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Comparative Analysis of Shear Walls and Bracing Systems in Irregular Buildings Under Wind and Seismic Loads

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***Abstract*: The structural integrity and stability of irregular buildings under lateral forces such as wind and seismic loads pose significant challenges in modern construction practices. Irregularities in a building's geometry and mass distribution can lead to uneven force distribution, making the structure more vulnerable to lateral displacement and potential failure. To enhance the resilience of such structures, shear walls and bracing systems are commonly employed to improve lateral load resistance. This study conducts a comparative analysis of shear walls and different types of bracing systems, focusing on their effectiveness in minimizing lateral displacement, reducing base shear, and enhancing overall structural stiffness. Using numerical modeling and finite element analysis, the research evaluates various configurations and placements of shear walls and bracings in irregular buildings. The study aims to identify the most efficient structural system for optimizing building performance under different wind and seismic loading conditions. The results provide valuable insights into the behavior of irregular buildings with shear walls and bracings, helping engineers and architects select the most suitable structural design to ensure safety, stability, and cost-effectiveness. The findings can contribute to the development of improved construction guidelines and design standards for irregular high- rise and mid-rise buildings in earthquake-prone and high-wind regions.**

***Keywords*: Shear Wall, Bracing System, Irregular Buildings, Wind Load, Seismic Load, Structural Stability, Lateral Load Resistance, Base Shear, Structural Stiffness, Numerical Modeling, Earthquake-Resistant Design, High-Rise Buildings, Structural Optimization.**

1. Introduction

In recent years, the demand for high-rise and irregular buildings has increased due to urbanization, aesthetic preferences, and functional requirements. However, such structures are highly susceptible to lateral forces induced by wind and seismic activities. The presence of geometric and structural irregularities, such as mass asymmetry, plan irregularity, and vertical irregularity, leads to non-uniform force distribution, which affects the stability and performance of the building. To mitigate these effects, structural elements like shear walls and bracing systems are incorporated into building designs to enhance lateral load resistance and improve overall structural stability.

A. Summary of Papers Referred

The study highlights gaps in research on shear wall and bracing performance in irregular buildings under wind and seismic loads. It highlights the need for more comprehensive studies to evaluate individual and combined performance. The study also highlights the impact of building geometry on shear wall and bracing performance. It also highlights the need for more research on non-linear behavior and material properties, as well as the interaction between seismic and wind loads. The study also highlights the need for more exploration on dynamic behavior, experimental validation, and full-scale testing. The study concludes that more research is needed to improve the performance of shear walls and bracings in irregular buildings.

2. Research Methodology

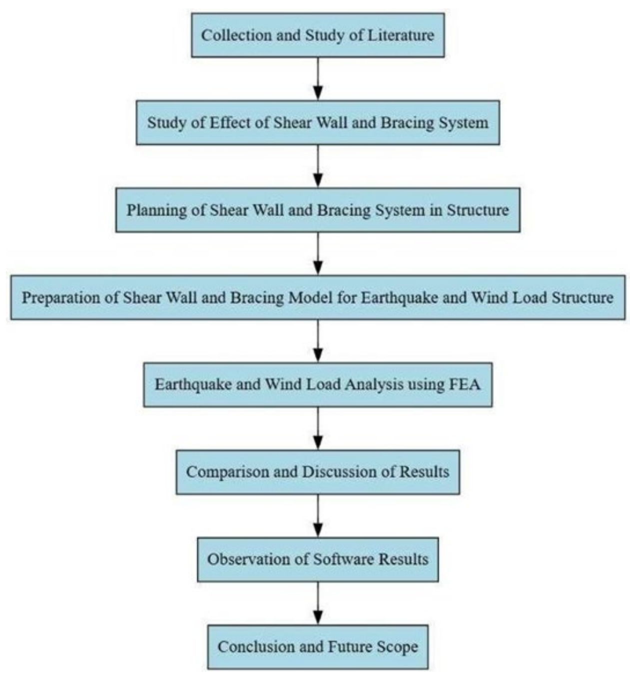

Fig. 1. Methodology flow chart

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- Collection and study of literature.
- Study of effect of shear wall and bracing system.
- Planning of shear wall and bracing system in structure.
- Preparation of shear wall and type of bracing model for earthquake and wind load structure
- Earthquake and wind load analysis by using FEA for determination of fundamental natural time period, story drift, peak displacement, peak acceleration of structure.
- Compare, discussion of results for without shear wall and bracing system and with shear wall and bracing system
- Observation for the results obtained from software
- Conclusion and future scope

A. Design of L-Shaped Model with Bracing Design

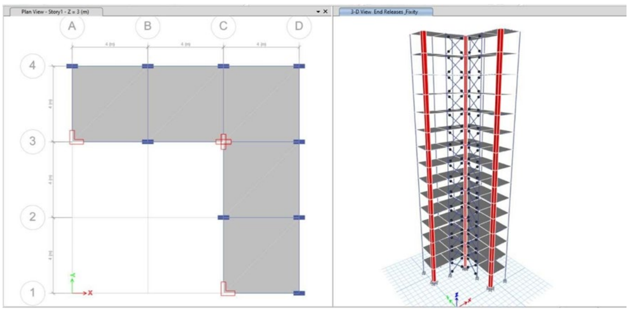

Fig. 2. Plan and elevation

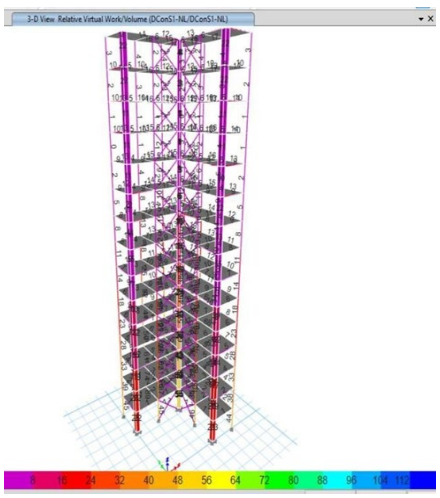

Fig. 3. Virtual work diagram

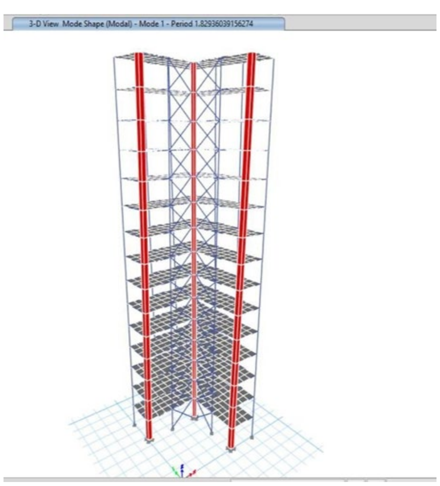

Fig. 4. Mode shape-01

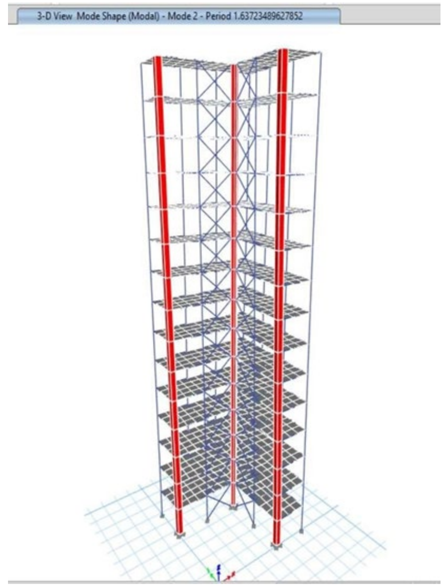

Fig. 5. Mode shape-02

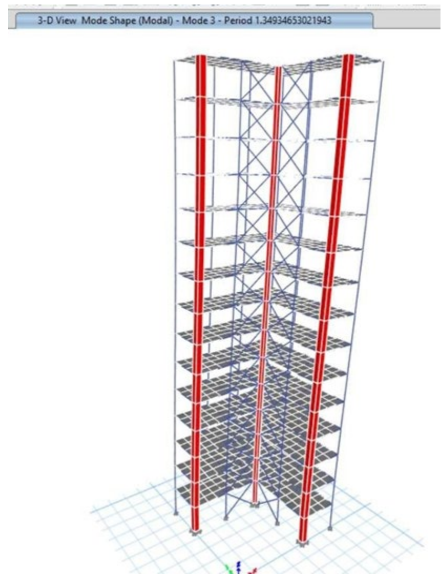

Fig. 6. Mode shape-03

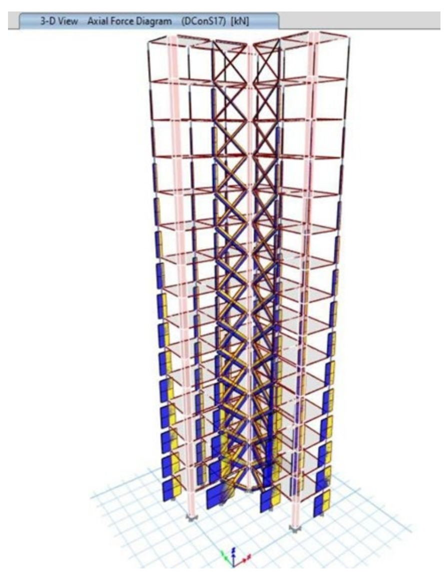

Fig. 7. Axial force diagram

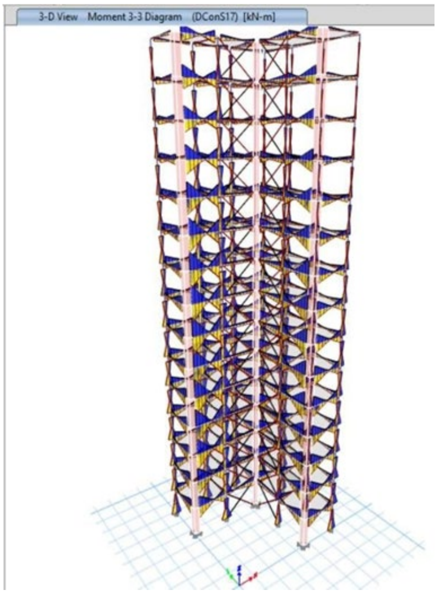

Fig. 8. Bending moment diagram

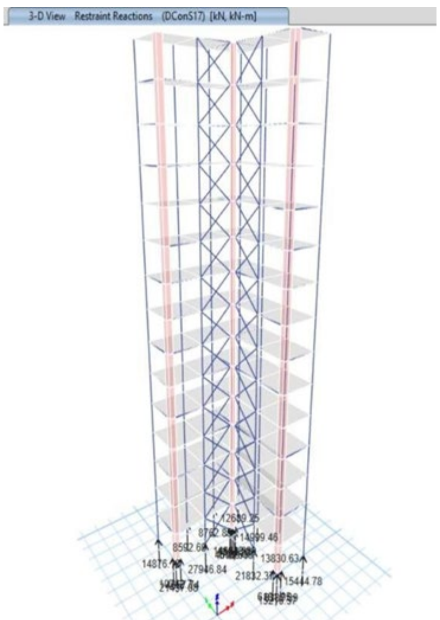

Fig. 9. Base reaction

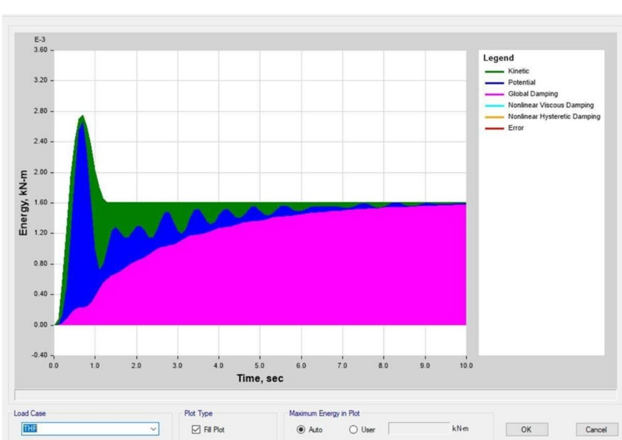

Fig. 10. Cumulative work diagram

B. *Design of L-Shaped Model without Bracing Design*

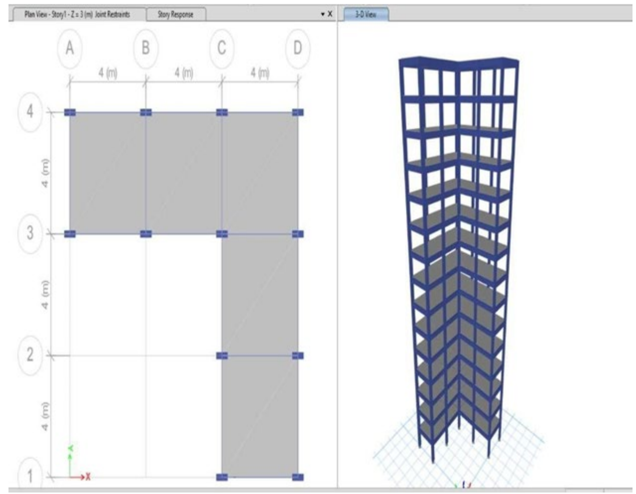

Fig. 11. Plan and elevation

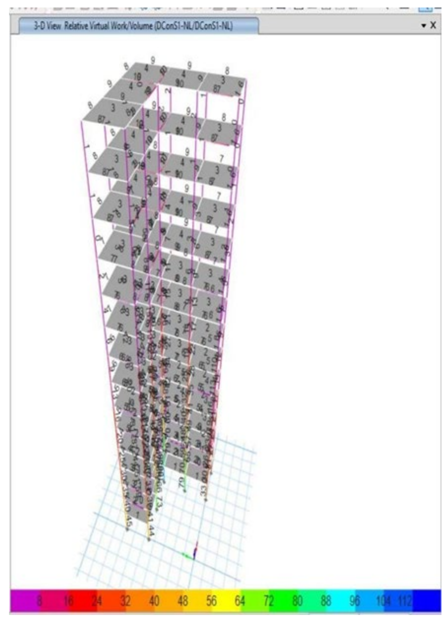

Fig. 12. Virtual work diagram

C. *Mode Shape Model for the L- Shaped Design*

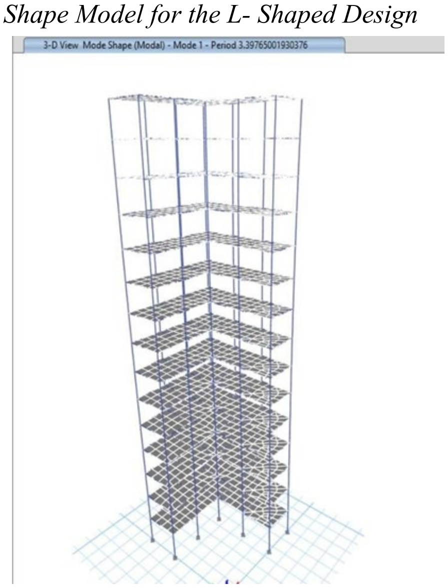

Fig. 13. Mode shape-01

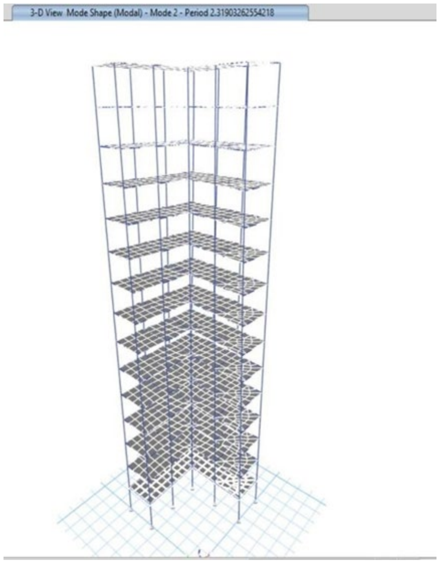

Fig. 14. Mode shape-02

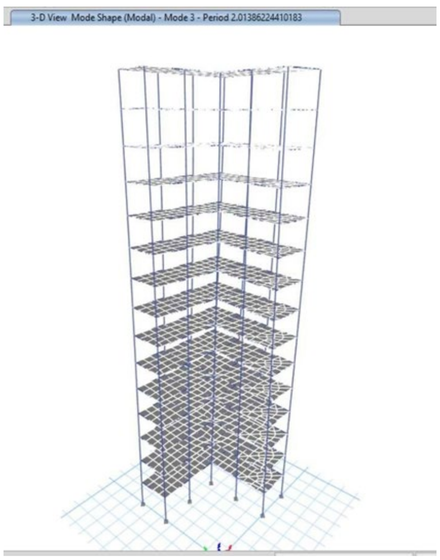

Fig. 15. Mode shape-03

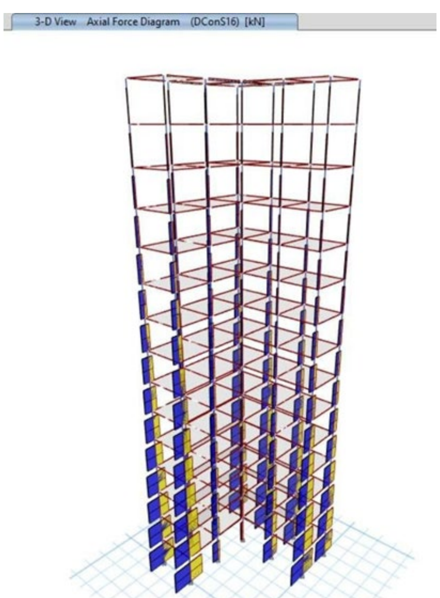

Fig. 16. Axial force diagram

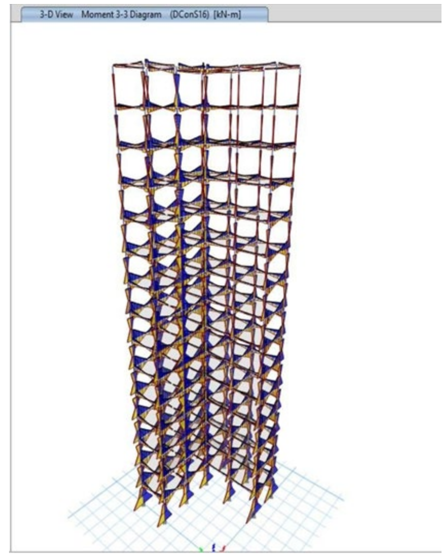

Fig. 17. Bending moment diagram

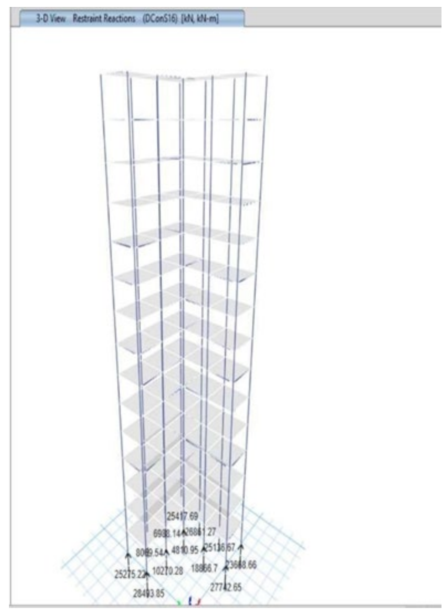

Fig. 18. Base reaction

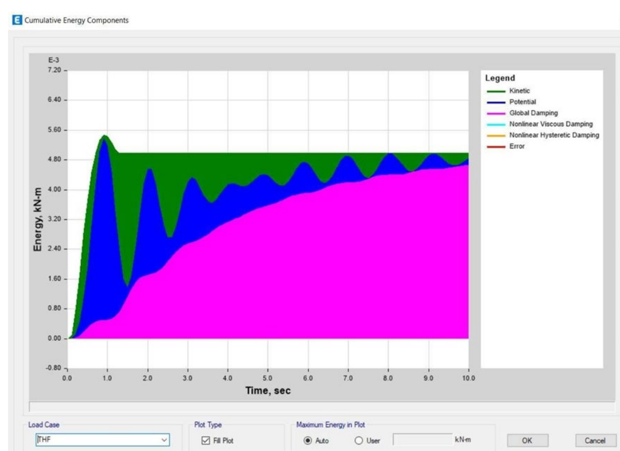

Fig. 19. Cumulative work diagram

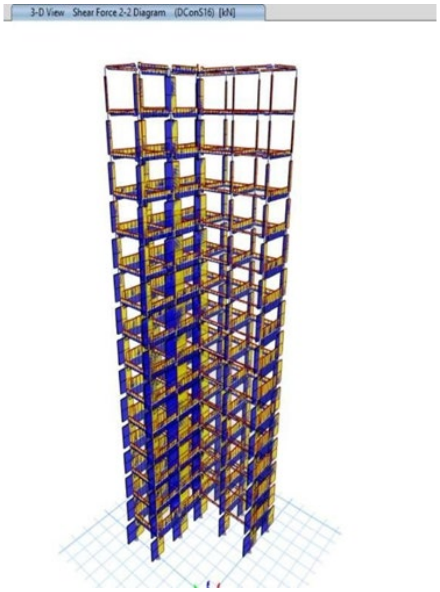

Fig. 20. Shear force diagram

D. *Software Results with Bracing*

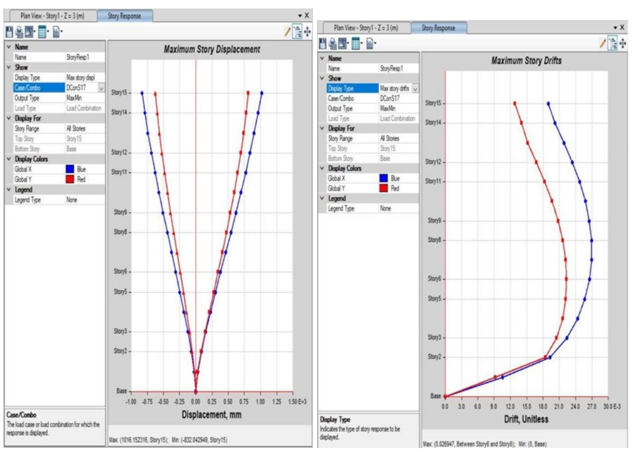

Fig. 21. Maximum story displacement and maximum storey drift

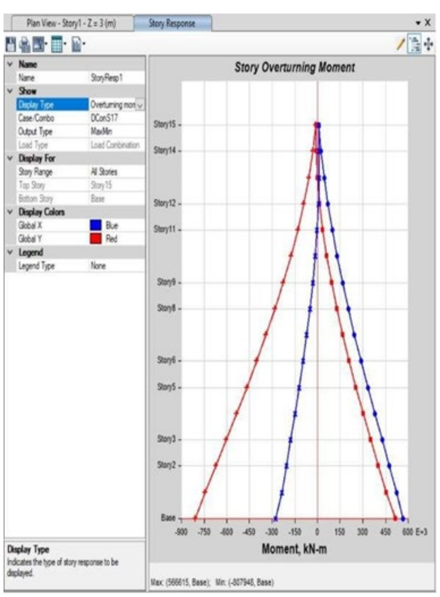

Fig. 21. Storey overturning moment

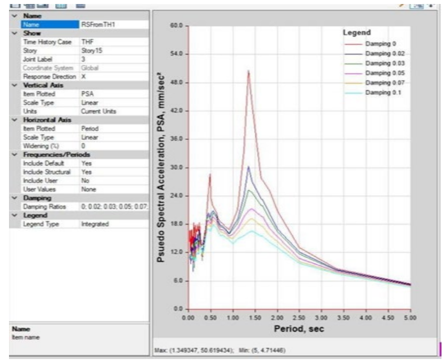

Fig. 22. Response spectrum curve for X-Dir

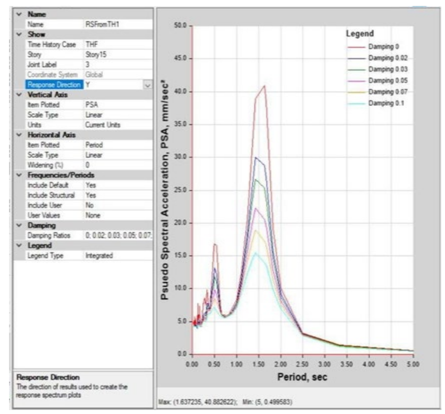

Fig. 23. Response spectrum curve for Y-Dir

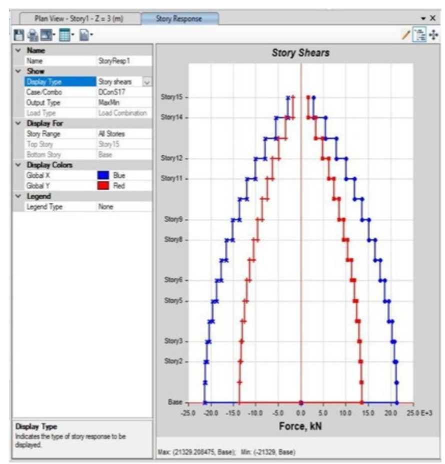

Fig. 24. Storey shear

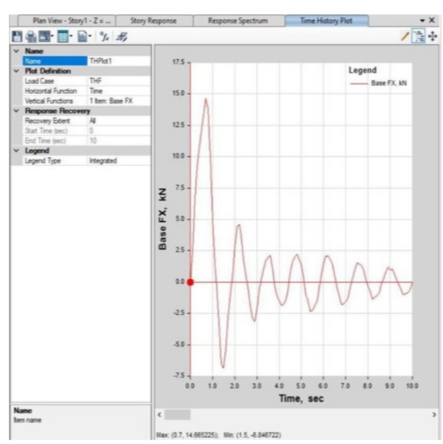

Fig. 25. Time history plot

E. Software Results without Bracing

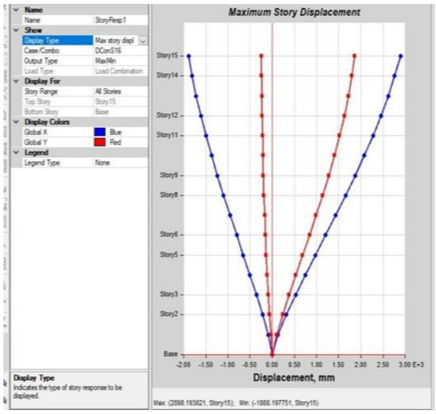

Fig. 26. Maximum story displacement

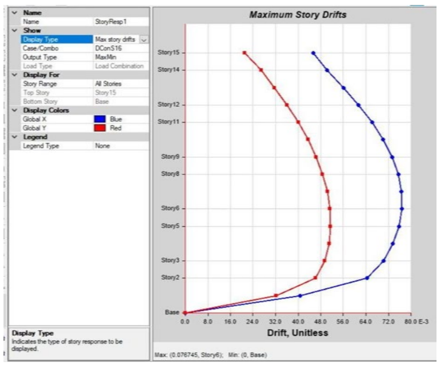

Fig. 27. Maximum storey drift

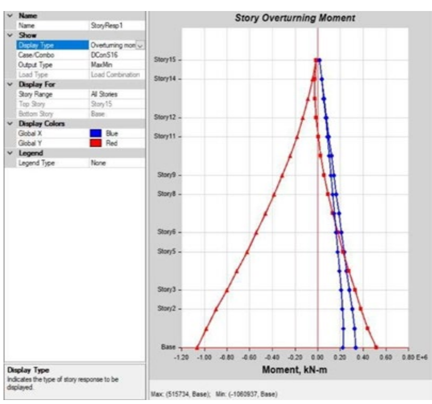

Fig. 28. Storey overturning moment

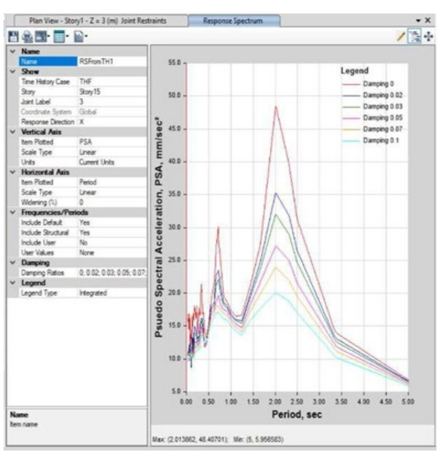

Fig. 29. Response spectrum curve for X-Dir

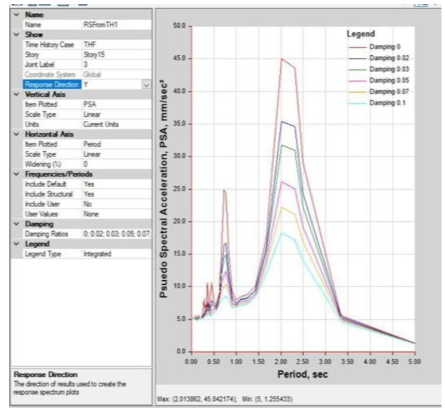

Fig. 30. Response spectrum curve for Y-Dir

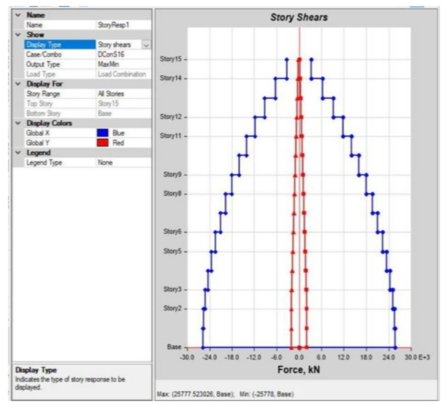

Fig. 31. Storey shear

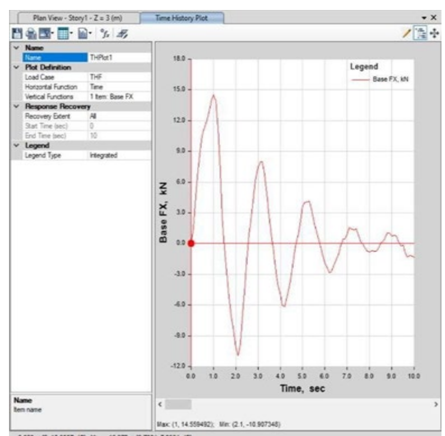

Fig. 32. Time history plot

Table1
Maximum storey displacement (mm)

Story	Without Bracing	With Bracing
Story15	2898.194	1016.152
Story14	2765.485	960.794
Story13	2618.764	901.849
Story12	2454.553	837.853
Story11	2273.951	769.168
Story10	2078.853	696.351
Story9	1871.487	620.228
Story8	1654.353	541.711
Story7	1430.196	461.832
Story6	1201.991	381.732
Story5	972.922	302.633
Story4	746.385	225.9
Story3	525.955	152.955
Story2	315.316	85.827
Story1	122.029	31.655
Base	0	0

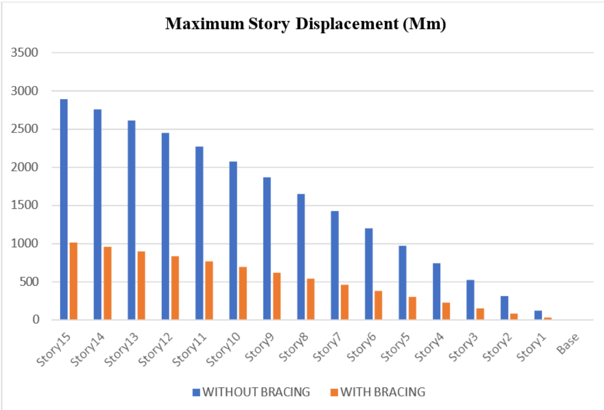

Fig. 33. Maximum storey displacement (mm)

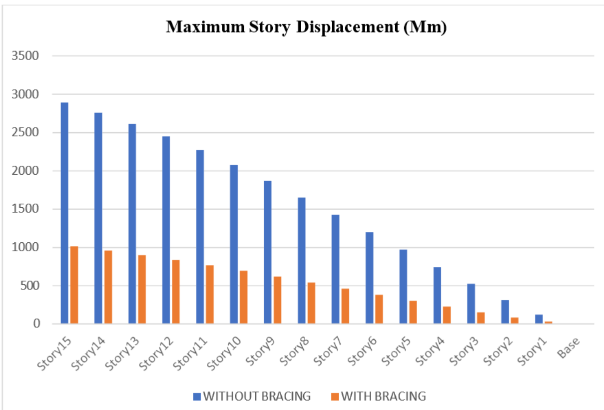

Fig. 34. Maximum storey displacement (mm)

The table presents the maximum story displacement values (in mm) for a multi-story structure, comparing cases with and without bracing. Displacement generally decreases from the top (Story 15) to the base.

1) Without Bracing

- The highest displacement occurs at Story 15 (2898.194 mm), showing significant lateral movement.
- As we move downward, displacement gradually decreases, reaching 122.029 mm at Story 1 and 0 mm at the base.
- This pattern highlights structural flexibility and susceptibility to lateral forces.

2) With Bracing

- The introduction of bracing significantly reduces displacement at all levels.
- The maximum displacement at Story 15 drops to 1016.152 mm, nearly a 65% reduction compared to the unbraced case.
- A similar trend is observed in lower stories, with Story 1 experiencing a reduction from 122.029 mm to 31.655 mm.
- The base remains at 0 mm, indicating no movement at the foundation level.

The data confirms that bracing significantly enhances structural stability, reducing lateral displacement by a substantial margin. This proves the effectiveness of bracing systems in mitigating structural deformation due to lateral forces, ensuring better safety and performance.

The table presents the maximum story drift values for a multi-story structure, comparing cases with and without bracing. Story drift represents the relative displacement between consecutive floors, which is critical for evaluating structural stability under lateral loads.

3) Observations without Bracing

- The highest story drift is observed at Story 7 (0.076623) and Story 6 (0.076745), indicating maximum lateral deformation occurs in the mid-height of the structure.
- Drift values increase from Story 1 (0.040669) to Story 6, then slightly decrease toward the top, with Story 15 recording 0.045377.
- This trend suggests that the middle stories are more vulnerable to lateral forces without additional support.

Table2
Maximum storey drift

Story	Without Bracing	With Bracing
Story15	0.045377	0.019
Story14	0.050147	0.020238
Story13	0.056004	0.0219
Story12	0.061448	0.023429
Story11	0.066204	0.024758
Story10	0.070171	0.025803
Story9	0.073275	0.026541
Story8	0.075447	0.026933
Story7	0.076623	0.026947
Story6	0.076745	0.026552
Story5	0.075756	0.025706
Story4	0.073607	0.024387
Story3	0.070273	0.022422
Story2	0.064452	0.019267
Story1	0.040669	0.010552
Base	0	0

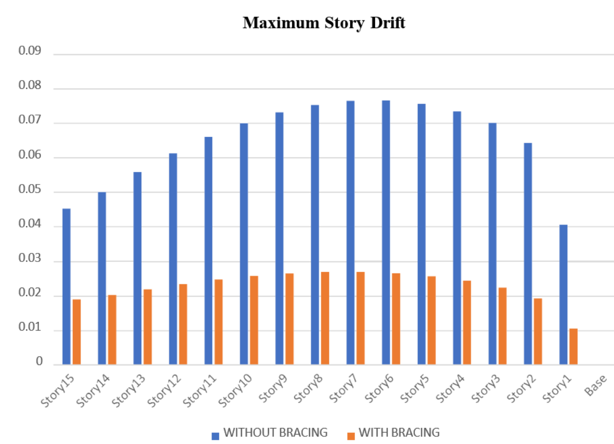

Fig. 35. Maximum storey drift

4) With Bracing

- Bracing significantly reduces drift across all stories.
- The highest drift in the braced case occurs at Story 10 (0.025803), which is significantly lower than the unbraced case.
- The drift at Story 1 is reduced from 0.040669 to 0.010552, indicating an overall reduction in structural deformation.

- The pattern remains similar to the unbraced case, but with lower drift values throughout.

The bracing system effectively reduces story drift, enhancing the structural rigidity and minimizing lateral deformation under loading. This is essential for maintaining the integrity of the structure and reducing the risk of instability or damage due to excessive sway.

The table presents the overturning moment (in kNm) at various story levels, comparing values with and without bracing. Overturning moment is a critical factor in structural stability, representing the rotational effect due to lateral forces such as wind or seismic loads.

Table 3
Overturning moment

Overturning Moment		
Story	**Without Bracing**	**With Bracing**
Story15	17435.5901	9011.0395
Story14	36876.2928	24086.6317
Story13	56923.7363	44199.7603
Story12	77480.5482	68806.0256
Story11	98460.0003	97456.1282
Story10	119804.2394	129736.3491
Story9	141493.8846	165264.355
Story8	163540.6018	203679.4649
Story7	185967.9495	244636.1568
Story6	208793.0956	287800.4534
Story5	232018.7137	332845.9491
Story4	255633.983	379449.4683
Story3	279616.7126	427288.4115
Story2	303930.0944	476040.003
Story1	324749.6091	525385.7643
Base	332099.1981	566615.1258

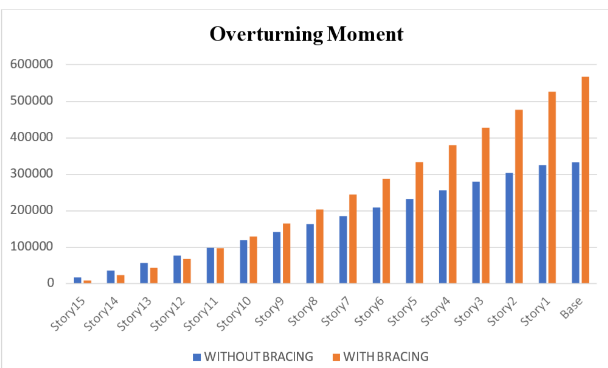

Fig. 36. Overturning moment

5) Observations Without Bracing

- The overturning moment increases progressively from Story 15 (17,435.59 kNm) to the Base (332,099.20 kNm).
- The highest overturning moment is at the Base, as it must resist the cumulative effect of moments generated from all stories above.
- The increasing trend indicates that the structure is experiencing significant rotational forces at the foundation.

6) With Bracing

- Lower overturning moments are observed at upper stories, starting from 9,011.04 kNm at Story 15.
- The overturning moment at higher stories is significantly reduced, indicating that bracing absorbs and redistributes lateral forces effectively.
- However, the overturning moment at lower stories and the Base increases, reaching 566,615.13 kNm at the Base, which is higher than the unbraced case.
- This suggests that bracing transfers forces downward efficiently, making the foundation resist a larger share of the overall overturning effect.

Bracing reduces overturning moments at higher stories, improving lateral stability. However, it shifts greater forces to the lower stories and foundation, requiring a stronger base design to counteract increased loads. Proper foundation reinforcement and anchoring are essential when using bracing systems.

Table 4
Storey acceleration

Story Acceleration		
Story	**Without Bracing**	**With Bracing**
Story15	15263.74	13339.14
Story14	14197.7	12114.62
Story13	13095.95	10944.77
Story12	12082.02	9998.98
Story11	11225.95	9332.51
Story10	10571.57	8817.39
Story9	9992.03	8292.43
Story8	9373.11	7714.9
Story7	8756.96	7177.44
Story6	8196.79	6761.32
Story5	7625.63	6326.95
Story4	6839.6	5680.78
Story3	5622.71	4635.34
Story2	3880.29	3184.48
Story1	1705.1	1328.18
Base	0	0

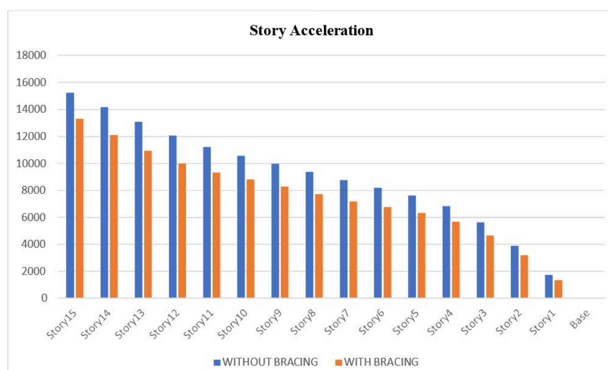

Fig. 37. Storey acceleration

The table presents the story acceleration values (in mm/s²) for a multi-story structure, comparing cases with and without bracing. Story acceleration is crucial in understanding the dynamic response of a structure under external forces like earthquakes and wind loads.

7) Observations without Bracing

- The highest acceleration is observed at Story 15 (15,263.74 mm/s²).
- As we move downward, acceleration decreases, reaching 1,705.10 mm/s² at Story 1 and 0 at the Base.
- The trend suggests that higher stories experience

Table 5
Base shear

Model	Name	Period Type	Z	Site Type	I	R	Period Used	Weight Used	Base Shear
							sec	kN	kN
Without Bracing	EQX	Program Calculated	0.36	II	1	5	2.014	6781.692	164.8731
	EQY	Program Calculated	0.36	II	1	5	3.398	6781.692	162.7606
With Bracing	EQX	Program Calculated	0.36	II	1	5	1.349	6216.215	225.5506
	EQY	Program Calculated	0.36	II	1	5	1.637	6216.215	185.8902

greater acceleration due to reduced mass and increased flexibility.

8) With Bracing

- A reduction in acceleration is observed at all stories, with Story 15 experiencing 13,339.14 mm/s², about 12.6% lower than the unbraced case.
- Lower stories also exhibit less acceleration, with Story 1 reducing from 1,705.10 mm/s² to 1,328.18 mm/s².
- The base remains at 0 mm/s², indicating it is a fixed point with no movement.
- The overall reduction suggests bracing effectively absorbs and redistributes dynamic forces, enhancing stability and reducing vibrational impact.

Bracing significantly reduces story acceleration, particularly in upper stories, which helps in minimizing the risk of damage due to seismic or wind-induced vibrations. This results in a more stable and controlled structural response, making bracing an essential design consideration for high-rise buildings in earthquake-prone areas.

The table presents data on base shear (in kN) for a structure under seismic loading in two directions: EQX (X-direction) and EQY (Y-direction). The comparison is made for cases with and without bracing, considering factors such as seismic zone factor (Z), site type, importance factor (I), and response reduction factor (R).

9) Observations without Bracing

- The fundamental period is 2.014 sec (EQX) and 3.398 sec (EQY), indicating a flexible structure.
- The base shear is lower, with values 164.87 kN (EQX) and 162.76 kN (EQY).
- The higher period values suggest that the structure has a longer oscillation time, making it more susceptible to lateral movements under seismic loads.

10) With Bracing

- The fundamental period decreases to 1.349 sec (EQX) and 1.637 sec (EQY), indicating increased stiffness.
- The base shear increases to 225.55 kN (EQX) and 185.89 kN (EQY).
- The decrease in period shows that the structure is stiffer and responds faster to seismic forces, reducing the risk of excessive deformation.

1. Bracing significantly reduces the structure's fundamental period, increasing stiffness and improving seismic resistance.
2. Base shear is higher in the braced structure, meaning it attracts greater seismic forces but is better able to resist them due to improved stability.
3. Without bracing, the structure is more flexible, leading to lower base shear but higher displacement and drift, making it more vulnerable to lateral loads.

3. Conclusion

The structural analysis comparing braced and unbraced conditions highlights the significant impact of bracing on story displacement, drift, overturning moment, acceleration, and base shear. The key findings are:

A. Story Displacement & Drift Reduction

- Bracing effectively reduces lateral displacement across all stories.
- Maximum displacement at Story 15 reduces from 2898.19 mm (unbraced) to 1016.15 mm (braced), improving overall stability.
- Story drift also decreases significantly, reducing lateral deformations that can lead to structural damage.

B. Overturning Moment Redistribution

- In the unbraced structure, overturning moments gradually increase from top to base, with a maximum of 332,099.20 kNm at the base.
- With bracing, overturning moments reduce at upper stories but increase at the base (566,615.13 kNm), indicating that bracing transfers more force downward, requiring a stronger foundation design.

C. Reduced Story Acceleration

- Bracing minimizes accelerations at all story levels, particularly in higher floors, reducing vibrations and improving occupant comfort.
- At Story 15, acceleration drops from 15,263.74 mm/s² (unbraced) to 13,339.14 mm/s² (braced), demonstrating improved seismic resistance.

D. Base Shear & Structural Stiffness

- Braced structures exhibit higher base shear due to increased stiffness, attracting more seismic forces.
- The fundamental period decreases from 2.014 sec (EQX) and 3.398 sec (EQY) in the unbraced case to 1.349 sec (EQX) and 1.637 sec (EQY) in the braced case, signifying enhanced stiffness and faster response to seismic loads.
- Base shear increases from 164.87 kN (unbraced) to 225.55 kN (braced) in EQX direction, requiring stronger lateral force-resisting systems.

E. Remarks

Bracing significantly improves structural performance by reducing displacement, drift, acceleration, and the fundamental period, making the structure more resistant to seismic forces and lateral loads. However, it increases base shear and overturning moments at the foundation, necessitating reinforced base and foundation elements. Proper design considerations, material selection, and load distribution strategies are essential to ensure both efficiency and safety in high-rise structures.

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