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Wind-Induced Responses in Tall Buildings Using International Standards: A Review

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Abstract: This study investigates the impact of international wind loading regulations on tall buildings by analyzing major codes from the United States (ASCE 7), Australia (AS/NZS 1170.2), Canada (NBC), and India (IS 875). The research reveals significant differences in the estimation of wind loads, attributed to variations in exposure categories, wind speed profiles, and calculation methodologies. Notably, the gust loading factor is commonly used across these standards. The parameters used to estimate wind loads by the international standards are also discussed. The findings underscore the necessity for global wind load limitations and emphasize the importance of considering local factors to ensure the structural safety and integrity of tall buildings under varying wind conditions.
Keywords: Wind engineering, international standards, tall steel buildings, wind load estimation, gust loading factor, exposure categories

I. INTRODUCTION

Wind load regulations are crucial for high-rise building design, especially in non-seismic regions. Most countries have developed standards and requirements for wind load analysis to effectively analyze structures. Wind refers to the natural horizontal motion of air near the earth's surface, with horizontal motion being larger than vertical. In meteorology, vertical motion is less significant, but horizontal motion is crucial in building engineering.

The construction of skyscrapers globally increases building height annually, affecting occupant comfort. As height increases, lateral load-resisting systems take precedence over structural systems, which can only withstand gravitational stresses. Wind effects on structures, both static and dynamic, cause elastic bending and twisting. Dynamic analysis is crucial for tall, long-span, and thin structures due to fluctuating forces.

II. REVIEW OF LITERATURE

The following works of literature are studied to compare wind load provisions specified in the major national standards i.e. IS 875 (III):2015, ASCE 7-16, AS/NZS 1170.2-2011, and NBCC 2015.

1) Yin Zhou, Tracy Kijewski, and Ahsan Kareem (2002), paper examine the disparity in wind effects estimated by international codes and standards for tall structures, focusing on ASCE 7-98 for the US, AS1170.2-89 for Australia, NBC-1995 for Canada, RLBAIJ-1993 for Japan, and Eurocode-1993 for Europe.
2) M. Gu, and Y. Quan (2004), This paper explores the dynamic responses of super-tall buildings in a wind tunnel using high-frequency force balance techniques, identifying 15 models, and generating new power spectra, coefficients, and shear force formulas.
3) Yukio Tamura, John D. Holmes, Prem Krishna, Lu Guo, and Akira Katsumura (2009), study compares wind load calculations on a medium-rise building using fifteen Asia-Pacific wind loading regulations and standards. Results show no significant correlation between dynamic response factors and along-wind load effects, but a clear correlation between net peak cladding force coefficients and cladding pressures. The coefficients of variance are projected to be between 17% and 23%.
4) Muhammad Azhar Saleem (2012), This study aimed to simplify wind load calculations for tall, regularly shaped buildings using NBC 2005 and ASCE 7-05 wind loads. A simplified equation was developed for exposure scenarios, with ASCE 7-05 and NBC 2005 results consistent with the simplified computation.
5) Kiran Kamath, N. Divya, Asha U Rao (2012), This paper investigates the behavior of 3D models for reinforced concrete structures with central core walls and without outriggers using ETABS software. The study considers bending moments, shear force, lateral deflection, peak acceleration, and inter-story drifts. The study finds that an outrigger's performance is most effective when its relative height is equal to 0.5.

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6) R. M. Faysal (2014), The article compares the wind load of BNBC codes (BNBC1993 and BNBC2010) with NBC-India-2005, IBC 2009, and ASCE 7-05 using factored total wind pressure. BNBC 2010 has a slightly lower wind load than IBC 2009 and ASCE 7-05.
7) A.U. Weerasuriya and M.T.R. Jayasinghe's (2014), study calculates wind load for a medium-rise building in Sri Lanka using five international codes and standards. The analysis reveals that Australian and Eurocode specifications provide higher wind loads than British specifications.
8) M. R. Wakchaure, Sayali Gawali (2015), This study analyzes building shapes using analytical techniques, calculating wind loads using I.S. 875(part 3)-1987, and comparing models using ETAB's 13.1.1v. The building form with structural efficiency and good wind loading is chosen.
9) Muftha A. Abdusemed and Ashok K. Ahuja (2015), The paper describe an experimental study on high-rise building models under stand-alone and interference conditions using an open circuit boundary layer wind tunnel. It measures base shear, base moment, twisting moment, wind incidence angle, and distance between the building and the interfering building.
10) J. Pandya, G. Acharya, Y. Shah (2016), This study compares wind load calculations for tall buildings using Australian/New Zealand and Indian standards, focusing on wind speed, pressure, and force. It concludes that while the theoretical foundation and methodology are similar, the calculated load may differ for the same structure.
11) Shams Ahmed, Prof. S Mandal (2017), The study compares the Indian code for wind load computation on tall structures with five major foreign codes and standards, focusing on the gust factor method. It reveals that the dynamic response factor achieved varies significantly due to each code's distinct mean wind velocity profile.
12) Daniel C, Levin Daniel J V, Joel Shelton J, Arun Raj E, Vincent Sam Jebadurai S, Hemalatha G (2017), The study compares the Indian code and American code for wind load design on a G+4-story building. The American code deforms less under wind impact, making it more effective for wind design due to decreased failure risk.
13) T.J. Nikose, Dr. R.S. Sonparote (2018), The study compares the dynamic wind response of tall structures using IS 875, IS 875 (part-3):1987, 2015, and AS/NZS 1170.2-2011. It found that the Australian and Indian wind loading codes allow similar allowances for dynamic along-wind force.
14) Md Ahesan, Md Hameed, Amit Yennawar (2018), This paper compares wind load requirements of worldwide and Indian standards using three wind-loading codes: IS 875 (part-3):1987/2015, ASCE 7-05, and AS/NZS 1170.2:2011. The American standard doesn't allow force variation, while Indian and Australian standards allow it.
15) Md Ahesan Md Hameed, Salman Shaikh (2019), This paper compares IS 875 (part-3):2015 and IS 875 (part-3):87, using Indian and American standards. It analyzes plan areas of regular forms like squares, rectangles, ellipses, circles, and rectangular with two semicircular shapes. The study concludes that an elliptical rectangle minimizes wind load.
16) Saba Rahaman, Arvind K. Jain, S. D. Bharti, T. K. Datta (2020), The paper compares seven international code methods for designing reinforced concrete chimneys for wind forces, demonstrating equivalent static formulas follow Vickery and Basu's or Ruscheweyh's methods, emphasizing aero-elastic effects in design.
17) J X Lim and NZN Azizan (2021), study compares high-rise building performance using BS 8110, EC-2, and EC-2 and EC-8 design codes. It found that BS 8110's safety factor demands the highest cost, and incorporating seismic load consideration into structural design reduces expenses.
18) B. Kiriparan, J.A.S.C. Jayasingle, and U.I. Dissanayake (2021), This paper discusses dynamic wind loading history and international wind codes. It uses a 46-story wall frame structure as an example. The study concludes that current wind codes can predict across-wind loading with some precision and along-wind loading more accurately.

III. IMPORTANT PARAMETERS

Table 1 summarizes the key parameters utilized by various international codes and standards to estimate the gust factor. The table illustrates all the important parameters used by the codes and standards of India, America, Australia, and Canada.

Table 1: Important Parameters

Parameters	IS 875 (Part-3): 2015	ASCE 7-2016	AS/NZS 1170-2: 2011	NBCC 2015
Design wind speed	$V_{z,d} = V_b k_1 k_2 k_3 k_4$	Velocity pressure $q_z = 0.613 K_z K_{zt} K_d K_e V^2$	$V_{des,\theta} = V_R M_d (M_{z,cat} M_s M_t)$	$V_H = \bar{V}\sqrt{C_{eH}}$

(m/s) at height z,				
Gust Effect factor	$G = 1 + r\sqrt{[g_v^2 B_s(1+\phi)^2 +}$	$G = 0.925\left(\frac{1+0.7 g_Q I_z Q}{1+0.7 g_v I_z}\right)$	$C_{dyn} = \frac{1+2I_h\sqrt{\left[g_v^2 B_s + \frac{H_s g_R^2 SE}{\zeta}\right]}}{1+2g_v I_h}$	$C_g = 1 + g_p\frac{\sigma}{\mu}$ $\frac{\sigma}{\mu} = \sqrt{\frac{K}{C_{eH}}\left(B + \frac{sF}{\beta}\right)}$
Equivalent height of structure	H	0.6H	H	H
Peak factor for resonant response	$g_R = \sqrt{2\ln(3600 f_a)}$	$g_R = \sqrt{2\ln(3600 n_1)} + \frac{}{\sqrt{2\ln}}$	$g_R = \sqrt{2\log_e(600 f_o)}$	$g_p = \sqrt{2\log_e(3600\nu)} + \frac{}{\sqrt{2}}$
Size reduction factor	$S = \frac{1}{\left[1+\frac{3.5 f_a h}{V_{h,d}}\right]\left[1+\frac{4 f_a b_{0h}}{V_{h,d}}\right]}$	$R = \sqrt{\frac{1}{\beta}R_n R_h R_B (0.53 + 0.47R_L)}$	$S = \frac{1}{\left[1+\frac{3.5 n_a h(1+g_v I_h)}{V_{des,\theta}}\right]\left[1+\frac{4 n_a b_{0h}(1+g_v I_h)}{V_{des,\theta}}\right]}$	$S = \frac{\pi}{3}\left[\frac{1}{1+\frac{8 f_{nD} H}{3V_H}}\right] * \left[\frac{1}{1+}\right]$
Background factor	$B_s = \frac{1}{\left[1+\frac{\sqrt{0.26(h-s)^2+0.46 b_{sh}^2}}{L_h}\right]}$	$Q = \sqrt{\frac{1}{1+0.63\left(\frac{B+h}{L_z}\right)^{0.63}}}$	$B_s = \frac{1}{\left[1+\frac{\sqrt{0.26(h-s)^2+0.46 b_{sh}^2}}{L_h}\right]}$	A function of w/H determined from Figure 4.1.7.8
Gust energy factor	$E = \frac{\pi N}{(1+70.8N^2)^{5/6}}$	$R_n = \frac{7.47 N_1}{(1+10.3N_1)^{5/3}}$	$E = \frac{\pi N}{(1+70.8N^2)^{5/6}}$	$E = \frac{x_0^2}{(1+x_0^2)^{4/3}}$
Effective reduced frequency	$N = \frac{f_a L_h}{V_{h,d}}$	$N_1 = \frac{n_1 L_z}{V_z}$	$N = \frac{n_a L_h(1+g_v I_h)}{V_{des,\theta}}$	$N = \frac{f_{nD} H}{V_H}$
Measure of turbulence length scale	For Terrain category 1 to 3 $L_h = 85\left(\frac{h}{10}\right)^{0.25}$ For Terrain category 4 $L_h = 70\left(\frac{h}{10}\right)^{0.25}$	$L_z = l\left(\frac{z}{33}\right)^{\epsilon}$ $L_z = l\left(\frac{z}{10}\right)^{\epsilon}$ Table 26.11-1	$L_h = 85\left(\frac{h}{10}\right)^{0.25}$	$L_h = 1220$ (Constant for all)

These parameters are essential in determining the gust factor, with each code providing specific methodologies for their application in wind load calculations.

IV. CONCLUSIONS

The literature analysis on global wind loading standards for tall structures finds significant variations in wind load estimations across several codes, including ASCE 7-98 (US), AS1170.2-89 (Australia), NBC-1995 (Canada), RLBAIJ-1993 (Japan), and Eurocode-1993 (Europe).

These variations result from various approaches to defining exposure categories, wind speed profiles, and calculating methodologies. Studies focus on developing specific formulas to better predict dynamic wind responses, hence improving structural design skills. The study highlights the importance of established processes for ensuring consistent safety and efficiency while designing tall buildings to resist different wind conditions.

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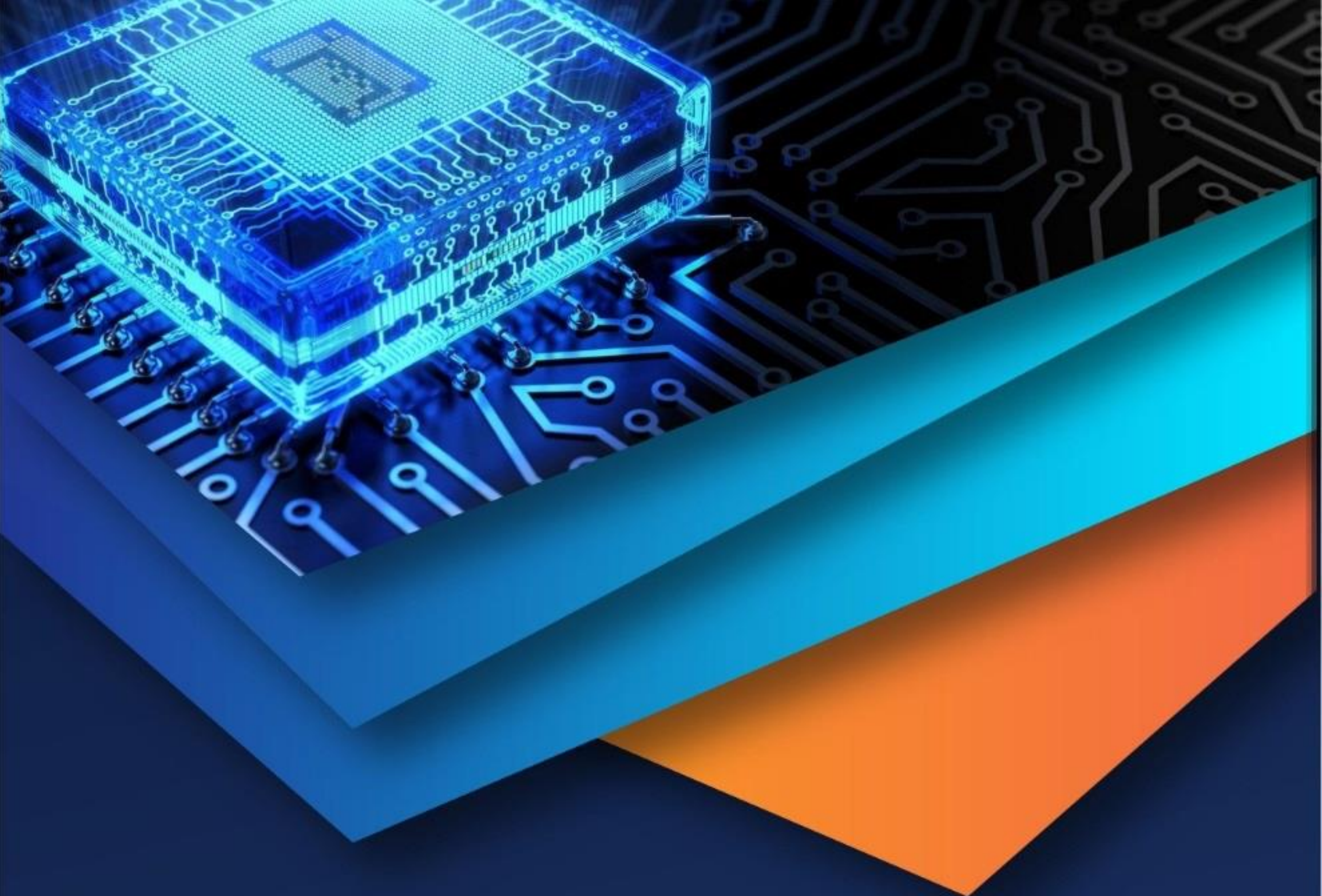

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