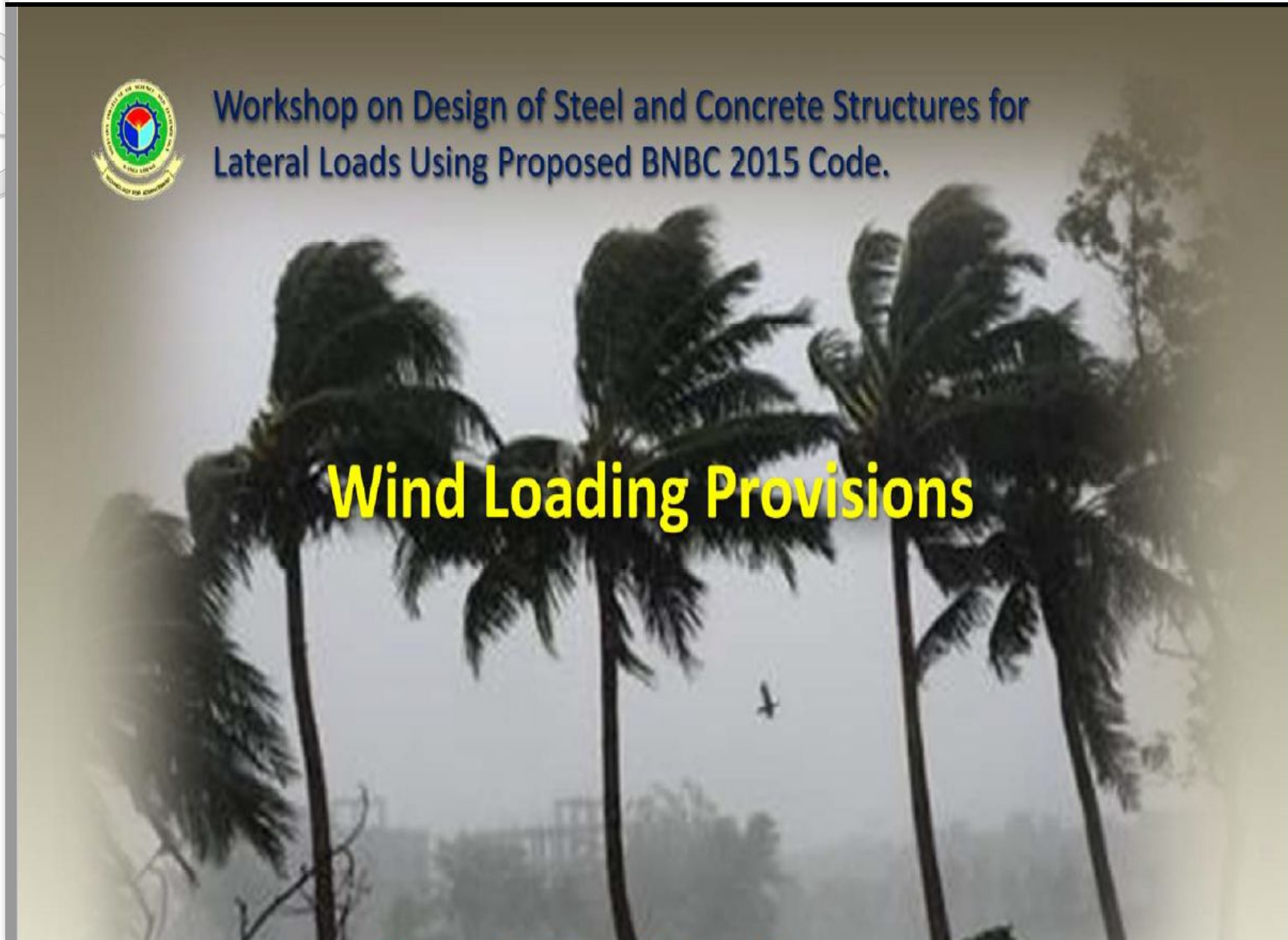
# Structural Analysis & Design I



# Structural Analysis & Design I



## Wind pressure fundamentals

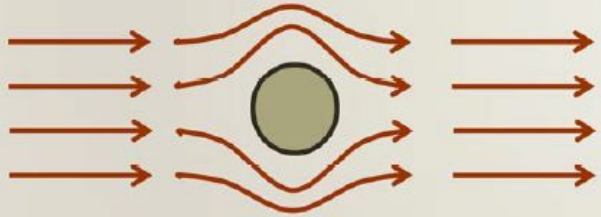
Laminar streamlined flow,
Density of air = $\rho$
Velocity of air = $V$

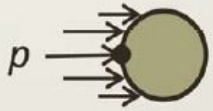
Pressure at a point $q = \frac{1}{2}\rho V^2$



Dynamic pressure represents the kinetic energy per unit volume of a moving fluid and is represented by q = 1/2 V^2

A point is dimensionless, a real object like a building has dimensions.






$p = \frac{1}{2} C_p \rho V^2$

$C_p$ is called pressure co-efficient which depends on shape of the building.

Considering other factors, we can write $p = \frac{1}{2} K C_p \rho V^2$ where $K$ is a constant

**Wind pressure $\propto$ Velocity $^2$**

# Structural Analysis & Design I



## Wind Speed

Wind speed is the first and the most important parameter in wind load calculation. In wind design codes, it is generally termed as

**Basic Wind Speed, *V***

Basic wind speed, *V*, is a pre-defined parameter for a particular area and is mentioned in building codes. *V* for a particular area is determined on the basis of the climatic characteristics of that area over a period of several years.

# Structural Analysis & Design I



## Wind Speed

Wind flow is generally not steady, it always fluctuates.

Therefore, in defining the wind speed, we need to average the speed over a certain period of time.

Wind speed is typically measured by 3-cup anemometer. It has a typical response time of 3 second.

There are other more modern devices too.

A typical 3-cup anemometer



# Structural Analysis & Design I



## Wind Speed Definitions

**Three Second Gust, $V_{3s}$:**
Wind speed averaged over a period of three seconds.
Codes: BS CP3, BNBC 2015 (proposed), ASCE 7-05

**Mean hourly, $V_{mean}$:**
Wind speed averaged over a period of an hour.
Codes: BS8100 (tower code).

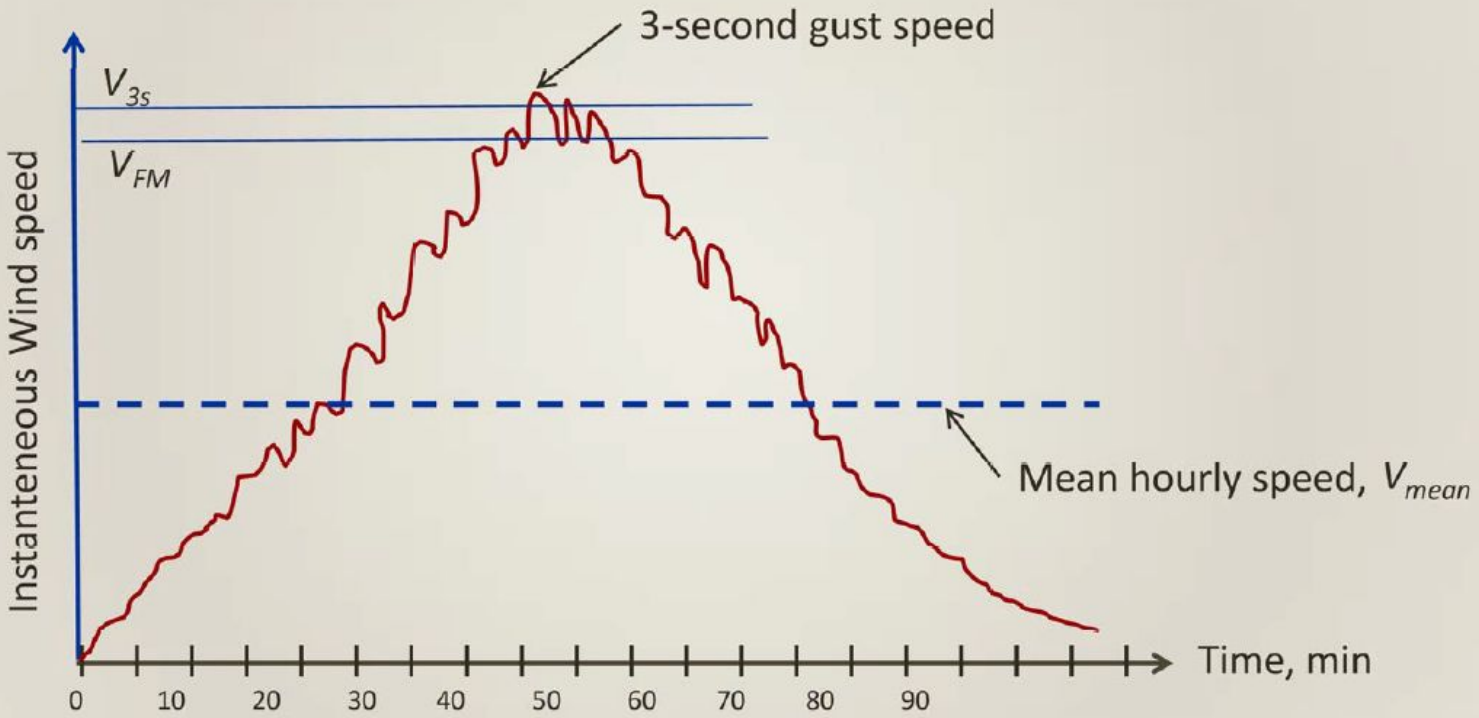
**Fastest Mile Wind, $V_{FM}$:**
Average speed of a one mile long sample of wind crossing a fixed point.
Codes: BNBC 1993, TIA-EIA-F

**BNBC, 2015: Basic wind speed $V = V_{3s}$**
**3-sec gust wind at a height of 10m above ground in a terrain Exposure B having a return period of 50 years.**

# Structural Analysis & Design I



**3-cup anemometer gives speed averaged over a period of 3 seconds. Therefore, speed measured by such an anemometer is generally termed as 3-second gust speed.**




Wind speed vs. time graph of a typical storm.

# Structural Analysis & Design I



## SURFACE ROUGHNESS AND TERRAIN EXPOSURE

**Wind flow characteristics depends on the objects/obstacles present on the earth surface. Based on the obstacles present on the ground surface, surface roughness and terrain exposure is defined.**

**Surface Roughness A:** Urban and suburban areas, wooded areas, or other terrain with numerous closely spaced obstructions having the size of single-family dwellings or larger.

**Surface Roughness B:** Open terrain with scattered obstructions having heights generally less than 9.1 m. This category includes flat open country, grasslands, and all water surfaces in cyclone prone regions.

**Surface Roughness C:** Flat, unobstructed areas and water surfaces outside cyclone prone regions. This category includes smooth mud flats and salt flats.

**Exposure A:** When Surface Roughness A prevails in the upwind direction for a distance of at least 792 m or 20 times the height of the building, whichever is greater.

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

**Exposure C:** When Surface Roughness C prevails in the upwind direction for a distance greater than 1,524 m or 20 times the building height, whichever is greater. Exposure C shall extend into downwind areas of Surface Roughness A or B for a distance of 200 m or 20 times the height of the building, whichever is greater.

# Structural Analysis & Design I



## Exposure A



New York



Dhaka

# Structural Analysis & Design I



## Exposure B









# Structural Analysis & Design I

Workshop on Design of Steel and Concrete Structures for Lateral Loads Using Proposed BNBC 2015 Code.

Wind Loading Provisions

## Exposure C







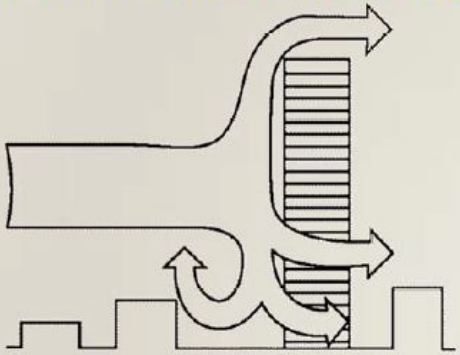


# Structural Analysis & Design I

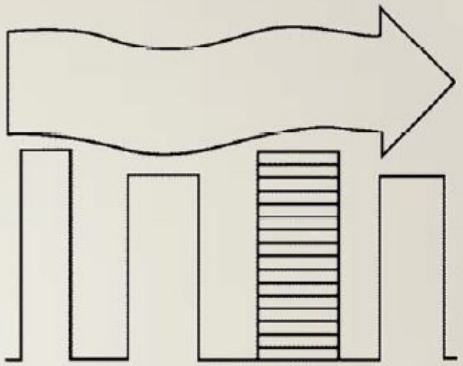


## CHARACTERISTICS OF WIND

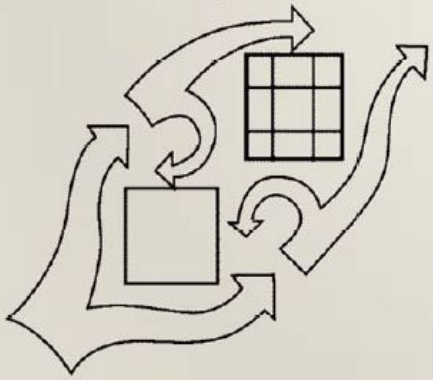
**The flow of wind is complex because many flow situations arise from the interaction of wind with structures.**



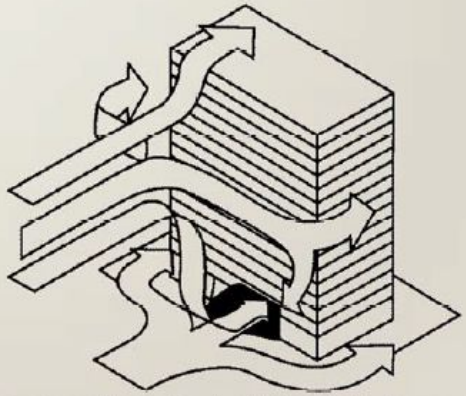
A building significantly taller than its surroundings can experience high wind loads and concentrate pedestrian-level winds



A building of height similar to its surroundings may be protected from large wind loads and concentrated pedestrian winds



Adjacent building placement may protect from high winds, reducing wind loads and pedestrian-level winds



Openings through a building at the base may induce high velocities in the opening

# Structural Analysis & Design I



## Conversion of Wind Speed

A single storm can have $V_{3s}$, $V_{FM}$ and $V_{mean}$ ( or $\overline{V}$ ).

Therefore, there must be a correlation between these quantities.

**BNBC 1993, For Dhaka:**

$V_b = V_{FM}$ = 210 km/h = 130.45 mph

$\therefore$ Averaging period

= 60x60/130.45 = 27.6 sec.

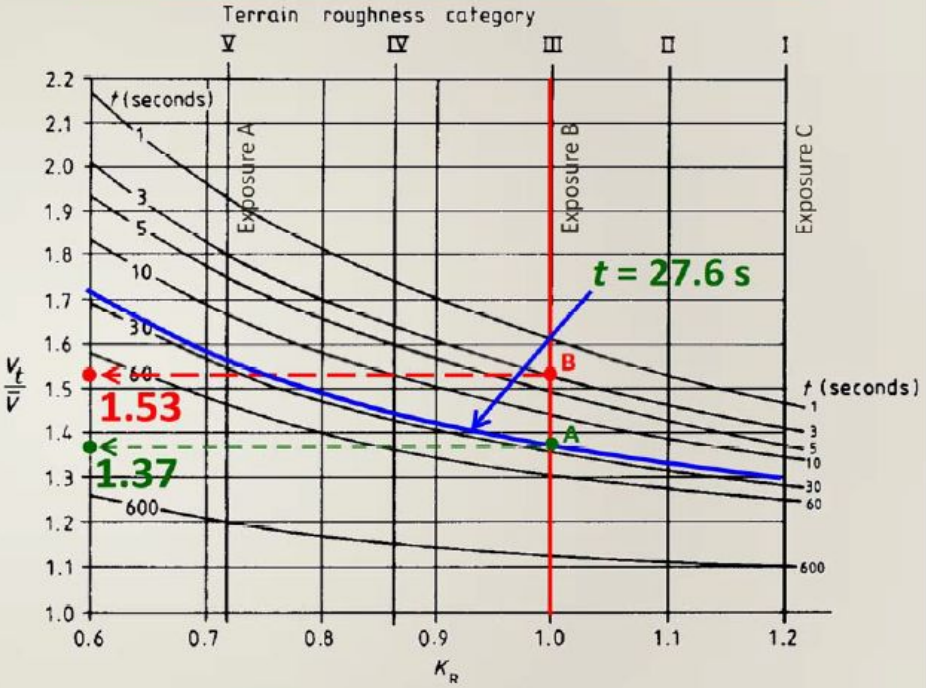
From point A on graph,

$\therefore V_t / V_{mean} = V_{FM} / V_{mean} = 1.37$

$\therefore V_{mean} = V_{FM} / 1.37 = 130.45/1.37$

= 95.22 mph = 153.3 km/h.

**BS8100: Relation between $V_{mean}$ and $V_t$**




From point B on graph,

$\therefore V_t / V_{mean} = V_{3s} / V_{mean} = 1.53$

$V_{3s} = V_{mean}$ x1.53 = 95.22x1.53

=145.69 mph = 234.6 km/h

# Structural Analysis & Design I



## Conversion of Wind Speed

**Therefore, wind load calculated using**

$V_{3s}$ = 234.6 km/h or $V_{FM}$ = 210 km/h or $V_{mean}$ = 153.3 km/h

**all should produce forces of similar magnitude.**

Wind pressure $q = \frac{1}{2} K C_p \rho V^2$

ASCE 7-05, BNBC 2015 $q = \frac{1}{2} K_1 C_p \rho V_{3S}^2$

BNBC 1993, TIA/EIA $q = \frac{1}{2} K_2 C_p \rho V_{FM}^2$

BS 8100 $q = \frac{1}{2} K_3 C_p \rho V_{mean}^2$

If we want same pressure, then $K_1$, $K_2$ and $K_3$ must be different.

Thus, different codes have pressure formulas with different numerical co-efficients due to different definitions of basic wind speed.

Before using a specific code, proper understanding and use of wind speed is essential.

Wind speed from one code or source cannot be used in another code without proper conversion.

# Structural Analysis & Design I



## Wind speed Conversion Chart, TIA/EIA

**ANNEX L: WIND SPEED CONVERSIONS (Normative)**

This annex provides conversion of wind speeds based on various averaging periods to the 3-sec gust wind speed. Wind data based on other averaging periods are to be converted to a 3-sec gust wind speed for use with the Standard.

| 3-sec gust (mph) | Fastest-mile | | 10-min avg. (mph) | Hourly mean (mph) |
|---|---|---|---|---|
| | Wind speed (mph) | Averaging period (sec) | | |
| 60 | 50 | 72 | 42 | 40 |
| 70 | 58 | 62 | 49 | 46 |
| 80 | 66 | 55 | 56 | 53 |
| 85 | 70 | 51 | 59 | 56 |
| 90 | 75 | 48 | 62 | 60 |
| 95 | 78 | 46 | 66 | 63 |
| 100 | 80 | 45 | 69 | 66 |
| 105 | 85 | 42 | 73 | 70 |
| 110 | 90 | 40 | 76 | 73 |
| 115 | 95 | 38 | 80 | 76 |
| 120 | 100 | 36 | 83 | 79 |
| 125 | 105 | 34 | 87 | 83 |
| 130 | 110 | 33 | 90 | 86 |
| 135 | 115 | 31 | 94 | 89 |
| 140 | 120 | 30 | 97 | 93 |
| 145 | 125 | 29 | 101 | 96 |
| 150 | 130 | 28 | 104 | 99 |
| 155 | 135 | 27 | 108 | 103 |
| 160 | 140 | 26 | 111 | 106 |
| 165 | 145 | 25 | 115 | 109 |
| 170 | 150 | 24 | 118 | 113 |

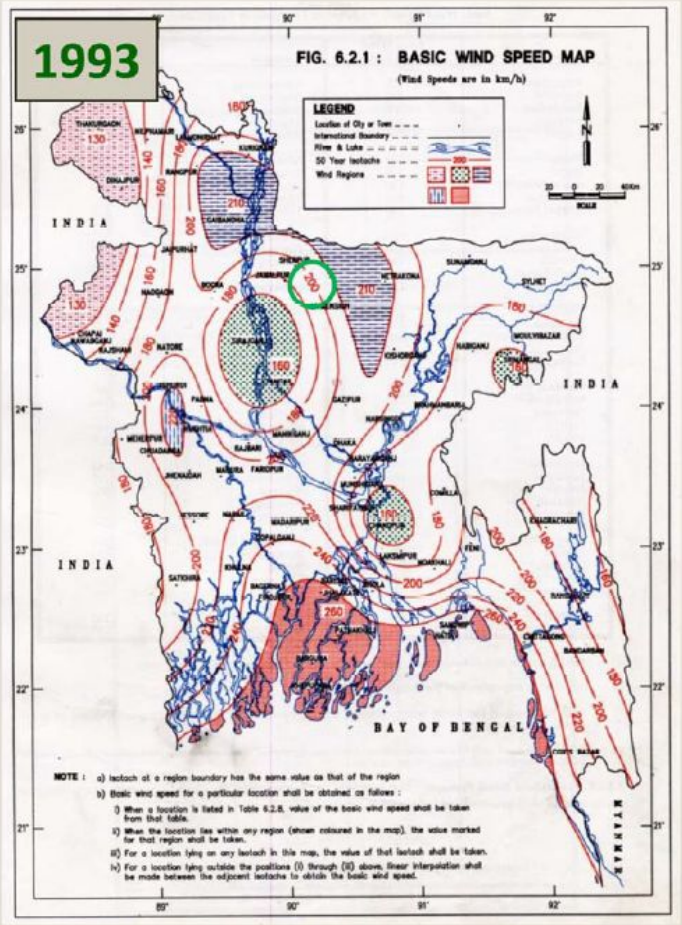
Notes: 1. For conversion to [m/s] multiply the above values by 0.447.
2. Linear interpolation may be used between the values shown

# Structural Analysis & Design I

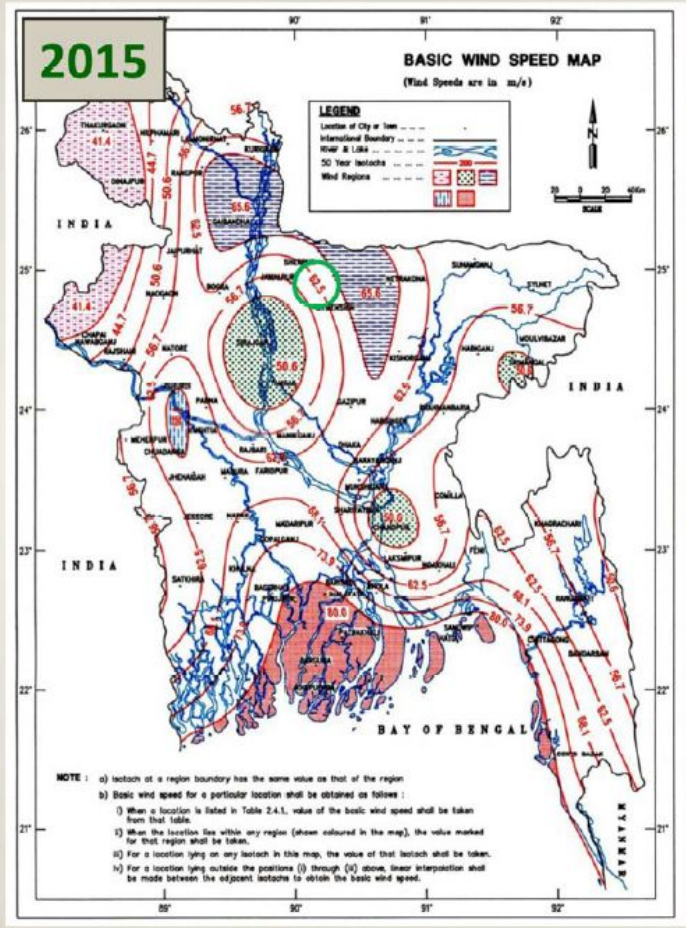
Workshop on Design of Steel and Concrete Structures for Lateral Loads Using Proposed BNBC 2015 Code.

Wind Loading Provisions

## BNBC Basic Wind Speed Comparison




$V_b$ = 200 km/h (Fastest Mile)




$V_b$ = 62.5 m/s = 225 km/h (3-s gust)

# CHARACTERISTICS OF WIND

The flow of wind is complex because many flow situations arise from the interaction of wind with structures. However, in wind engineering, simplifications are made to arrive at design wind loads by distinguishing the following characteristics:

- Variation of wind velocity with height.
- Wind turbulence.
- Statistical probability.
- Vortex shredding phenomenon.
- Dynamic nature of wind–structure interaction.

# Structural Analysis & Design I



## WIND SPEED VARIATION WITH HEIGHT

The viscosity of air reduces its velocity adjacent to the earth's surface to almost zero. The effect of slowdown reduces at each layer as the height increases, and eventually becomes negligible. The height at which the slowdown effect ceases to exist is called ***gradient height***, and the corresponding velocity, ***gradient velocity***.

This characteristic increase of wind velocity with height is a well-understood phenomenon, as evidenced by higher design pressures specified at higher elevations in most building standards.

At heights of approximately 1200 ft (366 m) above ground, the wind speed is virtually unaffected by surface friction. Its movement at and above this level, is solely a function of seasonal and local wind effects. The ensueing height in which the wind speed is affected by topography is called the ***atmospheric boundary layer.***

# Structural Analysis & Design I



## WIND SPEED VARIATION WITH HEIGHT

$$V_z = V_g \left( \frac{z}{z_g} \right)^{\alpha} \leq V_g$$

where

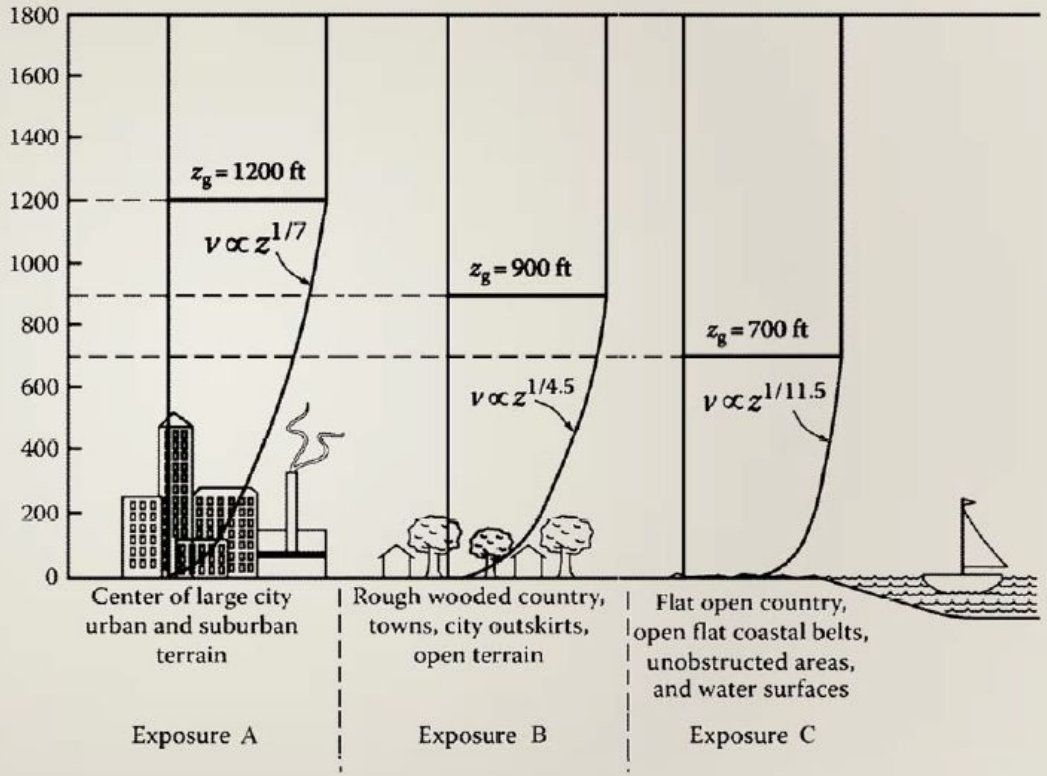
$V_z$ = average wind speed at height $z$ *above ground*

$V_g$ = gradient wind speed assumed constant above the boundary layer

$z$ = height above ground

$z_g$ = nominal height of boundary layer, which depends on the exposure.

$\alpha$ = power law coefficient



# Structural Analysis & Design I



## BNBC 2015 WIND LOAD PROVISIONS

Three procedures for calculating wind loads for the design of buildings, main wind-force-resisting systems (MWFRS), and components and cladding.

**Method 1: Simplified Method:** It was first published in the 2000 IBC. It was developed from research done for Metal Building Manufactures Association, MBMA, in the 1980s using wind-tunnel tests. Method 1 is restricted to regular-shaped "simple diaphragm buildings," has many constraints, and is restricted to a maximum height of 60 ft (18.3m).

**Method 2: Analytical Procedure:** May be used for buildings of any heightthat are regular in shape, provided they are not sensitive to across-wind loading, vortex shedding, or instability due to galloping or flutter; or do not have a site for which channeling effects warrant special consideration.

**Method 3: Wind-Tunnel Procedure:** To be used in lieu of Methods 1 and 2 for any building. Method 3 is recommended for buildings that exhibit the following characteristics:

- Non-uniform shapes
- Flexible with natural frequencies less than 1 Hz
- Subject to significant buffeting by the wake of upwind buildings, subject to accelerated flow of wind by channeling or local topographic features.

# Structural Analysis & Design I



## BNBC 2015 WIND LOAD PROVISIONS

### Method 2: Analytical Procedure

Applies to a majority of buildings. It takes into account

a. Basic wind speed
b. Mean recurrence interval of the wind speed considered appropriate for the design
c. Characteristics of the terrain surrounding the building
d. Height at which the wind load is being determined
e. Directional properties of the wind climate
f. Size, geometry, and aerodynamics of the building
g. Positions of the area acted on by the wind fl ow
h. Magnitude of the area of interest
i. Porosity of the building envelope
j. Structural properties that may make the building susceptible to dynamic effects
k. Speed-up effect of topographic features such as hills and escarpments

# Structural Analysis & Design I



## BNBC 2015 WIND LOAD PROVISIONS

### Method 2: Analytical Procedure

**Advantages**

- Robust design procedure which applies for most "rigid" structures of all heights and shapes.
- Applicable to "flexible" structures with some limitations. Most practicing engineers use this method.
- Applicable to a large variety of structures. It provides pressure coefficients for myriad shapes and heights of any type of regular-shaped buildings and structures.
- In this method, both internal and external pressure coefficients are accounted for depending on the type of enclosure.

# Structural Analysis & Design I



## BNBC 2015 WIND LOAD PROVISIONS

### Method 2: Analytical Procedure

Built around two fundamental equations, the velocity pressure, $q_z$ equation, and the design wind pressure, $p$, equation:

**Velocity pressure, $q_z$**

$q_z = 0.000613\, K_z K_{zt} K_d V^2 I$, kN/m², $V$ in m/s

**Compare**

$$q = \frac{1}{2} C_p \rho V^2$$

where

- $q_z$ is the velocity pressure at height $z$ above ground level
- $K_z$ is the velocity exposure coefficient
- $K_{zt}$ is the topographic factor
- $K_d$ is the directionality factor
- $V$ is the wind speed at an elevation 33 ft (10 m) above ground in flat open county (Exposure B), as given in Figure 6.2.1
- $I$ is the wind importance factor commonly denoted as $I_w$

# Structural Analysis & Design I



## BNBC 2015 WIND LOAD PROVISIONS

### Directionality factor, $K_d$

The wind directionality factor, $K_d$, accounts for the wind force variation due to directionality of wind. This fact used to be taken into account in load factor of 1.3 on the effect of wind in strength design (LRFD) load combinations in the past codes (before 1998).

To facilitate ASD design $K_d = 0.85$ (in most cases) was prescribed in ASCE 1998 and later codes. To compensate for strength design, the 1.3 load factor on wind was adjusted up. A load factor of 1.3/0.85 = 1.53 would have maintained status quo exactly. However, it was rounded up to 1.6, which resulted in an effective 5% increase in the wind load factor.

| Current Code | Past Code (before 1998) |
|---|---|
| $1.2D + 1.6W + 0.5L + 0.5\ (L_r \text{ or } R)$ | $1.2D + 1.3W + f_1L + 0.5\ (L_r \text{ or } R)$ |
| $0.9D + (1.6W \text{ or } 1.0E)$ | $0.9D + (1.3W \text{ or } 1.0E)$ |

The above discussion emphasizes a fact that same code provisions must be maintained through the loading, analysis and design process. Mixing up of different provisions e.g. BS or IS with BNBC is not acceptable.

# Structural Analysis & Design I



## BNBC 2015 WIND LOAD PROVISIONS

### Velocity pressure co-efficient, $K_z$

**The velocity pressure exposure coefficient $K_z$ adjusts the basic wind speed V to a height $z$ and terrain roughness (i.e., exposure category).**

$$K_z = 2.01(z/z_g)^{2/\alpha} \qquad \text{for } 4.57\text{m} \le z \le z_g$$

$$K_z = 2.01(4.57/z_g)^{2/\alpha} \qquad \text{for } z < 4.57\text{m}$$

**Table 6.2.10: Terrain Exposure Constants**

| Exposure | $\alpha$ | $z_g$ (m) | $\hat{a}$ | $\hat{b}$ | $\bar{\alpha}$ | $\bar{b}$ | c | $l$ (m) | $\bar{\epsilon}$ | $z_{min}$ (m)* |
|---|---|---|---|---|---|---|---|---|---|---|
| A | 7.0 | 365.76 | 1/7 | 0.84 | 1/4.0 | 0.45 | 0.30 | 97.54 | 1/3.0 | 9.14 |
| B | 9.5 | 274.32 | 1/9.5 | 1.00 | 1/6.5 | 0.65 | 0.20 | 152.4 | 1/5.0 | 4.57 |
| C | 11.5 | 213.36 | 1/11.5 | 1.07 | 1/9.0 | 0.80 | 0.15 | 198.12 | 1/8.0 | 2.13 |

*$z_{min}$ = Minimum height used to ensure that the equivalent height $z$ is greater of $0.6h$ or $z_{min}$.
For buildings with $h \le z_{min}$, $\bar{z}$ shall be taken as $z_{min}$.

# Structural Analysis & Design I



## BNBC 2015 WIND LOAD PROVISIONS

### Importance factor, *I*

The wind importance factor *I*, sometimes denoted as $I_w$, is a factor that accounts for the degree of hazard to human life and damage to property.

Table 6.2.9: Importance Factor, I (Wind Loads)

| Occupancy Category[1] or Importance Class | Non-Cyclone Prone Regions and Cyclone Prone Regions with V = 38-44 m/s | Cyclone Prone Regions with V > 44 m/s |
|---|---|---|
| I | 0.87 | 0.77 |
| II | 1.0 | 1.00 |
| III | 1.15 | 1.15 |
| IV | 1.15 | 1.15 |

[1] The building and structure classification categories are listed in Table 6.1.1

# Structural Analysis & Design I



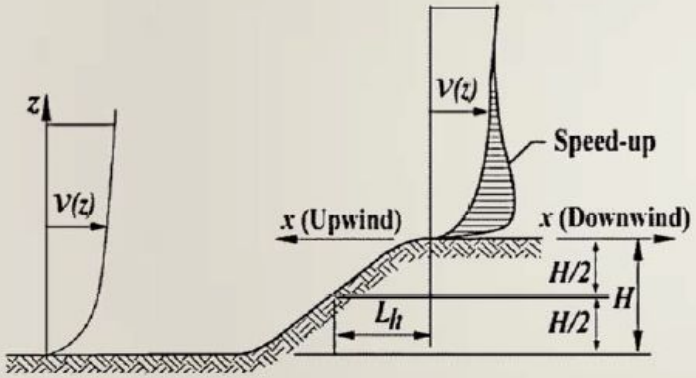
## BNBC 2015 WIND LOAD PROVISIONS

### Topographic factor, $K_{zt}$

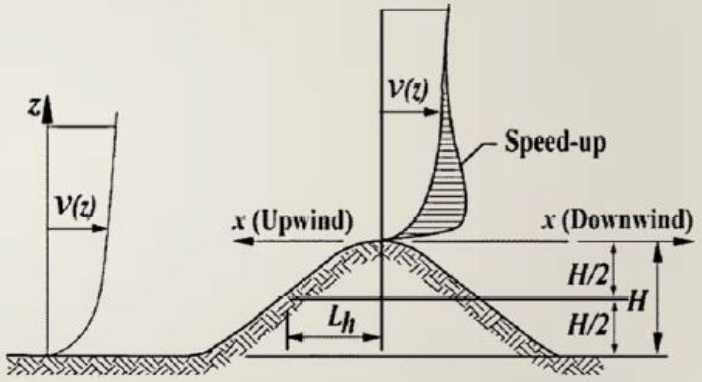
The topographic factor $K_{zt}$ is given by

$$K_{zt} = (1 + K_1K_2K_3)^2$$

It reflects the speedup effect over hills and escarpments.




ESCARPMENT




2-D RIDGE OR 3-D AXISYMMETRICAL HILL

The multipliers $K_1$, $K_2$, and $K_3$ are given in Figure 6.2.4 of the BNBC 2016.

# Structural Analysis & Design I



## BNBC 2015 WIND LOAD PROVISIONS

**Design wind pressure, *p***

$p = q\,GC_p - q_i(GC_{pi})$

Where,

| | |
|---|---|
| $q = q_z$ | for windward walls evaluated at height $z$ above the ground |
| $q = q_h$ | for leeward walls, side walls, and roofs, evaluated at height $h$ |
| $q_i = q_h$ | for windward walls, side walls, leeward walls, and roofs of enclosed buildings and for negative internal pressure evaluation in partially enclosed buildings. |
| $q_i = q_z$ | for positive internal pressure evaluation in partially enclosed buildings where height $z$ is defined as the level of the highest opening in the building that could affect the positive internal pressure. |
| $G$ | gust effect factor from Sec 2.4.8 |
| $C_p$ | external pressure coefficient from Figures 6.2.6 or 6.2.8 |
| $C_{pi}$ | internal pressure coefficient from Figure 6.2.5 |

# Structural Analysis & Design I



## BNBC 2015 WIND LOAD PROVISIONS

**Design wind pressure, *p***

$p = q\,GC_p - q_i\,(GC_{pi})$

For enclosed buildings internal pressures and suctions do not affect wind load calculations for the MWFRS. Therefore, pressures and suctions may be calculated using the following simplified equations:

$p_z = q_z G_f C_p$ (windward positive pressures)

$p_z = q_h G_f C_p$ (leeward negative pressures)

The overall wind load is the summation of positive and negative pressures on the windward and leeward walls, respectively. Using the permitted value of $G_f = 0.85$, and $C_p = 0.8$ and 0.5 for the windward and leeward walls, the overall wind pressure (on projected area) at $z$ for a typical building is given by

$p_z = 0.85(0.8q_z + 0.5q_h)$

# Structural Analysis & Design I



## BNBC 2015 WIND LOAD PROVISIONS

### METHOD 2: ANALYTICAL PROCEDURE

Design wind pressure or suction on a building surface is given by the equation:

$$p_z = q_z \times G_f \times C_p$$

where

$p_z$ is the design wind pressure or suction, at height z, above ground level

$q_z$ is the velocity pressure, determined at height *z* above ground for positive pressure, and at roof height *h* for suction

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

$G_f$ is the gust effect factor, dimensionless, denoted as *G* for rigid buildings, and $G_f$ for flexible buildings

$C_p$ is the external pressure coefficient, which varies with building height acting as pressure (positive load) on windward face, and as suction (negative load) on the leeward face and roof.

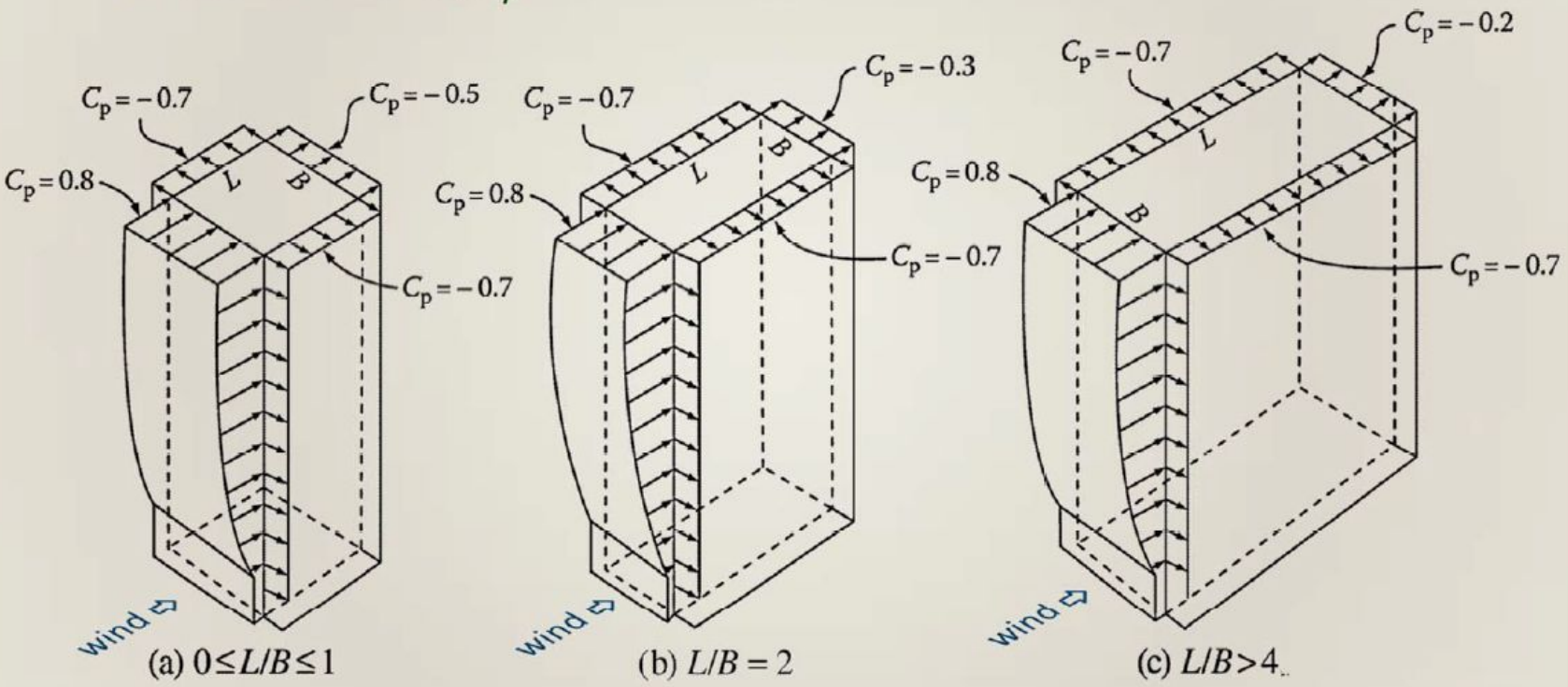
# Structural Analysis & Design I



## BNBC 2015 WIND LOAD PROVISIONS

### METHOD 2: ANALYTICAL PROCEDURE

**Pressure co-efficient, $C_p$**



# Structural Analysis & Design I



## BNBC 2015 WIND LOAD PROVISIONS

### METHOD 2: ANALYTICAL PROCEDURE

**Gust factor, *G***

***Rigid Structure: Simplified Method***

**Structures having a natural frequency of vibration greater than 1 Hz (or period less than 1 sec), the engineer may use a single value of *G* = 0.85, irrespective of exposure category.**

***Rigid Structure: Improved Method***

**We may calculate a more accurate value by including specific features of the wind environment at the building site.**

**Gust factor,** $G = 0.925 \frac{1+1.7 g_Q I_{\bar{z}} Q}{1+1.7 g_v I_{\bar{z}}}$

**Intensity of turbulence at height** $\bar{z}$, $I_{\bar{z}} = c \left(\frac{10}{\bar{z}}\right)^{1/6}$

$\bar{z} = 0.6h < z_{min}$, ***h*** **= height of the building.**

**Parameters $z_{min}$ and *c* are listed in Table 6.2.10 [see slide 25]**

$g_Q = 3.4$, $g_V = 3.4$

# Structural Analysis & Design I



## BNBC 2015 WIND LOAD PROVISIONS

### METHOD 2: ANALYTICAL PROCEDURE

**Gust factor, *G***

***Rigid Structure: Improved Method (contd...)***

Background response, $Q = \sqrt{\frac{1}{1+0.63\left(\frac{B+h}{L_{\bar{z}}}\right)^{0.63}}}$

***B*** = width of the building across the wind, ***h*** = mean height of the building.

Integral length scale of turbulence at the equivalent height, $L_{\bar{z}} = l\left(\frac{\bar{z}}{10}\right)^{\bar{\epsilon}}$

In which $l$ and $\bar{\epsilon}$ are constants listed in Table 6.2.10.

# Structural Analysis & Design I



## BNBC 2015 WIND LOAD PROVISIONS

### METHOD 2: ANALYTICAL PROCEDURE

**Gust factor, *G***

***Flexible Structure*: Buildings having natural frequency less than 1.0 Hz**

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

**$g_Q$ and $g_v$ shall be taken as 3.4 and $g_R$ is given by**

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

***R*, the resonant response factor, is given by**

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

# Structural Analysis & Design I



## BNBC 2015 WIND LOAD PROVISIONS

### METHOD 2: ANALYTICAL PROCEDURE

**Gust factor, *G***

***Flexible Structure*: (contd...)**

$$R_n = \frac{7.47N_1}{(1+10.3N_1)^{5/3}} \qquad N_1 = \frac{n_1 L_{\bar{z}}}{\bar{V}_{\bar{z}}}$$

$$R_\ell = \frac{1}{\eta} - \frac{1}{2\eta^2}(1 - e^{-2\eta}) \text{ for } \eta > 0$$

$R_\ell = 1$ for $\eta = 0$ where, the subscript $l$ in $R_l$ shall be taken as $h$, $B$, and $L$ to determine $R_h$, $R_B$ or $R_L$ respectively.

$n_1$ = building natural frequency = $1/T$ where $T$ = natural period

$R_l = R_h$ setting $\eta = 4.6n_1 h/\bar{V}_{\bar{z}}$

$R_l = R_B$ setting $\eta = 4.6n_1 B/\bar{V}_{\bar{z}}$

$R_l = R_L$ setting $\eta = 15.4n_1 L/\bar{V}_{\bar{z}}$

$\beta$ = damping ratio, percent of critical

# Structural Analysis & Design I



## BNBC 2015 WIND LOAD PROVISIONS

### METHOD 2: ANALYTICAL PROCEDURE

**Gust factor, *G***

***Flexible Structure*: (contd...)**

$\overline{V}_{\bar{z}}$ = mean hourly wind speed at height $\bar{z}$, where $\bar{z} = 0.6h < z_{min}$, $h$ = height of the building.

$$\overline{V}_{\bar{z}} = \bar{b}\left(\frac{\bar{z}}{10}\right)^{\overline{\alpha}} V$$

where $\bar{b}$ and $\overline{\alpha}$ are constants listed in Table 6.2.10.
$V$ is the basic wind speed.

**Table 6.2.10: Terrain Exposure Constants**

| Exposure | $\alpha$ | $z_g$ (m) | $\hat{a}$ | $\hat{b}$ | $\overline{\alpha}$ | $\bar{b}$ | c | $l$ (m) | $\overline{\in}$ | $z_{min}$ (m)* |
|---|---|---|---|---|---|---|---|---|---|---|
| A | 7.0 | 365.76 | 1/7 | 0.84 | 1/4.0 | 0.45 | 0.30 | 97.54 | 1/3.0 | 9.14 |
| B | 9.5 | 274.32 | 1/9.5 | 1.00 | 1/6.5 | 0.65 | 0.20 | 152.4 | 1/5.0 | 4.57 |
| C | 11.5 | 213.36 | 1/11.5 | 1.07 | 1/9.0 | 0.80 | 0.15 | 198.12 | 1/8.0 | 2.13 |

*$z_{min}$ = Minimum height used to ensure that the equivalent height $z$ is greater of $0.6h$ or $z_{min}$.
For buildings with $h \leq z_{min}$, $\bar{z}$ shall be taken as $z_{min}$.

# Structural Analysis & Design I



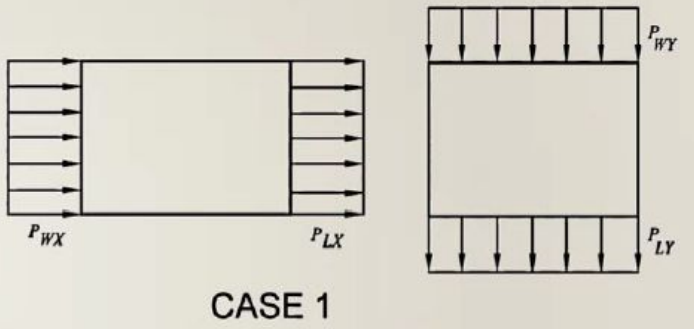
## BNBC 2015 WIND LOAD PROVISIONS

### METHOD 2: WIND LOAD CASES

**BUILDINGS ARE TO BE ANALYZED AND DESIGN FOR FOUR CASES (Fig. 6.2.9)**

**Case 1.**

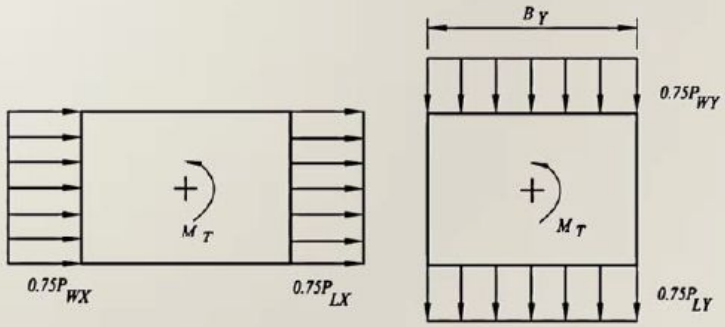
Full design wind pressure acting on the projected area perpendicular to each principal axis of the structure, considered separately along each principal axis.




CASE 1

**Case 2.**

Three quarters of the design wind pressure acting on the projected area perpendicular to each principal axis of the structure in conjunction with a torsional moment as shown, considered separately for each principal axis.




$M_T = 0.75\,(P_{WX} + P_{LX})\,B_X e_X$
$e_X = \pm 0.15\,B_X$

$M_T = 0.75\,(P_{WY} + P_{LY})\,B_X e_Y$
$e_Y = \pm 0.15\,B_Y$

CASE 2

# Structural Analysis & Design I



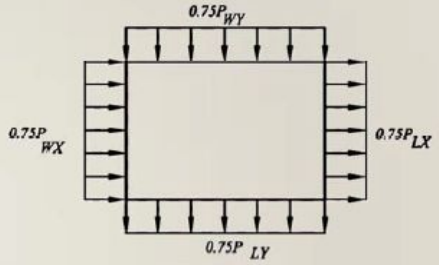
## BNBC 2015 WIND LOAD PROVISIONS

### METHOD 2: WIND LOAD CASES

**BUILDINGS ARE TO BE ANALYZED AND DESIGN FOR FOUR CASES (Fig. 6.2.9)**

**Case 3.**

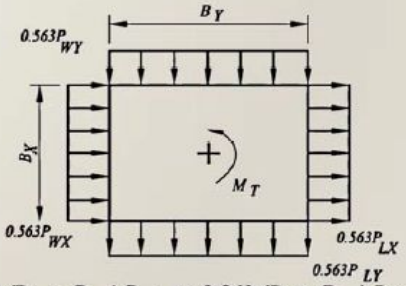
Wind loading as defined in Case 1, but considered to act simultaneously at 75% of the specified value.




CASE 3

**Case 4.**

Wind loading as defined in Case 2, but considered to act simultaneously at 75% of the specified value.




$$M_T = 0.563\,(P_{WX} + P_{LX})\,B_X e_X + 0.563\,(P_{WY} + P_{LY})\,B_Y e_Y$$

$$e_X = \pm 0.15\,B_X \qquad e_Y = \pm 0.15\,B_Y$$

CASE 4

## Wind Load Calculation

### Method 2: Analytical Procedure

2.4.3.4 Design procedure

(1) The basic wind speed $V$ and wind directionality factor $K_d$ shall be determined in accordance with Sec 2.4.4.

(2) An importance factor $I$ shall be determined in accordance with Sec 2.4.5.

(3) An exposure category or exposure categories and velocity pressure exposure coefficient $K_z$ or $K_h$, as applicable, shall be determined for each wind direction in accordance with Sec 2.4.6.

(4) A topographic factor $K_{zt}$ shall be determined in accordance with Sec 2.4.7.

(5) A gust effect factor $G$ or $G_f$, as applicable, shall be determined in accordance with Sec 2.4.8.

(6) An enclosure classification shall be determined in accordance with Sec 2.4.9.

(7) Internal pressure coefficient $GC_{pi}$ shall be determined in accordance with Sec 2.4.10.1.

(8) External pressure coefficients $C_p$ or $GC_{pf}$, or force coefficients $C_f$, as applicable, shall be determined in accordance with Sections 2.4.10.2 or 2.4.10.3, respectively.

(9) Velocity pressure $q_z$ or $q_h$, as applicable, shall be determined in accordance with Sec 2.4.9.5.

(10) Design wind load $P$ or $F$ shall be determined in accordance with Sec 2.4.11.

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# Structural Analysis & Design I

## Guest Factor

No chart- Use Formula $G = 0.925\frac{1+1.7g_Q I_{\bar{z}} Q}{1+1.7g_v I_{\bar{z}}}$

## Topographic factor

2.4.7.2 Topographic factor

The wind speed-up effect shall be included in the calculation of design wind loads by using the factor $K_{zt}$:

$$K_{zt} = (1 + K_1 K_2 K_3)^2 \qquad (6.2.5)$$

Where, $K_1$, $K_2$, and $K_3$ are given in Figure 6.2.4. If site conditions and locations of structures do not meet all the conditions specified in Sec 2.4.7.1 then $K_{zt}$= 1.0.

## Velocity Pressure

2.4.9.5 Velocity pressure

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

$$q_z = 0.000613 K_z K_{zt} K_d V^2 I \;;\; (\text{kN/m}^2),\ V \text{ in m/s} \qquad (6.2.17)$$

Where $K_d$ is the wind directionality factor, $K_z$ is the velocity pressure exposure coefficient defined in Sec 2.4.6.6, $K_{zt}$ is the topographic factor defined in Sec 2.4.7.2, and $q_z$ is the velocity pressure calculated using Eq. 6.2.17 at mean roof height $h$. The numerical coefficient 0.000613 shall be used except where sufficient climatic data are available to justify the selection of a different value of this factor for a design application.

# Structural Analysis & Design I

## Design Wind Loads on Enclosed and Partially Enclosed Buildings

2.4.11.2 Main wind-force resisting systems

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

$$p = qGC_p - q_i(GC_{pi}) \quad (\mathrm{kN/m^2}) \qquad (6.2.19)$$

**Enclosed, Partially Enclosed, and Open Buildings: Walls & Roofs**

| Enclosure Classification | $GC_{pi}$ |
|---|---|
| Open Building | 0.00 |
| Partially Enclosed Building | +0.55<br>-0.55 |
| Enclosed Building | +0.18<br>-0.18 |

Notes:
1. Plus and minus signs signify pressures acting toward and away from the internal surfaces, respectively.
2. Values of $GC_{pi}$ shall be used with $q_z$ or $q_h$ as specified in Sec 2.4.11.
3. Two cases shall be considered to determine the critical load requirements for the appropriate condition:
   (i) a positive value of $GC_{pi}$ applied to all internal surfaces
   (ii) a negative value of $GC_{pi}$ applied to all internal surfaces.

**Figure 6.2.5 Internal pressure coefficient, $GC_{pi}$ main wind force resisting system component and cladding - Method 2 (All Heights)**

# Structural Analysis & Design I

**Table 6.2.9: Importance Factor, I (Wind Loads)**

| Occupancy Category[1] or Importance Class | Non-Cyclone Prone Regions and Cyclone Prone Regions with V = 38-44 m/s | Cyclone Prone Regions with V > 44 m/s |
|---|---|---|
| I | 0.87 | 0.77 |
| II | 1.0 | 1.00 |
| III | 1.15 | 1.15 |
| IV | 1.15 | 1.15 |

[1] The building and structure classification categories are listed in Table 6.1.1

**Table 6.2.10** Is used for Gust co-efficient factor

**Table 6.2.10: Terrain Exposure Constants**

| Exposure | $\alpha$ | $z_g$ (m) | $\hat{a}$ | $\hat{b}$ | $\bar{\alpha}$ | $\bar{b}$ | c | $l$ (m) | $\bar{\epsilon}$ | $z_{min}$ (m)* |
|---|---|---|---|---|---|---|---|---|---|---|
| A | 7.0 | 365.76 | 1/7 | 0.84 | 1/4.0 | 0.45 | 0.30 | 97.54 | 1/3.0 | 9.14 |
| B | 9.5 | 274.32 | 1/9.5 | 1.00 | 1/6.5 | 0.65 | 0.20 | 152.4 | 1/5.0 | 4.57 |
| C | 11.5 | 213.36 | 1/11.5 | 1.07 | 1/9.0 | 0.80 | 0.15 | 198.12 | 1/8.0 | 2.13 |

*$z_{min}$= Minimum height used to ensure that the equivalent height $z$ is greater of $0.6h$ or $z_{min}$.
For buildings with $h \leq z_{min}$, $\bar{z}$ shall be taken as $z_{min}$.

# Structural Analysis & Design I

Table 6.2.11: Velocity Pressure Exposure Coefficients, $K_h$ and $K_z$

| Height above ground level, z | Exposure (Note 1) | | | |
|---|---|---|---|---|
| | A | | B | C |
| (m) | Case 1 | Case 2 | Case 1 & 2 | Case 1 & 2 |
| 0-4.6 | 0.70 | 0.57 | 0.85 | 1.03 |
| 6.1 | 0.70 | 0.62 | 0.90 | 1.08 |
| 7.6 | 0.70 | 0.66 | 0.94 | 1.12 |
| 9.1 | 0.70 | 0.70 | 0.98 | 1.16 |
| 12.2 | 0.76 | 0.76 | 1.04 | 1.22 |
| 15.2 | 0.81 | 0.81 | 1.09 | 1.27 |
| 18 | 0.85 | 0.85 | 1.13 | 1.31 |
| 21.3 | 0.89 | 0.89 | 1.17 | 1.34 |

# Structural Analysis & Design I

Table 6.2.12: Wind Directionality Factor, $K_d$

| Structure Type | Directionality Factor $K_d$* | Structure Type | Directionality Factor $K_d$* |
|---|---|---|---|
| Buildings | | Solid Signs | 0.85 |
| Main Wind Force Resisting System | 0.85 | Open Signs and Lattice Framework | 0.85 |
| Components and Cladding | 0.85 | Trussed Towers | |
| Arched Roofs | 0.85 | Triangular, square, rectangular | 0.85 |
| Chimneys, Tanks, and Similar Structures | | All other cross section | 0.95 |
| Square | 0.90 | | |
| Hexagonal | 0.95 | | |
| Round | 0.95 | | |

* Directionality Factor $K_d$ has been calibrated with combinations of loads specified in Sec 2.7. This factor shall only be applied when used in conjunction with load combinations specified in Sections 2.7.2 and 2.7.3.

# Structural Analysis & Design I

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