International Journal of Research Publication and Reviews

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

A study on seismic response of Multi-Storey(G+9) building structures using without frame, Stepped frame, and Plaza frame diaphragms for zone V

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ABSTRACT :

Using STAAD.Pro V8i software, this analysis incorporates the specific challenges presented by seismic zone V on a multistoried building (G+9), which requires rigorous examination of P-Delta effects and overall stiffness to mitigate risks associated with lateral deflections. The P-Delta effect, where horizontal loading induces additional moments due to gravity loading, must be analyzed through various methods, including direct second-order adjustments for structures. Adequate lateral stiffness is crucial for limiting lateral deflection, with drift index values needing to be carefully selected based on the building's intended use and design criteria. In this context, dynamic comfort criteria also play a vital role, as excessive lateral movement can adversely affect occupant comfort. Therefore, all these factors must be integrated into the structural design process to ensure the safety and usability of high-rise buildings in seismic areas.

In this paper, we examined buildings with regular frames, including those with rigid and semi-rigid diaphragms. After analyzing the software results for seismic zone V, we obtained various parameters such as shear force, bending moment, axial force, and maximum displacement. The maximum displacements recorded were 168.16 mm for the frame without a diaphragm, 56.14 mm for the rigid diaphragm, and 165.79 mm for the semi-rigid diaphragm. Similar analyses were conducted for stepped and plaza frames, where shear force, bending moment, and axial force were also evaluated.

KEYWORDS: Semi-Rigid Diaphragm Frame, Rigid Diaphragm, Seismic Zone V, Maximum Displacement, Axial Force, Shear Force, Maximum Bending Moment, Regular Frame

1.INTRODUCTION :

In this paper, we focus on the critical design requirements for tall buildings, particularly in seismic zone V, where structures must withstand significant lateral forces. The ultimate limit state demands that buildings possess sufficient strength and stability throughout their lifespan. This includes analyzing forces and stresses for critical load combinations, incorporating additional moments from P-Delta effects, and ensuring that critical structural members are thoroughly evaluated to prevent progressive collapse. Design considerations must also account for factors such as restrained differential movements due to creep, shrinkage, and temperature changes. Furthermore, stability assessments are essential, as the increased height of buildings often reduces reserves of stiffness, necessitating careful evaluation of both overall structural stability and the stability of individual components.

1.1Roles and Actions of Diaphragms

A diaphragm is a flat structural element, typically found in floors and roofs, that acts like a deep, thin beam. When vertical and horizontal diaphragms are interconnected, they form a cohesive structural unit. Diaphragms play several key roles in resisting both gravity and lateral forces in buildings:

- **Gravity Load Resistance**: Diaphragms support gravity loads as part of the roof and floor framing.
- **Lateral Support**: They connect vertical components of the earthquake force-resisting system, preventing buckling and mitigating second-order forces caused by lateral displacements.
- **Out-of-Plane Force Resistance**: Diaphragms provide resistance against out-of-plane forces from seismic activity and wind pressure acting on walls.
- **Lateral Inertial Force Transfer**: They transfer lateral inertial forces, including those from columns and walls, to vertical elements of the seismic force-resisting system.
- **Force Transfer at Discontinuities**: Significant force transfers occur at discontinuities in vertical components, such as offsets, facilitating load distribution.
- **Soil Load Support**: In buildings with basements, diaphragms help manage soil pressure against basement walls, producing compressive reaction forces.

  Overall, diaphragms are essential for ensuring structural stability and resilience during seismic events.

1.2Objective of this Study

1. To prepare G+9 building frame in STAAD Pro
2. To perform the analysis of Multi-storey building (G+9) under dead load, live load,and seismic load by using STAAD Pro.
3. A comparative analysis of building frames with rigid diaphragms, semi-rigid diaphragms, and those without diaphragms, comparing the values of shear force, bending moment, axial force and maximum displacement across seismic zone V.

2.LITERATURE REVIEW :

Previous research highlights recent contributions related to diaphragms and earlier efforts that align closely with the current study's objectives. This section presents a brief review of diaphragm discontinuity from prior studies. The literature demonstrates the impact of diaphragm discontinuity on the seismic response of selected multi-storey buildings.

Kunnath (1991) highlighted that the seismic response of reinforced concrete structures is influenced by the in-plane flexibility of floor-slab systems. Although stiff floor diaphragm assumptions simplify analysis, flexibility is critical for certain structures, especially long, narrow ones and those with offsets. The paper presents a macro modeling scheme to include inelastic floor flexibility in seismic response analysis, considering both moment and shear effects.

El-Hawary (1994) emphasizes the importance of considering horizontal diaphragm flexibility in the P-delta analysis method, particularly for loads on intermediate frames not part of the lateral force-resisting system. The study analyzed structural systems with rigid jointed plane frames or vertical trusses, varying in storeys, bays, and diaphragm stiffness.

Sindel et al. (1996) noted that a tall building's safety during earthquakes is largely influenced by its ability to control inter-storey displacements. Without proper restraint from shear walls, a frame building meeting strength and ductility requirements can still suffer significant non-structural damage.

Dong-Guen et al. (2002) examined constructions using the box system, using simply RC walls and slabs. This study analyses high-rise box system structures while taking the effects of floor slabs into account.

Prakash (2004) discusses the opportunities for Performance-Based Engineering (PBE) in India, highlighting the factors that enabled its development in California, including earthquake-resistant design requirements from the Bureau of Indian Standards (BIS). The updated IS 1893-2002 combines seismic zones I and II into four zones and adopts a modified CIS-64 scale for seismic zoning.

Barron and Hueste (2004) investigated the role of floor diaphragms in transferring lateral earthquake loads to the vertical lateral force-resisting system (LFRS). While it's common to assume horizontal diaphragms are stiff and neglect their in-plane movement, this study aims to assess the impact of diaphragm deformation on the structural response of typical RC rectangular buildings using a performance-based approach. Three-story and five-story RC buildings with end shear walls and two aspect ratios (approximately 2:1 and 3:1) were designed following existing code standards, assuming rigid diaphragm behavior.

Ho Jung et al. (2007) a straightforward technique was discussed to more precisely estimate peak inter-storey drifts that takes higher mode effects into account for low-rise perimeter shear wall systems with flexible diaphragms or even rigid diaphragms.

Fan et al. (2009) to construct the finite element (FE) model of the tall structure, it was conducted a shaking table test to ascertain the constitutive relationships for the concrete filled steel tube (CFT) columns and steel members. Then, a numerical analysis of the tall building's earthquake responses was performed.

Hu et al. (2012) We came to the conclusion that modern software cannot handle calculations and analyses. In this work, various types of analytic methods, including dynamic analysis, were carried out utilising proprietary software.

Liang and Lucia (2012) explores the inelastic behaviour of the 4, 8 and 12-story elastic zipper braced frame (E-ZBF) buildings under crustal, subduction, and near-field ground movement ensembles in Victoria, British Columbia, a seismically active area.

Polastri et al. (2019) examined the seismic behavior of multi-story heavy-frame timber buildings with Cross-Laminated Timber (CLT) shear walls through computational linear dynamic simulations. The study maintained consistent building dimensions and configurations while varying the number of storeys (3, 5, or 7) and shear-wall anchoring techniques. Key findings highlighted the impact of vertical joints on seismic response, revealing that mid-rise buildings are vulnerable to lateral flexibility, resulting in significant uplift loads on foundations. This necessitates specialized design strategies to limit lateral drifts within standards. Simplified connection models may lead to inaccurate drift predictions and design flaws. Future designs should incorporate effective connecting mechanisms, like metal tie-downs, to mitigate inter-storey drift and manage foundation stresses without damaging shear walls.

Kesavan and Menon (2022) explored how the seismic incidence angle influences the structural assessments of existing buildings. Since seismic excitation is random, predicting the direction of ground motion is challenging. Currently, load patterns are applied in two mutually orthogonal directions during nonlinear static analysis of 3D building models, leading to variable structural responses depending on the seismic demand direction. To address this, the authors propose a nonlinear static method for unreinforced masonry buildings based on the N2 method, eliminating the need for extensive multi-directional analyses. Their report includes polar charts illustrating the significant impact of seismic incidence angles on floor level displacements.

Jyothirmayee et al. (2024) highlight the vital role of engineers in project planning and structural design, focusing on stiffness, strength, and stability. Despite available software, many students struggle with load calculations and design parameters. This study aims to analyze and design commercial buildings using STAAD Pro, adhering to IS 456:2000 and SP-16 guidelines. It focuses on enhancing analyses for load scenarios, combinations, and beam reinforcement, with results that compare design outcomes like displacement, axial force, shear forces, and bending moments.

Liu and Li (2023) note that low-rise light timber-framed (LTF) buildings, which adhere to the NZS 3604:2011 standard, dominate residential construction in New Zealand. This standard outlines methods for assessing the seismic resistance of proprietary LTF walls, typically made of plasterboard, and specifies seismic demand. Designers must ensure that the seismic bracing capacity meets or exceeds the demand, provided the bracing arrangements comply with irregularity limits established from engineering best practices.

3.Methodology And Analysis of Building Frames

This paper conducts a comparative analysis of high-rise building frame behavior under earthquake forces, focusing on various geometrical configurations and diaphragm constraints. Results are compared in terms of moments, shear forces, displacements, and Storey displacements. The methodology involves the following steps:

Methodology Steps

1. Building Geometry Selection: Choose three geometrical configurations.
2. Diaphragm Models:
- Type 1: Without Diaphragm
- Type 2: Rigid Diaphragm
- Type 3: Semi-Rigid Diaphragm
3. Seismic Zones: Assess based on IS 1893 (Part-1): 2016 for RCC structures in zones II, III, IV, and V.
4. Load Combinations: Include various cases such as:
- Earthquake loads in X and Z directions
- Dead and live loads
- Various combinations of these loads.
5. Modeling: Use STAAD.Pro software for building frame analysis.
6. Analysis: Evaluate different diaphragm models and seismic zones across 36 cases.
7. Comparative Study: Analyze results regarding beam forces, column forces, storey displacements, and overall displacements.

Modeling of Building Frames

The analysis considers the following cases:

- RCC Regular Structures (with/without diaphragms)
- RCC Irregular (Stepped/Plaza) Structures (with/without diaphragms)

Modeling in STAAD.Pro involves:

1. Model Creation: Define the building geometry, materials,and structural elements.
2. Load Definition: Set up load combinations, including dead, live, and seismic loads as per IS 1893:2016.
3. Diaphragm Configuration: Specify diaphragm types (rigid, semi-rigid, or without diaphragm).
4. Seismic Parameters: Input seismic zone characteristics and response spectrum data for Zone V.
5. Analysis Setup: Conduct nonlinear static or dynamic analyses to assess structural response.
6. Result Evaluation: Review outcomes, focusing on forces, displacements, and overall stability.

Table 1: Material properties

MATERIAL PROPERTIES	DETAILS
RCC Unit Weight	25 kN/m³
Masonry Unit Weight	20 kN/m³ (assumed)
Modulus of Elasticity	$5000\sqrt{fck}$

Poisson's Ratio	0.17
Foundation Depth	2m
Floor Height	3m

Seismic Loads: Seismic calculation according to IS code

1. Seismic zone-V (where Z= 0.36)
2. Importance Factor: 1.5
3. Response Reduction Factor: 5

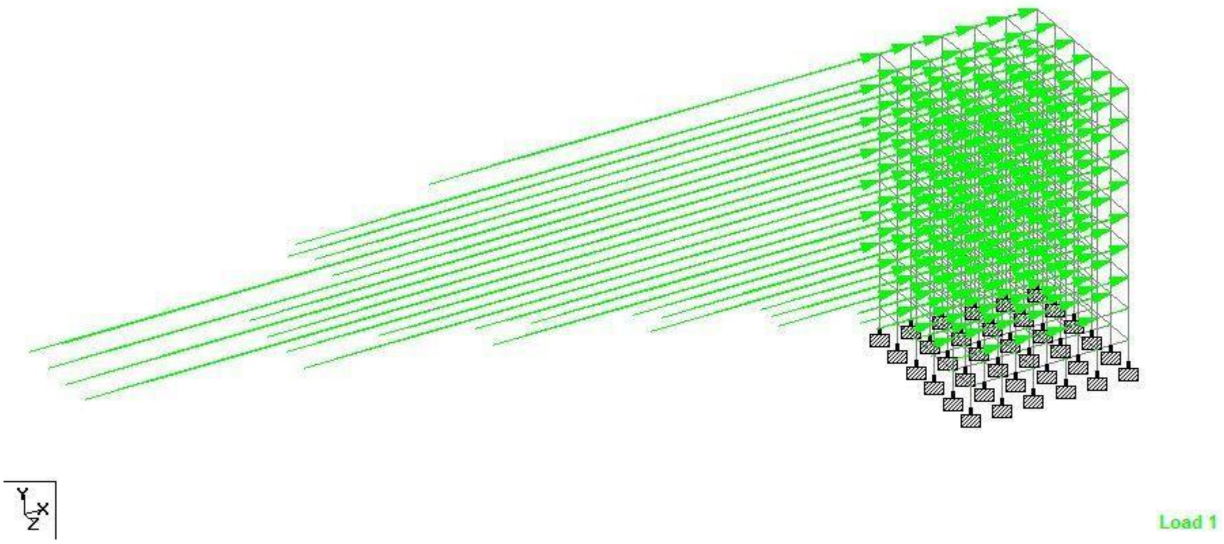


Fig. 1: Seismic load in X direction

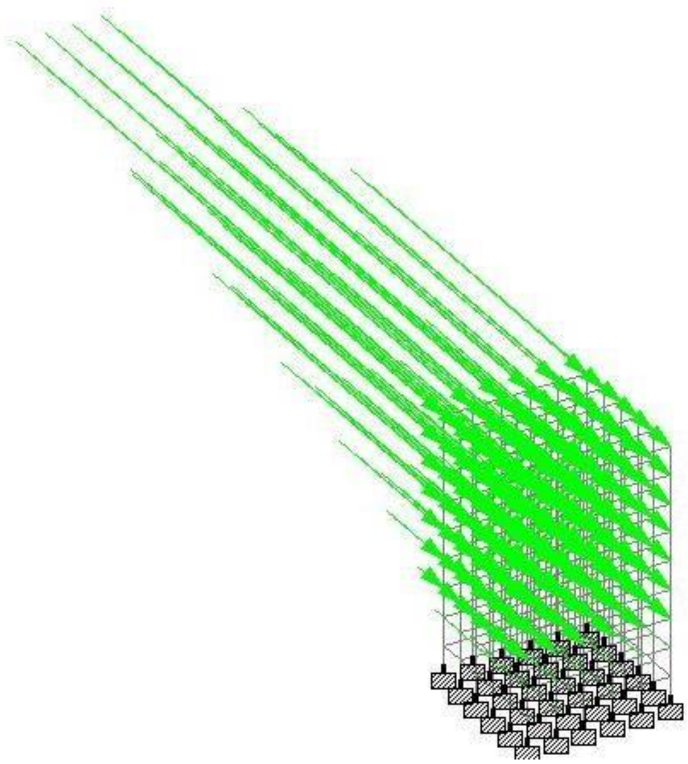


Fig.2: Seismic load in Z direction

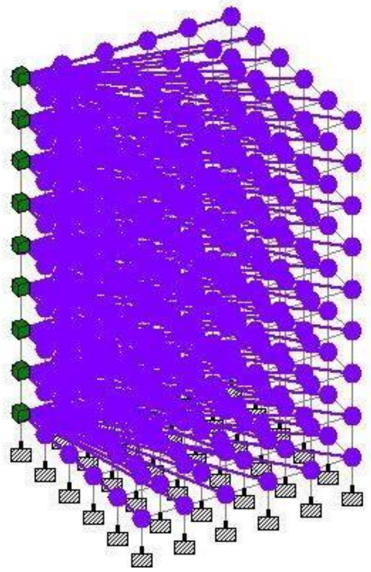


Fig.3: 3D diagram for diaphragm building

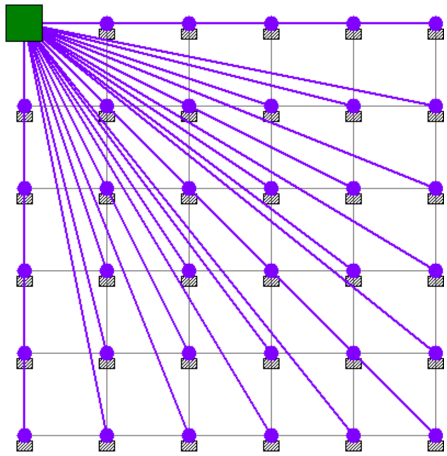
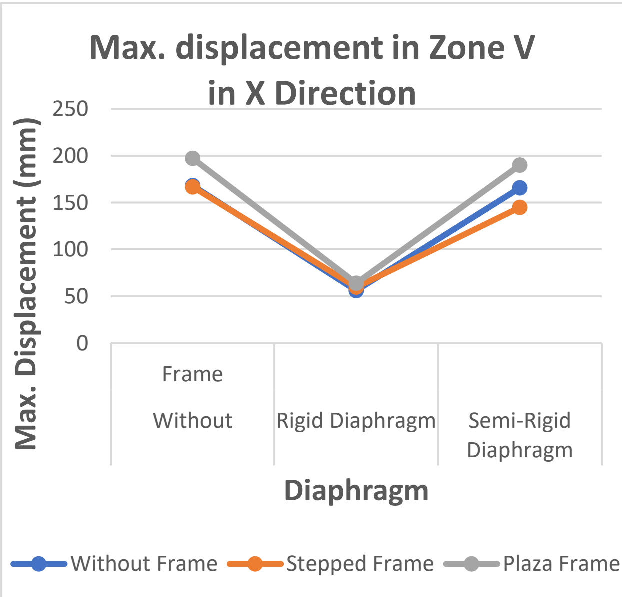


Fig. 4: Plan of diaphragm building

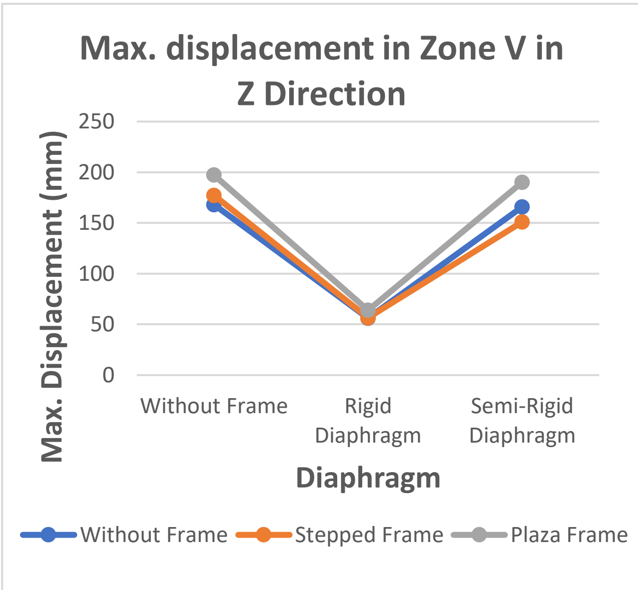
4. RESULT AND ANALYSIS OF ALL DIAPHRAGMS

1.Maximum Displacement

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

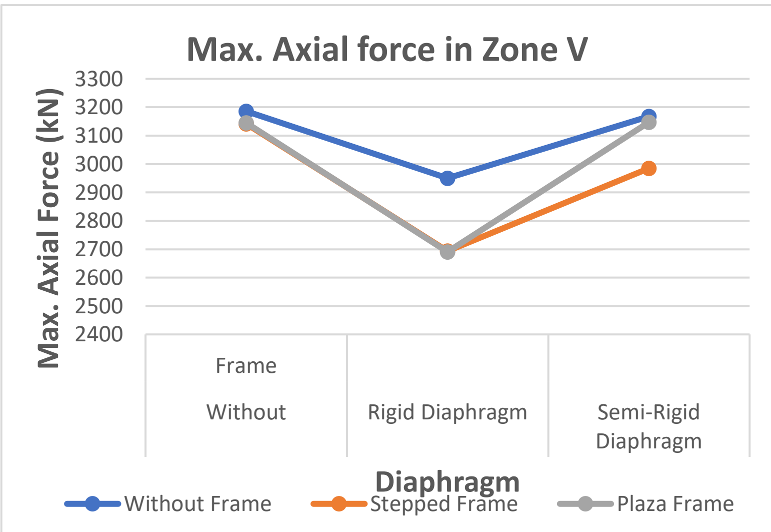


Graph 2: Diaphragm V/S Max. displacement in Z-direction

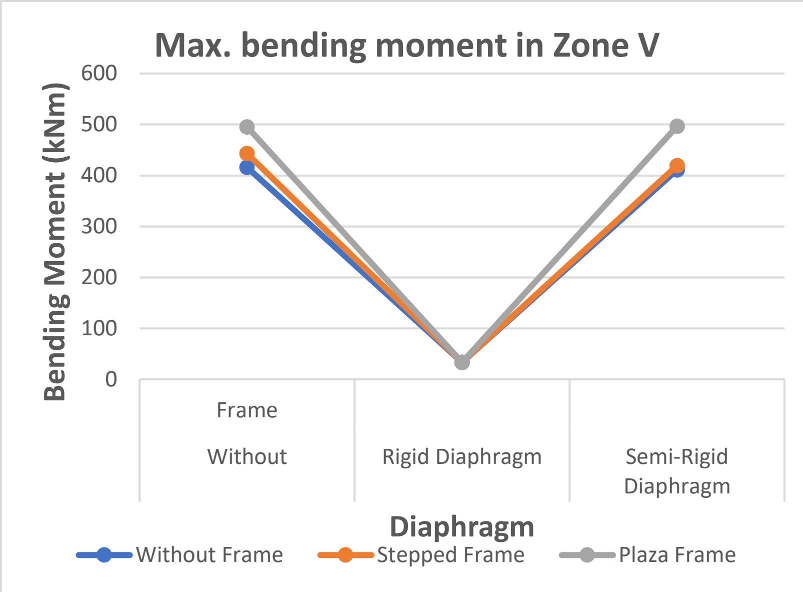


2.Column Axial force

Graph 3: Diaphragm V/S Max. axial force

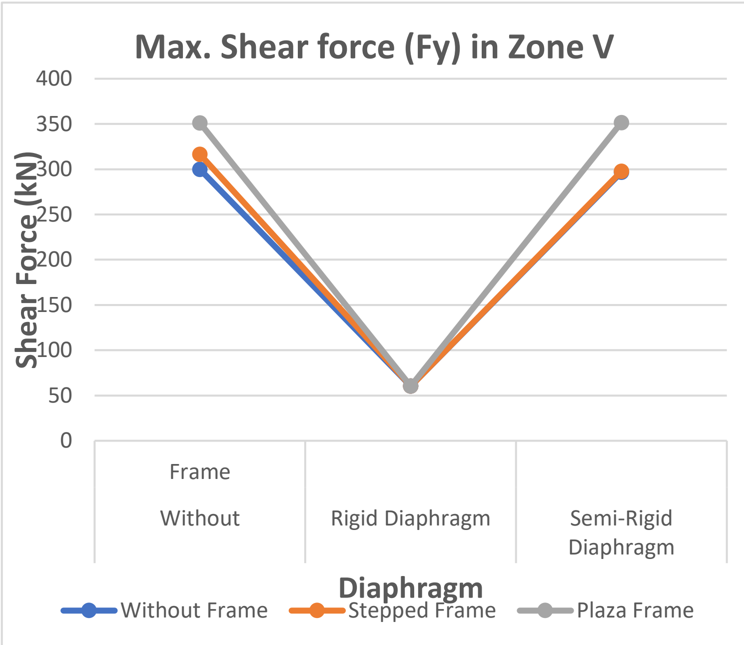


3.Maximum bending moment in Beam



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 V in X-direction the values found to be for without frame 168.16mm, rigid diaphragm 56.14mm, semi-rigid diaphragm 165.79mm. Similarly for stepped frame the corresponding values are 166.88mm, 59.68mm, 145.09mm. and for Plaza frame the corresponding values are 197.27mm,63.89mm,190.16mm.
- By analysis of software Max. displacement in zone V in Z-direction the values found to be for without frame 168.16mm, rigid diaphragm 56.14mm, semi-rigid diaphragm 165.79mm. Similarly for stepped frame the corresponding values are 177.28mm, 56.54mm, 151.09mm. and for Plaza frame the corresponding values are 197.27mm, 63.89mm, 190.16m
- 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 V the values found to be for without frame 415.80kNm, rigid diaphragm 33.46kNm, semi-rigid diaphragm 411.11KNm. Similarly for stepped frame the corresponding values are 442.73kNm, 33.46kNm, 419.27kNm. and for Plaza frame the corresponding values are 495.39kNm, 33.46kNm, 496.27kNm.
- 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 V the values found to be for without frame 3186.08kN, rigid diaphragm 2950.17kN, semi-rigid Diaphragm 3168.20kN. Similarly for stepped frame the corresponding values are 3141.87kN, 2693.43kN, 2984.53kN. And for Plaza frame the corresponding values are 3144.66kN, 2690.77kN, 3147.17kN.

4.Max. Shear force (Fy)

- After Analyzing the building in Staad.Pro software Max Shear force in Seismic zone V the values found to be for without frame 299.86kN, rigid diaphragm 60.33kN, semi-rigid Diaphragm 296. 88kN.Similarly for stepped frame the corresponding values are 316.49kN, 60.33kN, 297.67kN. And for Plaza frame the corresponding values are 351.08kN, 60.33kN, 351.64kN.

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