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STUDY OF WIND FORCE ON A HIGH RISE STRUCTURE BY USING ANALYTICAL METHOD

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ABSTRACT

This paper discuses the necessity of study wind force on high rise structure .This paper tell brief description of related works in the field, i.e., historical paper, wind tunnel test, full scale measurements for Dynamic and Pressure measurement studies, and analytical estimate along wind response and across wind response. There are two approaches to find out the Response of the High rise structures to the Wind loads. One is Analytical approach given by Davenport and mentioned in the IS 875: part 3 -1987 is used which is only legit to a regular shape building and the other is Analytical Analysis by International Code ASCE/SEI 7-05. This paper deals with the analytical studies carried out on a high rise structure named IREO VICTORY VALLEY TOWER - C going to be build in SECTOR 67, GARUGRAM, HARYANA .Which is 147m in height, consists 41 floors. The experimental results have been projected to estimate the full scale values by using appropriate scaling laws. We use victory valley tower –c for calculations wind force of a terrain category of 3rd and basic wind speed of 38m/sec. Here we find storey wise lateral force on the structure with an equal interval of 10m. The story wise lateral design forces are computed by analytical method discussed in Conclusion. In the result the value of total wind pressure and the total force by this wind pressure on the building is calculated and comparison of both methods is done.

KEYWORDS: Analytical, Wind Force, High Rise Structure, IS 875: part 3 -1987, ASCE/SEI 7-05., Davenport 'Gust Factor Approach, IREO VICTORY VALLEY TOWER - C.

INTRODUCTION

In recent years, especially in the crowded cities where land prizes are becomes extremely high, now a day's buildings with more than 30 floors , which are also called high rise structure are started to be designed and constructed all over the world. When we talk about buildings, these are defined as a structures used by the people as shelter for living, working or storage. On the other side the technical advancement has provided the opportunity of design and construction of more slender and tall structures which are inveigled by the wind action more. Due to flexibility of building, wind can interact with it so the wind induced oscillations can be significantly magnified. In order to analyze the response of such high rise structures under wind effects we use Davenport's 'Gust Factor Approach'.

There are two main effects of wind on the High rise structures:

- First is, wind exerts forces and moments on the structure and its cladding
- Second one is, wind distributes the air in and around the building mainly termed as Wind Pressure

Sometimes due to unpredictable nature of wind, during some Wind Storms it can upset the internal ventilation system of the building. For that why the study of air-flow is become more important during the planning and designing of a building and its environment. Because of all these all facts the Wind Load estimation for High rise structures are very much important.

LITERATURE REVIEW

Between 1931 and 1936, J. Rathbun made full-scale measurements on the Empire State Building [Rathbun (1940)]. In 1933, Dryden & Hill study measurements on a five -foot scaled model of the Empire State Building.

During wind load calculation on buildings and structures many factors are responsible, and the inventory of those various factors is presented, including indications of their relative effects on the global response by [A.G. Davenport (1998)].

Bodhisatta H. And P. N. Godbole (2006) discuses the most international codes and standards have stored pace with the changing schemes in wind engineering and have updated their codes and standards. The IS - 875 (part-3)

-1987 study use of hourly mean wind speed and inconvenient charts to arrive at the Gust Factor for calculating Along Wind response on a high rise structure. A document "Review of Indian Wind Code – IS - 875 (part-3) 1987",prepared by the Indian Institute of Technology, Kanpur told revision in the present IS - code to make it useful for further use and bring it close to the available international standards. This paper discusses the present IS-code, the revisions suggested by IIT Kanpur together with other international codes for finding out the Along Wind response on a high rise structure with the help of various examples of high rise structures.

METHODOLOGY

The design wind force for buildings and other structures shall be determined according to one of the following method:

1) Method 1 – Analytical procedure by Davenport 'Gust Factor Approach' for high-rise regular shaped buildings.
2) Method 2 – Wind load study by International code, with references ASCE/SEI 7-05.

3.1 METHOD - 1 – DAVENPORT 'GUST FACTOR APPROACH'

This method is used for determining and applying wind pressures in the design of simple regular shaped building. Following are the steps of the simplified procedure:

1. Determined the basic wind speed, V, In accordance with IS: 875 (PART 3) - 1987 section 5.2 and Figure – 1.
2. Determine the importance factor, K_1, In accordance with IS: 875 (PART 3) - 1987 section 5.3.1 and table – 1.
3. Determine the exposure category coefficient K_2, In accordance with IS: 875 (PART 3) – 1987 section 5.3.2 and table - 2
4. Determine the height and exposure adjustment coefficient K_3, from IS: 875 (PART 3) – 1987 section 5.3.3 and appendix - c.
5. Determine P, the simplified wind pressure for exposure B, at given height for k_1=1.0, from IS: 875 (PART 3) – 1987 section 5.4 and section 6.1.

Simplified design wind pressure, P_s, for the main wind force resisting system of low rise diaphragm building is determined by the following equation:

$$P_S = K_1 \times K_2 \times K_3\ P_Z$$

Where P_S represents the net pressure (sum of internal and external) to be applied to the horizontal and vertical projections of building surfaces. For the horizontal pressure, P_s is the combination of the windward and leeward net pressures.

3.2 Method – 2 International Code (ASCE /SEI 7 -05)

Wind loads for buildings and structure that do not satisfy the conditions for using the simplified procedure can be computed using the analytical procedure provided that is a regular shaped building or structure, and it does not have response component making it subject to across wind loading, vortex shedding, instability due to galloping or agitate, or does not have a site location that require special consideration.

The steps of analytical procedure, described in ASCE 7 section 6.5.3

1. Determine the basic wind speed, V, and wind directionality factor, K_D in accordance with ASCE 7 section 6.5.4.
2. Determine the importance factor, K_1, in accordance with ASCE section 6.5.5.
3. Determine the exposure category coefficient K_z and velocity pressure coefficients according to ASCE section 6.5.6.
4. Determine the topographic factor, K_{zt}, according to ASCE section 6.5.7.
5. Determine the gust factor G in accordance with ASCE section 6.5.8.
6. Determine the internal pressure coefficient GC_{PI} in accordance with ASCE section 6.5.11.1
7. Determine the external pressure coefficients C_P, or GC_{PE}, or force coefficients in accordance with ASCE section 6.5.11.2 or 6.5.11.3.
8. Determine the velocity pressure, Q_Z in accordance with ASCE section 6.5.10. The velocity pressure , Q_Z at a height Z is calculated by the following equations

$$Q_Z = 0.00256 \times K_2 \times K_{zt} \times K_d \times V^2 \times I \quad (N/m^2)$$

$$Q_Z = 0.613 \times K_2 \times K_{zt} \times K_d \times V^2 \times I \quad (N/m^2)$$

9. Determine the design wind pressure, P or the design wind load. F, in accordance with ASCE 7 section 6.5.12 and 6.5.13. The design wind pressure is given by this equation

$$P = Q_z \times G \times C_P - Q_I \times (G \times C_{PI}) \quad (N/m^2)$$

The design wind load, F on a building is calculated by the following equation

$$F = Q_Z \times G \times C_F \times A_F \quad (N)$$

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FIG 4.1 VICTORY VALLEY TOWER – C, GURUGRAM (HARYANA, INDIA)

4.1 DAVENPORT 'GUST FACTOR APPROACH'

Let us consider a high rise structure of height 'h', being subjected to a mean wind speed V_H at top. Then the mean wind pressure at top of building is given by the equation

$$P_H = \frac{1}{2}\,\rho_a c_D V_H^2$$

Where,

ρ_a =The air density is influenced by altitude and depends on the temperature and pressure to be expected in the region during wind storms. If the value is not given then value of ρ_a shall be 1.208 kg/m3.

C_D= is Drag co-efficient of structure which depend on the shape and size of the building.

The mean wind velocity variation with height is given by the equation below,

$$\frac{V_Z}{V_G} = (Z/Z_G)^{\alpha}$$

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Where,
V_z is the means wind velocity at height Z,
V_G is the mean velocity at the gradient height,
α is power law coefficient
The coefficient α depends upon the roughness of the terrain to where building is situated.
From the nature of the wind which a structure is subjected to wind will experience a steady wind load arise with the mean wind velocity and a fluctuating component arises with the gust and turbulence.
Davenport (1961a) gives an empirical expression in the non dimensional form from measurements,

$$\frac{f s_u(f)}{V_{10}} = \frac{4.0KX^2}{(1+X^2)^{4/3}}$$

Where,

$$X = \left(\frac{n_o L}{v_H}\right)$$

In which $S_u(f)$ is the power spectral density of wind variations at frequency n_o, V_{10} is a reference wind velocity seized at 10m height, L is a length scale which is near 1200m, and 'k' is the Drag co-efficient of topography defined in Davenport(1961a&b)
Davenport tell the average largest response during a period 'T' is given by,

$$X_{max} = \bar{X} + gf\sigma_x$$

Where,
$\bar{X}$ is the response to mean wind load, and
g_f is the peak factor

$$g_f = \sqrt{2\log v}\ T + \frac{0.577}{\sqrt{2\log vt}}$$

Where ν is the number of times the mean value is crossed per unit time. For a slightly damped system ν= n_o, the natural frequency of the system. Davenport has suggested 600secs to 3600secs as the applicable averaging period 'T', taking the spectral gap in the wind spectrum. Now the important component to be evaluated are the mean ($\bar{X}$), RMS response (σ_x), and the peak factor (g_f), from the equations

$$\frac{X_{max}}{\bar{X}} = 1 + g_f\frac{\sigma_x}{\bar{x}}$$

This gives,

$$G = 1 + g_f\frac{\sigma_x}{\bar{x}}$$

Where G, is called the 'Gust Factor', and it is define as the ratio of maximum response to the mean response.

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4.2 Analytical Analysis The Analytical Response Of Victory Valley Tower C Davenport's Gust Factor Method And Code Procedure

Given:-

α	=	0.18	
Z (ref)	=	10	m
Plan length	=	85	m
Plan width	=	70	m
Height of building	=	147	m
Bulk density	=	110	Kg/m^3
Face width	=	85	m
Face depth	=	70	m
Interval	=	10	m
Natural period	=	5.10	sec.
Critical damping	=	0.035	

Calculations:-

From IS 875: part 3 – 1987

V_b	=	38	m/sec.
K_1	=	1	
K_2	=	0.50	(at height 10 m)
K_3	=	1	
V_{ref} (at 10m)	=	$V_b \times k_1 \times k_2 \times k_3$	
	=	$38 \times 1 \times 0.50 \times 1$	
	=	19	m/sec.

At top of building

K_1	=	1	
K_2	=	0.84	(At 147 m)
K_3	=	1	
V_z	=	$38 \times 1 \times 0.84 \times 1$	
	=	31.92	m/sec.

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V_z / V_G = $(Z / Z_G)^\alpha$

V_z = $V_G (Z / Z_G)^\alpha$

= $19(147/10)^{0.18}$

= 30.82 m/sec

P_z = $0.6(V_z)^2$

= $0.6 \times (30.82)^2$

= 569.92 N/m^2

Calculation for Gust Factor, (G)

T = 3600 sec.

Building frequency n_0 = 1/Natural period

= 1/5.10

= 0.196

m_0 = building mass/m height

= $\rho_b \times B \times D$

= 110×85×70

= 654500 Kg/m

M_0 = concluded mass in 1st mode

= 1/3 m_0 H

= 1/3×654500×147

= 3.2×10^6 Kg

g_f = is the peak factor, given by

$$g_f = \sqrt{2\log v}\ T + \frac{0.577}{\sqrt{2\log vt}}$$

g_f = 3.78

C_f from graph = 1.2

K_o = concluded stiffness in 1st mode

K_o = $4\pi^2 M_o n_o^2$

= $4 \times 3.14^2 \times 3.2 \times 10^6 \times 0.196^2$

= 4855179.14 N/m

L_h = from graph (IS – CODE)

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= 1800

$$X = \left(\frac{n_o L}{v_H}\right)$$

X = 0.196×1800/30.8

X = 11.45

$$E = \frac{(X)^2}{\{1+(X)^2\}^{\frac{4}{3}}}$$

E = 0.15

$$\varepsilon_o = \frac{hn_o}{\bar{v}}$$

ε_o = 147×0.196/30.8

= 0.9354

S = is size reduction factor

$$S = \frac{\pi}{3}\frac{1}{\left(1+\frac{8\varepsilon_o}{3}\right)}\frac{1}{\left(1+\frac{b10\varepsilon_o}{h}\right)}$$

S = 0.054

R = is resonant response excitation

$$R = \frac{sF}{\zeta}$$

R = 0.054×0.224/0.035

= 0.345

B = background turbulence excitation,

$$B = 2\left[1-\frac{1}{\left\{1+\left(\frac{457}{h}\right)^2\right\}^{\frac{1}{3}}}\right]$$

B = $2 \times (1-1/(1+(457/147)^2)^{1/3})$

B = 1.02

K = 0.011

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r = is roughness factor

$$r = 4.0\sqrt{k}\left(\frac{10}{h}\right)^2$$

r = $4\times(0.011)^{.5}(10/147)^{0.18}$

r = 0.256

$$F = \frac{bhC_dP_h}{2(1+\alpha)}$$

F = (1.2×570×85×147)/ (2(1+0.18))

F = 3621432.2 N

$$\bar{X} = \frac{\text{Mean generalised force in first mode}}{\text{Generalised stiffness in first mode}}$$

$\bar{X}$ = F/K_o

$\bar{X}$ = 362143202/4855179.14

$\bar{X}$ = 0.74

$$G = 1 + g_f r\sqrt{(B+R)}$$

G = $1+3.78\times0.256\times(1.02+0.345)^{1/2}$

G = 2.320

Calculation for Force, (F)

A_e = Effective frontal area at ht. 'Z'

= width × interval

= 85×10

= 850

A_e = effective frontal area at ht. 'Z' for top level

= width ×interval/2

= 85×5

= 425 m^2

F_h = $G\times A_e\times C_f\times P_z$

= 2.234×425×1.2×569.92/1000

= 649.33 KN

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TABLE 4.1 ANALYTICAL RESPONSE OF THE VICTORY VALLEY TOWER – C AND SHOWING THE STOREY WISE LATERAL FORCES

Height (m)	K_2	V_h (m/sec.)	V_z (m/sec.)	P_z (N/m ^{2})	F_z (KN)
0	0	0	0	0	0
10	0.5	19	19	216.60	246.18
20	0.29	22.42	21.32	272.72	310.73
30	0.64	24.32	23.15	321.55	366.35
40	0.67	25.46	24.58	356.63	406.32
50	0.7	26.60	25.38	386.48	440.33
60	0.718	27.284	26.23	412.80	470.31
70	0.736	27.968	26.96	436.10	496.86
80	0.754	28.652	27.62	457.71	521.48
90	0.772	29.336	28.04	477.48	544.01
100	0.79	30.02	28.75	495.93	565.03
110	0.8	30.40	29.25	513.33	584.85
120	0.81	30.78	29.71	529.61	603.43
130	0.82	31.16	30.14	545.05	620.99
140	0.83	31.54	30.55	559.98	638.00
147	0.84	31.92	30.82	569.92	649.33
				Total	7464.2

4.3 RESULT DISCUSSION FOR ANALYTICAL ANALYSIS OF BUILDING BY DAVENPORT 'GUST FACTOR APPROACH'.

The analytical response of the Victory Valley Tower – C is determined. In the analytical response by using the Davenport Gust Factor Approach given in the code IS 875: part 3-1987 the Storey wise Lateral forces are determined with the help of given data. The calculation's for the topmost height (147m) is being shown and on the similar grounds and by using the same methods and formulas the wind pressure and wind forces are determined for every height with a 10m interval height.

The total force acted on a 147m tall building named as Victory Valley Tower – C, located Sector 67, Gurugram, Haryana is 7464.2 KN

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4.4 ANALYTICAL ANALYSIS THE ANALYTICAL RESPONSE OF VICTORY VALLEY TOWER C BY USING INTERNATIONAL CODE, ASCE/SEI 7-05

Given:-

I	=	1.15	
Z (ref)	=	10	m
Plan length	=	85	m
Plan width	=	70	m
Height of building	=	147	m
Bulk density	=	110	Kg/m^3
Face width	=	85	m
Face depth	=	70	m
Interval	=	10	m
K_d	=	0.85	
Critical damping	=	0.035	

Calculations:-

From ASCE/SEI 7-05

V_b	=	38	m/sec.
K_1	=	1	
K_2	=	1.01	(at height 10 m)
K_3	=	1	
K_{zt} (at 10m)	=	$(1 + k_1 \times k_2 \times k_3)^2$	
	=	$(1 + 1\times1.01\times1)^2$	
	=	4.04	m/sec.
Q_Z	=	$0.00256 \times K_2 \times K_{zt} \times K_d \times V^2 \times I$	(N/m^2)
	=	$0.00256\times1.01\times4.04\times0.85\times88^2\times1.15$	
	=	79.07	N/m^2
P (windward side)	=	$Q_z\times G\times C_P – Q_I \times (G\times C_{PI})$	(N/m^2)
	=	79.07((0.85×0.8) – (0.85×-0.5))	
	=	87.37	
P (leeward side)	=	$Q_z\times G\times C_P + Q_I \times (G\times C_{PI})$	(N/m^2)
	=	79.07((0.85×0.8) + (0.85×– 0.5))	

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= 11.86

P (Total) = p (windward + leeward)

= 99.23

F = $Q_Z \times G \times C_F \times A_F$ (N)

= 79.07×0.85×0.5×85×70

= 199948 (N)

= 199.948 (KN)

At top of building (Z= 147m)

K_{zt} (at147m) = $(1 + k_1 \times k_2 \times k_3)^2$

= $(1 + 1 \times 1.97 \times 1)^2$

= 8.82 m/sec.

Q_Z = $0.00256 \times K_2 \times K_{zt} \times K_d \times V^2 \times I$ (N/m²)

= $0.00256 \times 1.97 \times 8.82 \times 0.85 \times 88^2 \times 1.15$

= 336.56 N/m^2

P (windward side) = $Q_z \times G \times C_P - Q_I \times (G \times C_{PI})$ (N/m^2)

= 336.56((0.85×0.8) – (0.85×-0.5))

= 371.89

P (leeward side) = $Q_z \times G \times C_P + Q_I \times (G \times C_{PI})$ (N/m^2)

= 336.56((0.85×0.8) + (0.85×– 0.5))

= 50.484

P (Total) = p (windward + leeward)

= 422.374

F = $Q_Z \times G \times C_F \times A_F$ (N)

= 336.56×0.85×0.5×85×70

= 851076 (N)

= 851.076 (KN)

TABLE 4.2 - ANALYTICAL RESPONSE OF THE VICTORY VALLEY TOWER – C AND SHOWING THE STOREY WISE LATERAL FORCES BY INTERNATIONAL CODES PROCEDURE

Height(m)	K_2	K_{zt}	Q z	P (WS)	P (LS)	P(T)	F (KN)
0	0	0	0	0	0	0	0
10	1.01	4.04	79.07	87.37	11.86	99.23	199.948
20	1.08	4.32	90.37	99.85	13.55	113.40	228.523
30	1.13	4.53	99.15	109.56	14.87	124.43	250.725
40	1.20	4.84	112.50	124.31	16.87	141.18	284.484
50	1.27	5.15	126.68	139.98	19.00	158.98	320.342
60	1.34	5.47	141.97	156.87	21.29	178.16	359.006
70	1.41	5.80	158.40	175.03	23.76	198.79	380.324
80	1.48	6.15	176.30	194.81	26.44	221.25	445.818
90	1.55	6.50	195.15	215.64	29.27	244.91	493.485
100	1.62	6.86	226.87	250.69	34.03	284.78	573.697
110	1.69	7.23	236.67	261.52	35.50	297.02	598.479
120	1.76	7.61	259.43	286.71	38.92	325.63	656.134
130	1.83	8.00	283.57	313.34	42.53	355.87	717.077
140	1.90	8.41	309.51	342.07	46.42	388.49	782.673
147	1.97	8.82	336.56	371.89	50.48	422.37	851.076
						Total	7141.791

4.5 Result Discussion For Analytical Analysis By International Code Of Building

The analytical response by international code of the Victory Valley Tower – C is determined. In the analytical response by using ASCE/SEI 7-05 the Storey wise Lateral forces are determined with the help of given data. The calculation's for the topmost height (147m) is being shown and on the similar grounds and by using the same methods and formulas the wind pressure and wind forces are determined for every height with a 10m interval height.

The total force acted on a 147m tall building named as Victory Valley Tower – C, located Sector 67, Gurugram, Haryana is 7141.791 KN

4.6 COMPARISON OF THE RESULT FOR VICTORY VALLEY TOWER – C FOR ANALYTICAL RESPONSE BY DAVENPORT'S 'GUST FACTOR APPROACH' AND INTERNATIONAL CODE WITH REFERENCE ASCE/SEI 7-05.

The comparison of the Storey Wise Lateral force for the Victory Valley Tower – C is shown in table 4.5. In both the comparison of Storey Wise Lateral Forces are much higher in Davenport's 'Gust Factor Approach than those for the International Code with reference ASCE/SEI 7-05 in the Analytical Analysis.

TABLE 4.3 COMPARISON BETWEEN THE TOTAL FORCES USING ANALYTICAL RESPONSE BY DAVENPORT'S 'GUST FACTOR APPROACH' AND INTERNATIONAL CODE WITH REFERENCE ASCE/SEI 7-05.

S.No.	Victory Valley Tower – C	IS – Code (Davenport Approach)	International Code (ASCE/SEI 7-05.)
1	Total Force	7464.20 KN	7141.791 KN

CONCLUSIONS

In the present study we examine the variation of wind loads on the given Victory Valley Tower – C. Here we used Analytical method given by Davenport and IS 875-part 3-1987 to find out the wind pressure and wind force on the victory Valley Tower – C. The building has been examined for the Terrain Category 3 and providing with the flow conditions with a basic wind speed of 38m/sec., in the region given by IS 875-part 3-1987.

In the analytical method of the analysis we used Davenport 'gust factor approach' to calculate wind force on a high rise structure , which is named as Victory Valley Tower –C, Even the Storey Wise Lateral Forces obtained on the 10m interval heights by Davenport Approach of IS 875: part 3-1987 code can be seen in the table 4.3. The total wind force on the structure is also concluded

Here the wind load on Victory Valley Tower – C is also examined by analytical method of International code ASCE/SEI 7-05. The Storey Wise Lateral Forces obtained on the 10m interval heights by International code ASCE/SEI 7-05 can be seen in the table 4.4. The total wind force on the structure is also concluded

5.0 Main Conclusion

In the Analytical Analysis of the Victory Valley Tower –C, The comparison has been made in the Total Forces obtained from the Analytical Approach by Davenport 'Gust Factor Approach' and International code with reference ASCE/SEI 7-05 .Which concludes that the Values of Total Forces obtained from Davenport 'Gust Factor Approach' are much greater than those from the Analytical Analysis by International code with reference ASCE/SEI 7-05 as listed in **Table 4.3.**

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