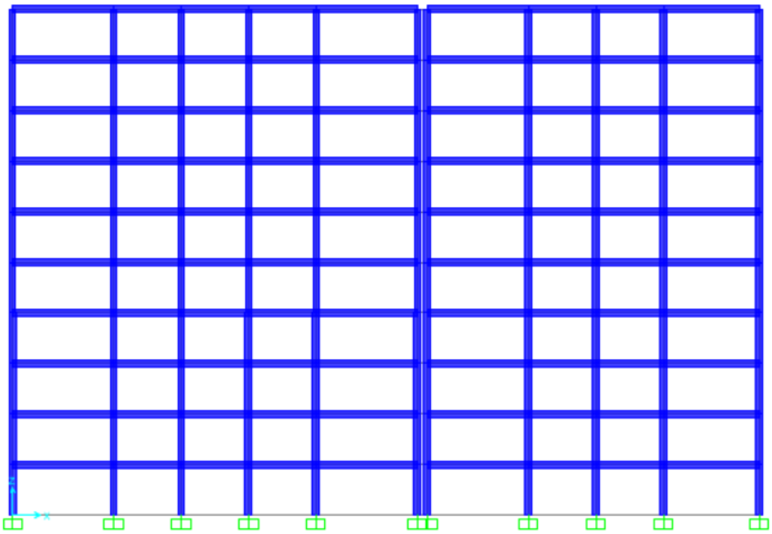

Figure 2. Elevation of structure, 3m without FVD.

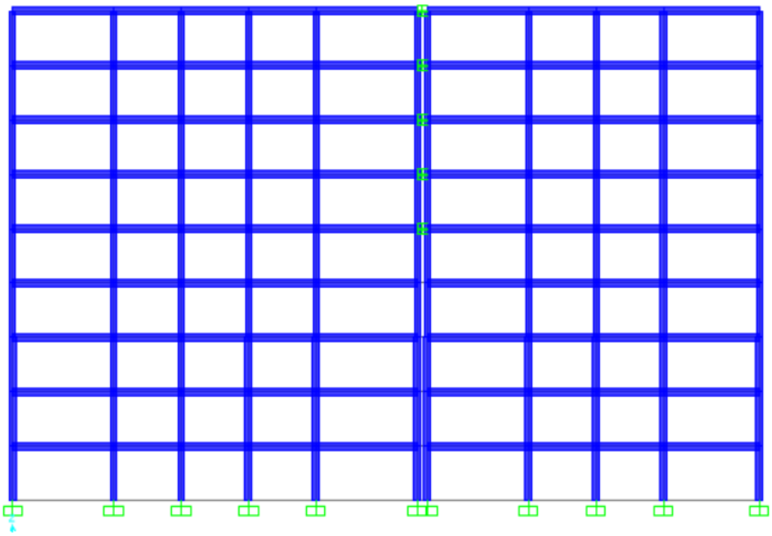

Figure 3. Elevation of the structure, 3m with FVD.

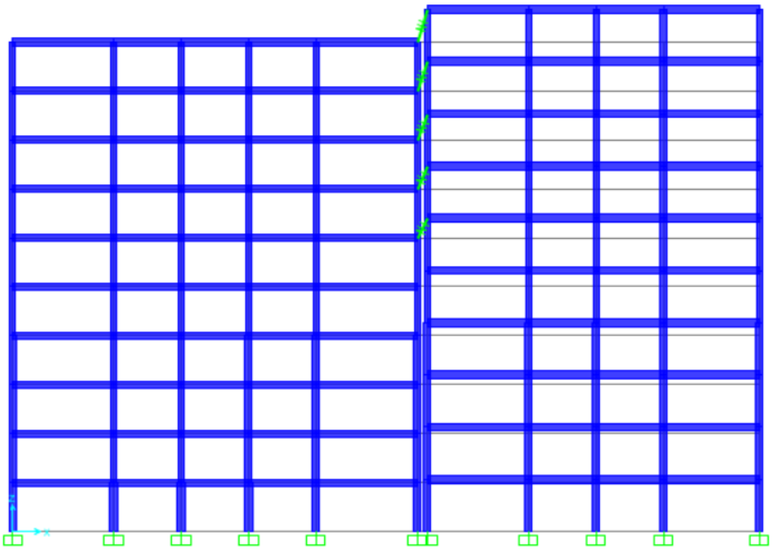

Figure 4. Elevation of structure, 3 m (left) and 3.2 m (Right) without FVD.

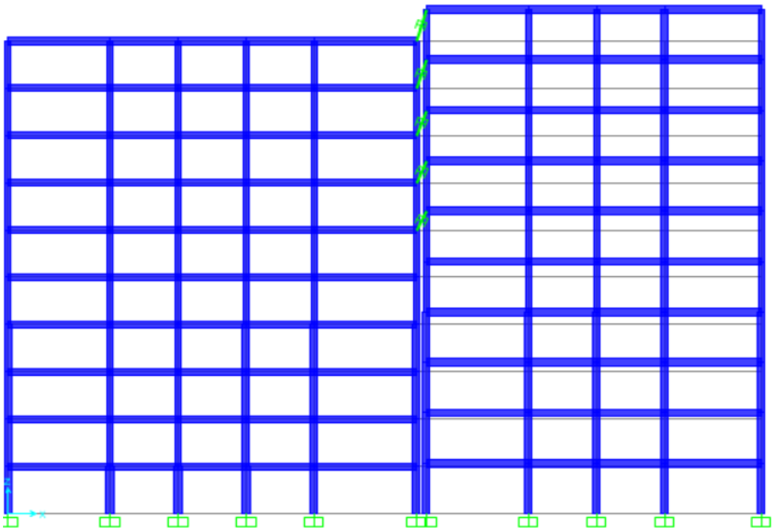

Figure 5. Elevation of structure, 3 m (left) and 3.2 m (Right) with FVD.

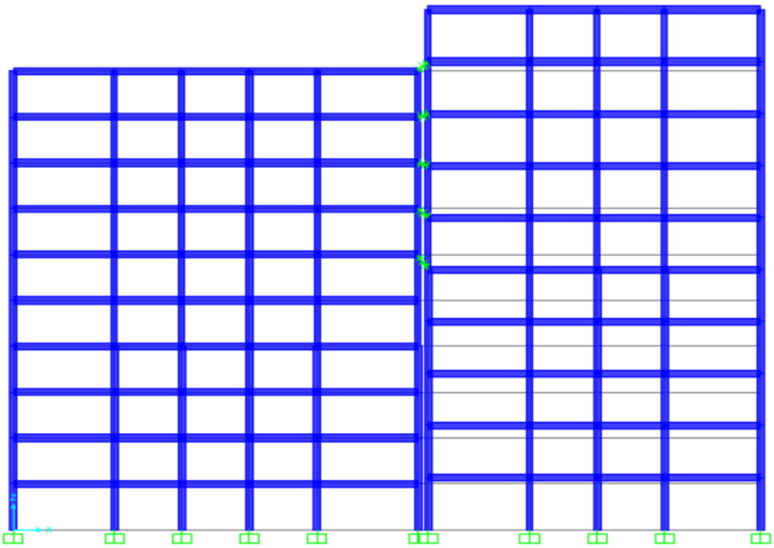

Figure 6. Elevation of structure, 3 m (left) and 3.4 m (Right) without FVD.

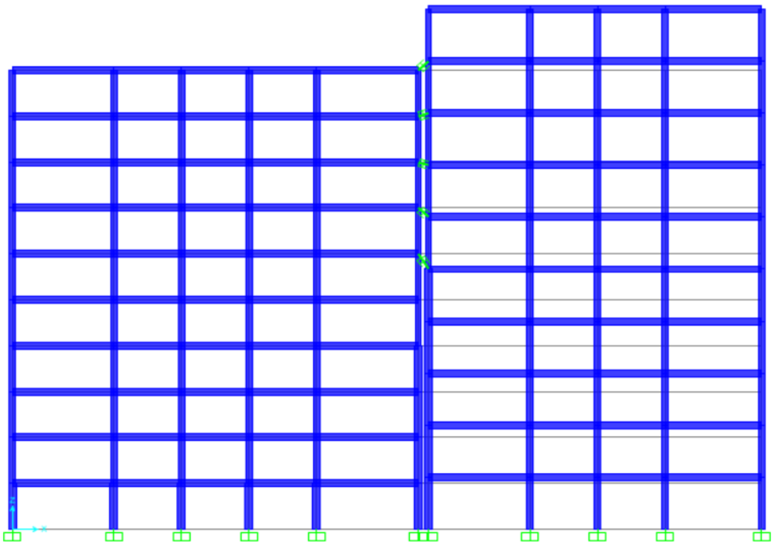

Figure 7. Elevation of the structure, 3 m (left) and 3.4 m (Right) with FVD.

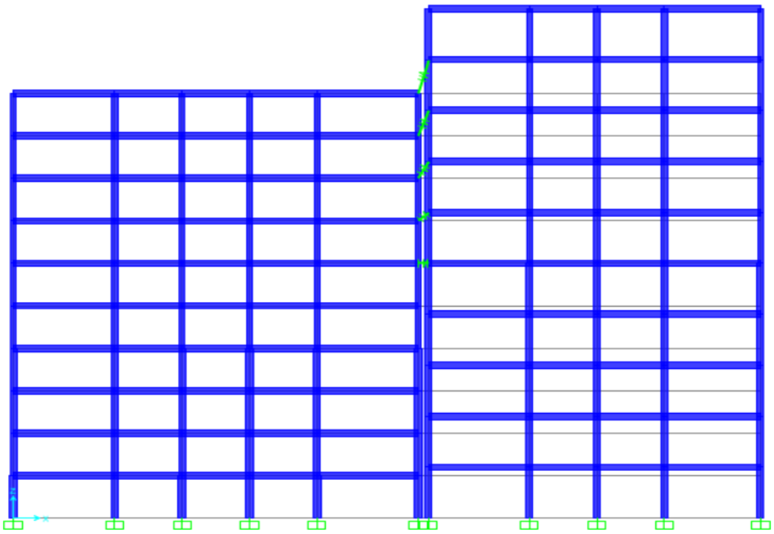

Figure 8. Elevation of the structure, 3m (left) and 3.6m (Right) without FVD.

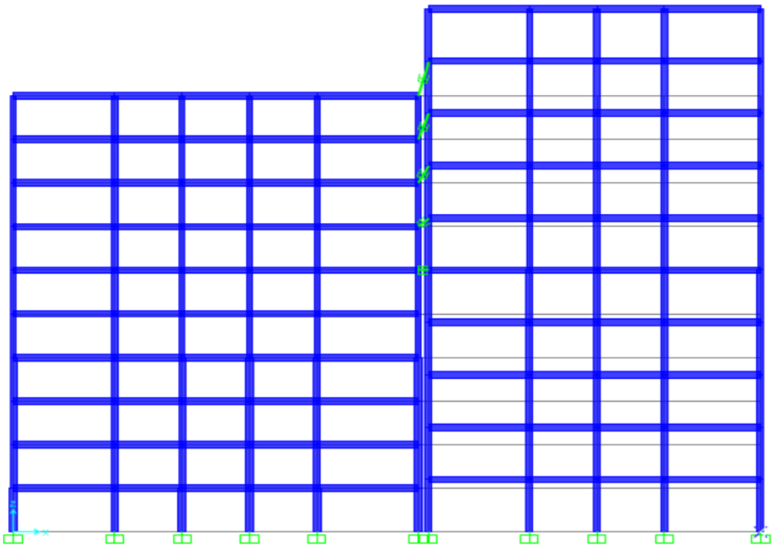

Figure 9. Elevation of the structure, 3 m (left) and 3.6 m (Right) with FVD.

RESULT

The results are shown graphically and in tabular form in Tables 2 to 5 and graphically in Figures 10 to 13. All models, including those with and without fluid viscous dampers between the symmetric buildings, were analyzed using SAP2000 software with the EL Centro ground motion data.

BASE SHEAR

Base shear refers to the shear force acting on a particular floor or story of a building or structure. It influences the distribution of forces and deformation patterns within the structure. The base shear force is typically caused by lateral loads, such as wind or seismic forces, that act on the building. Table 2 and Figure 10 illustrate the base shear values differing across all structural cases. Among them, case II records the highest base share, while case VII shows the lowest. Indicating a generally uniform structural response in similar scenarios.

Table 2. Base shear.

S.N.	Model	Base Shear in KN
1	I	23982.73
2	II	28173.2718
3	III	25300.7721
4	IV	25319.111
5	V	24407.656
6	VI	23578.863
7	VII	21808.942
8	VIII	22059.839

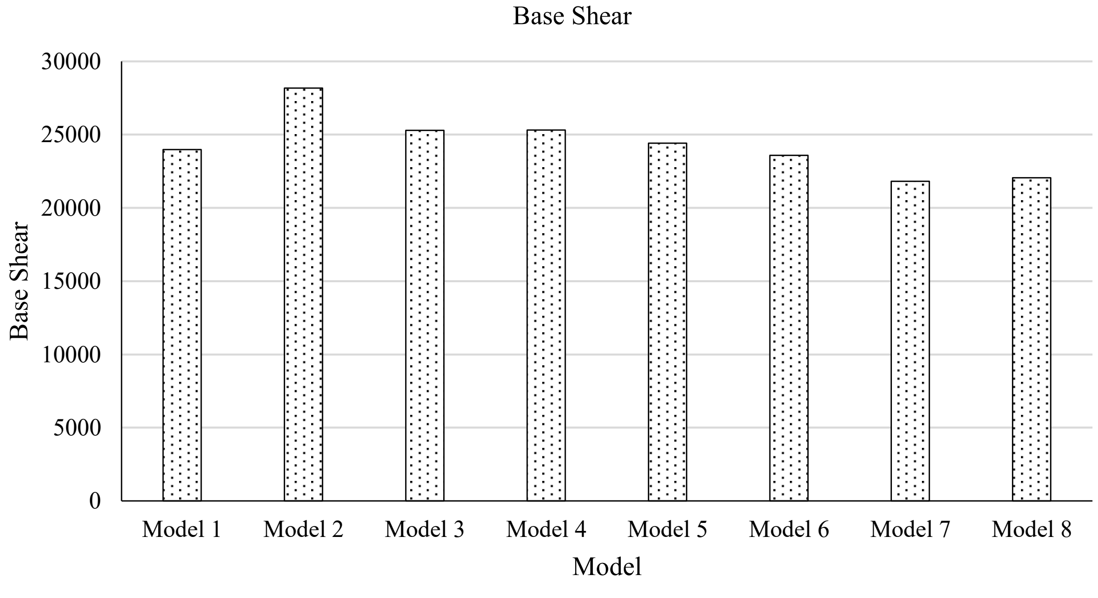

Figure 10. Base shear.

MAXIMUM LATERAL DISPLACEMENT

The data presented in Table 3 and Figure 11 indicate that Building B experiences greater lateral displacements compared to Building A, raising concerns about potential pounding during seismic activity. The largest displacement difference is observed in Case VII, suggesting a significant risk of collision. However, in Case II, both buildings exhibit identical displacements, which eliminates the possibility of pounding. These discrepancies emphasize the importance of ensuring adequate separation between neighboring structures to prevent such issues.

Table 3. Maximum lateral displacement.

S.N.	Model	Maximum Lateral Displacement (in mm)	
		Building A	***Building B***
1	I	150.341	193.589
2	II	35.4097	35.4097
3	III	160.95	194.0245
4	IV	142.48	154.759
5	V	116.094	281.42
6	VI	68.634	261.67
7	VII	98.696	337.640
8	VIII	66.959	316.542

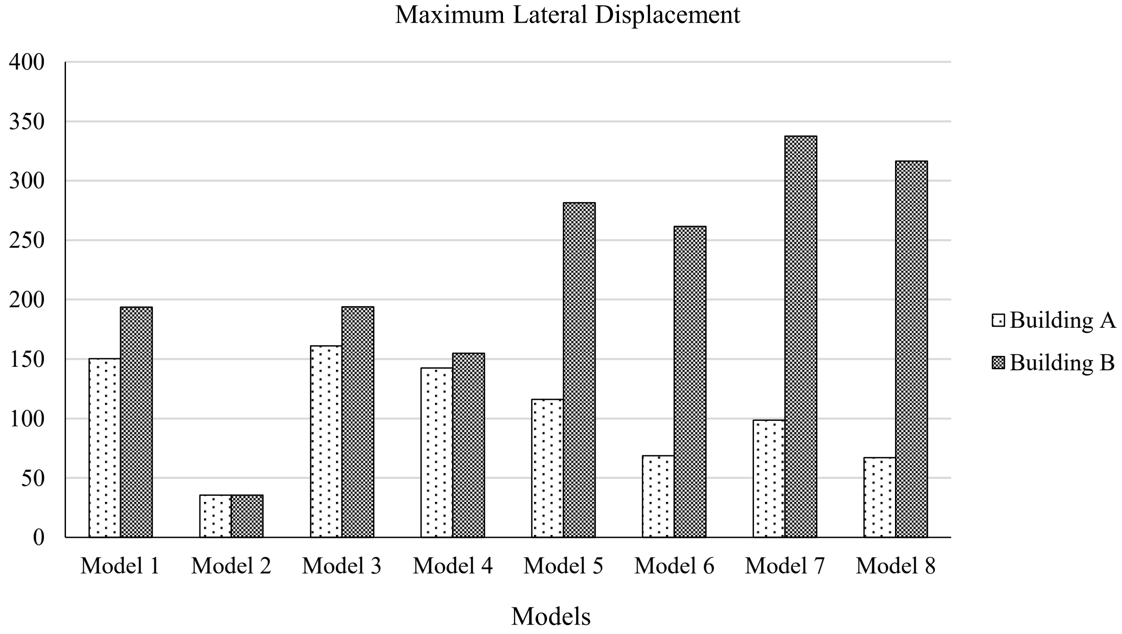

Figure 11. Maximum lateral displacement.

Maximum Story Drift Ratio

Building B generally experiences higher story drift ratios compared to Building A, particularly in cases, like VII and VIII as shown in Table 4 and Figure 12, indicating more significant deformation. In Case II, both buildings have the same drift ratio, suggesting similar behavior under those conditions. The differences in drift values highlight the varying stiffness between the buildings, with Building B being more prone to greater movements during seismic events.

Table 4. Maximum story drift ratio.

S.N.	Model	Maximum Story Drift Ratio (in mm)	
		Building A	***Building B***
1	I	0.0980	0.127
2	II	0.024	0.024
3	III	0.0438	0.0126
4	IV	0.087	0.093
5	V	0.039	0.160
6	VI	0.0685	0.149
7	VII	0.03655	0.1760
8	VIII	0.0541	0.189

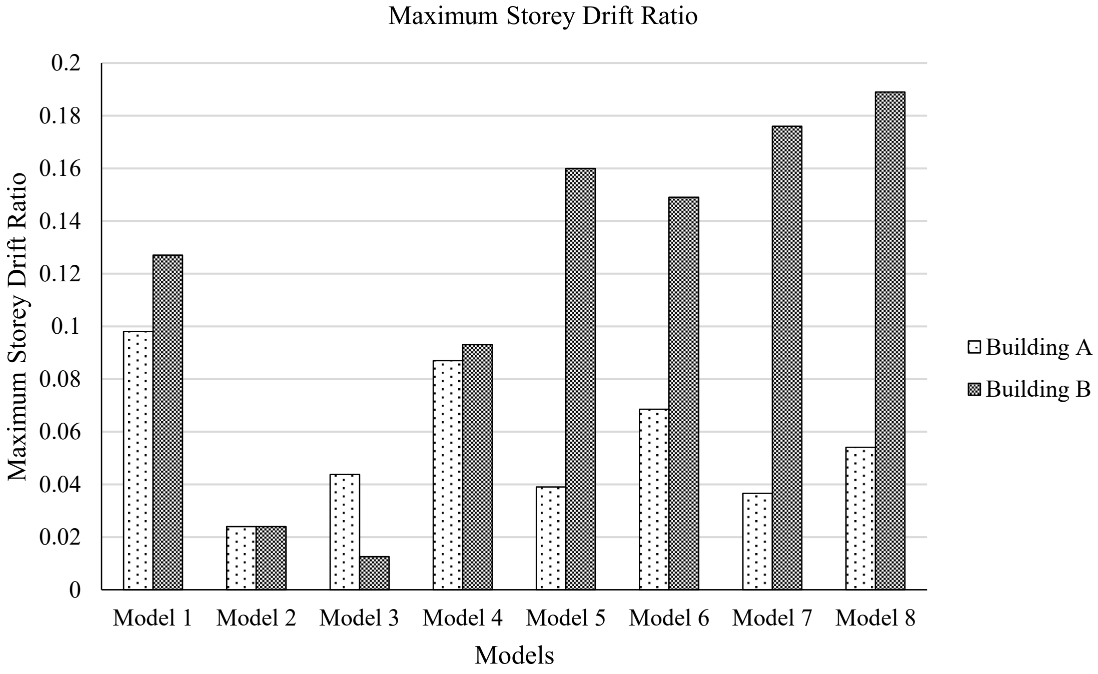

Figure 12. Maximum story drift ratio.

TIME PERIOD

The time values for each case in Table 5 and Figure 13 represent a trend for T1 being the longest, followed by T2 and T3, with slight variations. Case VIII has the highest time, especially for T1, indicating slower oscillations, while Case II has the shortest values, particularly for T3, suggesting a quicker response. Overall, the data reflects changes in structural stiffness or loading conditions affecting the time periods across cases.

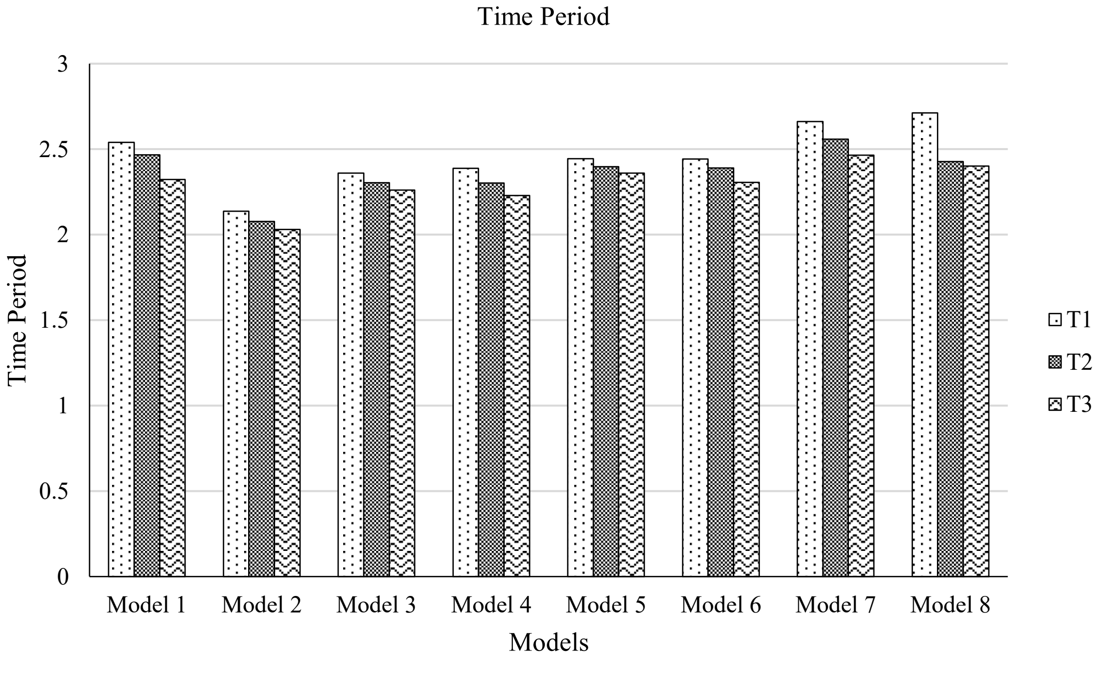

Figure 13. Time period.

MINIMUM SEISMIC GAP REQUIREMENT FOR A SYMMETRIC BUILDING

The minimum seismic gap required for the different cases is studied in this research. The structures with provided seismic data can be designed with the minimum separation gap mentioned in Table 6.

Table 5. Time period.

S.N.	Model	Time Period (In Sec)		
		T1	*T2*	*T3*
1	I	2.539	2.467	2.323
2	II	2.137	2.077	2.030
3	III	2.359	2.303	2.260
4	IV	2.388	2.301	2.228
5	V	2.445	2.398	2.359
6	VI	2.442	2.389	2.305
7	VII	2.661	2.559	2.465
8	VIII	2.712	2.427	2.401

Table 6. Minimum seismic gap requirement.

S.N.	Cases	Gap Provided (in mm)	As Per IS 1893:2016 (in mm)	As Per IBC (in mm)
1	I	400	343.93	245.11
2	II	400	70.82	50.08
3	III	400	354.97	252.09
4	IV	400	297.24	210.36
5	V	400	397.51	304.43
6	VI	400	330.30	270.52
7	VII	400	436.34	351.77
8	VIII	400	383.50	323.55

CONCLUSIONS

The research analyzed how two adjacent structures behaved during EL Centro earthquake. The conclusions for Base Shear, Maximum Lateral Displacement, Story Drift and time are discussed below.

- When the floor height increased, a general reduction in base shear was observed. Increasing floor height reduces the base shear due to a change in dynamic properties. However, the values remained within a stable range across cases.
- The use of dampers significantly reduces the maximum lateral displacement across all building heights compared to cases with gap elements. Confirms that dampers are most effective in reducing lateral displacement at lower building heights.
- The introduction of dampers effectively reduces the story drift ratio in both buildings across varying heights.
- As the building height increases, the efficiency of dampers becomes less consistent, especially in Building B where drift slightly increases. Overall, dampers are more effective in controlling drift than gap elements at lower to mid-rise configurations.
- The time is generally higher without the use of dampers, indicating more flexible structural behavior and longer oscillation durations.
- When dampers are used, the time periods reduce slightly, showing improved stiffness and energy dissipation.
- This demonstrates that dampers effectively enhance structural stability. Overall, the use of dampers contributes to a quicker response and better control of vibrations.

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