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Structural Response of Tall Buildings under Dynamic Wind Loading (Various Codal Provisions)

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***Abstract**: Rapid urbanization leads to the development of tall structures due to less availability of land and higher growth in the population. High rise structures are more vulnerable to wind forces and at higher elevation point's structure may acts as a dynamic sensitive structure. Various countries has provided a pseudo-static constant for the calculation of dynamic wind forces known as the gust factor.*

Present study aims to evaluate and compare the structural response of three structure i.e. Braced Frame, Hull-Core and Shear Wall Structures under dynamic wind loading as per five different codal provisions viz. India (IS 875 (III):2015, America (ASCE 07-10), Australia/New Zealand (AZ/NZS 1170.2:2011), Canada (NBCC 2015) and British Standards (BS EN 1991-1-1-4:2005) for different structure heights and analyzed in ETABSv.16. All the structures gives satisfactory results in Open and Rough Exposure categories. Evaluated dynamic lateral forces are compared and conclusions are made. Hull-core structure has outperformed rest of the two structures. Results are evaluated on the basis of maximum storey displacement.

Keywords : Dynamic Wind Loading, Gust Factor, Braced Frame Structure, Hull-Core Structure, Shear Wall Structure, IS 875 (III):2015, ASCE 07-10, AZ/NZS 1170.2:2011, NBCC 2015, EN 1991-1-1-4:2005.

I. INTRODUCTION

In this era of rapid urbanization tall building has receiving lot of importance among other engineering structures because it results in high space usability in less provided land and also it symbolizes the prosperity of any country. But as the structure height increases, safety and stability of any structure more vulnerable due to nature forces and wind forces are one of them. Wind effects on structure changes with time resulting in a dynamic problem to the structural engineer. These effects vary with height, location and the vicinity of the structure, so evaluation of these loads has done by an equivalent static wind load approach termed as Gust Factor Method. This method depends on various factors such as wind field characteristics, wind spectrum, background turbulence factor, turbulence length scale, size reduction factor, peak resonance factor, energy ratio etc which basically depends on the structure height, exposure category, wind velocity profile and turbulence intensity profile.

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In this study five country codes India (IS 875 (III):2015, America (ASCE 07-10), Australia/New Zealand (AZ/NZS 1170.2:2011), Canada (NBCC 2015) and British Standards (BS EN 1991-1-1-4:2005) has been used for the evaluation of the dynamic wind forces on G+40 (142.50 m Height), G+50 (174.00 m Height) and G+55 (189.00 m Height) structures placed in two different exposure categories i.e. Open and Rough.

II. MODELING OF STRUCTURES

In ETABSv.16 following structural models has been generated with respect to two different exposure conditions that is Open and Rough Exposures. Square Structure of 40.65 m width is used for the research work and rounded corners are provided to minimize the effect of vortex shedding. Structural categories are listed below and their detailed description is shown in table 2.1:

1. Braced Frame Structure termed as G+40B, G+50B and G+55B.
2. Hull-Core Structure termed as G+40C, G+50C and G+55C.
3. Shear Wall Structure termed as G+40S, G+50S and G+55S.

Here, G+40, G+50 and G+55 are the 40, 50 and 55 storied structures with 142.50, 174.00 and 189.00 m height respectively.

Table 2.1: Structure Parameters

S. No	Particular	G+55	G+50	G+40
1	Structure Types	Braced Framed		
		Hull Core		
		Shear Wall		
2	No of story	56	51	41
4	Building Plan	40.65m x 40.65 m		
5	Building Height	189.00 m	174.00 m	142.50 m
6	Storey Height			
	G - G+4	4.00 m	4.00 m	4.00 m
	G+5 - G+30	3.50 m	3.50 m	3.50 m
	G+31 - G+40	3.15 m	3.15 m	3.15 m
	G+41 - G+50	3.15 m	3.15 m	3.15 m
	G+51 - G+55	3.00 m	3.00 m	3.00 m
7	Column Size (Main)			
	G - G+4	800x1200mm	800x1200mm	800x1200mm
	G+5 - G+30	600x1000mm	600x1000mm	600x1000mm

	G+31 - G+40	450x900mm	450x900mm	450x900mm
	G+41 - G+50	450x900mm	450x900mm	-
	G+51 - G+55	400x800mm	-	-
8	Column Size (Elevator)	300x300 mm	300x300 mm	300x300 mm
9	Beam Size (Main)			
	G - G+4	600x1200mm	600x1200mm	600x1200mm
	G+5 - G+30	600x1000mm	600x1000mm	600x1000mm
	G+31 - G+40	450x900mm	450x900mm	450x900mm
	G+41 - G+50	450x900mm	450x900mm	-
	G+51 - G+55	400x800mm	-	-
10	Beam Size (Elevator)	300x500mm	300x500mm	300x500mm
11	Bracings in Braced Frame Structure	230x500mm	230x500mm	230x500mm
12	Core Column in Hull Core Structure	Same as Main Column		
13	Shear Wall in Shear Wall Struture	200 mm thick		
14	Slab thickness	150 mm thick		
15	Shear Wall Thickness	200 mm thick		
16	Density of concrete	25.00 KN/cu.m.		
17	Density of steel	78.50 KN/cu.m.		
18	Partition Wall Density	20.00 KN/cu.m.		
19	Exposure Category	Open and Rough		
20	Column-Foundation Joint	Fixed at base		

Table 2.2: Material Properties of Buildings

S.No.	Material	Grade
1	Concrete (Beam Column)	M40
2	Concrete (Shear Wall)	M40
3	Concrete (Slab)	M40
4	Reinforcement (Rebar)	HYSD-500

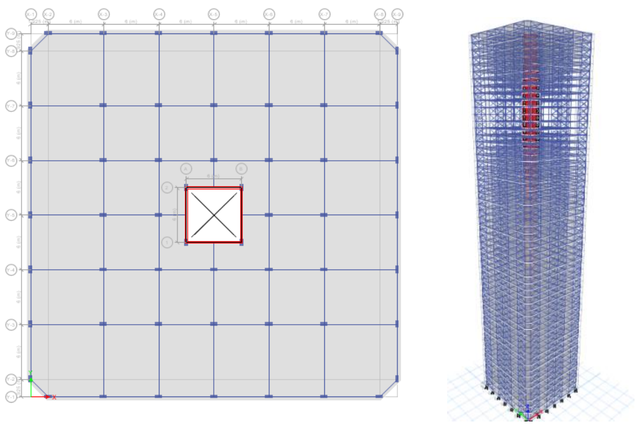

Fig 2.1 Plan and 3D Elevation for Braced Frame Structure

Plan and 3d diagram explaining the models as been attached as fig 2.1, fig 2.2 and fig 2.3 for braced frame, hull-core and shear wall structure respectively.

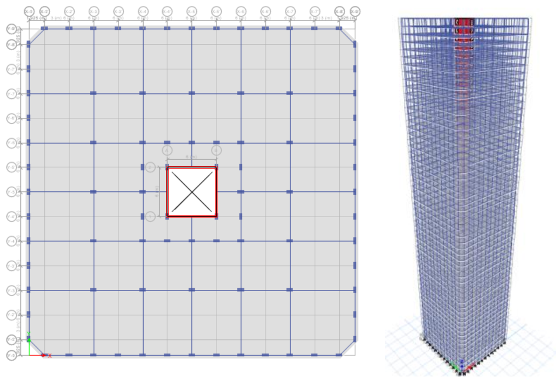

Fig 2.2: Plan and 3D Elevation for Hull-Core Structure

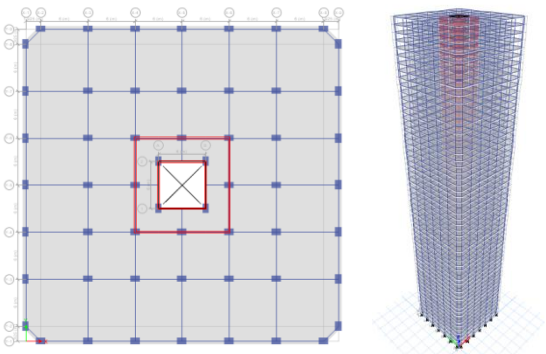

Fig 2.3: Plan and 3D Elevation for Shear Wall Structure

III. PARAMETER'S EVALUATION

Gust factor method to calculate the dynamic wind loading depends on various parameters. The calculation involves in each code is based on resonance response peak factor, size reduction factor, turbulence length scale etc. Evaluated parameters are compared below in table 3.1.

Table 3.1 Dynamic Wind Load Parameters

Parameters	Description		IS	ASCE	AZ/NZS	EN/BS	NBCC
Resonance response peak factor (g_R)	Exposure Open	G+40	3.87	4.019	3.375	3.527	3.984
		G+50	3.818	3.969	3.316	3.475	3.944
		G+55	3.797	3.949	3.291	3.453	3.927
	Exposure Rough	G+40	3.87	4.019	3.375	3.506	3.968
		G+50	3.818	3.969	3.316	3.458	3.935
		G+55	3.797	3.949	3.291	3.437	3.92
Size Reduction factor(S)	Exposure Open	G+40	0.098	0.034	0.061	0.14	0.121
		G+50	0.098	0.041	0.071	0.169	0.136
		G+55	0.112	0.055	0.075	0.183	0.142
	Exposure Rough	G+40	0.05	0.021	0.03	0.103	0.071
		G+50	0.055	0.027	0.038	0.135	0.085
		G+55	0.065	0.03	0.047	0.15	0.09

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Background Turbulence Factor (B)	Exposure Open	G+40	0.68	0.815	0.68	0.7	0.763
		G+50	0.651	0.803	0.651	0.67	0.755
		G+55	0.639	0.798	0.639	0.65	0.752
	Exposure Rough	G+40	0.636	0.791	0.68	0.7	0.754
		G+50	0.606	0.782	0.651	0.67	0.751
		G+55	0.593	0.778	0.639	0.65	0.75
Energy Ratio (E)	Exposure Open	G+40	0.079	0.077	0.063	0.095	0.311
		G+50	0.086	0.087	0.071	0.103	0.359
		G+55	0.089	0.091	0.074	0.106	0.378
	Exposure Rough	G+40	0.066	0.077	0.047	0.081	0.271
		G+50	0.074	0.085	0.053	0.086	0.324
		G+55	0.078	0.089	0.056	0.089	0.347
Reduced Frequency (N)	Exposure Open	G+40	1.211	1.707	2.536	5.375	1.56
		G+50	1.059	1.433	2.082	4.162	1.345
		G+55	0.989	1.334	1.921	3.747	1.277
	Exposure Rough	G+40	1.603	2.673	2.575	6.767	2.048
		G+50	1.319	2.193	2.144	5.003	1.843
		G+55	1.219	2.008	1.989	4.423	1.767
Turbulent Length Scale (L_h) in m.	Exposure Open	G+40	165.2	165.2	258.94	263.7	1220 (Constant for all)
		G+50	173.6	173.6	265.48	284.5	
		G+55	177.2	177.2	268.25	293.6	
	Exposure Rough	G+40	136	165.2	199.09	239.1	
		G+50	143	173.6	212.77	273.3	
		G+55	146	177.2	218.74	288.8	

IV. RESULTS

1. **Max Dynamic Gust load:** Dynamic Lateral wind loads varies with structure height and exposure category. For various country codes gust forces are calculated and listed below in Table 4.1.

Table 4.1: Max. Dynamic Gust Load

	G+40		G+50		G+55	
	OPEN	ROUGH	OPEN	ROUGH	OPEN	ROUGH
ASCE	394.12	302.14	403.59	312.48	407.28	317.77
AZ/NZS	461.11	288.31	465.35	295.64	467.24	300.62
EN/BS	1733.89	1080.1	1793.7	1159.8	1814.1	1183
INDIA	287.94	187.37	289.82	198.89	292.91	199.36
NBCC	1245.38	924.28	1329.7	1158.7	1367	1199.3

2. **Max. Storey Displacements**: The sway in the storey as compared to its initial position is termed as storey displacements. Maximum storey displacement occurs on the top storey of the structure. Storey displacements play a vital role in the safety and serviceability of the structure. More the storey displacement more vulnerable the structure to lateral loading. Comparative chart for different structures is listed in table 4.2, 4.3 and 4.4 while fig 4.1-6 shows the bar chart comparisons.

Table 4.2: Max Storey Displacement for G+40 Structure

Country Code	Exposure Open			Exposure Rough		
	Braced	Hull-Core	Shear Wall	Braced	Hull-Core	Shear Wall
ASCE	82.469	71.074	85.931	62.88	54.156	65.561
AZ/NZS	114.595	103.26	122.02	72.133	64.871	76.832
EN/BS	360.59	310.57	375.96	221.24	190.23	231.05
INDIA	59.454	51.185	62.013	37.404	32.09	39.147
NBCC	260.066	224.08	271.05	191.98	165.31	200.21

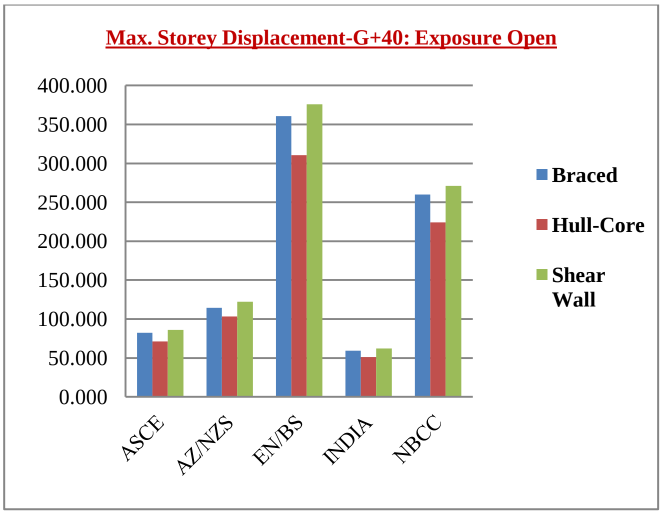

Fig 4.1: Max Storey Displacement for G+40 Building in Open Exposure

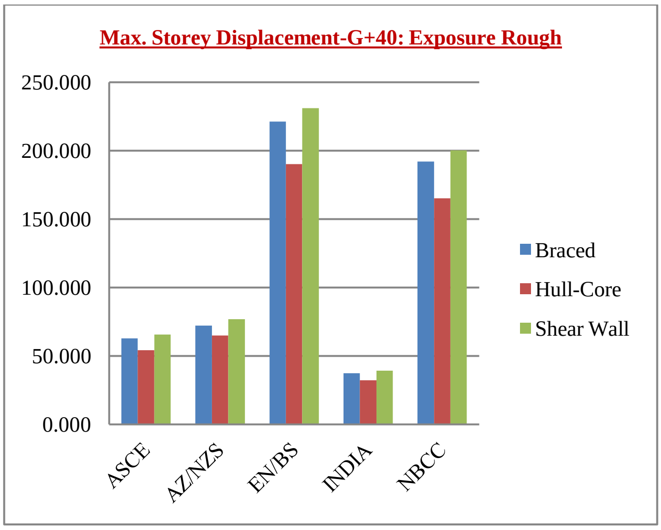

Fig 4.2: Max Storey Displacement for G+40 Building in Rough Exposure

Table 4.3: Max Storey Displacement for G+50 Structure

Country Code	Exposure Open			Exposure Rough		
	Braced	Hull-Core	Shear Wall	Braced	Hull-Core	Shear Wall
ASCE	159.099	132.24	85.931	124.14	103.12	131.22
AZ/NZS	210.585	182.93	224.51	139.39	120.87	148.62
EN/BS	709.656	589.51	750.09	453.75	376.39	480.17
INDIA	114.548	95.123	121.11	73.106	60.533	77.477
NBCC	525.46	436.65	555.24	461.59	383.36	487.98

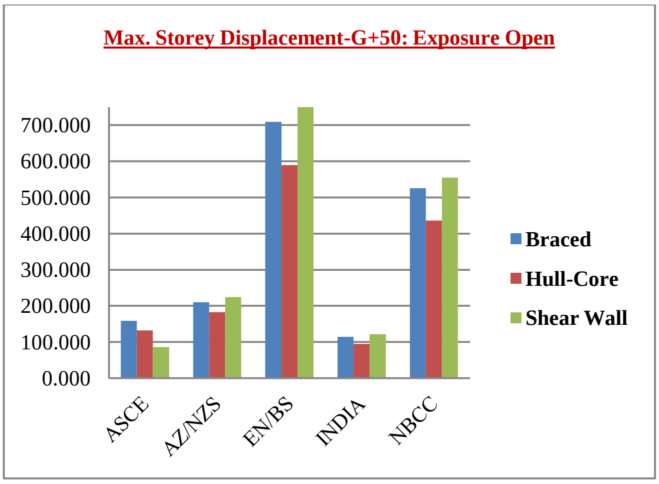

Fig 4.3: Max Storey Displacement for G+50 Building in Open Exposure

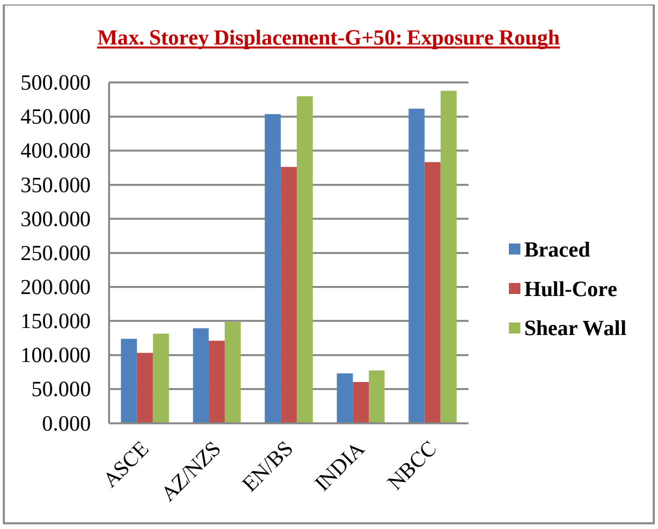

Fig 4.4: Max Storey Displacement for G+50 Building in Rough Exposure

Table 4.4: Max Storey Displacement for G+55 Structure

Country Code	Exposure Open			Exposure Rough		
	Braced	Hull-Core	Shear Wall	Braced	Hull-Core	Shear Wall
ASCE	211.632	173.12	224.9	167.31	136.79	177.87
AZ/NZS	274.623	234.59	292.93	186.6	159.12	199.04
EN/BS	950.124	776.83	1010.1	620.09	506.31	659.91
INDIA	164.417	125.68	163.51	99.111	80.791	105.61
NBCC	713.389	583.46	758.22	634.36	518.54	676.31

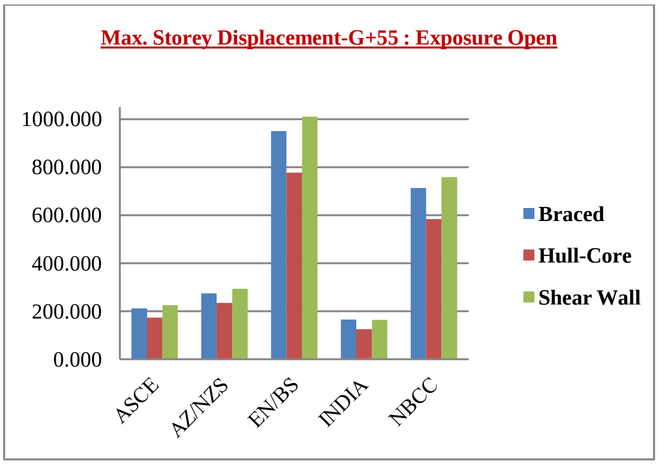

Fig 4.5: Max Storey Displacement for G+55 Building in Open Exposure

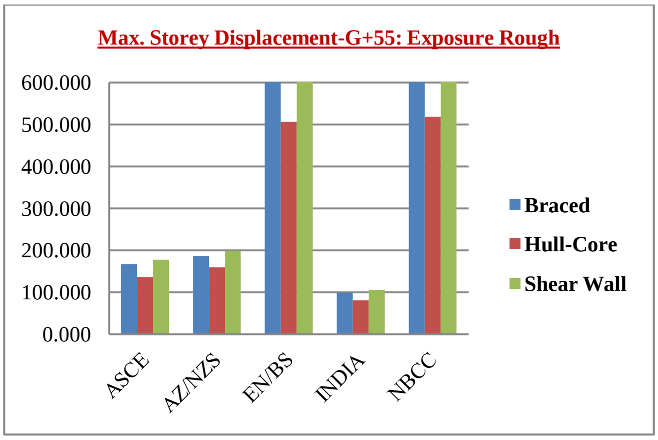

Fig 4.6: Max Storey Displacement for G+55 Building in Rough Exposure

V. CONCLUSIONS

Now, based on this research on structural performance under dynamic wind loading calculated and compared with different country codes viz. India, America, Australia/ New Zealand, United Kingdom and Canada can be concluded as follows:

- Maximum lateral wind forces has been observed in EN/BS while NBCC gives second most maximum results which is nearly 10% less than the EN/BS.
- Lowest value for wind forces forces has been determined by Indian code calculation as the wind forces are not those much predominant in the country.
- ASCE and AZ/NZS codes gives nearly same values for dynamic wind loading calculated by gust factor method.
- In all the cases, analysed by different country codes for dynamic wind laoding the maximum storey displacement observed in shear wall structure.
- Hull core structure outperformed rest of the structures as it shows the lowest value of storey displacement in both the exposure categories for all structure heights.
- All the structures i.e. braced, hull-core and shear wall structure, gives satisfactory results on the basis of serviceability expect for EN/BS.

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