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The effect of zone factors on wind and earthquake loads of high-rise structures

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ABSTRACT: *This paper presents a comparative study of wind and earthquake loads to decide the design loads of a multistoried building. The significant of this work is to estimate the design loads of a structure which is subjected to wind and earthquake loads in a particular region. It is well known fact that the earthquake loads may be estimated in particular zone with a specified zone factor. Then the wind load of that zone can also be estimated based on the basic wind speed and other factors of that particular region. However, the wind velocity is stochastic and time dependent. In the present study a multistoried building is analyzed for earthquake loads in various zones based on IS 1893 and for wind loads IS 875 code is used. The wind loads are estimated based on the design wind speed of that zone with a variation of 20%. The wind loads so obtained on the building have been compared with that of earthquake loads. Finally it is found the wind loads are more critical than the earthquake loads in most of the cases.*

Keywords: *Zone factor, wind loads, earthquake loads, design loads, high rise buildings*

I. INTRODUCTION

Recently there has been a considerable increase in the number of tall buildings, both residential and commercial, and the modern trend is towards taller structures. Thus the effects of lateral loads like winds loads, earthquake forces are attaining increasing importance and almost every designer is faced with the problem of providing adequate strength and stability against lateral loads. For this reason to estimate wind load and earthquake loading on high-rise building design.

The importance of wind engineering is emerging in India ever since the need for taller and slender buildings. Considering the ever increasing population as well as limited space, horizontal expansion is no more a viable solution especially in metropolitan cities. There is enough technology to build super-tall buildings today, but in India we are yet to catch up with the technology which is already established in other parts of the world.

A comparison of wind loads on low, medium and high rise buildings by Asia-Pacific codes has shown varying degrees of agreement [1]. An attempt has been made to develop information through wind tunnel studies on I-shape and cross shape buildings [2]. For preliminary design including the proportioning of the structure, the variation of wind force on a structure with variation of site parameters and structural parameters have been studied by Halder and Datta [3] based on Indian wind code. It is found that the evolution of tall building's structural systems and the technological driving force behind tall building developments. For the primary structural systems, a new classification – interior structures and exterior structures – is presented by Ali and Moon [4].

The structural design consideration, the lateral force-resisting system, sloping outer concrete columns, long span post-tensioned transfer girder and other design challenges are faced in the design of tall buildings [5]. The comparison of the Indian Code (IS) and International Building Codes (IBC) in relation to the seismic design and analysis of ordinary RC moment resisting frame (OMRF), intermediate RC moment-resisting frame (IMRF) and Special RC moment-resting frame (SMRF) presented by Itti et al [6]. The development of high strength concrete, higher grade steel, new construction techniques and advanced computational technique has resulted in the emergence of a new generation of tall structures that are flexible, low in damping, slender and light in weight [7].

Many times, wind engineering is being misunderstood as wind energy in India. On the other hand, wind engineering is unique part of engineering where the impact of wind on structures and its environment being studied. More specifically related to buildings, wind loads on claddings are required for the selection of the cladding systems and wind loads on the structural frames are required for the design of beams, columns, lateral bracing and foundations. Wind in general governs the design when buildings are above 150 m height. However the other force which effect most on high rise building are the lateral forces caused by earthquakes. When buildings grow taller, they become flexible and they are moving away from the high frequency earthquake waves. This paper describes wind and seismic analysis of high-rise building in various zones of Indian subcontinent. For the analysis purpose a twelve story reinforced concrete framed structure is selected. The wind loads are estimated by Indian code IS: 875 (Part-3)-1987 [9] and earthquake loads are estimated by IS 1893: 1984 [8].

Wind analysis

The basic wind speed (V_b) for any site shall be obtained IS 875 and shall be modified to get the design wind velocity at any height (V_z) for a chosen structure.

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

Where, V_z = design wind speed at any height z in m/s, V_b = Basic wind speed in m/s, k_1 = probability factor (risk coefficient), k_2 = terrain roughness and height factor and k_3 = topography factor

The basic wind speed map of India, as applicable at 10 m height above mean ground level for different zones of the country selected from the code. The design wind pressure at any height above mean ground level shall be obtained by the following relationship between wind pressure and wind velocity.

$$P_z = 0.6\, V_z^2 \qquad (2)$$

Where, P_z = wind pressure in N/m^2 at height z and V_z = design wind speed in m/s at height z.

2.1. Wind Load on Individual Members (F)

When calculating the wind load on individual member such as roof and walls, and individual cladding units and their fittings, it is essential to take account of the pressure difference between opposite force such elements or units. For clad structures, it is therefore necessary to know the internal pressure as well as the external pressure.

$$F = (C_{pe} - C_{pi})\, A\, P_d \qquad (3)$$

where , C_{pe} = external pressure coefficient, C_{pi} = internal pressure coefficient (Table No.4), A = surface area of structural element or cladding unit, and P_d = design wind pressure in N/m^2.

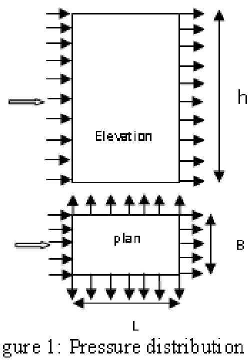

Figure 1: Pressure distribution on the external surface of a building.

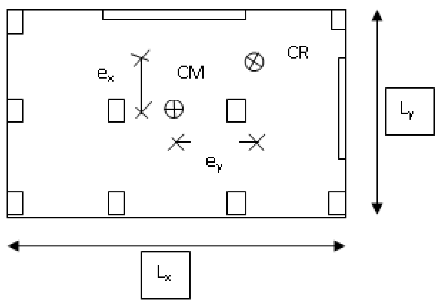

Figure 2 : Centre of mass and centre of rigidity

3. Earthquake analysis

In equivalent lateral force procedures the magnitude of force is base on an estimate of the fundamental period and on the distribution of force, as given by the simple formulas appropriate for regular buildings using IS: 1893 (Part 1)-2002. The total design lateral force or design seismic base shear (V_B) along any principal direction shall be determine by the following expression.

$$V_B = A_h\, W \qquad (4)$$

Where , A_h = Design horizontal seismic coefficient, W = Seismic weight of the building
The design horizontal seismic coefficient (A_h) is given by

$$A_h = \frac{Z\,I\,Sa}{2\,R\,g} \qquad (5)$$

Where, Z = Zone factor (Table No.2), Z = 0.10 for zone-II , for zone-III , 0.24 for zone-IV , 0.36 for zone-V, I = Importance factor, R = response reduction factor and Sa/g = Spectral acceleration coefficient.
The fundamental natural period (Ta) is taken for moment resisting frame building without brick infill panels as

$$Ta = 0.075h^{o.75} \qquad (6)$$

where , h = Height of the building in m.
Distribution of design force (Q_i) is given by

$$Q_i = V_B \frac{W_i h_i^{\,2}}{\sum_{j=1}^{n} W_j h_j^{\,2}} \qquad (7)$$

where, Q_i = Design lateral force at floor i, W_i = Seismic weight of floor i, h_i = height of floor i measure from base, and n = Number of stories.
The Design eccentricity (e_{di}) are calculated as

$$e_{di} = 1.5\, e_{si} + 0.05\, b_i \quad \text{or} \quad e_{di} = e_{si} - 0.05\, b_i \qquad (8)$$

Where , e_{si} = static eccentricity at floor i define as the distance between CM and CR.
b_i = floor plan dimension of floor i, perpendicular to the direction of the force.
centre of mass, X_{cm} and Y_{cm} , is calculating by taking statical moment about point, say, south west corner , using the respective weights of wall as force in the moment summation.

$$Xcm = \frac{\sum A_i\, M_i\, X_i}{\sum A_i\, M_i} \quad , \quad Y_{cm} = \frac{\sum A_i\, M_i\, Y_i}{\sum A_i\, M_i} \qquad (9)$$

Where , A_i = Area of the portion I, M_i = Mass intensity of the portion i (Kg/m^2), X_i = C.G of the portion i in X-direction, Y_i = C.G of the portion i in Y-direction.
The centre rigidity, Xcr and Ycr is calculating by taking statical moment about point, say, south west corner , using the respective weights of wall as force in the moment summation. The stiffness of slab and parapet height are not considered in the determination of centre of rigidity.

$$X_r = \frac{\sum K_x X_j}{\sum K_x} \quad , \quad Y_r = \frac{\sum K_y Y_j}{\sum K_y} \qquad (10)$$

where , K_x = the stiffness of each column or wall about X axes respectively, K_y = the stiffness of each column or wall about Y axes respectively, X_j = distance from origin in the X-direction, Y_j = distance from origin in the Y-direction.

II. DESIGN EXAMPLE

This example studies the effect of the wind and earthquake using the Indian code on a twelve-story office building 18x30 m shown in Fig. The story height is 3m. The structural system resisting lateral forces consists of beam, columns and shear walls as shown in the Fig. Interior columns are 0.7x0.7 m, exterior columns are 0.5x0.5 m in X and Y directions shear walls are 0.25x6.0 m and beams are 0.3x0.6 m. The building is located in seismic zone 3 and medium soil. The live load is 3 KN/m^2, and the average dead load of each floor is 7000 KN and for the roof floor equal to 4000 KN.

III. ANALYSIS RESULTS

5.1 Wind loads: The wind loads are calculated for a zone whose basic wind speed is 44 m/m^2, then design wind speed (V_z) and the design wind pressures (p_z) are calculated.

$$V_z = V_b\, k_1\, k_2\, k_3 = 44 \text{ X } 1.00 \text{ X } k_2 \text{ X } 1.00 = 44\, k_2 \quad \text{m/s} .$$

$$P_z = 0.6\, V_z^2 = 0.6 \text{ X } (44\, k_2)^2 = 1.1616\, K_2^2 \;\; \text{KN/m}^2$$

Category = 2 , Class = B structures

$$\frac{h}{w} = \frac{36}{18} = 2.00\text{---------------}\frac{3}{2} < \frac{h}{w} < 6 .$$

$$\frac{l}{w} = \frac{30}{18} = 1.67 \text{ --------------}\frac{3}{2} < \frac{l}{w} < 4 .$$

External pressure coefficient (C_{pe}) :

$\theta = 0^0$ -------- +0.7 -0.4 -0.7 -0.7

$\theta = 90^0$ -------- -0.5 -0.5 +0.8 -0.1

Table 1: Wind pressures on structure

Height (m)	k_2	P_z (kN/m^2)	Wind pressure Along 0 degree (kN/m^2)				Wind pressure Along 90 degree (kN/m^2)			
			A	B	C	D	A	B	C	D
3	0.98	1.12	1.34	1.00	1.34	1.34	1.12	1.12	1.45	0.67
6	0.98	1.12	1.34	1.00	1.34	1.34	1.12	1.12	1.45	0.67
9	0.98	1.12	1.34	1.00	1.34	1.34	1.12	1.12	1.45	0.67
12	0.99	1.14	1.37	1.02	1.37	1.37	1.14	1.14	1.48	0.68
15	1.02	1.21	1.45	1.09	1.45	1.45	1.21	1.21	1.57	0.73
18	1.03	1.23	1.48	1.11	1.48	1.48	1.23	1.23	1.60	0.74
21	1.05	1.28	1.54	1.15	1.54	1.54	1.28	1.28	1.66	0.77
24	1.07	1.33	1.60	1.20	1.60	1.60	1.33	1.33	1.73	0.80
27	1.08	1.35	1.63	1.22	1.63	1.63	1.35	1.35	1.76	0.81
30	1.1	1.41	1.69	1.26	1.69	1.69	1.41	1.41	1.83	0.84
33	1.11	1.43	1.72	1.29	1.72	1.72	1.43	1.43	1.86	0.86
36	1.12	1.46	1.75	1.31	1.75	1.75	1.46	1.46	1.89	0.87

Table 2: Wind forces on structure

Storey level	Force Along 0 degree (kN)				Force Along 90 degree (kN)			
	A	B	C	D	A	B	C	D
1	60.24	45.18	36.15	36.15	50.20	50.20	39.16	18.07
2	120.48	90.36	72.29	72.29	100.40	100.40	78.32	36.15
3	120.48	90.36	72.29	72.29	100.40	100.40	78.32	36.15
4	122.96	92.22	73.77	73.77	102.46	102.46	79.92	36.89
5	130.52	97.89	78.31	78.31	108.77	108.77	84.84	39.16
6	133.09	99.82	79.86	79.86	110.91	110.91	86.51	39.93
7	138.31	103.73	82.99	82.99	115.26	115.26	89.90	41.49
8	143.63	107.72	86.18	86.18	119.69	119.69	93.36	43.09
9	146.33	109.75	87.80	87.80	121.94	121.94	95.11	43.90
10	151.80	113.85	91.08	91.08	126.50	126.50	98.67	45.54
11	154.57	115.93	92.74	92.74	128.81	128.81	100.47	46.37
12	78.68	59.01	47.21	47.21	65.57	65.57	51.14	23.61
TOTAL	1501.11	1125.83	900.66	900.66	1250.92	1250.92	2501.84	450.33

The wind loads are evaluated for various wind zones with variation of basic wind speeds for V_b=33, 39, 44, 47, 50 and 55 m/s. It is found that the total wind force increases with increase in basic wind speed.

5.2 Earthquake loads: The earthquake loads are calculated for the zone whose zone factor is 0.16. The horizontal seismic coefficients (Ah) are calculated along the x- and y-directions.

The horizontal seismic coefficient along the x-direction is, $Ah_x = \frac{0.16\times1\times2.2992}{2\times3} = 0.0613$

The horizontal seismic coefficient along the y-direction is, $Ah_Y = \frac{0.16\times1\times1.7810}{2\times3} = 0.0474$

Design seismic base shear is along the x- and y-directions respectively obtained as:

V_{BX} = 0.0613 X 85455 = 5238.3915 KN.

V_{BY} = 0.0474 X 85455 = 4050.5670 KN.

Table 3: Lateral load distribution with height

Storey	Load (wi) kn	Height (hi) m.	$Wihi^2$	Load dist. X-direction	Load dist. Y-direction
12	4000	36	5184000	697.98	539.71
11	7405	33	8064045	1085.75	839.55
10	7405	30	6664500	897.31	693.85
9	7405	27	5398245	726.82	562.01
8	7405	24	4265280	574.28	444.06
7	7405	21	3265605	439.68	339.98
6	7405	18	2399220	323.03	249.78
5	7405	15	1666125	224.33	173.46
4	7405	12	1066320	143.57	111.02
3	7405	9	599805	80.76	62.45
2	7405	6	266580	35.89	27.75
1	7405	3	66645	8.97	6.94
		TOTAL	38906370	5238.39	4050.57

The earthquake loads are estimated for various zones with variation of zone factor as z=0.10, 0.16, 0.24 and 0.36. As zone factor increases the earthquake forces also increased gradually.

IV. CONCLUSIONS

The wind loads and earthquake loads are estimated for a twelve storied RC framed structure. Based on the results obtained the following conclusions are made.

The wind and earthquake loads increases with height of structure.

Wind loads are more critical for tall structures than the earthquake loads.

Structures should be designed for loads obtained in both directions independently for critical forces of wind or earthquake.

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