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Comparative Study of Along-Wind Response of Major International Codes with Indian Code

Indian Code (IS 875 Part-III (2015))

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***Abstract*— The research paper discusses a comparative study of five major international codes and standards with the latest Indian Code for wind load i.e. IS 875 Part-III(2015) for along wind loads on tall buildings and other provisions for along wind response on tall buildings by Gust Factor Method (GFM). The major international codes and standards of wind loads included within the scope of this research paper are ASCE-7-98 (United States)[3], AS1170.2-89 (Australia)[5], NBC-1995 (Canada), RLB-AIJ-1993 (Japan)[4], Eurocode 1-4 (1993)[7]. The research work is basically an inclusion of latest Indian Code IS-875 Part-III (2015) in the comparative study published by Yin Zhou, Tracy Kijewski and Ahsan Kareem[1]. Major emphasis is put on the gust factor method approach for estimating along wind loads on tall buildings. A detailed example is also solved at the end so as to facilitate quantitative comparison.**

***Keywords*— *Building, Wind Loads, Gust Factor Method, Along Wind Effects, Building Codes*.**

I. INTRODUCTION

In modern era buildings are made very tall, slender and asymmetrical, with special architectural and aesthetic requirements. Due to developments of new building materials and construction techniques, these buildings are becoming much lighter and more slender than earlier. Buildings of modern era are very susceptible to wind load. These buildings are often built in groups as in case of a metropolis, and their responses are different from the response of an isolated building. This is due to complex interference effects induced by turbulent wind flow field.

In order to estimate these wind loads on various types of structures, codes of practice of several countries are available. These codes have different approaches to estimate wind load such as gust factor method etc. This paper is mainly based upon the comparative study of dynamic response factor as determined using the gust factor method of latest Indian standard code for wind loads, i.e., IS 875 Part-III (2015) and five other major international codes and standards. All the values and data of five major international codes is obtained from the recent comparative study published by Zhou, Kijewski and A Kareem [1] (2002) whereas and all the values and data for Indian code is calculated by the author(s).

For the evaluation of wind loads on buildings using gust factor method determination of Turbulence Intensity, Peak factor, Gust factor and Gust wind speed are required. In order to determine the aforementioned parameters, wind speed averaging is done with respect to time. This averaging times differs from code to code. Apart from averaging time, definition of several other wind characteristic parameters also differ from each other. The salient parameters are category wise turbulence intensity vs. height curve, dynamic response factor, background factor, peak factor, size reduction factor etc.

Many comparative studies have pointed out a large scatter in predicting the wind loads hence an in-depth investigation is required. As due to globalization and unification of construction industries around the globe unification of these standard is important and understanding the underlying differences is a must.

Significant works have already been published by various authors on gust factor method. Gust factor application in civil engineering was first introduced by Davenport(1967)[6]. Several modifications to Davenport's work have been made, notably by Vellozzi and Cohen (1968)[8], Vickery (1970)[9]. Notable comparative studies focussing on Gust factor method have been done by Lee and Ng (1988), recently Kijewski and Kareem (1998) also compared few standard international codes. S. Behra and A. K. Mittal (2012)[11] also conducted a similar comparative study for buildings and towers.

Averaging Time:

The averaging time is basically the observation time during wind monitoring operation using anemometers. The averaging time varies from country to country depending on the way wind data is collected in different regions. In Indian Code IS-875 Part-III (2015) the averaging time used is 1Hour (3600 seconds). The ASCE 7 (1998) and AS1170.2 (1989) codes uses 3 seconds averaging time whereas Eurocode (1993) and RLB-AIJ (1993) uses 10 minutes (600 seconds) averaging time.

Table 1 The given below highlights the various averaging time used in different codes under the consideration.

TABLE I. AVERAGING TIME IN CODES AND STANDARDS[1]

	IS 875 Part-III (2015)	ASCE 7 (1998)	AS1170.2 (1989)	NBC (1995)	RLB-AIJ (1993)	Eurocode (1993)
Basic wind velocity or Basic wind pressure	1 Hour	3 Sec	3 Sec	1 H	10 Min	10 Min

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II. DETAILED COMPARISON OF RELEVANT PARAMETERS :

Table 2 presents comparison of all the important parameters used in estimation of Gust Factor. Following is the list of terms:

Cdyn : Dynamic Response Factor

B : Background Factor

s : Size Reduction Factor

gr, gv, gf : Peak Factors

TABLE II. PARAMETERS FOR CALCULATION OF GUST-LOADING FACTORS IN CODES AND STANDARDS[1]

	IS 875 Part-III (2015)	ASCE 7(1998)	AS1170.2(1989)	NBC(1995)	RLB-AIJ(1993)	Eurocode (1993)
G[a]	$\frac{1+2I_h\left[g_v^2B_s+\frac{H_s g_r^2 SE}{\beta}\right]^{0.5}}{1+2g_v.I_h}$	$\frac{0.925(1+\sqrt{g_Q^2B+g_r^2R})}{1+g_v.r}$	$1 + r\left(g_v^2B(1+w)^2+g_f^2R\right)^{0.5}$	$1+g_f r(B+R)^{0.5}$	$1+g_f r(B+R)^{0.5}$	$\frac{1+g_f r(B+R)^{0.5}}{1+3.5r}$
T	*3600 s*	*3600 s*	*3600 s*	*3600 s*	*600 s*	*600 s*
$\bar{z}$	H	$0.6H$	H	H	H	$0.6H$
r	$2.I_{\bar{z}}$	$1.7.I_{\bar{z}}$	$2.I_{\bar{z}}$	$\sqrt{2K/C_{eH}}$	$(3+3\alpha)/(2+\alpha).I_{\bar{z}}$	$2.I_{\bar{z}}$
g	$g_R=\sqrt{2\ln(3600f_0)}$ $g_v=3.5$	$g_Q=g_v=3.4$ $g_R=g_R(Tf_1)^h$	$g_f=\sqrt{2\ln(Tf_1)}$ $g_v=3.7$	$g_f=g_R(T.v)$ $v=f_1\sqrt{SE/(SE+\varepsilon\beta)}$	$g_f=\sqrt{2\ln(T.v)+1.2}$ $v=f_1\sqrt{(R)/(B+R)}$	$g_f=g_R(T.v)$ $v=\sqrt{(v_0^2B+f_1^2R)/(B+R)}$
B	$\left(1+\frac{[66(h-s)^2+64b_{sh}^2]^{0.5}}{2L_h}\right)^{-1}$	$\frac{1}{1+0.63\left(\frac{B+H}{L_{\bar{z}}}\right)^{0.63}}$	$\frac{1}{1+\frac{\sqrt{36H^2+64B^2}}{L_H}}$	$\frac{2}{3}\int_0^{914/H}\frac{x.dx}{\left(1+\frac{xH}{457}\right)\left(1+\frac{xB}{122}\right)(1+x^2}$	$1 - \frac{1}{\left\{1+5.1\left(\frac{L_H}{\sqrt{HB}}\right)^{1.3}\left(\frac{B}{H}\right)^k\right\}^{1/3}}$	$\frac{1}{1+0.9\left(\frac{B+H}{L_{\bar{z}}}\right)^{0.63}}$
E	$\frac{\pi N}{(1+70N^2)^{5/6}}$	$\frac{9.5N_1}{(1+10.3N_1^2)^{5/3}}$	$\frac{0.6N_1}{(2+N_1^2)^{5/6}}$	$\frac{2N_1^2}{3(1+N_1^2)^{4/3}}$	$\frac{4N_1^2}{(1+71N_1^2)^{5/6}}$	$\frac{6.8N_1}{(1+10.2N_1)^{5/3}}$
S	$\frac{1}{\left[1+\frac{4f_0h(1+g_vI_h)}{V_h}\right]\left[1+\frac{4f_0b_{0h}(1+g_vI}{V_h}\right.}$	$R_HR_B(0.53+0.47R_D)$	$\frac{1}{\left[1+\frac{3.5f_1H}{V_H}\right]\left[1+\frac{4f_1B}{V_H}\right]}$	$\frac{1}{\left[1+\frac{3.5f_1H}{V_H}\right]\left[1+\frac{4f_1B}{V_H}\right]}$	$\frac{1}{\left[1+\frac{3.5f_1H}{V_H}\right]\left[1+\frac{4f_1B}{V_H}\right]}$	R_HR_B
L_h	$100\left(\frac{h}{10}\right)^{0.25}$	$I\left(\frac{h}{10}\right)^{\varepsilon}$	$1000\left(\frac{h}{10}\right)^{0.25}$	$100\left(\frac{h}{30}\right)^{0.5}$	$100\left(\frac{h}{10}\right)^{0.25}$	$300\left(\frac{h}{1300}\right)^{\varepsilon}$

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III. COMPARISON OF WIND VELOCITY PROFILE:

The mean wind velocity profile is affected by averaging time, ground roughness, fetch length. As different codes and standards included within the scope of this work have different averaging time hence different wind velocity profiles are observed. Broadly the wind velocity profile can be classified as either logarithmic or power law, ASCE 7 (1998) and Eurocode utilize logarithmic wind velocity profile whereas the remaining codes and standards including IS 875 Part-III (2015) uses power law type wind velocity profiles. However all the wind velocity profiles can be represented as a general power law of form:

$$V_z = V_0.b.(z/10)^a$$

In the above general power law a, b are constants which depend upon the terrain category. For an open terrain case exposure 2(C) at 10 m height, b is equal to unity since the basic wind velocity is defined for this exposure. Table 3 presents values of a, b for respective codes and standards for category 2(C) terrain.

TABLE III. MEAN WIND VELOCITY PROFILE IN CODES AND STANDARDS[1]

Category	IS 875 part-III(2015)		ASCE 7(1998)		AS1107.2(1989)		NBC(1995)		RLB-AIJ(1993)		Eurocode(1993)	
	a	b	a	b	a	b	a	b	a	b	a	b
2(C)	0.092	1.00	0.11	1.00	0. 7	1.00	0.14	1.00	0.15	1.00	0.16	1.00

IV. COMPARISON OF TURBULENCE INTENSITY PROFILE

The turbulence intensity profile can also be expressed in terms of a power law as follows:

$$I(z)=c.(z/10)^{-d}$$

where c and d are constants depending on the terrain category and z denoted height in 'm'. These coefficients are given in codes and standards or can be found by using simple mathematical techniques.

In order to determine the value of c, the z is chosen as 10 m and corresponding value of Iz is determined. In order to determine the value of d following mathematical manipulations were carried out.

Taking natural logarithm both sides in the equation(i), we get

$$ln(I_Z) = ln(c) - d.ln(z/10)$$

$$d = \left(ln\left(\frac{c}{I_z}\right) \Big/ ln\left(\frac{z}{10}\right) \right).$$

The average of various values of d obtained from above equation is taken as approximate value for coefficient d. In order to determine the coefficient the above process is repeated on a spread sheet as shown in Table 4.

For the purpose of comparison between turbulence intensity values with respect to height and for various exposure terrains of various codes the coefficients c, d have been shown below in Table 5.

V. QUANTITATIVE COMPARISON OF CODES AND STANDARDS :

In order to compare the codes and standards in a quantitative manner a numerical was solved and final results are compared quantitatively for better understanding

An example is solved for better understanding and comparison of various codes and standards. The building considered has following parameters H = 200 m, B = D = 33 m, f1 = 0.2 Hz, and linear mode shape in two translation directions, z = 0.01, Cd = 1.3; and building density = 180 kg/m3. The building is located so that it has exposure 4(A) on one side and exposure 2(C) on the other, and the basic 3 s wind velocity = 40 m/s. The table below shows the values for the numerical from different codes and standards.

TABLE IV. CALCULATION OF COEFFICIENT C, D USING SPREADSHEET FOR IS 875 PART-III (2015)

Height (z) mtrs	category 1	category 2	category 3	category 4	d_1	d_2	d_3	d_4
10	0.157	0.183	0.239	0.342				
15	0.152	0.176	0.225	0.342	0.07982	0.09619	0.14887	0
20	0.147	0.171	0.215	0.342	0.09494	0.09784	0.15267	0
30	0.14	0.162	0.203	0.305	0.10431	0.11094	0.1486	0.10422
40	0.133	0.156	0.195	0.285	0.11966	0.11514	0.14676	0.13151
50	0.128	0.151	0.188	0.27	0.12688	0.11942	0.14913	0.14687
75	0.118	0.14	0.176	0.248	0.14172	0.13293	0.15185	0.1595
100	0.108	0.131	0.166	0.233	0.16247	0.14518	0.15828	0.16667
150	0.095	0.117	0.15	0.21	0.1855	0.16517	0.17201	0.18009
200	0.085	0.107	0.139	0.196	0.20482	0.17914	0.18092	0.18583
250	0.08	0.098	0.129	0.183	0.20945	0.19401	0.19157	0.19426
300	0.074	0.92	0.121	0.173	0.22115	0.20219	0.20012	0.20037
400	0.068	0.082	0.108	0.155	0.22682	0.21761	0.21533	0.21453
500	0.58	0.074	0.098	0.141	0.25455	0.23144	0.22788	0.22649
Average					0.164007	0.1544	0.172615	0.146949
coeff. *c*	0.157	0.183	0.239	0.342				

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TABLE V. TABLE 5: COMPARISON OF COEFFICIENTS C, D OF DIFFERENT CODES AND STANDARD[1]

Category	IS 873 Part-III (2015)		ASCE 7 (1998)		AS1107.2 (1989)		NBC (1995)		RLB-AIJ (1993)		Eurocode (1993)	
	c	*d*	*c*	*d*	*c*	*d*	*c*	*d*	*c*	*d*	*c*	*d*
4(A)	0.342	0.147	0.45	0.167	0.453	0.3	0.621	0.36	0.402	0.4	0.434	0.45
3 (B)	0.239	0.173	0.3	0.167	0.323	0.3	0.335	0.25	0.361	0.32	0.285	0.3
2(C)	0.183	0.154	0.2	0.167	0.259	0.3	0.2	0.14	0.259	0.25	0.189	0.2
1 (D)	0.157	0.164	0.15	0.167	0.194	0.3			0.204	0.2	0.145	0.15
E									0.162	0.15		

VI. QUANTITATIVE COMPARISON OF CODES AND STANDARDS :

In order to compare the codes and standards in a quantitative manner a numerical was solved and final results are compared quantitatively for better understanding. An example is solved for better understanding and comparison of various codes and standards. The building considered has following parameters H = 200 m, B = D = 33 m, f1 = 0.2 Hz, and linear mode shape in two translation directions, z = 0.01, Cd = 1.3; and building density = 180 kg/m3. The building is located so that it has exposure 4(A) on one side and exposure 2(C) on the other, and the basic 3 s wind velocity = 40 m/s. The table below shows the values for the numerical from different codes and standards.

TABLE VI. QUANTITATIVE COMPARISON OF CODES AND STANDARDS[1]

	IS 875 Part-III (2015)		ASCE 7 (1998)		AS1107.2(1989)		NBC(1995)		RLB-AIJ(1993)		Eurocode (1993)	
	4(A)	2(C)	4(A)	2(C)	4(A)	2(C)	4(A)	2(C)	4(A)	2(C)	4(A)	2(C)
V_0	26	26	40	40	40	40	26	26	27	27	27	27
z	200	200	120	120	200	200	200	200	200	200	120	120
V_z	33.0	33.8	27.5	38.1	26.7	37.3	32.6	39.5	30.4	42.3	30.7	39.3
L_z	211	211	190	250	2115	2115	1220	1220	1220	258	258	197
B	0.616	0.616	0.583	0.624	0.633	0.633	0.300	0.300	0.582	0.582	0.500	0.529
E	0.054	0.063	0.140	0.144	0.094	0.117	0.170	0.191	0.080	0.100	0.106	0.109
S	0.046	0.064	0.048	0.079	0.080	0.123	0.077	0.101	0.154	0.212	0.087	0.121
R	0.248	0.403	0.525	0.889	0.596	1.138	1.031	1.524	0.967	1.655	0.726	1.039
g_v g_R	3.5 3.63	3.5 3.63	3.40 3.79	3.40 3.79	3.70 3.63	3.70 3.63	3.759 3.768	3.759 3.768	3.209 3.325	3.209 3.325	3.208 3.225	3.208 3.225
G	0.965	1.01	2.691	1.854	2.495	2.021	2.833	2.544	2.103	1.868	2.500	2.026

VII. RESULTS AND DISCUSSION :

The results obtained are quite different in-spite of same basic gust wind velocity with averaging time of 3 seconds, this is due to widely varied definitions of wind characteristics in different codes and standards. The dynamic response factor obtained is quite different for different codes because each code uses different mean wind velocity profile.

The GLF (Gust Loading Factor) values estimated by ASCE 7 and Eurocode 1-4 (1993) are also distinct due their varied definition of wind characteristic parameters [1]. The Indian code IS 875 Part III (2015) has strikingly predicted the lowest values among all the codes the lower value may be due to wrong estimation of design wind speed as the wind speed was given for 3 s averaging time but IS 875 Part-III uses 1 h averaging time due to which this speed has to be reduced for 1 h averaging time, error may have crept in during this reduction. Moreover, after discussion it can be concluded that the final values of dynamic response factor vary greatly from code to code so the values of 0.965 and 1.01 are deemed to be rightly representing the prediction of dynamic response factor as per IS 875 Part-III (2015).

It can be concluded that the scatter in values obtained from different codes is mainly due to variation in definition of wind characteristics parameters and different averaging times involved. To achieve unification in codes and standards it is necessary to arrive at unified and common definition of all the wind characteristic parameters such as size reduction factor, peak factor, background factor etc, including the averaging times.

REFERENCES

[1] Y. Zhou, T. Kijewski and A. Kareem, “Along-Wind Load Effects on Tall Buildings: Comparative Study of Major International Codes and Standard”, Journal of Structural Engineering vol III June 2002 pp 231-237

[2] M.M. Majed, P. Srinivas Rao, “A Comparative Study of Wind Forces on Tall Building by Static Method and Dynamic Method Per IS 875-Part-III

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(1987)", International Journal of Scientific and Technology Research, ISSN 2319-8885, vol. 02,,Issue.15 November-2013.

[3] ASCE (1999) "Minimum Design Loads for Buildings and Other Structures" ASCE 7-98, Reston, Va

[4] Architectural Institute of Japan Recommendations for Loads on buildings, Architectural Institute of Japan, Tokyo (1996),

[5] "Australian Standards: SAA Loading code, Part 2 - wind loads" (1989) AS1170.2-89, Australia

[6] A. G. Davenport,. (1967), "Gust Loading Factors", J. Struct. Div., ASCE,93(3), 11 - 34

[7] Eurocode 1. (1995), Basis of Design and Actions on Structures- Part 2-4: Actions on Structures - wind actions, European Pre standard ENV 1991-2-4

[8] J. Vellozzi, E. Cohen, Gust response factors, J. Struct Div., ASCE 94 vol 6, pp1295-1313. (1968),

[9] B. J. Vickery, "On the reliability of Gust loading factors, Proc., technical meeting Concerning Wind Loads on Buildings and Structures", building Science Series 30, National bureau of Standards, Washington, D. C., 296-312 1970

[10] India Standards (IS), (2015), Draft Indian Standard Code of practice for Design Loads (other than earthquake) for Buildings and Structures (Part 3) Wind Loads (Third revision), Doc: CED37, 7792

[11] S. Behra and A.K. Mittal, "A Comparative Study of Wind Forces on Tall Building and Tower as per IS 875-Part-III (1987)", VI National Conference on Wind Engineering 2012 pp256-262

[12] Rahman Abdur, Fancy Saiada and Bobby Shami Ara (2012). "Analysis of drift due to wind loads and earthwuake loads on tall structures by programming language c'" International Journal of Scientific and Engineering Research, Vol. 3, Issue 6, June-2012 1/ISSN 2229-5518/pp 1-4.

[13] P. Harikrishna, A. Abraham, S. Arunachalam, S. Selvi Rajan and G. Ramesh Babu "Pressure measurement studies on a model of a tall building with different plan shapes along the height" ,The seventh Asia-Pacific conference on wind engineering, Taipei, Taiwan, November 8-12, 2009.

[14] Hemil Chauhan, Manish Pomal, Gyayak Bhuta "A comparartive study of wind forces on high-rise buildings as per IS 875(III)-1987 and proposedd draft code (2011)" Global research analysis, ISSN no.2277-8160, Vol. 2, No. 5, May 2013..

[15] Ranjitha K. P, Khalid Nayaz Khan, Dr. N. S. Kumar, Syed Ahamed Raza. "Effect of Wind Pressure on R.C Tall Buildings usin gust Factor Method" journal of engineering research and technology, ISSN"2278-0181, Vol. 3, No. 7, July 2014

[16] Dr. B. Dean Kumar and Dr. B. L. p Swami "Critical gust pressures on tall building frames-review of codal provisions" Journal of advanced technology in civil engineering, ISSN:2231-5721, Vol. 1, No. 2, 2012

[17] Yin Zhou, Ahsan Kareem and Ming Gu "Gust loading factors for design application" Journal of structural engineering, ASCE Vol. 127, No. 2, pp.168-175.

[18] Ryan Merrick and Girmaa Bitsuamlak "Shape effects on the wind induced reponse on high rise buildings" Journal of Wind and Engineering, Vol. 6, No. 2, July 2009, pp. 1-18.

[19] Hajra B and Godbole P.N.(2006). "along Wind load on Tall Buildings Indian Codal Provisions." National Conference on Wind Engineering 2006 Kolkata, pp 285-292.

[20] Hasan Noor sadiqul, Sayed Shiblee, Sobuz Habibur Rahman and Ioannou Costas (2011). "Effect of non sway and sway methods for analysis and design of reinforced concrete frames for multi-storey building", International Journal of the Pysical Scieces Vol. 6(17), 2 September,(2011), pp. 4294-4301.