International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Efficient seismic response of Multi-Storey building structures using without frame, Stepped frame, and Plaza frame diaphragms for zone IV

Shivam Verma[1], Abhay Kumar Jha[2]

[1] M. Tech Scholar (Structural engineering) LNCT Bhopal
[2] Professor LNCT Bhopal

ABSTRACT :

In this paper, a comprehensive seismic analysis of zone IV is conducted using STAAD-Pro v8i software. This analysis enables the evaluation of structural behavior under various loading conditions, ensuring the design meets safety and performance criteria. By leveraging STAAD-Pro's advanced modeling capabilities, the study effectively assesses the performance of different building designs, facilitating informed decisions in the structural engineering process.

In this present study (G+9) building Regular frame, rigid diaphragm and semi-rigid diaphragm frames are considered. After analyzing software result in seismic zone IV various parameters like shear force, bending moment, axial force and maximum displacement are found. Max. displacement for without frame 112.13mm, rigid diaphragm 37.42mm, semi-rigid diaphragm 110. 52mm.Similarly for Stepped frame and Plaza frame the values are found out. And in same way other parameters like shear force, bending moment, and axial force are analyzed.

KEYWORDS: Seismic Zone IV, Regular frame, rigid diaphragm, and semi-rigid diaphragm frame, STAAD.PRO, Max. displacement, Shear force, max. Bending moment, Axial force.

1.INTRODUCTION :

Multi-Storey buildings are essential structures that accommodate large populations and represent considerable financial investments. Their design and construction require advanced seismic analysis techniques to ensure safety and resilience, especially in earthquake-prone areas. This study aims to evaluate the performance of various building designs—rigid, semi-rigid, and non-diaphragm—across different seismic zones while maintaining constant plan areas. Through an extensive literature review and structural analysis, the research will emphasize effective construction methods and the necessity of adopting modern approaches to enhance the seismic performance of multi-storey buildings. Given their complexity, understanding how different structural systems respond to seismic forces is crucial for engineers and architects to mitigate risks and protect occupants.

The historical development of high-rise building structural systems reflects significant advancements over the past century. In the early 1900s, reinforced concrete construction emerged, but traditional beam-column frames limited building height. The introduction of shear wall frame systems in the 1950s allowed for structures reaching up to 30 stories, though taller buildings struggled with insufficient stiffness. As urban populations grew, innovative solutions were needed. In the 1960s and 1970s, Fazlur Rahman Khan transformed high-rise construction with systems like tube-in-tube and framed-tube designs, enhancing structural efficiency and reducing costs, as seen in iconic buildings such as the Sears Tower and John Hancock Center. The design philosophy for these high-rises emphasizes limit states to prevent catastrophic failures and maintain functionality, ensuring that multi-Storey buildings not only meet structural integrity standards but also enhance occupant quality of life. Additionally, tall buildings often face oscillatory movements from lateral loads, which can lead to discomfort for occupants. In some 40 to 50-storey buildings in New York City, excessive sway and noise have caused unease during high winds, sometimes resulting in motion sickness. Mitigating noticeable motion is vital in tall building design, with acceleration being a key factor influencing human response to vibrations, alongside period and amplitude. While there are no universally accepted standards for discomfort, preliminary guidelines outline acceptable limits for acceleration and period, aiding designers in improving occupant comfort and usability.

1.1 Objective of This Study

1. The primary objective of this paper is to evaluate the effectiveness of various building geometries in relation to different seismic parameters. This will be achieved through a comparative analysis of building frames, specifically focusing on those with rigid diaphragms, semi-rigid diaphragms, and frames without diaphragms. This aims to provide insights into the performance and resilience of these structural systems under seismic loads for specially zone IV.
2. To find shear force, bending moment, axial force and maximum displacement across seismic zone IV.

2. LITERATURE REVIEW

This section reviews prior research on diaphragm behavior and its impact on the seismic response of multi-storey buildings. It highlights key studies, beginning with Sheng-Jin Chen (1988), who analyzed reinforced concrete floor systems, focusing on fundamental characteristics like strength and stiffness. Kunnath (1991) discussed how the in-plane flexibility of floor slabs affects seismic response, advocating for a simplified modeling approach while acknowledging the limitations of assuming stiff diaphragms in certain structures.

Subsequent studies, including those by Moon and Lee (1994) and El-Hawary (1994), emphasized the need to consider diaphragm flexibility in seismic analyses. Sindel et al. (1996) identified the importance of controlling inter-storey displacements to minimize non-structural damage during earthquakes. Further research explored structural responses under seismic loads, examining the effects of various configurations and construction methods. Prakash (2004) contributed insights on Performance-Based Engineering (PBE) and earthquake-resistant design, referencing the seismic zoning guidelines outlined in IS 1893-2002.

The seismic behavior of building structures, particularly focusing on the role of floor diaphragms and their interactions with lateral force-resisting systems (LFRS). Barron and Hueste (2004) investigated the effects of in-plane diaphragm deformation on reinforced concrete (RC) buildings, challenging the common assumption of rigid diaphragms in analyses. Wilkinson and Hiley (2006) introduced yield hinges in a plane-frame model to assess seismic displacements more accurately. Additionally, Ho Jung et al. (2007) developed a method for estimating peak inter-Storey drifts in buildings with both flexible and rigid diaphragms. Gardiner et al. (2008) examined force patterns in concrete diaphragms during earthquakes, highlighting the influence of inertial forces on structural responses.

Fan et al. (2009) conducted shaking table tests and numerical simulations to analyze the earthquake responses of tall structures, while Wang et al. (2009) created a design strategy for accelerograph arrays to effectively measure seismic reactions in these buildings. Roy and Dutta (2010) explored how soil-structure interaction impacts inelastic responses, particularly in asymmetric structures, and Wakchaure and Ped (2012) studied the effects of brick walls on tall buildings using linear dynamics and various structural models. Hu et al. (2012) critiqued modern seismic analysis software, advocating for a variety of analytical approaches to enhance accuracy. Liang and Lucia (2012) analyzed the inelastic behavior of elastic zipper braced frame buildings under different seismic conditions. Finally, Polastri et al. (2019) focused on the seismic performance of timber buildings with Cross-Laminated Timber (CLT) shear walls, emphasizing the importance of effective connections to manage lateral flexibility and uplift loads during seismic events. Collectively, these studies underscore the complexities of diaphragm behavior and the critical need to incorporate their flexibility into seismic design.

Zhong Ma et al. (2022) examined how ceiling diaphragm rigidity and bracing wall irregularities impact the seismic performance of single-storey LTF buildings in New Zealand, finding that eccentric bracing configurations significantly increased damage during earthquakes. Kesavan and Menon (2022) proposed a nonlinear static method for analyzing unreinforced masonry buildings, highlighting the effect of seismic incidence angles on structural responses.

Ruggieri and Vukobratovic (2023) studied acceleration demands in single-story RC structures, noting that diaphragm flexibility significantly affects peak floor accelerations and response spectra. Intekhab et al. (2023) addressed the challenges posed by irregularities in high-rise buildings, emphasizing the limitations of current design codes.

Srivastava and Gupta (2023) explored optimal shear wall placement in 'C'-shaped structures to mitigate torsional effects, while Krishnan and Sivakumar (2023) discussed the importance of shear wall design in resisting lateral forces. Liu and Li (2023) assessed the seismic bracing capacity of LTF homes under New Zealand's building standards, identifying the vulnerabilities of irregular designs.

Kukwas et al. (2023) reviewed seismic zoning in China, comparing methodologies for seismic analysis across various structures. Bhosale et al. (2024) applied the Response Spectrum Method to analyze the seismic performance of irregular buildings, while Jha et al. (2024) investigated the seismic response of multi-story RCC structures, stressing the importance of proper load distribution.

Bhosale et al. (2024) highlight that earthquakes are major natural disasters capable of causing extensive damage to property and loss of life. The effectiveness of a building during an earthquake largely depends on its size and shape. Many high-rise structures, with their complex geometries, often perform poorly in seismic events. To address this, the Response Spectrum Method (RSM) is used to assess the dynamic effects of ground motions, focusing on the seismic analysis of both regular and irregular buildings, as outlined in the Indian Standard Code IS-1893 (Part-I).

Finally, Jyothirmayee et al. (2024) emphasized the need for effective structural design tools to ensure the stability and durability of commercial buildings. Overall, these studies highlight the complexities of seismic analysis and the critical need for appropriate design strategies in varying contexts.

3.METHODOLOGY

This Present work deals with comparative study of behaviour of (G+9) Storey high rise building frames considering different geometrical configurations and diaphragm constraints under earthquake forces. A comparison of results in terms of moments, shear force, displacements, and Storey displacement has been made.

3.1Following geometries of building frames are considered for analysis-

Case-1: RCC Regular Structure Without Diaphragm
Case-2: RCC Regular Structure with Rigid Diaphragm
Case-3: RCC Regular Structure with Semi-Rigid Diaphragm
Case-4: RCC Irregular (Stepped) Structure Without Diaphragm
Case-5: RCC Irregular (Stepped) Structure with Rigid Diaphragm
Case-6: RCC Irregular (Stepped) Structure with Semi-Rigid Diaphragm
Case-7: RCC Irregular (Plaza) Structure Without Diaphragm

Case-8: RCC Irregular (Plaza) Structure with Rigid Diaphragm
Case-9: RCC Irregular (Plaza) Structure with Semi-Rigid Diaphragm

3.2Following steps are applied in this study: -

Step-1 Selection of building geometry, bays, and Storey (3 geometries)
Step-2 Selection of diaphragm models –

1. Without Diaphragm
2. Rigid Diaphragm
3. Semi-Rigid Diaphragm

Step-3 Selection of all four seismic zones

Table1: Seismic zones for all cases

Seismic zone	II	III	IV	V
Seismic intensity	Low	Moderate	Severe	Very severe
Z	0.10	0.16	0.24	0.36

Step-4 Considering of load thirteen combination
1. E.Q. IN X_DIR.
2. E.Q. IN Z_DIR.
3. DEAD LOAD
4. LIVE LOAD
5. 1.5 (DL + LL)
6. 1.5 (DL + EQ_X)
7. 1.5 (DL - EQ_X)
8. 1.5 (DL + EQ_Z)
9. 1.5 (DL - EQ_Z)
10. 1.2 (DL + LL + EQ_X)
11. 1.2 (DL + LL - EQ_X)
12. 1.2 (DL + LL + EQ_Z)
13. 1.2 (DL + LL - EQ_Z

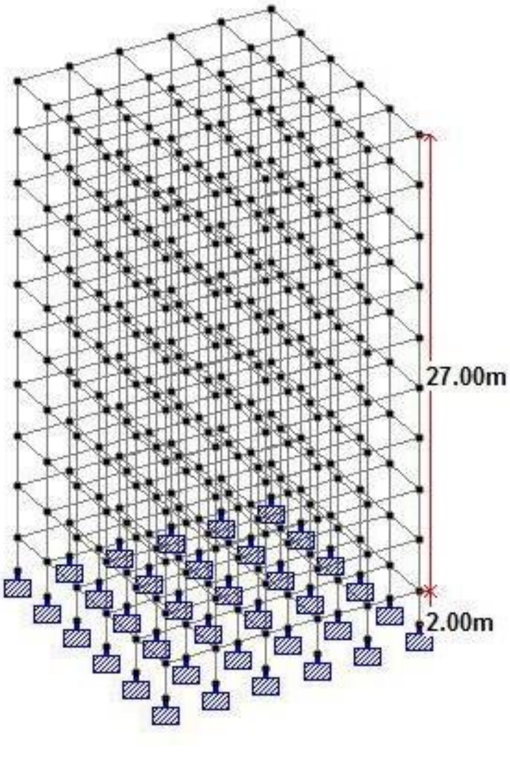
Step-5 Modelling of building frames using STAAD.Pro software.

The modeling is carried out using STAAD.Pro, a widely used software for structural analysis and design. The overall analysis process includes three key tasks:

a. Model Creation: Building the structural model in the software.
b. Calculating Analytical Results: Performing calculations to assess the structure's performance under various loads.
c. Verification of Results: Checking the results for accuracy using STAAD.Pro's graphical interface.

This structured approach ensures a thorough analysis and effective design of the building frames

Fig.1: Isometric view of regular structure in STAAD-Pro software.



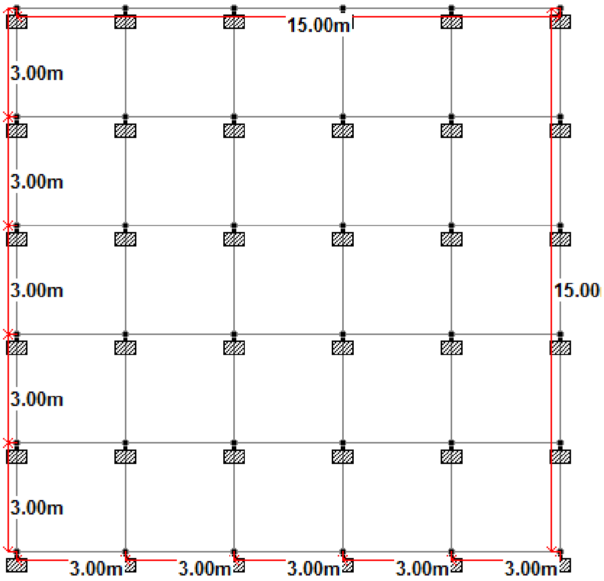


Fig.2: Plan of regular structure in STAAD-Pro software.

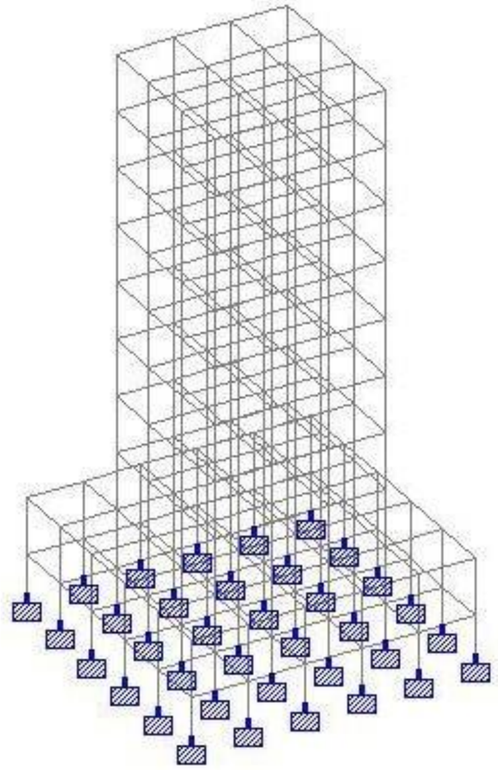
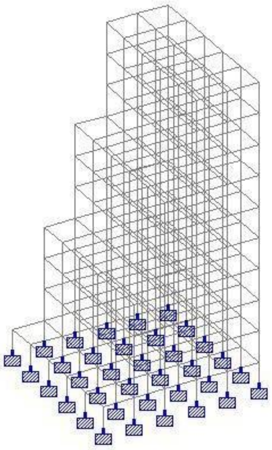


Fig.3 : Isometric view of irregular plaza building in STAAD-Pro software.

Fig.4: Isometric view of irregular stepped building in STAAD-Pro software.



Step-6 In analyses different diaphragm models, seismic zones and 13 load combinations (3cases) are considered.
Step-7 Comparative study of results in terms of beam forces, column force, storeydisplacement and displacement

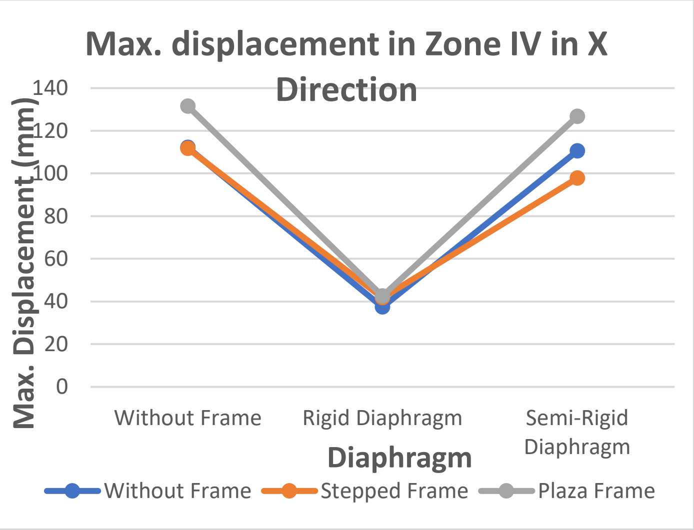
MATERIAL AND GEOMERICAL PROPERTIES-
1.Unit weight of RCC: 25 kN/m3
2. Unit weight of Masonry: 20 kN/m3
3. (Assumed) Modulus of elasticity, of concrete: $5000\sqrt{fck}$
3. Poisson's ratio: 0.17
4.The depth of foundation is 2 m
5. Height of floor is 3 m.
6.Seismic Loads: Seismic calculation according to IS code 1893 (2016)

a) Seismic zone- IV
b) Importance Factor: 1.5
c) Response Reduction Factor: 5
d) Damping: 5%
e) Soil Type: Medium Soil (Assumed)
f) Period in X direction (PX): $\frac{0.09xh}{\sqrt{dx}}$ seconds
g) Period in Z direction (PZ): $\frac{0.09xh}{\sqrt{dz}}$ seconds

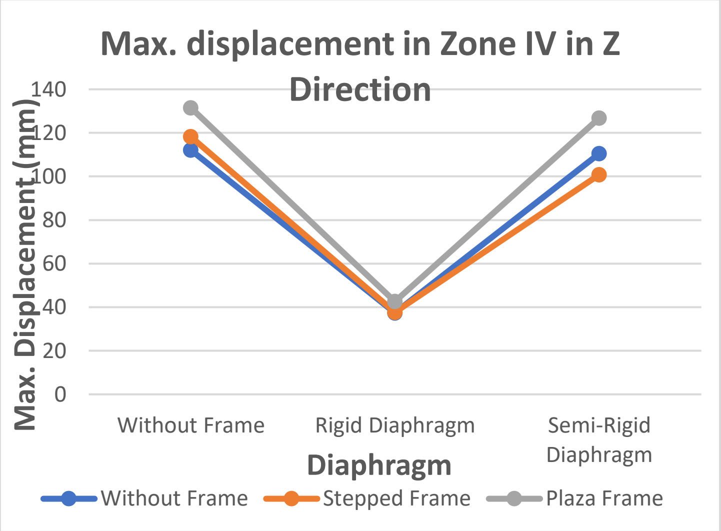
4.ANALYSIS OF RESULTS-

COMPARATIVE ANALYSIS OF ALL DIAPHRAGMS

1.Maximum Displacement

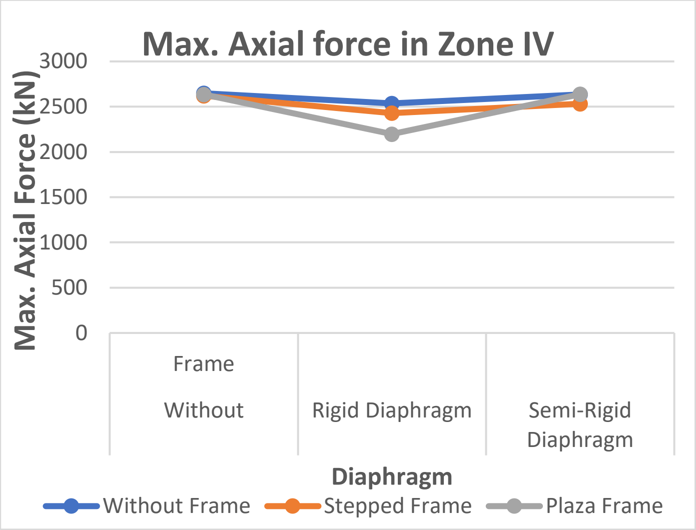


Graph 1: Diaphragm V/S Max. displacement in X-direction



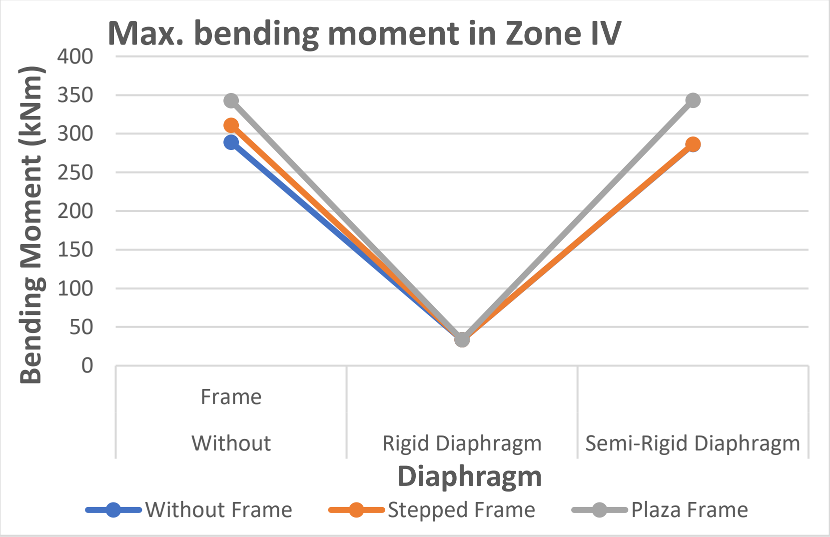
Graph 2: Diaphragm V/S Max. displacement in Z-direction

2.Axial Force on columns



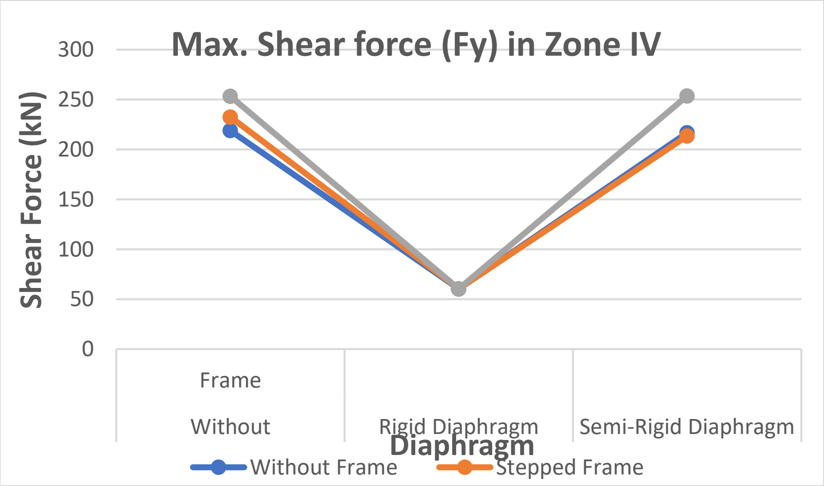
Graph 3: Diaphragm V/S Max. axial force

3.Maximum bending moment on Beams



Graph 4: Diaphragm V/S Max. bending moment (kNm)

4.Maximum shear force



Graph 5: Diaphragm V/S Shear force (kN)

5.Conclusion

This study has led to several key conclusions regarding the performance of different diaphragm types in structural analysis:

Maximum Displacement

- By analysis of software Max. displacement in zone IV in X-direction the values found to be for without frame 112.13mm, rigid diaphragm 37.42mm, semi-rigid diaphragm 110.52mm. Similarly for stepped frame the corresponding values are 111.71mm, 41.73mm, 97.85mm. and for Plaza frame the corresponding values are 131.53mm,42.59mm,126.77mm.
- By analysis of software Max. displacement in zone IV in Z-direction the values found to be for without frame 112.13mm, rigid diaphragm 37.42mm, semi-rigid diaphragm 110.52mm. Similarly for stepped frame the corresponding values are 118.21mm, 37.69mm, 100.74mm. and for Plaza frame the corresponding values are 131.53mm,42.59mm,126.77mm.
- Overall, the rigid diaphragm reduces displacement by approximately 1/3rd compared to remaining diaphragm types.

Beam Forces

- By analysis of software Max. Bending Moment in zone IV the values found to be for without frame 289.12kNm, rigid diaphragm 33.46kNm, semi-rigid diaphragm 286KNm. Similarly for stepped frame the corresponding values are 311kNm, 33.46kNm, 286.7kNm. and for Plaza frame the corresponding values are 342.7kNm, 33.46kNm, 343.3kNm.
- Structures without a diaphragm show maximum bending moments, while those with a rigid diaphragm demonstrate the minimum. This reinforces that a structure without a diaphragm is critical and highlights the efficiency of the rigid diaphragm.

3.Maximum Axial force

- After Analyzing the building in Staad.Pro software Max Axial force in Seismic zone IV the values found to be for without frame 2648kN, rigid diaphragm 2536.41kN, semi-rigid Diaphragm 2636.24kN.Similarly for stepped frame the corresponding values are 2621.23kN, 2428.9kN, 2533kN. And for Plaza frame the corresponding values are 2636kN, 2198kN, 2637.52kN.

4.Max. Shear force (Fy)

- After Analyzing the building in Staad.Pro software Max Shear force in Seismic zone IV the values found to be for without frame 218.81kN, rigid diaphragm 60.33kN, semi-rigid Diaphragm 216. 82kN.Similarly for stepped frame the corresponding values are 232.51kN, 60.33kN, 213.53kN. And for Plaza frame the corresponding values are 253.30kN, 60.33kN, 253.68kN.

6.Summary

This study firmly establishes that rigid diaphragms are far more effective than other types in minimizing bending moments, storey displacement, and peak displacement. The analysis clearly indicates that semi-rigid diaphragm models lead to higher moments and frame displacements compared to their rigid counterparts. Among various building types analyzed, the plaza building stands out as the most significant, while the without-frame structure is less critical. Rigid diaphragms enhance structural integrity, providing considerable savings on reinforcement steel.

7. REFERENCES :

1. Prabakaran Kesavan and Arun Menon,A nonlinear static procedure for seismic assessment of unreinforced masonry buildings with rigid-diaphragms considering the effect of seismic incidence angle Published Online:November 10, 2022,International Journal of Masonry Research and InnovationVol. 8, No. 1pp 46-77https://doi.org/10.1504/IJMRI.2023.127480.

2. Hawary-El M. M., Effect of horizontal diaphragm flexibility on the P-deltaanalysis,Published by Elsevier Ltd, 53(6), December 1994, pp. 1275–1280.

3. Banerjee, R., Srivastava, J.B., & Gupta, N. (2023). "Computational optimization of shear wall location in a C-shaped reinforced concrete framed building for enhanced seismic performance." *International Journal of Interactive Design and Manufacturing*. https://doi.org/10.1007/s12008-023-01302-y

4. Barron, M. J., & Hueste, B. D. M. (2004). "Diaphragm effects in rectangular reinforced concrete buildings." *ACI Structural Journal*, October, 615-624.

5. Adit Kukwas; Ritik Khawas; Vivek Pandey; Tushar Solanki; Kartik Naik; Kuldeep Dabhekar; Isha Khedikar; Neha Pawar(2023) A review on seismic analysis of tall building (G+10) AIP Conference Proceedings 2759, 050010 (2023)https://doi.org/10.1063/5.0145307.

6. Kunnath S., Panahshahi N., and Reinhorn A., Seismic Response of RC Buildings withInelastic Floor Diaphragms, Journal of Structural Engineerin, 117(4), April 1991, pp. 1218–1237.

7. Chen Sheng-Jin, Huang Ti, Lu Le-Wu, Diaphragm Behaviour of Reinforced Concrete Floor Slabs, Proceedings of ninth world conference on Earthquake Engineering, TokyoJapan, August 1988.

8. Prakash vipul, Whither Performance-Based Engineering in India, ISET Journal ofEarthquake Technology, 41(1), March 2004, pp. 201-222

9. Zeynep Sindel, Ragip Akbaş, Semih S. Tezcan, Drift control and damage in tallbuildings, Engineering Structures, 18(12) 1996, pp. 957-96.

10. Wilkinson S.M., Hiley R.A., A non-linear response history model for the seismic analysis of high-rise framed buildings, Computers 84(5–6), 2006, pp.318–329.

11. Damian Alexandru et al. (2000). "Diaphragm behaviour of the floor with prestressed beam and filler blocks." *Proceedings of the 12th World Conference on Earthquake Engineering*.

12. Danay, A. (1976). "A general element for analysis of asymmetric multi-storey buildings with varying cross-section." *Building and Environment*, 11(1), 57-67.

13. Dong-Guen Lee, Hyun-Su Kim, Min Hah Chun. (2002). "Efficient seismic analysis of high-rise building structures with the effects of floor slabs." *Engineering Structures*, 24(5), 613-623.

14. Fintel, M. F. (1986). *Handbook of Concrete Engineering*. CBS Publishers and Distributors.

15. Gardiner, D. R., Bull, D.K., & Carr, A. J. (2008). "Internal forces of concrete floor diaphragms in multi-storey buildings." *New Zealand Society Earthquake Engineering Conference*, Paper No. 21.

16. Guoxin Wang, Weizheng Wang, Katayoun B. Aafshar, Dragi Dojcinovski. (2009). "Seismic instrumentation of high-rise buildings." *Progress in Natural Science*, 19(2), 223-227.

17. Hawary-El, M. M. (1994). "Effect of horizontal diaphragm flexibility on the P-delta analysis." *Elsevier Ltd*, 53(6), 1275-1280.

18. Ho Jung Lee, Mark A. Aschheim, Daniel Kuchma. (2007). "Interstory drift estimates for low-rise flexible diaphragm structures." *Engineering Structures*, 29(7), 1375-1397.

19. Hong Fan, Q.S. Li, Alex Y. Tuan, Lihua Xu. (2009). "Seismic analysis of the world's tallest building." *Journal of Constructional Steel Research*, 65(5), 1206-1215.

20. Intekhab, M., Das, S., Jajnery, M.A. et al. (2023). "Analysis methods of irregular high-rise buildings subjected to seismic loads." *Journal of Vibration Engineering and Technologies*, 11, 1359-1382. https://doi.org/10.1007/s42417-022-00636-3

21. IS 1893: 2016. *Indian Standard criteria for earthquake resistant design of structures, Part 1: General provisions and buildings*. Bureau of Indian Standards, New Delhi.

22. S Jyothirmayee, B Dileep Kumar Reddy, M Rakesh, S Pooja, T Neha and G Kullai Naik,A Comparative Study on Design of Commercial Building using Etabs and Staad Pro Journal of Physics: Conference Series, Volume 2779, International Conference on Materials Innovation and Sustainable Infrastructure 02/02/2024 - 03/02/2024 Bhimavaram, India, DOI 10.1088/1742-6596/2779/1/012035.

23.Zhong Ma, Minghao Li, Angela Liu, Jingfeng Wang, Lina Zhou, Wenchen Dong, Seismic performance of single-storey light timber-framed buildings braced by gypsum plasterboards considering rigidity of ceiling diaphragms, Structures,Volume 41,2022,Pages 1207-1219, ISSN 2352-0124,https://doi.org/10.1016/j.istruc.2022.05.076.