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Earthquake Response In Multistory Buildings With Bracing Systems And Shear Walls Using STAAD.Pro Software: A Comparative Study

Suraj Kumar Joshy[1], Gaurav Kumar Agrawal[2], Vivek Mishra[3], Khub Chand Sahu[4]

[1,4]M. Tech. Scholar, [2,3]Assistant Professor

Department of Structural Engineering, University Teaching Department

Chhattisgarh Swami Vivekanand Technical University, Bhilai – 491107, Chhattisgarh, India.

Abstract: Ensuring buildings can withstand earthquakes is crucial, requiring careful material selection, weight calculations, and structural planning. Techniques like special braces and walls are tailored to the seismic risk of the location. Strong concrete, flexible floors, and retrofitting existing structures are also vital. This research presents a comprehensive evaluation of 36 structural models across six seismic scenarios, focusing on 8, 10, and 12-story buildings in Seismic Zones IV and V, with and without seismic enhancements. Using STAAD.Pro Connect Edition software, the study assesses different bracing systems and shear walls under earthquake loads, presenting findings in tables. Results show shear walls consistently reduce bending and increase shear force, while diagonal and inverted V-shaped bracings also effectively reduce bending. The study emphasizes project-specific requirements when selecting earthquake-resistant designs, weighing trade-offs between bending moment, shear force, and deflection. Location and height significantly impact seismic performance, with shear walls performing well in Zone V but potentially inducing more bending. In Zone IV, diagonal or inverted V-shaped bracings exhibit less deflection and shear force. In conclusion, the optimal earthquake-resistant design depends on specific needs. This research provides insights for developing earthquake-resistant buildings in high-risk areas, considering both structural performance and regional seismic characteristics.

Keywords: Seismic, Multistorey building, Bracing system, Structural analysis, Shear wall

1. Introduction:

Multistorey buildings, also known as high-rise structures, have become essential features of urban landscapes, accommodating numerous levels within a single edifice. Their emergence is a response to the challenges of urbanization, aiming to optimize land utilization in densely populated areas. In today's era, high-rise buildings play a crucial role in accommodating growing populations, preserving green spaces, and enhancing economic efficiency by consolidating businesses, residences, and amenities.

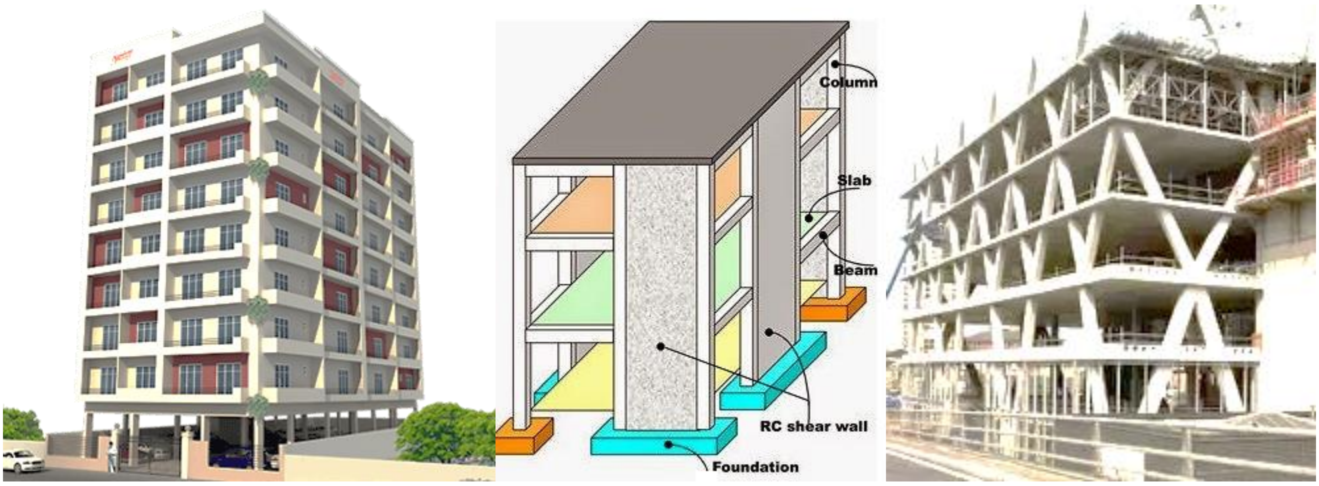

Figure: Multistorey Building, Shear wall and Bracings in RC Structure (Source: Internet)

Urbanization and the Rise of High-Rise Buildings: High-rise buildings have become increasingly important due to rapid urbanization and population growth. They efficiently utilize land resources, offering solutions to urban density while maintaining green spaces. By consolidating various functions vertically, they reduce commuting times and energy consumption, fostering economic efficiency.

Roles and Functions of Multistorey Buildings: Multistorey buildings serve diverse purposes, including residential, commercial, and mixed-use applications. In residential contexts, they provide housing solutions while minimizing ground impact and offering amenities such as elevators and fire safety measures. In commercial settings, they serve as centers for businesses and retail establishments, often becoming iconic landmarks in urban skylines. Mixed-use buildings combine residential, commercial, and recreational functions, promoting dynamic urban lifestyles.

Engineering Considerations in Multistorey Building Design: The design and engineering of multistorey buildings require careful consideration of structural robustness, safety protocols, spatial organization, vertical transport systems, and aesthetic appeal. Advances in architectural and construction technologies have enabled the development of taller and more intricate structures, reshaping urban landscapes and providing solutions for contemporary urban habitation and work environments.

Seismic Design of Multistorey Buildings: The influence of seismic hazards on multistorey buildings is significant. Events like earthquakes pose a threat to these structures, potentially causing structural failures and endangering occupants. Seismic design focuses on creating buildings capable of withstanding seismic forces while ensuring occupant safety and operational continuity. This involves selecting appropriate materials, calculating load-bearing capacities, and implementing seismic-resilient approaches such as bracing systems, shear walls, damping devices, and base isolation techniques.

Strategies for Earthquake-Resistant Structural Design: Seismic structural design techniques encompass various approaches to enhance a building's capacity to withstand seismic forces. These include bracing systems, shear walls, damping devices, base isolation, reinforced concrete and steel, flexible floor systems, retrofitting, adherence to building codes, performance-based design, soil analysis, foundation design, computer modelling, and architectural layout considerations. The selection of techniques depends on factors such as location, design, and purpose, aiming to create structures resilient to diverse seismic scenarios.

Importance of Bracing Systems: Bracing systems play a crucial role in enhancing a multistorey building's resistance to lateral forces, particularly those induced by seismic events. They distribute seismic forces and minimize structural distortions, contributing to overall stability. Various types of bracing systems, including diagonal, cross, knee, chevron, and V bracing, are employed to achieve structural resilience while considering both engineering and architectural requirements.

Significance of Shear Walls: Shear walls are fundamental components in multistorey buildings, designed to withstand lateral forces and enhance structural stability during seismic events. They vertically bear loads and resist lateral forces by redistributing them across the structure. Shear walls are strategically placed throughout the building, often using reinforced concrete to ensure strength and ductility. Their careful integration into architectural designs ensures both structural efficacy and aesthetic appeal, contributing to the overall seismic resilience of the building.

Multistorey buildings address urbanization challenges, with seismic design strategies like bracing systems, shear walls etc ensures safety in earthquake-prone areas.

2. Literature Review:

Chandurkar, P. P., and Dr PS Pajgade., focuses on optimizing shear wall placement in multistorey buildings to enhance seismic resistance. Their study compares different structural systems and concludes that short corner span shear walls are most cost-effective for ten-storey structures.

Mohammed, Nauman, and Islam Nazrul., address retrofitting techniques to reinforce structures in seismic areas, emphasizing the effectiveness of bracing systems, particularly steel bracing, for minimal mass increase and enhanced seismic resistance.

Rahangdale, Himalee, and S. R. Satone., highlight the importance of shear walls as vital lateral load resistors in high-rise buildings. Their research shows that shear wall locations significantly impact column loads and emphasize the ease of construction and robust lateral force resistance of shear walls.

Shinde, Nitin N., and R. M. Phuke., delve into the significance of braced frames in seismic design, showcasing their superior performance over unbraced counterparts. Their study, using SAP2000 software, concludes that X-braced buildings exhibit superior overall performance compared to other types.

Chavan, Krishnaraj R., and H. S. Jadhav., evaluate the seismic behavior of RC frames with steel bracing systems, concluding that X-type steel bracing notably enhances structural stiffness and decreases inter-storey drift.

Kumar et al., investigate the seismic behavior of multi-storied buildings, emphasizing the importance of well-designed structures in preventing collapse during earthquakes. Their study shows that Special Moment Resisting Frames exhibit better seismic resistance compared to Ordinary Moment Resisting Frames.

Mishra, Rishi, Dr Abhay Sharma, and Dr Vivek Garg., analyze various bracing systems' efficiency in lateral load resistance, concluding that steel bracing, particularly Inverted V bracing, effectively controls lateral displacement and member forces.

Atif, Mohd, Laxmikant Vairagade, and Vikrant Nair., compare the seismic performance of a G+15 building stiffened with bracings and shear walls in different seismic zones. Their study reveals that shear walls are highly effective in reducing lateral displacement compared to braced and plane frames.

Azad, Md Samdani, and Syed Hazni Abd Gani., investigate the performance of shear wall and steel bracing systems in mitigating seismic effects in RC and steel buildings. Their research suggests that shear walls are more robust against seismic displacement, emphasizing the critical role of shear wall placement.

Kalra, Megha., Investigates seismic resistance strategies for multi-storey buildings, focusing on steel bracing systems. X-bracing proves most effective in improving building performance against seismic forces.

Khan, M., Faheem Ahmad Khan, and Bilal Siddiqui., Evaluates bracing systems (X, V, and inverted V) for a 14-storey reinforced concrete structure. X-bracing emerges as the most effective method for enhancing seismic performance.

Patel, Pratik, et al. []: Proposes bracing systems in RCC structures to mitigate seismic effects, with X-braced frames outperforming moment resisting and V-braced frames in earthquake scenarios.

Patel, Pratik, et al., Investigates concrete-framed high-rise buildings with various bracing systems. X-bracing significantly reduces storey displacement and drift ratio, proving most effective for seismic performance.

Patil, Saurav P., and S. S. Angalekar., Introduces a hybrid lateral load resisting system integrating shear walls and bracings. This system optimally reduces storey displacement and drift ratio, especially in taller structures.

3. Methodology:

This study examines the structural behaviour of buildings in Seismic Zones IV and V through various bracing and shear wall configurations. Using STAAD.Pro software, the analysis focuses on deformation and performance under seismic loading conditions. The methodology includes a comprehensive literature review, model creation, boundary condition application, and structural behaviour analysis. Findings are presented in tabular form, highlighting the importance of design parameters for structural resilience. The study emphasizes optimizing configurations for enhanced seismic performance in high-risk zones.

Description of Modelling Cases: The study evaluates 36 models across six cases, each focusing on the impact of parameters on structural response under different seismic configurations. Each case examines G+8, G+10 & G+12 buildings in Seismic Zone IV & V, with models incorporating different seismic features such as diagonal, inverted V, V, cross bracing, and shear walls. There are Six cases and each case contains six number of models, as described below:

Case-1: This Case outlines different structural models for G+8 buildings in Seismic Zone IV. Model 4G+8 does not have special seismic features, while 4G+8BD incorporates diagonal bracing for improved seismic performance. 4G+8BIV utilizes inverted V bracing, 4G+8BV incorporates V bracing, and 4G+8BX utilizes cross bracing to enhance seismic stability. Lastly, 4G+8SW integrates shear walls to increase seismic resistance in these structures, addressing various seismic challenges in Zone IV were analyzed according to different Boundary conditions.

Table: Overview of the Design for a G+8-Storey Models in Zone IV

S.No.	Model Cases	Description
1	4G+8	Model Having G+8 Stories at Seismic Zone IV.
2	4G+8BD	Model Having G+8 Stories at Seismic Zone IV with diagonal bracings.
3	4G+8BIV	Model Having G+8 Stories at Seismic Zone IV with inverted V Bracing.
4	4G+8BV	Model Having G+8 Stories at Seismic Zone IV with V Bracing.
5	4G+8BX	Model Having G+8 Stories at Seismic Zone IV with cross Bracing.
6	4G+8SW	Model Having G+8 Stories at Seismic Zone IV with shear wall.

Case-2: This Case is similar to previous Case, G+10 storey building with different configurations in Zone IV were analysed according to different Boundary conditions.

Table: Overview of the Design for G+10 Storey Models in Zone IV

S.No.	Model Cases	Description
1	4G+10	Model Having G+10 Stories at Seismic Zone IV.
2	4G+10BD	Model Having G+10 Stories at Seismic Zone IV with diagonal bracings.
3	4G+10BIV	Model Having G+10 Stories at Seismic Zone IV with inverted V Bracing.
4	4G+10BV	Model Having G+10 Stories at Seismic Zone IV with V Bracing.
5	4G+10BX	Model Having G+10 Stories at Seismic Zone IV with cross Bracing.
6	4G+10SW	Model Having G+10 Stories at Seismic Zone IV with shear wall.

Case-3: This Case is similar to previous Case, G+12 storey building with different configurations in Zone IV were analyzed according to different Boundary conditions.

Table: Overview of the Design for G+12 Storey Models in Zone IV

S.No.	Model Cases	Description
1	4G+12	Model Having G+12 Stories at Seismic Zone IV.
2	4G+12BD	Model Having G+12 Stories at Seismic Zone IV with diagonal bracings.
3	4G+12BIV	Model Having G+12 Stories at Seismic Zone IV with inverted V Bracing.
4	4G+12BV	Model Having G+12 Stories at Seismic Zone IV with V Bracing.
5	4G+12BX	Model Having G+12 Stories at Seismic Zone IV with cross Bracing.
6	4G+12SW	Model Having G+12 Stories at Seismic Zone IV with shear wall.

Case-4: G+8 storey building with different configurations in Zone V were analysed according to different Boundary conditions.

Table: Overview of the Design for 8-Storey Models in Zone V

S.No.	Model Cases	Description
1	5G+8	Model Having G+8 Stories at Seismic Zone-V.
2	5G+8BD	Model Having G+8 Stories at Seismic Zone-V with diagonal bracings.
3	5G+8BIV	Model Having G+8 Stories at Seismic Zone-V with inverted V Bracing.
4	5G+8BV	Model Having G+8 Stories at Seismic Zone-V with V Bracing.
5	5G+8BX	Model Having G+8 Stories at Seismic Zone-V with cross Bracing.
6	5G+8SW	Model Having G+8 Stories at Seismic Zone-V with shear wall.

Case-5: G+10 storey buildings with different configurations in Zone V were analysed according to different Boundary conditions.

Table: Overview of the Design for G+10 Storey Models in Zone V

S.No.	Model Cases	Description
1	5G+10	Model Having G+10 Stories at Seismic Zone-V.
2	5G+10BD	Model Having G+10 Stories at Seismic Zone-V with diagonal bracings.
3	5G+10BIV	Model Having G+10 Stories at Seismic Zone-V with inverted V Bracing.
4	5G+10BV	Model Having G+10 Stories at Seismic Zone-V with V Bracing.
5	5G+10BX	Model Having G+10 Stories at Seismic Zone-V with cross Bracing.
6	5G+10SW	Model Having G+10 Stories at Seismic Zone-V with shear wall.

Case-6: This Case is similar to previous Cases, G+12 storey buildings with different configurations in Zone-V were analysed according to different Boundary conditions.

Table: Overview of the Design for G+12 Storey Models in Zone V

S.No.	Model Cases	Description
1	5G+12	Model Having G+12 Stories at Seismic Zone-V.
2	5G+12BD	Model Having G+12 Stories at Seismic Zone-V with diagonal bracings.
3	5G+12BIV	Model Having G+12 Stories at Seismic Zone-V with inverted V Bracing.
4	5G+12BV	Model Having G+12 Stories at Seismic Zone-V with V Bracing.
5	5G+12BX	Model Having G+12 Stories at Seismic Zone-V with cross Bracing.
6	5G+12SW	Model Having G+12 Stories at Seismic Zone-V with shear wall.

3.6 ASSIGNED PROPERTIES

In STAAD.Pro, "Assigned Properties" refer to specific attributes and parameters assigned to structural elements, influencing their behavior and characteristics within the analysis of a model.

Table: Specifications of Models

S. No.	Parameters	Dimensions/Type
1	Plan dimension	18m x 9 m
2	Number of stories	G+8, G+10 & G+12
3	Total height of building	27, 33, & 39m
4	Height of each storey	3m
5	Column size	230 X 600 mm
6	Beam size	230 x 400 mm
7	Grade of concrete	M20
8	Frame type	OMRF
9	Soil type	Medium soil
10	Live load	3 kN/m^2
11	Floor finish	1 kN/m^2
12	Inner wall	230 mm
13	Outer wall	230 mm
14	Unit weights of Concrete	25 kN/m^3
15	Unit weights of brick work	19 kN/m^3
16	Shear wall thickness	200 mm
17	Section for steel bracing	ISA 110 X 110 X 10mm

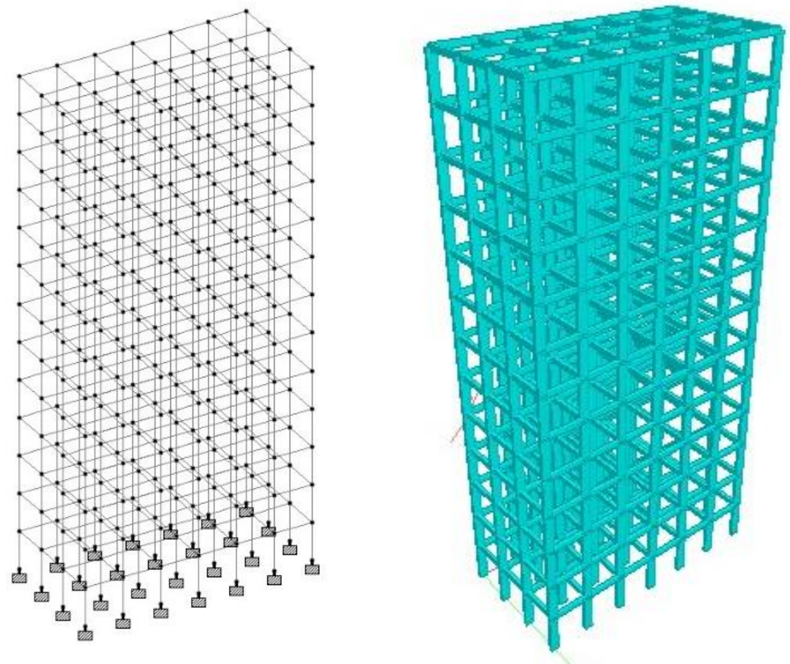

Fig. : Finite Element Model in STAAD.Pro without any Seismic Configuration

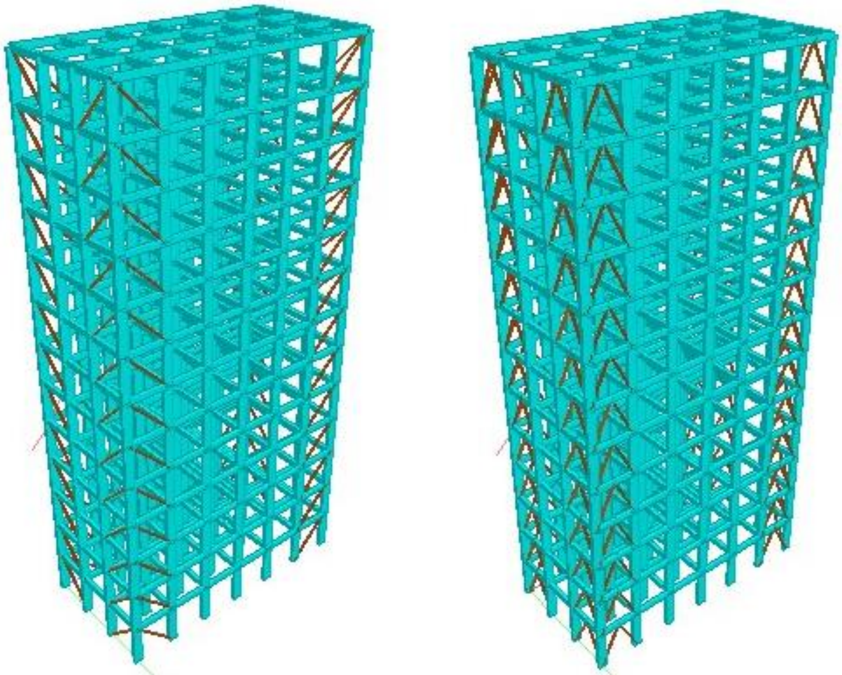

Fig. : Building With Diagonal and Inverted V Bracings

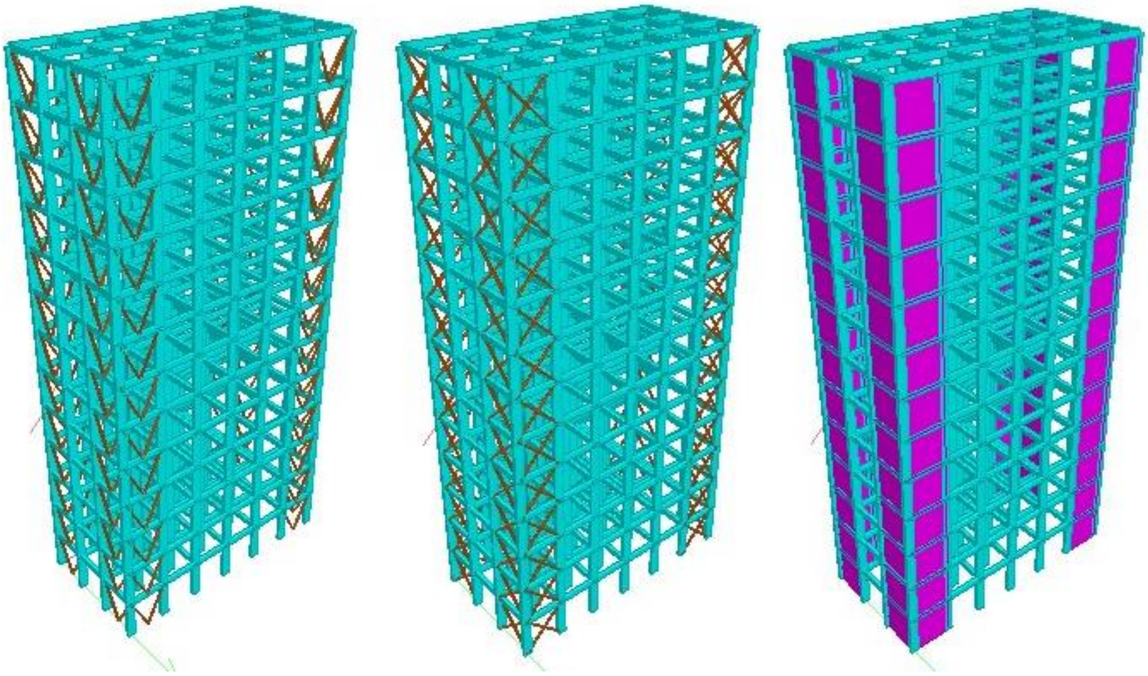

Fig. : Building With V Bracings, Cross Bracings and Shear Wall

4. Results & Discussions

The results and discussion provide a comprehensive comparative analysis of different structural configurations for multistorey buildings in Seismic Zones IV and V. It highlights the impact of bracings and shear walls on deflection, shear forces, and bending moments, offering valuable insights for seismic design strategies.

Results and discussion for seismic zone IV:

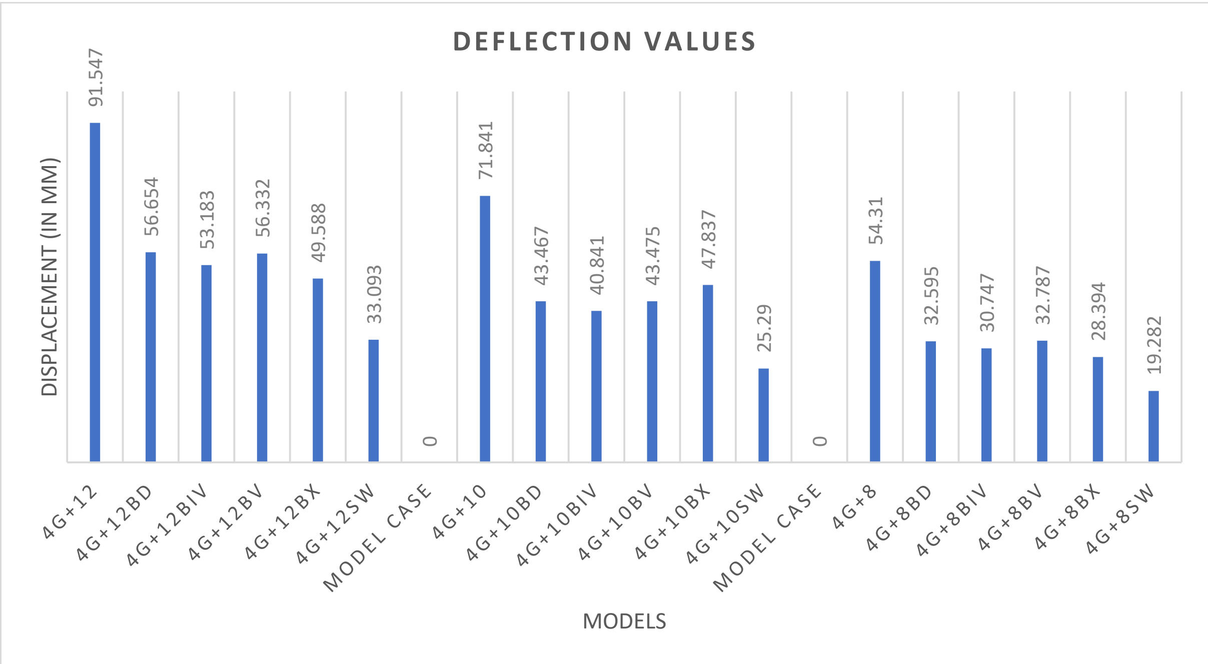

Chart: Deflection (mm) of models under Seismic Zone 4

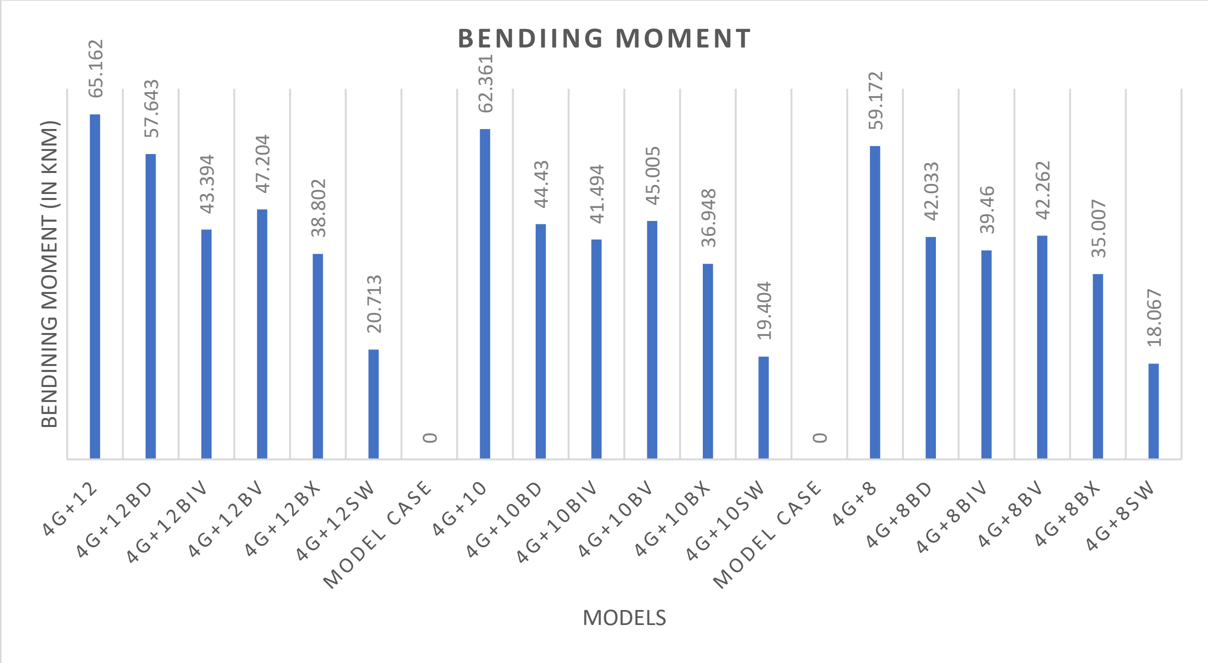

Chart: Bending Moments (kN-m) of models under Seismic Zone 4

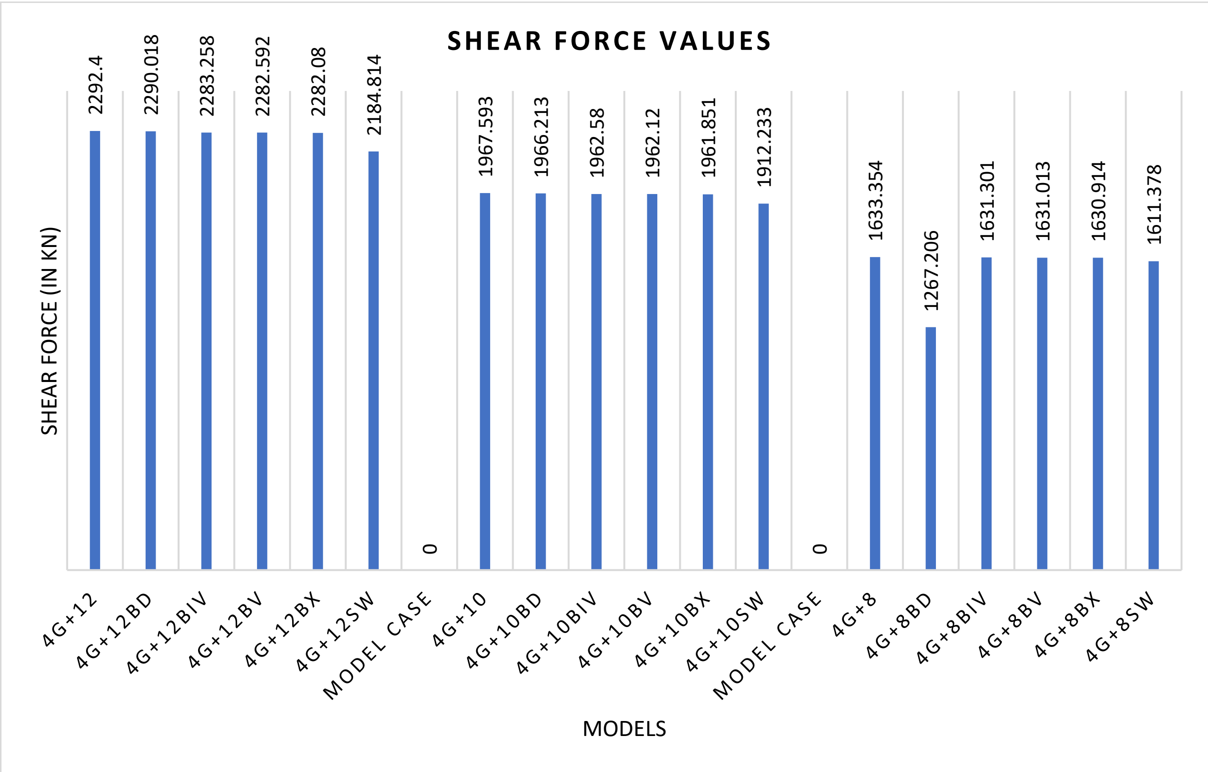

Chart: Shear (kN) Values of models under Seismic Zone 4

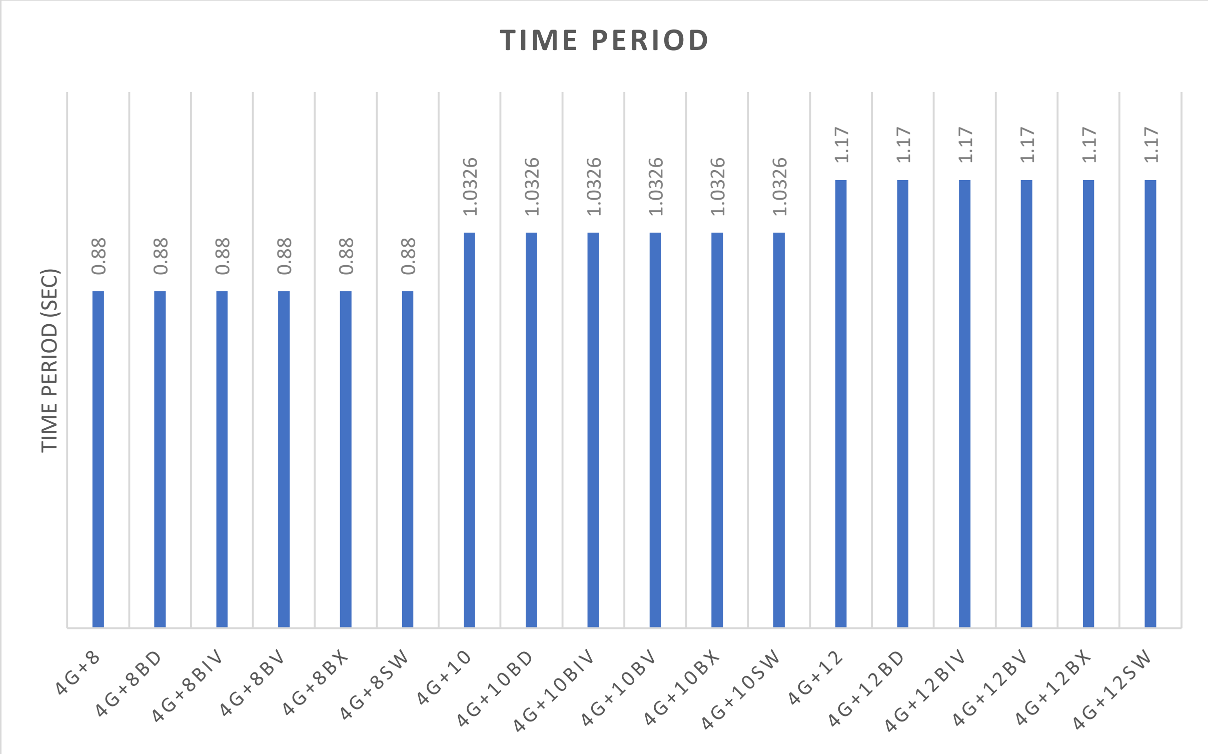

Chart: Time Period (Sec) Values of models under Seismic Zone 4

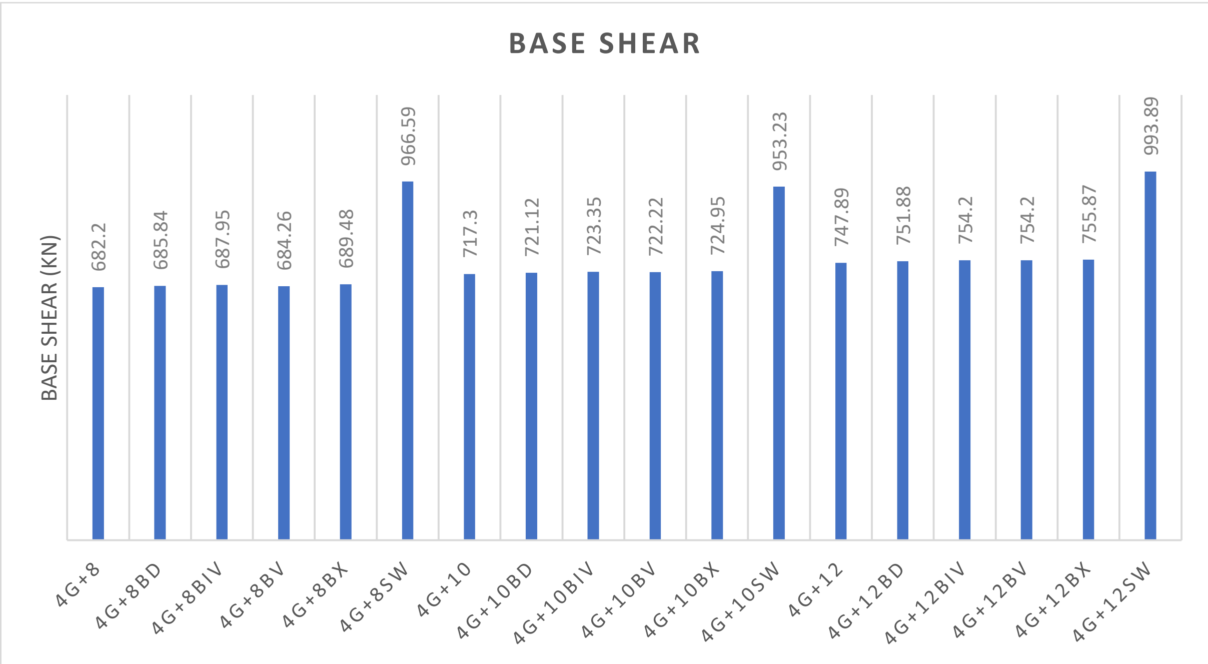

Chart: Base Shear (kN) Values of models under Seismic Zone 4

Performance Comparison in Zone IV (4G+8, 4G+10, 4G+12):

1. MAX Def (Deflection):
    - In Zone IV, the 4G+8 model has the lowest MAX Def (deflection) as it's the baseline.
    - 4G+10 has a 57.2% increase in MAX Def compared to 4G+8.
    - 4G+12 has a 58.9% increase in MAX Def compared to 4G+8.
    - Among the Zone IV models, 4G+8 performs the best in terms of deflection.
2. MAX BM (Bending Moment):
    - In Zone IV, the 4G+8 model has the lowest MAX BM (bending moment) as it's the baseline.
    - 4G+10 has a 26.6% increase in MAX BM compared to 4G+8.

- 4G+12 has a 17.1% increase in MAX BM compared to 4G+8.
- Among the Zone IV models, 4G+8BD performs the best in terms of bending moment.

3. MAX SF (Shear Force):

- In Zone IV, the 4G+8 model has the lowest MAX SF (shear force) as it's the baseline.
- 4G+10 has a 20.1% increase in MAX SF compared to 4G+8.
- 4G+12 has a 47.9% increase in MAX SF compared to 4G+8.
- Among the Zone IV models, 4G+8BD performs the best in terms of shear force.

Results and discussion for seismic zone V:

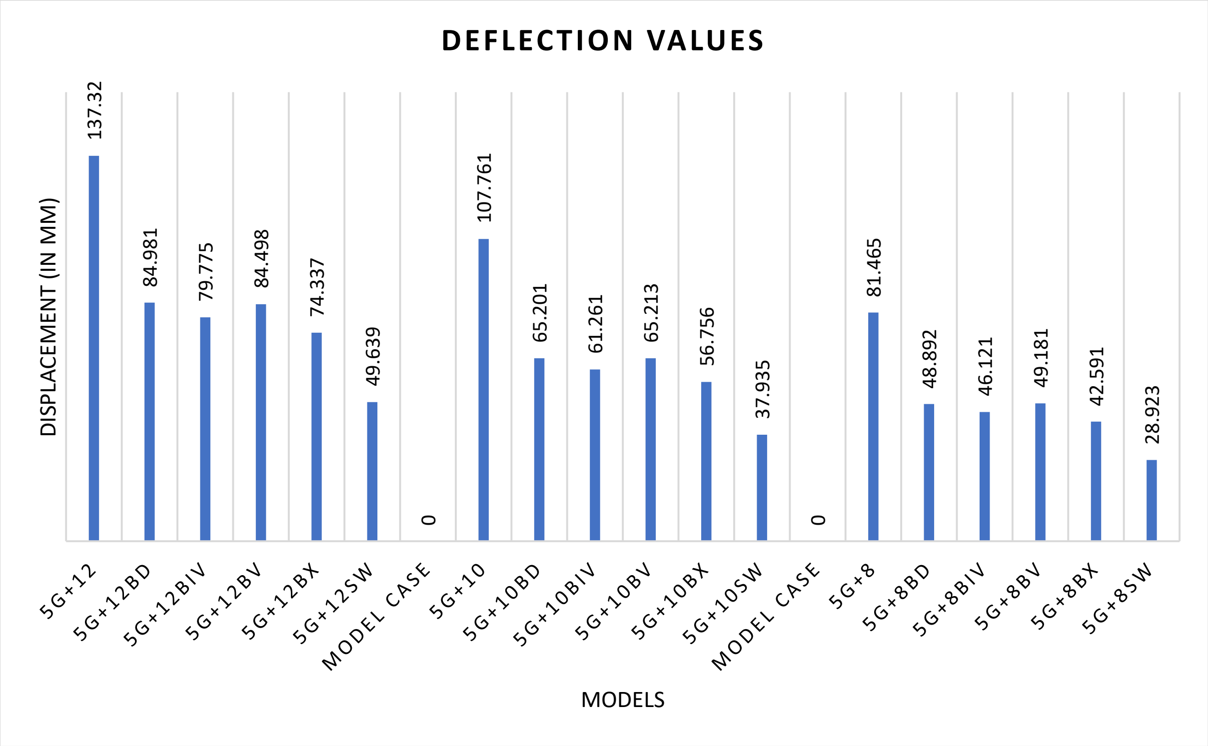

Chart 4.6: Deflection (mm) of models under Seismic Zone 5

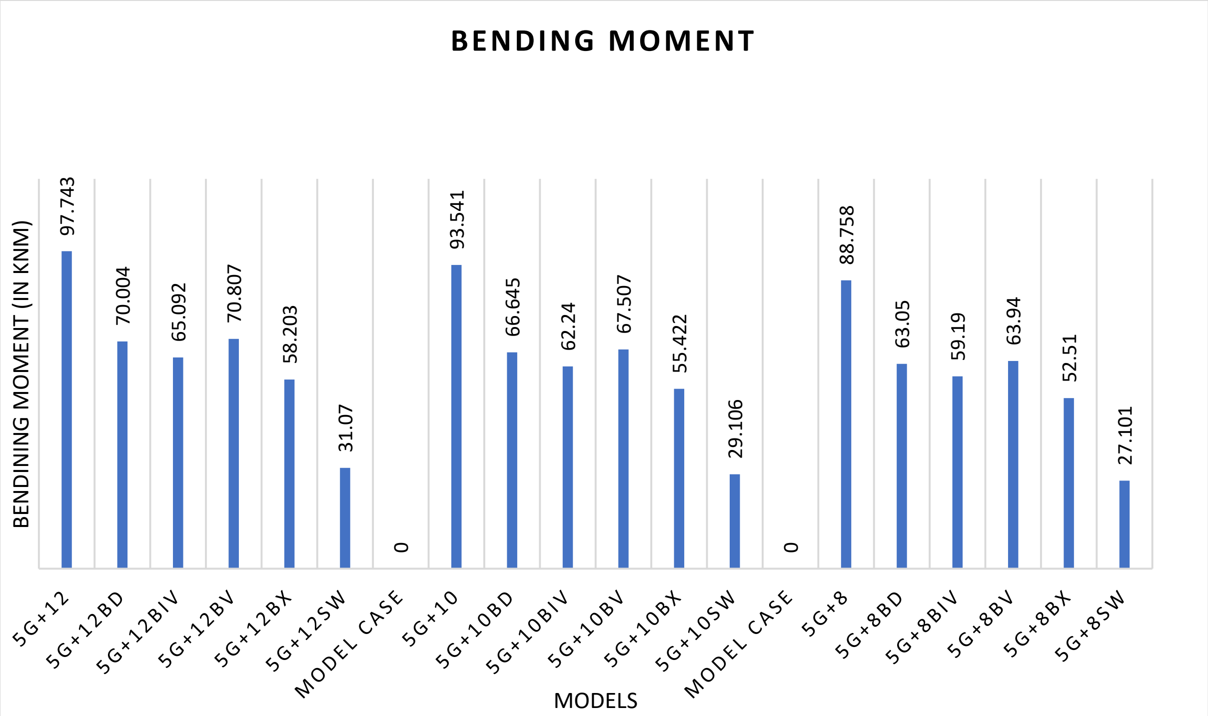

Chart 4.7: Bending Moment (kN-m) of models under Seismic Zone 5

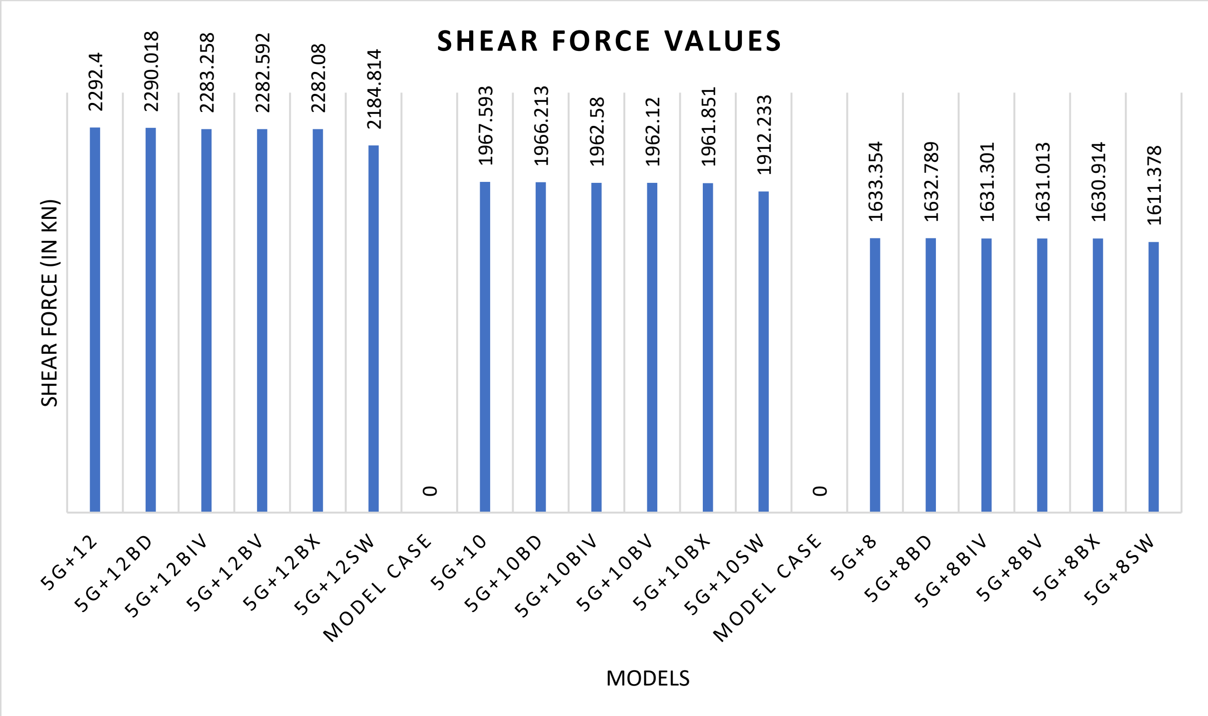

Chart 4.8: Shear Values (kN) of models under Seismic Zone 5

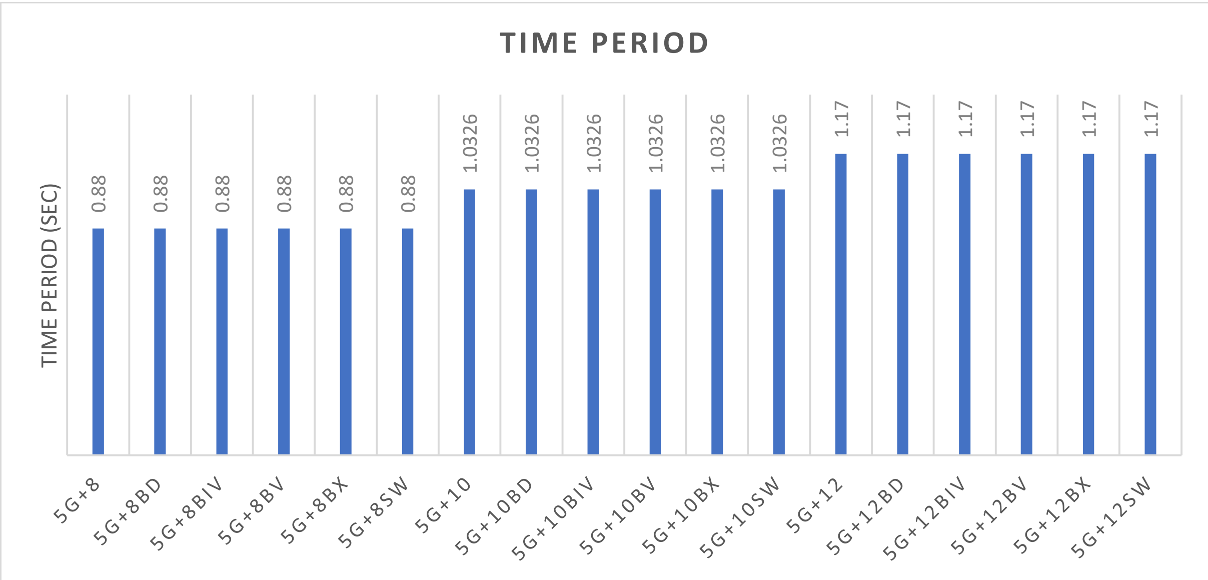

Chart 4.9: Time Period (Second) of models under Seismic Zone 5

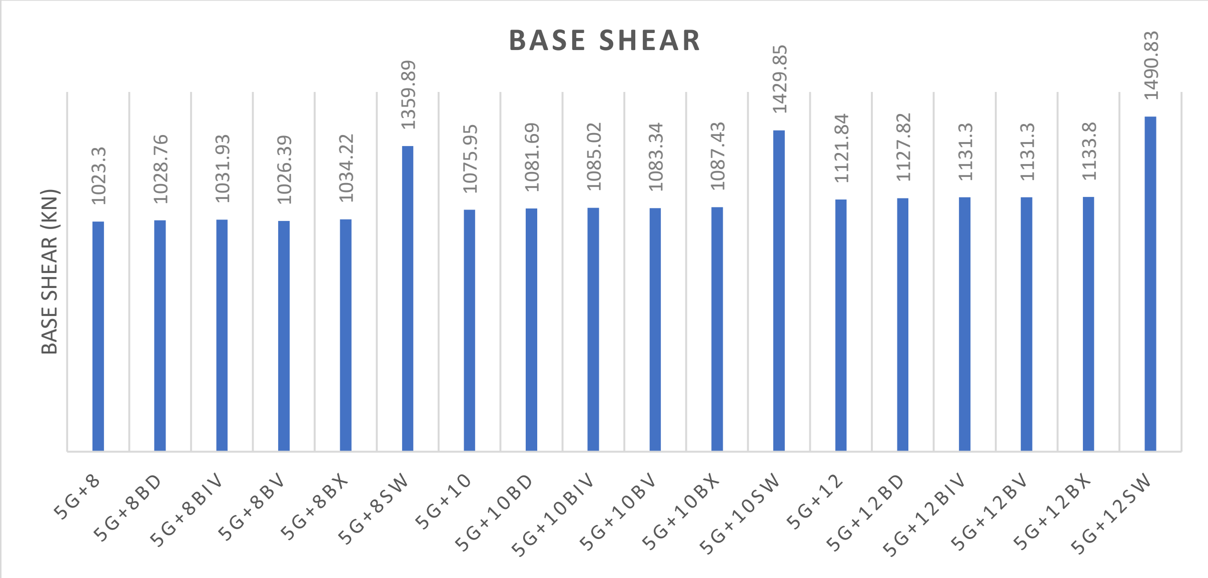

Chart 4.10: Base Shear (kN) Values of models under Seismic Zone 5

Performance Comparison in Zone V (5G+8, 5G+10, 5G+12):

1. MAX Def (Deflection):

- In Zone V, the 5G+8 model has the lowest MAX Def (deflection) as it's the baseline.
- 5G+10 has a 24.9% increase in MAX Def compared to 5G+8.
- 5G+12 has a 72.3% increase in MAX Def compared to 5G+8.
- Among the Zone V models, 5G+8SW performs the best in terms of deflection.

2. MAX BM (Bending Moment):

- In Zone V, the 5G+8 model has the lowest MAX BM (bending moment) as it's the baseline.
- 5G+10 has a 41.6% increase in MAX BM compared to 5G+8.
- 5G+12 has a 70.2% increase in MAX BM compared to 5G+8.
- Among the Zone V models, 5G+8SW performs the best in terms of bending moment.

3. MAX SF (Shear Force):

- In Zone V, the 5G+8 model has the lowest MAX SF (shear force) as it's the baseline.
- 5G+10 has a 37.9% increase in MAX SF compared to 5G+8.
- 5G+12 has a 48.7% increase in MAX SF compared to 5G+8.
- Among the Zone V models, 5G+8SW performs the best in terms of shear force.

4. Base Shear Observation

- For G+8 -V bracing- less base shear than inverted V bracing and diagonal bracing
- For G+10 -V bracing - less base shear than inverted V bracing but more base shear than diagonal bracing
- For G+12 -V bracing- equal to inverted V bracing but more than diagonal bracing for both zone(iv) and zone (v)

5. CONCLUSION

In this work, an analysis of the Multistorey Building with different seismic configuration has been done using STAAD.Pro software. The bending moment, shear force, deflection, and base shear due to loading conditions for different parameters have been compared and evaluated. Based on the results of model analysed for loads, The following key findings emerge from the analysis:

- Shear walls (SW) consistently minimized deflection across all seismic zones and building heights, with reductions of 40% to 65%. Diagonal and inverted V bracing (BD & BIV) also offered significant deflection reductions (25% to 35%) compared to unenhanced models.
- Shear walls (SW) significantly increased maximum shear forces (40% to 70%) compared to other models. Inverted V bracing (BIV) generally outperformed diagonal bracing (BD) in reducing shear forces across all zones.
- Shear walls (SW) had the highest maximum bending moments, but have deflection values. Diagonal bracing (BD) resulted in lower bending moments (10% to 30% change) compared to other enhancements.
- Deflection, shear forces, base shear, time period, and bending moments increase with building height (i.e., from G+8 to G+12). The trend in results for both bracing systems and shear walls remains approximately similar as the number of stories increases.
- Base shear increases as the number of stories increases (i.e., from G+8 to G+12). The 12-story shear wall model (5G+12SW) experiences the highest base shear.
- The ideal solution depends on project priorities. Diagonal/Inverted V bracing (BD/BIV) prioritizes deflection reduction. Shear walls (SW) prioritize deflection resistance (but may increase base shear). Diagonal bracing (BD) offers a balanced performance, particularly in Zone IV.
- Zone V: Shear walls perform better but have higher bending moments. Diagonal/Inverted V bracing improves deflection and shear force without significantly increasing bending moments.
- Zone IV: Diagonal/Inverted V bracing improves deflection and shear force without significantly increasing bending moments.

In conclusion, the selection of the optimal seismic enhancement strategy is a function of the specific project requirements and the desired balance between deflection control, shear force resistance, and bending moment considerations.

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