EFFECTS OF GUST LOAD ON TALL BUILDINGS

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Abstract :With the rapid growth in building construction and urbanization in India, buildings are getting taller than ever. As the height of building increases it becomes more flexible. The structure of high-rise buildings is usually more sensitive to effects of wind. The wind pressures are fluctuating in nature and thus there is possibility of the fundamental natural frequency of the structure matching the wind frequency. The gust effectiveness factor method of IS: 875 (Part 3) – 1987 takes into account the dynamic properties of the structure, the wind-structure interaction and then determines the wind loads as equivalent static loads. In the present project work, square and rectangular buildings of 30, 40 and 50 storeys are considered for wind load analysis. Equivalent static wind load is calculated using provisions of IS: 875 (Part 3) – 1987. The structures are analysed using CSI ETABs 2015 for maximum storey displacement, storey drift and storey shear. Comparison is made between structures loaded under static wind load and equivalent static gust load.

***IndexTerms* - Gust, Static Method, Gust Effectiveness Factor (GEF) Method, Storey Displacement, Storey Drift, Storey Shear.**

I. INTRODUCTION

Due to increasing population and scarcity of land available for construction coupled with the development of modern materials and construction techniques, structures are getting taller, bigger and lighter. This kind of structures are vulnerable to two types of dynamic forces, i.e. Earthquake and Wind Forces.

Wind is the motion of air relative to the surface of earth. It varies with time and space. Due to unpredictable nature of wind it is critical to design a tall structure by considering the dynamic nature of the wind.

The wind force depends upon terrain and topography of location and also on nature of wind, size, shape and dynamic properties of the structure. It is very important to take in account the fluctuating nature of the wind while designing a building Due to increasing population and scarcity of land available for construction coupled with the development of modern materials and construction techniques, structures are getting taller, bigger and lighter. This kind of structures are vulnerable to two types of dynamic forces, i.e. Earthquake and Wind Forces.

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Thus it has become necessary to develop tools to estimate the effects of wind on a structure with higher accuracy than was previously required.

II. LITERATURE REVIEW

A. A Comparative Study of Wind Forces on Tall Building by Static Method and Dynamic Method Per IS 875 Part III (1987)

M. Majed and P. Rao, 2013 [1] carried out a study comparing the static and dynamic methods of IS: 875 (Part 3) – 1987 for calculating wind load on a structure. A 100m tall square framed structure of plan dimensions 25m x 25m was analysed for shear force and bending moment under wind loads calculated using static and Gust Effectiveness Factor Method of IS: 875 (Part 3) – 1987.

From the analysed data it was concluded that:

- The gust factor increases with increase in height
- The gust pressure increases with increase in height.

B. Effects of Shape on Wind Forces of High Rise Buildings using Gust Factor Approach:

M. Wakchaure and S. Gawali, 2015 [2] studied the effect of change in plan of a building using the Gust Effectiveness Facator Method of IS: 875 (Part 3) – 1987. Buildings of square, rectangular, circular and elliptical plan having a height of 150m were analysed for various parameters such as storey displacement, storey drift, storey shear, etc.

Based on the data obtained it was concluded that:

- The wind pressure on circular and elliptical buildings was considerably less as compared to that on buildings with prismatic plan.
- The wind load was reduced by maximum percentage with an elliptical plan.

C. Study on the Effect of Gust Loads on Tall Buildings:

I. Srikanth and V. Krishna, 2014 [3] studied the effect of increase in height of building using Gust Effectiveness Factor Method of IS: 875 (Part 3) – 1987. Tall buildings of 20 to 80 storeys were considered for wind analysis. The resulting effects such as beam moments, column moments, axial forces, etc. were compared.

D. Wind Effects on Tall Building Frames-Influence of Dynamic Parameters:

B. Kumar and B. L. P. Swami, 2010 [4] used the Gust Effectiveness Factor Method for computing the wind loads on flexible tall slender structures and tall building towers. Frames of different heights were analysed and studied.

Following conclusions were drawn:

- The gust pressures computed by gust effectiveness factor method increases with the height of the building and they are more critical than static pressure.
- The overall gust factor decreases from one building frame to other as the height is increased.

III. Gust Effectiveness Factor (GEF) Method

Use of the existing theories of gust factor method requires knowledge of maximum wind speeds averaged over one hour at a particular location. Hourly mean wind speeds at different heights in different terrain is given in Table 33 of IS: 875 (Part) – 1987.

The variation of hourly mean wind speed with height shall be calculated as follows:

$$V_z' = V_b * k_1 * k_2' * k_3 \qquad (1)$$

Where,

$V_z{}'$= hourly mean wind speed m/s at height z;

V_b= regional basic wind speed in m/s (fig. 1 of IS: 875 (Part 3) – 1987);

k_1= probability factor (risk coefficient) (cl. 5.3.1 of IS 875 (Part 3) – 1987);

k_2'= terrain and height factor (Table 33 of IS 875 (Part 3) – 1987);

k_3= topography factor (cl. 5.3.3 of IS 875 (Part 3) – 1987);

Along wind load on a structure on a strip area (A_e) at any given height z is given by:

$$F_z = C_f * A_e * P_z' * G \qquad (2)$$

Where,

F_z= along wind load on the structure at any height z corresponding to strip area A_e;

C_f= force coefficient for the building;

A_e= effective frontal area considered for the structure at height z;

P_z'= design pressure at height z due to hourly mean wind obtained as 0.6 ${V_z'}^2$ (N/m2)

G= gust factor ($= \frac{peak\ load}{mean\ load}$), and is given by

$$G = 1 + g_f r \sqrt{[B(1+\emptyset)^2 + \frac{SE}{\beta}]} \qquad (3)$$

Where,

g_f= peak factor defined as the ratio of the expected peak value to the root mean value of a fluctuating load;

r= roughness factor which is dependent on the size of the structure in relation to the ground roughness;

The value of '$g_f r$' is obtained from (IS 878 PART-3)

B= background factor indicating a measure of slowly varying component of fluctuating wind load and is obtained from (IS PART-3);

$\frac{SE}{\beta}$= measure of the resonant component of the fluctuating wind load;

S= size reduction factor is obtained from (IS 875 PART-3);

E= measure of available energy in the wind stream at the natural frequency of the structure which is obtained from (IS 875 PART-3);

β= damping coefficient (as fraction of critical damping) of the structure;

$\emptyset = \frac{g_f r \sqrt{B}}{4}$ and is to be accounted only for buildings less than 75m height in terrain Category 4 and for buildings less than 25m height in terrain category 3 and is to be taken as zero in all other cases;

$V_h = V_z$= hourly mean wind speed at height "z".

IV. Modeling and Analysis

In this study, square and rectangular buildings of 30, 40 and 50 storeys are modeled and analyzed using ETABs v15.2.2 by applying wind load calculated using static and GEF method as per IS: 875 (Part 3) – 1987.

Table 1: Modeling Data

No. of Storey	30, 40 and 50
Bottom Storey Height	3m
Storey Height	3m
Basic Wind Speed	44 m/s
Terrain Category	II
Shape of Buildings	Square: 25m x 25m
Rectangle: 45m x 15m	
Size of Bay	5m x 5x
Column Size	1000mm x 1000mm
Beam Size	450mm x 500mm
Slab Thickness	150 mm
Grade of Concrete	M30: For Beams and Column

	M25: For Slabs
Grade of Steel	Fe415
Live Load Intensity	3 kN/m^2

The natural frequency of the structures was calculated using STAAD.Pro V8i SS6.

SQUARE FRAME

Square frames of 25m x 25m plan dimensions of 30, 40 and 50 storey were analysed using ETABs v15.2.2. Auto lateral load generation function was used for generation of static wind load on the structure.

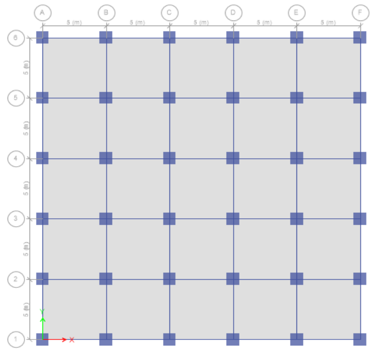

Figure 1: Plan of Square Frame

Gust factors calculated using charts and tables from IS: 875 (Part3) – 1987 for square frames are listed in the table below

Table 2: Gust Factor of Square Frame

Height	Gust Factor G		
	30 Storey	40 Storey	50 Storey
10	2.27	2.217	2.244
15	2.313	2.261	2.299
20	2.338	2.288	2.33
30	2.372	2.324	2.37
50	2.423	2.388	2.44
90	2.471	2.463	2.52
100		2.463	2.52
120		2.481	2.56
150			2.56

RECTANGULAR FRAME

Rectangular frames of 45m x 15m plan dimensions of 30, 40 and 50 storey were analysed using ETABs v15.2.2. Auto lateral load generation function was used for generation of static wind load on the structure.

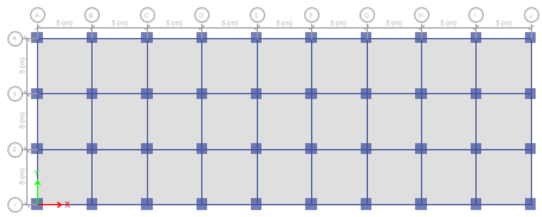

Figure 2: Plan of Rectangular Frame

Gust factors calculated using charts and tables from IS: 875 (Part3) – 1987 for rectangular frames are listed in the table below

Table 3 : Gust Factor for Rectangular Frame

Height (m)	Gust Factor G					
	30 Storey		40 Storey		50 Storey	
	X	Y	X	Y	X	Y
10	2.37	2.218	2.26	2.2	2.17	2.19
15	2.41	2.25	2.3	2.24	2.21	2.23
20	2.43	2.27	2.32	2.27	2.24	2.25
30	2.47	2.29	2.36	2.31	2.28	2.30
50	2.52	2.33	2.41	2.37	2.34	2.32
90	2.56	2.37	2.48	2.44	2.41	2.42
100			2.48	2.44	2.41	2.42
120			2.49	2.46	2.45	2.46
150					2.45	2.46

V. RESULTS AND DISCUSSION

The maximum storey displacement, storey drift and storey shear are tabulated below.

Table 4: Maximum Storey Response for 30 Storey Frame

	Square Frame		Rectangular Frame			
	Static Method	GEF Method	Static Method		GEF Method	
			X	Y	X	Y
Maximum Storey Displacement (mm)	81.19367	147.086	40.571	190.77	68.786	268.129
Maximum Storey Drift Ratio	0.000223	0.000397	8.4×10^{-5}	0.0007	0.00014	0.001
Maximum Storey Shear	4817.802	8413.785	3015.225	10605.77	4911.975	14256

Table 5: Maximum Storey Response for 40 Storey Frame

	Square Frame		Rectangular Frame			
	Static Method	GEF Method	Static Method		GEF Method	
			X	Y	X	Y
Maximum Storey Displacement (mm)	170.3426	280.7305	119.419	542.962	135.135	604.973
Maximum Storey Drift Ratio	0.000402	0.000787	0.00019	0.00189	0.000212	0.002101
Maximum Storey Shear	6928.295	13193.55	6286.703	19568.66	6871.455	20906.1

Table 6: Maximum Storey Response for 50 Storey Frame

	Square Frame		Rectangular Frame			
	Static Method	GEF Method	Static Method		GEF Method	
			X	Y	X	Y
Maximum Storey Displacement (mm)	309.7773	671.47	208.119	1032.436	230.357	1153.67
Maximum Storey Drift Ratio	0.0007	0.001516	0.000293	0.003527	0.000323	0.003941
Maximum Storey Shear	9235.666	19275.75	8342.433	25807.62	8903.286	27837

V. CONCLUSION

Following conclusions can be drawn from the data obtained:

- The Gust Factor increases with the increase in height of a particular building.
- The overall gust factor decreases from one building frame to other as the height is increased.
- Square frame has smaller surface perpendicular to the wind as compared to rectangular frame. Thus the wind pressure is observed to be more on rectangular building.
- Storey Displacement, Storey Drift and Storey Shear obtained using Gust Effectiveness Factor Method is more as compared to that obtained from Static Method.

The Gust Effectiveness Method provides a more realistic and rational approach for wind analysis of a structure. Thus it should be considered for calculating wind loads on very tall and slender structures.

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