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Comparison of Wind Load among BNBC and other Codes in different type of areas

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Abstract: Wind load as a part of lateral load is very important concern in structural analysis. Rationale wind load can be ensured in a structure by following established and tested building codes. In Bangladesh this purpose has been served by BNBC since 1993. The current BNBC 1993 is going to be replaced by an updated BNBC code which is popularly known as BNBC 2010. In this paper both BNBC codes are studied and compared between them as well as with NBC-India- 2005, IBC 2009 and ASCE 7-05 in terms of wind load using a parameter termed as factored total wind pressure. The investigation reveals that wind load in urban areas (Exposure A) according to BNBC 2010 is slightly higher than BNBC 1993. But wind load in obstructed and unobstructed open terrain type areas (Exposure B and C) according to BNBC 2010 is notable lower than BNBC 1993. Further wind load according to BNBC 2010 is exactly equal to wind load according ASCE 7-05 and slightly less than IBC 2009. Again, in urban and obstructed open terrain type areas NBC-India- 2005 is most conservative while BNBC 1993 is most conservative in unobstructed open terrain type areas in terms of wind load among the comparing codes.

Keywords: *BNBC, Other codes, Factored total wind pressure, Different type of areas, Increase or Decrease.*

1. Introduction:

Bangladesh National Building Code (BNBC) was first organized in the year of 1993(Atique & Wadud, 2001). Afterwards initiative has been taken to update BNBC 1993 and a draft copy has already been prepared (BRTC & BUET,2010 ; Shafi, 2010). A total change at wind load provision in the proposed draft of the code are noticed. The new wind load provision in BNBC 2010 is an adaptation from ASCE 7-05. This proposed copy will be termed as BNBC 2010 in the rest portion of the discussing paper.

This paper aims at the comparison of provisions of wind load analysis given between BNBC 1993 and BNBC 2010. The designers who use BNBC 1993 as their basis to calculate the design wind load, this comparative study will provide them with a relation showing percent increase or decrease of design wind load in the new code with respect to the old one. Again, the comparison of BNBC with other building codes will inform how much factor of safety against wind disaster is imposed considering the economical aspects and population of our country.

2. Methodology:

For wind pressure, BNBC 2010 has been compared with BNBC 1993, NBC-India- 2005 and IBC 2009. Basic features of these codes are presented in table 1. In all codes, calculation of design wind pressure is a two-step process. In BNBC 1993, first the sustained wind pressure is calculated on the basis of importance of structure, height and exposure condition and basic wind speed, which in turn depends on the region the structure is located in. The sustained wind pressure is then converted to design wind pressure by multiplication with the gust coefficient and pressure coefficient for the structure.

In BNBC 2010, first the sustained wind pressure is calculated on the basis of importance of structure, exposure and topographic condition of the region, directionality factor and wind basic wind speed, which in turn depends on the region where the structure is located. Finally, the design wind pressure is calculated by multiplying the sustained wind pressure with gust effect factor and external pressure co-efficient and adjusting the value for internal pressure. For both code, the exposure of the structure to wind forces is a function of terrain type, vegetation and built up environment in the surrounding and Pressure coefficient considers the direction of wind relative to the structure and roof slope.

In NBC-India-2005, the design wind speed at various heights is determined first on the basis of risk level, terrain roughness, local topography and geometry (height, size etc.) of the structure. The terrain factor refers to exposure category. In addition another factor describes the local topography e.g. hills, valleys, cliffs, ridges etc. In the second step, design wind speed is converted to pressure by a simple conversion factor.

In IBC 2009, first the stagnation pressure is determined from basic wind speed by a simple conversion factor. Then design wind pressures for buildings and structures is determined for any height on the basis of height, exposure and gust, direction of wind relative to structure, roof slope, importance of the structure and wind stagnation pressure.

***Table 1**: Comparison of building codes with respect to wind force determination*

BNBC 1993	BNBC 2010/ASCE 7-05	NBC 2005	IBC 2009
$q_z=C_C C_I C_Z V_b^2$ q_z = sustained wind pressure at height z, kN/m^2 C_c = velocity-to-pressure conversion coefficient = 47.2x10^{-6} C_I = structure importance coefficient C_z = combined height and exposure coefficient V_b = basic wind speed in km/hr (HBRI and BSTI, 1993:6-32)	$q_z=0.000613K_z K_d K_{zt} V^2 I$ q_z = velocity pressure at height z, kN/m^2 K_z = velocity pressure exposure coefficient K_d= wind directionality factor K_{zt}= topographic factor I = structural importance factor V = basic wind speed in m/s (HBRI and BRTC, 2010: Part 6- Chap 2) (ASCE/ SEI 7-05, 2006: chap 6- page 27)	$V_z = V_b k_1 k_2 k_3$ V_z = design wind speed at any height z in m/s V_b = basic wind speed in m/s k_1 = probability factor k_2 = terrain height and structure size factor k_3 = topography factor (BIS,2005: part 6- page 21)	$q_s = 0.00256\ V^2$ q_s=Wind stagnation pressure in psf. V= basic wind speed in mph. (INC, 2009:326)
$P_z=C_G C_P q_z$ p_z = design wind pressure at height z , kN/m^2 C_G = gust coefficient C_p=pressure coefficient for structures or components (HBRI and BSTI, 1993:6-34)	$P=qGC_p-q_i(GC_{pi})$ p = design wind pressure G = gust effect factor C_p = external pressure coefficient GC_{pi} =internal pressure coefficient (HBRI and BRTC, 2010: Part 6- Chap 2) (ASCE/ SEI 7-05, 2006: chap 6- page 28)	$p_z = 0.6\ V_z^2$ p_z = design wind pressure in N/m^2 at height z (BIS, 2005: part6- page 16)	$P_{net} = q_s K_z C_{net}[IK_{zt}]$ K_z=Velocity pressure exposure coefficient. C_{net}= Net-pressure coefficient. I=Importance factor. K_{zt}= Topographic factor. (INC, 2009:326)

3. Illustrations:

3.1 Basic wind speed V & V_b

In comparing the basic wind speeds given between BNBC 1993 and BNBC 2010, it is important to note that BNBC 1993 specifies fastest-mile wind speeds whereas BNBC 2010 provides basic wind speed in terms of 3-second gust wind speeds. The fastest mile speed is the average speed of a particle traveling with the wind over the distance of one mile. The 3-second gust speed is the peak gust speed averaged over a short time interval of 3 seconds duration.

Both BNBC 1993 and BNBC 2010 provide basic wind speed associated with an annual probability of occurrence of 0.02 (50 year recurrence interval) measured at a point 33 ft (10m) above the mean ground level in a flat and open terrain. In both BNBC 1993 & BNBC 2010, tornadoes have not been considered in developing the basic wind speed distribution.

Since square of the basic wind speed is used in determining sustained wind pressure, the increased wind speed results in approximately 26.58 percent increase in sustained wind pressure. Following equation is found satisfactory for converting fastest mile per hour wind speed into three second gust wind speed and used later for comparison –

$$V_{3s}=0.2986*V_{fmph}+2.986 \quad (1)$$

Where,
V_{3s}= three second gust wind speed in m/s
V_{fmph}= Fastest mile per hour wind speed in Km/hr ;
(Faysal, 2013:Chap 4-Page 15)
(INC, 2009: Chap16-page 319)

***Table 2**: Comparison of BNBC 1993 & BNBC 2010 with respect to basic wind speeds*

LOCATION	BNBC 2010 Basic Wind Speed V (m/s)	BNBC 1993 Basic Wind Speed, V_b (km/hr)	BNBC 1993 Basic Wind Speed, V_b(m/s)	RATIO, V/V_b	RATIO^2, $(V/V_b)^2$	% INCREASE
Angarpota	47.8	150	41.67	1.15	1.32	31.61
Bagerhat	77.5	252	70.00	1.11	1.23	22.58
Bandarban	62.5	200	55.56	1.13	1.27	26.56
Barguna	80.0	260	72.22	1.11	1.23	22.70
Barisal	78.7	256	71.11	1.11	1.22	22.48
Bhola	69.5	225	62.50	1.11	1.24	23.65
Bogra	61.9	198	55.00	1.13	1.27	26.66
Brahmanbaria	56.7	180	50.00	1.13	1.29	28.60
Chandpur	50.6	160	44.44	1.14	1.30	29.62
Chapai Nawabganj	41.4	130	36.11	1.15	1.31	31.44
Chittagong	80.0	260	72.22	1.11	1.23	22.70
Chuadanga	61.9	198	55.00	1.13	1.27	26.66
Comilla	61.4	196	54.44	1.13	1.27	27.18
Cox’s Bazar	80.0	260	72.22	1.11	1.23	22.70
Dahagram	47.8	150	41.67	1.15	1.32	31.61
Dhaka	65.7	210	58.33	1.13	1.27	26.85
Dinajpur	41.4	130	36.11	1.15	1.31	31.44
Faridpur	63.1	202	56.11	1.12	1.26	26.46
Feni	64.1	205	56.94	1.13	1.27	26.71
Gaibandha	65.6	210	58.33	1.12	1.26	26.47
Gazipur	66.5	215	59.72	1.11	1.24	23.99
Gopalganj	74.5	242	67.22	1.11	1.23	22.83
Habiganj	54.2	172	47.78	1.13	1.29	28.69
Hatiya	80.0	260	72.22	1.11	1.23	22.70
Ishurdi	69.5	225	62.50	1.11	1.24	23.65
Joypurhat	56.7	180	50.00	1.13	1.29	28.60
Jamalpur	56.7	180	50.00	1.13	1.29	28.60
Jessore	64.1	205	56.94	1.13	1.27	26.71
Jhalakati	80.0	260	72.22	1.11	1.23	22.70
Jhenaidah	65.0	208	57.78	1.13	1.27	26.56
Khagrachhari	56.7	180	50.00	1.13	1.29	28.60
Khulna	73.3	238	66.11	1.11	1.23	22.93
Kutubdia	80.0	260	72.22	1.11	1.23	22.70
Kishoreganj	64.7	207	57.50	1.13	1.27	26.61
Kurigram	65.6	210	58.33	1.12	1.26	26.47
Kushtia	66.9	215	59.72	1.12	1.25	25.48
Lakshmipur	51.2	162	45.00	1.14	1.29	29.45
Lalmonirhat	63.7	204	56.67	1.12	1.26	26.36
Madaripur	68.1	220	61.11	1.11	1.24	24.18
Magura	65.0	208	57.78	1.13	1.27	26.56
Manikganj	58.2	185	51.39	1.13	1.28	28.26
Meherpur	58.2	185	51.39	1.13	1.28	28.26

Maheshkhali	80.0	260	72.22	1.11	1.23	22.70
Moulvibazar	53.0	168	46.67	1.14	1.29	28.98
Munshiganj	57.1	184	51.11	1.12	1.25	24.81
Mymensingh	67.4	217	60.28	1.12	1.25	25.03
Naogaon	55.2	175	48.61	1.14	1.29	28.95
Narail	68.6	222	61.67	1.11	1.24	23.75
Narayanganj	61.1	195	54.17	1.13	1.27	27.24
Narsinghdi	59.7	190	52.78	1.13	1.28	27.95
Natore	61.9	198	55.00	1.13	1.27	26.66
Netrokona	65.6	210	58.33	1.12	1.26	26.47
Nilphamari	44.7	140	38.89	1.15	1.32	32.12
Noakhali	57.1	184	51.11	1.12	1.25	24.81
Pabna	63.1	202	56.11	1.12	1.26	26.46
Panchagarh	41.4	130	36.11	1.15	1.31	31.44
Patuakhali	80.0	260	72.22	1.11	1.23	22.70
Pirojpur	80.0	260	72.22	1.11	1.23	22.70
Rajbari	59.1	188	52.22	1.13	1.28	28.07
Rajshahi	49.2	155	43.06	1.14	1.31	30.58
Rangamati	56.7	180	50.00	1.13	1.29	28.60
Rangpur	65.3	209	58.06	1.12	1.27	26.51
Satkhira	57.6	183	50.83	1.13	1.28	28.39
Shariatpur	61.9	198	55.00	1.13	1.27	26.66
Sherpur	62.5	200	55.56	1.13	1.27	26.56
Sirajganj	50.6	160	44.44	1.14	1.30	29.62
Srimangal	50.6	160	44.44	1.14	1.30	29.62
St. Martin's Island	80.0	260	72.22	1.11	1.23	22.70
Sunamganj	61.1	195	54.17	1.13	1.27	27.24
Sylhet	61.1	195	54.17	1.13	1.27	27.24
Sandwip	80.0	260	72.22	1.11	1.23	22.70
Tangail	50.6	160	44.44	1.14	1.30	29.62
Teknaf	80.0	260	72.22	1.11	1.23	22.70
Thakurgaon	41.4	130	36.11	1.15	1.31	31.44
					Average	26.58

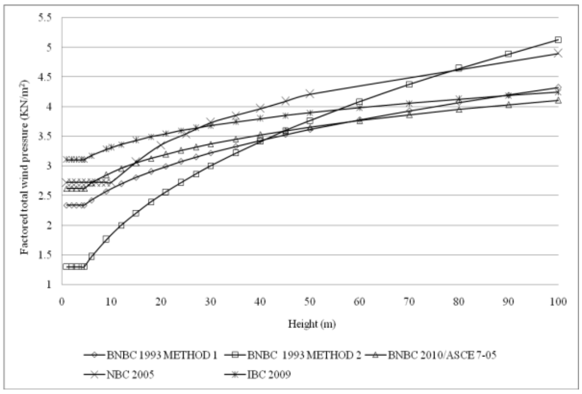
3.2 Factored total wind pressure comparison of different codes

The basic wind speed is determined on the basis of three second gust speed for all the discussed codes except for BNBC 1993. BNBC 1993 specifies basic wind speed on the basis of fastest-mile wind speed. So, for comparison wind speed of 180 km/hr has taken for BNBC 1993 which is equivalent to 3s gust of 56.70 m/s (see, equation 1). For other codes, a velocity of 56.70 m/s has chosen. ASCE 7-05 is not compared separately as proposed BNBC 2010 gives factored total wind pressure exactly same to ASCE 7-05. So, ASCE 7-05 and BNBC 2010 can be used interchangeably.

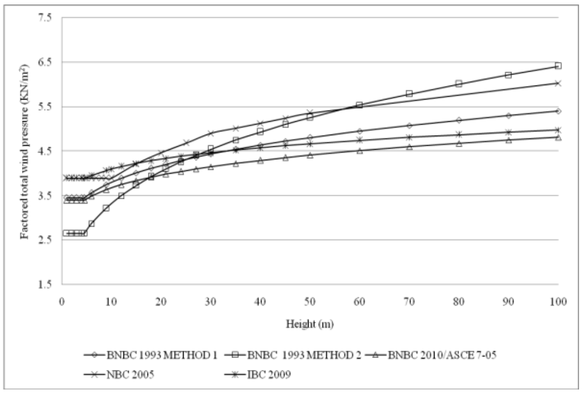
The effect of surrounding objects and height of structures are considered through various parameters in different building codes such as class, Terrain category, Exposure category etc. These parameters are not same for all codes. So, for comparison purpose surrounding conditions are broadly classified into three categories. They are urban, obstructed open terrain and unobstructed open terrain type areas which are defined in BNBC as exposure A, B and C respectively. All the codes are compared for these major surrounding conditions. For only BNBC 1993 instead of single method, two alternative methods are presented. In the Method 1, the windward and the leeward pressure are separately considered and then combined. But in Method 2, the overall pressure coefficient is used to determine the design wind pressure directly. Finally, all pressures are multiplied with respective wind load factor to calculate factored total wind pressure The following pressure variation is typical for structures of 100 m height. Both length and width of the structures have taken equal to 20 m. Corresponding parameters used in the respective codes are presented in the following table and the comparison results are presented graphically in Graph 1, Graph 2 and Graph 3.

Table 3 *: Data used in Graph 1, 2 and 3.*

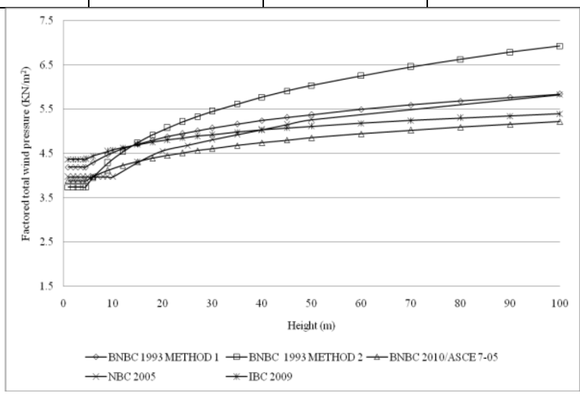
		BNBC 1993 Method 1	BNBC 1993 Method 2	BNBC 2010/ ASCE 7-05	NBC 2005	IBC 2009
Basic Wind speed	Graph 1	180 km/hr	180 km/hr	56.70 m/s	56.70 m/s	128.86 mph
	Graph 2	180 km/hr	180 km/hr	56.70 m/s	56.70 m/s	128.86 mph
	Graph 3	180 km/hr	180 km/hr	56.70 m/s	56.70 m/s	128.86 mph
Terrain Category (BIS, 2001-chap-3)	Graph 1	-	-	-	3	-
	Graph 2	-	-	-	2	-
	Graph 3	-	-	-	1	-
Class	Graph 1	-	-	-	C	-
	Graph 2	-	-	-	C	-
	Graph 3	-	-	-	C	-
Exposure Category	Graph 1	A	A	A	-	B
	Graph 2	B	B	B	-	C
	Graph 3	C	C	C	-	D
Building type	Graph 1	-	-	Enclosed	-	Enclosed
	Graph 2	-	-	Enclosed	-	Enclosed
	Graph 3	-	-	Enclosed	-	Enclosed
Wind load Multiplying factor	All Graphs	1.3	1.3	1.6	1.5	1.6



Graph 1*: Factored total Wind Pressure comparison of different codes for urban areas.*



Graph 2*: Factored total wind Pressure comparison of different codes for obstructed open terrain type areas.*



Graph 3*: Factored total Wind Pressure comparison of different codes for unobstructed open terrain type areas.*

4. Conclusions:

Before BNBC 1993 a simple empirical formula is used to determine wind load which do not consider effect of surrounding objects and height of structures in wind pressure. This shortcoming has overcome in BNBC 1993 by introduction of concept of exposure category and gust factor. The effect of surrounding objects and height of structures is further upgraded in proposed BNBC 2010 wind provision. As a result Wind load in urban areas (Exposure A) according to BNBC 2010 is found considerably higher (7-12 %) than BNBC 1993. But wind load in obstructed and unobstructed open terrain type areas (Exposure B and C) according to BNBC 2010 is found significant lower (2-10 %) than BNBC 1993. Further wind load according to BNBC 2010 is found exactly equal to wind load according ASCE 7-05 and considerably less (7-18 %) than IBC 2009. Again, the wind load according to Indian NBC 2005 wind provision gives the highest wind load among all comparing codes in urban and obstructed open terrain type areas. In obstructed open terrain type areas BNBC 1993 gives highest wind load.

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