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Dynamic Wind Analysis of Different Shapes Tall Building

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Abstract: Tall buildings are increasingly becoming a norm in urban landscapes, and their design and construction require careful consideration of various factors, including wind loads. This study investigates the dynamic wind analysis of different shape tall buildings, with a focus on understanding the effects of wind loads on building stability and safety. analyse the wind load effects on different shape tall buildings. The results show that wind load effects vary significantly depending on building shape, size, and orientation. The study provides valuable insights into the design of tall buildings, highlighting the importance of considering wind load effects in the design process.

In this we are study G+50 stories tall building with different shapes, Shapes can influence wind interacts with the structure. By different studies we already know buildings with sharp edges or irregular geometries tend to create more turbulence and, thus, experience higher dynamic loads than those with streamlined, cylindrical, or uniform shapes. Wind loads are modelled based on wind speed, direction, turbulence intensity, and other atmospheric conditions. These factors are combined to predict the wind's impact on a building at various heights. Different building shapes have different responses to wind. Tall buildings with tapered or rounded shapes generally experience lower wind loads due to better airflow around them, while those with sharp angles or corners may lead to vortex shedding and higher wind-induced forces.

Dynamic wind analysis of tall buildings is essential for ensuring structural integrity, occupant comfort, and safety. It requires an understanding wind effect to predict and mitigate the effects of wind on various building shapes.

Keywords: Gust Factor Method, ETABS Software, Dynamic Response, IS 875: (Part-3): 2015, Effects of Building Shape, Tall buildings, Along wind, across wind

I. INTRODUCTION

Tall buildings have become an integral part of modern urban landscapes, and their design and construction require careful consideration of various factors, including wind loads. Wind load theory is an essential part of structural engineering, particularly for the design of tall buildings and structures in windy areas. By understanding how wind interacts with a structure's shape, height, and environment, engineers can design buildings that withstand wind forces safely. The calculation of wind loads requires knowledge of dynamic forces, local wind patterns, and the structure's ability to resist or absorb those forces through appropriate design and materials. Wind loads have a significant impact on the stability and safety of tall buildings, and their effects vary depending on the building's shape, size, and orientation. Wind loads one of the critical factors in the design and safety of buildings. In recent years, advances in computational fluid dynamics (CFD) and wind tunnel testing have enabled researchers to study the effects of wind loads on tall buildings in greater detail. Dynamic wind analysis, which involves simulating the dynamic behaviour of wind flows around buildings, has emerged as a powerful tool for evaluating the wind load effects on tall buildings. This study investigates the dynamic wind analysis of different shape tall buildings, with a focus on understanding the effects of wind loads on building stability and safety. The study employs ETABS Software analyse the wind load effects on different shape tall buildings When tall buildings are geometrically irregular it is become more essential to calculate and analysis wind effect. In this study also we are going to calculate wind load dynamically by Gust Factor Method. Gust Factor Method which is given in IS 875 Part 3:2015 in detail give all formulas and criteria to understand and calculate wind load.

Dynamic wind analysis of tall buildings involves the study of the wind-induced behaviour of structures under varying wind conditions. This analysis is critical for understanding the structural performance and safety of tall buildings, as they are more susceptible to dynamic forces caused by wind.

II. OBJECTIVE

The main objective of this research is to investigate and analyze the Wind effect on tall buildings with different shapes. This study focuses on G+50 story buildings dynamic wind analysis done by gust factor method with IS 875: (Part-3): 2015.

The specific objectives of this research include:

1) To calculate the wind forces acting at each floor level of building in along & across
2) To study the behavior of high-rise buildings which is subjected to wind loads.
3) To study the effect of the shape of the building in the plan on the behavior of the structure
4) To determine the effect of wind force on various parameters like maximum displacements, maximum story drift, base shear, overturning moment in the building.
5) Examine how the height of the building influences the wind load distribution and dynamic response, particularly in tall buildings located in different terrain types.
6) Utilize the ETABS software to conduct structural analysis, ensuring that the study aligns with standards and modern engineering practice.

III. METHODOLOGY

The methodology employed in the analysis and design of building in ETABS software. We will follow a systematic methodology. Here's an overview of the steps we will take:

1) *Model Creation:* Create a detailed 3D model of the structure in ETABS, incorporating all the necessary geometric and material properties. This will include defining the building's dimensions, floor plans, column and beam layouts, and assigning appropriate material properties.
2) *Load Assignments:* Apply wind loads and load combinations to the structure based on the specific design codes. These loads will be representative of the wind forces that the structure may experience.
3) *Define Diaphragm:* Define diaphragms property and apply on stories.
4) *Wind Analysis:* Using the defined model and load assignments, we will perform a wind analysis in ETABS. This analysis will simulate the response of the structure to wind forces.
5) *Gust Factor Method Manual Calculation:* Using analysis result details we done dynamic wind analysis by gust factor method and get F_x & F_y values for respectively along and across wind. Putting these values in ETABS user load we again done analysis and get dynamic wind analysis values.
6) *Results Evaluation:* Analyze and evaluate the results obtained from the wind analysis. This will involve examining the behavior of the different shapes building. We will compare the response of different shapes structures to identify any significant differences.
7) *Interpretation and Conclusion:* Based on the analysis results, we will draw conclusions regarding the wind behavior of different shapes building. We will discuss the results and provide recommendations for the design and construction of such structures.
8) *Method for Analysis:*

a) *Static Method*

- Suitable for regular and low-rise structures.
- Wind pressure is considered constant over the height of the structure.
- Used for buildings up to 50m in height in normal terrain.
- Load calculations are based on basic wind speed (Vb) and pressure coefficients.
- F=Cd×A×Pz

b) *Dynamic Method*

- Required for tall, flexible, or irregular structures.
- Considers the effect of gusts and turbulence.
- Necessary when:
  - Height > 50m
  - Natural frequency < 1 Hz
  - Slender structures (height-to-width ratio > 5)
  - Along wind- F=G×Cd×A×Pz
  - Across wind- Fzc = (3Mc/h^2) *z/h

IV. MODELLING

The structure is G+50 stories with different shapes. The height of the stories is uniform throughout for all models used in analysis. ETABS 2021 software has been used for the analysis of models.

Table1: Design Consideration

Sr. No.	Parameter	Size
1.	No. of stories	51 Story
2.	Plan dimensions	25m X 25m
3.	Total height of the building	153m
4.	Height of each story	3m
5.	Size of beam	550 X 550mm
6.	Size of column	700 X 700mm
7.	Thickness of slab	150mm
8.	Shear wall thickness	200mm
9.	Density of concrete	25 KN/m3
11.	Concrete grade for column	M60
12.	Concrete grade for Beam and Slab	M30
13.	Grade of steel	Fe 415

Table2: Load Considerations

Cladding load	1.1KN/m
Live Load	2.5KN/m^^{2}
Dead Load	3.75KN
Wind Load X wind ward	0.7
Wind Load X leeward	0.4
Wind Load Y wind ward	0.8
Wind Load Y leeward	0.1

Table3: Design Parameters

Location	Mumbai
Terrain Category	4
Importance factor	1
Wind Speed	44m/s
Topography factor	1
Risk coefficient	1
Base Restraint	Fixed

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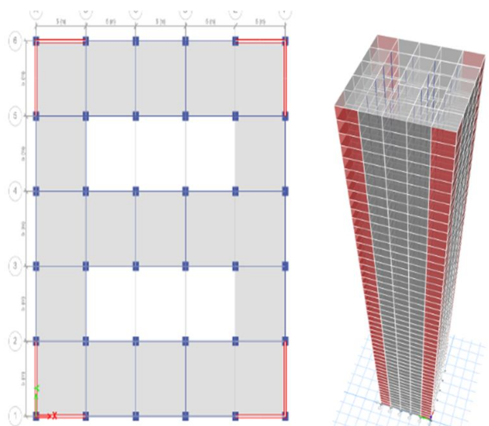
A. Load Combinations

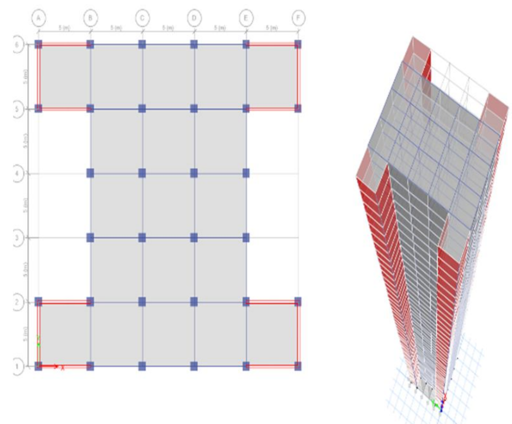
1) 1.2 (DL+LL+WLX)
2) 1.2 (DL+LL-WLX)
3) 1.2 (DL+LL+WLY)
4) 1.2 (DL+LL-WLY)
5) 0.9 (DL + WLX)
6) 0.9 (DL - WLX)
7) 0.9 (DL + WLY)
8) 0.9 (DL - WLY)
9) 1.5 (DL + WLX)
10) 1.5 (DL - WLX)
11) 1.5 (DL + WLY)
12) 1.5 (DL - WLY)

B. Structural Analysis

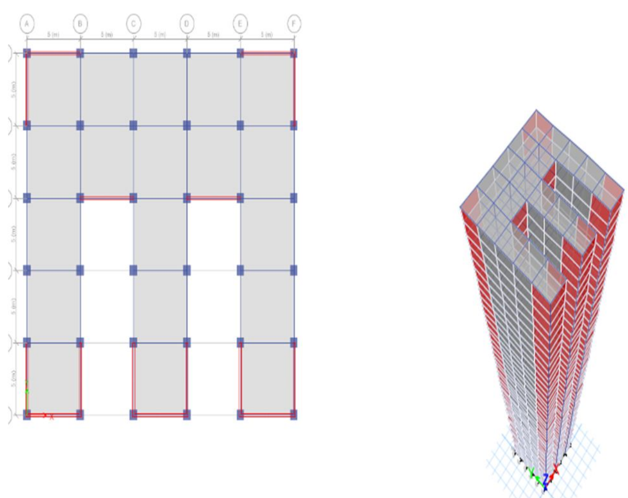
fig.1 B Shape Building Plan

2) fig.2 I Shape Building Plan

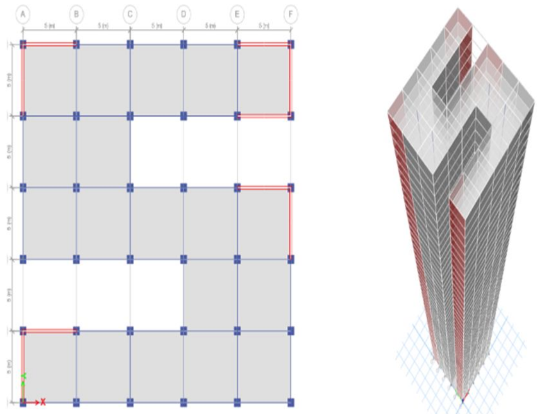




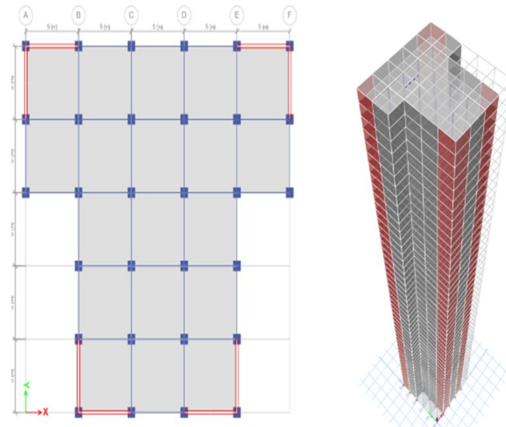
3) fig.3 *M Shape Building Plan*



4) fig.4 S Shape Building Plan



5) fig.5 T Shape Building Plan



V. RESULT AND DISCCUSSION

A comparative behavioral study of tall building has been done, with the aim of response optimization of the building against the wind loads and to verify more adoptable arrangements of the shapes, so that the building is exposed to minimum wind pressure. different shaped building models are compared with the help of results obtained from the analysis to arrive at the best shaped building model. To assess the best shape among the models, the buildings are studied for story displacements, story drifts and story shear, and overturning moment.

The analyzed results of wind analysis of different shaped Tall Buildings are below-

A. Displacement

B, I, M, S and T shape building respectively-
Max Displacement in X – direction by dynamic wind analysis model is found out to be 27.409mm, 25.651mm, 38.553mm, 25.159 mm, 36.767mm.
Max Displacement in Y – direction by dynamic wind analysis model is found out to be 26.191mm, 26.498mm, 23.201mm, 45.873mm, 28.541mm.

B. Table 4

Max Displacement	**X – direction**	**Y – direction**
B Shape Building	27.409mm	26.191mm
I Shape Building	25.651mm	26.498mm
M Shape Building	38.553mm	23.201mm
S Shape Building	25.159 mm	45.873mm
T Shape Building	36.767mm	28.541mm.

Check- Allowable Max Displacement is 1/500 of building height
=1/500 X 153000mm (153M)
= 306mm
Max displacement of all models 27.409mm, 26.498mm, 38.553mm, 45.873mm, 36.767mm.
306mm> 27.409mm, 26.498mm, 38.553mm, 45.873mm, 36.767mm
Hence Safe in displacement.

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G+50 story building of different shape buildings in X direction

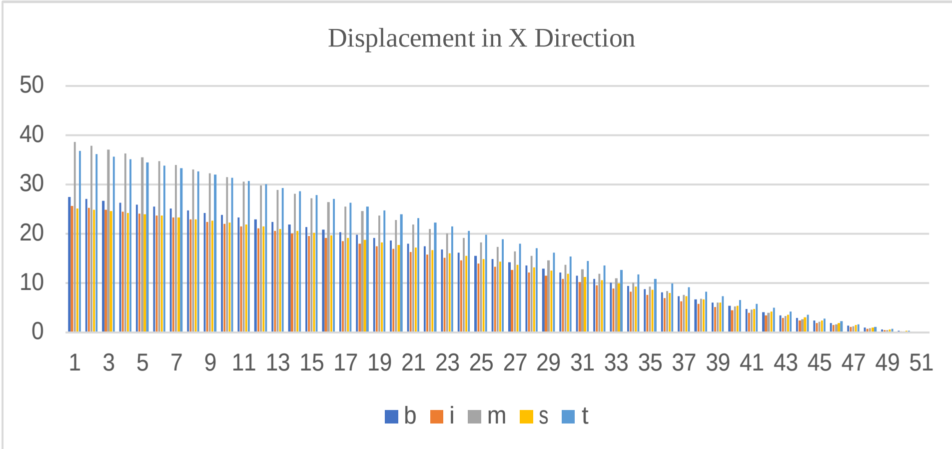

Fig.6 Displacement in X Direction

By going through the graphs shown above, it can be clearly stated that the M-shape model undergoes more displacement in the X-direction primarily due to its slenderness, larger exposed surface area to wind loads, and greater flexibility. These factors contribute to more lateral movement when lateral forces are applied. On the other hand, the S-shape model in X direction experiences less displacement due its smaller exposed area to wind loads and higher stiffness, which results in less lateral movement under similar lateral forces.

G+50 story building of different shape buildings in Y direction

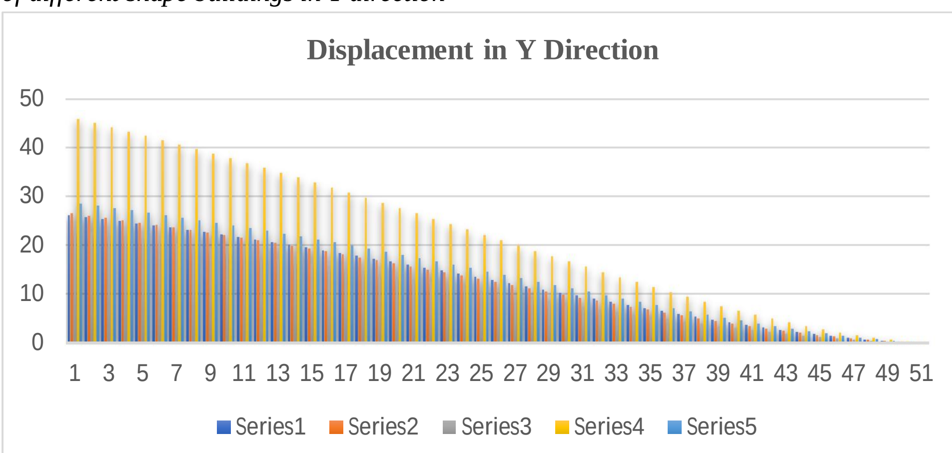

Fig.7 Displacement in /y Direction

By going through the graphs shown above, it can be clearly stated that the S-shape model undergoes more displacement in the Y-direction primarily due to its slenderness, larger exposed area to wind load, and potential for torsional effects. On the other hand, the M-shape model experiences less displacement due to its compact geometry, smaller exposed surface area, and higher stiffness, which help it resist lateral forces more effectively.

C. Drift

B, I, M, S and T shape building respectively-
Drift in X – direction by dynamic wind analysis model is found out to be- 0.00023, 0.000214, 0.000293, 0.000215, 0.000299.
Drift in Y – direction by dynamic wind analysis model is found out to be- 0.000211, 0.000209, 0.000176, 0.000352, 0.000228.

Table 5

Max Drift	**X – direction**	**Y – direction**
B Shape Building	0.00023,	0.000211
I Shape Building	0.000214	0.000209
M Shape Building	0.000293	0.000176
S Shape Building	0.000215	0.000352
T Shape Building	0.000299.	0.000228

Check- Allowable Max Drift is 1/400 to 1/500 of building height
=1/400 to 1/500 X 153m
= 0.3825 to 0.306
For seismic: 0.004 times of story height
=0.004 X 3m
=0.012

Max drift of all models 0.00023, 0.000214, 0.000293, 0.000352, 0.000299.
0.3825 to 0.306 or 0.012 > 0.00023, 0.000214, 0.000293, 0.000352, 0.000299.
Hence Safe in storey drift.

G+50 story building of different shape buildings in X direction

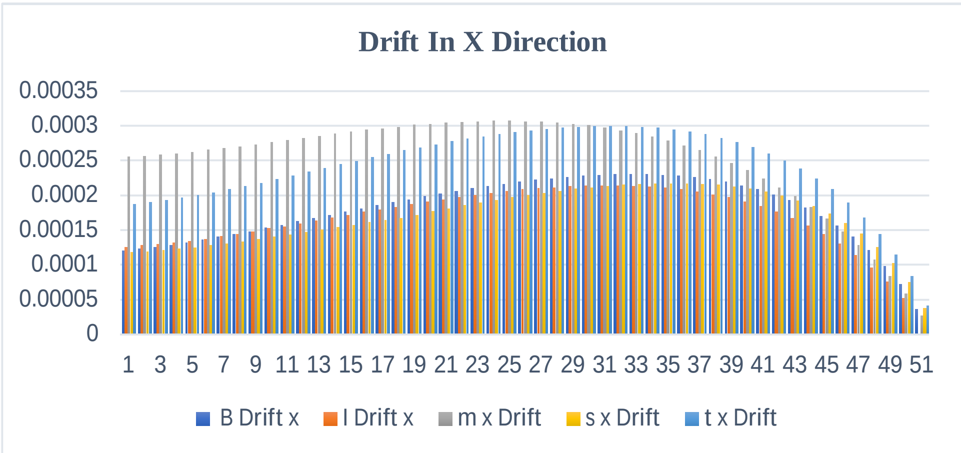

Fig.8 Drift in X Direction

By going through the graphs shown above, it can be clearly stated that Among B, I, M, S, and T models, T shaped model has got maximum Storey drift in the X-direction due to its asymmetric geometry, torsional effects, and flexibility whereas I shaped model is having minimum Storey drift in the X-direction due to its symmetry, stiffness, and efficient distribution of lateral loads.
M shape, B shape and S shaped models have intermediate Storey drift values between T and I shape.

G+50 story building of different shape buildings in Y direction

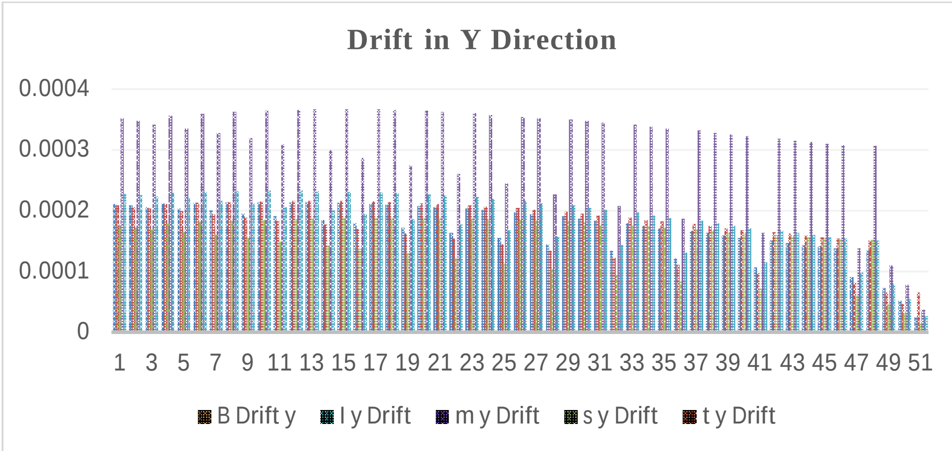

Fig.9 Drift in X Direction

By going through the graphs shown above, it can be clearly stated that Among B, I, M, S, and T models, S shaped model has got maximum Storey drift ue to asymmetry, torsion, flexibility, and larger exposed area to lateral forces whereas M shaped model is having minimum Storey drift Minimum storey drift due to symmetry, rigidity, and even distribution of forces.
T shape, B shape and I shaped models have intermediate Storey drift values between M and S shape.

D. Base Shear

B, I, M, S and T shape building respectively-

Table 6

Max Base Share	X – direction	Y – direction
B Shape Building	-1235.64kn	-793.234KN
I Shape Building	-1229.75kn	-779.479KN
M Shape Building	-1255.85kn	-701.826KN,
S Shape Building	-1238.2022kn	-1028.76KN
T Shape Building	-1244.28kn	-766.443KN

G+50 story building of different shape buildings in X direction

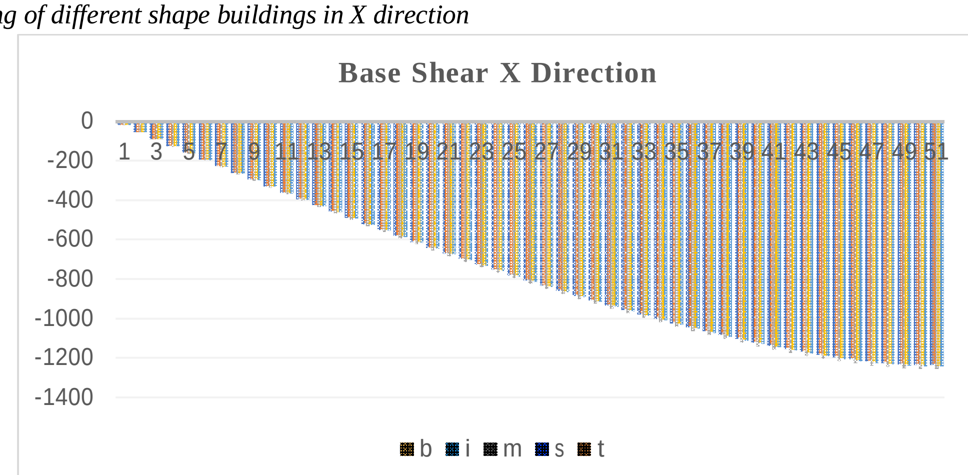

Fig.10 Base Shear in X Direction

By going through the graphs shown above, it can be clearly stated that Among B, I, M, S, and T models, the M-shape model has a higher base shear in the X-direction due to its complex geometry and flexibility, while the I-shape model is more efficient at resisting lateral loads, leading to lower base shear.

G+50 story building of different shape buildings in Y direction

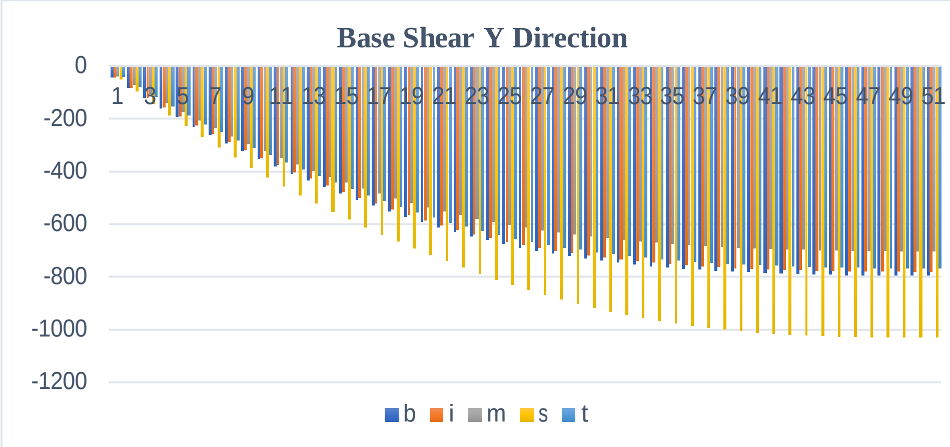

Fig.11 Base Shear in Y Direction

By going through the graphs shown above, it can be clearly stated that S-shape model experiences the maximum base shear in the Y-direction because of its irregular geometry, flexibility, and torsional effects, while the M-shape model experiences the minimum base shear due to its symmetry, stiffness, and more efficient distribution of lateral forces.

E. Overturning Moment

B, I, M, S and T shape building respectively-

Max base shear- 90120knm, 88727.5704knm, 80351.62knm, 113177.7knm, 87073.98knm

Table 7

Max Base Share	X – direction	Y – direction
B Shape Building	90120knm,	-114752knm
I Shape Building	88727.5704knm	-114092knm
M Shape Building	80351.62knm	-116843knm
S Shape Building	113177.7knm,	-114985knm
T Shape Building	87073.98knm	-115626knm.

G+50 story building of different shape buildings in X direction

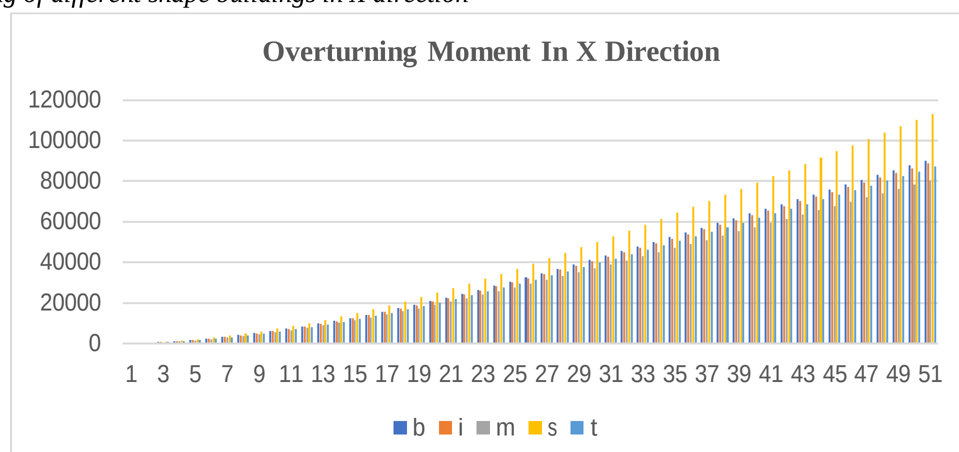

Fig.12 Overturning Moment in X Direction

By going through the graphs shown above, it can be clearly stated that the S-shape model experiences maximum overturning moments in the X-direction because of its irregular geometry, flexibility, and torsional effects, which cause uneven wind load distribution and increase the structural response to lateral forces. In contrast, the M-shape model experiences minimum overturning moments in the X-direction due to its symmetry, stiffness, and efficient force distribution, which result in a more balanced and stable structural response to wind loads.

G+50 story building of different shape buildings in Y direction

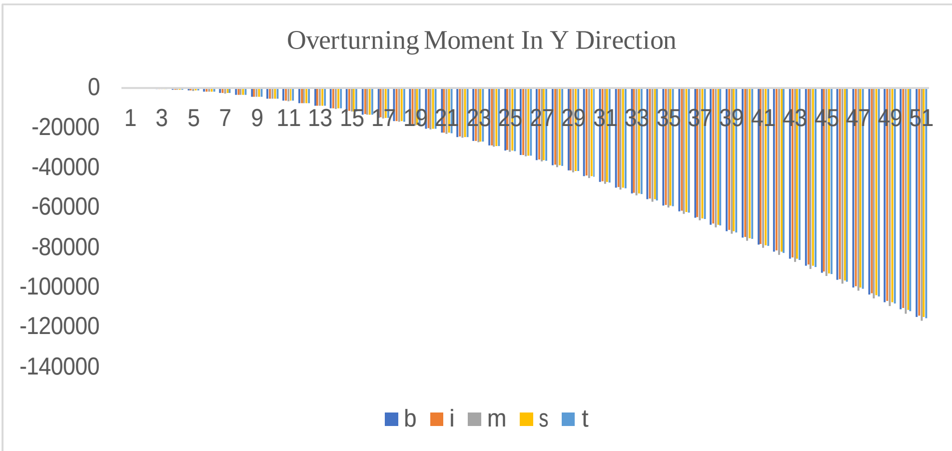

Fig.13 Overturning Moment in Y Direction

By going through the graphs shown above, it can be clearly stated that I-shape model experiences the maximum overturning moment in the Y-direction due of its slender profile, flexibility, and susceptibility to torsional effects, which amplify the bending response under wind load. while the M-shape model experiences the minimum overturning moment in the Y-direction due to its symmetry, stiffness, and efficient distribution of lateral forces, which helps prevent large bending moments and reduces the structure's deformation under wind load.

F. *Time Period*

Table 8

Mode	B shape	I shape	M shape	S shape	T shape
	cyc/sec	cyc/sec	cyc/sec	cyc/sec	cyc/sec
1	4.022	3.961	4.298	4.88	3.976
2	3.754	3.553	3.688	3.802	3.932
3	2.525	2.728	2.803	2.993	2.547
4	1.137	1.072	1.07	1.253	1.105
5	1.078	0.979	1.022	1.11	1.101
6	0.731	0.742	0.777	0.823	0.716
7	0.552	0.501	0.486	0.594	0.534
8	0.532	0.461	0.484	0.541	0.529
9	0.357	0.341	0.358	0.383	0.341
10	0.338	0.301	0.289	0.371	0.327
11	0.33	0.274	0.289	0.325	0.325
12	0.232	0.207	0.21	0.257	0.223

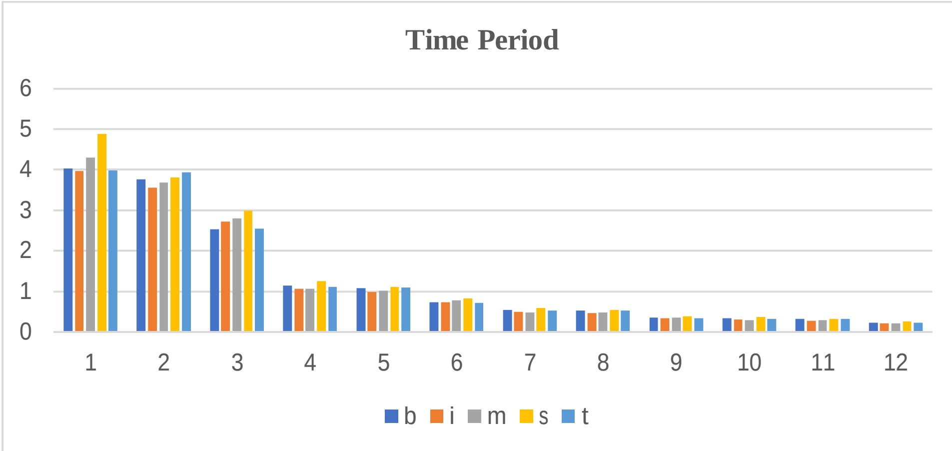

Fig.14 Time period

This graph shows time period for B shape, I shape, M shape, S shape and T shape tall buildings. I shape building has less time period t than other, shorter time period typically indicates that the building is stiffer and more resistant to lateral movement and less flexible. I shape building has less time period t than B shape building by 1.54%, M shape building by 8.5%, S shape building by 23.2%, T shape building by 0.378%. S Shape building has maximum time period due to its flexible geometry and potential for torsional effects, it will experience more lateral displacement and oscillate more slowly, resulting in a longer time period.

G. Frequency

Table 9

Mode	B shape	I shape	M shape	S shape	T shape
	cyc/sec	cyc/sec	cyc/sec	cyc/sec	cyc/sec
1	0.249	0.252	0.233	0.205	0.251
2	0.266	0.281	0.271	0.263	0.254
3	0.396	0.367	0.357	0.334	0.393
4	0.879	0.933	0.935	0.798	0.905
5	0.928	1.022	0.978	0.901	0.908
6	1.368	1.349	1.288	1.214	1.396
7	1.811	1.996	2.058	1.685	1.872
8	1.881	2.169	2.065	1.849	1.89
9	2.802	2.93	2.791	2.608	2.935
10	2.957	3.319	3.456	2.698	3.063
11	3.032	3.648	3.461	3.079	3.079
12	0.232	0.207	0.21	0.257	0.223

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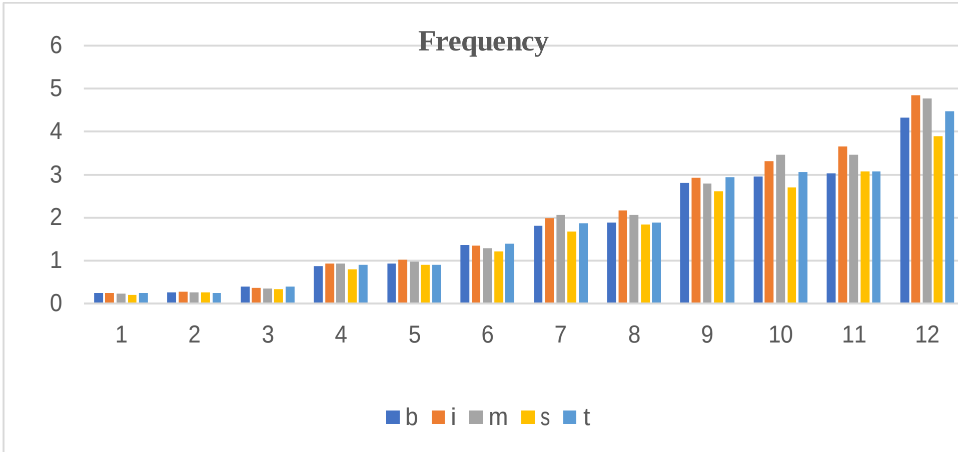

Fig.15 Time period

This graph shows frequency for B shape, I shape, M shape, S shape and T shape tall buildings. S shape building has less frequency than other, S shape has Lower frequency due to a higher time period, B shape building by 21.46%, I shape building by 22.92%, M shape building by 13.658%, T shape building by 22.439%. S-shape sways more slowly, with a longer time period and lower frequency. I Shape building has maximum frequency. I-shape resists lateral movement better, with a shorter time period and higher frequency. I shape has Higher frequency due to a shorter time period

VI. CONCLUSION

A. Story Displacement

With increase in height of the building with top floor story displacement increases-

- B, I, M, S and T shape building displacement respectively change in x and y direction by Maximum story displacement knows that max displacement comes in S Shape tall building which have 45.873mm max displacement is comparingly more than other models.
- B, I, M, S and T shape building displacement respectively change in x and y direction by Maximum story displacement knows that max displacement comes in I Shape tall building which have 26.498mm max displacement is comparingly less than other models.
- With each story displacement of B, I, M, S and T shape building respectively increased 1.3%, 1.7%, 1.98%, 1.86% and 1.52%.
- I shape tall building has least max displacement.

B. Story Drift

- B, I, M, S and T shape building drift respectively change in x and y direction by Maximum story drift knows that max drift comes in S Shape tall building which have max story drift 0.000352 which is comparingly more than other models.
- B, I, M, S and T shape building drift respectively change in x and y direction by Maximum story drift knows that max drift comes in I Shape tall building which have 0.000214 max story drift which is comparingly less than other models.
- With each story drift of B, I, M, S and T shape building respectively increased 0.43%, 0.46%, 1.36%, 1.42% and 0.33%.
- I shape tall building has least max story drift.

C. Story Overturning moment

With increase in height of the building with top floor overturning moment decreases-

- B, I, M, S and T shape building overturning moment respectively change in x and y direction by max overturning moment knows that max overturning moment comes in S Shape tall building which have 113177.7kNm overturning moment which is comparingly more than other models.
- B, I, M, S and T shape building overturning moment respectively change in x and y direction by max overturning moment knows that max overturning moment comes in M Shape tall building which have 80351kNm overturning moment which is comparingly less than other models.
-

- With each story overturning moment of B, I, M, S and T shape building respectively decrease 3.75%, 2.63%, 2.62%, 2.72% and 2.64%.
- M shape tall building has least overturning moment.

D. Base Shear

With increase in height of the building with top floor overturning moment decreases-

- B, I, M, S and T shape building base shear respectively change in x and y direction by max base shear knows that max base shear comes in M Shape tall building which have -1255.8506kN base shear which is comparingly more than other models.
- B, I, M, S and T shape building base shear respectively change in x and y direction by max base shear knows that max base shear comes in I Shape tall building which have -1229.75kN base shear which is comparingly less than other models.
- With each story base shear of B, I, M, S and T shape building respectively decrease 0.041%, 0.041%, 0.04%, 0.041% and 0.041%.
- I shape tall building has least base shear.

E. Time Period

With increase in height of the building with top floor Time period increases -

- B, I, M, S and T shape building Time period respectively change by different modes by max Time period knows that max Time period comes in S Shape tall building which have 4.88sec Time period which is comparingly more than other models.
- B, I, M, S and T shape building Time period respectively change by different modes by max Time period knows that least Time period comes in I Shape tall building which have 3.961sec Time period which is comparingly less than other models.
- With each story Time period of B, I, M, S and T shape building respectively Increase 6.66%, 11.48%, 14.19%, 22.09% and 1.1%.
- I shape tall building has least time period in different modes.

F. Frequency

With increase in height of the building with top floor frequency increases -

- B, I, M, S and T shape building frequency respectively change by different modes by max frequency knows that max frequency comes in I Shape tall building which have 0.252cyc/sec frequency which is comparingly more than other models.
- B, I, M, S and T shape building frequency respectively change by different modes by max frequency knows that least frequency comes in S Shape tall building which have 0.205cyc/sec frequency which is comparingly less than other models.
- With each story frequency of B, I, M, S and T shape building respectively Increase 6.8%, 11.5%, 16.3%, 28.29% and 1.19%.
- S shape tall building has least frequency in different modes

G. Other Observations

- With increase in time period or decrease in frequency of building gust factor will increase.
- The shape of the tall buildings playing a major role in reducing the wind load effect in terms of different design parameters that should be taken into consideration before designing any building.
- In the frequency of building along wing value will decrease and become constant. But across wind results are unchanged.
- It is observed that along wind results are less compare to across wind.
- Maximum design wind pressure and displacement is coming at top of the building.

The comparative analysis between different shapes was made to find out which shape is more efficient against wind load. I shape model has least value wind effect of factors maximum storey displacement, Base shear and maximum storey drift So, can conclude by saying that I shape building is more stable safe and rigid against wind load

VII. SCOPE OF FUTURE WORK

To study the behavior of the structures for higher storey structures and combination of structural irregularity configurations.

1) As a part of extension of this work the effect of internal wind pressures can also be studied by considering openings in external walls.

2) For more accuracy as a part of extension of the work Computational Fluid Dynamics method can be used to compute wind loads.

3) Along and across wind-induced reactions of tall buildings with various structural systems.
4) Study of wind load effects with different material of building.
5) Dynamic seismic analysis of different shapes of tall building

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