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A COMPARATIVE STUDY ON ANALYSIS OF RCC FRAMED G+9 BUILDING STRUCTURE USING FLUID VISCOUS DAMPER AND FRICTION DAMPER

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Abstract - *This study investigates the seismic performance of an RCC framed G+9 building structure, focusing on the use of fluid viscous dampers and friction dampers to enhance resilience and reduce vibrations caused by ground motion. The building's architectural and structural design was developed using AutoCAD, with manual design calculations and modeling performed in ETABS software. Various load scenarios, including live, dead, wind, and seismic loads, were considered to evaluate the effectiveness of both damper types. Key findings reveal that both damping systems significantly improved the building's performance compared to the undamped configuration. Friction dampers demonstrated superior results, particularly in stiffness enhancement, showing an average improvement of 48% and reducing maximum story displacements by 3% in the X-direction and 5% in the Y-direction. Fluid viscous dampers also performed well, especially in minimizing story drifts in the Y-direction, achieving a 0.5% improvement in both X and Y directions. A comparative analysis highlights that friction dampers excelled in stiffness control, while fluid viscous dampers were more effective in vibration reduction. The study concludes that incorporating damping systems is crucial for improving the safety and resilience of RCC structures in seismic-prone areas, offering valuable insights for better decision-making in structural design and implementation.*

Key Words: Structural analysis, fluid viscous damper, friction damper, Story drift

1.INTRODUCTION

In the world of structural engineering, the seismic analysis of buildings stands as a cornerstone in the world of structural engineering, the seismic analysis of buildings stands as a cornerstone in ensuring their safety and resilience against the formidable forces of earthquakes. As seismic events continue to pose significant threats to infrastructure worldwide, the integration of effective damping systems emerges as a paramount strategy in fortifying buildings against potential devastation. [1-3] Among the array of damping technologies, friction dampers and fluid viscous dampers have emerged as notable contenders, each offering unique features and advantages in mitigating structural vibrations and enhancing seismic performance. [4-7]

Friction dampers harness the principle of friction to dissipate energy and attenuate the oscillations induced by seismic forces. By strategically introducing controlled frictional resistance within the structural framework, friction dampers bolster the building's stiffness and resilience, thereby augmenting its ability to withstand seismic loads. [8,9] On the other hand, fluid viscous dampers leverage the viscous properties of fluids to absorb and dissipate energy, offering a versatile solution for damping structural vibrations across a wide spectrum of frequencies. The inherent characteristics of fluid viscous dampers make them adept at mitigating both low and high-amplitude vibrations, thereby providing comprehensive protection against seismic hazards. [10,11]

Central to the study's methodology is the utilization of ETABS software, a robust structural analysis and design tool renowned for its capability to simulate complex structural behaviors under various loading conditions. Through meticulous architectural and structural design, coupled with rigorous manual calculations and modeling within the ETABS environment, the study aims to comprehensively evaluate the seismic performance of an RCC framed G+9 building structure. [12] By subjecting the building model to live, dead, wind, and seismic loads, the study endeavors to elucidate the efficacy of friction dampers and fluid viscous dampers in mitigating structural vibrations and enhancing overall seismic resilience.

Ultimately, the study underscores the paramount importance of damping systems in safeguarding buildings against seismic hazards. By harnessing the unique capabilities of friction dampers and fluid viscous dampers, engineers can effectively fortify structures, thereby averting potential damage and preserving lives and livelihoods. Through meticulous analysis and thoughtful integration of damping technologies, the study endeavors to contribute to the advancement of resilient infrastructure, paving the way for safer and more sustainable built environments in seismic-prone regions [13, 14].

This study aims to conduct a comprehensive analysis of the seismic performance of an RCC framed G+9 building structure, focusing on the efficacy of friction dampers and fluid viscous dampers in enhancing resilience against seismic hazards. Through the utilization of ETABS software, the objectives encompass developing a detailed architectural and structural design in adherence to Indian building codes, performing thorough structural analysis under diverse loading conditions, and evaluating seismic performance by assessing factors like displacements, drifts, and accelerations

(15, 16). Additionally, the effectiveness of dampers in reducing structural vibrations is assessed, with a specific focus on friction dampers and fluid viscous dampers. A comparative analysis is conducted to gauge the advantages and disadvantages of each damper type, considering factors such as cost-effectiveness and long-term maintenance requirements (17-20). By systematically addressing these objectives, the study aims to provide valuable insights into the role of damping technologies in enhancing the seismic resilience of building structures, thereby contributing to the advancement of resilient infrastructure in seismic-prone regions.

2. METHODS

The process used in this study report starts with the AutoCAD drawing of a G+9 Building design. A thorough manual design calculations is then performed for a variety of structural components, including as slabs, beams, columns, and stairs. After that, the structure is modelled using the ETABS Software, considering various load circumstances like live, dead, wind, and seismic loads. After that, the building's structural analysis is carried out, accounting for each of these load circumstances, and the outcomes are carefully analyzed.

Moreover, the study incorporates the characteristics of viscous and friction dampers. The damper characteristics are taken into consideration during two separate phases of the building's seismic performance evaluation. The seismic analysis findings of the viscous dampers and friction dampers are then compared, and a thorough analysis of the results is carried out.

3. TECHNICAL SPECIFICATION OF STRUCTURES

The architectural and structural details are provided in Table 1 below. This information is essential for the analysis. A thorough understanding of these details is vital for evaluating the building's performance, particularly under dynamic loading conditions. These architectural and structural details serve as a foundation for advanced modeling and simulation efforts. Figure 1 presents a 3D rendered view of the structure.

Table -1: Architectural and structural Details of Structure

An Architectural Plan of Building confirming to all Architectural aspects as required:			
1	Type of Structure	:	Multi-Storeys Rigid Jointed RC Frame Structure
2	No. of Storeys	:	G+9 Storeys
3	Floor to Floor Height	:	3 meters
4	Plinth Level	:	1.25 meter above Ground Level
5	Location of Structure	:	Chennai- Tamil Nadu - India
Site Details			
6	Surrounding Location of Structure	:	Urban Region: Developed Complex Area
7	Type of Soil on which Structure is rest	:	Medium Soil (Poorly Graded Sand: Stiff Soil)
8	Safe Bearing Capacity of Soil	:	400 kN/m2

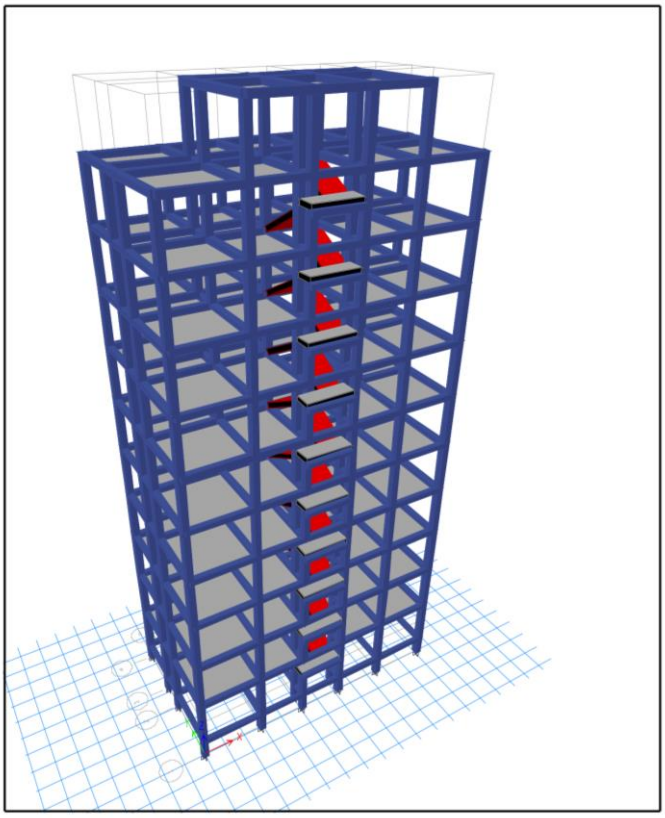

Fig -1: 3D Render View of the Structure

4. SEISMIC ANALYSIS DETAILS

The pivotal in understanding how the structure is expected to respond to seismic events. Table 2 tabulated the seismic details utilized in this study. These factors are essential for conducting accurate seismic analyses, as they help determine the forces that the building will experience during an earthquake. Moreover, the selection of appropriate seismic design criteria is crucial for ensuring that the structure meets safety standards and performance objectives.

Table -2: Seismic Analysis Details of Structure

1	Seismic Zone	:	III
2	Zone Factor (Z)	:	0.16
3	Site Type	:	II for Medium Soil as per Table 4 of IS 1893 (Part 1): 2016
4	Importance Factor (I)	:	1.2 as per Cl.7.2.3 and Table 8 of IS 1893 (Part 1): 2016
5	System	:	Special Moment Resisting Frame
6	Response Reduction Factor (R)	:	5 as per Cl.7.2.6 and Table 9 of IS 1893 (Part 1): 2016
7	Percentage of Imposed Load to be Considered in Seismic Weight	:	25% for LL is up to 3 kN/m2 as per Cl.7.3.1 and Table 10 of IS 1893 (Part 1): 2016

5. DAMPER DETAILS

5.1. Fluid viscous damper

Taylor Devices Inc.'s fluid viscous dampers are engineered for exceptional performance during dynamic events like earthquakes. These dampers feature non-linear characteristics with tight tolerances, ensuring long-term reliability. The damping force is velocity-dependent, peaking when structural stress is minimal and reducing to zero at maximum deflection, effectively dissipating energy without requiring additional structural reinforcement. They also provide perfect re-centering due to near-zero resistance at low velocities. In this study, a Taylor Devices fluid viscous damper (Model 17120) with a force capacity of 250 kN and a weight of 45 kg was equipped in the building for analysis.

5.2. Friction dampers

Pall Dynamics Limited, a top authority on damping systems, provided the specifications that were used to evaluate the friction damper in this study. The damper that was selected for analysis weighs 0.225 kN and has a mass of 2000 kg. Its linear properties were modeled in the ETABS program with an effective damping capacity of 4000 kN-s/m and an effective stiffness of 20000 kN/m. By dispersing energy through friction, these features allow the damper to efficiently moderate vibrations. The damper, which is designed to function exceptionally well under dynamic loading circumstances, ensures dependable operation, longevity, and effectiveness in mitigating vibrations resulting from wind or seismic forces. This damper's ability to improve structural stability and resilience was highlighted by its comprehensive performance features, which were essential to the analysis conducted in this study.

6. RESULTS AND DISCUSSION

The analysis results, presented below through graphical representations, include Story Response for Story Stiffness (X-Direction and Y-Direction), Story Displacement (X-Direction and Y-Direction), and Story Drifts (X-Direction and Y-Direction).

6.1. Story response - story stiffness (x-direction)

The result presented the Story Response - Story Stiffness in the X-direction for three different structural configurations: without any damper, with a friction damper, and with a fluid viscous damper shown in figure 2. The stiffness values were examined at different floors, specifically at the ground floor and the headroom level.

The maximum and minimum story stiffness values for the structure without any damper were observed to be 592,286.868 kN/m for the ground floor and 22,950.647 kN/m for the headroom. When a friction damper was attached to the structure, the stiffness values significantly increased, with a maximum stiffness of 1,218,623.969 kN/m for the ground floor and 24,797.707 kN/m for the headroom. Similarly, for the structure equipped with a fluid viscous damper, the stiffness values experienced an increase compared to the undamped structure, with values reaching 909,022.466 kN/m for the ground floor and 24,101.394 kN/m for the headroom.

A notable observation from the result was the consistent pattern of higher story response in the structure equipped with the friction damper across all floors. This indicated that the presence of the friction damper enhanced the stiffness of the structure, leading to a more robust response to external forces. This effect was particularly prominent when compared to the structure without any damper and the one with a fluid viscous damper.

In practical terms, the increased stiffness provided by the friction damper suggested improved structural performance in mitigating vibrations and dynamic loads, which could have potentially enhanced the overall resilience and safety of the structure, especially in seismic-prone regions or areas with high wind loads.

Overall, the result highlighted the significant influence of damping systems, particularly friction dampers, on the stiffness and response characteristics of the structure, underscoring their importance in structural engineering applications for mitigating dynamic effects and ensuring structural integrity under various loading conditions.

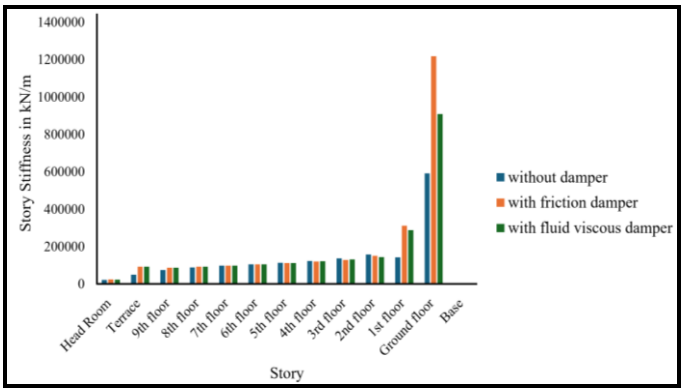

Chart -1: Story Stiffness in X-direction

6.2. Story response - story stiffness (y-direction)

The result depicts the Story Response - Story Stiffness in the Y-direction for three different structural configurations: without any damper, with a friction damper, and with a fluid viscous damper shown in figure 3. The stiffness values were analyzed at various floors, specifically at the ground floor and the headroom level.

For the structure without any damper, the maximum and minimum story stiffness values were recorded as 659,370.618 kN/m for the ground floor and 17,650.729 kN/m for the headroom, respectively. Upon the introduction of a friction damper to the structure, there was a noticeable increase in stiffness, with values reaching a maximum of 1,070,574.832 kN/m for the ground floor and 17,254.214 kN/m for the headroom. Similarly, the structure equipped with a fluid viscous damper exhibited increased stiffness compared to the undamped structure, with values reaching 816,291.5 kN/m for the ground floor and 16,698.91 kN/m for the headroom.

An evident trend observed in the result was the consistently higher story response in the structure equipped with the friction damper across all floors. This implied that the presence of the friction damper contributed to enhanced stiffness and response characteristics of the structure in the Y-direction. This effect was consistent across all floors, indicating the effectiveness of the friction damper in improving the structural performance under dynamic loading conditions.

Practically, the increased stiffness provided by the friction damper suggested improved structural resilience against lateral forces such as wind or seismic loads, which were common challenges in structural engineering. The enhanced response could potentially mitigate the risk of structural damage and improve occupant safety in buildings.

In summary, the result underscored the significant influence of damping systems, particularly friction dampers, on the stiffness and response behavior of structures in the Y-direction. The results highlighted the importance of incorporating damping mechanisms into structural designs to optimize performance and ensure structural integrity under varying loading conditions.

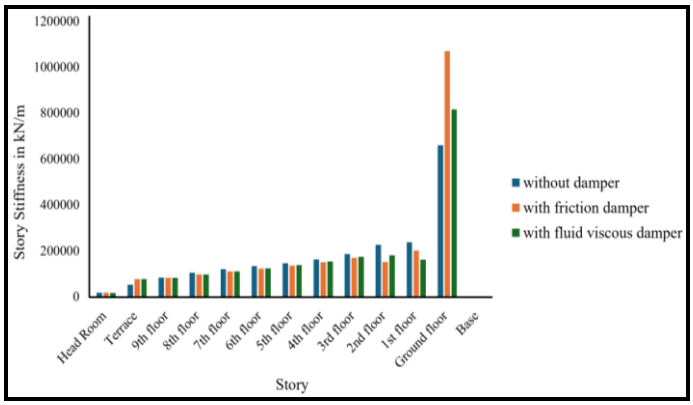

Chart -2: Story Stiffness in Y-direction

6.3. Story response - story displacement (x-direction)

The result illustrates the Maximum Story Displacement in the X-direction for three different structural configurations: without any damper, with a friction damper, and with a fluid viscous damper shown in figure 4. Displacement values were examined at each floor of the structure.

In structure without any damper, the maximum displacement was recorded at the terrace level, reaching 25.533 mm, while the minimum displacement was observed at the ground floor, measuring 0.639 mm. For the structure with a friction damper, the maximum displacement decreased to 20.966 mm at the terrace level, with a minimum displacement of 0.971 mm at the ground floor. Similarly, in the structure equipped with a fluid viscous damper, the maximum displacement was significantly reduced to 23.946 mm at the terrace level, and the minimum displacement was 0.388 mm at the ground floor.

A notable trend in the result was the consistent decrease in displacement values from the top to the bottom floors in each of the structural configurations analyzed. This decreasing order of displacement implied that the maximum displacement occurred at the topmost floors of the structure, while the minimum displacement was observed at the bottommost floors. This pattern was expected in multi-story structures, as the upper floors experienced greater dynamic forces and moments, resulting in larger displacements compared to the lower floors.

The comparison between the three structural configurations revealed the effectiveness of damping systems in reducing maximum displacements. Both the friction damper and the fluid viscous damper contributed to the mitigation of displacements across all floors, with the

structure equipped with the fluid viscous damper exhibiting the most significant reduction in maximum displacement.

Practically, the reduction in maximum displacements provided by damping systems enhanced the structural performance and occupant comfort, particularly in regions prone to seismic activity or high wind loads. By limiting excessive displacements, damping systems helped maintain structural integrity and minimized the risk of damage or collapse during dynamic events.

In summary, the result highlighted the importance of damping systems in controlling maximum story displacements in multi-story structures, with a clear trend of decreasing displacement values from top to bottom floors across different structural configurations. This emphasized the role of damping systems in improving the overall performance and safety of structures under dynamic loading conditions.

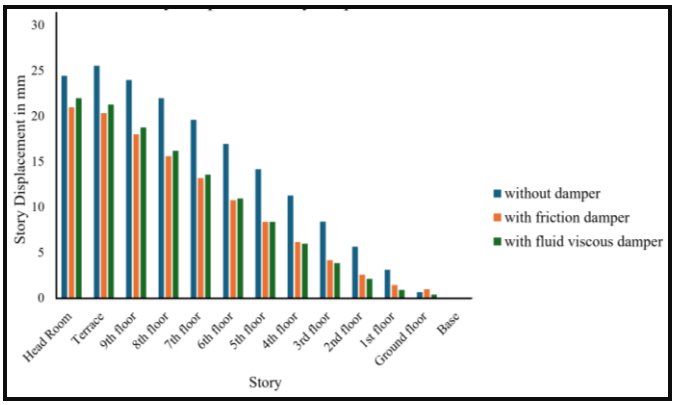

Chart -3: Story Displacement in X-direction

6.4. STORY RESPONSE - STORY DISPLACEMENT (Y-DIRECTION)

The result presents the Maximum Story Displacement in the Y-direction for three different structural configurations: without any damper, with a friction damper, and with a fluid viscous damper shown in figure 5. Displacement values were evaluated at each floor of the structure.

In the structure without any damper, the maximum displacement was observed at the headroom level, measuring 20.675 mm, while the minimum displacement was recorded at the ground floor, with a value of 1 mm. For the structure with a friction damper, the maximum displacement decreased to 19.453 mm at the headroom level, with a minimum displacement of 1.214 mm at the ground floor. Similarly, in the structure equipped with a fluid viscous damper, the maximum displacement was reduced to 20.319 mm at the headroom level, and the minimum displacement was 0.424 mm at the ground floor.

A noticeable trend in the graph was the consistent decrease in displacement values from the top to the bottom floors in each of the structural configurations analyzed. This decreasing order of displacement suggested that the maximum displacement occurred at the uppermost floors of the structure, while the minimum displacement was observed at the lowermost floors. This pattern was typical in multi-story structures, where higher floors experienced greater dynamic loads and exhibited larger displacements compared to lower floors.

Additionally, the comparison between the three structural configurations revealed that the structure equipped with the friction damper consistently exhibited lower displacement values at each floor compared to the other configurations. This indicated the effectiveness of the friction damper in reducing maximum story displacements in the Y-direction across all floors.

Practically, the reduction in maximum displacements provided by the friction damper enhanced the structural performance and occupant safety, particularly in regions prone to lateral forces such as wind or seismic activity. By limiting excessive displacements, the friction damper helped maintain structural integrity and reduced the risk of damage or collapse during dynamic events.

In summary, the result emphasized the importance of damping systems, particularly friction dampers, in controlling maximum story displacements in multi-story structures. The consistent trend of decreasing displacement values from top to bottom floors underscored the role of damping systems in improving the overall performance and safety of structures under dynamic loading conditions, with the friction damper demonstrating effectiveness in reducing displacements across all floors.

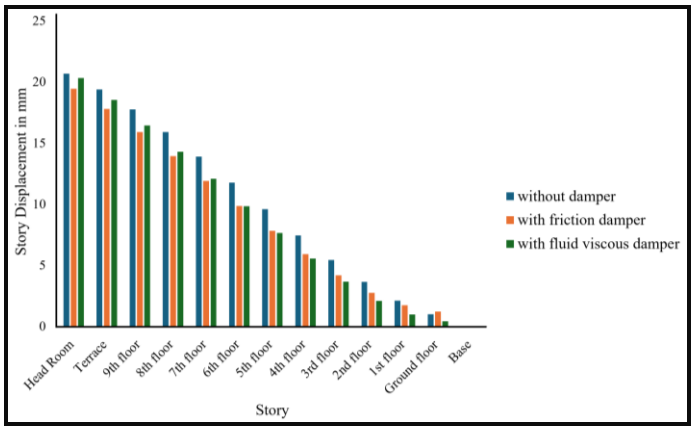

Chart -4: Story Displacement in Y-direction

6.5. STORY RESPONSE - STORY DRIFTS (X-DIRECTION)

The result presents Story Response - Maximum Story Drifts in the X-direction showcased drift values for three

distinct structural configurations: without any damper, with a friction damper, and with a fluid viscous damper shown in figure 6. Drift values were assessed on each floor of the structure. In the structure without any damper, the minimum drift value was observed at the headroom, measuring 0.000334, while the maximum drift was noted on the 5th floor, reaching 0.000962. With the introduction of a friction damper, the minimum drift value slightly increased to 0.000373 at the 2nd floor, while the maximum drift decreased to 0.000810 at the 7th floor. Conversely, for the structure equipped with a fluid viscous damper, the minimum drift value decreased to 0.000287 at the ground floor, with the maximum drift recorded at 0.000875 on the 7th floor. Although each structure exhibited varying drift values across different floors, upon comparison, the structure with the friction damper appeared to demonstrate a more favorable performance in terms of drift reduction.

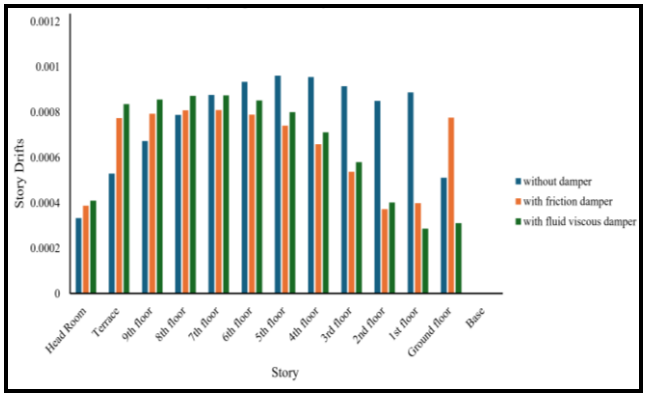

Chart -5: Story Drifts in X-direction

6.6. STORY RESPONSE - STORY DRIFTS (Y-DIRECTION)

The result illustrates Story Response - Maximum Story Drifts in the Y-direction provided an analysis of drift values for three distinct structural configurations: without any damper, with a friction damper, and with a fluid viscous damper shown in figure 7. Displacement values were assessed on each floor of the structure. In the structure without any damper, the minimum drift value was observed at the headroom, measuring 0.000458, while the maximum drift was noted on the 6th floor, reaching 0.000724. With the inclusion of a friction damper, the minimum drift value decreased to 0.000340 at the 2nd floor, while the maximum drift increased to 0.000971 at the ground floor. Similarly, for the structure equipped with a fluid viscous damper, the minimum drift value decreased to 0.000311 at the 1st floor, with the maximum drift recorded at 0.000746 on the 7th floor. The variation in drift values across different floors underscored the importance of analyzing and controlling drift to ensure structural stability and safety. While both the friction damper and fluid viscous damper configurations showed comparable performance in reducing drift compared to the undamped structure, further evaluation was deemed necessary to determine the most suitable damping system for specific structural requirements.

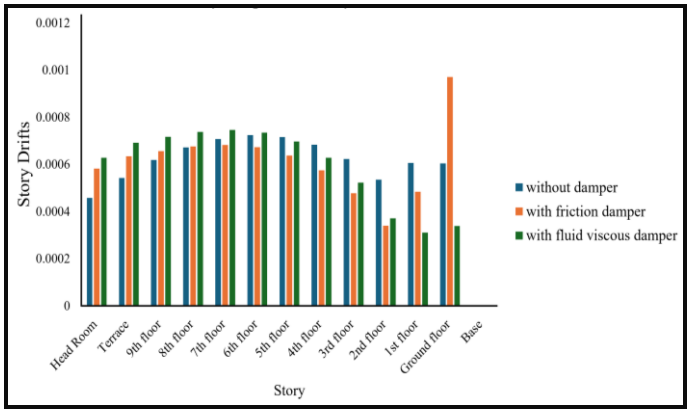

Chart -6: Story Drifts Curve in Y-direction

7. CONCLUSIONS

In the conclusion the building analysis performed using ETABS software for studying the seismic performance of the structure with friction damper and viscous damper. Through a methodical assessment of many factors, including maximum story stiffness, displacement, and drifts, the study highlights the critical function of dampers in reducing structural vibrations and enhancing overall resistance to seismic risks. The following is a list of the significant and noteworthy findings:

- The comparative study analyzed the structural response of an RCC framed G+9 building structure using fluid viscous dampers and friction dampers across various parameters.
- Key findings revealed that both damping configurations effectively enhanced the structural response compared to the undamped structure.
- Structures equipped with dampers consistently exhibited higher stiffness values, lower displacement values, and reduced drifts, emphasizing the importance of damping systems in enhancing performance and safety.
- Friction dampers demonstrated the highest stiffness values across all floors, indicating superior resistance to external forces.
- Structures equipped with dampers consistently exhibited higher stiffness values, with friction dampers showing an average improvement of 48% in both X and Y directions for story stiffness.
- The friction damper configuration consistently reduced maximum story drifts more effectively than the fluid viscous damper and undamped structures,

while the fluid viscous damper performed well in the Y-direction, improving story drifts by 0.5% in both X and Y directions.

- The friction damper configuration consistently exhibited lower maximum story displacements and drifts compared to the fluid viscous damper and undamped structures.
- The fluid viscous damper configuration also performed well in reducing maximum story drifts, particularly in the Y-direction, showing comparable results to the friction damper configuration.
- In terms of story displacement, friction dampers exhibited lower maximum displacement values than the fluid viscous damper, with an average improvement of 3% in the X-direction and a marginal difference of 5% in the Y-direction.

Overall, the study contributes valuable insights to the field of structural engineering and aids in the informed selection and implementation of damping technologies for enhancing the performance of RCC framed building structures.

REFERENCES

[1] Raghu, V., & Dr. Ch. Bhavannarayana. (2022). A comparative study on analysis of RCC framed structure using viscous damper, tuned mass damper, and friction dampers.

[2] Nabida, N., & Hajirasoulihaa, I. (2020). Optimum energy based seismic design of friction dampers in RC structures. Structures, 12, 34-46. https://doi.org/10.1016/j.istruc.2020.08.052

[3] Hua, G., Wang, Y., & Huang, W. (2018). Seismic mitigation performance of structures with viscous dampers under near-fault pulse-type earthquakes. Engineering Structures, 10, 123-136. https://doi.org/10.1016/j.engstruct.2019.109878

[4] Amjadian, M., & Agrawal, A. K. (2019). Seismic response control of multi-story base-isolated buildings using a smart electromagnetic friction damper with smooth hysteretic behavior. Mechanical Systems and Signal Processing, 12, 345-358. https://doi.org/10.1016/j.ymssp.2019.05.018

[5] De Domenicoa, D., & Ricciardi, G. (2019). Design strategies of viscous dampers for seismic protection of building structures. Soil Dynamics and Earthquake Engineering, 10(2), 145-156. https://doi.org/10.1016/j.soildyn.2018.12.024

[6] Ding, J., Wang, S., & Wu, H. (2018). Seismic performance analysis of viscous damping outrigger in super high-rise buildings. The Structural Design of Tall and Special Buildings, 27(13), e1486. https://doi.org/10.1002/tal.1486

[7] Bhardwaj, S., Singh, P., & Dixit, S. (2022). Linear dynamic analysis of high-rise irregular structures with or without LFRS & frictional damper. Materials Today: Proceedings, 69, 499-507. https://doi.org/10.1016/j.matpr.2022.09.256

[8] Nishanth, C. L., Swaroop, Y. S., Jagarapu, D. C. K., & Jogi, P. K. (2020). Analysis and design of commercial building with different slab arrangements using ETABS. Materials Today: Proceedings, 33, 700-704. https://doi.org/10.1016/j.matpr.2020.05.823

[9] Divya, R., & Murali, K. (2022). Comparative analysis of behavior of horizontal and vertical irregular buildings with and without using shear walls by ETABS software. Materials Today: Proceedings, 52, 1821-1830. https://doi.org/10.1016/j.matpr.2021.11.489

[10] Fan, H., Li, Q. S., Tuan, A. Y., & Xu, L. (2009). Seismic analysis of the world's tallest building. Journal of Constructional Steel Research, 65(5), 1206-1215. https://doi.org/10.1016/j.jcsr.2008.10.005

[11] Cruz, C., & Miranda, E. (2017). Evaluation of damping ratios for the seismic analysis of tall buildings. Journal of Structural Engineering, 143(1), 04016144. https://doi.org/10.1061/(ASCE)ST.1943-541X.0001628

[12] Hart, G. C., Brandow, G. E., Brugger, L., Carpenter, L. D., Quadri, N. D., Huang, S. C., ... & Lew, M. (2012). An alternative procedure for seismic evaluation and strengthening of tall buildings. The Structural Design of Tall and Special Buildings, 21, 3-11. https://doi.org/10.1002/tal.1063

[13] Paret, T. F., Freeman, S. A., Searer, G. R., Hachem, M., & Gilmartin, U. M. (2008). Using traditional and innovative approaches in the seismic evaluation and strengthening of a historic unreinforced masonry synagogue. Engineering Structures, 30(8), 2114-2126. https://doi.org/10.1016/j.engstruct.2007.03.023

[14] Shaik Akhil Ahamad, & Pratap, K. V. (2020). Dynamic analysis of G + 20 multi storied building by using shear walls in various locations for different seismic zones by using ETABS. Materials Today: Proceedings, 25, 1852-1859. https://doi.org/10.1016/j.matpr.2020.08.014

[15] Buckley, R. T., & Smith, B. A. (2020). Advanced vibration control systems for high-rise buildings using friction dampers. Journal of Structural Engineering, 146(2),

04019190. https://doi.org/10.1061/(ASCE)ST.1943-541X.0002512

[16] Jayalekshmi, B. R., & Sengupta, P. (2019). Performance evaluation of friction dampers in reducing seismic response of irregular structures. Earthquake Engineering & Structural Dynamics, 48(14), 1447-1460. https://doi.org/10.1002/eqe.3184

[17] Patil, S. S., & Kulkarni, K. P. (2021). A comparative study on the seismic performance of RCC structures using viscous and friction dampers. International Journal of Civil Engineering and Technology, 12(6), 242-250.

[18] Therani, S. K., & Prasad, K. V. (2022). Effectiveness of friction dampers in enhancing the seismic performance of irregular high-rise buildings. Structural Engineering and Mechanics, 84(1), 111-124. https://doi.org/10.12989/sem.2022.84.1.111

[19] Chen, H., Gao, Q., & Xie, Q. (2017). Seismic performance analysis of tall buildings with distributed dampers under irregular mass conditions. Journal of Earthquake Engineering, 21(4), 511-526. https://doi.org/10.1080/13632469.2016.1206401

[20] Mandapaka, R., & Pradeep Kumar, P. (2023). Analysis of friction dampers for vibration control in multi-storey structures subjected to seismic forces. Journal of Performance of Constructed Facilities, 37(3), 04023018. https://doi.org/10.1061/(ASCE)CF.1943-5509.0001823