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Impact of Sloping Ground on the Seismic and Wind Performance of High-Rise Buildings with Outrigger Bracing Systems

Md. Mahmudul Haque Ovi
Graduate in Civil Engineering
Department of Civil Engineering
Ahsanullah University of Science and Technology
Dhaka, Bangladesh

Baria Obaed Bintu
Graduate in Civil Engineering
Department of Civil Engineering
Ahsanullah University of Science and Technology
Dhaka, Bangladesh

Bipul Sarkar
Graduate in Civil Engineering
Department of Civil Engineering
Ahsanullah University of Science and Technology
Dhaka, Bangladesh

Dr. Sharmin Reza Chowdhury
Professor
Department of Civil Engineering
Ahsanullah University of Science and Technology
Dhaka, Bangladesh

Abstract*- In recent years, the construction of high-rise buildings in Bangladesh has increased dramatically, particularly in the cities Dhaka and Chittagong. Chittagong city faces some unique challenges while designing high-rise buildings due to its geographical and topographical conditions. Much of the city lies on the sloping terrain and located in seismic zone III, which is deemed to be an earthquake prone area. Besides, the wind turbulence due to its proximity to the sea makes the structural design even more complicated because the structure has to withstand both seismic and wind forces. These challenges underscore the importance of assessing the stability and performance of high-rise buildings constructed on sloping ground in such critical environmental conditions. In the construction of high-rise buildings, the core outrigger bracing system is one of the well-known frame strut systems that has been designed to improve the lateral stiffness and resistance to seismic and wind loads. This design system can enable the construction of taller and more slender buildings without compromising safety and performance. The goal of this study is to evaluate the structural performance of high-rise buildings on 5 degree and 10 degree sloping ground and also comparing configurations of without bracing, with two outrigger bracing and with three outrigger bracing systems. The study reveals that high-rise buildings situated on 5 degree sloping ground exhibit superior performance compared to those on 10 degree sloping ground. Furthermore, the study also reveals that sway displacement and story drift were reduced by 25.68 % and 14.81 %, respectively, with two outrigger bracing system and 36.88 % and 33.33 %, respectively, with three outrigger bracing system for 5 degree sloping ground. The findings conclude that three outrigger bracing system shows superior performance in enhancing stability and structural efficiency under challenging environmental conditions.

***Keywords*- Seismic Load, Wind Load, Outrigger Bracing System, Sloping Ground.**

1. INTRODUCTION

High-rise buildings are becoming common in modern urban landscapes due to the growing demand for vertical development. Only high-rise structures offer an acceptable solution to the challenges posed by limited land resources in urban areas. It enables greater population density and economic activity within a confined footprint [1]. These tall structures face significant challenges from dynamic loads such as seismic and wind loads, which can cause lateral instability, excessive displacement, and structural damage. The design and performance assessment of high-rise buildings are critical for ensuring safety, stability, and resilience under such conditions.

Outrigger bracing system represent a common and crucial structural system employed in buildings as a primary lateral load resisting system. These systems are specifically designed to counteract horizontal forces arising from environmental loads such as wind and earthquakes by ensuring the stability and integrity of the buildings under such conditions [2]. By connecting the building's core to its perimeter columns, outriggers improve structural performance by minimizing story displacement and story drift, thus making them a more effective solution for improving the seismic and wind resistance of high-rise buildings [3].

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2. LITERATURE REVIEW

Parsa et al. [4] analyzed multi story buildings on flat ground, 5 degree sloping ground and 10 degree sloping ground in India by using ETABS. Their findings revealed that the story drift, base shear, and time period of building was maximum for flat slope ground compared to 5 degree sloping ground and 10 degree sloping ground for seismic zone V. They concluded that sloping ground buildings were more earthquake resistant than flat ground buildings.

Gaikwad and Pujari [5] conducted a research on of low-rise, mid-rise, and high-rise reinforced concrete (RC) structures on 10 degree, 20 degree, and 30 degree sloping ground under seismic loads in India by using ETABS. According to their analysis the base shear, story displacement, and story drift were maximum at 10 degree sloping ground. In addition, mode period decreased with the increases in slope angle of ground.

Wajid and Babu [6] analyzed and compared the behavior of outrigger, belt wall, and bracing systems as lateral load resisting mechanisms in a 320 m high, elliptically planned building comprising 80 stories (78 stories above ground level, 2 stories below ground level) subjected to wind forces in India by using ETABS. They reported that both 600 mm outriggers and belt walls at levels 73 and 19 significantly reduced lateral displacement by 50% and 52%, respectively and core moments by 38% and almost 40%, respectively. Conversely, the combined system lowered the lateral displacement by almost 60%, core moment by 48%, and core stress by 39%, indicating a synergistic effect in resisting wind induced forces. According to their finding it can be concluded that the combined outrigger and belt system yielded the most substantial improvements.

Nanduri et al. [7] explored the optimal placement of outrigger systems in high-rise (RC) buildings subjected to both wind and earthquake loads in India by using ETABS. Their analysis revealed that placing an outrigger at the top storey as a cap truss reduced the maximum drift from 50.63 mm (for a core-only structure) to 48.20 mm and 47.63 mm with and without a belt truss, respectively. The introduction of a second outrigger at mid height of building significantly improved performance and yielding drift reductions about 18.55% and 23.01% with and without a belt truss system. Their research confirmed that the incorporation of outrigger and belt truss system can enhances stiffness and lateral load efficiency of a high-rise building and the most effective location for an outrigger system is at the mid height of the building.

Bhargavi and Devi [8] conducted a study on a 40 story high-rise building in India subjected to earthquake loads with focusing on optimizing the placement of outrigger structural systems by using ETABS. Their findings revealed that strategically located outriggers effectively reduced base shear, displacement, and story drift, leading to more efficient structural performance and potentially lower construction costs. In addition, they found that the optimal placement for one outrigger was at mid-height, for two outriggers at one-third and two-thirds height, for three at one-quarter, one-half and three-quarters height and for four at one-fifth, two-fifths, three-fifths and four-fifths height. They concluded that four outrigger configuration provides the most effective seismic resistance.

3. OBJECTIVES

- To evaluate the performance of high-rise building with core outrigger bracing system according to BNBC 2020.
- To investigate the effect of story displacement, story drift, and efficiency of bracing systems of high-rise building with outrigger bracing system.
- To compare the performance of high-rise buildings with and without outrigger bracing system on sloping ground.

4. METHODOLOGY

This research examines the structural response of a G+29 storied regular RC frame building utilizing Static Linear Analysis in ETABS. The study involved the creation of 6 structural models, each incorporating rigid outrigger systems with variations in both the number of bracings (two and three) and sloping ground (5 degree and 10 degree). These outrigger configurations were strategically placed at different levels of the building to assess their effectiveness in improving structural performance under static loading conditions.

5. MODEL DESCRIPTION

5.1 Design Data

The detail specification of G+29 storied regular building including modelling concepts are given in Table 1.

Table 1: Structural Details.

Contents	Corresponding Data
Type of Structure	G+29 storied building
Project Location	Chittagong, Bangladesh
Column Size	20” x 20”
Beam Size	12” x 15”
Steel Section	W 24 X 94
Thickness of Shear Wall	10”
$F_{c'}$	4000 psi
F_y	60000 psi
Seismic Zone	III
Loads	LL, DL, PW, FF applied according to BNBC 2020

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5.2 Building Models

Model 1: Without Outrigger Bracing System for 5 Degree Sloping Ground
Model 2: Without Outrigger Bracing System for 10 Degree Sloping Ground
Model 3: Two Outrigger Bracing System for 5 Degree Sloping Ground
Model 4: Two Outrigger Bracing System for 10 Degree Sloping Ground
Model 5: Three Outrigger Bracing System for 5 Degree Sloping Ground
Model 6: Three Outrigger Bracing System for 10 Degree Sloping Ground

The 3D view and elevation view of without outrigger bracing system, two outrigger bracing system and three outrigger bracing system for 5 degree and 10 degree sloping ground has shown in Figure 1 to 9.

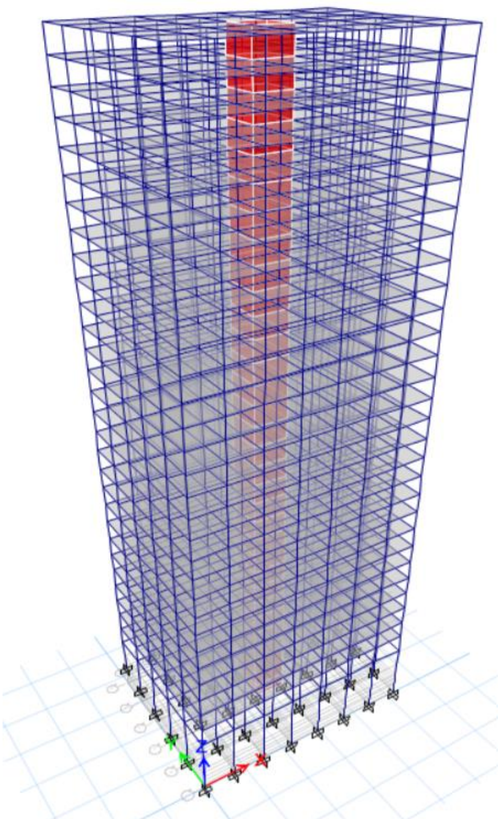

Fig. 1: 3D view of without outrigger bracing system.

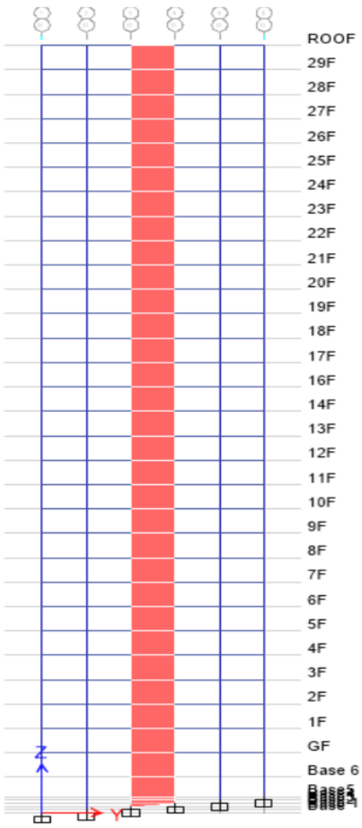

Fig. 2: Elevation view of without outrigger bracing system for 5 degree sloping ground.

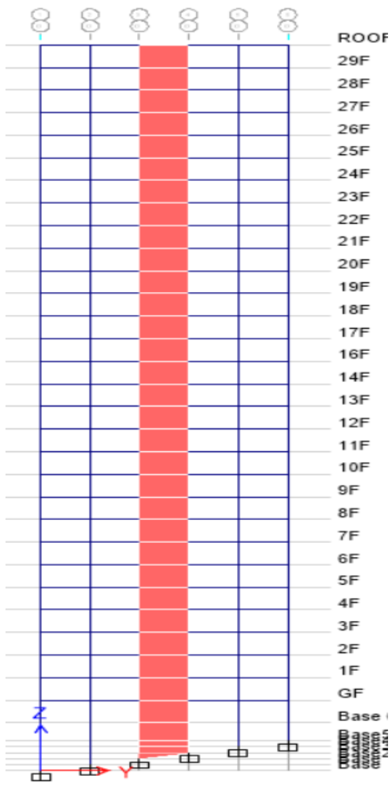

Fig. 3: Elevation view of without outrigger bracing system for 10 degree sloping ground.

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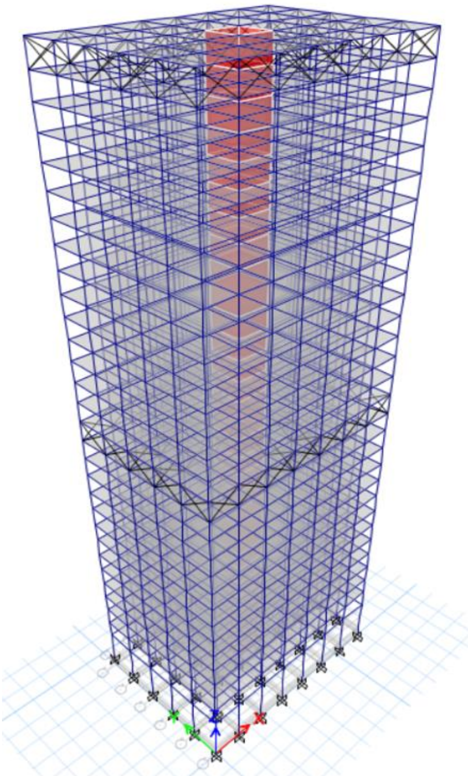

Fig. 4: 3D view of two outrigger bracing system.

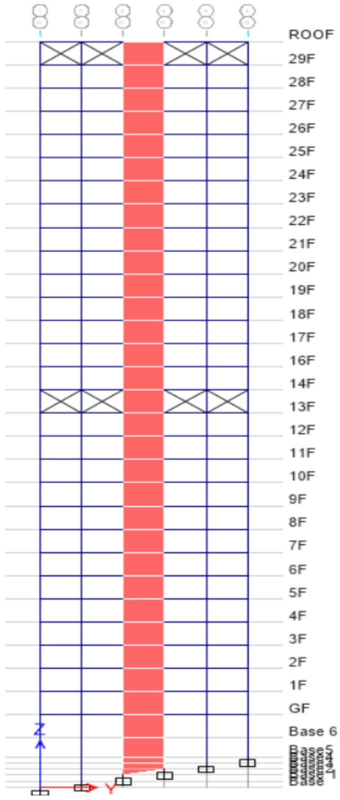

Fig. 6: Elevation view of two outrigger bracing system for 10 degree sloping ground.

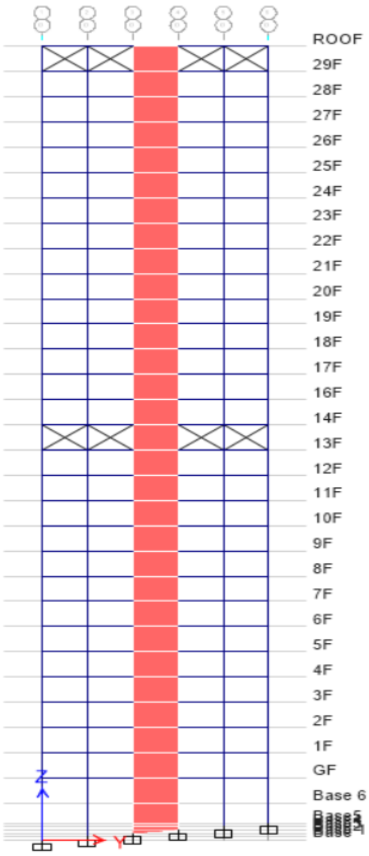

Fig. 5: Elevation view of two outrigger bracing system for 5 degree sloping ground.

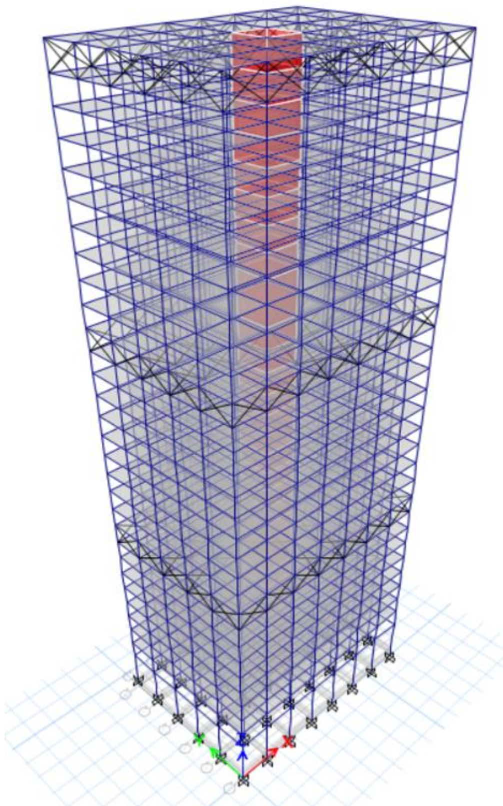

Fig. 7: 3D view of three outrigger bracing system.

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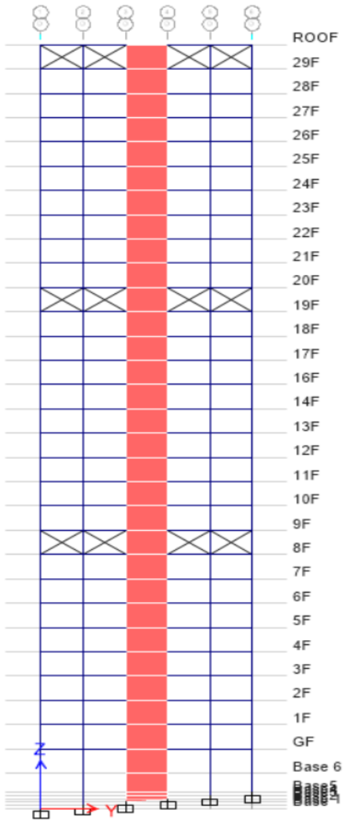

Fig. 8: Elevation view of three outrigger bracing system for 5 degree sloping ground.

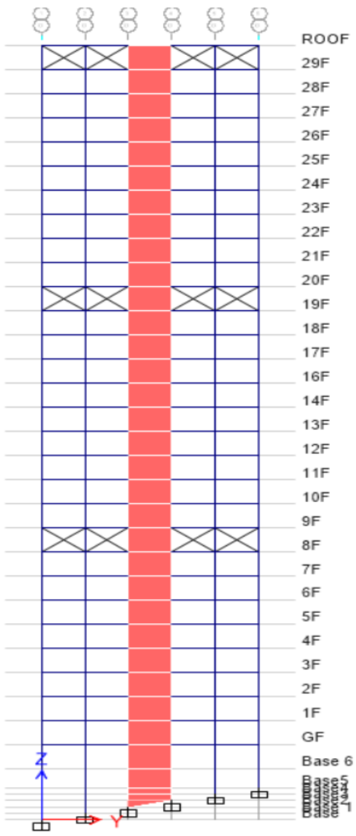

Fig. 9: Elevation view of three outrigger bracing system for 10 degree sloping ground.

6. RESULT AND DISCUSSIONS

6.1 Member Design Check for Gravity Load

Finite element analysis of the structural model in ETABS revealed that all the concrete frame elements were passed the design check. This indicates that the structural system under the influence of gravity loads exhibits the necessary strength and stability as mandated by the applicable standards.

6.2 Maximum Sway Displacement

The results for sway displacements at Figures 10 and 11, which represent a 5 degree slope, show significant variations in displacement based on the type of bracing system used. In the long direction, the maximum displacement without a bracing system is approximately 5.99 inches, while a two outrigger system reduces this to about 4.80 inches and a three outrigger system further decreases it to approximately 3.98 inches. In the short direction, the maximum displacement without a bracing system is around 11 inches, which is significantly reduced to 8.1 inches with a two outrigger system and to 6.98 inches with a three outrigger system. These results indicate that the building without a bracing system experiences the highest displacement, whereas the three outrigger system offers the lowest displacement, thus providing the most effective lateral stability in both directions.

Figures 12 and 13 represent a steeper 10 degree slope, showing similar trends in displacement reduction based on the number of outriggers. In the long direction, the maximum sway displacement for without a bracing system is 6.25 inches. On the other hand, using a two outrigger system reduces the displacement to 5 inches and a three outrigger system reduces it further to 4.23 inches. In the short direction, the maximum displacement without bracing is about 11.3 inches, with a two outrigger system reducing it to 8.24 inches and a three outrigger system further decreasing it to 7.15 inches. These findings reinforce the trend observed in the 5 degree slope: the building without any bracing system experiences the highest displacement, while the three outrigger system results in the lowest displacement. The comparison of maximum sway displacement between 5 degree and 10 degree sloping ground has shown in Figure 14.

International Journal of Engineering Research & Technology (IJERT)
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Vol. 14 Issue 08, August - 2025

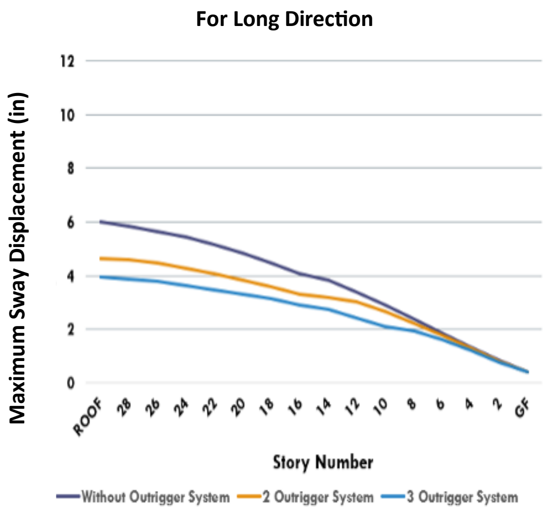

Fig. 10: Maximum Sway Displacement at Long Direction for 5 Degree Slope.

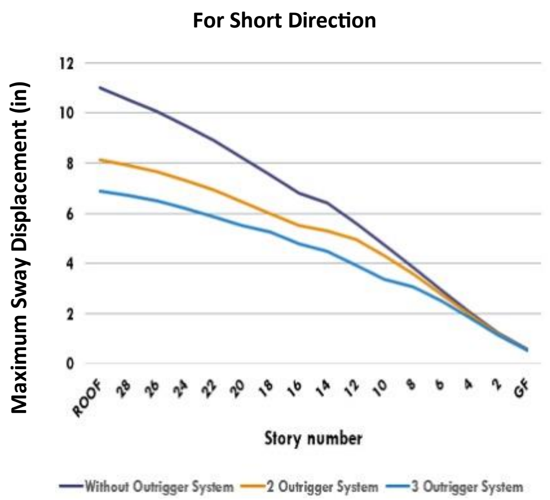

Fig. 11: Maximum Sway Displacement at Short Direction for 5 Degree Slope.

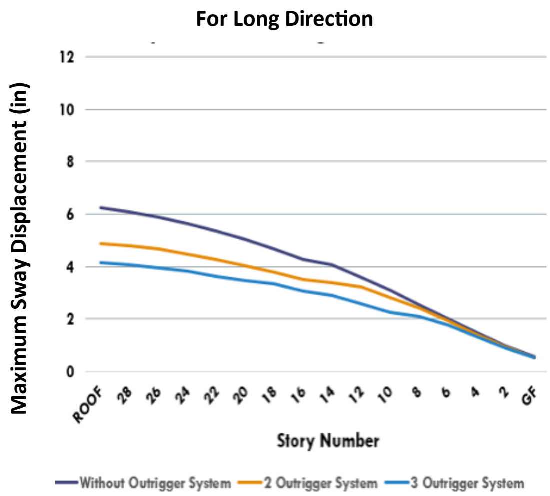

Fig. 12: Maximum Sway Displacement at Long Direction for 10 Degree Slope.

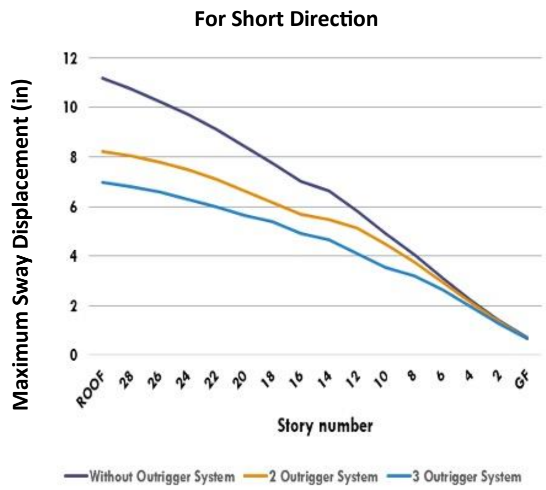

Fig. 13: Maximum Sway Displacement at Short Direction for 10 Degree Slope.

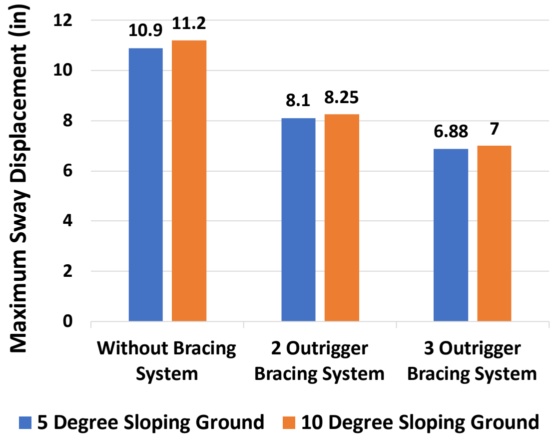

Fig. 14: Comparison of Maximum Sway Displacement for 5 Degree and 10 Degree Sloping Ground.

6.3 Maximum Story Drift

In the long direction for 5 degree sloping ground, the maximum drift without a bracing system is approximately 0.026, while with two outrigger systems, it reduces to about 0.022 and with three outrigger systems, it further decreases to approximately 0.016. Conversely, in the short direction for 5 degree sloping ground, the maximum drift without a bracing system is around 0.029, which decreases to 0.021 for two outrigger systems and 0.019 for three outrigger systems. This clearly demonstrates that the absence of a bracing system results in the highest drift values, while implementing a three outrigger system achieves the lowest drift values, indicating superior lateral stiffness.

In the long direction for 10 degree sloping ground, the maximum drift without a bracing system is about 0.027, reducing to 0.022 for two outrigger systems and 0.017 for three outrigger systems. In the short direction for 10 degree sloping ground, the maximum drift is approximately 0.029 without a bracing system, 0.024 for two outrigger systems and 0.019 for three outrigger systems. These results again highlight that the absence of a bracing system leads to the maximum drift, whereas the three outrigger system provides the least drift, offering better lateral stiffness and stability for buildings on sloped ground. The comparison of maximum story drift between 5 degree and 10 degree sloping ground has shown in Figure 19.

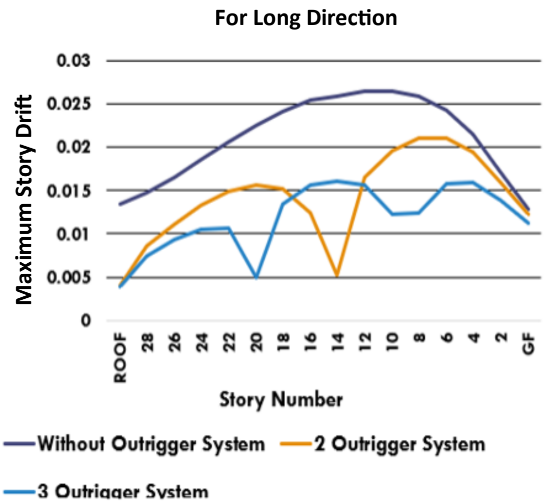

Fig. 15: Maximum Story Drift at Long Direction for 5 Degree Slope.

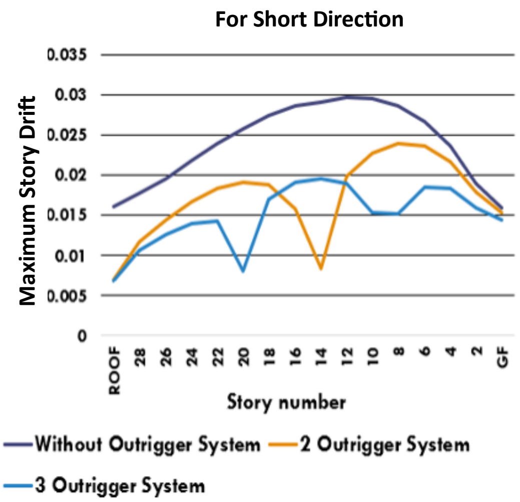

Fig. 16: Maximum Story Drift at Short Direction for 5 Degree Slope.

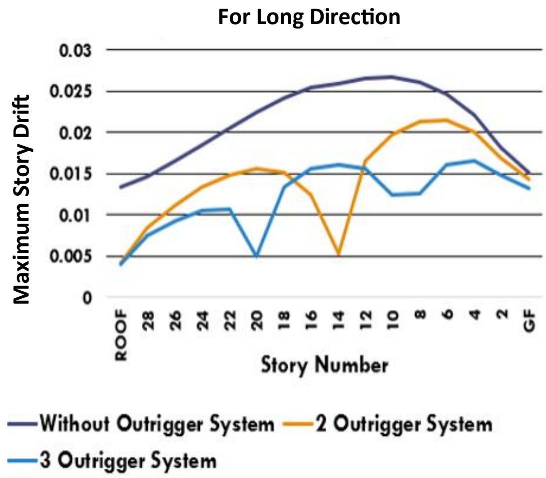

Fig. 17: Maximum Story Drift at Long Direction for 10 Degree Slope.

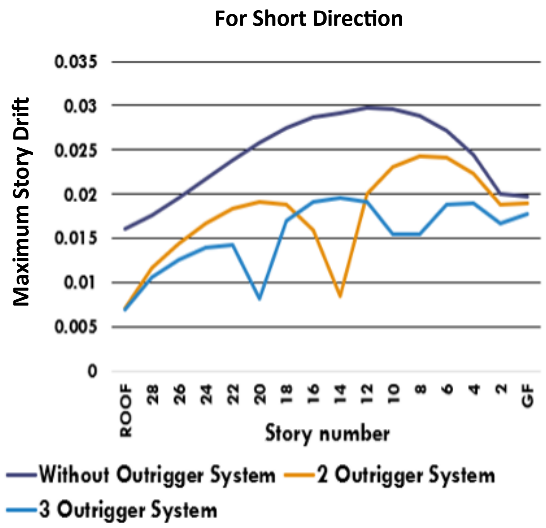

Fig. 18: Maximum Story Drift at Short Direction for 10 Degree Slope.

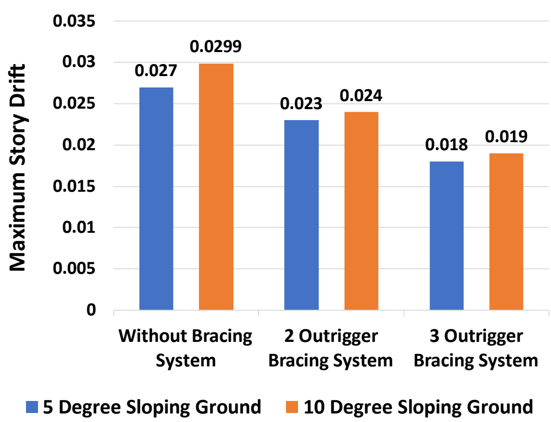

Fig. 19: Comparison of Maximum Story Drift for 5 Degree and 10 Degree Sloping Ground.

6.4 Comparison of Efficiency between Two Outrigger System and Three Outrigger System Across 5 Degree and 10 Degree Slopes

The result of drift reduction efficiency for buildings on 5 degree and 10 degree slopes have been presented in Figure 20. Where the Y axis represents the drift reduction efficiency as a percentage, while the X axis represents percentage of load of the building. For 45% and 58% of the total load both bracing systems exhibit the same level of efficiency. For 70% of the total load three outrigger bracing system reaches its peak drift reduction efficiency of approximately 82%. After attaining this peak, the efficiency of the three outrigger bracing system begins to decline.
According to the findings it can be concluded that two outrigger bracing system demonstrates a more consistent performance at moderate loads. On the other hand, three outrigger bracing system proves to be more effective at higher load percentages.

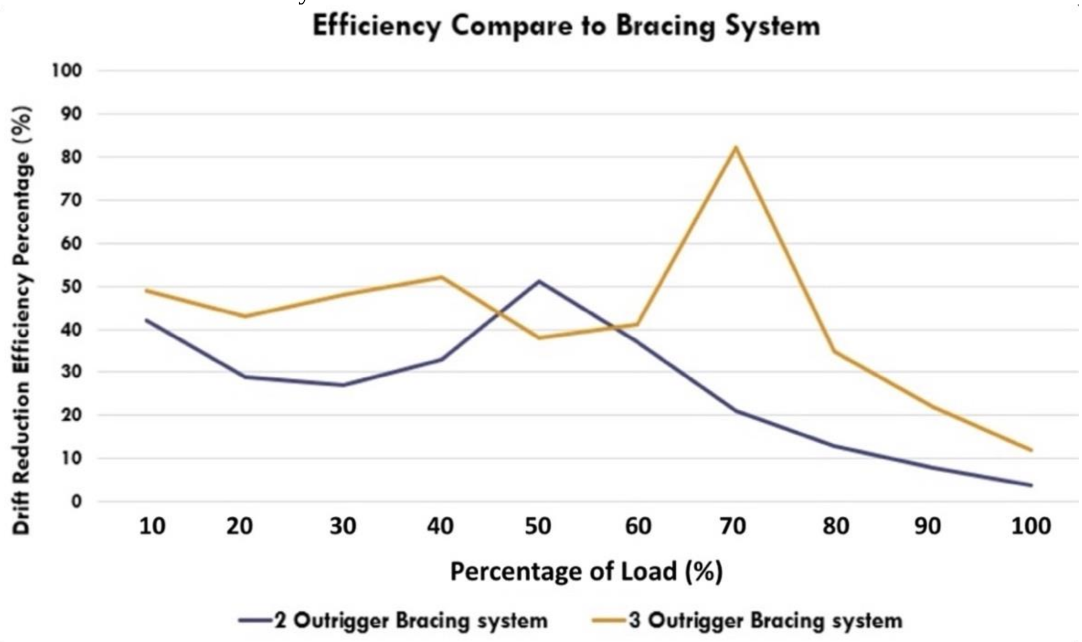

Fig. 20: Comparison of Efficiency between Two and Three Outrigger Bracing System.

CONCLUSIONS

This study assessed the overall behavior of outrigger braced building under wind and seismic load by using Static Linear Analysis from which the following conclusion can be made:

- Increasing the number of outriggers in bracing system leads to a significant reduction in the maximum sway displacement of building. The implementation of a 3 outrigger bracing system results in a lower maximum sway displacement compared to both a 2 outrigger bracing system and a structure without any outrigger bracing system.
- Buildings experience greater maximum sway displacement on the 10 degree sloping ground compared to the 5 degree sloping ground for all considered bracing configurations.
- Increasing the number of outriggers in bracing system leads to a significant reduction in the maximum story drift of building. The implementation of a 3 outrigger bracing system results in a lower maximum story drift compared to both a 2 outrigger bracing system and a structure without any outrigger bracing system.
- Buildings experience greater maximum sway displacement on the 10 degree sloping ground compared to the 5 degree sloping ground for all considered bracing configurations.

SCOPE OF FUTURE STUDY

- Further studies can focus on conducting a comprehensive dynamic analysis to understand and compare the response of different building models.
- Further research can investigate the seismic performance and structural response of irregular buildings situated on sloping ground, considering the unique challenges posed by varying foundation levels and potential torsional effects.
- The building models can be compared by changing the soil-structure interaction to provide better information about the response of the buildings.
- Future research can explore the optimum placement of outrigger bracing systems.
- The comparative analysis of various outrigger bracing systems can be conducted to evaluate their relative efficiency and effectiveness in mitigating story displacement and story drift.

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REFERENCE

[1] M. B. Sajjanshetty and Galanna, "A study on static and dynamic behaviour of outrigger structural system for different structural configuration," Journal of Scientific Research and Technology (JSRT), vol. 1, no. 7, pp. 37-52, 2023.

[2] M. Hussini and S. Nasier, "A review paper on seismic pareformance of high-rise building using bracing, diagrid and outrigger system," International Journal of Engineering Research & Technology (IJERT), vol. 9, no. 6, pp. 1148-1150, 2020.

[3] A. H. Etemad and A. K. Tiwary, "Comparison of tubular, outrigger and bracing system for stabilization of high-rise buildings," International Journal of Civil Engineering and Technology (IJCIET), vol. 10, no. 3, pp. 1968-1977, 2019.

[4] S. Parsa, B. Nikhil and E. Pranay, "Analysis and design of multi story building on sloping ground and flat ground by using ETABS," Material Science and Technology, vol. 21, no. 6, pp. 390-400, 2022.

[5] A. A. Gaikwad and D. A. B. Pujari, "Seismic analysis of low rise, mid rise and high rise rcc structure on sloping ground," International Research Journal of Engineering and Technology (IRJET), vol. 6, no. 7, pp. 1357-1365, 2019.

[6] M. A. Wajid and S. A. Babu, "Use of outrigger, belt wall and bracing systems in high rise building subjected to wind loads," International Journal of Engineering Development and Research, vol. 8, no. 1, pp. 75-81, 2020.

[7] P. R. K. Nanduri, B. Suresh and M. I. Hussain, "Optimum position of outrigger system for high-rise reinforced concrete buildings under wind and earthquake loadings," American Journal of Engineering Research (AJER), vol. 2, no. 8, pp. 76-89, 2013.

[8] V. Bhargavi and M. S. Devi, "Analysis of outrigger structural system for high-rise building subjected to earthquake loads," International Journal of Innovations in Engineering Research and Technology (IJIERT), vol. 7, no. 8, pp. 20-32, 2020.

Md. Mahmudul Haque Ovi was born in Rajbari, Dhaka, Bangladesh, in 2001. He is recently graduated in Civil Engineering from the Faculty of Civil Engineering, Ahsanullah University of Science and Technology (AUST), Dhaka, Bangladesh. Currently, he is preparing for his postgraduate study. His current research interests include performance-based seismic design & resilience, assessment & retrofitting of buildings, analytical & numerical modeling of structural members, and performance enhancement of concrete through additives.

Baria Obaed Bintu was born in Dhaka, Bangladesh, in 2001. She is recently graduated in Civil Engineering from the Faculty of Civil Engineering, Ahsanullah University of Science and Technology (AUST), Dhaka, Bangladesh. Currently, she is preparing for her postgraduate study. Her current research interests include earthquake-resistant design and retrofitting, high-performance and sustainable materials including fiber-reinforced and self-healing concrete, structural health monitoring, and innovative design approaches for bridges and high-rise buildings.

Bipul Sarker was born in Dhaka, Bangladesh and completed his Bachelor's degree in Civil Engineering from Ahsanullah University of Science and Technology. With a strong academic background in structural engineering, his interests lie in sustainable concrete materials and structural retrofitting. He is passionate about developing long-lasting, environmentally friendly construction solutions and aims to contribute to safer and more resilient infrastructure.

Dr. Sharmin Reza Chowdhury received his B.Sc. and M.Sc. degrees in Civil Engineering and Structural Engineering, respectively, from Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh, in 1996 and 2000. He also received his PhD degree in Structural Engineering from Bogazici University, Istanbul, Turkey, in 2011. He currently works as the Treasurer and a Professor of the Department of Civil Engineering at Ahsanullah University of Science and Technology, Dhaka, Bangladesh. He has contributed significantly to the accreditation process as an evaluator for the Board of Accreditation for Engineering and Technical Education (BAETE) under the Institution of Engineers, Bangladesh (IEB). He also contributed significantly as a researcher and coordinator on behalf of AUST in an international project funded by the Japan International Cooperation Agency (JICA) and the Government of Bangladesh (GoB). Furthermore, he has served as an expert member on interview boards for the Public Service Commission (PSC) and on the tender document evaluation committee of the Civil Aviation Authority, Bangladesh (CAAB). He was honored with the prestigious IEB (Institution of Engineers, Bangladesh) Award for the Best Paper in 2000. Additionally, he was awarded the Bogazici University Foundation Fellowship in Turkey, a recognition specifically designed for international PhD students. He has authored or co-authored more than 70 publications in international journals and conference proceedings. His current research interests are seismic analysis of buildings, analytical and numerical modeling of RC members, building materials and construction, assessment and retrofitting of buildings, and experimental studies.