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Dynamic Wind Analysis of High-Rise Building

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Abstract - *Due to extensive urbanization, high-rise construction is a new trend in Indian metropolitan areas. High-rise buildings have distinct design requirements than low- and mid-rise structures. Typically, the wind is the critical load that must be taken into account in tall buildings for the structure's safety and serviceability. Due to along-wind and across-wind, any tall building may shake and oscillate in both directions. Even though the structural damage is not imminent, these oscillations could nonetheless be uncomfortable for the occupants. As a result, serviceability requires a precise measurement of building motion. Both the national building code and other Indian standard codes fall short in addressing the various problems associated with towering buildings. BIS just published the Code IS 16700: 2017 "Criteria for Structural Safety of Tall Concrete Buildings". This Work deals with the detailed wind analysis of 180m tall building as per IS 16700: 2017.*

Key Words: High-Rise, wind, along, across, oscillations etc.

1. INTRODUCTION

The wind-induced response of a tall building depends on a variety of factors. These include the building's geometrical and dynamical characteristics as well as the approach flow's turbulence characteristics. There are a few analytical methods available for calculating the wind-induced response of tall buildings in both along and across wind directions. Aerodynamic forces, such as the drag force and lift force, act on structures under the influence of wind flow. There is a drag force acting parallel to the mean wind and a lift force acting perpendicular to that force.

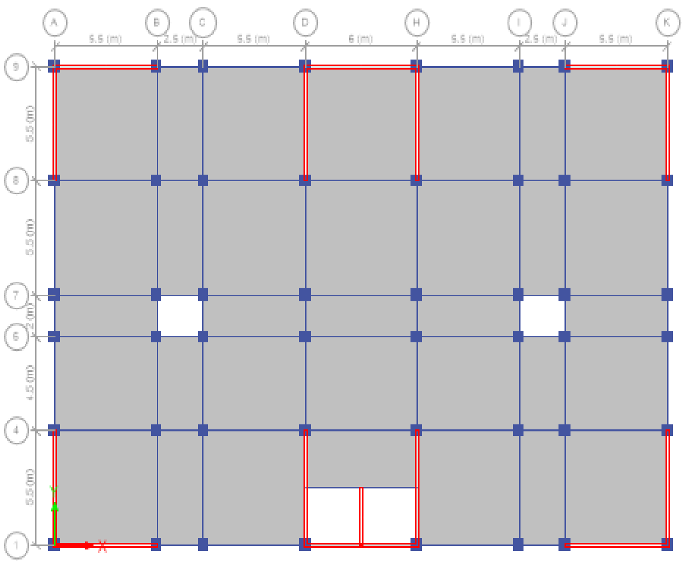

Fig.1. Structural plan

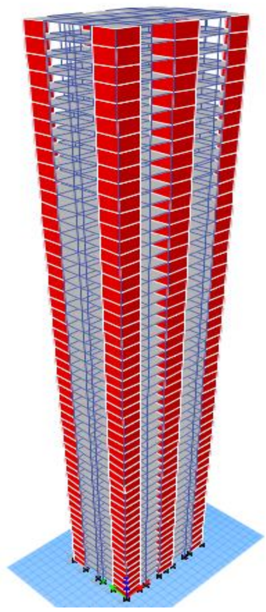

Fig.2. Analysis model

2. METHODOLOGY

Methodology that will be adopted is as follows,

1. Carry out literature review to understand the tall building design philosophy.
2. Analytical Estimation of the Dynamic Wind Response as per IS 875: 2015 (part 3)

3. Study of Gust factor method which is performed on single tower with 54 floors + terrace having an approximate height of 180 m.
4. The Modelling will be done in ETABS.
    - Model – Structure with Dynamic wind loading as per code.
5. Analyze the Result obtained.

2.1 PARAMETER CONSIDERED FOR ANALYSIS

The load along wind or drag load is calculated using the gust factor approach. The Code IS 875:2015 provides the "gust factor method," but these methods for computing load along wind, across wind, or for other components are not yet fully developed. for all building kinds. However, a designer is permitted to calculate all wind speeds using the gust factor approach. Elements of load on a structure utilizing any theory that is accessible. As a result, the following factors are taken into:

Table -1 Structural member information

floor	Column size	Beam size	Shear wall
1 to 6	1000x1000mm	600x800mm	230mm
7 to 12	900x900mm	600x800mm	230mm
13 to 18	800x900mm	600x800mm	230mm
19 to 30	800x800mm	600x800mm	230mm
31 to 42	700x700mm	600x800mm	230mm
43 to 54	600x600mm	600x800mm	230mm

Table -2 Building details

Number of stories	G + 53
Floor height	3.3 m
Base dimension of building	33.00 m X 23.00 m
Aspect ratio (height/width)	7.74
Grade of slabs & beams	M60
Grade of column/shear wall	M50
Grade of steel	Fe 500
Depth of slab	150
Dead load	2.5kn/m^2
Impose load	3.5kn/m^2
Assumed City	Mumbai
Basic wind Speed	44m/s
Terrain Category	4

Table -3 Wind loads will be calculated in accordance with IS 875: 2015 (Part 3)

Basic wind velocity for Mumbai V_b	44 m/s
Probability factor (Risk coefficient) k_1	1.0
Terrain category factor 4 for 180m height k_2	1.26
Topography factor k_3	1.0
Importance factor k_4	1.0

2.2 DESIGN WIND SPEED AND WIND PRESSURE

To get design wind velocity at every height (Vz) for the selected structure, the basic wind speed (Vz) for any location must be obtained from Fig.1 IS: (875(Part 3)-1987) and adjusted to include the following effects:

$$Vz = Vb.k1.k2.k3$$

The following connection between wind pressure and wind velocity shall be used to determine the design wind pressure at any height above mean level:

$$Pz=0.6\ (Vz)^2$$

2.3 Wind load calculation as per IS 875 (part 3):2015

The variation of wind force on a structure must be known for the preliminary design, which includes the proportioning of the structure. The meteorological departments' extensive data on wind speeds and the findings of research done to comprehend wind features and their impact on structures, based on these data and experiments conducted in wind tunnels, form the foundation of the wind loading codes. Depending on the kind of building or structure, the IS 875 (Part 3): 2015 suggests using either the force coefficient approach or the gust factor method for the computation of wind loads. So, in order to calculate the wind load, dynamic analysis must be done if the aspect ratio, or the height to minimum lateral dimension ratio, is more than 5 or the natural frequency. less than 1.0 is present in the first mode. The code advises taking into consideration an interference factor (IF) as a multiplication factor for the wind loads corresponding to isolated buildings in order to account for the interference effect of another interfering tall building of the same or different height, based on studies on tall rectangular buildings. According to the code, the interference zones have been divided into four zones based on the distance to the interfering structure's position.

Along wind load

Tall buildings are considered flexible slender structures, and IS 875 (Part 3): 2015 defines a gust factor or gust effectiveness factor technique for determining along wind load or drag load. The process calculates the Gust Factor using hourly mean wind speed. The design peak along wind base bending moment was calculated by adding the moments brought on by design peak along wind loads acting along the building's height at various heights as follows::

$$M\text{a} = \Sigma\, Fz\, Z$$

The along wind load on a structure on a strip area at any height z (m) is given by:

$$F_z = C_{f,z}\ A_z\ P_d\ G$$

where Cf,z is the drag force coefficient for the building corresponding to Az, Az is the effective frontal area considered for the structure at height z in P_d , is the design hourly mean wind pressure at height z due to hourly mean wind and G is the gust factor.

Across wind load

An empirical formula proposed by IS 875 (Part 3): 2015 is suggested for taking into account the dynamic impacts of across wind load flexible constructions. For enclosed buildings, the crosswise wind design peak base bending moment Mc is provided by:

Mc = 0.5gh ph bh^2(1.06-0.06k)√(∏*Cfs/β)

Where gh = √2loge (3600fa), a peak factor in cross wind direction for resonant response, P_h is hourly mean wind pressure at Height h (Pa), k is a mode shape power exponent for representation of the fundamental mode shape and Cfs is across wind Force spectrum coefficient generalized for a linear mode.
Then, the across wind load distribution on the building obtained from Mc using linear distribution of loads as:

Fzc = (3Mc/h^2)*z/h

Table -4 Along wind and across wind calculation using gust factor method.

Along wind and across wind									
		Long body orientation				Short body orientation			
Story data	Abs. height	Fx along KN	Fy across KN	MX KNm	MY KNm	Fy along KN	Fx across KN	MY KNm	MX KNm
54	178.2	1181.244	301.0255	210497.7	53642.74	629.9968	301.0255	112265.4	53642.74
53	174.9	1176.875	295.5025	205835.4	51683.39	627.6664	295.5025	109778.9	51683.39
52	171.6	1172.361	290.0828	201177.1	49778.22	625.259	290.0828	107294.4	49778.22
51	168.3	1167.706	284.7664	196525	47926.18	622.7767	284.7664	104813.3	47926.18
50	165	1144.388	279.5531	188824	46126.27	610.3402	279.5531	100706.1	46126.27
49	161.7	1139.559	274.4431	184266.8	44377.46	607.7651	274.4431	98275.61	44377.46

48	158.4	1134.626	269.4364	179724.8	42678.72	605.1338	269.4364	95853.2	42678.72
47	155.1	1129.602	264.5328	175201.3	41029.04	602.4546	264.5328	93440.71	41029.04
46	151.8	1124.504	259.7325	170699.8	39427.4	599.7357	259.7325	91039.88	39427.4
45	148.5	1101.367	255.0355	163552.9	37872.77	587.3955	255.0355	87228.24	37872.77
44	145.2	1096.25	250.4416	159175.5	36364.12	584.6668	250.4416	84893.62	36364.12
43	141.9	1091.105	245.951	154827.9	34900.45	581.9229	245.951	82574.86	34900.45
42	138.6	1085.945	241.5636	150512	33480.72	579.1709	241.5636	80273.09	33480.72
41	135.3	1063.28	237.2795	143861.8	32103.92	567.0829	237.2795	76726.31	32103.92
40	132	1058.209	233.0986	139683.6	30769.01	564.3783	233.0986	74497.93	30769.01
39	128.7	1053.156	229.0209	135541.2	29474.99	561.6832	229.0209	72288.63	29474.99
38	125.4	1048.13	225.0465	131435.5	28220.83	559.0024	225.0465	70098.91	28220.83
37	122.1	1026.107	221.1753	125287.7	27005.5	547.2573	221.1753	66820.11	27005.5
36	118.8	1021.238	217.4073	121323.1	25827.99	544.6605	217.4073	64705.67	25827.99
35	115.5	1016.417	213.7425	117396.2	24687.26	542.089	213.7425	62611.28	24687.26
34	112.2	994.9962	210.181	111638.6	23582.31	530.6647	210.181	59540.57	23582.31
33	108.9	990.3636	206.7227	107850.6	22512.11	528.1939	206.7227	57520.32	22512.11
32	105.6	985.7927	203.3677	104099.7	21475.63	525.7561	203.3677	55519.84	21475.63
31	102.3	981.2875	200.1159	100385.7	20471.85	523.3533	200.1159	53539.05	20471.85
30	99	960.6387	196.9673	95103.24	19499.76	512.3407	196.9673	50721.73	19499.76
29	95.7	956.3483	193.9219	91522.53	18558.33	510.0524	193.9219	48812.01	18558.33
28	92.4	936.1974	190.9798	86504.64	17646.53	499.3053	190.9798	46135.81	17646.53
27	89.1	916.3963	188.1409	81650.91	16763.36	488.7447	188.1409	43547.15	16763.36

		Long body orientation				Short body orientation			
Story data	Abs. height	Fx along KN	Fy across KN	MX KNm	MY KNm	Fy along KN	Fx across KN	MY KNm	MX KNm
26	85.8	912.4731	185.4053	78290.19	15907.77	486.6523	185.4053	41754.77	15907.77
25	82.5	893.1637	182.7728	73686.01	15078.76	476.354	182.7728	39299.2	15078.76
24	79.2	874.1963	180.2436	69236.35	14275.3	466.238	180.2436	36926.05	14275.3
23	75.9	870.6428	177.8177	66081.79	13496.36	464.3428	177.8177	35243.62	13496.36
22	72.6	852.1564	175.495	61866.55	12740.93	454.4834	175.495	32995.49	12740.93
21	69.3	834.0022	173.2755	57796.35	12007.99	444.8012	173.2755	30824.72	12007.99
20	66	830.8157	171.1592	54833.83	11296.51	443.1017	171.1592	29244.71	11296.51
19	62.7	827.7136	169.1462	51897.64	10605.46	441.4473	169.1462	27678.74	10605.46
18	59.4	795.763	167.2364	47268.32	9933.84	424.407	167.2364	25209.77	9933.84
17	56.1	792.9369	165.4298	44483.76	9280.612	422.8997	165.4298	23724.67	9280.612
16	52.8	776.0226	163.7265	40973.99	8644.758	413.8787	163.7265	21852.8	8644.758
15	49.5	759.4179	162.1264	37591.18	8025.255	405.0229	162.1264	20048.63	8025.255
14	46.2	729.4202	160.6295	33699.21	7421.083	389.0241	160.6295	17972.91	7421.083
13	42.9	700.1898	159.2359	30038.14	6831.219	373.4346	159.2359	16020.34	6831.219
12	39.6	671.7138	157.9455	26599.87	6254.64	358.2473	157.9455	14186.59	6254.64
11	36.3	643.979	156.7583	23376.44	5690.326	343.4555	156.7583	12467.43	5690.326
10	33	604.5716	155.6744	19950.86	5137.254	322.4382	155.6744	10640.46	5137.254
9	29.7	578.5663	154.6936	17183.42	4594.401	308.5687	154.6936	9164.49	4594.401

8	26.4	507.1775	153.8162	13389.49	4060.747	270.4947	153.8162	7141.059	4060.747
7	23.1	451.2604	153.0419	10424.11	3535.269	240.6722	153.0419	5559.528	3535.269
6	19.8	388.8739	152.3709	7699.703	3016.944	207.3994	152.3709	4106.508	3016.944
5	16.5	397.8794	151.8031	6565.01	2504.752	212.2024	151.8031	3501.339	2504.752
4	13.2	397.0276	151.3386	5240.765	1997.669	211.7481	151.3386	2795.074	1997.669
3	9.9	396.226	150.9773	3922.638	1494.675	211.3205	150.9773	2092.073	1494.675
2	6.6	395.4749	150.7192	2610.134	994.7467	210.9199	150.7192	1392.072	994.7467
Base 1	3.3	394.7745	150.5644	1302.756	496.8624	210.5464	150.5644	694.8031	496.8624

3. RESULT

Results obtained from the analysis of the Etabs models using above value are as follows:
Base Shear Results:
Base shear in X – direction by dynamic wind analysis model is found out to be 45500 kN.
Base shear in Y – direction by dynamic wind analysis model is found out to be 24661 kN.
Deflection Results:
Deflection in X – direction by dynamic wind analysis model is found out to be 322.29mm.
Deflection in Y – direction by dynamic wind analysis model is found out to be 255.03 mm.
Drift Results:
Drift in X – direction by dynamic wind analysis model is found out to be 0.00228.
Drift in Y – direction by dynamic wind analysis model is found out to be 0.001787.

4. CONCLUSIONS

1. The gust effectiveness factor approach provides critical wind pressures to be taken into consideration in the design of multistory frames because the gust pressures computed by this method rise with the height of the building and are more important than static pressures.

2. The energy content of the wind's changing component also rises as building frame height does.

5. SCOPE FOR FUTURE WORK

1. Tall buildings with varied aspect ratios and various aerodynamic modifications exhibit various wind-induced responses along and across them.

2. Along and across wind-induced reactions of tall buildings with various structural systems and aspect ratios.

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