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Wind-Induced Responses in Tall Steel Buildings Using International Standards

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***Abstract:** Tall buildings are being developed due to rapid urbanization, as land availability decreases and population growth increases. High-rise buildings are more susceptible to wind forces, making their structures dynamically sensitive at greater elevations. The gust factor, a pseudo-static constant, is provided by several nations to compute dynamic wind forces. This study compares the structural response of tall steel buildings with V-bracing, X-bracing, and Chevron bracing under dynamic wind loading, using four different codes and standards: India (IS 875:2015 part-3), America (ASCE 7-16), Australia/New Zealand (AZ/NZS 1170.2:2011), and Canada (NBCC 2015) for varying structure heights and exposure conditions (Open and Rough). The finite element software ETABSv.18 is utilized for analysis. All the structures produce acceptable outcomes in both the Open and Rough Exposure categories. Finally, conclusions are drawn from comparing evaluated dynamic lateral forces, showing that Chevron bracing produces the most satisfying results. The story drifts, maximum story displacement, base shear, and overturning moments are used to evaluate the results.*

***Keywords:** Dynamic wind loading, Gust factor, Braced frame structure, Steel structure with bracing, IS 875:2015 part-3, ASCE 7-16, AZ/NZS 1170.2:2011, NBCC 2015.*

I. INTRODUCTION

Tall buildings have gained significant relevance in this age of rapid urbanization as they maximize space use on limited land and serve as symbols of national success. However, as structures grow taller, natural forces, including wind, become more powerful, posing a dynamic challenge to structural engineers. The Gust Factor Method, an equivalent static wind load approach, evaluates wind loads based on the structure's height, location, and exposure. This approach depends on several factors including the wind velocity profile, turbulence intensity, and other wind field characteristics.

This study evaluates the dynamic wind forces on G+34 (105.00 m) and G+40 (123.00 m) structures in two different exposure categories, Open and Rough, using four country codes: India (IS 875 (III):2015), America (ASCE 07-16), Australia/New Zealand (AZ/NZS 1170.2:2011), and Canada (NBCC 2015).

II. MODELING OF STRUCTURES

The following structural models were created for the Open and Rough Exposures in ETABSv.18. A square structure with a width of 27.0 m is used. The structural categories and their descriptions are provided in Table 2.1. The material properties are given in Table 2.2 and see Figure 2.1 for a plan and 3D view of the modeled structure.

1) Steel building with V-Bracing termed as G+34V, and G+40V.
2) Steel building with X-Bracing termed as G+34X, and G+40X
3) Steel building with Chevron-Bracing termed as G+34C, and G+40C.

Here, G+34, and G+40 are the 34, and 40-storied structures with 105.0m, and 123.0m heights respectively.

Table 2.1: Structure Parameters

S. No.	Particular	G+34	G+40
1.	Structure Types	Steel Building with V-bracing	
		Steel Building with X-bracing	
		Steel Building with Chevron-bracing	
2.	Number of stories	35	41
3.	Building Height	105.00m	123.00m
4.	Building Plan	27.0m x 27.0m	27.0m x 27.0m

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5.	Story Height	3.0m	3.0m
6.	Column Size	ISWB 600-2	ISWB 600-2
7.	Beam Size	ISMB 600	ISMB 600
8.	Secondary Beam for Slab	ISMB 300	ISMB 300
9.	Size of Bracing	ISMB 600	ISMB 600
10.	Slab Thickness	120.0mm	120.0mm
11.	Column-foundation Joint	Fixed at base	Fixed at base
12.	Exposure Category	Open and Rough	Open and Rough

Table 2.2: Material Properties of Buildings

S.No.	Material	Grade
1.	Steel Grade	Fe345
2.	Density of Steel	7850 Kg/m^3
3.	Rebar	HYSD500
4.	Young's Modulus (E)	2.10 x 10^5 N/mm^2
5.	Shear Modulus	80,000 N/mm^2
6.	Poisson's Ratio (μ)	0.30
7.	Concrete Grade	M30

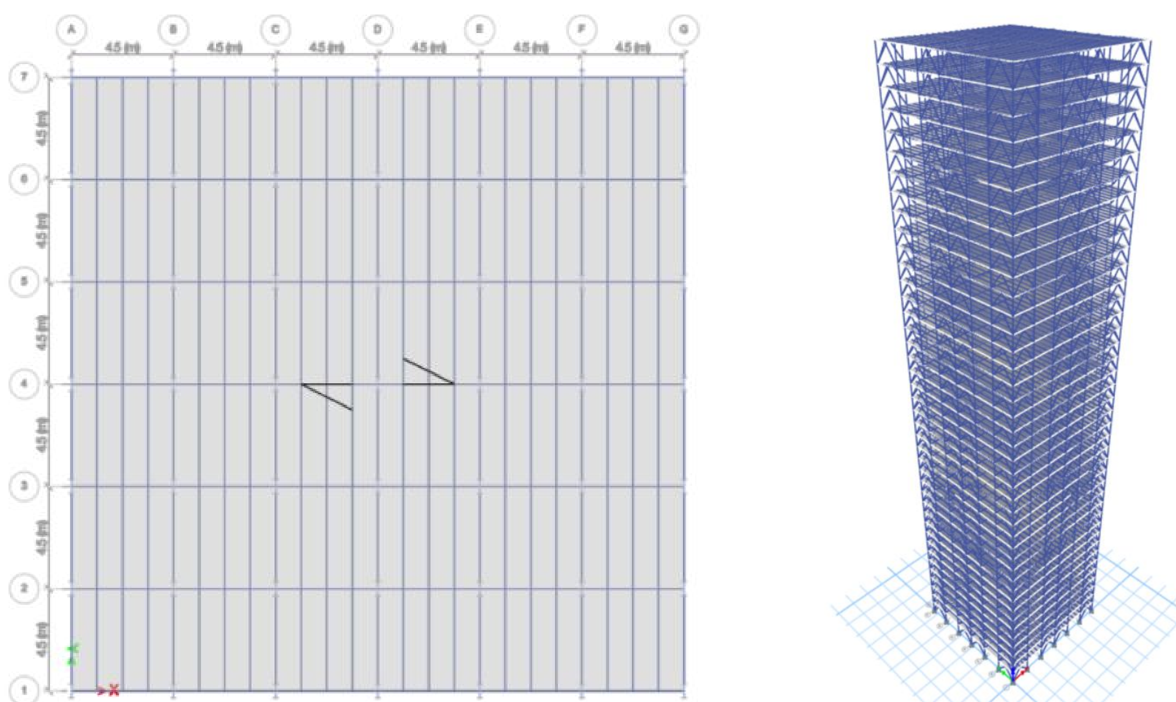

Figure 2.1 Plan and 3D model of braced frame structure

III. PARAMETRIC EVALUATION

The calculation of dynamic wind loading using the gust factor approach is influenced by numerous factors. Each code's computation involves parameters like the resonance response peak factor, size reduction factor, background turbulence factor, energy ratio, reduced frequency, and turbulence length scale shown in Table 3.1.

Table 3.1: Dynamic Wind Load Parameters

S. No.	Parameters	Description		IS	ASCE	AZ/NZS	NBCC
1	Resonance response peak factor (gR)	Exposure Open	G+34	3.896	4.108	2.244	3.947
			G+40	3.855	4.070	2.213	3.919
		Exposure Rough	G+34	3.896	4.108	2.244	3.918
			G+40	3.855	4.070	2.213	3.899
2	Size reduction factor (S)	Exposure Open	G+34	0.090	0.444	0.081	0.044
			G+40	0.100	0.502	0.091	0.062
		Exposure Rough	G+34	0.042	0.339	0.037	0.034
			G+40	0.050	0.392	0.046	0.050
3	Background turbulence factor (B)	Exposure Open	G+34	0.756	0.839	0.730	0.768
			G+40	0.763	0.831	0.709	0.732
		Exposure Rough	G+34	0.718	0.811	0.730	0.768
			G+40	0.726	0.804	0.709	0.732
4	Energy ratio (E)	Exposure Open	G+34	0.064	0.062	0.060	0.149
			G+40	0.070	0.068	0.066	0.181
		Exposure Rough	G+34	0.051	0.063	0.042	0.135
			G+40	0.057	0.068	0.048	0.167
5	Reduced frequency (N)	Exposure Open	G+34	1.687	3.671	1.829	1.489
			G+40	1.477	3.143	1.585	1.289
		Exposure Rough	G+34	2.341	3.588	3.108	1.726
			G+40	1.999	3.102	2.551	1.468
6	Turbulence length scale (L_h), in m	Exposure Open	G+34	153.010	251.700	153.009	1220 (Constant for all)
			G+40	159.180	256.900	159.182	
		Exposure Rough	G+34	126.010	179.000	153.009	
			G+40	131.090	188.600	159.182	

Table 3.1 shows a comparison of the calculated dynamic parameters. India demonstrates a more conservative approach with higher resonance response peak factors and energy ratios, explaining higher safety under dynamic wind loads. ASCE shows higher size reduction factors and reduced frequencies, reflecting detailed considerations of structural response. AZ/NZS provides consistent turbulence factors, indicating a balanced approach to wind effects. NBCC with higher turbulence length scales, gives a different perspective on turbulence impact. These variations highlight the different values used by each code.

IV. RESULTS AND DISCUSSION

Results are computed for V-bracing, X-bracing, and Chevron bracing structures using all four country codes. This section summarizes the maximum dynamic gust load, story displacement, story drift, story shear, and overturning moment.

A. Max Dynamic Gust Loa

The exposure category and height of the structure affect the dynamic lateral wind loads. Table 1.1 lists the calculated gust forces from the different country codes.

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Table 1.1: Max. Dynamic Gust Load

Country Code	G+34		G+40	
	OPEN	ROUGH	OPEN	ROUGH
ASCE	224.266	169.545	233.136	179.537
AZ/NZS	255.456	155.678	260.978	166.251
INDIA	302.25	207.90	317.70	223.84
NBCC	222.469	200.317	238.059	215.511

The Indian code gives the highest loads, especially in open terrain, reflecting a conservative approach. AZ/NZS also predicts high loads with a sharp terrain influence, while ASCE offers moderate values. NBCC shows minimal variation between open and rough terrains. Overall, all codes show increased loads with building height, the magnitude of variation may depend on each standard account for terrain and wind exposure. These differences highlight the varying safety margins and assumptions used globally.

B. Max. Story Displacements

Storey displacement is the term used to describe the swing in a story relative to its starting position. The top story of the building has the maximum story displacement. Story displacements significantly impact the structure's serviceability and safety. The structure is increasingly susceptible to lateral loading as more stories are displaced.

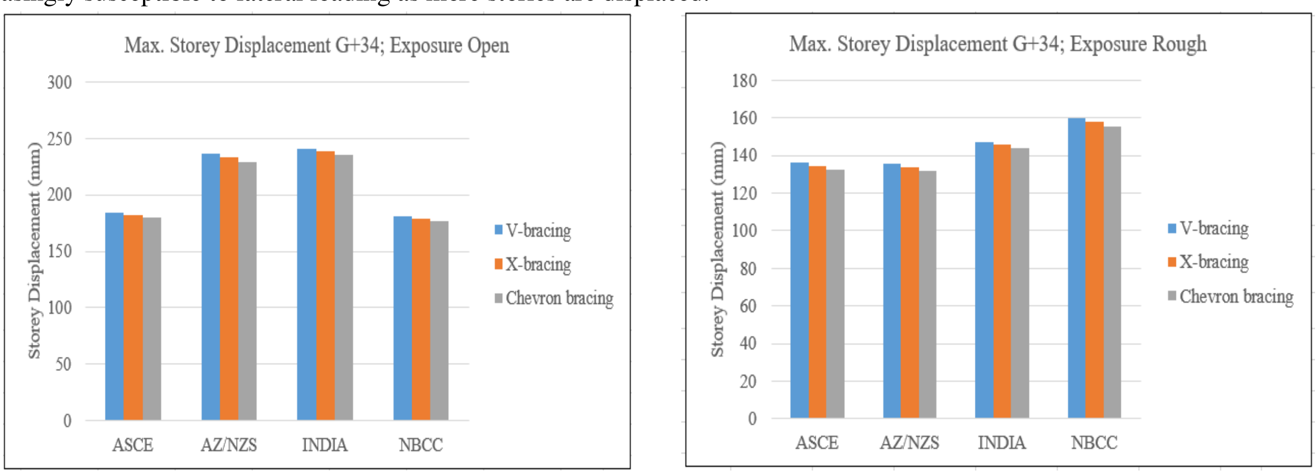

Figure 2.1: Maximum story displacement (G+34 story)

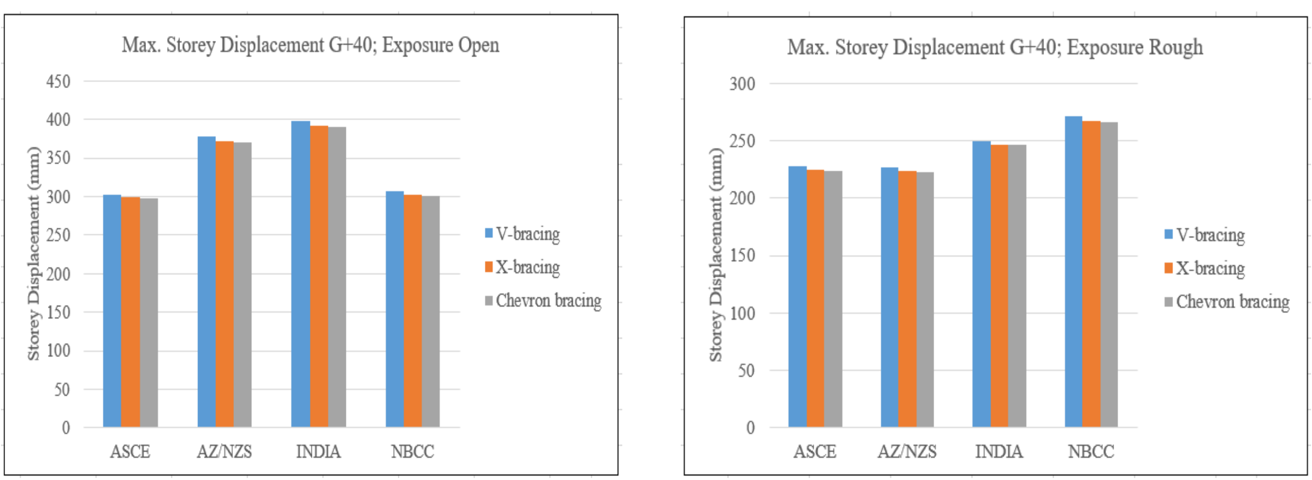

Figure 2.2: Maximum story displacement (G+40 story)

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Figures. 2.1 and 2.2 display the bar chart comparisons for maximum story displacement. India shows the highest story displacements, allowing more movement due to its more flexible design approach and higher displacement limits. NBCC has the lowest displacements, reflecting stronger control and conservative design parameters. ASCE and AZ/NZS fall in between, with differences influenced by their varying wind load assumptions and structural flexibility requirements.

C. Max. Story Drift

It refers to the relative lateral displacement of one story of a building relative to the story below it due to applied lateral forces such as wind or seismic loads. It is an important parameter in structural engineering to ensure the safety and serviceability of a building under such loads.

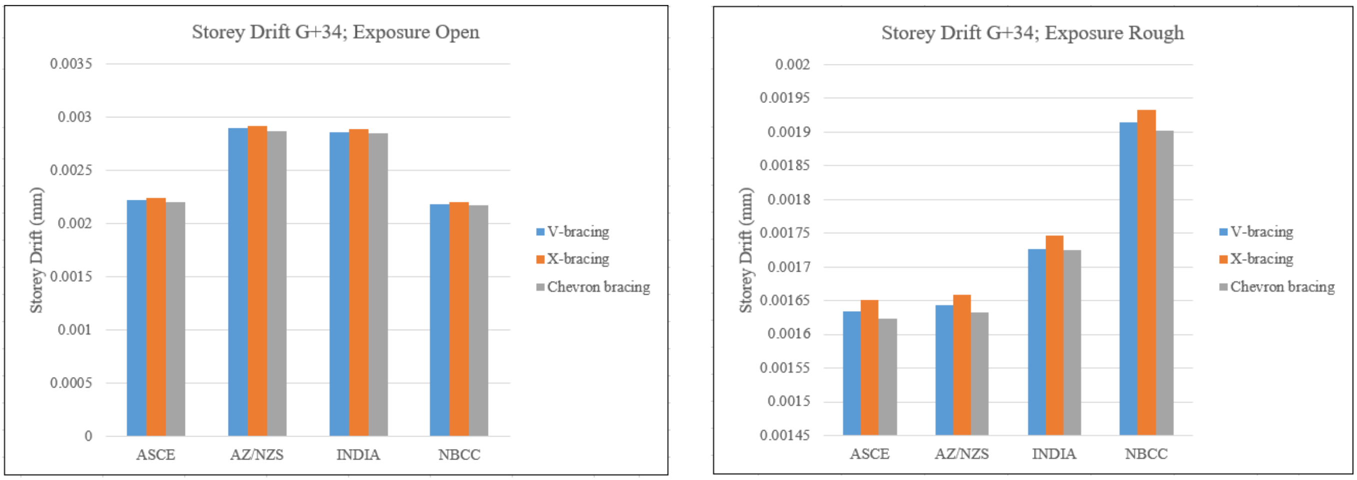

Figure 3.1: Maximum story drift (G+34 story)

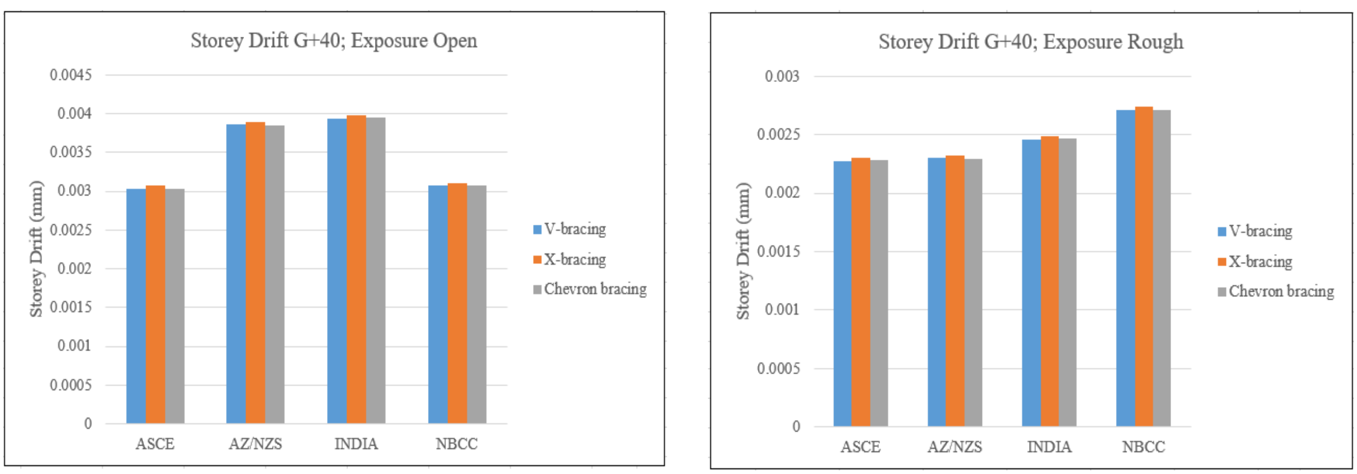

Figure 3.2: Maximum story drift (G+40 story)

Figures. 3.1 and 3.2 display the bar chart comparison for story drifts. India consistently shows the highest story drifts, indicating a design that allows more building movement and permits greater flexibility. AZ/NZS also provides for higher drifts based on its design standards. Conversely, NBCC and ASCE show the lowest drifts, reflecting restrictions and a more rigid approach to design.

D. Base Shear

It is the total horizontal force acting at the base of a structure due to lateral loads such as wind, earthquakes, or other external forces. It represents the sum of all horizontal forces generated at the base of a building during such loading conditions. The base shear is a critical parameter in structural engineering as it helps determine the overall stability and design requirements of the building.

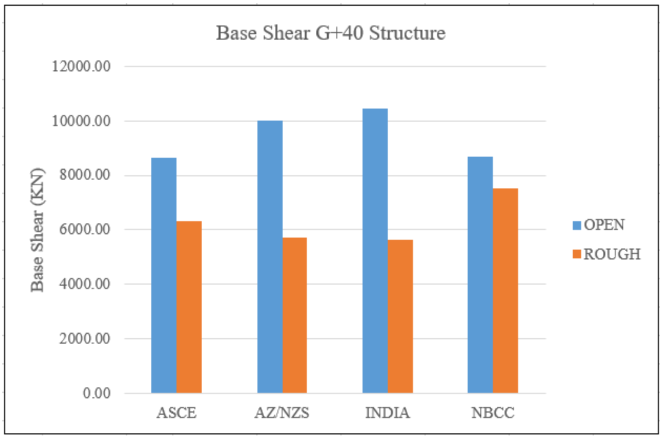

Figure 4.1 Base Shear (G+40 story)

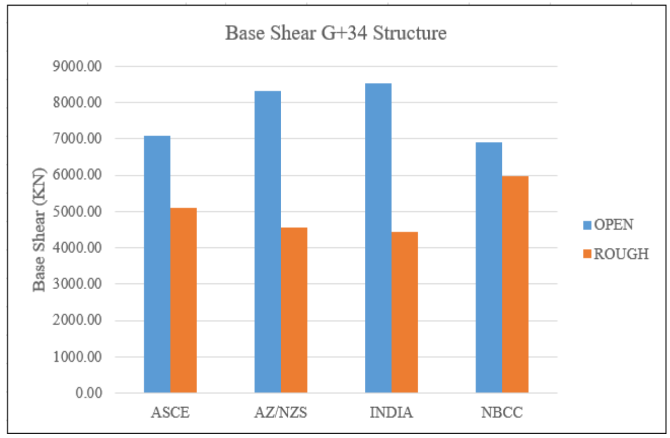

Figure 4.2 Base Shear (G+34 story)

Figures. 4.1 and 4.2 display the bar chart comparison for base shear values. India shows the highest base shear values due to its more conservative wind load assumptions and higher safety factors. AZ/NZS also reports high base shears, especially in open conditions. ASCE presents moderate values, with notable increases in open conditions due to its wind load provisions. NBCC shows higher base shear in rough terrains, indicating terrain-specific adjustments. The variations arise from differences in wind load assumptions and safety margins, as well as how each code accounts for terrain effects, with NBCC focusing more on rough conditions, while India and AZ/NZS focus on wind intensity in open exposures.

E. Overturning Moment

It is a critical design parameter in structural engineering that represents the tendency of a structure to rotate or overturn due to lateral forces such as wind or seismic loads. It is the moment created by these lateral forces acting at a distance from the base of the structure, causing potential rotational effects that can compromise the stability of the building.

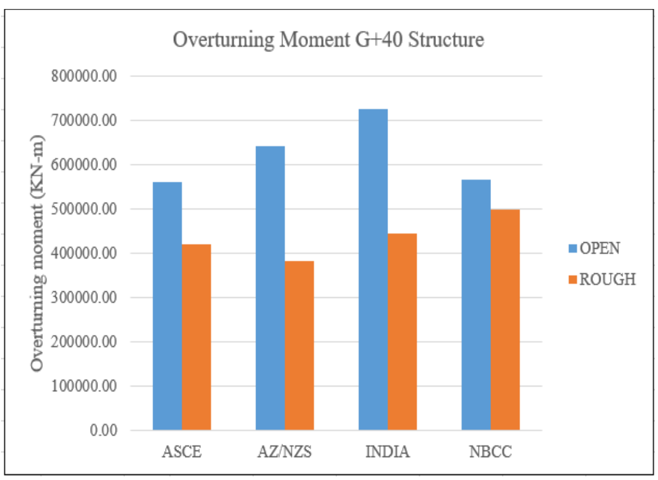

Figure 5.1 Overturning Moment

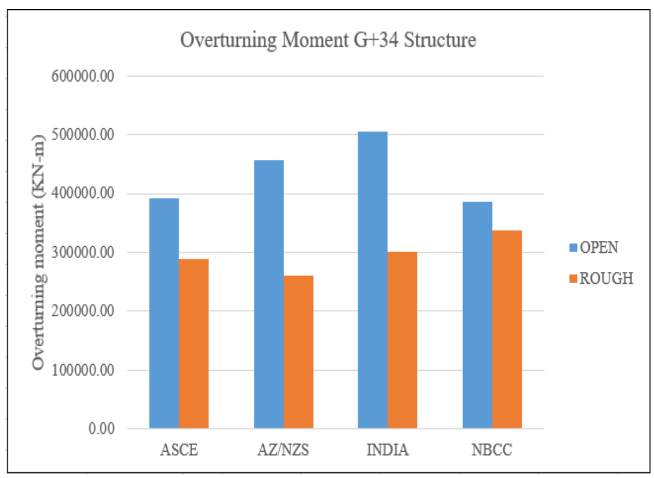

Figure 5.2 Overturning Moment

Figures. 5.1 and 5.2 display the bar chart comparison for overturning moments. India and AZ/NZS show high moments. ASCE presents lower values overall, with notable increases in open conditions. NBCC demonstrates higher moments in rough terrains, indicating adjustments for terrain-specific effects. These variations are influenced by each code's wind load assumptions, safety margins, and how they account for different terrain conditions.

In the results, the varying velocity profiles and gust averaging times across the four wind codes have a noticeable impact on wind load predictions. The Indian code, with its power law profile and 3-second gust averaging, produces higher wind loads due to its more conservative design approach.

In contrast, ASCE and AZ/NZS use logarithmic profiles with the same 3-second gust, yet their wind load assessments vary due to differences in terrain considerations. NBCC's use of a logarithmic profile with a 1-hour average wind speed leads to lower wind loads by smoothing out peak effects. These variations in wind profiles and averaging times result in differing wind-induced responses and structural performance outcomes across the codes.

V. CONCLUSIONS

The following conclusions may now be drawn from this study on structural performance under dynamic wind loading that was computed and compared with several country codes, namely those for America, Canada, Australia/New Zealand, and India: -

1) The Indian standard consistently predicts gust loads with the highest values, typically showing a percentage difference of approximately 20% to 30% higher than ASCE and NBCC standards, and around 10% to 20% higher than AZ/NZS standards. This reflects its conservative approach and robust safety margins in gust load estimation.
2) Across various bracing systems and exposure conditions, the Indian standard forecasts the highest displacements, with values typically 15% to 25% higher than ASCE and NBCC standards, and around 10% to 15% higher than AZ/NZS standards. V-bracing consistently results in higher displacements across all standards, indicating structural flexibility and response to wind forces.
3) The Indian standard also shows higher drift values compared to other standards, with approximately 20% to 30% higher values than ASCE, AZ/NZS, and NBCC standards. Chevron bracing consistently offers the lowest drift values, suggesting its effectiveness in minimizing structural movement.
4) In terms of base shear, the Indian standard predicts values that are generally 15% to 25% higher than ASCE and NBCC standards, and about 10% to 20% higher than AZ/NZS standards, reflecting its cautious design approach. ASCE and NBCC standards demonstrate more balanced responses to exposure conditions.
5) The Indian standard consistently forecasts overturning moments that are approximately 20% to 30% higher than ASCE, AZ/NZS, and NBCC standards, highlighting its conservative approach to structural stability against dynamic wind forces.

The study highlights how different design principles and how sensitive ASCE, AZ/NZS, Indian, and NBCC standards are to dynamic wind loads. For the majority of indicators, the Indian norm typically yields higher values, suggesting a cautious design strategy with large safety margins. The analysis reveals that all structures perform well under both Open and Rough exposure conditions, but Chevron bracing consistently produces the most satisfactory results in terms of minimizing maximum story displacement and maximum story drift across all evaluated standards. The findings suggest that Chevron-braced structures are more efficient in resisting dynamic wind loads, followed by X-bracing and V-bracing configurations.

VI. ACKNOWLEDGMENTS

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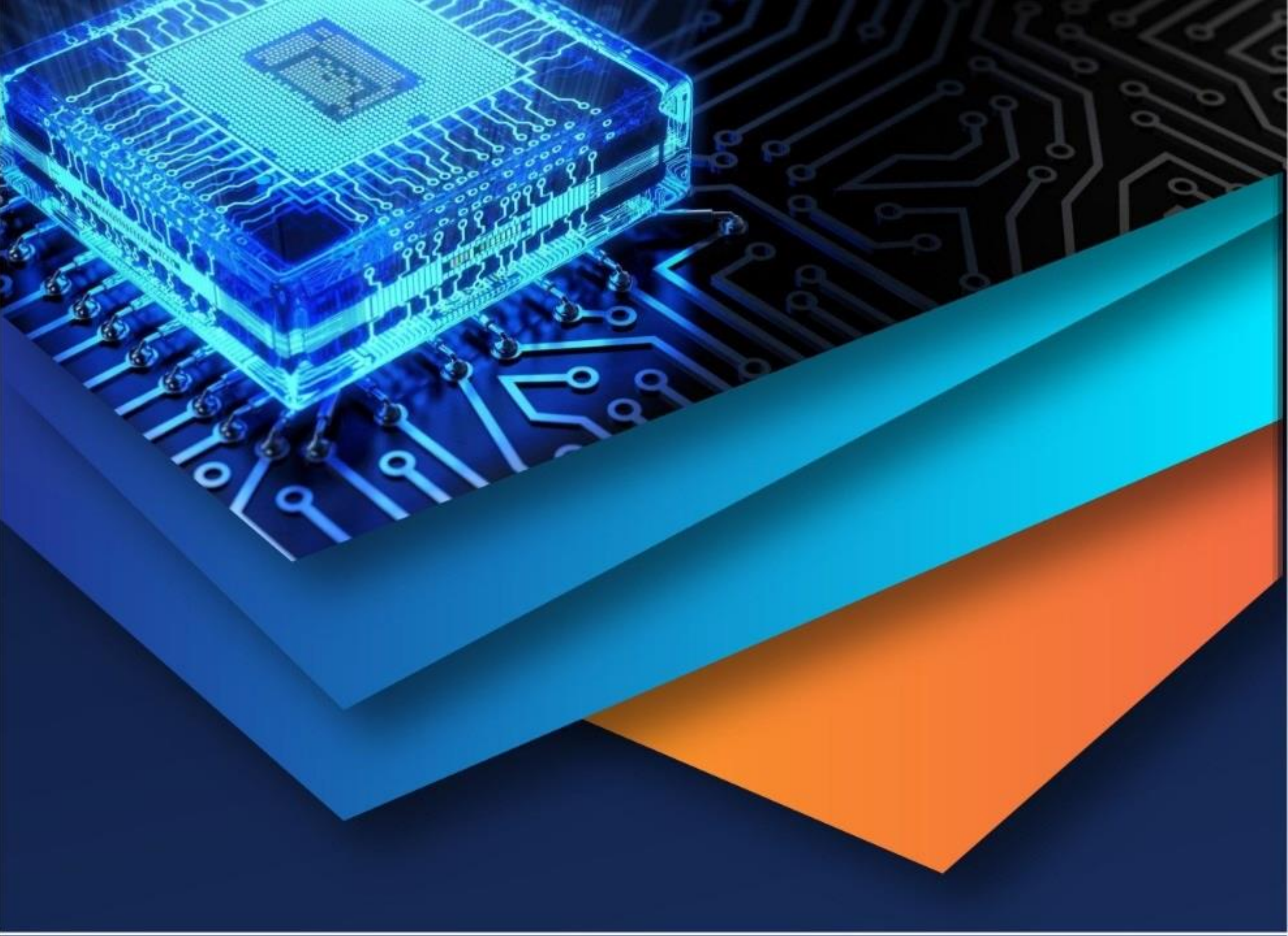

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