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Effect of Wind and Structural Parameters on Wind-Induced Acceleration of RC Building

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***Abstract*:** *The purpose of this study is to evaluate the performance of tall building on human comfort on wind-induced acceleration using ASCE7-10 method. Along-wind accelerations for three building models (40, 30 and 20 storey) for various categories of surface roughness and structural damping were analyzed. The natural frequencies of all the buildings were determined by carrying out numerical analysis. The results of the along-wind acceleration by ASCE7-10 method signify that the buildings with low structural damping increase their acceleration levels under even moderate wind speeds. Further, analysis results of different categories of surface roughness show significant change in the pattern between along-wind acceleration and structural damping.*

Keywords: *along-wind acceleration, terrain categories, structural damping.*

1. Introduction

Wind-induced vibrations in tall buildings for human comforts are usually evaluated by the along-wind or across-wind acceleration. High-rise buildings are likely to be light in weight and flexible and therefore, more significant to wind dynamic motion problems. Different terrains or surface roughness categories may affect wind dynamic motion of high rise building. Closer to the surface the wind speed is affected by frictional drag of the air stream over the terrain. There is a boundary layer within which the wind speed varies from almost zero at the surface to the gradient wind speed at a height known as the gradient height.

When considering the response of a tall building to wind dynamic loads, wind induced acceleration must be considered. Also, it is necessary to evaluate the buildings dynamic behavior related to wind-induced accelerations at top storey to assess occupants' comfort [1]. These arise due to buffeting effects of wind caused by turbulence. [2] Discussed on comfort criteria: human response to building motion, authors have discussed that their is no international standard for comfort criteria in tall building design. However, considerable research has been carried out into the important physiological and psychological parameters that affect human perception to motion and vibration encountered in tall buildings. These parameters include accelerations for both the translational and rotational motions to which the occupant is subjected. Guidelines on general human perception levels are given in Table 1. [3] Studied on acceleration indexes for occupant comfort in tall building using rms and peak values of acceleration. Human perception of vibration and tolerance of wind-induced tall building vibration are essentially a subjective assessment [4]. Hence, there is currently no single internationally accepted occupant comfort serviceability criteria which set a design standard for satisfactory levels of wind-induced vibration in tall buildings.

It is evident from the literature, the most important criterion for verifying comfort of building's occupants is the peak acceleration they are likely to experience. It is thus important to estimate the probable maximum accelerations in along-wind directions.

In this paper, first, numerical analysis had been carried out to find natural frequencies of forty, thirty and twenty storey buildings of different height. Then, along-wind accelerations were computed for all buildings using ASCE7-10 [5] method. Different categories of surface roughness and structural damping of the building were used to calculate along-wind accelerations.

TABLE I: Human sensitivity levels against acceleration [2].

Level	Acceleration (m/sec^2)	Effect
1	< 0.05	Humans cannot perceive motion.
2	0.05 - 0.1	Sensitive people can perceive motion. Hanging objects may move slightly.
3	0.1 - 0.25	Level of motion may affect desk work. Long term exposure may produce motion sickness.
4	0.25 - 0.4	Desk work becomes difficult or almost impossible.
5	0.4 - 0.5	Difficult to walk naturally and standing people may lose balance.
6	0.5 - 0.6	Unable to walk naturally.
7	0.6 - 0.7	People cannot tolerate motion or walk.
8	> 0.85	Objects begin to fall.

2. Gust factor

For flexible or dynamically sensitive buildings ASCE7-10 [5] recommends gust effect factor (G_f). Gust effect factor depends on basic wind speed (V), exposure category B, C, or D, building natural frequency and building damping. ASCE7-10 defines a rigid building as "When buildings height exceeds four times the least horizontal dimension or when the natural frequency is less than 1 Hz, the natural frequency for it should be investigated". The G_f for Main Wind Force Resisting System (MWFRS) of flexible buildings and other structures can be obtained by Eq. (1) [5].

$$G_f = 0.925\left(\frac{1+1.7I_{\bar{z}}\sqrt{g_Q^2Q^2+g_R^2R^2}}{1+1.7g_vI_{\bar{z}}}\right) \tag{1}$$

where g_Q and gv shall be taken as 3.4

g_Q = peak factor for background response

g_R = peak factor for resonance response

g_v = peak factor for wind response

Q = background response factor

R = resonant response factor

$I_{\bar{z}}$ = intensity of turbulence

3. Along-wind displacement and acceleration [5]

ASCE7-10 recommends a method for calculating along-wind displacement and peak acceleration. The maximum along-wind displacement as a function of height above the ground surface is given by Eq. (2).

$$X_{\max(z)} = \frac{\phi_{(z)}\rho BhC_{fz}\hat{V}_{\bar{z}}^2}{2m_1(2\pi n_1)^2}KG_f \tag{2}$$

where $\phi_{(z)}$ is the fundamental model shape = (z/h)ξ, ρ is the air density, B = horizontal dimension of building measured normal to wind direction, h is height of building, C_{fx} is the mean along-wind force coefficient, $\hat{V}^2_{\bar{z}}$ is 3-second gust speed at height $\bar{z}$, n_1 is natural frequency at first mode, m_1 = modal mass. Modal mass can be calculated by Eq. (3).

$$\int_0^h \mu(z)\phi^2(z)dz \tag{3}$$

where μ(z) = mass per unit height.

$$k = \frac{1.65^{\bar{\alpha}}}{\bar{\alpha}+\xi+1} \tag{4}$$

The rms along-wind acceleration $\sigma_{\ddot{x}(z)}$ as a function of height above the ground surface is given in Eq. (5).

$$\sigma_{\ddot{x}(z)} = \frac{0.85\phi_z \rho BhC_{fx} \overline{V_{\bar{z}}}^2}{m_1} I_z KR \tag{5}$$

where $\bar{V}_{\bar{z}}$ is the mean hourly wind speed at height z, ξ is the mode exponent. The maximum along-wind acceleration as a function of height above the ground surface is given in Eq. (6).

$$\ddot{X}_{\max}(z) = g_{\ddot{x}} \sigma_{\ddot{x}}(z) \tag{6}$$

$$g_{\ddot{x}} = \sqrt{2In(n_1 T)} + \frac{0.5772}{\sqrt{2In(n_1 T)}} \tag{7}$$

where T is the length of time over which the acceleration is computed, usually taken to be 3600 seconds to represent 1 hour.

4. Surface Roughness Categories

According to ASCE7-10 [5], ground surface roughness for the purpose of assigning an exposure category can be defined as follows. *Surface Roughness B:* Urban and suburban areas or other terrain with numerous closely spaced obstructions having the size of single-family dwelling or larger. *Surface Roughness C:* Open terrain with scattered obstructions having heights generally less than 30 ft (9.1 m). This category includes flat open country and grasslands. *Surface Roughness D:* Flat, unobstructed areas and water surfaces. This category includes smooth mud flats, salt flats, and unbroken ice. For a site located in the transition zone between exposure categories, the category resulting in the largest wind forces shall be used.

5. Building configuration

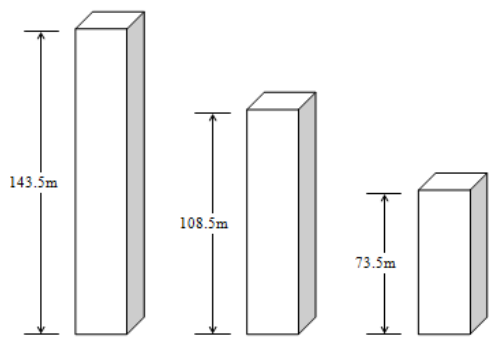

Fig 1: Rectangular prism shape buildings (40, 30, and 20 storey)

Basic rectangular prism shape buildings were chosen for the present study. To calculate natural frequencies of forty, thirty and twenty storey reinforced concrete buildings numerical studies were performed. The plan dimension of the building were: width W = 36 m and length L = 20 m. whereas, height of buildings are 143.5 m, 108.5 m and 73.5 m for 40, 30 and 20 storey buildings respectively. Rectangular prism shape buildings are shown in Figure 1. Natural frequencies and density for forty, thirty and twenty storey building are shown in Table 2.

TABLE II: Building configurations selected for present study

Building	Storey	Height (m)	Natural Frequency		Density (kN/m^3)
			x-direction	z-direction	
A	40	143.5	0.147	0.122	4.3
B	30	108.5	0.216	0.185	4.3
C	20	73.5	0.333	0.289	4.3

6. Results and discussion

Along-wind acceleration for forty, thirty and twenty storey reinforced concrete buildings were computed using ASCE7-10 method. Natural frequencies and densities of buildings were determined by numerical analysis

and used for the calculation of along-wind acceleration. Analyses were carried out for varying structural damping (0.01 to 0.07) and different categories of wind (B, C and D). Results for along-wind acceleration are shown in Figure 2 and Figure 3 for wind velocities 177 km/hr and 80.5 km/hr respectively. From the results it is evident that variation of along-wind acceleration is not linear for varying values of structural damping as shown in Figure 2 and 3. Minimum values of acceleration found at maximum structural damping and this values increased by 2.65 times when damping is minimum.

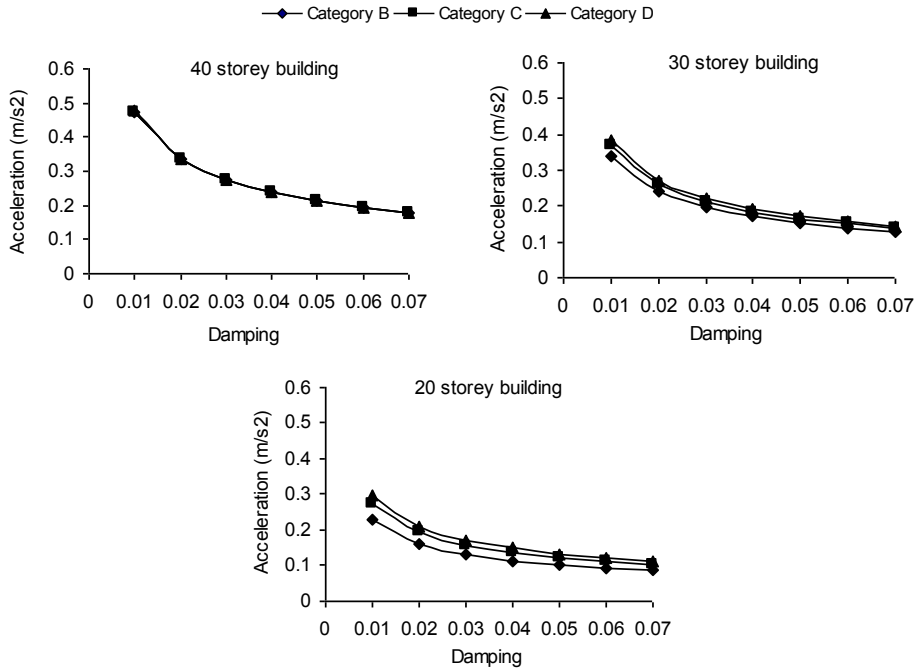

Fig 2: Along-wind acceleration of RC building for different structural damping and categories of surface roughness at wind velocity of 170 km/hr

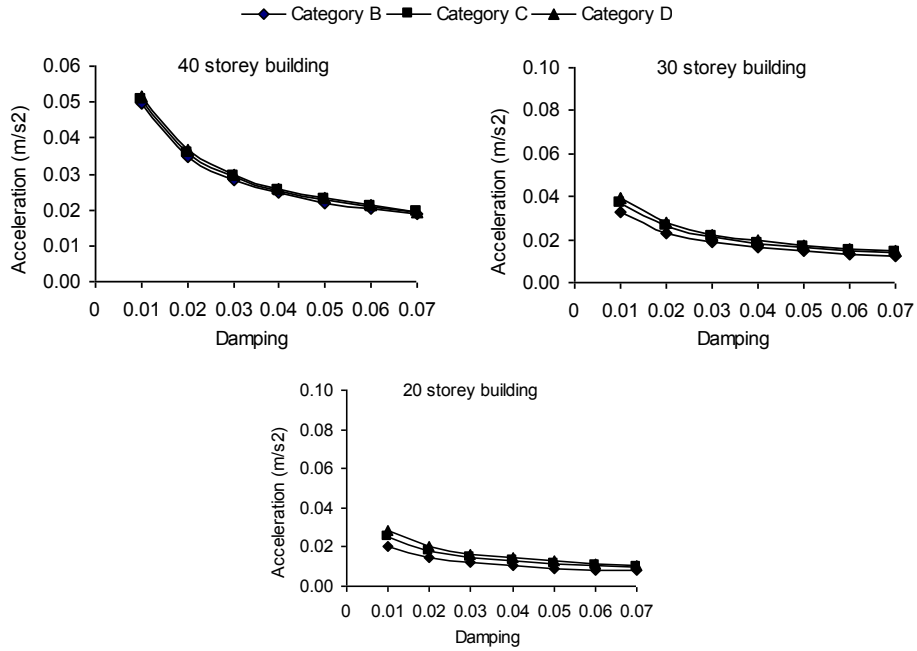

Fig 3: Along-wind acceleration of RC building for different structural damping and categories of surface roughness at wind velocity of 80.46 km/hr

Surface roughness categories show significant change in acceleration values for all the buildings particularly when wind velocity is low. Table 3 shows percentage change in acceleration values for surface roughness category B and C compared to category D where maximum acceleration found to be maximum. Acceleration values have been shown in Table 3 for two different velocities of wind.

TABLE III. Percentage change in along-wind acceleration

Wind velocity	Building storey	Percentage change in along-wind acceleration for different surface roughness categories B and C compared to D	
		B	C
170 km/hr	40	0.33%	0.34%
	30	3.84%	11.03%
	20	8.31%	23.80%
80.46 km/hr	40	2.28%	4.69%
	30	10.51%	15.27%
	20	5.81%	28.23%

Further, from Table 3 it is observed that percentage change in along-wind acceleration values are maximum for twenty storey building for different categories of surface roughness compared to acceleration values for 30 and 40 storey building.

7. Conclusion

Along-wind acceleration for forty, thirty and twenty storey buildings was evaluated using ASCE7-10 method. Surface roughness categories (B, C and D) and structural damping values between 0.01 and 0.07 were considered. It is found that variation of acceleration values for varying damping and different surface roughness categories is not linear. Also, it is found that, although magnitude of along wind acceleration is less for twenty storey building, it has maximum percentage change in the acceleration values for different surface roughness categories compared to thirty and forth storey buildings.

8. References

[1] B. S. Taranath, “Reinforced concrete design of tall buildings”, CRC Press, Taylor & Francis Group, Boca Raton, FL, USA, 2010.

[2] P. Mendis, T. Ngo, N. Haritos, A. Hira, “Wind loading on tall buildings”, *Electronic Journal of Structural Engineering*, EJSE Special Issue: Loading on Structures, 2007, pp 41-54.

[3] D, Boggs, “Acceleration indexes for human comfort in tall buildings - peak or rms?” In: CTBUH Monograph Chapter 13: Motion Perception Tolerance and Mitigation, 1997.

[4] K. C. S. Kwok, P. A. Hitchcock, M. D. Burton, “Perception of vibration and occupant comfort in wind-excited tall buildings”, *Journal of Wind Engineering and Industrial Aerodynamics*, vol. 97, pp 368–380, 2009.
http://dx.doi.org/10.1016/j.jweia.2009.05.006

[5] ASCE7-10, “Minimum design loads for buildings and other structures”, American Society of Civil Engineers, Reston, VA, USA, 2010.