Determination of Governing case of Along Wind loading for RCC Chimney

[1]Foram Trivedi, [2]Noopur Shah, [3]Satyen Ramani
[1] P.G. Student [2,3] Assistant Professor
Civil Engineering Department,
Sal Institute of Technology & Engineering Research
Ahmadabad, India

Abstract*— Chimneys are generally designed for critical (dynamic) loads produced by loads due to self- weight, wind and earthquake. Because in the change in dimension of chimney, structural analysis such as response to earthquake and wind oscillation have become more critical. Chimney (Stacks) being tall and flexible structure so it is expected that wind loads will be more critical than earthquake loads. In this present study analysis of RCC chimney done for Along wind loading. The reinforced concrete chimney with 100m, 200m and 300m height having a basic wind speed 33m/s & 55m/s with different height to base diameter ratio (slenderness ratio) and top to base diameter ratio (aspect ratio) is considered for analysis. Wind analysis is carried out as per procedure of IS: 4998 – 2015 to calculate the Along wind load and base moment. It is also carried out using MS EXCEL.

***Index Terms*— RCC chimney, Along wind analysis, Slenderness ratio, Aspect ratio, MS EXCEL**

I. INTRODUCTION

Due to increases large scale industrial developments and also population, it requires a large supply of power for smooth running in modern world. Thus, leading to increase in the number of power plants. The flue gas produced contains an increased concentration of different compounds. As per Environmental Protection Act and Pollution control standards, this flue gas is to be engaged at a greater height for them to diffuse into an external atmosphere where it will not cause any ill effects to the eco system. Chimneys are characterizing landmark of power plant and industrial set up to control air pollution. Generally, the height of chimneys used in power plants are 100-400m.

1.1 Function of chimney

A chimney is tall and slender structure that require to carry vertically and discharge, gaseous products of combination, chemical waste gases and exhaust air from industry boiler, stove, furnace or fireplaces to the outside atmosphere. Chimney achieves simultaneously decreases in concentration of a number of pollutants like SO_2, fly ash etc. being highly reliable and doesn't require any standby.

1.2 Need of study

As per the procedure of IS: 4998 – 2015 some criteria have changed for Along wind load effects on RCC chimney compare to the IS: 4998 (part 1) – 1992. In IS: 4998 (part 1) – 1992 there are two methods such as Simplified method and Random response method is included whereas in IS:4998 – 2015 only one method is given for Along wind load.

II. WIND ANALYSIS

Wind load on structures, depend on gust factor of wind, topography of terrain and also on the interaction of wind with structures. Dynamic wind loads induce Along and Across wind loads on chimneys. Here, as per IS: 4998 – 2015 method is used for analysis of RCC chimneys.

2.1 Along-wind analysis:

Basic wind speed, V_b

The value of basic wind speed, V_b, as recommended in IS 875 (Part 3), shall be considered for design. This corresponds to 3 second averaged wind speed at 10m height above the ground level, in an open terrain country, having an annual exceedance probability of 0.02.

Design hourly mean wind speed, $\bar{V}_{(z)}$

$$\bar{V}_{(z)} = V_b\ k_1\ \bar{k}_2\ k_3\ k_4$$

Where; k_1 and k_3 can be obtained from IS 875 (Part 3) - 2015

k_4 shall be taken as 1.15 as recommended in IS 875 (Part 3) for industrial structures

The value of shall be obtained using the following empirical expression for z > 10 m,

$$\bar{k}_2 = 0.1423\left[ln\left(\frac{z}{zo}\right)\right](zo^{0.0706})$$

Where; zo is the aerodynamic roughness height which shall be taken as 0.02m for all terrain categories.

Design wind pressure due to hourly mean wind speed, $\bar{p}_{(z)}$

The design wind pressure due to hourly mean wind speed, $\bar{p}(z)$, in N/m2, corresponding to $\bar{V}(z)$ shall be computed as follows:

$$\bar{p}_{(z)} = \frac{1}{2}\rho_a\left[\bar{V}_{(z)}\right]^2$$

Where; ρ_a is the mass density of air, taken equal to1.2 kg/m3.

Along- wind Load

The along-wind load, $F(z)$ per unit height at any level, z on a chimney is equal to the sum of the mean along-wind load, and the fluctuating component of along-wind load, and shall be calculated as given below:

$$F(z) = \bar{F}(z) + F'(z)$$

Here, the mean along-wind load, $\bar{F}(z)$ shall be computed as:

$$\bar{F}(z) = \overline{C_D}\ d(z)\ \bar{p}_{(z)}$$

Where; $\overline{C_D}$ is the mean drag coefficient taken as 0.8

$d(z)$ is the outer diameter of chimney at height z

The fluctuating component of along-wind, $F'(z)$ in N/m, at height z shall be computed as,

$$F'(z) = 3\ \frac{(G-1)}{H^2}\left(\frac{z}{H}\right)\int_0^H \bar{F}(z) z dz$$

Where; G is the gust response factor H is the total height of the chimney above ground level (in m).

Gust response factor:

The Gust response factor is computed as:

$$G = 1 + g_f\, r_t \sqrt{B + \left(\frac{SE}{\beta}\right)}$$

Where; g_f is the peak factor, defined as the ratio of expected peak value to root mean square value of the fluctuating load, given by:

$$g_f = \sqrt{2\ln(\nu T)} + \frac{0.577}{\sqrt{2\ln(\nu T)}}$$

$$\nu T = \frac{3600\, f_1}{\left(1 + \frac{B\beta}{SE}\right)^{1/2}}$$

Where, ν is the effective cycling rate

T is the sample period taken as 3600s

rt is the twice the turbulence intensity at the top of the chimney, given by

$$r_t = 0.622 - 0.178 \log_{10} H$$

B is the background factor indicating the slowly varying component of wind load fluctuations, given by

$$B = \left\{1 + \left(\frac{H}{265}\right)^{0.63}\right\}^{-0.88}$$

E is a measure of available energy in the wind at the natural frequency, given by

$$E = \frac{\left\{123\left(\frac{f1}{\overline{V(10)}}\right) * H^{0.21}\right\}}{\left\{1 + \left(330\frac{f1}{\overline{V(10)}}\right) * H^{0.42}\right\}^{0.83}}.$$

S is the size reduction factor, given by

$$S = \left\{1 + 5.78\left(\frac{f1}{\overline{V(10)}}\right)^{1.14} * H^{0.98}\right\}^{-0.88}$$

Where, $\overline{V}_{(10)}$ is the mean hourly wind speed at 10 m height above ground level (m/s)

β is the structural damping as a fraction of critical damping to be taken as 0.016 for along wind loads

f_1 is the natural frequency of unlined chimney in the first mode of vibration in Hz

$$f1 = 0.2 * \left(\frac{do}{H^2}\right)\left(\frac{to}{th}\right)^{0.3} * \sqrt{\frac{Eck}{\rho ck}}$$

Where; t_o is the thickness of the shell at bottom (m)

t_h is the thickness of the shell at top (m)

d_o is the centerline diameter of the shell at bottom (m)

ρ_{ck} is the mass density of concrete (kg/m3)

E_{ck} is the dynamic modulus of elasticity of concrete in N/m^2

Table 1: Dynamic modulus of elasticity of concrete E_{ck} (N/m^2)

Grade of concrete	Dynamic modulus of elasticity (N/m^2)
M25	$3.2*10^{10}$
M30	$3.35*10^{10}$
M35	$3.5*10^{10}$
M40	$3.6*10^{10}$
M45	$3.72*10^{10}$
M50	$3.82*10^{10}$

Example Chimneys

As per the literature study of D. Menon and P. Srinivasa Rao, the heights of wind sensitive chimneys typically lie in the range 100-400m. So, for the analysis purpose height of RCC chimney is considered as 100m, 200m and 300m. Other chimney parameter subjected to variation in practical designs are listed in table 2 below. And minimum thickness at top is required as 0.2m.

Table 2: Chimney parameter and its typical value

Chimney parameter	Practical range	Typical value
Slenderness ratio, h/D_b	7 - 17	12
Taper ratio, D_t/D_b	0.3 – 1.0	0.6
Base diameter to thickness ratio, D_b/t_b	20 – 50	35
Mean, base thickness ratio, t_m/t_b	0.3 – 0.8	0.55
Top, mean thickness ratio, t_t/t_m	0.7 – 1.0	0.85
Concrete cylinder strength(MPa), f_{ck}	15 – 35	25

The height of RCC chimney 100m, 200m and 300m and other parameter have been taken according to table 3 & 4 for Along wind analysis. Basic wind speed 33m/s and 55m/s and concrete cylinder strength 25MPa was used for both the cases. MS EXCEL is used to calculate the base moment.

Case 1:

Table 3: Dimensions considered for case 1 chimneys

Height of chimney (m)	Slenderness ratio, h/D_b	Taper ratio D_t/D_b	Top & base thickness (m)	Basic wind speed, V_b (m/s)	Concrete cylinder strength(MPa), f_{ck}
100	7,12,17	0.3,0.6,1	0.3	33 & 55	25
200	7,12,17	0.3,0.6,1	0.6	33 & 55	25
300	7,12,17	0.3,0.6,1	0.9	33 & 55	25

Case 2:

Table 4: Dimensions considered for case 2 chimneys

Height of chimney (m)	Slenderness ratio, h/D_b	Taper ratio D_t/D_b	Base diameter to thickness ratio, D_b/t_b	Top thickness (m) [Minimum =0.2 m]	Basic wind speed, V_b (m/s)	Concrete cylinder strength(MPa), f_{ck}
100	7,12,17	0.3,0.6,1	35	=0.4*base diameter	33 & 55	25
200	7,12,17	0.3,0.6,1	35	=0.4*base diameter	33 & 55	25
300	7,12,17	0.3,0.6,1	35	=0.4*base diameter	33 & 55	25

III Results and discussion

Case 1:

Table 5: Along wind base moment for 100m chimney

Chimney ht. = 100m			
h/D_b	D_t/D_b	V_b = 33m/s	V_b = 55m/s
		Along wind moment (KN.m)	Along wind moment (KN.m)
7	0.3	40911.07	131894.66
12	0.3	25796.25	87650.02
17	0.3	19740.74	69352.76
7	0.6	64926.87	207184.30
12	0.6	40585.68	135895.88
17	0.6	30799.05	106431.07
7	1	96947.95	307570.48
12	1	60304.93	200223.68
17	1	45543.45	155868.82

Table 6: Along wind base moment for 200m chimney

Chimney height = 200m			
h/D_b	D_t/D_b	V_b = 33m/s	V_b = 55m/s
		Along wind moment (KN.m)	Along wind moment (KN.m)
7	0.3	340903.78	1129102.78
12	0.3	221331.77	773104.92
17	0.3	172744.97	619450.63
7	0.6	551452.06	1798972.89
12	0.6	353177.30	1209836.68
17	0.6	272444.06	957345.76
7	1	832183.10	2692133.04
12	1	528971.35	1792145.69
17	1	405376.17	1407872.61

Table 7: Along wind base moment for 300m chimney

Chimney height = 300m			
h/D_b	D_t/D_b	V_b = 33m/s	V_b = 55m/s
		Along wind moment (KN.m)	Along wind moment (KN.m)
7	0.3	1153596.80	3877292.21
12	0.3	760917.42	2685878.46
17	0.3	598618.21	2153947.22
7	0.6	1891309.73	6240352.02
12	0.6	1226486.80	4234184.55
17	0.6	951885.10	3350206.87
7	1	2874926.97	9391098.45
12	1	1847245.97	6298592.65
17	1	1422907.63	4945219.73

Case 2:

Table 8: Along wind base moment for 100m chimney

Height of chimney =100m			
h/D_b	D_t/D_b	V_b = 33m/s	V_b = 55m/s
		Along wind moment (KN.m)	Along wind moment (KN.m)
7	0.3	40200.95	127500.76
12	0.3	25515.64	86186.55
17	0.3	19888.26	70034.37
7	0.6	63929.91	201015.47

12	0.6	40191.72	133841.24
17	0.6	31006.16	107388.02
7	1	95568.52	299035.09
12	1	59759.82	197380.81
17	1	45830.01	157192.89

Table 9: Along wind base moment for 200m chimney

Chimney height = 200m			
h/D_b	D_t/D_b	V_b = 33m/s	V_b = 55m/s
		Along wind moment (KN.m)	Along wind moment (KN.m)
7	0.3	329913.75	1065965.74
12	0.3	208698.76	711004.27
17	0.3	163954.32	581228.34
7	0.6	536047.82	1710476.49
12	0.6	335470.17	1122792.94
17	0.6	260122.59	903771.27
7	1	810893.25	2569824.15
12	1	504498.72	1671844.49
17	1	388346.95	1333828.50

Table 10: Along wind base moment for 300m chimney

Chimney height = 300m			
h/D_b	D_t/D_b	V_b = 33m/s	V_b = 55m/s
		Along wind moment (KN.m)	Along wind moment (KN.m)
7	0.3	1108542.05	3631769.11
12	0.3	709797.49	2447946.71
17	0.3	546951.35	1939361.51
7	0.6	1828211.34	5896501.22
12	0.6	1154894.23	3900965.28
17	0.6	879526.58	3049683.33
7	1	2787770.39	8916144.03
12	1	1748356.56	5838323.37
17	1	1322960.21	4530112.43

3.1 Graphs

Case 1:

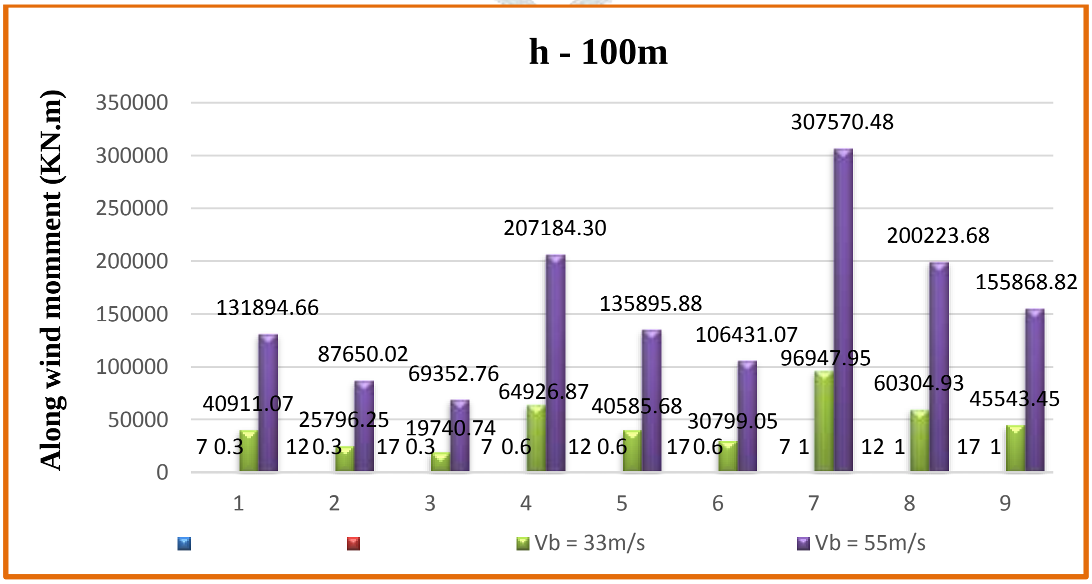

Fig 1: Along wind base moment graph for 100m (case 1)

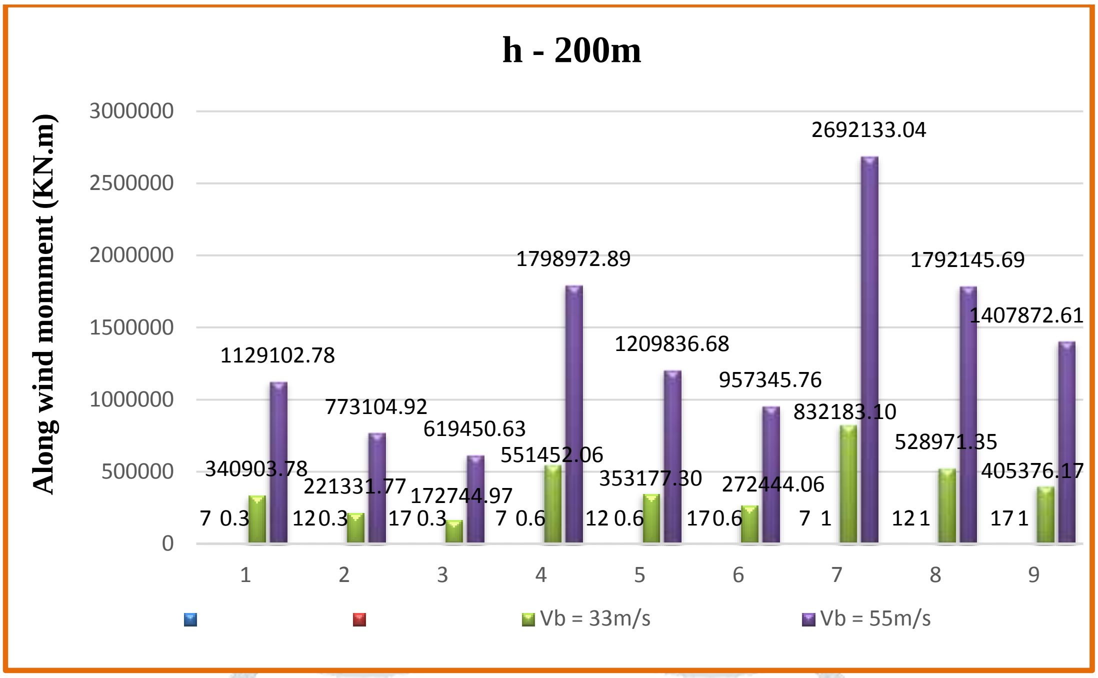

Fig 2: Along wind base moment graph for 200m (case 1)

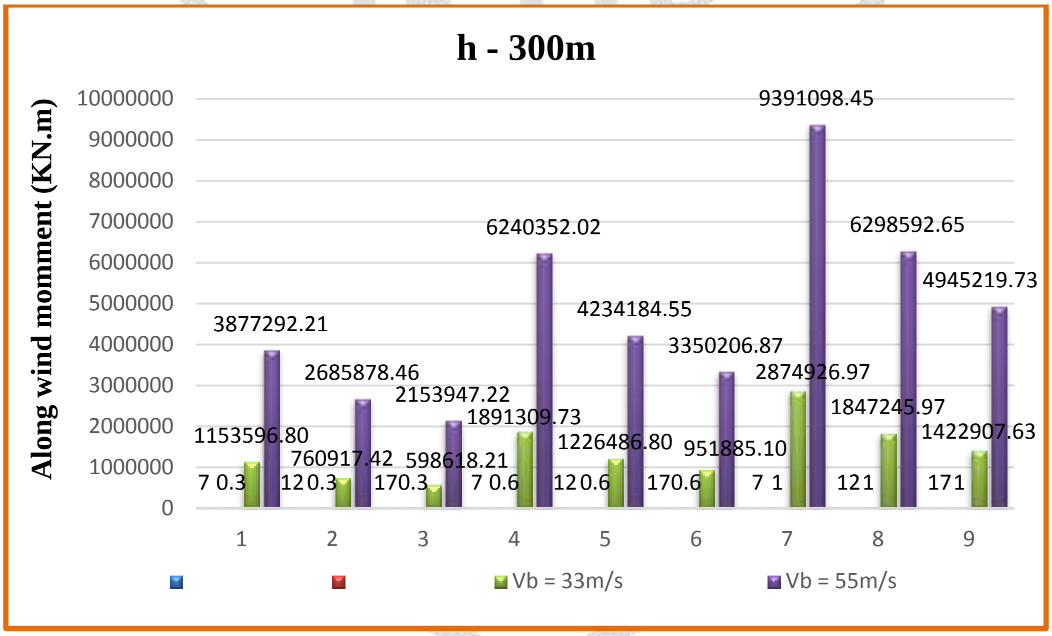

Fig 3: Along wind base moment graph for 300m (case 1)

Case 2:

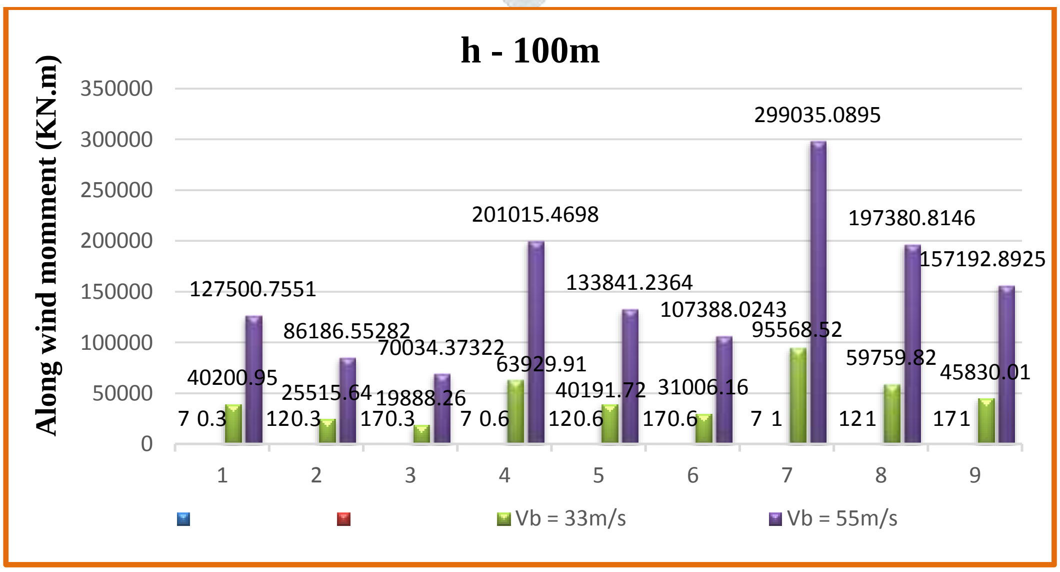

Fig 4: Along wind base moment graph for 100m (case 2)

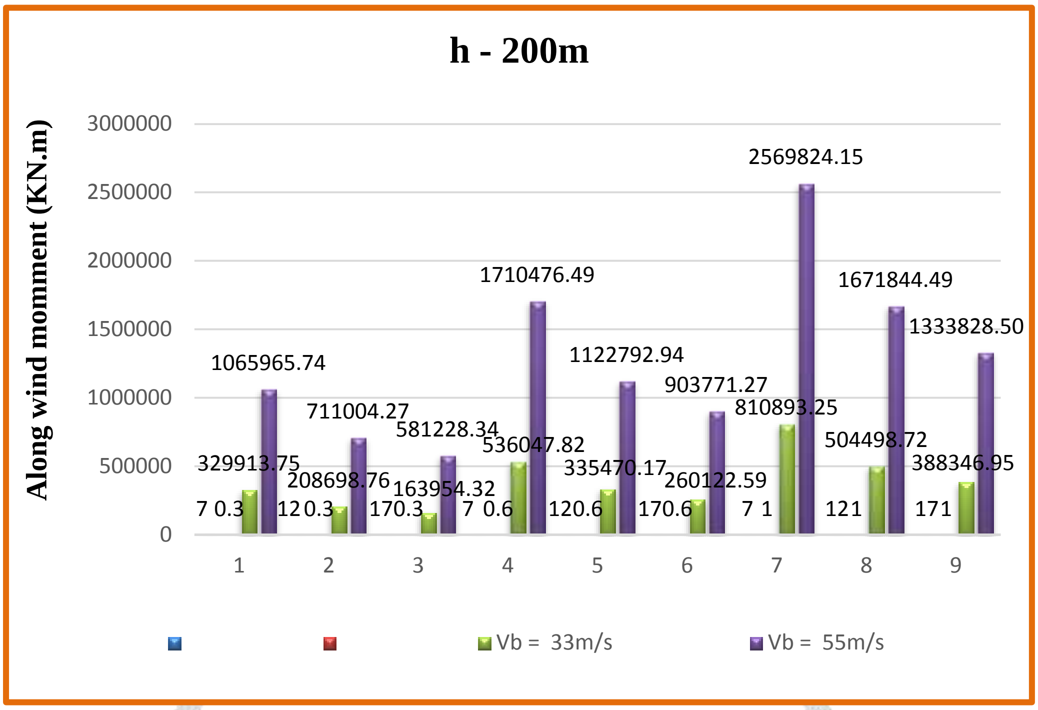

Fig 5: Along wind base moment graph for 200m (case 2)

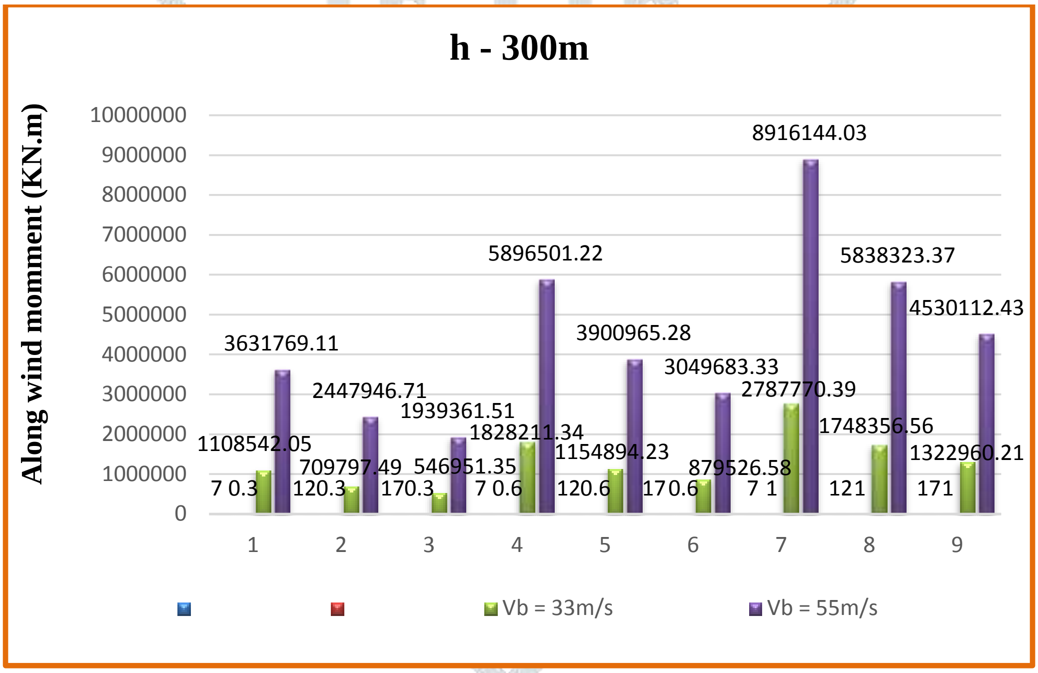

Fig 6: Along wind base moment graph for 300m (case 2)

III. Conclusion

- Along wind moment decreases with slenderness ratio (h/D_b) increases for constant aspect ratio(D_t/D_b) in both the cases & basic wind speed.
- For the constant slenderness ratio (h/D_b) and increases aspect ratio (D_t/D_b) Along wind moment increases.
- Chimney height 100m, 200m and 300m maximum Along wind moment obtained at slenderness ratio (h/D_b) = 7 and aspect ratio (D_t/D_b) = 1 for V_b = 55m/s in both the cases.

References

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