

## COMPARISON OF WIND LOAD AMONG BNBC – 1993 AND PROPOSED BNBC - 2015

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### ABSTRACT

Before BNBC 1993 a simple empirical formula is used to determine wind load which do not consider the effect of surrounding objects and height of structure in wind pressure. This shortcoming has overcome in BNBC 1993 by introducing the concept of exposure category and gust factor. The effect of surrounding objects and height of structures is further upgraded in proposed BNBC 2015. This paper aims at the comparison of provisions of wind load analysis given in existing BNBC 1993 to that in proposed BNBC 2015. Both are studied and compared in terms of wind load using parameters termed as Basic wind speed, Height and exposure coefficient, Gust factor, Sustained wind pressure, External pressure coefficient and Design wind pressure. This study reveals that wind load in urban areas according to BNBC 2015 found considerably higher than BNBC 1993. But wind load in obstructed and unobstructed open terrain type area according to BNBC 2015 is found significant lower than BNBC 1993.

**Keywords:**BNBC, Gust factor, Building code, exposure coefficient, wind pressure etc.

### 1. INTRODUCTION

Wind is a suddenly varying dynamic incident & a function of time & velocity. This is caused by the air flowing when air is moving from high pressure to low pressure. Bangladesh National Building Code (BNBC) was first introduced in the year of 1993. The code is further updated in proposed BNBC 2015 wind provision. The design of wind loads on a building is substantially more complex as a result a comparative study has been made to see the basic difference between BNBC 1993 and proposed BNBC 2015. This comparative study on design wind load will provide a relation showing percent increase or decrease of design wind load in the new code with respect to the old one.

### 2. METHODOLOGY

In this study, basic wind speed is compared between BNBC 1993 and BNBC 2015 for 8 divisions of Bangladesh to have an idea about variation of wind speed. By which we can get the overall idea of wind speed throughout the country. For comparison of wind load between BNBC 1993 and BNBC 2015, different parameters i.e. design wind load, basic wind speed, height and exposure coefficient, gust factor, sustained wind pressure, external pressure coefficient etc. are considered. Finally, three exposure conditions (i.e. Exposure A, Exposure B & Exposure C) have been studied for a typical multi-storeyed residential building to identify the changes in analysis and design with BNBC 2015 as compared to BNBC 1993.

### 3. COMPARISON OF WIND SPEED

#### 3.1 Wind Speed of Dhaka Division

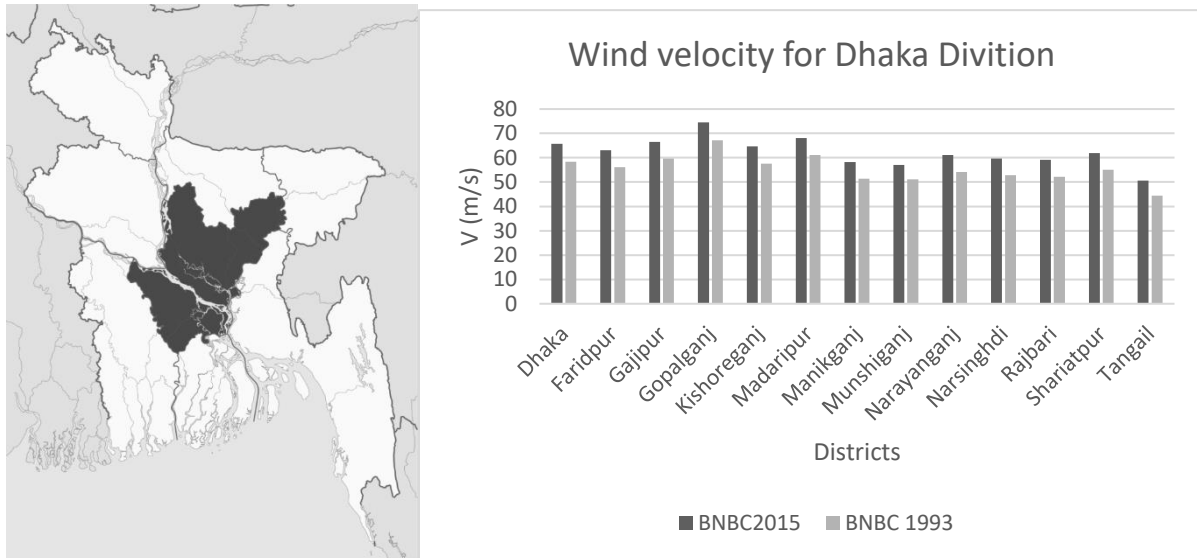


Figure 1: Comparison of wind speed in Dhaka Division.

Dhaka division is one of the most important divisions in Bangladesh. The location of this division is 24°10' N 90°25' E and its elevation is about 13.12 ft. with area 20,508.8 km<sup>2</sup> (7,918 sq mi). Total population is 36,433,505 & density is 1,800 /km<sup>2</sup> (4,600 / sq mi) . There are total 18 rivers. The average wind speed for this division was 55.46923 m/s according to BNBC 1993. The wind speed is increased about 12.38389 % by 2015. The maximum velocity was found in Gopalganj district & minimum was found in Tangail district.

#### 3.2 Wind Speed of Mymensingh Division

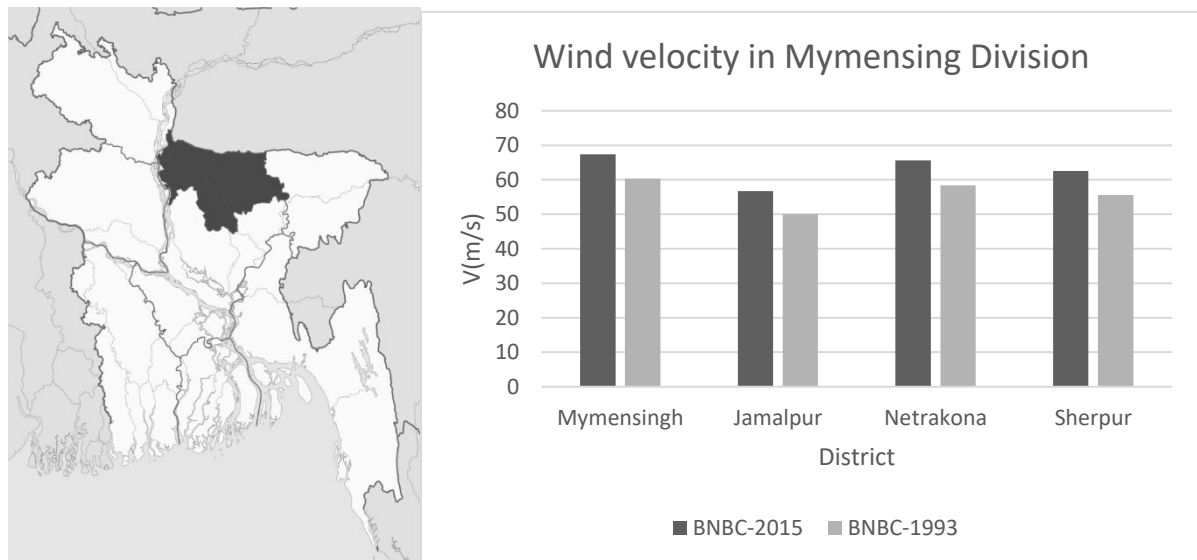


Figure 2: Comparison of wind speed in Mymensingh Division.

Coordinate of Mymensingh division is 24°10' N 90°25' E with an elevation of about 62 ft. Its area is about 10,584 km<sup>2</sup> (4,087 sq mi). Population, by 2011 census is total 11,370,000 & density is 1,100 / km<sup>2</sup> (2,800 / sqmi) .The average wind speed is 56.0425 m/s according to BNBC 1993 .The wind velocity increases 12.5034 % by 2015 . The maximum & minimum

velocities were in Mymensingh & Jamalpur districts respectively. There are 37 rivers in this division.

### 3.3 Wind Speed of Barisal Division

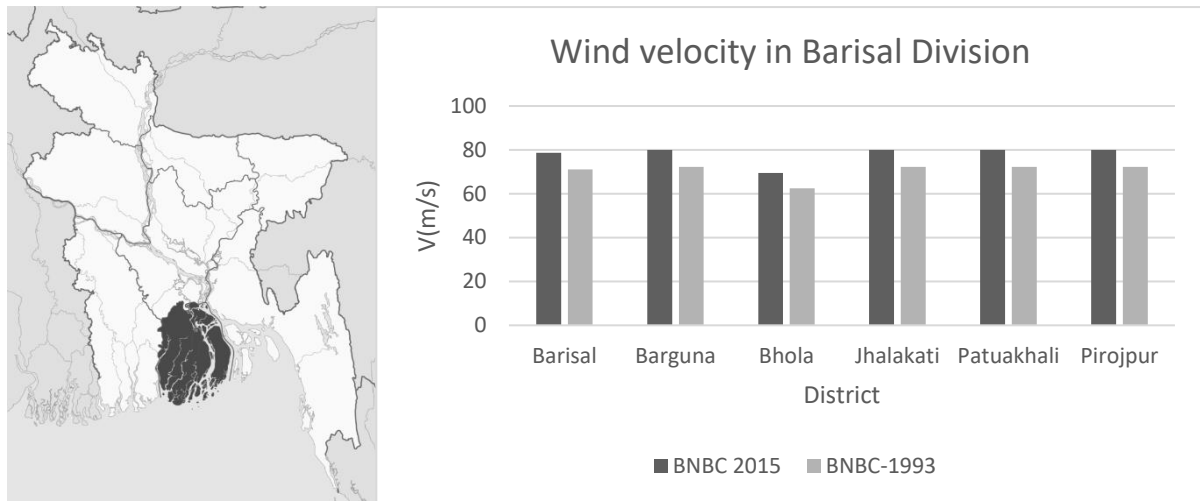


Figure 3: Comparison of wind speed in Barisal Division.

Position of this division is 22°30' N 90°20' E. Total area is 13,225.20 km<sup>2</sup> (5,106.28 sq mile). It is situated 3.9 ft above the sea level. This division consists of 6 districts. By census 2011, it is known that the total population is about 8,325,666 & lives about 630 people per km<sup>2</sup> or 1,600 per sqmi. Total 58 rivers flow through this division. The average wind speed is 70.415 m/s according to BNBC 1993. Maximum velocity was found in Borguna, Jhalokathi, Patuakhali & Pirojpur districts & minimum velocity is in Bholadistrict. Wind speed increases 10.819 % by 2015.

### 3.4 Wind Speed of Rajshahi Division

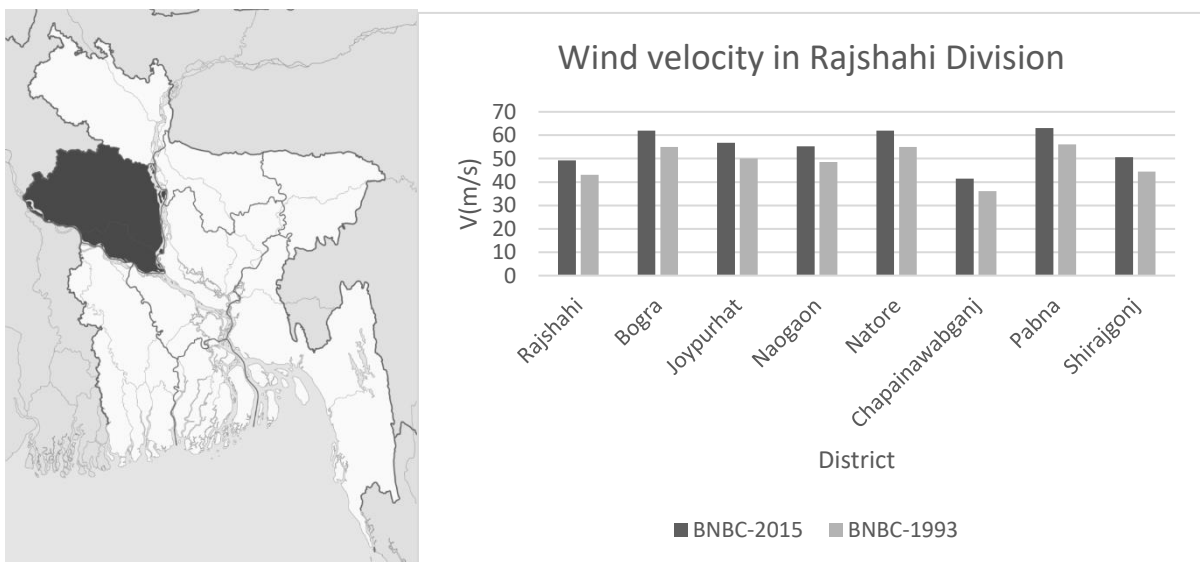


Figure 4: Comparison of wind speed in Rajshahi Division.

Rajshahi division is located at 25°00' N & 89°00' E with 18,174.4 km<sup>2</sup> (7,017.2 sq mi) area in total. The population is 18,484,858 with density of about 1,000 / km<sup>2</sup> (2,600sqmi). Average wind speed for this division is 48.54125 m/s according to BNBC 1993 & it is increased 13.3057 % by 2015. The maximum wind speed was found in Pabna, Natore & Bogra districts & minimum was in Chapainawabgonj district.

### 3.5 Wind Speed of Sylhet Division

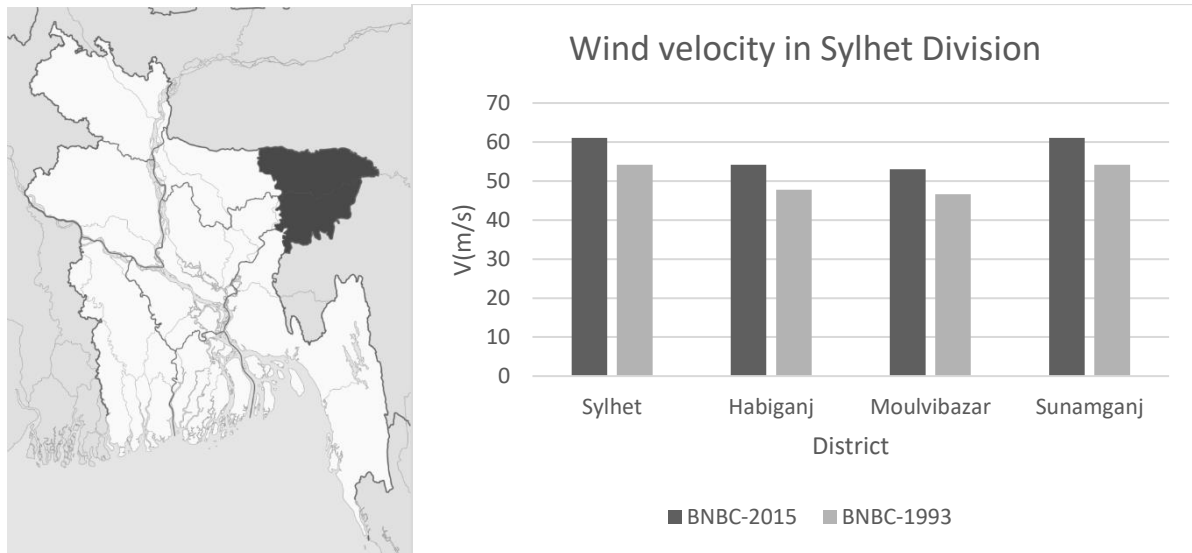


Figure 5: Comparison of wind speed in Sylhet Division.

Sylhet division is located in 24°30' N & 91°40' E. Its elevation is 15 ft with an area of 12,298.4 km<sup>2</sup> (4,748.4 sq mi). It has a population of 9,910,219 & is populated with 810 / km<sup>2</sup> (2,100 sq mi) according to census 2011. It comprises 4 huge districts. The average wind speed for this division was 50.6975 m/s according to BNBC 1993 & it increases 13.1219 % by 2015. Maximum velocity was found in Sylhet & Sunamganj districts & the minimum was found in Moulvibazar district.

### 3.6 Wind Speed of Khulna Division

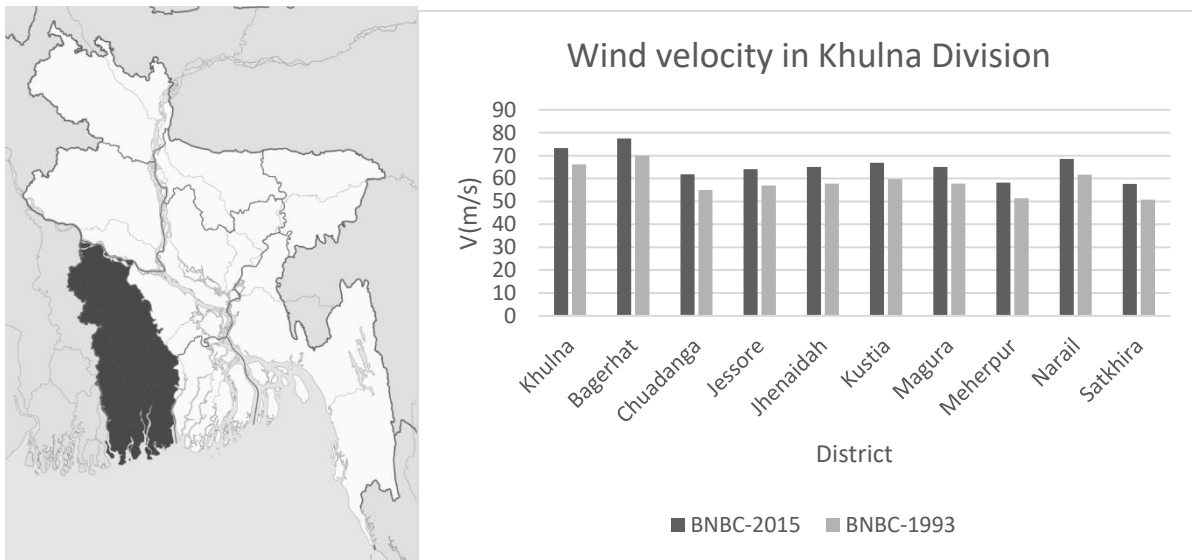


Figure 6: Comparison of wind speed in Khulna Division.

The next division is Khulna which is located at 22°55' N & 89°15' E. Total area is 22,284.22 km<sup>2</sup> ( 8,603.99 sq mi ), where lives 700 people per km<sup>2</sup> (1,800 / sq mi) area with a population of 15,687,759 found by 2011 census. It is situated with an elevation of 30 ft. There are total 10 districts in this division. The average wind speed was 58.722 m/s according to BNBC 1993. Wind velocity was maximum in Bagerhat & Khulna districts & minimum in Chuadanga district. It increases 12.0704 % by 2015.

### 3.7 Wind Speed of Rangpur Division

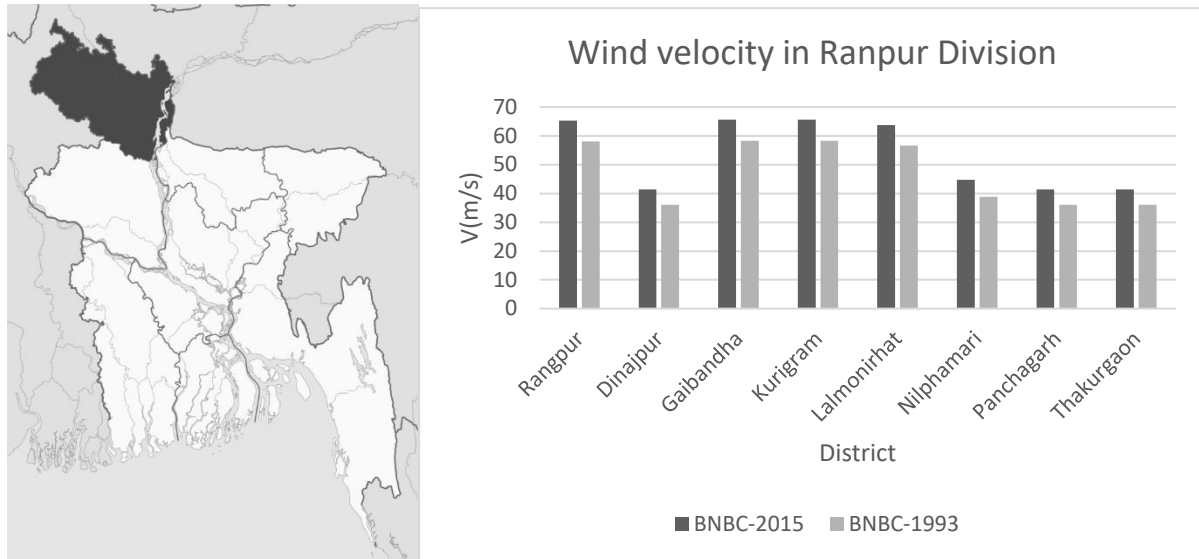


Figure 7: Comparison of wind speed in Rangpur Division.

The position of this division is 25°50' N 89°50' E. It comprises 16,184.99 km<sup>2</sup> (6,249.06 sq. mi) area with a population of 15,787,758 whose density is 980 / km<sup>2</sup> (2,500 / sq. mi) according to 2011 census. Average wind velocity was 47.32625 m/s which was found through BNBC 1993; maximum was found in Rangpur, Gaibandha, Kurigram, Lalmonirhat districts & minimum was found in Dinajpur, Panchagarh, Thakurgaon districts. The wind speed increases 13.3356 % by 2015.

### 3.8 Wind Speed of Chittagong Division

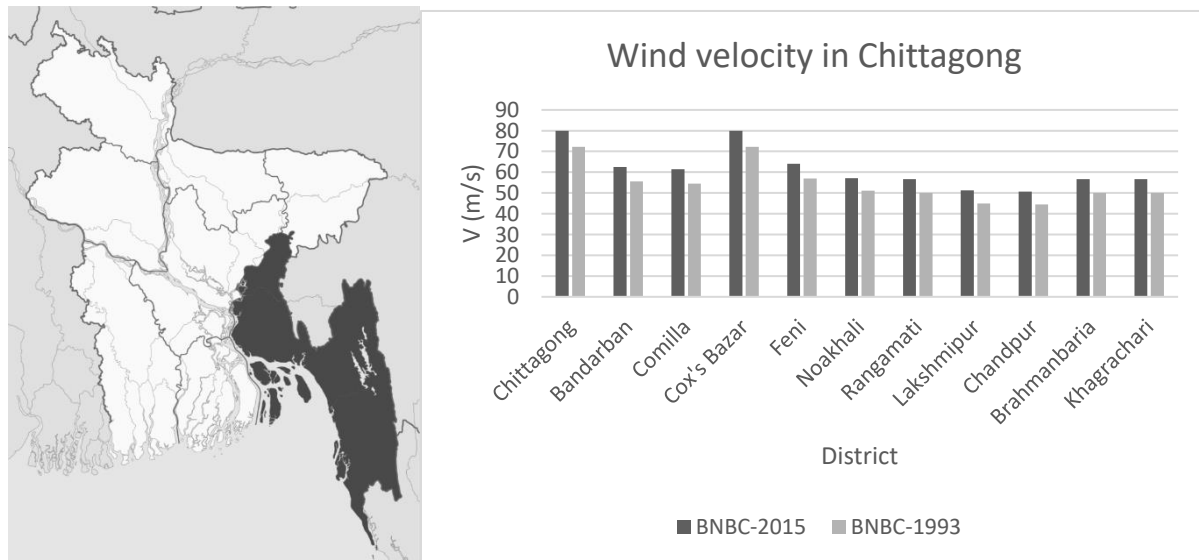


Figure 8: Comparison of wind speed in Chittagong Division.

Chittagong division is located at 22°55' N 91°30' E with an elevation of 1,152 ft. Total area of this division is 33,771.18 km<sup>2</sup> (13,039.13 sq. mi). Average wind speed for this division was 54.72091 m/s according to BNBC 1993 & maximum velocity was found in Chittagong & Cox's Bazaar districts; minimum velocity was found in Lakshmipur & Chandpur districts. The velocity increases 12.49812% by 2015. This is a hilly track region & it comprises many rivers.

## **4. COMPARISON OF WIND LOAD BETWEEN BNBC CODE 1993 AND PROPOSED CODE OF 2015**

### **4.1. Comparison of Exposure Category**

#### 4.1.1 According to BNBC 1993

The terrain exposure in which a building or structure is to be sited shall be assessed as being one of the following categories:

Exposure A: Urban and sub-urban areas, industrial areas, wooded areas, hilly and other terrain covering.

Exposure B: Open terrain with scattered obstructions. This category includes air fields, open park lands, and sparsely built-up outskirts of towns, flat open country and grasslands.

Exposure C: Flat and unobstructed open terrain, coastal areas and riversides facing large bodies of water.

#### 4.1.2 According to BNBC 2015

As exposure categories depends on wind directions and sectors and also surface roughness, so some of their categories are mentioned here-

Wind directions and sectors: For each selected wind direction at which the wind loads are to be evaluated, the exposure of the building or structure shall be determined for the two upwind sectors extending 45° either side of the selected wind direction.

Surface roughness categories:

Surface Roughness A: Urban and suburban areas, wooded areas, or other terrain with numerous closely spaced obstructions.

Surface Roughness B: Open terrain with scattered obstructions having heights generally less than 9.1 m.

Surface Roughness C: Flat, unobstructed areas and water surface outside cyclone prone regions.

Exposure Categories:

Exposure A: Exposure A shall apply where the ground surface roughness condition is as defined by surface roughness A. Exception is also there.

Exposure B: Exposure B shall apply for all cases where Exposure A or C do not apply.

Exposure C: Exposure C shall apply where the ground surface roughness is as defined by Surface Roughness C.

There are also some of the Exposure categories for:

Main wind-force resisting system

Buildings and other structures

Low-Rise Buildings

Components and cladding.

Velocity pressure exposure coefficient

### **4.2 Comparison of Topographic Effects**

According to BNBC 1993

If a structure or any portion is thereof is located within a local topographic zone, such as regions around hills and ridges, the sustained wind pressure obtained from sec 2:4:6:2 shall be modified by multiplying by a local topographic coefficient,  $c_t$ .

According to BNBC 2015:

Topographic Effects:

Wind speed-up over hills, ridges and escarpments:

The wind speed-up effects shall be included in the design when buildings and other site conditions and locations of structures meet all the following conditions:

The hill, ridges, or escarpment is isolated and unobstructed upwind by other similar topographic features of comparable height for 100 times the height of the topographic feature or 3.22 km, whichever is less.

The hill, ridges, or escarpment protrudes above the height of upward terrain features within a 3.22 km radius in any quadrant by a factor of two more.

The structure is located as shown in Figure 6.2.4 in the upper one-half of a hill or ridge or near the crest of an escarpment.

$$H/L_h \geq 0.2$$

H is greater than or equal to 4.5 m for Exposure B and C and 18.3 m for Exposure A.

Topographic factor:

The wind speed-up effect shall be included in the calculation of design wind loads by using the factor

$$K_{zt}:K_{zt} = (1 + K_1 K_2 K_3)^2$$

### 4.3 Comparison of Gust Effect Factor:

According to BNBC 1993:

Wind Gust Effects:

Wind gusts causes additional loading effects due to turbulence over the sustained wind speed. A slender or wind-sensitive building shall be one having -

A height exceeding five times the least horizontal dimension, or

A fundamental natural frequency less than 1.0 Hz.

Gust coefficient,  $C_G$  shall account for such additional gust loading effects on non-slender and slender buildings and shall be set equal to Gust Response Factors  $G_h$ ,  $G_z$ , or  $G$  as set forth below:

Gust Response Factor,  $G_h$  for Non-slender Buildings and Structures: Value of gust response factor,  $G_h$  shall be determined from Table 6.2.11.

Gust Response Factor,  $G_z$  for Building Components: Gust response factor,  $G_z$  shall be determined from Table 6.2.11.

Gust Response Factor,  $G$  for Slender Buildings and Structures: Gust response factor,  $G$  shall be calculated by the following relations.

$$G = 0.65 + \sqrt{\left(\frac{P}{\beta} + \frac{11.0T_1^2 S}{1 + KC}\right)}$$

$$\text{Where, } P = fJ; f = \frac{55.44fh}{sV_b}; T_1 = \frac{2.35\sqrt{D_0}}{\left(\frac{h}{13.72}\right)^\alpha}$$

According to BNBC 2015:

Gust Effect Factor:

Rigid Structures:

For rigid structures as defined in Sec 2.1.3, the gust-effect factor shall be taken as 0.85 or calculated by the formula:

$$G = 0.925 \frac{1 + 1.7g_{Q1z}Q}{1 + 1.7g_{v1z}}; I_z = c\left(\frac{10}{z}\right)^{\frac{1}{6}}$$

The background response Q is given by,

$$Q = \sqrt{\frac{1}{1 + 0.63\left(\frac{B+h}{L_z}\right)^{0.63}}}$$

Where B, h are defined in Sec 2.1.4; and  $L_z$ =the integral length scale of the turbulence at the equivalent height given by,

$$L_z = l \left( \frac{z}{10} \right)^\epsilon$$

Flexible or dynamically sensitive structures:

For flexible or dynamically sensitive structures as defined in Sec 2.1.3, the gust-effect factor shall be calculated by,

$$G_f = 0.925 \left( \frac{1 + 1.7 I_z \sqrt{g_Q^2 Q^2 + g_R^2 R^2}}{1 + 1.7 g_v I_z} \right)$$

The value of both  $g_0$  and  $g_v$  shall be taken as 3.4 and  $g_R$  is given by,

$$g_R = \sqrt{2 \ln(3600 n_1)} + \frac{0.577}{\sqrt{2 \ln(3600 n_1)}}$$

R, the resonant response factor, is given by,

$$R = \sqrt{\frac{1}{\beta} R_n R_h R_g (0.53 + 0.47 R_L)}$$

Rational analysis and limitations of gust-factors are also mentioned there.

#### 4.4 Comparison of Sustained Wind Pressure and Velocity Pressure

According to BNBC CODE 1993

Sustained Wind Pressure:

The sustained wind pressure,  $q_z$  on a building surface at any height z above ground shall be calculated from the following relation:

$$q_z = C_c C_I C_z V_b^2$$

According to BNBC CODE 2015:

Velocity pressure:

Velocity pressure,  $q_z$  evaluated at height z shall be calculated by the following equation:

$$q_z = 0.000613 K_z K_{zt} K_d V^2 I; (\text{KN/m}^2), V \text{ in m/s}$$

#### 4.5 Comparison of Design Wind Pressure

According to BNBC CODE 1993

Design Wind Pressure:

The design wind pressure,  $p_z$  for a structure or an element of a structure at any height, z above mean ground level shall be determined from the relation:  $P_z = C_G C_P q_z$

According to BNBC CODE 2015:

Design wind pressures for the MWFRS of buildings of all heights shall be determined by the following equation:

$$P = q G C_{P-q_i} (G C_{p_i})$$

#### 4.6 Comparison of Pressure and Force Coefficient

According to BNBC CODE 1993



### Pressure Coefficient for Buildings, Structures and Components:

The pressure coefficient  $C_p$  to be used in Eq (2.4.2) for the determination of design wind pressure shall be equal to the values described below:

$C_{pe}$  : External pressure coefficient as given in Fig 6.2.5 and Fig 6.2.6 and in Table 6.2.13 for external surfaces of buildings or structures.

$C'_{pi}$  : Internal peak pressure coefficient as given in Table 6.2.14 for internal surfaces of building. The coefficient shall be used along with the coefficients  $C'_{pi}$  for design wind load on components, or with  $C_{pe}$  for design wind load on buildings as per provisions of Sec 2.4.6.4 a(ii)

$C'_{pe}$  : External peak pressure coefficient as given in Fig 6.2.7 and Fig 6.2.8 to be applied on external surfaces of buildings to obtain wind load on individual components and cladding in accordance with Sec 2.4.6.5.

$\bar{c}_p$  : Overall pressure coefficient as given in Tables 6.2.15 through 6.2.21 for various cross-sectional shapes to be used with the projected area of the buildings or structures when Method 2 in Sec 2.4.6.4(b) is used.

If pressure coefficient  $C_{pe}, C'_{pi}, C'_{pe}$  or  $\bar{c}_p$  are not provided herein for certain buildings, structures or components, reliable references shall be followed or specialist advice shall be sought.

According to BNBC CODE 2015

Pressure and Force Coefficient:

Internal Pressure Coefficient:

Internal pressure coefficient,  $G C_{pi}$  shall be determined from Figure 6.2.5 based on building enclosure classifications determined from Sec 2.4.9.

Reduction factor for Large Volume Buildings,  $R_i$ ; For a partially enclosed building containing a single, unpartitioned large volume, the internal pressure coefficient,  $G C_{pi}$  shall be multiplied by the following reduction factor,  $R_i$ :

$$R_i = 1.0 \quad \text{or} \quad R_i = 0.5 \left( 1 + \frac{1}{\sqrt{1 + \frac{v_i}{6951 A_0 g}}} \right) \leq 1.0$$

External Pressure Coefficient:

There are two kind of system in external pressure coefficient:

Main Wind-Force Resisting Systems

Components and Cladding.

### 4.7 Comparison of Design of Wind load

According to BNBC CODE 1993

For Buildings and Structures:

Design wind load on the main wind force resisting systems of buildings and structures shall be determined by using one of the following two methods:

Method 1 (Surface Area Method):

For all framing systems:  $F_1 = \sum p A_z$

For gabled frames and single-storey rigid frames:  $F_1 = \sum (p - P_i) A_z$

Method 2 (Projected Area Method):  $F_2 = \sum p_z A_z$

For Components and Cladding:

Design wind load on individual structural components shall be determined in accordance with the following relation:

$$F' = \sum (C'_{pe} q - C'_{pi} q_i) A_z$$

There are also definite conditions for determination of the pressure  $q$  and  $q_i$ .

According to BNBC CODE 2015:

On Enclosed and Partially Enclosed Buildings:

Rigid Buildings of All Heights:

Design wind pressures for the MWFRS of buildings of all heights shall be determined by the following equation:

$$P = qG C_p - q_i(G C_{pi}) \text{ (KN/m}^2\text{)}$$

Low-Rise Building:

Design wind pressures in this case can be determined by the following equation:

$$P = q_h [(G C_{pf}) - (G C_{pi})] \text{ (KN/m}^2\text{)}$$

Flexible Buildings:

Design wind pressure shall be determined from the following equation:

$$p = q G_f C_p - q_i (G C_{pi}) \text{ (KN/m}^2\text{)}$$

## 5. RESULT AND DISCUSSION

For comparison purpose a typical multi-storeyed residential building is analysed for three exposure conditions (i.e. Exposure A, Exposure B & Exposure C). Two alternative methods are used in BNBC 1993 whereas single method is used in BNBC 2015. All pressures are multiplied with respective wind load factor to calculate factored total wind pressure. Corresponding parameters used in the respective two codes are presented below. The comparison results are presented graphically in Figure 9, Figure 10 and Figure 11.

Height of the building : 100 m

Length and width : 20 m

Basic Wind speed : 180 km/hr for BNBC 1993 and 56.70 m/s for BNBC 2015

Building type : Enclosed

Multiplying factor : 1.3 for BNBC 1993 and 1.6 for BNBC 2015

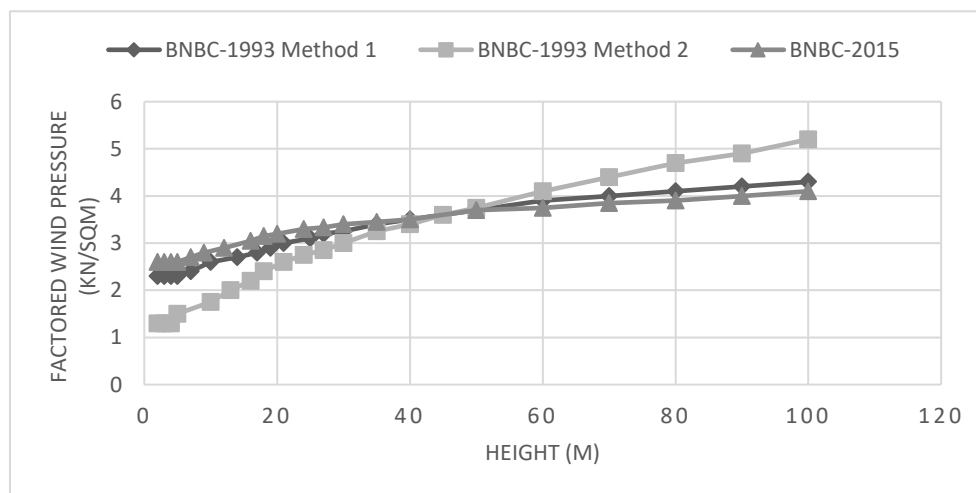


Figure 9: Factored total Wind Pressure for Exposure A condition

Findings are given below:

The change in factored total wind pressure with height in BNBC 2015 is more uniform than BNBC 1993.

Factored wind pressure in BNBC 2015 is 7-12% higher than BNBC 1993 up to 50 m. Then it gradually decreases with the increase of height.

At the height of 50 m, both BNBC 2015 & BNBC 1993 shows same factored total wind pressure.

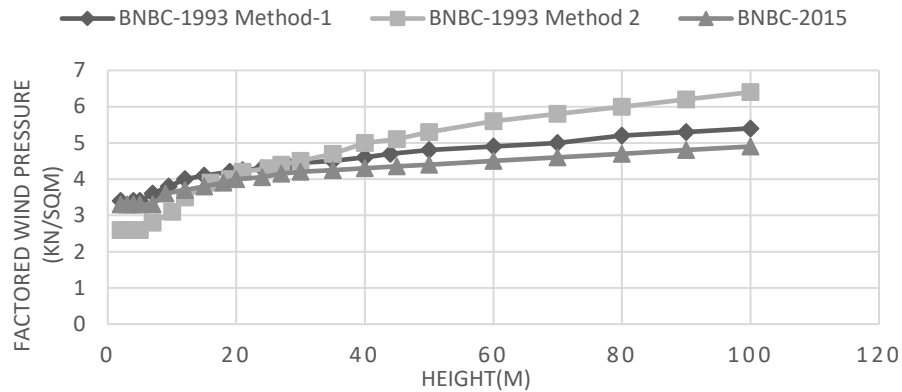


Figure 10: Factored total Wind Pressure for Exposure B condition

Findings are given below:

Factored total wind pressure with height in BNBC 2015 is lower than BNBC 1993.

Method 2 in BNBC 1993 shows a significant change in factored total wind pressure from height 10 m to 30 m.

The change in factored total wind pressure with height in BNBC 2015 is more uniform than BNBC 1993.

At the height of 20 m, both BNBC 2015 & BNBC 1993 shows almost same factored total wind pressure.

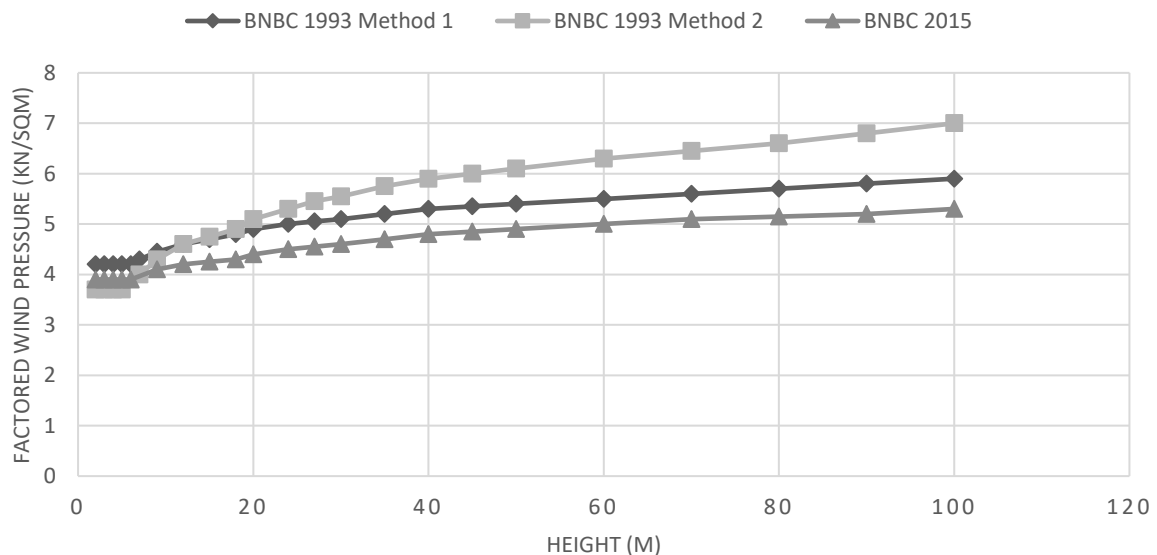


Figure 11: Factored total Wind Pressure for Exposure C condition

Findings are given below:

Factored total wind pressure with height in BNBC 2015 is lower than BNBC 1993.

The change in factored total wind pressure with height in BNBC 2015 is more uniform than BNBC 1993.

## 6. CONCLUSION

Following are the findings from the study for which BNBC 2015 seems to be more suitable for structural design purposes than BNBC 1993:

The effect of surrounding objects and height of structures are considered in proposed BNBC 2015. BNBC 1993 mentions basic wind speed in terms of fastest-mile wind speed whereas BNBC 2015 provides basic wind speed in terms of 3-second gust wind speed. Again the rate of increase in wind load with respect to numbers of stories is more uniform in BNBC 2015 in comparison with BNBC 1993. Both BNBC 1993 and BNBC 2015 provide basic wind speed associated with an annual probability of occurrences of 0.02 ( 50 year recurrence interval) measured at a point 3 ft (10m) above the mean ground level in a flat and open terrain. The calculation procedure for design wind pressure in BNBC 2015 is totally different than that of BNBC 1993. Two new terms topographic factor & directionality factor has been introduced in BNBC 2015. BNBC 2015 uses single method for the calculation of factored wind pressure whereas BNBC 1993 used two alternative methods. In Method 1, the windward and the leeward pressure are separately considered than combined but in Method 2, the overall pressure coefficient is used to determine the design wind pressure directly. All the factors related to wind speed has changed from BNBC 1993 to BNBC 2015. The wind load in Exposure A according to BNBC 2015 is found considerably higher by 7-12% than that of BNBC 1993. But for Exposure B & C according to BNBC 2015 is found significantly lower by 2-10% than BNBC 1993.

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