© February 2025 | IJIRT | Volume 11 Issue 9 | ISSN: 2349-6002

Dynamic Response and Seismic Pounding Analysis of Adjacent Reinforced Concrete Multistorey Buildings Through Time History Simulation Using ETAB

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Abstract—**Earthquakes pose a significant threat to structures, particularly when buildings are closely spaced. Seismic pounding occurs when nearby high-rise buildings collide due to differences in their dynamic vibrations, leading to potential structural damage that may compromise the building's safety. The rise of multi- story buildings in urban areas, driven by urbanization and population growth, increases the risk of seismic pounding. Despite building design safeguards, these structures often fail to account for the severe impact of seismic pounding, especially in densely populated metropolitan cities. The study addresses the lack of a precise database to understand and mitigate the issue of seismic pounding. The interaction between structures during earthquakes remains poorly understood, and there is no established solution to manage the effects of pounding in urban environments.**

The thesis aims to enhance the understanding of seismic pounding by analyzing the structural interaction between nearby buildings during earthquakes. Using time-history modeling and analysis, the study evaluates building separation lengths and design factors, providing recommendations to reduce pounding and improve structural resilience. The study also seeks to identify structural issues that contribute to seismic pounding and guide improvements in building design. A comparative analysis of lateral force-resisting systems, such as shear walls and bracing systems, will be conducted to assess their effectiveness in reducing structural weaknesses.

The overall goal is to enhance seismic design practices by focusing on the complex dynamics of seismic pounding. This study provides practical recommendations for improving the seismic resilience of multi-story structures in earthquake-prone areas, using models developed with ETABS software in compliance with Indian Standard Codes IS456 for reinforced concrete design, IS800 for steel design, and IS1893 for earthquake-resistant design.

Index Terms—**Mitigation, Seismic Pounding, Time-History Simulation, ETABS**

I. INTRODUCTION

Seismic activities pose a significant threat to infrastructure worldwide, causing severe damage and loss of life. In earthquake-prone areas, the structural strength and performance of buildings during seismic events are crucial. While earthquake design standards aim to ensure safety and resilience, the issue of seismic pounding, where nearby buildings with small gaps collide during an earthquake, is often overlooked. This collision severely damages both buildings, compromising their functionality. Although buildings' vibratory properties help mitigate damage, seismic pounding disrupts this response, especially when buildings with different vibratory properties are closely spaced.

Severe structural damage due to seismic pounding was observed in major earthquakes, such as the 1985 Mexico, 1989 Loma Prieta, and 1995 Kobe earthquakes, where buildings with minimal separation suffered significant destruction. The 2011 New Zealand earthquake also caused similar damage, affecting both high-rise and low-rise buildings. Other notable events, including the 1994 Northridge and 2001 Lorca earthquakes, reported damages due to pounding between nearby structures. Such incidents highlight the widespread impact of seismic pounding on infrastructure globally.

Separation gaps are a widely discussed strategy to mitigate seismic pounding between nearby buildings. Flexible components between structures are commonly used to reduce impacts. While current standards specify minimum gap requirements, response spectrum analysis often overlooks the non-linear behavior of buildings, leading to insufficient separation. Field data shows that many "as-built" buildings may lack adequate clearance during seismic events, and seismic codes globally define minimum separation lengths to prevent damage from structural collisions.

The aim of this study is to critically examine the dynamic response and seismic pounding effects in adjacent reinforced concrete multistory buildings during seismic events. Key objectives include investigating seismic pounding impacts, evaluating structural responses under time history excitations, optimizing building separation distances and design parameters to reduce pounding, and assessing structural vulnerabilities to propose design improvements for better seismic resilience.

II. LITERATURE REVIEW

In this study by Muzaffer Borekci and Birkan Dag (2024), the authors analyze the seismic vulnerability in closely spaced urban buildings is increased by the risk of pounding during earthquakes, especially when separation distances are insufficient. Pounding between buildings with different story heights can generate significant shear forces in columns. While studies on floor-to-floor pounding exist, the more complex scenario involving multiple buildings needs further investigation to understand its full structural impact. Aditi V. Khurd, et. al. (2023) explained seismic pounding occurs when adjacent buildings with different dynamic characteristics collide during earthquakes, causing high-intensity forces and potential damage. While modern codes require separation distances, many older buildings in seismically active regions, especially in India, remain vulnerable. These structures may experience forces greater than those from the quake itself. Effective mitigation strategies are essential to reduce damage and casualties in high-density urban areas. Kosmas E. Bantilas et al. (2023) explored the seismic performance of an eight-story reinforced concrete (RC) frame structure subjected to pounding during intense ground motions. The study evaluated the effects of six different separation gap distances, expressed as fractions of the EC8 minimum, and considered the influence of adjacent building heights by analyzing interactions with rigid structures of varying story counts (1–4 stories). Fragility curves for different limit states were derived and combined with hazard data for a probabilistic seismic performance assessment. The study highlighted the significant impact of insufficient separation gaps on seismic vulnerability, emphasizing the need for improved design to reduce pounding risks. **S.** Gautam et al. (2023) explained in the past few years, the requisite to plan high-rise buildings in reinforced concrete structures due to aggrandize in population, so the structure is designed based on structural reliability theory to assure their safety. Over time, structures undergo unintended acts, both natural and man-made, leading to damage or failure. The" Progressive Collapse Analysis of Building" studies this type of failure. When a vertical load-bearing component of a building is removed due to a man-made or natural hazard, the building’s weight is redistributed to the adjacent columns. This increased load can cause the failure of these neighboring structural elements, potentially leading to a cascading failure that may result in the partial or total collapse of the structure. Mazza & Labernarda (2021) focused on internal pounding within seismically isolated structures, an often-overlooked issue in pounding assessments. The study investigated the interactions of components within isolated buildings, providing valuable insights into potential risks and mitigation strategies for internal pounding effects. While the theoretical findings were useful, the lack of experimental validation limited their real-world applicability, restricting the implementation of the proposed mitigation methods.

Cayci & Akpinar (2021) examined the effects of earthquake pounding on structures, incorporating soil-structure interaction. The study demonstrated how soil conditions impact the seismic response of buildings during pounding events, providing a more comprehensive understanding of pounding susceptibility. However, the study’s limitation lies in its failure to account for variations in structural configurations and ground motion properties, which could influence the generalizability of the findings. Despite this, the study offers valuable design recommendations for addressing seismic pounding and soil-structure interaction. Flenga & Favvata (2021) assessed the fragility of inter-story pounding between adjacent buildings using a probabilistic seismic demand model. This study’s strength lies in its use of a probabilistic approach that accounts for uncertainties in ground motion data and structural factors, offering insights into managing seismic pounding risks. The study provides recommendations for retrofitting and risk-informed structural designs to mitigate the impacts of pounding. Rupakhety et al. (2020) explored shared tuned mass dampers to reduce seismic pounding effects, with a focus on using a tuned frame damper for mitigation. While the study provided valuable insights into potential mitigation strategies, it was limited by the lack of experimental validation. Nevertheless, their numerical simulations and theoretical analysis offer promising directions for future research on using shared tuned mass dampers for seismic pounding response in buildings. Raheem et al. (2019) investigated the impact of seismic pounding on nearby symmetric structures with eccentric alignments, an area that had previously been underexplored. The study provided valuable insights into the dynamic behavior and vulnerability of such buildings to pounding-induced damage. However, the findings were somewhat limited by the narrow range of structural configurations considered.

RESEARCH GAP

1. Experimental validation of numerical models and mitigation techniques.
2. Inclusion of complex building configurations and multi-building interactions.
1. In-depth exploration of soil-structure interactions.
3. Development of robust probabilistic and multi-hazard approaches.
4. Comparative studies of seismic isolation systems and innovative mitigation techniques.
5. Real-world applications in dense urban environments and economically constrained regions.

III. METHODOLOGY

Two multistorey RCC structures of different floors are considered to assess the effects of Seismic Pounding on the adjacent constructions and understand how building separation affects the severity of pounding. These buildings are analyzed under different separation distances of 50mm, 500mm and 1000mm in CSI ETABS building information modelling software. These different configurations of separation distances are compared with buildings standing alone without any obstruction. Further particulars of models are labelled in section Time History analysis techniques are used to simulate realistic seismic ground motions that are used to assess the dynamic response of the building. Factors like displacement acceleration and entered story drifts are analyzed in structural engineering. Time history examination is one of the critical approaches for analyzing the earthquake response of the structure and forecasting how the will structure behaves under this seismic loading. Symmetric nineteen-story (G+18) and fourteen-story (G+13) buildings are adopted as models for this study. Table 1 provides detailed building specifications, including structural configurations, materials, and characteristics used in the design process. The configurations of models used are as follows:

1. Standalone G+18 Building
2. Standalone G+13 Building
3. Adjacent G+18 and G+13 with a separation gap of 50mm
4. Adjacent G+18 and G+13 with a separation gap of 500mm
5. Adjacent G+18 and G+13 with separation gap 1000mm

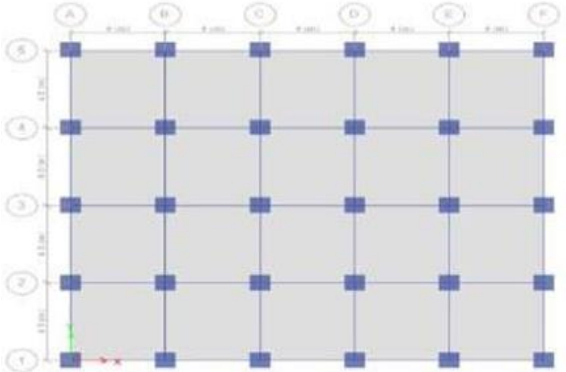

Fig. 1: Standalone G+18 Building Plan

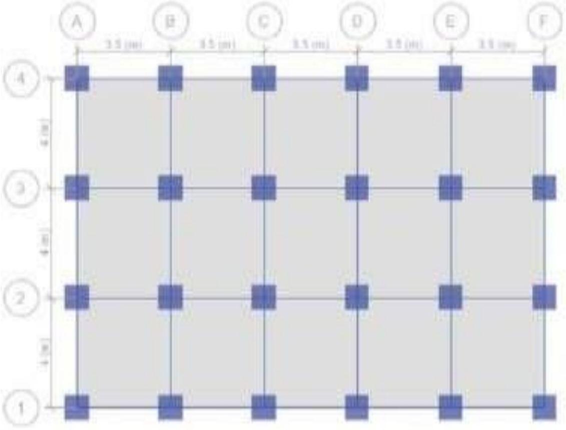

Fig. 2: Standalone G+13 Building Plan

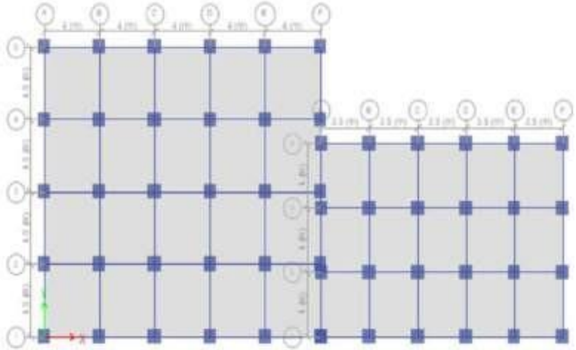

Fig. 3: Adjacent G+18 and G+13 with a separation gap of 50mm

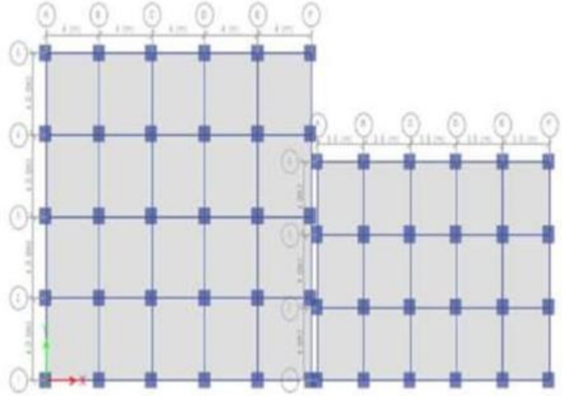

Fig. 4: Adjacent G+18 and G+13 with a separation gap of 500 mm

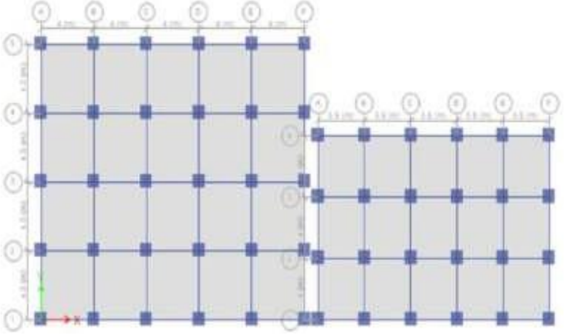

Fig. 5: Adjacent G+18 and G+13 with a separation gap of 1000 mm

Table I: Geometry of Building

Type of frame	R.C.C Frame
Type of Structure	ltistorey Residential Building
Geometry of Building	Symmetrical
Number of storeys	G+18 and G+13
Storey Height	3.6m
Slab Thickness	225 mm
R.C.C Beam Size	450mm x 900mm
R.C.C Column Size	900mm x 900mm
Buildings Separation Gap	50mm, 500mm and 1000mm
Seismic Zone	IV and V
Software	ETABS 21
Grade of Concrete	M-45
Grade of Steel	HYSD-550
Method of Analysis	Response Spectrum Analysis

IV. RESULTS AND DISCUSSION

Dynamic study related to G+18 and G+13 buildings at various gap distances and standalone situations produced a plethora of data. This section summarizes the key findings, emphasizing the greatest displacements, peak accelerations, inter-story drift ratios, and pounding forces found during the simulations. These results are classified based on separation distances (50mm, 500mm, and 1000mm) and compared to freestanding building scenarios.

A. Displacement Response

The displacement reactions of the G+18 and G+13 buildings were monitored during the earthquake simulations. The Figures below depict the displacement responses of the structures with 50mm, 500mm, and 1000mm separation as well as of the standalone structures in X direction.

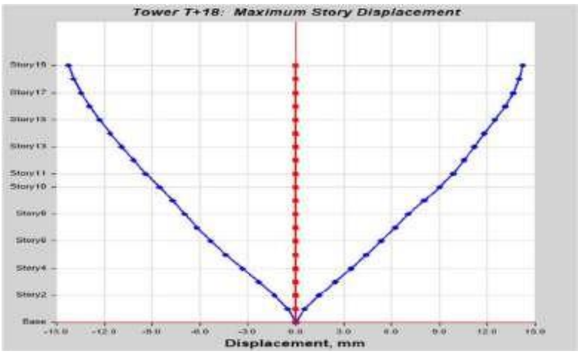

Fig. 6: Max and Min displacement of G+18

Fig. 7: Max and Min displacement of G+13

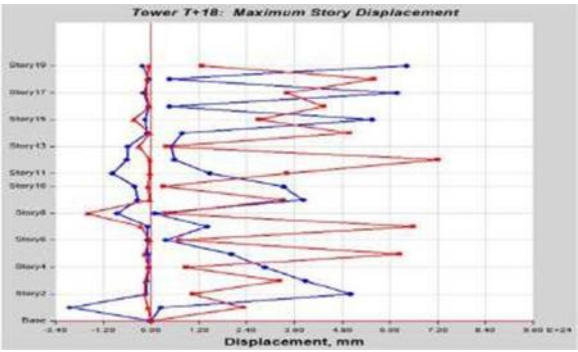

Fig. 8: Max and Min displacement with 50mm Separation Gap for G+18 building

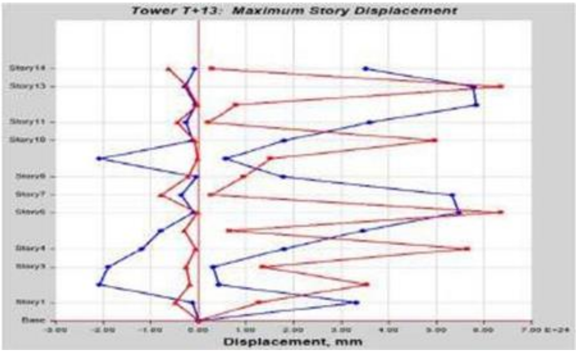

Fig. 9: Max and Min displacement with 50mm Separation Gap for G+13 building

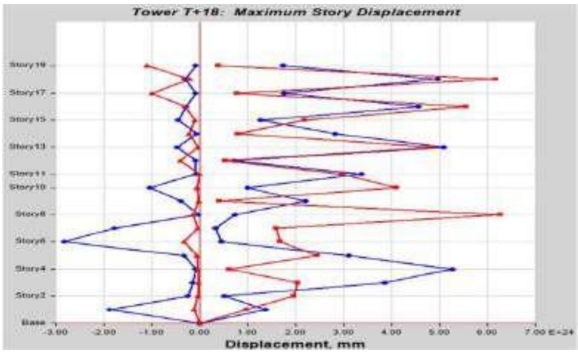

Fig. 10: Max and Min displacement with 500mm Separation Gap for G+18 building

Fig. 11: Max and Min displacement with 500mm Separation Gap for G+13 building

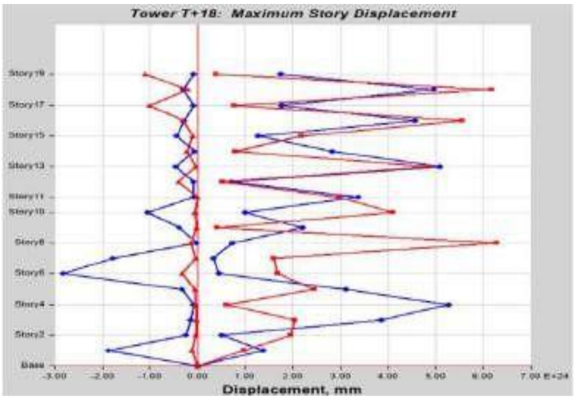

Fig. 12: Max and Min displacement with 1000mm Separation Gap for G+18 building

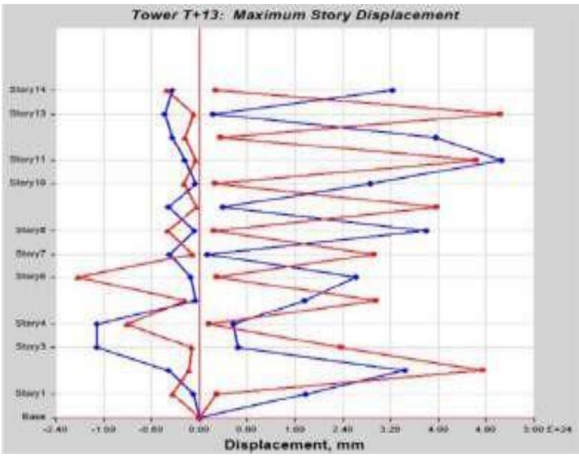

Fig. 13: Max and Min displacement with1000mm Separation Gap for G+13 building

B. Inter-Story Drift Ratio

Inter-story drift ratios are crucial for determining the extent of structural and non-structural mutilation. The graphs below depict the story drift for all the configurations.

Fig. 14: Max and Min story-drift of G+18 (X-Direction)

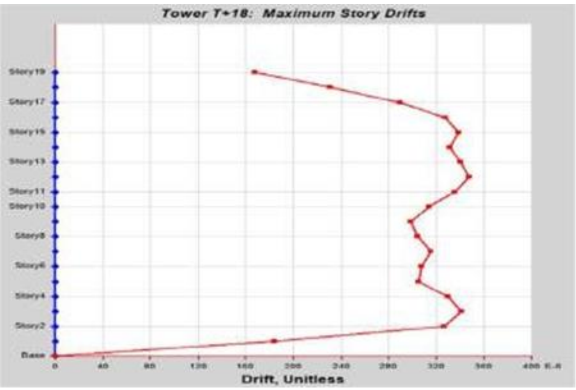

Fig. 15: Max and Min story-drift of G+18 (Y-Direction)

Fig. 16: Max and Min story-drift of G+13 (X-Direction)

Fig. 17: Max and Min story-drift of G+13 (Y-Direction)

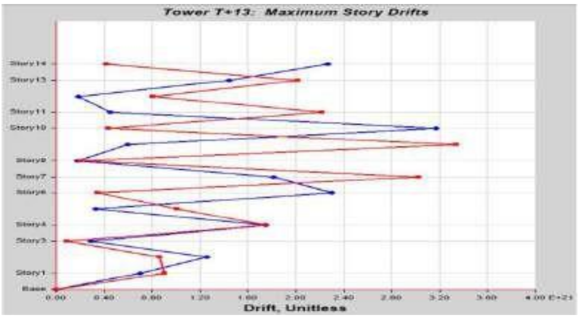

Fig. 18: Max and Min story drift with 50mm Separation Gap for G+18 building (X - Direction)

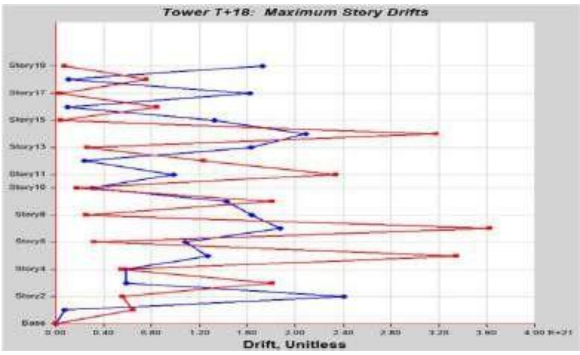

Fig. 19: Max and Min story drift with 50mm Separation Gap for G+13 building (X - Direction)

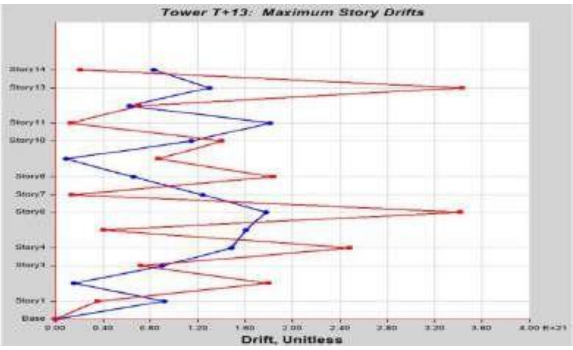

Fig. 20: Max and Min story drift with 50mm Separation Gap for G+18 building (Y - Direction)

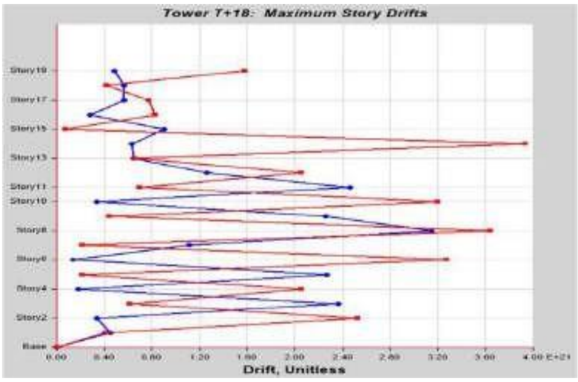

Fig. 21: Max and Min story drift with 50mm Separation Gap for G+13 building (Y - Direction)

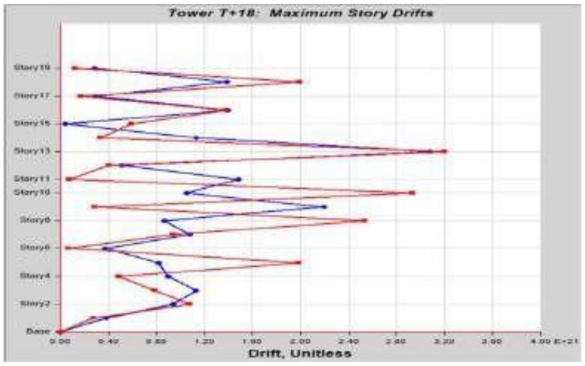

Fig. 22: Max and Min story drift with 500mm Separation Gap for G+18 building (X - Direction)

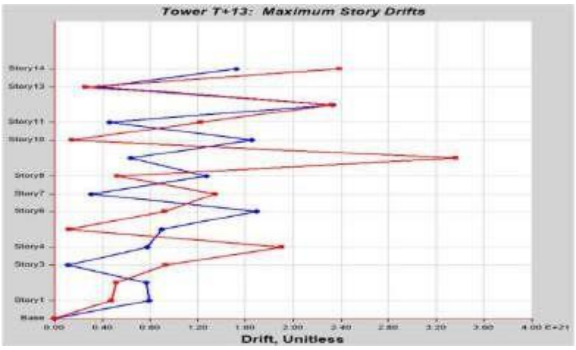

Fig. 23: Max and Min story drift with 500mm Separation Gap for G+13 building (X - Direction)

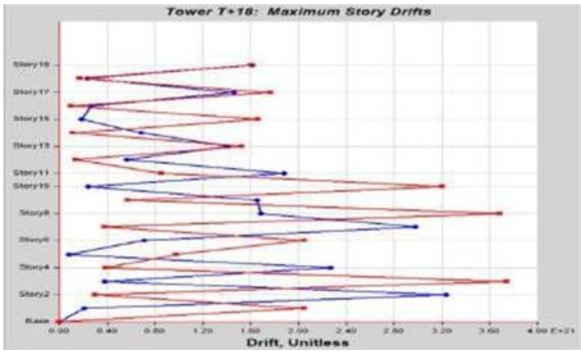

Fig. 24: Max and Min story drift with 500mm Separation Gap for G+18 building (Y - Direction)

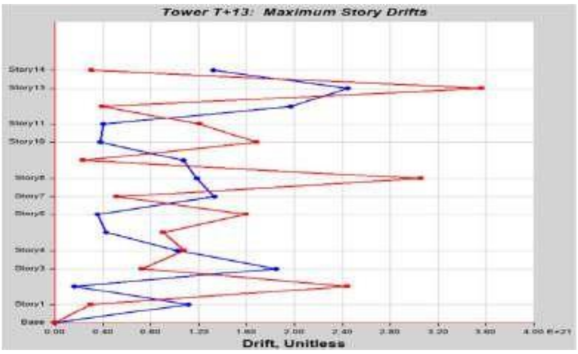

Fig. 25: Max and Min story drift with 500mm Separation Gap for G+13 building (Y – Direction)

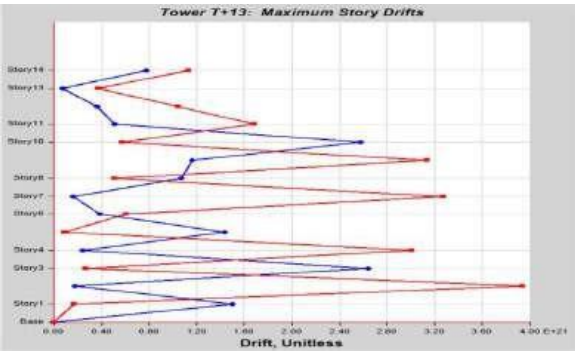

Fig. 26: Max and Min story drift with 1000mm Separation Gap for G+18 building (X - Direction)

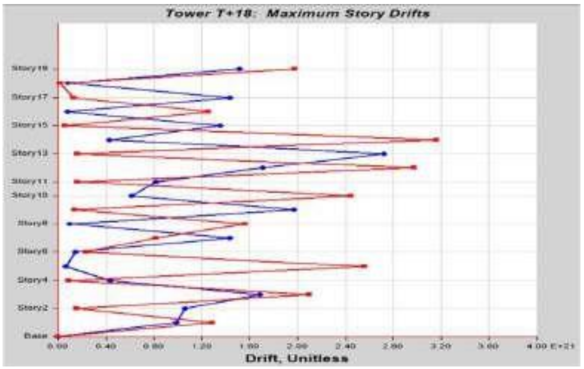

Fig. 27: Max and Min story drift with 1000mm Separation Gap for G+13 building (X - Direction)

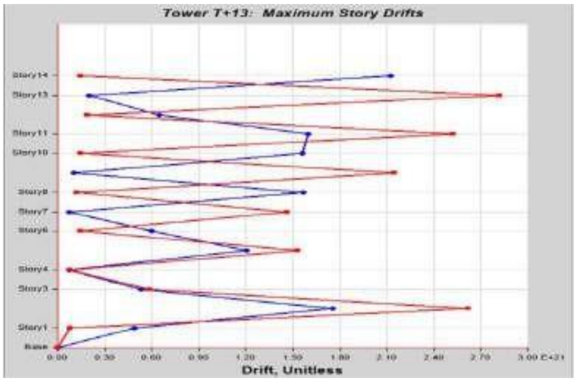

Fig. 28: Max and Min story drift with 1000mm Separation Gap for G+18 building (Y - Direction)

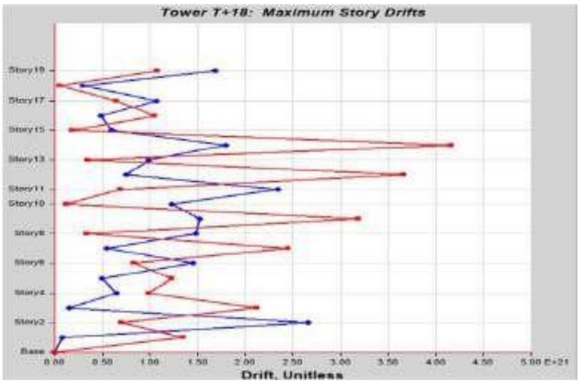

Fig. 29: Max and Min story drift with 1000mm Separation Gap for G+13 building (Y - Direction)

C. Story-Overturning Moments Force

The story-overturning moment plays a significant factor in the project of the building and building. Links must properly be designed and constructed to overcome over-turning movement to ensure the safety of occupants and prevent failures in X direction.

Fig. 30: Max and Min story overturning moments of G+18

Fig. 31: Max and Min story overturning moments of G+13

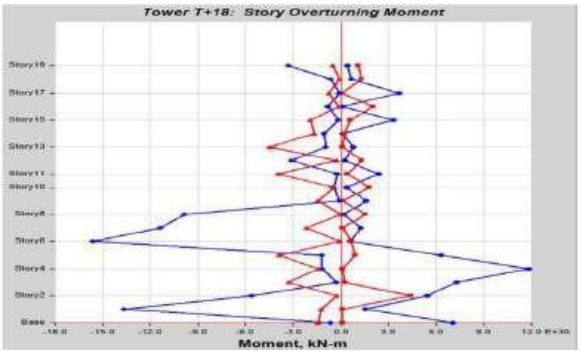

Fig. 32: Max and Min story overturning moments with 50mm gap for G+18

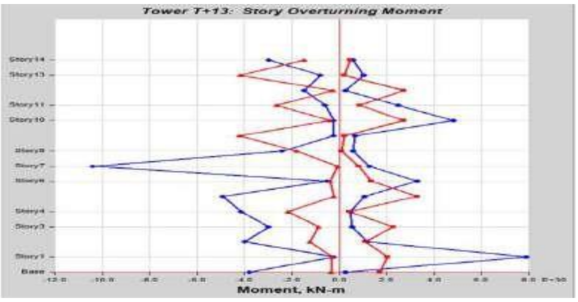

Fig. 33: Max and Min story overturning moments with 50mm gap for G+13

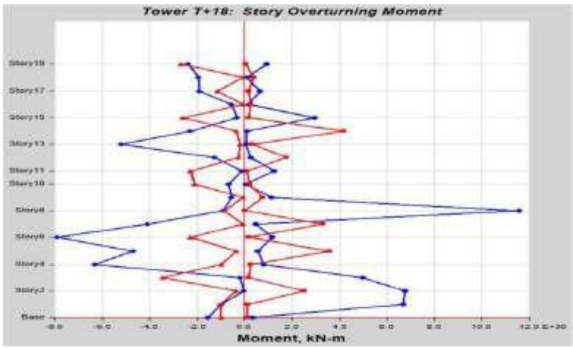

Fig. 34: Max and Min story overturning moments with 500mm gap for G+18

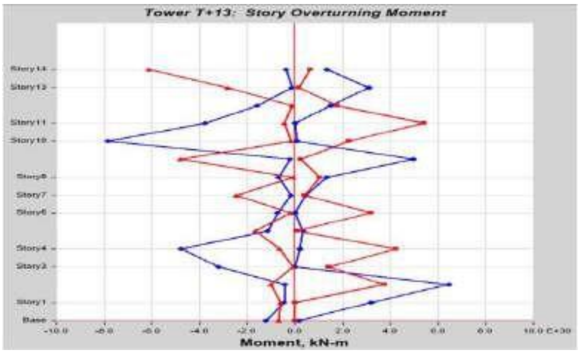

Fig. 35 Max and Min story overturning moments with 500mm gap for G+13

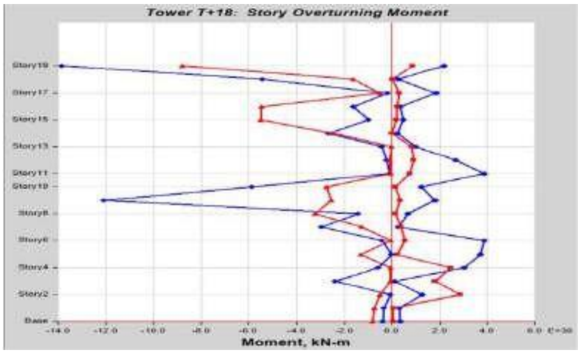

Fig. 36: Max and Min story overturning moments with 1000mm gap for G+18

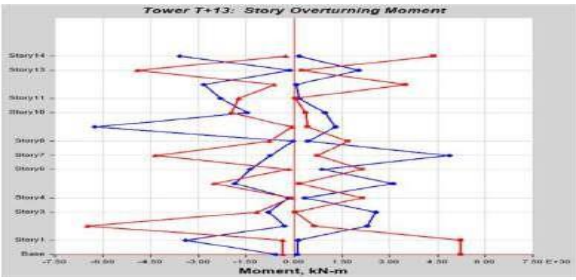

Fig. 37: Max and Min story overturning moments with 1000mm gap for G+13

D. Story Shear Response

Story shear responses for the building during seismic events or key indications on how seismic loads are distributed and resisted throughout their building's various levels. The analysis of story-shear responses provides an improved knowledge of how the separation distance of adjacent buildings affects seismic response and damage possibility in X direction.

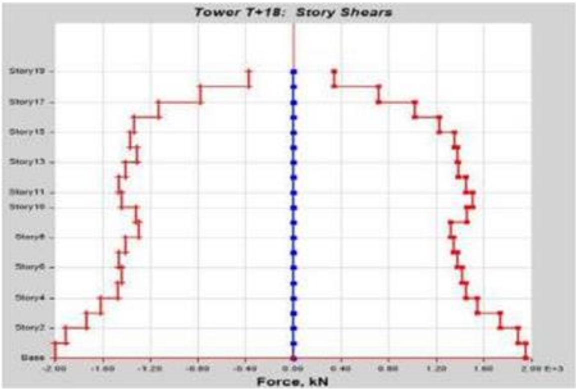

Fig. 38: Max and Min story shear of G+18

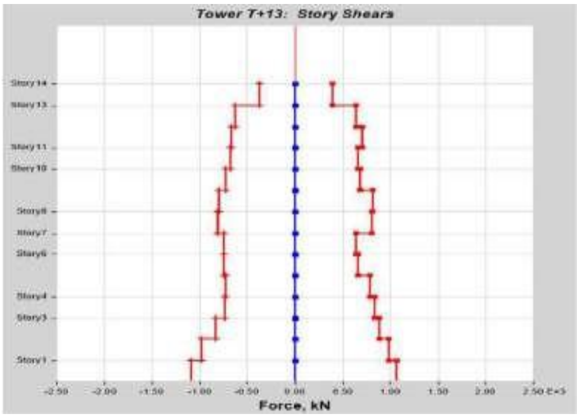

Fig. 39: Max and Min story shear of G+13

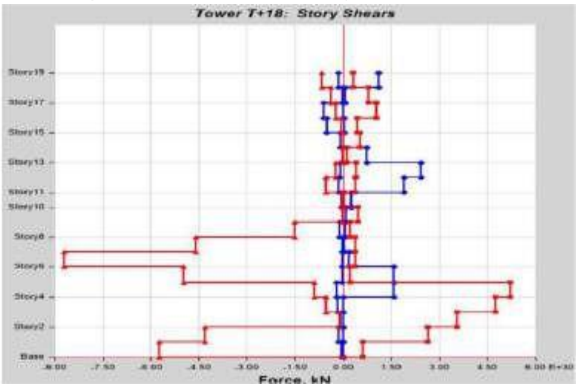

Fig. 40: Max and Min story shear with 50mm gap for G+18

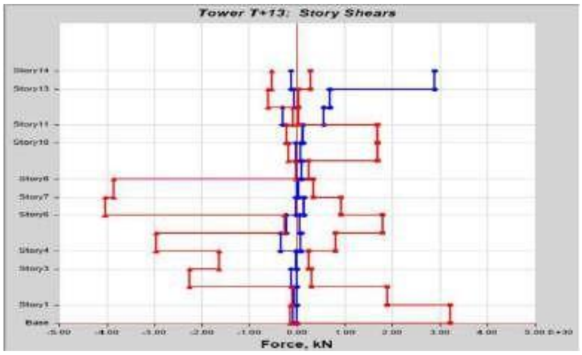

Fig. 41: Max and Min story shear with 50mm gap for G+13

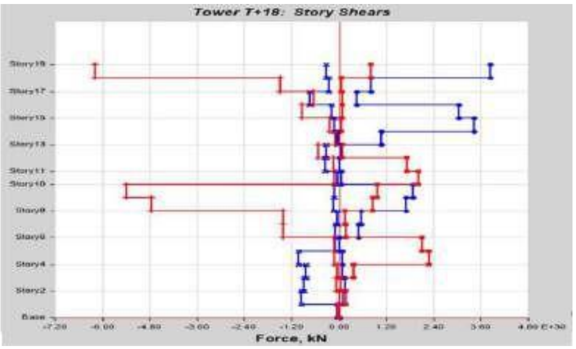

Fig. 42: Max and Min story shear with 500mm gap for G+18

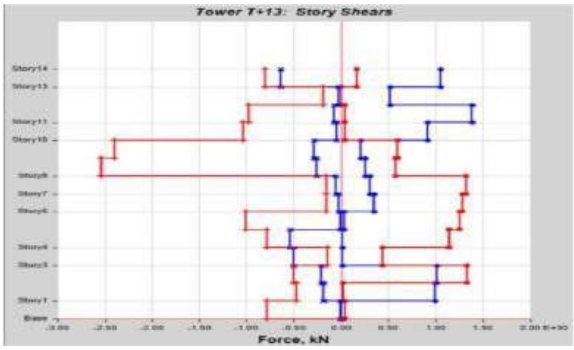

Fig. 43: Max and Min story shear with 500mm gap for G+13

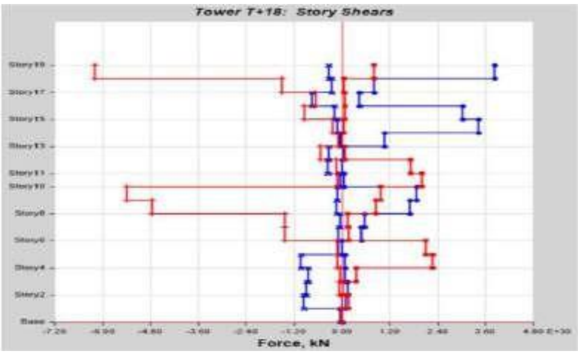

Fig. 44: Max and Min story shear with 1000mm gap for G+18

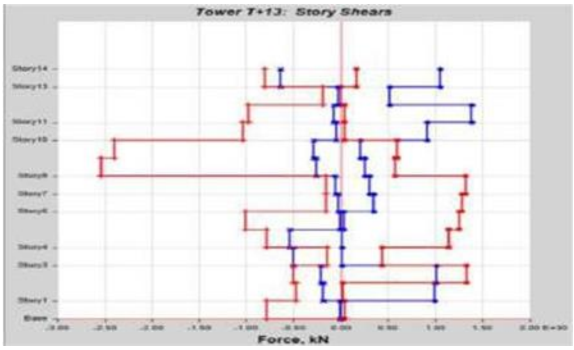

Fig. 45: Max and Min story shear with 1000mm gap for G+13

V. CONCLUSIONS

This research highlights the critical importance of adequate separation gaps between adjacent high-rise buildings in seismic zones, emphasizing the potential damaging effects of seismic pounding. The key findings and conclusions are as follows:

Displacement Response: The study reveals that the displacement of structures is significantly influenced by the separation distance. When the gap between the buildings is small (50 mm), the displacement, particularly in the taller G+18 building, is much higher due to increased pounding forces. As the separation distance increases, the displacement reduces, indicating that adequate spacing between buildings can mitigate the severity of the seismic impact.

Inter-Story Drift Ratio: The analysis demonstrates that inter-story drift ratios, a key indicator of structural damage, are considerably higher when buildings are positioned close together. The G+13 building experiences increased drift ratios at smaller separation gaps (50 mm), making it more susceptible to damage. As the separation distance increases, the drift ratios approach those observed in freestanding scenarios, highlighting the need for larger gaps to minimize structural failure.

Overturning Moments: The study shows that the proximity of structures influences overturning moments, particularly at higher floors. Smaller separation gaps (50 mm) amplify the overturning moments, potentially leading to significant stress concentrations and structural damage. As the gap increases, the pounding effect diminishes, reducing the overturning moments and the risk of structural failure.

Story Shear Response: The research demonstrates that the shear forces experienced by the structures are higher in closer proximity, with a significant increase in story shear forces at smaller separation gaps. These forces are particularly noticeable at lower and upper floors. Larger gaps reduce the shear forces, although they remain elevated compared to freestanding scenarios, further emphasizing the need for adequate separation to reduce seismic pounding.

Seismic Pounding Impact and Design Recommendations: The findings underscore the severe impact of seismic pounding, particularly when the separation gaps between structures are insufficient. This study confirms that small gaps between buildings lead to increased seismic forces, resulting in higher displacement, drift, shear, and overturning moments. Consequently, the buildings are more vulnerable to damage and failure during seismic events. The research strongly recommends maintaining sufficient separation distances between adjacent structures, particularly in seismic-prone areas.

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