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Parametric Analysis of Tall Structures with Pentagrid Lateral Load Resisting System

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Abstract - In The Modern Age, Architects And Engineers Are Developing Cities Vertically Due To The Decrease In Availability Of Free Land, Increase In Land Prices, And The Widespread Urbanization. However, There Are Practical Constraints To Bound The Vertical Limits Of Skyscrapers. Therefore, It Is Essential For Architecture And Structural Engineering To Understand The Study Of Structural Systems For Tall Buildings.

This Paper Focuses On A Parametric Study Of Tall Structures With A Pentagrid Structural System. The Pentagrid Is An Exterior Structural System That Resists Lateral Forces Through Axial Actions Of Diagonals Provided In The Periphery. The Study Analyzes Five Steel Buildings Of Typical Plan Area, Including All Loads. The Buildings With 24,48,72, And 96 Storeys Are Analyzed For Modules Of 4, 6, 8, And 12 Pentagrid Modules In The Plan Using Staad.Pro Software.

The Present Study Considers Parameters Such As Fundamental Time Period, Maximum Story Displacement, Maximum Storey Drift, And Maximum Base Shear.

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Keywords - Tall buildings, Pentagrid system, Tall buildings in India, Conventional frame system, lateral loads, Optimum design, Parametric Study, STAAD.Pro

1 INTRODUCTION

The Pentagrid Lateral Load Resisting System Is A Type Of Structural System that Is Commonly Used In Tall Structure To Resist Lateral Loads Such As Wind And Earthquake Forces. The System Consists Of A Grid Of Diagonal Members That From A Five-Pointed Star Shape, With Each Point Of The Star Attached To A Central Core.

A Parametric Analysis Of Tall Structures With A Pentagrid Lateral Load Resisting System Would Involve Varying Certain Parameters Of The System And Analyzing The Effects On The Structural Behavior And Performance. Some Parameters That Could Be Varied Include:

1. Height Of The Structure: Increasing The Height Of The Structure Would Increase The Lateral Load That It Is Subjected To And Would Require A Stronger Pentagrid System To Resist Those Loads.
2. Number Of Floors: Increasing The Number Of Floors Would Increase That Weight Of The Structure And Could Affect The Performance Of The Pentagrid System.

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3. Shape Of The Central Core: The Shape Of The Central Core Could Be Varied To Determine The Effect On The Behavior Of The Pentagrid System.
4. Material Properties: The Properties Of The Materials Used In The Pentagrid System Could Be Varied To Determine The Effect On The Performance Of The System.
5. Load Scenarios: Different Load Scenarios Could Be Considered, Such As Wind Loads, Earthquake Loads And Thermal Loads, To Determine The Effect On The Performance Of The Pentagrid System.

The Parametric Analysis Would Involve Running Simulations And Analyzing The Results To Determine The Optimal Design Parameters For The Pentagrid System. This Would Help To Ensure That Tall Structures With A Pentagrid Lateral Load Resisting System Are Designed To Be Safe And Efficient.

2 EVOLUTION OF TALL BUILDINGS

The use of the pentagrid lateral load resisting system has evolved over time with the advancement of technology and understanding of structural behavior. A parametric analysis of tall structures with a pentagrid system could explore this evolution and how it has affected the design of tall buildings.

One parameter to consider is the development of new materials and their impact on the performance of the pentagrid system. For example, the use of high-strength steel or advanced composite materials could allow for the use of thinner members in the pentagrid system, resulting in a more lightweight and efficient structure.

Another parameter to consider is the influence of changing building codes and regulations on the design of tall buildings with pentagrid systems. For example, changes in wind load provisions or seismic design criteria could impact the design of the pentagrid system and the overall structural design.

Additionally, the parametric analysis could explore how the shape and configuration of the pentagrid system have evolved over time. For example, the use of curved or tapered members in the pentagrid system could provide increased stiffness and resistance to lateral loads.

Finally, the analysis could also consider the use of advanced computational tools and software for the analysis and design of pentagrid systems. This could include the use of finite element analysis or computational fluid dynamics to better understand the behavior of the pentagrid system and optimize its design.

A parametric analysis of tall structures with pentagrid systems in the context of the evolution of tall buildings would provide insights into how the design and performance of these systems have changed over time, and how they may continue to evolve in the future.

3 STRUCTURAL SYSTEM FOR TALL BUILDINGS

The pentagrid lateral load resisting system is a popular structural system used for tall buildings. A parametric analysis of this system for tall buildings could consider various design parameters to optimize its performance and ensure the safety and stability of the structure.

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One parameter to consider is the aspect ratio of the building, which is the ratio of the building's height to its base dimensions. Tall buildings with high aspect ratios experience greater lateral loads and require stronger lateral load resisting systems, such as the pentagrid system. The analysis could explore how varying the aspect ratio affects the design of the pentagrid system and the overall structural behavior.

Another parameter to consider is the material properties of the members used in the pentagrid system. This includes the material type, strength, stiffness, and ductility. By varying these properties, the analysis can determine the optimal design parameters for the pentagrid system, such as member sizes and connection details.

The analysis could also consider the impact of different load scenarios, such as wind, earthquake, and thermal loads, on the behavior of the pentagrid system. By analyzing the response of the system under various load scenarios, the design can be optimized to ensure that the structure remains stable and safe under all expected conditions.

Other parameters to consider include the geometry and arrangement of the pentagrid system, such as the shape of the central core, the spacing of the diagonal members, and the connection details. The analysis could explore how varying these parameters affects the performance of the pentagrid system and the overall structural behavior.

Finally, the parametric analysis could also consider the impact of construction tolerance and potential uncertainties on the performance of the pentagrid system. By accounting for these factors, the design can be optimized to ensure that the structure remains stable and safe even in the presence of construction variations.

4 PENTAGRID STRUCTURAL SYSTEMS

A parametric analysis of tall structures with pentagrid lateral load-resisting systems could explore various design parameters to optimize the performance and efficiency of the system. The following are some parameters that could be considered in such an analysis:

1. Member properties: The properties of the diagonal members, including their size, shape, and material properties, could be varied to determine their effect on the behavior of the pentagrid system. For example, increasing the strength of the members could allow for a more lightweight system, while increasing the stiffness could improve the lateral resistance.
2. Grid configuration: The configuration of the pentagrid system, including the number and spacing of the diagonal members, could be varied to determine its effect on the behavior of the system. A denser grid could provide greater lateral resistance but could also increase the weight and complexity of the system.
3. Core shape and size: The shape and size of the central core of the pentagrid system could be varied to determine its effect on the behavior of the system. A larger core could provide more stability and stiffness to the system, but could also increase the weight and complexity of the design.
4. Load scenarios: Different load scenarios, such as wind loads or earthquake loads, could be considered to determine the effect on the behavior of the pentagrid system. This could include varying the direction and magnitude of the load, as well as considering different types of loads.

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5. Connection details: The details of the connections between the members of the pentagrid system could be varied to determine their effect on the behavior of the system. This could include varying the size, shape, and material Properties for the connection.

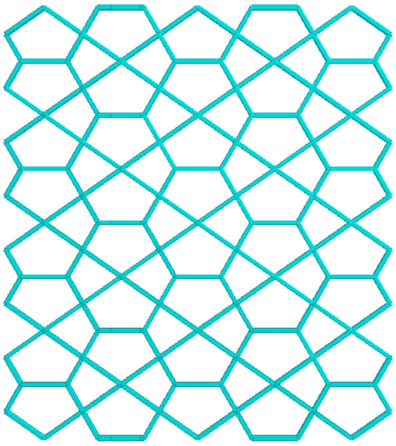

Figure 4.1 Pentagrid Structural Systems

5 BUILDING CONSIDERED

A steel building with rectangular base plan of 75m x 75m is selected for this parametric study. Four buildings are designed with different number of storeys as 20,30,40 and 50 for Pentagrid structure systems.

Plan Area:	75m x 75m
Location :	Ahemedabad
Storey Height :	3m
Storey :	All Typical
Steel Sections :	Fe 250
Concrete (Slabs) :	M25
Dead Load :	3 kN/m^2
Wall/Cladding Load:	4 kN/m
Live Load :	2.5 kN/m2
Slab thickness :	120 mm
Earthquake Load :	IS 1893 (Part 1) : 2016
Zone :	V
Seismic Analysis :	Static
Importance Factor :	1.5
Response Spectrum:	5
Modal Damping Ratio :	3%
Wind Load :	IS 875 (Part 3) : 2015
Basic Wind Speed :	50 m/s
Steel Design Code :	IS 800:2007

Limiting Top Storey Displacement :H/500 ;
H = Building Height
Limiting Inter Storey Drift : 0.004

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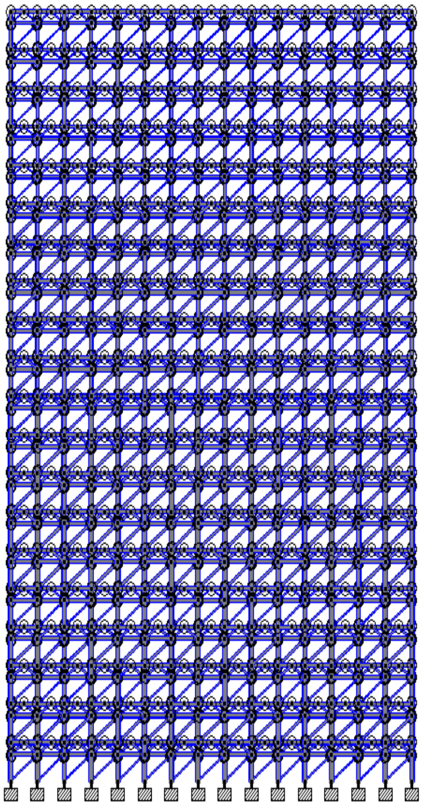

Figure 5.2 75x75 Elevation for 20 floor

5.1 Pentagrid Buildings

For this parametric study, total 15 numbers of structures are analyzed as well as designed. The buildings are modeled as steel structure in STAAD.PRO. The structural elements such as columns, beams and pentagrids are assigned structural steel properties while the slabs are considered to be of RCC. Furthermore, conceptually pentagrids are assumed as truss elements and they are subjected to axial loads only. So, the pentagrids are assigned with the moment releases at both the ends.

All sections in buildings are optimized for minimum possible design sections of columns, beams and pentagrids. For that, all buildings are grouped into three parts along the height of the buildings. For such buildings, columns and pentagrids are optimized for each divided part of the whole building. Beams at each floor level are grouped in three categories and beam sections at each floor level are typical.

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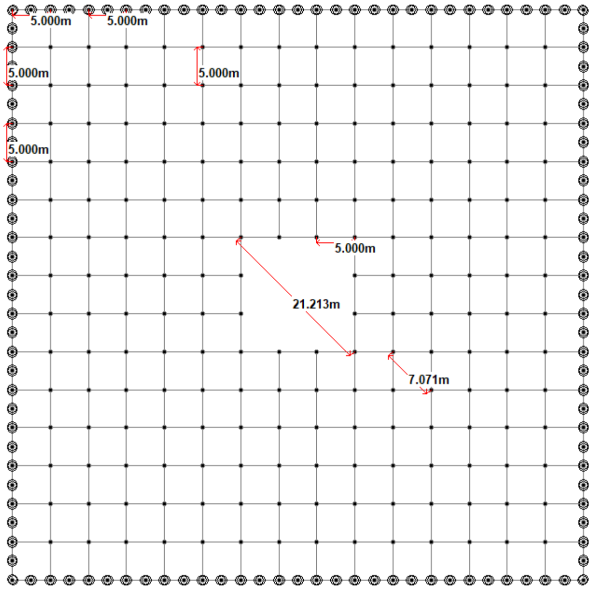

Figure 5.1 75x75 pentagrid Typical Floor Plan for Aspect Ratio Comparison

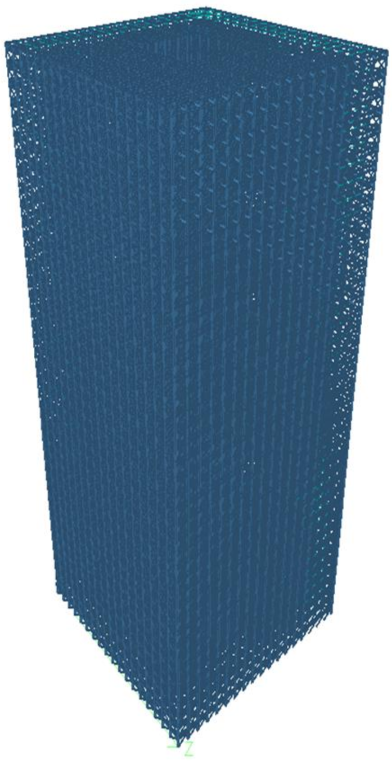

Figure 5.3 75x75 3D view for 50 floor

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Aspect Ratio	Floor	From	To	Pentagrid	Column
1	20	0	10	ISHB200H	WPB850
		11	20	ISHB300H	NPB700
2	30	0	10	ISHB200H	WPB850
		11	20	ISHB300H	NPB700
		21	30	ISHB400H	ISWB600
3	40	0	10	ISHB200H	WPB850
		11	20	ISHB300H	NPB700
		21	30	ISHB400H	ISWB600
		31	40	ISHB500H	ISWB500
4	50	0	10	ISHB200H	WPB850
		11	20	ISHB300H	NPB700
		21	30	ISHB400H	ISWB600
		31	40	ISHB500H	ISWB500
		41	50	ISHB600H	ISWB400

Table 5-1 Design Section for Pentagrid structures

Floors		Column Section				% reduction in c/s area
		Penta grid		Conventional		
From	To	Section	Area (cm^2)	Section	Area (cm^2)	
1	10	WPB 850x300x230.55	293.7	WPB 900x300x291.45	371.3	20.9
11	20	NPB 700x250x171.47	218.4	WPB 700x300x240.51	306.4	28.7
21	30	ISWB 600	170	NPB 700x250x171.47	218.4	22.16
31	40	ISWB 500	121	ISWB 600	170	28.82
41	50	ISWB 400	85	ISWB 500	121	29.75
					Avg-red	26.066

Table 5-2 Comparison of steel used in pentagrid & conventional building

5.2 Governing Loads In Design

After analyzing for all the structures, the governing loads for each building for all Four kinds of pentagrid structural systems are tabulated in the Table 3-2. In which EQ stands for Earthquake Load and WL stands for Wind Load. It is

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observed that wind forces are dominant after aspect ratio 2 for 20- storey pentagrid system and for 30-storey, 40-storey and 50-storey after aspect ratio 3. Here it is noted that 20-storey pentagrid is relatively flexible with respect to 30-storey, 40-storey and 50-storey pentagrid structures. Which shows that pentagrid system resists wind forces upto higher heights as the storey size decreases.

Aspect ratio	20	30	40	50
1	EQ	EQ	EQ	EQ
2	EQ	EQ	EQ	EQ
3	EQ	EQ	WL	WL
4	WL	WL	WL	WL
5	WL	WL	WL	WL

Table 5-3 Governing loads

6 RESULTS COMPARISON ANS DISCUSSION

In this section, parametric comparison of Four types of pentagrid structural systems is presented in graphical form. Parameters included are time period, maximum top Storey displacements and maximum base shear. The comparison is presented using the graphs of parameter Vs. Aspect Ratios.

For the purpose of simplicity in interpretation and explanation, 20-storey, 30-storey, 40-storey and 50-storey pentagrid system buildings respectively in this thesis.

6.1 Time Period

The Figure 6.1 represents the comparison of the time period of all Four pentagrid systems 20-storey, 30-storey, 40-storey and 50-storey buildings

As the height of a building increases, its fundamental time period also increases. For example, a 20-story building has a lower time period than a 30-story building, and a

40-story building has a lower time period than a 50-story building. Therefore, it can be concluded that for a structure with the same plan dimension and height, the time period of the building increases and it becomes more flexible as the size of each story increases.

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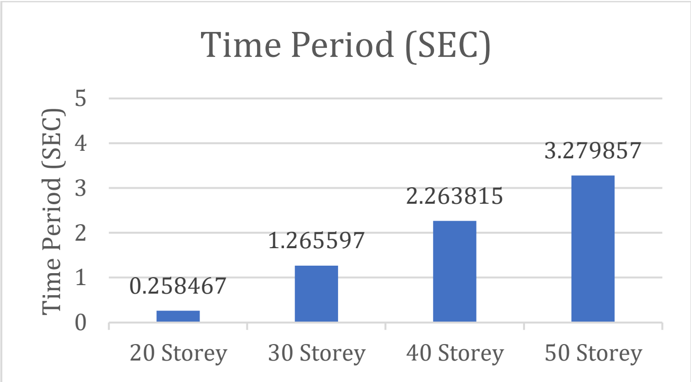

Figure 6.1 Time period comparison between different pentagrid structures

6.2 Maximum Top Storey Displacement

In this section, graphs showing displacements at each storey level for each type of buildings are presented in Figure 6.2. Storey displacement curves are observed nearly uniform in all the cases. The trend of plots for all pentagrids is found to be almost linear. It is observed that for all cases. As the building is rectangular, results in both directions are different.

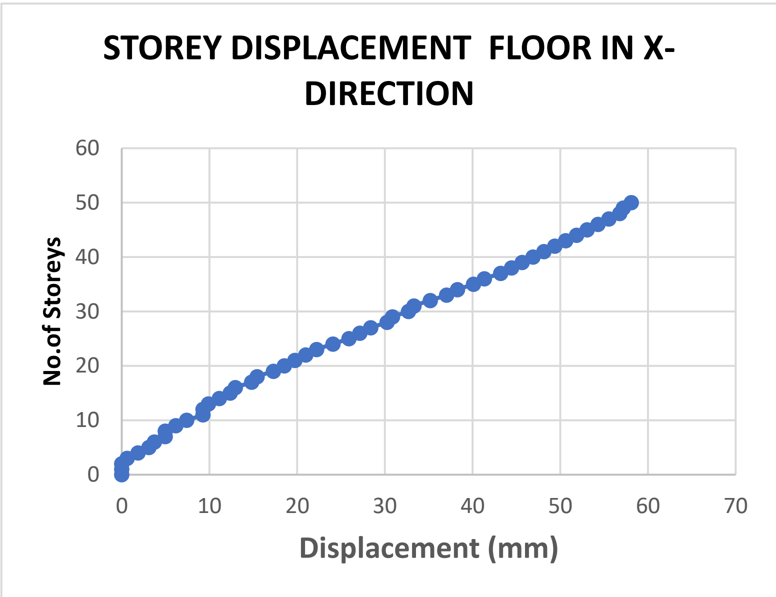

Figure 6.2 Storey displacement for 50 floor pentagrid buildings

6.3 Maximum Storey Drift Plots

In this section, storey drifts graphs at each storey level for each type of structures are presented in Figure 6.3 below. In all buildings sudden variations are observed at the storeys where the pentagrid sections are changed. As the building is rectangular, results in both directions are different.

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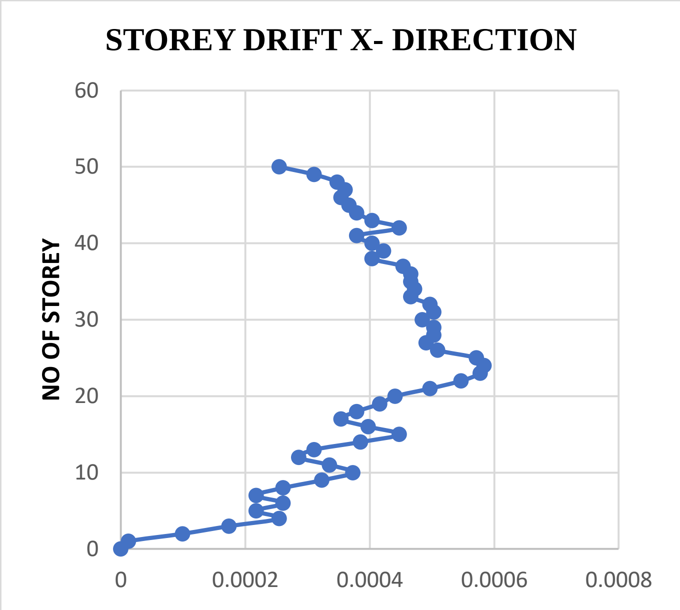

Figure 6.3 Storey drift for 50 floor pentagrid buildings

6.4 Maximum Base Shear

The Figure 6.4 represents the comparison of the maximum base shear in the direction having maximum effect for all pentagrid systems buildings

Ass mentioned in the previous sections, it is known that 20 story buildings have more stiffness than 30 story, 40 storey and 50 storey buildings and 30 story buildings are stiffer than 40 storey buildings. Naturally 20 story buildings attracts comparatively more lateral force and more base shear and 20 story and 50 storey buildings resists relatively moderate and low base shear respectively; until aspect ratio reaches to 3. As building height increases for a fixed base dimensions and aspect ratio around 3, wind loads become governing forces in 50 storey buildings firstly as they are more flexible than other systems and then the trend is followed by 20 storey and 50 storey buildings respectively. When aspect ratio crosses the value of 3, static wind load takes hold and the base shear is governed by static wind loads. That is why after aspect ratio 3 the base shear for all the systems comes out to be nearly equal.

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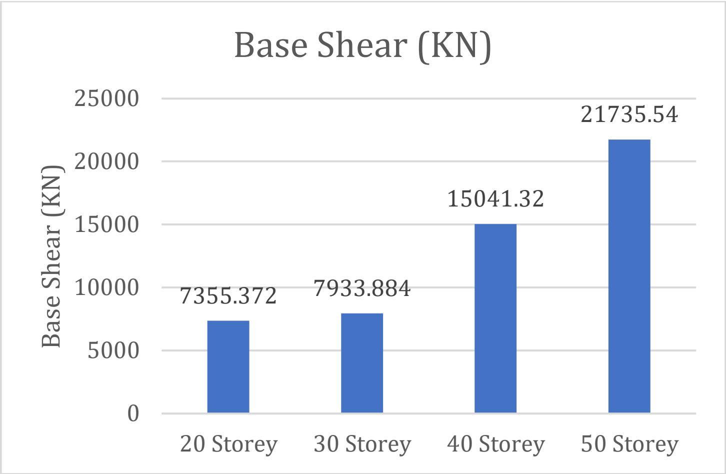

Figure 6.4 Storey shear comparison between different pentagrid structures

7 CONCLUSION

The pentagrid structural system is a better solution to resist wind forces up to greater heights.

For buildings with less than 50 stories, pentagrids provide an economical design. The average reduction in the top storey displacement is 15% and it ranges between 12% to 16% when compared to conventional building. The average reduction in usage of steel is 26% in a 50 storey building.

The aspect ratio can be considered as the point of transition for pentagrid structures, where wind forces become more predominant than earthquake forces.

Formulae for the preliminary design of buildings have been derived using a simple yet accurate method, and it has been found that they are fairly accurate and provide speedy solutions. This approach for deriving such formulae can be used to develop generalized formulae for the preliminary design of pentagrids

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