A Comparative study on response of RC Column and composite column with varying Slab System under the influence of Seismic Zones using Pushover Analysis

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Abstract: The research work is mainly aimed to study the behavior of columns when the structure is subjected to seismic loading conditions. When seismic loads are applied to the structure, the resultant seismic forces are distributed unevenly to the components of the structural system a group of columns may be subjected to larger intensity of loads than other one. If the column arrangement is not done properly considering load path and configuration of the system, the compression members may experience more stress than their design strength or capacity resulting in permanent deformation or failure.

In recent research, major work has been done on investigating the seismic response of whole structural system. No individual element has been analyzed thoroughly. So, for filling this research gap, the project aims to conduct a detailed study on the response of columns with respect to lateral with focus on seismic loads. Reinforced concrete columns have been chosen for analysis. These have been analyzed under different slab types i.e., flat slabs, flat plate slabs and conventional slab which rest on beams. These models have been analyzed under influence of earthquake loading conditions especially by changing the seismic zones.The analysis and design have been carried out based on Indian Standard Codes.

Index Terms- Reinforced Concrete Columns, Flat Plate Slabs, Shell Systems, Pushover Analysis.

I. INTRODUCTION

Design and analysis are two distinct yet complementary responsibilities of structural engineers. When using contemporary hand tools, there are several requirements that must be met in order to model a structure accurately. However, these requirements often result in some degree of variation between the modeled structure and the actual geometry. Therefore, from a structural engineer's perspective, the primary goal of design is to create a structural system that can be reliably constructed, rather than simply providing a detailed description of what to expect during usage.

The emergence of nonlinear analysis has significantly reduced the uncertainties that were prevalent when only linear analysis was available. As the ability to model structures continues to advance, the results will continue to improve, and the uncertainties associated with nonlinear analysis will be eliminated.

Columns are vertical load-bearing structural members that primarily resist compressive loads. In reinforced concrete (RC) construction, the main reinforcement in columns is used to resist these compressive loads. According to IS code, a column is a compression member whose effective length is greater than three times its least lateral dimension; otherwise, it is considered a short column or a pedestal.

Columns are particularly important in seismic design, where they can experience large forces due to the effects of lateral loads. These lateral loads can cause significant shear and bending in columns, which can lead to instability or failure if not properly designed. Designers must carefully consider the geometry and detailing of columns to ensure they are capable of resisting the expected seismic loads.

Seismic design involves analyzing the lateral forces that are exerted on a building during an earthquake. These forces are typically represented by a proportion of the building's weight, known as the base shear, which must be resisted by the foundation. Base shear induces both horizontal and vertical loads on columns, which can result in significant bending and shear stresses. Designers must carefully consider the magnitude and direction of these loads when designing columns for seismic resistance.

During an earthquake, the eccentricity of the ground motion can cause the applied loads to be displaced away from the centroid of the column, resulting in eccentric loading. This eccentricity can induce both in-plane and out-of-plane bending moments in the column, depending on the direction and orientation of the applied loads. The magnitude of the eccentricity increases with the magnitude of the earthquake, which can result in higher bending moments and shear forces in the column. Designers must carefully consider the effects of eccentric loading on the strength and stability of columns when designing for seismic resistance.

To check the response of columns in a pushover analysis, the capacity curves of the columns are generated by applying incremental loads to the structure until it reaches a failure condition. The capacity curve of a column is a graph that shows the relationship between the applied load and the corresponding displacement of the column.

During pushover analysis, the column's response is checked by comparing its capacity curve to the demand curve, which represents the expected load distribution on the structure during a seismic event. If the demand curve intersects with the capacity curve at a point where the column has exceeded its ultimate strength and has started to deform plastically, then the column is considered to have failed.

The response of the column can be further analyzed by examining the plastic hinge formation and failure mechanisms. Plastic hinge formation is a common failure mode in columns during seismic events and occurs when the column's cross-section undergoes significant plastic deformation. The location and magnitude of the plastic hinge can affect the column's overall seismic response, and identifying the plastic hinge location can help in determining the column's vulnerability to seismic loads.

II. LITERATURE SURVEY

G.S. Saisaran et. Al. discuss the use of Pushover analysis, a static nonlinear technique used to estimate seismic structural deformations, in the analysis of a reinforced concrete building frame. In this method, a computer model of the building is incrementally subjected to horizontal loads of a certain shape, while the sequence of cracks, yielding, plastic hinge formation and failure of various structural components is recorded. Pushover analysis can provide insight into the weak links in seismic performance of the structure, and in this study, the authors carry out a pushover analysis of a multi-story building frame designed according to Indian Standards using E-tabs software for only a zone-3 earthquake. The main objective of this study is to check the kind of performance a building can give when designed as per Indian Standards.

The paper by Chung Yue Wang proposes a method for determining the parameters of plastic hinge properties (PHP) for structures containing RC walls in pushover analysis. The nonlinear relationship between the lateral shear force and lateral deformation of RC walls is calculated using the Response-2000 and Membrane-2000 code. The PHP value of each parameter for the pushover analysis function of SAP2000 or ETABS is defined as the product of two parameters α and β. The values of α are determined at states of cracking, ultimate strength, and failure of the concrete wall under shear loading. The corresponding β value of each PHP parameter is obtained from the regression equations calibrated from the experimental results of pushover tests of RC frame-wall specimens. The accuracy of the proposed method is verified by other experimental results, showing that the presented method can effectively assist engineers in conducting the performance design of structures containing RC shear walls using the SAP2000 or ETABS codes.

The research done by Dr. A.S. Pant et. Al. discusses on designing columns for earthquake loading, where 229 column sections are designed according to IS 456:2000 for a specific load action. The evaluation of the sections is based on different criteria such as strength reduction factor, buffer capacity, cost, and weight. The results show that there is no single design that satisfies all the criteria at once. However, a smart section is identified that performs well in all attributes consistently.

Putul Haldar et. Al. conducted a study to examine the adequacy of the force-based seismic design philosophy currently used in India and the relative importance of various code provisions. The expected performance of a set of code-designed buildings was estimated using FEMA-440 and HAZUS methodologies in deterministic as well as probabilistic terms. The study showed that the Special Moment-Resisting Frame design under the current design provisions of Indian standards has a higher probability of damage compared to the Ordinary Moment-Resisting Frame design due to the higher allowable ultimate drift limit. Additionally, the deterministic framework of performance-based seismic design does not provide complete insight into the expected performance and associated risks of the designed buildings.

The research work conducted by Krishna Prasad Chaudhary and Ankit Mahajan aimed to analyze the seismic performance of different high-rise buildings of H-shaped, O-shaped, and C-shaped configurations using the response spectrum analysis method in the CSI ETABS software. The study considered 12 storey and 16 storey buildings of each configuration.The response spectrum method is a commonly used seismic analysis technique that utilizes the acceleration response spectra of an earthquake to predict the response of a structure. The response spectra give the peak response of a structure for a range of natural periods and damping ratios.

The results of the study showed that the seismic performance of the different configurations varied significantly. The H-shaped building showed better results compared to the other configurations. The 12 storey buildings also performed better than the 16 storey buildings.It was observed that the transference of heavy masses had minimal effect on the lateral sway of the structures. The maximum displacement was found in the L-shaped 16 storey building with a value of 87.804 mm. The transference of heavy masses had little effect on the total quantity and cost of the 16-storey building.The study also found that the bending moments and shear forces increased from 1.17% to 1.84% in the different buildings. The O-shaped building produced the maximum variation in bending moments and shear forces. The L-shaped building produced the maximum displacement from all the three irregular shapes.

In conclusion, the study highlights the importance of considering the shape and height of the building in seismic design. The response spectrum analysis method was found to be a useful tool in evaluating the seismic performance of high-rise buildings. The results of the study can be used to optimize the design of high-rise buildings to enhance their seismic performance.

III. Geometrical Parameters of Structural Systems

This passage discusses the analysis and design of a commercial building in Noida, specifically for office use. To analyze the building's structure, eight different models were considered. Four of these models used flat slabs while the other four used conventional slabs supported by beams. The models were analyzed with different numbers of stories, including 30, 25, 20, and 15 storied structural systems. The general specifications of the structures were consistent across all four types of structural systems, with the only variations being the type of slab and the number of stories. Types of slab systems considered for comparison are ribbed system, flat slab system, flat plate system and conventional beam integrated slab system.

To further elaborate, the analysis and design of a commercial. building is a complex process that involves careful consideration of various factors such as the building's intended use, location, and structural stability. In this case, the building in question is designed for office use and is located in Noida. To analyze the building's structure, different models were considered, each with varying slab types and number of stories. The use of flat slabs versus conventional slabs supported by beams can have a significant impact on the building's overall strength and stability. Additionally, the number of stories can also affect the building's overall structural integrity, as taller buildings are subject to greater stresses and forces. By considering these factors and analyzing each model under different conditions, a better understanding of the building's structural behavior can be gained, ultimately leading to a safer and more reliable design.

A. General grid data for building structural systems

Table 1: Grid data in X-Direction

Name	Grid line direction	Label/ ID	Ordinate (in m)
COLUMNS	X (Cartesian)	A	0
COLUMNS	X (Cartesian)	B	10
COLUMNS	X (Cartesian)	C	20
COLUMNS	X (Cartesian)	D	30
COLUMNS	X (Cartesian)	E	40

Table 2: Grid data in Y-direction

Name	Grid line direction	Label/ ID	Ordinate (in m)
COLUMNS	Y (Cartesian)	1	0
COLUMNS	Y (Cartesian)	2	10
COLUMNS	Y (Cartesian)	3	20
COLUMNS	Y (Cartesian)	4	30
COLUMNS	Y (Cartesian)	5	40

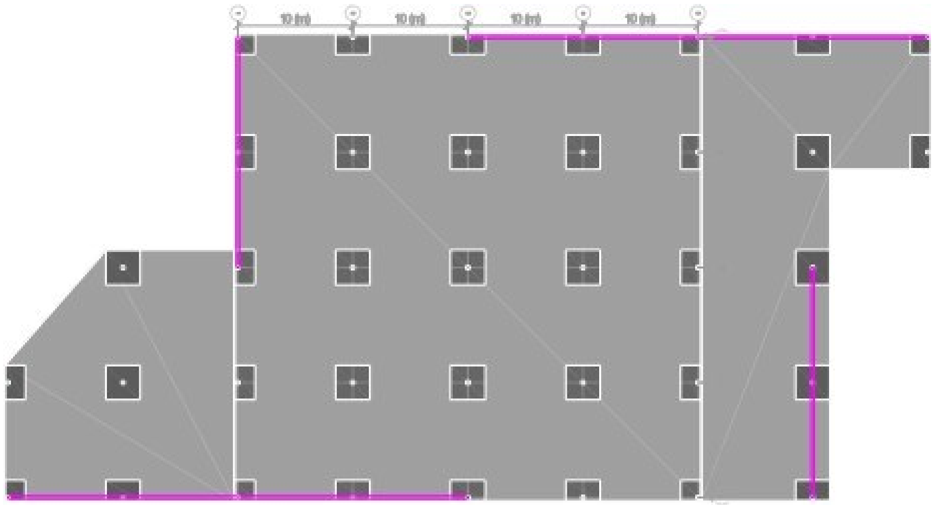

Figure 1: Typical structural Plan for flat slab structural system

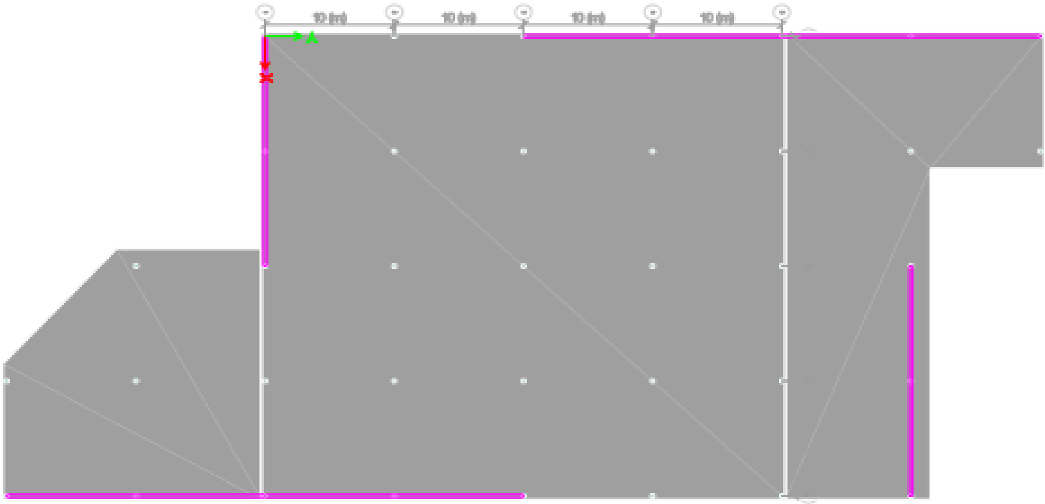

Figure 2: Typical structural Plan for flat plate structural system

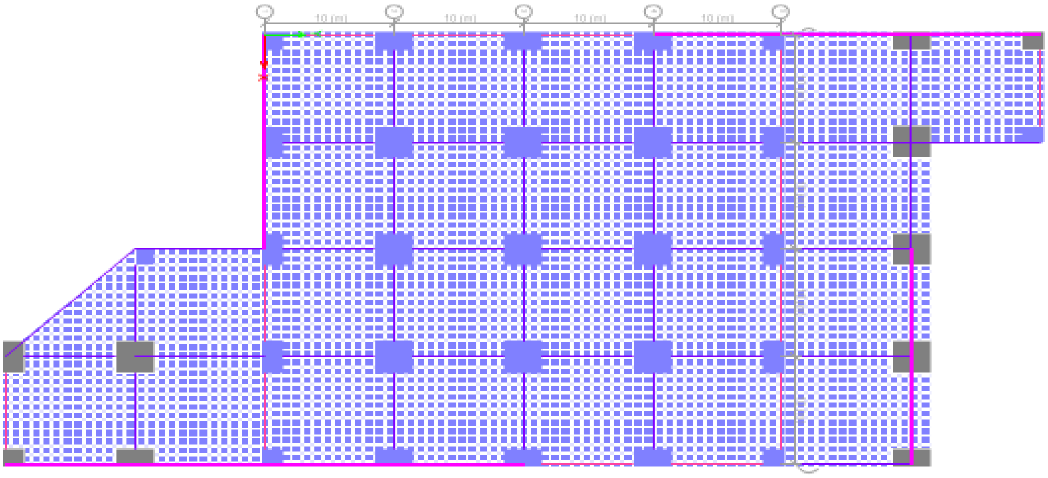

Figure 3: 2D Plan for Waffle Slab type System

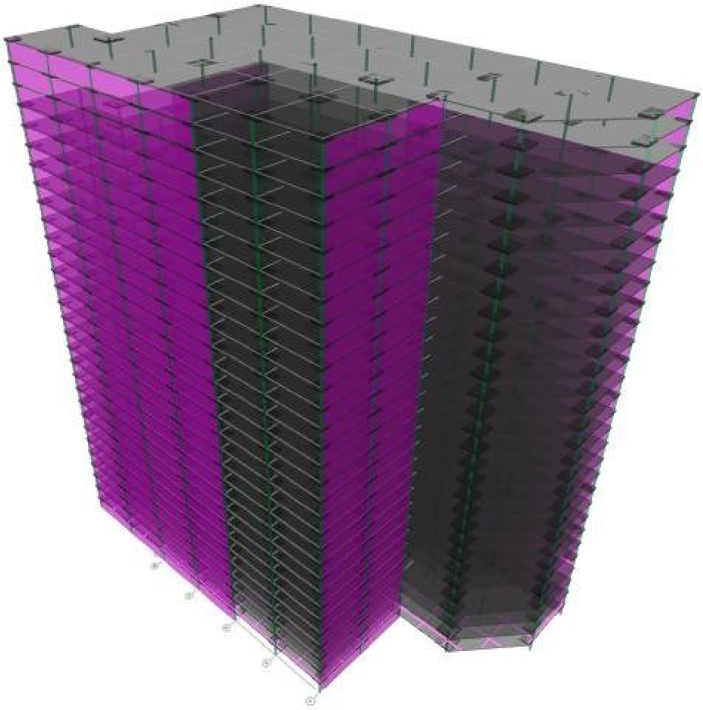

Figure 4: 30 Storied Flat Slab Structural Model

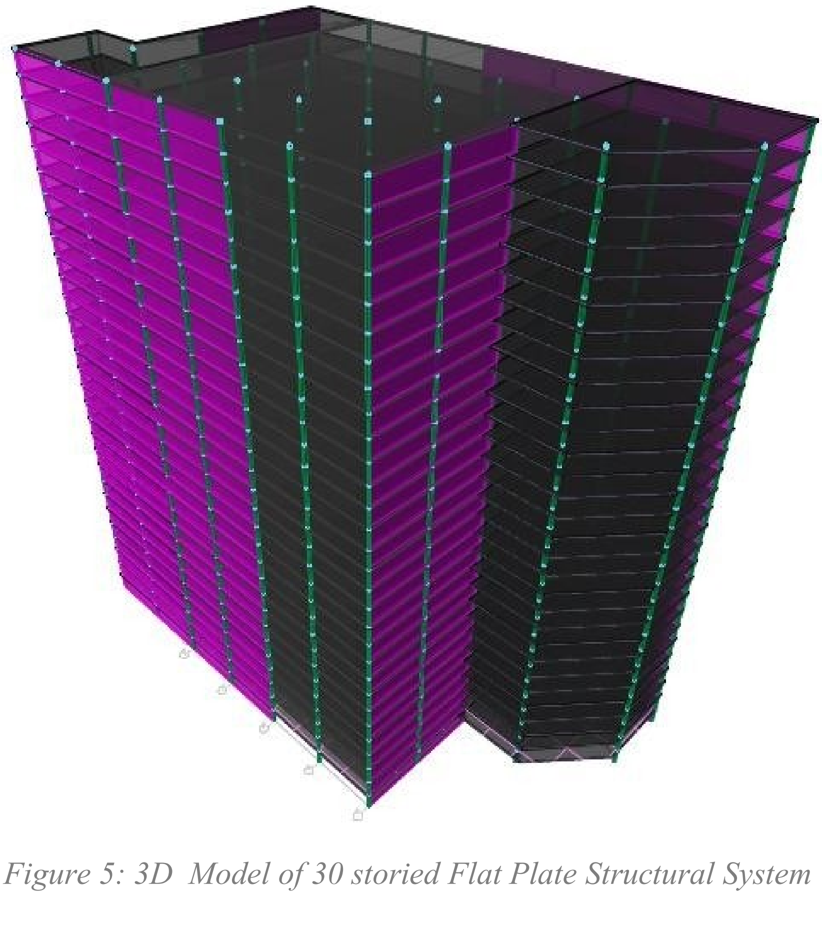

Figure 5: 3D Model of 30 storied Flat Plate Structural System

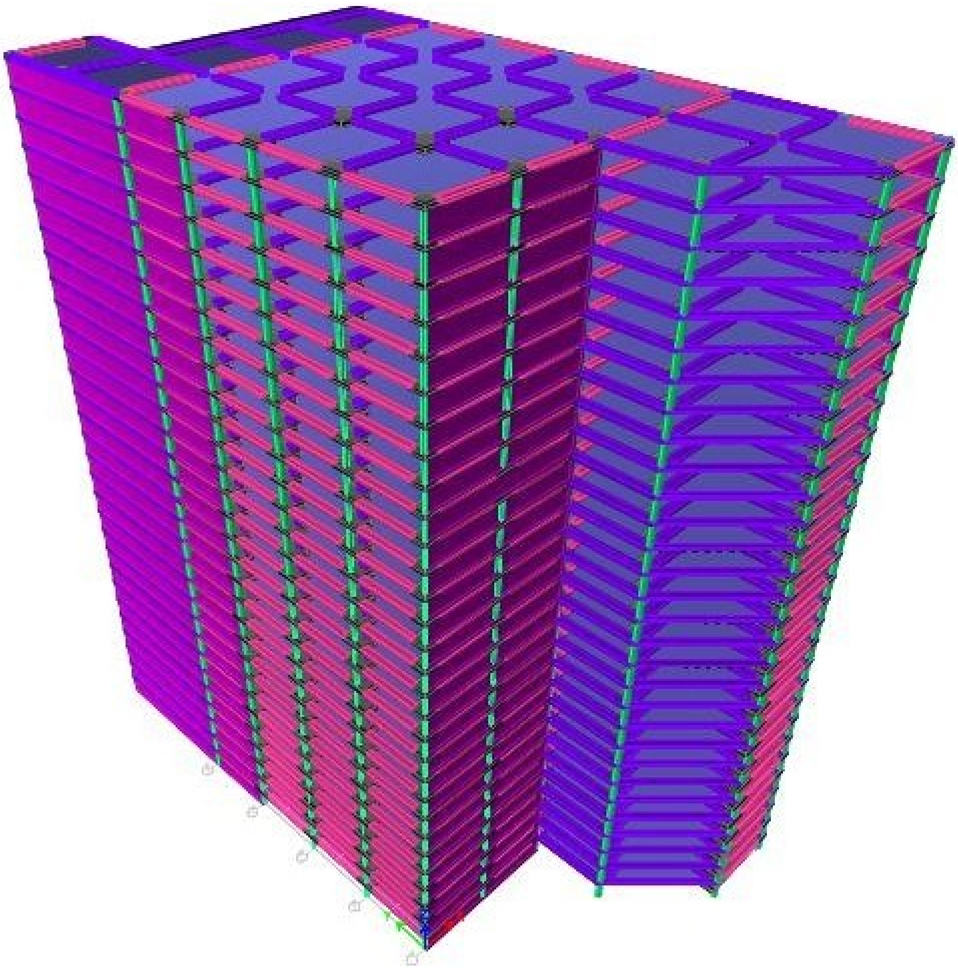

Figure 6: Waffle Slab 3D Model

B. Material and section selection

Material properties and section properties are critical inputs for the design and analysis of structural components in a system. Material properties refer to the physical and mechanical characteristics of the materials used in the construction, including their type, density, elasticity, strength, and durability. Section properties, on the other hand, describe the geometry and dimensions of the cross-section of structural members, such as beams, columns, and slabs.

1) Flat Slab Structural System

a) Slab Details

Thickness of slab = 200 mm

Concrete grade used = M30

Rebar Grade used = HYSD 550

b) Drop Panel Details

Thickness of Drop Panel = 400 mm

Concrete grade used = M30

Rebar Grade used = HYSD 550

c) Columns Details

Column Size = 1000X1000 mm^2

Concrete grade used = M30

Rebar Grade used = HYSD 550

d) Shear Wall Details

Thickness of Shearwall = 400 mm

Concrete grade used = M40

Rebar Grade used = HYSD 550

2) Flat Plate Structural System

a) Slab Details

Thickness of slab = 200 mm

Concrete grade used = M30

Rebar Grade used = HYSD 550

b) Columns Details

Column Size = 1000X1000 mm^2

Concrete grade used = M30

Rebar Grade used = HYSD 550

c) Shear Wall Details

Thickness of Shearwall = 400 mm

Concrete grade used = M40

Rebar Grade used = HYSD 550

3) Waffle Slab Structural System

a) Slab Details

Thickness of slab = 200 mm

Stem Width at top = 100

Stem Width at Bottom = 125

Spacing of ribs = 120

Overall depth of the slab = 350 mm

Concrete grade used = M30

Rebar Grade used = HYSD 550

b) Beam Details

Beam Size = 500X900 mm^2

Concrete grade used = M30

Rebar Grade used = HYSD 550

c) Columns Details

Column Size = 1000X1000 mm^2

Concrete grade used = M30

Rebar Grade used = HYSD 550

d) ShearWall Details

Thickness of Shearwall = 400 mm

Concrete grade used = M40

Rebar Grade used = HYSD 550

4) Conventional Slab Structural System

a) Slab Details

Thickness of slab = 200 mm

Concrete grade used = M30

Rebar Grade used = HYSD 550

b) Beam Details

Beam Size = 500X900 mm^2

Concrete grade used = M30

Rebar Grade used = HYSD 550

c) Columns Details

Column Size = 1000X1000 mm^2

Concrete grade used = M30

Rebar Grade used = HYSD 550

d) ShearWall Details

Thickness of Shearwall = 400 mm

Concrete grade used = M40

Rebar Grade used = HYSD 550

IV. Results

A. Response From Columns

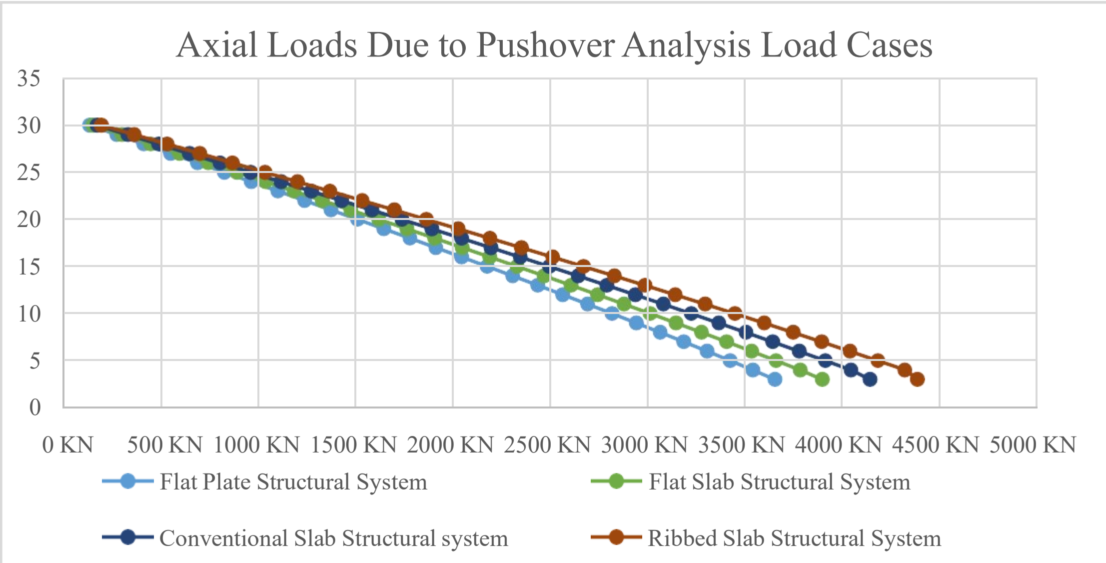

Figure 7: Comparison of Axial Forces in Columns

The given Figure 7 presents the axial force pushover load cases for four different types of floor systems, namely Plate, Flat Slab, Conventional, and Ribbed, at various storeys. The axial force values are given in kilonewtons (KN). A higher axial force indicates a greater force acting in a direction parallel to the axis of the column, and this can lead to structural instability and failure.

At the highest storey (30), the axial force values for Plate, Flat Slab, Conventional, and Ribbed systems are 133.24 KN, 151.40 KN, 171.39 KN, and 193.38 KN, respectively. The axial force values generally increase as the storey number decreases, indicating that the higher storeys experience greater forces. This trend is consistent across all four floor systems.At the lowest storey (3), the highest axial force values are for the Conventional system (4146.09 KN), followed by the Ribbed system (4389.98 KN), Flat Slab system (3902.20 KN), and Plate system (3658.31 KN). This suggests that the Conventional and Ribbed systems are more susceptible to failure at lower storeys compared to the Plate and Flat Slab systems.The difference between the highest and lowest axial force values increases as the storey number decreases. For example, at the highest storey, the difference between the highest and lowest values is 60.14 KN, while at the lowest storey, the difference is 1231.89 KN. This indicates that the structural integrity of the building is more vulnerable at lower storeys due to the greater variation in axial forces.

Figure 8shows the bending moments for pushover analysis of column in structures with different types of reinforced concrete slabs, including flat slab, flat plate, conventional, and ribbed. The bending moments are listed for each storey of the building, from 3 to 30. The values are given in KN-m and KN, which are units of force multiplied by distance and force, respectively. As the storey number increases, the bending moment values generally increase as well. The highest bending moments are seen in the ribbed slab design, with values ranging from 41.88 KN at the third storey to 139.55 KN at the thirtieth storey. The flat slab and flat plate designs generally have lower bending moment values than the conventional and ribbed designs. These bending moment values are important for understanding the structural behavior of reinforced concrete slabs and can be used to inform the design process.

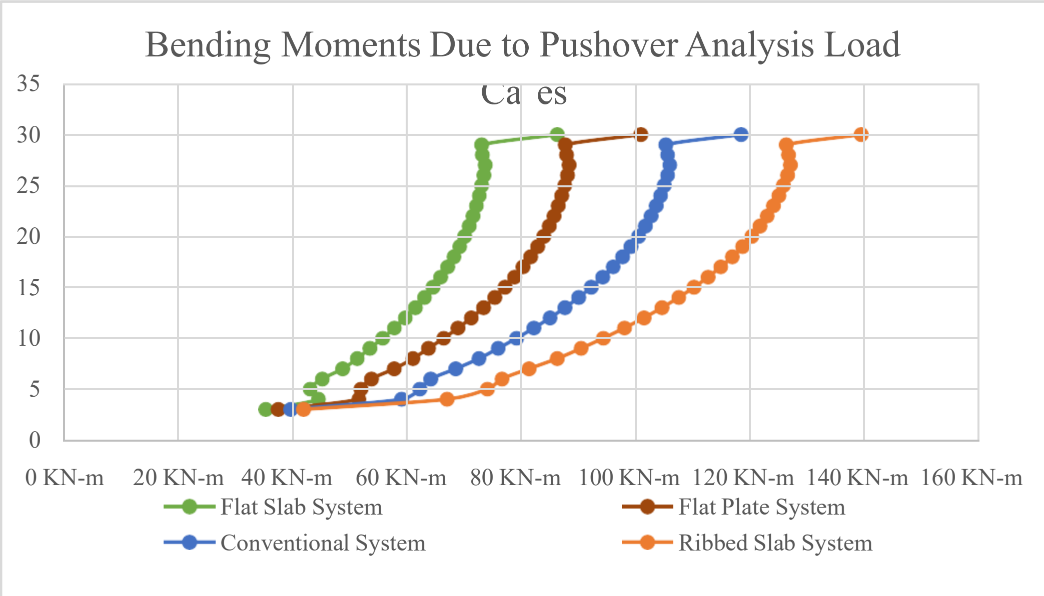

Figure 8: Comparison of max. Bending Moments in Columns

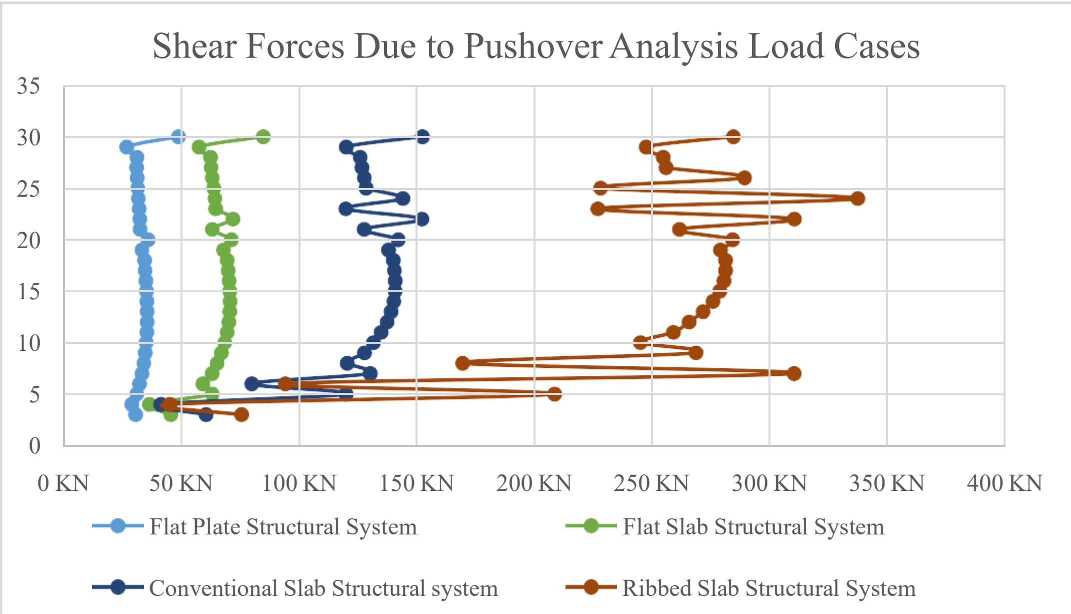

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Figure 9: Comparison of max. Shear Forces in Columns- 15 &20 Storey structures

Figure 9show the maximum shear forces due to pushover load case. In case of gravity loads combined with wind loads, the maximum magnitude of the shear force is produced in the columns present in conventional structural system having 30 stories. This shear force peaks in the column present in highest story. Flat slab structural system with 15 stories shows safest response with respect to LS load case. On other hand, when pushover load case is chosen for the behaviour of column, 30 storied conventional structural system shows maximum magnitude of shear force and 20 storied flat slab structure is in the safest zone.

B. Response from whole structural system

The graph presented below follows the NTC 2008 standards for seismic design in which the spectral acceleration is plotted on the Y-axis, typically measured in multiples of the gravitational constant, while the spectral displacement is plotted on the X-axis. The green line with intermediate crosses on the legend corresponds to the capacity curve of the structure, which is also known as the base shear vs displacement curve. This curve governs the global response of the structure and represents its ability to withstand seismic forces.

The red curve on the graph represents the elastic perfectly plastic (EPP) representation of the pushover curve, which is also known as the Bilinear Force-Displacement Curve. This curve is used to model the response of the structure in the event of an earthquake and provides insight into the structure's behavior under different levels of seismic activity.The yellow line on the graph represents the demand curve of the structure, which indicates the expected level of seismic demand that the structure will experience during an earthquake. The time period of the equivalent reduced Single Degree of Freedom (SDOF) system is represented by T*, while Tc denotes the corner period between the short and medium period range, which is typically measured in seconds.

Overall, the graph provides valuable information regarding the behavior of the structure under seismic activity and is an essential tool for designing and evaluating the structural integrity of buildings and other infrastructure in seismic-prone areas.

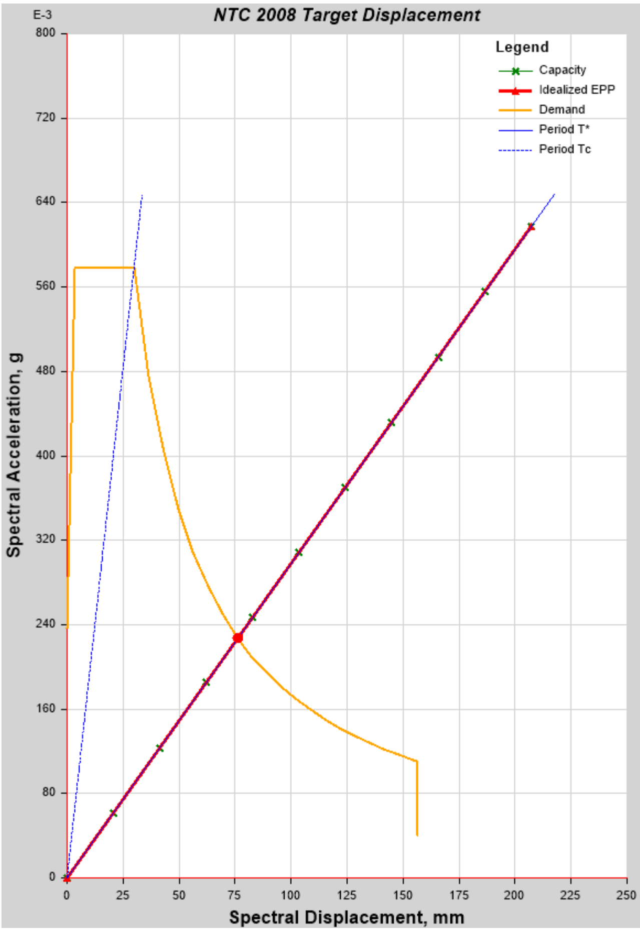

Figure 10: Target Displacement curve for Flat Plate Structural System

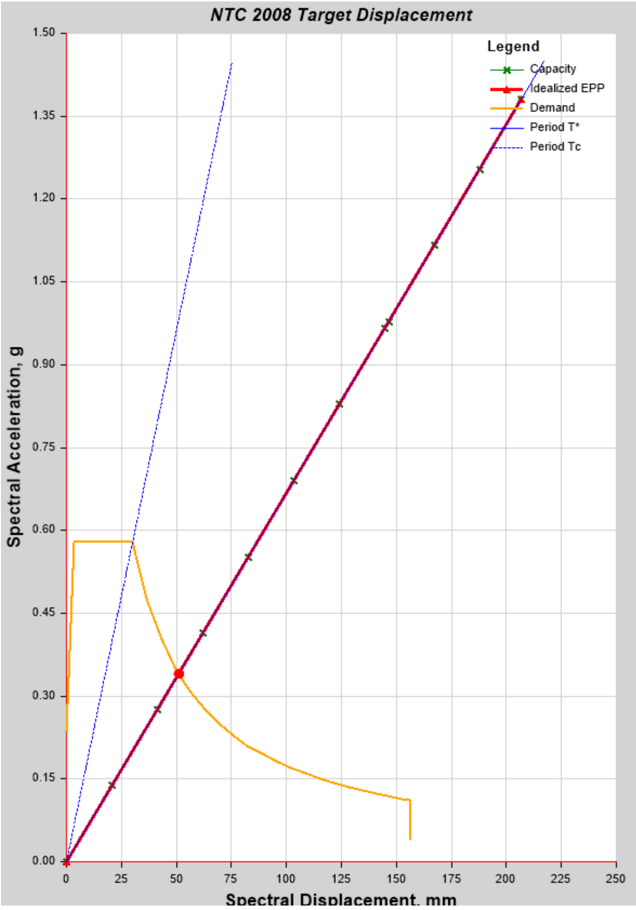

Figure 11: Target Displacement curve for flat slab Structural System

Table 3: \ Conventional Slab Structural System- NTC Target Displacement Table

Spectral Displacement	Spectral Acceleration	Period (Sec)
0.00 mm	0.00 g	0.00 Sec
20.70 mm	0.06 g	1.16 Sec
41.40 mm	0.12 g	1.16 Sec
62.10 mm	0.19 g	1.16 Sec
82.80 mm	0.25 g	1.16 Sec
103.50 mm	0.31 g	1.16 Sec
124.20 mm	0.37 g	1.16 Sec
144.91 mm	0.43 g	1.16 Sec
165.61 mm	0.49 g	1.16 Sec
186.31 mm	0.56 g	1.16 Sec
207.01 mm	0.62 g	1.16 Sec

Table 4:Flat Slab Structural System- NTC Target Displacement Table

Spectral Displacement	Spectral Acceleration	Period (Sec)

0.00 mm	0.00 g	0.00 Sec
19.96 mm	0.04 g	1.38 Sec
39.91 mm	0.08 g	1.38 Sec
59.87 mm	0.13 g	1.38 Sec
79.82 mm	0.17 g	1.38 Sec
99.78 mm	0.21 g	1.38 Sec
119.73 mm	0.25 g	1.38 Sec
139.69 mm	0.29 g	1.38 Sec
159.64 mm	0.34 g	1.38 Sec
179.60 mm	0.38 g	1.38 Sec
199.56 mm	0.42 g	1.38 Sec

Table number 4 provides the NTC (Italian Building Code) target displacement graph values for seismic analysis. The table includes spectral displacement, spectral acceleration, and period values for earthquake-resistant building design. The spectral displacement ranges from 0.00 mm to 199.56 mm, with corresponding spectral acceleration values ranging from 0.00 g to 0.42 g. The period remains constant at 1.38 seconds.

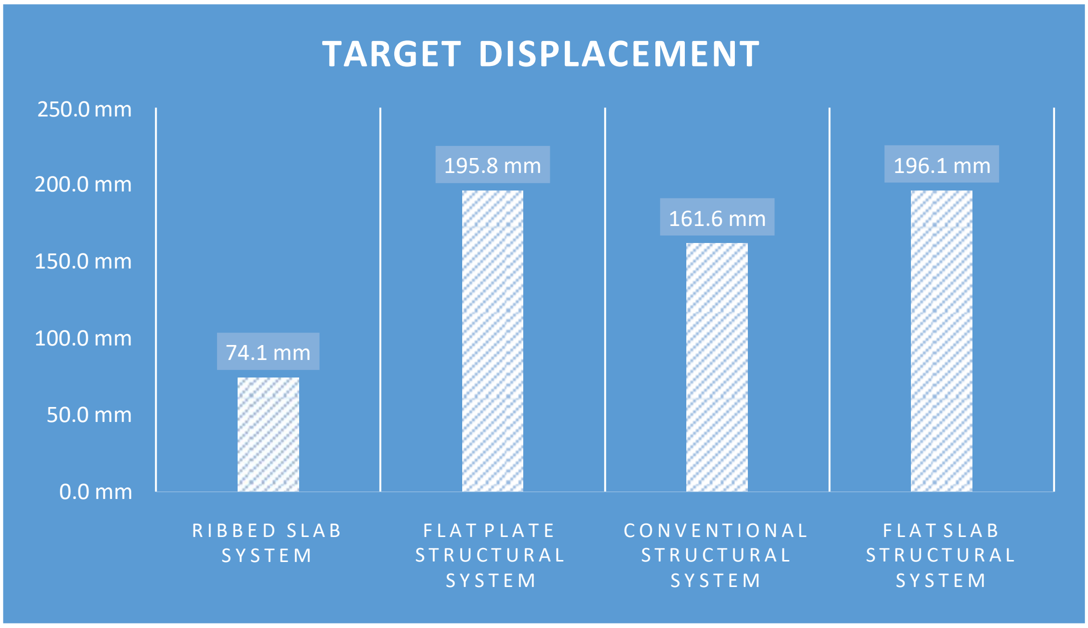

Figure 12: Comparison of Target Displacement from Pushover Curves

Figure 12 summarizes the target displacement and spectral acceleration achieved by four different structural systems, namely Ribbed Slab System, Flat Plate Structural System, Conventional Structural System, and Flat Slab Structural System.

For Ribbed Slab System, the spectral acceleration achieved is 0.341 g, and the target displacement achieved is 74.1 mm. For Flat Plate Structural System, the spectral acceleration achieved is 0.133 g, and the target displacement achieved is 195.8 mm. For Conventional Structural System, the spectral acceleration achieved is 0.156 g, and the target displacement achieved is 161.6 mm. Finally, for Flat Slab Structural System, the spectral acceleration achieved is 0.127 g, and the target displacement achieved is 196.1 mm.

V. CONCLUSION

By comparing axial forces, it can be concluded that the axial forces have maximum intensity in the inner ribbed slab structural system, as the presence of ribs in the slabs can increase the dead weight of the structure. However, this can help in protecting the structure from overturning while lateral forces are simulated. Likewise, when considering bending movements, bending moments are highest in intensity in the case of ribbed or waffle slab structural systems and least in the case of flat slab structural systems. Shear forces act similarly to bending moments.

Furthermore, according to the target displacement data, the target displacement is maximum in flat plate structural systems due to the unavailability of drop panels, ribs, or beams to provide stability to the slabs and restraints to the columns. Hence, the target displacement in flat plate structural systems is maximum, whereas it is least in ribbed or waffle slab structural systems, where there are abundant lateral restraints to the columns present in the structural form.

VI. REFERENCES

[1] S. Mahesh, Dr. B. Panduranga Rao,"Comparison of analysis and design of regular and irregular configuration of multi-Story building in various seismic zones and various types of soils using ETABS and STAAD", Journal of Mechanical and Civil Engineering | Volume 11, Issue 6 Ver. I (Nov- Dec. 2014), PP 45-52

[2] Abhilash R., Biju V., Rahul Leslie "Effect of Lateral Load Patterns in Pushover Analysis", 10th National Conference on Technological Trends (NCTT09) 6-7 Nov 2009

[3] Mrugesh D. Shah, Sumant B. Patel: Non-Linear Static Analysis of RCC Frames (Software Implementation Etabs 9.7), National Conference on Recent Trends in Engineering & Technology

[4] G. S. Sai saran, V. Yogendra Durga Prasad, T. Venkat Das "Push Over Analysis for Concrete Structures at Seismic Zone-3 using Etabs Software", International Journal of Engineering Research & Technology (IJERT)

[5] Chung- Yue Wang, Shaing-Yung Ho "Pushover Analysis for Structure Containing RC Walls, The 2nd International Conference on Urban Disaster Reduction", Taipei, Taiwan | November 27-29, 2007

[6] Rahul Rana, Limin Jin and Atila Zekioglu "Pushover Analysis of A 19 Story Concrete Shear Wall Building, 13th World Conference on Earthquake Engineering Vancouver", B.C., Canada August 1-6, 2004, Paper No. 133

[7] S. R. Kangle, D. S. Yerudkar "Response Spectrum Analysis for Regular Multistory Structure in Seismic Zone III", International Journal of Engineering Research & Technology (IJERT) | Vol. 9 Issue 09, September-2020

[8] Krishna Prasad Chaudhary, Ankit Mahajan "Response spectrum analysis of irregular shaped high-rise buildings under combined effect of plan and vertical irregularity using Etabs", IOP Conf. Series: Earth and Environmental Science | 889 (2021) 012055

[9] Putul Haldar and Yogendra Singh "Seismic Performance and Vulnerability of Indian Code designed RC Frame Buildings", Journal of Earthquake Technology | Paper No. 502, Vol. 46, No. 1, March 2009, pp. 29–45

[10] Madhusudan G. Kalibhat, Kiran Kamath, Prasad S. K., Ramya R. Pai "Seismic Performance of Concentric Braced Steel Frames from Pushover Analysis", Journal of Mechanical and Civil Engineering | e-ISSN: 2278-1684 | PP 67-73