Seismic response of the combination of various slab systems with lateral load resisting systems.

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ABSTRACT.

With the ongoing modernisation of the construction industry, flat slab and post-tensioned slab systems have become prevalent choices. Architects and clients often favour these systems for their aesthetic appeal and significant structural advantages over conventional slab arrangements. These advantages include reduced slab depth, increased floor-to-floor height, longer spans, elimination of beam projections, and decreased building self-weight. However, they also present their drawbacks, such as the risk of brittle punching (shear) failure, necessitating additional reinforcement at column-slab connections, and increasing the required longitudinal steel. In regions prone to higher seismic activity, slab-column connections are particularly susceptible to yielding, especially in buildings lacking a lateral load-resisting system (LLRS). In such seismic zones, slabs may only bear gravity loads and require supplementary LLRS to withstand lateral dynamic loads like seismic and wind forces.

Consequently, it's crucial to investigate the seismic behaviour of conventional slabs, flat slabs, and post-tensioned slab systems in tall reinforced concrete structures with and without various LLRS configurations. This study aims to analyse the impact of lateral loads on flat and post-tensioned slab systems and different LLRS options to enhance structural resilience and cost-effectiveness against lateral loads. Parameters include storey displacement, base shear, storey drift, and period.

Keywords: RCC high-rise structure, Lateral load resisting system, Seismic response, Bracing systems and Steel braces.

1 INTRODUCTION

In RCC structures, flat and post-tensioned slab systems offer several advantages over conventional ones. They provide greater architectural flexibility and enhanced aesthetic appeal [1]. However, when switching from a conventional slab system to flat or post-tensioned systems, the loads from the slabs are typically transferred directly to the columns through the slab-column connections. This connection between slabs and columns plays a crucial role in absorbing seismic-induced lateral displacements while maintaining the ability to transfer vertical loads from the slab to the columns [2]. This can impact the building's lateral resistance.

In high-rise RCC structures, two primary lateral loads are seismic and wind forces. These loads are typically analysed using two main methods: static analysis and dynamic analysis. Dynamic analysis usually leads to a more cost-effective design [3]. A lateral load-resisting system (LLRS) is incorporated into the structure to withstand these loads effectively. LLRS can take various forms, such as RCC bracing systems, steel bracing systems, and shear walls [4]. These systems enhance the building's ability to resist lateral forces and ensure structural stability under seismic and wind conditions. [5,6,7,11]

1.1 SLAB SYSTEM.

The three most commonly used slab systems are conventional slabs, flat slabs, and post-tensioned slabs. In conventional slabs, loads are typically transferred from the slabs to beams and then to vertical elements such as columns or shear walls.

In contrast, flat and post-tensioned slabs often transfer loads directly from the slab to the columns or shear walls through the slab-column connections. This direct transfer makes the slab-column connection susceptible to punching shear, where concentrated loads can cause failure at the connection [2,8].

As a consequence, these connections tend to be less stiff laterally, necessitating the incorporation of additional lateral load-resisting systems to enhance overall structural stability [2]. These systems are crucial for improving the building's ability to withstand lateral forces, such as seismic activity or wind, thereby ensuring structural integrity and safety [4].

1.2 LLRS (LATERAL LOAD RESISTING SYSTEM.)

Selecting an appropriate lateral load-resisting system is crucial in the design of reinforced concrete (RC) multi-storey structures for seismic scenarios. The choice of system is a fundamental design decision. Several factors must be carefully considered when determining the seismic force-resisting system, including architectural requirements, construction costs, performance expectations, design constraints, and coordination with non-structural elements [4].

The configuration of the lateral load-resisting system within the building should adhere to sound design principles, addressing challenges such as torsion, structural irregularities, redundancy, and integrating different systems. Generally, shear wall, braced, and moment-resisting frames are used.

2 NEED OF RESEARCH

While the I.S. code 1893:2016 does not encourage the use of flat and post-tensioned slabs alone in high seismic prone areas because of their low seismic resistance, these slab systems can be combined with an adequate lateral load resisting system to improve their seismic performance [15,16]. This slab system provides architectural flexibility, less floor-to-floor height, increased several floors, faster and easier construction, economical, etc [1].

Slab–column connections are the first yield point in higher seismic zones in high-rise RCC buildings without a lateral load-resisting system (LLRS). Flat and PT slabs undergo brittle punching failure (punching shear) due to the absence of beams [2]. This requires additional reinforcement along the connections between the column and slab. In higher seismic zones, the slabs may not be able to resist the high lateral dynamic loading. Hence, an additional lateral load resisting system (LLRS) may be required to resist lateral loads such as seismic and wind loads. Thus, studying the seismic behaviour of conventional, flat, and PT slab systems in high-rise RCC structures with and without various lateral load resisting systems becomes essential.

3 AIM AND OBJECTIVES

The purpose of this study is to compare the seismic performance of flat and PT slab systems with and without lateral load resisting systems due to high lateral loadings and determine whether it is justifiable to use these slab systems over conventional slab systems in higher seismic zones.

OBJECTIVES.

1. To analyse the response of flat and PT slabs subjected to seismic loading of higher zones with and without a bracing system.
2. To achieve a similar deflection, storey displacement, base shear, storey drift and other seismic parameters in flat and post-tensioned slab systems with the help of lateral load resisting systems and conventional slab systems.
3. To analyse the base shear, maximum storey displacement and storey drift of the combinations of slab and bracing systems in high-rise buildings.

4 METHODOLOGY.

A total of 5 models are analysed on ETABS 2021. All the models are analysed for gravity and lateral loads. The loads are according to the I.S.875-2016 provisions. All the RC frame sections are designed according to I.S.456-2000 and I.S.13920-2016.

The objective of this analysis is to achieve similar deflection, storey displacement, base shear, storey drift, and other seismic parameters in flat and post-tensioned slab systems with the help of lateral load-resisting systems to conventional slab systems.

1. MODEL 1 was a G+20 RC building with a conventionally framed structure.
2. MODEL 2 was a G+20 RC building with a flat slab system.
3. MODEL 3 was a G+20 RC building with a flat slab system and steel bracing
4. MODEL 4 was a G+20 RC building with a post-tensioned slab system.
5. MODEL 5 was a G+20 RC building with post-tensioned and steel bracing.

5 GEOMETRICAL PROPERTIES.

Table 1. Geometrical properties of the structure.

Sr no.	**Parameters**	**Values**
1	Building Type	Commercial + Residential
2	No. of Storey	G + 20
3	Length in X direction	48.51 m
4	Length in Y direction	10.7 m
5	Height of floors	3 m
6	Depth of conventional slab	125 mm
7	Depth of flat slab	230 mm
8	Depth of post tensioned slab	175 mm
9	Size of beams	300 x 600 mm (external)
10	Size of concealed beams	400 x 230 mm 400 x 175 mm
11	Shear wall thickness (G – 2nd floor)	300 mm
12	Shear wall thickness (3rd – 20th floor)	230 mm
13	Stell braces	ISMB (250 – 600)
14	Partition wall thickness	230 mm (external) 150 mm (internal)
	Material properties	
15	Grade of Concrete	M 30
16	Grade of Rebar	Fe 500 and Fe 415
17	Concrete Density	24 KN/m^3
18	AAC block density	8 KN/m^3
	Seismic Data	As per IS 1893 (Part-1):2016
19	Zone	V

20	Zone factor	0.36 (Clause 6.4.2, Table 3)
21	Importance Factor (I)	1.2 (Clause 7.2.3, Table 8)
22	Soil type	Type II (Medium stiff)
23	Response Reduction Factor (R)	As per (Clause 7.2.6, Table 9)
24	Damping Ratio	5% (Clause 7.2.4)
25	Earthquake Load	As per IS 1893 (part-1):2016

6 MODELLING.

The plan of the building is the same for all the floors and all the models.

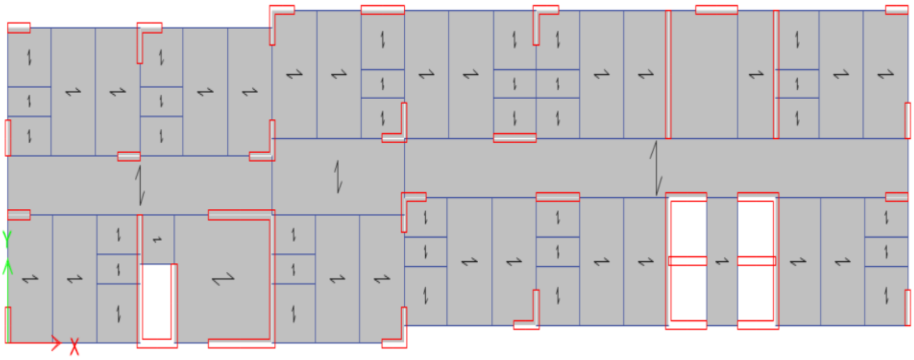

Fig. 1. - Floor plan of conventional slab system on ETABS 2021

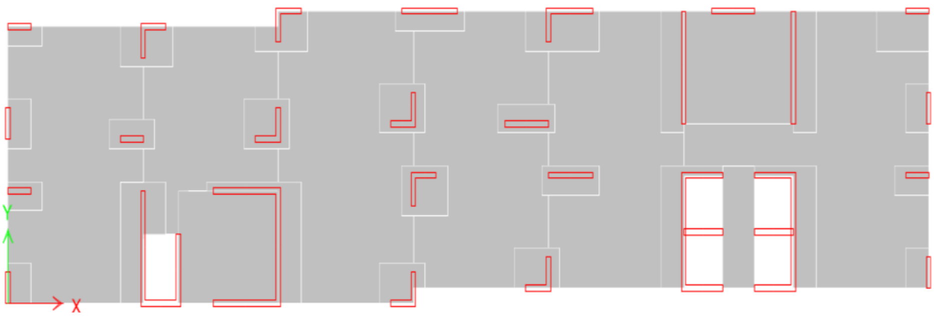

Fig. 2. - Floor plan of flat and post-tensioned slab system with drop panels on ETABS 2021

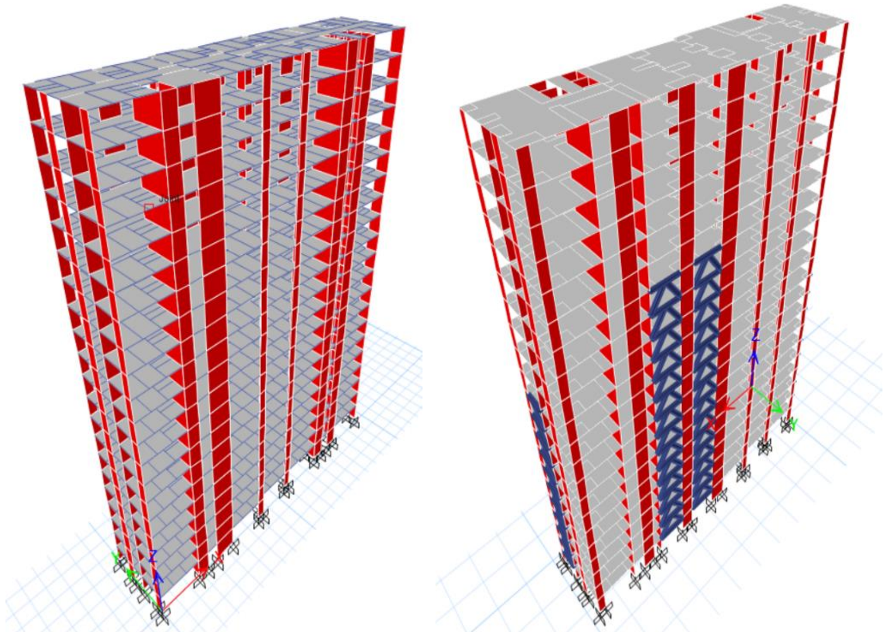

Fig. 3. 3D ETABS model of conventional slab system unbraced, and flat and pt slab system braced.

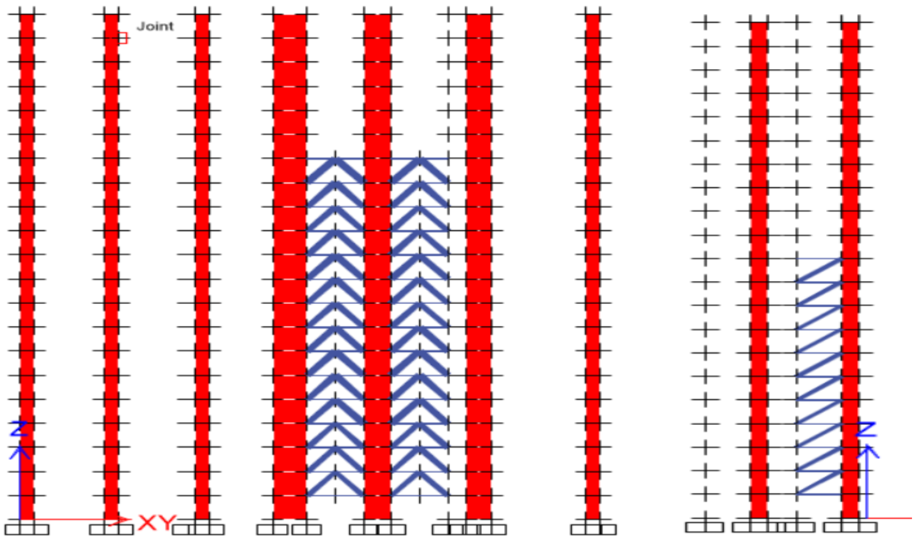

Fig. 4. Elevation of steel braces X-1 and Y-1 on ETABS 2021

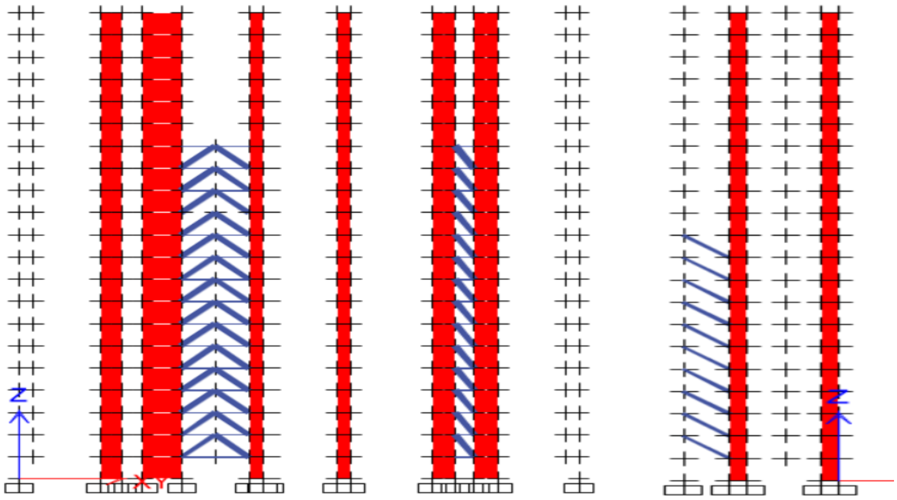

Fig. 5. Elevation of steel braces X-2 and Y-2 on ETABS 2021

7 RESULTS AND DISCUSSION.

All the models were analysed on ETABS 2021. The software's output data was obtained for various seismic parameters, such as maximum storey displacement, base shear, storey drift, time period, etc. This data is represented by the graph below.

1. CNS – CONVENTIONAL SLAB SYSTEM.
2. FS-UB – FLAT SLAB UNBRACED.
3. FS-B – FLAT SLAB WITH STEEL BRACES.
4. PT-UB – POST TENSIONED SLAB UNBRACED.
5. PT-B – POST TENSIONED SLAB WITH STEEL BRACES.

7.1 MAXIMUM STOREY DISPLACEMENT

The lateral displacement of a structure in both X and Y directions caused by the lateral forces is defined as storey displacements. The top-storey displacement of a structure in both directions is generally the maximum storey displacement. As per IS: 1893-2016, the allowable limit for maximum storey displacement for an RCC structure due to seismic forces is 0.004*H, where H is the structure's total height. The height of this structure is 63 m. Thus, the allowable limit for maximum storey displacement in either direction is 0.004*63000, i.e. 252 mm.

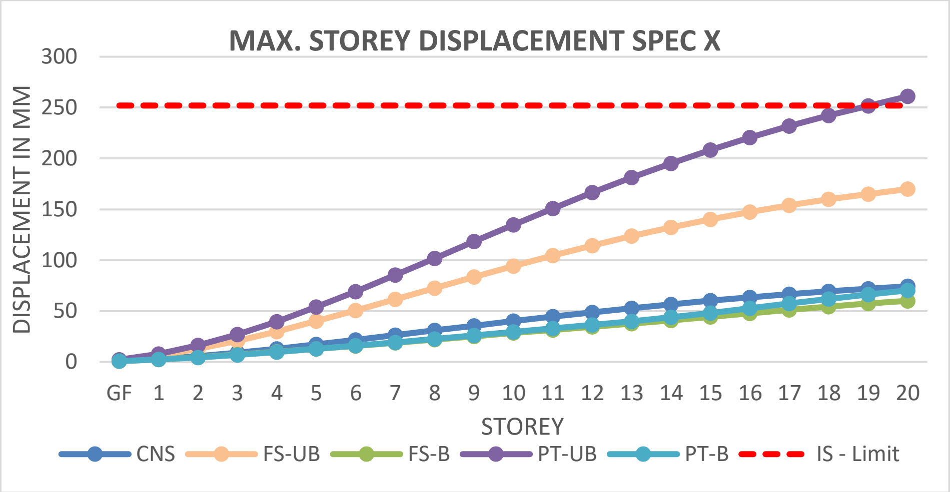

Fig. 6. Maximum displacement by response spectrum in X direction.

As shown in FIG. 6 through a graphical representation of data – The max. Storey displacement in the X direction of the conventional slab system is 74 mm, the Flat slab system unbraced is 170 mm, and the PT slab unbraced is 261 mm.

With the help of a combination of chevron and diagonal steel braces. The max. Storey displacement is reduced to 61 mm (65%) in the flat slab system and 71 mm (74%) in the PT slab system.

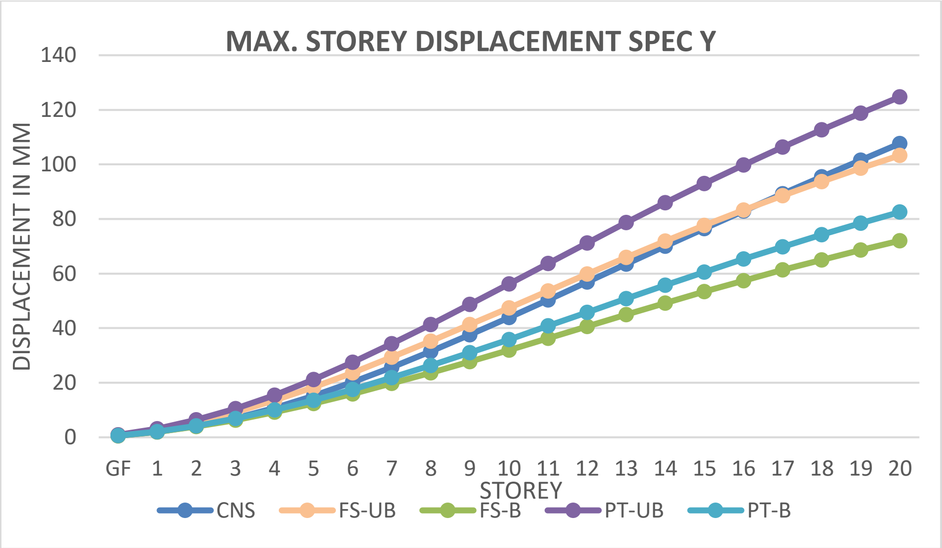

Fig. 7. Maximum displacement by response spectrum in Y direction.

As the structure along the Y direction has a very short length, it exhibits more stiffness, as seen from the graph above. This results in less displacement along the Y direction, which is within the limit of IS codes.

As shown in FIG. 7, through a graphical representation of data, the maximum storey displacement in the Y direction of the conventional slab system is 107 mm, the Flat slab system unbraced is 104 mm, and the PT slab unbraced is 125 mm. With the help of a combination of chevron and diagonal steel braces, the maximum storey displacement is reduced to 72 mm (31%) in the flat slab system and 82 mm (34%) in the PT slab system.

7.2 INTER-STOREY DRIFT

Drift refers to the horizontal displacement of a structure. Storey drift specifically denotes the slight, gradual movement of one level of a multi-storey building relative to the level below it. This drift, influenced by the storey height, can cause more damage to the structure. The inter-storey drift must not exceed the ratio of 0.004 as per IS 1893:2016. Storey drift typically increases up to the midpoint of the building and then decreases towards the top.

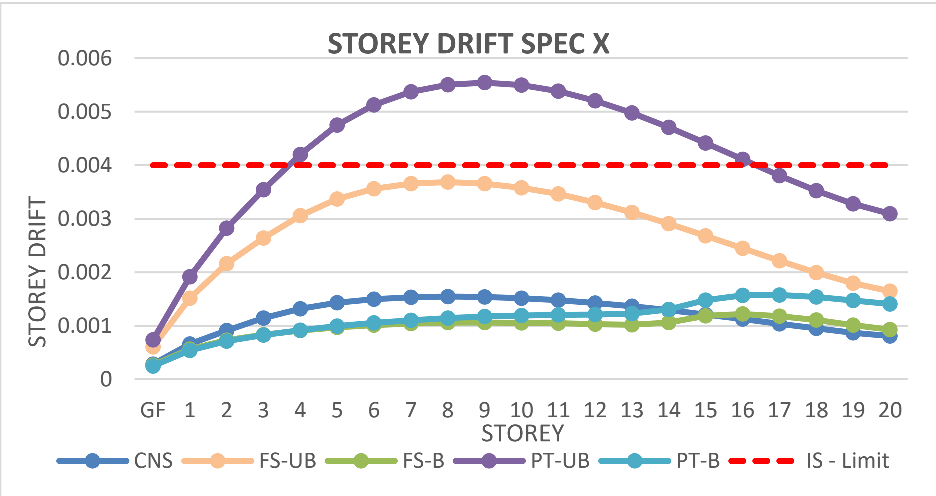

Fig. 8. Storey drift by response spectrum in X direction.

As shown in FIG. 8 through a graphical representation of data – The max. storey drift in the X direction of the conventional slab system is 0.001, the Flat slab system unbraced is 0.0037, and the PT slab unbraced is 0.0056, which exceeds the IS code limit.

With the help of a combination of chevron and diagonal steel braces. The max. Storey drift is reduced to 0.0012 (71%) in the flat slab system and 0.0015 (79%) in the PT slab system.

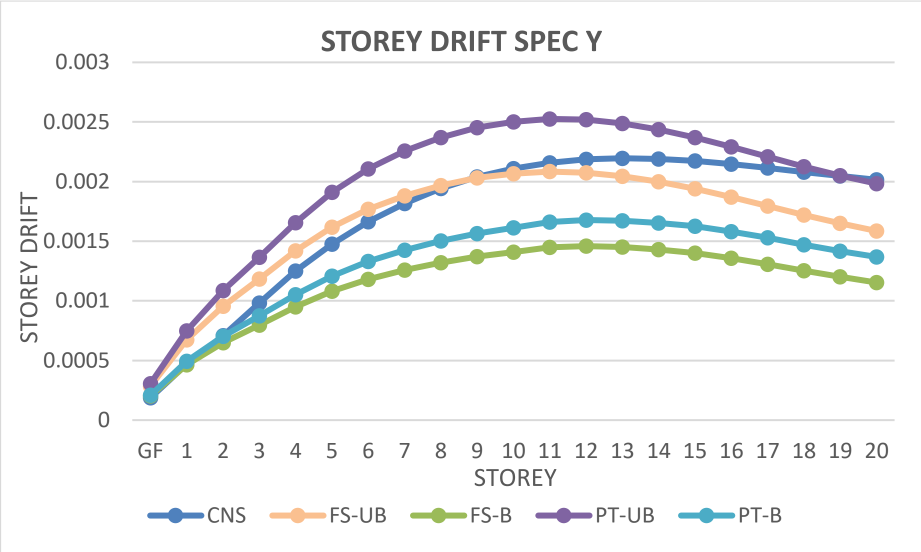

Fig. 9. Storey drift by response spectrum in the Y direction

As shown in FIG. 8 through a graphical representation of data – The max. Storey drift in the Y direction of the conventional slab system is 0.0021, the Flat slab system unbraced is 0.002, and the PT slab unbraced is 0.0025; all are well within the IS code limit due to the structure having more stiffness along the shorter span.

With the help of a combination of chevron and diagonal steel braces. The max. Storey drift is reduced to 0.0014 (31%) in the flat slab system and 0.0016 (35%) in the PT slab system.

7.3 BASE SHEAR

Base shear is the maximum lateral force exerted at the base or soffit of a structure due to seismic ground motion. This horizontal force at the base of the building depends on several factors: the soil conditions at the site, the proximity to potential seismic sources such as geological faults, the likelihood of substantial ground motion from earthquakes, the total weight of the building, and the building's vibration period.

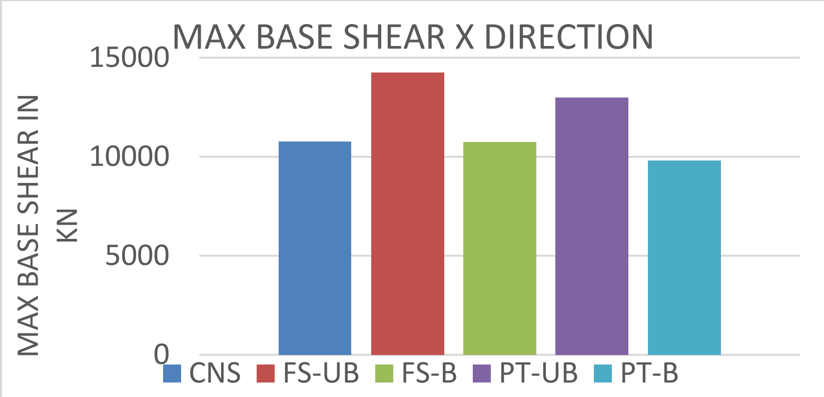

Fig. 10. Maximum base shear by response spectrum in X direction.

As shown in FIG.10 through a graphical representation of data - The max. Base shear in the X direction of the conventional slab system is 10770 kn, Flat slab system unbraced is 14246 kn, and PT slab unbraced is 13001 kn.

With the help of a combination of chevron and diagonal steel braces. The max. Base shear is reduced to 10741 kn (25%) in the flat slab system and 9823 kn (25%) in the PT slab system.

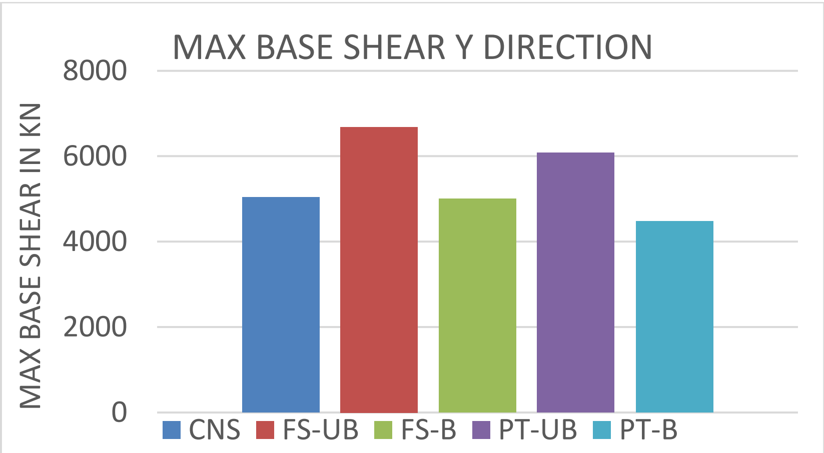

Fig. 11. Maximum base shear by response spectrum in Y direction.

As shown in FIG.11 through a graphical representation of data - The max. Base shear in the Y direction of the conventional slab system is 5047 kn, Flat slab system unbraced is 6685 kn, and PT slab unbraced is 6075 kn.

With the help of a combination of chevron and diagonal steel braces. The max. Base shear is reduced to 5009 kn (25%) in the flat slab system and 4480 kn (27%) in the PT slab system.

8 CONCLUSION.

The conventional slab system with shear walls meets the seismic parameters in zone 5 and does not require additional steel braces (LLRS). PT slab unbraced performed worse than flat slab unbraced due to the slab's lesser thickness, even though both models failed to achieve the required parameters.

1. The research demonstrates that implementing chevron and diagonal steel braces significantly enhances the seismic performance of various slab systems. As illustrated by the data, the maximum storey displacement in the X direction is notably reduced with the addition of these braces, decreasing by 65% in the flat slab system and 74% in the PT slab system. Similarly, in the Y direction, the maximum storey displacement is reduced by 31% for the flat slab system and 34% for the PT slab system, reflecting improved structural resilience.
2. Furthermore, storey drift values, which initially exceeded IS code limits for unbraced flat and PT slab systems, are significantly reduced with the use of braces. Specifically, storey drift in the X direction decreases by 71% in the flat slab system and 79% in the PT slab system, bringing these values within acceptable limits. Storey drift in the Y direction also benefits from the braces, with reductions of 31% in the flat slab system and 35% in the PT slab system, maintaining compliance with IS code standards due to the inherent stiffness along the shorter span.
3. In terms of base shear, the addition of braces results in a reduction of the maximum base shear forces. In the X direction, base shear is reduced by 25% in both the flat slab and PT slab systems. Similarly, in the Y direction, the reduction is 25% for the flat slab system and 27% for the PT slab system.
4. Overall, integrating chevron and diagonal steel braces is an effective strategy for reducing lateral displacements and drifts while minimising base shear forces. This approach enhances the structural stability and seismic performance of both flat and PT slab systems, ensuring better compliance with seismic design standards and improving overall safety.

9 REFERENCE.

1. Omar Ahmad, Kabir Sadeghi and Fatemeh Nouban "Comparison of the post-tensioned, solid, hollow block, and flat slabs in terms of economy considering different span lengths" Int. J. of Applied Mechanics and Engineering, 2023, vol.28, No.2, pp.24-33
2. Navyashree K, Sahana T.S," Use of flat slabs in a multi-story commercial building situated in the high seismic zone", International Journal of Research in Engineering and Technology, Volume 03, Aug-2014.
3. Gauri G. Kakpure and Dr. A. R. Mundhada, "Comparative Study of Static and Dynamic Seismic Analysis of Multistoried RCC Buildings by ETAB", Int. Journal of Engineering Research and Application, Vol. 7, Issue 5, (Part -5) May 2017.
4. Divya C. Bhuta and Umang Pareekh," Comparative Study on Lateral Load Resisting System in Tall Buildings" - International Journal of Science Technology & Engineering, Volume 2, Issue 11, May 2016
5. Shahid Ul Islam and Shakeel A. Waseem," Comparative study on seismic behaviour of different types of reinforced cement concrete bracing system in high rise reinforced concrete structures", 8th International Symposium on Fusion of Science and Technology, ISFT 2020, January 6 , 2020.
6. Syed Ishaq, Abdul Majeed, Mohd Abdul Muddassir, S.Ramyakala "A Comparative Study on RCC Structure with and Without Shear Wall", International Journal of Advances in Engineering and Management (IJAEM) Volume 4, Issue 5 May 2022.
7. Arjun Poudel and Rajan Suwal "Seismic Performance Analysis of RC Frame Building Using Different Types of Steel Bracing", Proceedings of 8th IOE Graduate Conference, June 2020, volume-8.
8. Shital Borkar, Kuldeep Dabhekar, Isha Khedikar, Santosh Jaju "Analysis of Flat Slab Structures in Comparison with Conventional Slab Structures", IOP Conf. Series: Earth and Environmental Science, 822 (2021) 012049.
9. Apurb Kumar Jain, Prof. Rahul Sharma, Anurag Saraogi, "Comparative study of RCC building with and without gust factor method," International Research Journal of Modernization in Engineering Technology and Science, Volume 03, Issue 01, January 2021.
10. Jnanesh Reddy R and Pradeep A, "Comparative Study of Post Tensioned and RCC Flat Slab in Multi-Storey Commercial Building" International Research Journal of Engineering and Technology, Volume:04, Issue:06, June-2017.
11. Abhinav. V, Reddy S.S, Naidu V.M & Mohan S.M," Seismic analysis of Multistorey RCC building with Shear wall using Staad Pro", International Journal of Innovative and research, Vol-4, Issue-5, 2016.
12. Rafal Szydlowski and Barbara Labuzek, "Post-Tensioned Concrete Long-Span Slabs in Projects of Modern Building Construction", 2017 IOP Conf. Ser.: Mater. Sci. Eng
13. Sanjay P N, "Behavior of Flat Slab RCC Structure Under Earthquake Loading", International Journal of Engineering Research & Technology. Vol. 3 May- 2014.
14. IS 456-2000, "Plain and Reinforced Concrete Code of Practice".
15. IS 1893-2016, "Criteria for Earthquake Resistant Design of Structures".
16. IS 13920, "Ductile detailing of reinforced concrete structures subjected to seismic forces".
17. IS 1343-2012, "Prestressed Concrete — Code of Practice".
18. IS 875-2015 (Part 1-5), "Design Loads (Other than Earthquake) for Buildings and Structures".