Wind Loading Code for Building Design in Thailand

Virote Boonyapinyo[a], Panitan Lukkunaprasit[b]
Pennung Warnitchai[c] and Phoonsak Pheinsusom[d]

[a]Associate Professor, Department of Civil Engineering, Thammasat University, Rangsit Campus, Pathumthani, Thailand
[b]Professor, Department of Civil Engineering, Chulalongkorn University, Bangkok, Thailand.
[c]Associate Professor, School of Civil Engineering, Asian Institute of Technology, Pathumthani, Thailand
[d]Associate Professor, Department of Civil Engineering, Chulalongkorn University, Bangkok, Thailand.

ABSTRACT: The wind load in the existing building code under the Building Control Act 1979 is obsolete because it does not consider the terrain conditions and the typhoon influence. Therefore, the Wind Loading Code for Building Design has been newly published by the Engineering Institute of Thailand since 2003. The new code considers the wind speed zoning, surrounding terrain, dynamic properties, and building shapes. Three different approaches for determining design wind loads on buildings are given in the code, namely, the simple procedure for low-rise buildings, the detailed procedure for high-rise buildings, and wind-tunnel test procedure. The code includes the calculation of: (1) wind load of the main wind resistant system and cladding; (2) lateral deflection; and (3) building motion in the along-wind and across-wind directions.

1. INTRODUCTION

The wind load specified in the existing building code under Building Control Act (BCA) 1979 is obsolete because it does not consider the terrain conditions and the typhoon influence. In addition, the code value is too low for very tall building, and for building in open exposure, as well as buildings in the Southern part of Thailand which is prone to typhoon attack [1, 2]. Therefore, the Subcommittee on Wind and Earthquake Effects on Structures of the Engineering Institute of Thailand published the new Wind Loading Code for Building Design in 2003 [3]. It considers the wind speed zoning, surrounding terrain, dynamic properties, and building shapes. The new code is mainly based on the National Building Code of Canada 1995 [4] and partially on the International standard, ISO 4354, Wind Action on Structures [5]. The reference wind speed is based on the study of the wind climate in Thailand [1, 6]. The wind speed for the Southern Thailand reflects the influence of the rare event of the typhoons in the region.

2. WIND LOADING CALCULATION PROCEDURE

Three different approaches for determining design wind loads on buildings are given in the code as follows.

2.1 *Simple procedure*

The simple procedure is appropriate for use with the majority of wind loading applications, including the structure and cladding of low and medium rise building and the cladding design of high rise buildings. These are situations where the structure is relatively rigid. Thus, dynamic actions of the wind do not require detailed knowledge of the dynamic properties of the buildings and can be dealt with by equivalent static loads.

2.2 *Detailed Procedure*

The detailed procedure is appropriated for buildings whose height is greater than 4 times their minimum effective width or greater than 120 m and other buildings whose light weight, low frequency and low damping properties make them susceptible to vibration

2.3 *Wind tunnel test procedure*

Wind tunnel testing is appropriate when more exact definition of dynamic response is needed and for determining exterior pressure coefficients for cladding design on buildings whose geometry deviates markedly from more common shapes for which information is already available.

3. SPECIFIED WIND LOADING

The specified external pressure or suction due to wind on part or all of a surface of a building shall be calculated from

$$P = qC_eC_gC_p \tag{1}$$

where

P = the specified external pressure acting statically and in a direction normal to the surface either as a pressure directed to wards the surface or as a suction directed away from the surface,
q = the reference velocity pressure,
C_e = the exposure factor,
C_g = the gust effect factor,
C_P = the external pressure coefficient, averaged over the area of the surface considered

The net wind load for the building as a whole shall be the algebraic difference of the loads on the windward and the leeward surfaces, and in some cases may be calculated as the sum of the products of the external pressures or suctions and the areas of the surfaces over which they are averaged

The net specified pressure due to wind on part or all of a surface of a building shall be the algebraic difference of the external pressure or suction as given in Equation (1) and the specified internal pressure or suction due to wind calculated from

$$P_i = qC_eC_gC_{pi} \quad (2)$$

where

P_i = the specified internal pressure, acting statically and in a direction normal to the surface either as a pressure (directed outwards) or as a suction (directed in wards),

q = the reference velocity pressure,

C_e = the exposure factor, evaluated at the building mid-height instead of the height of the element considered,

C_g = the gust effect factor,

C_{pi} = the internal pressure coefficient

4. REFERENCE VELOCITY PRESURE

In both the simple and detailed procedures the reference wind speed, $\overline{V}$, is determined by extreme value analysis of meteorological observations of hourly mean wind speeds to be representative of a height of 10m in an open exposure as shown in Figure 1. The reference wind pressure, q, is determined from $\overline{V}$ by the following equation:

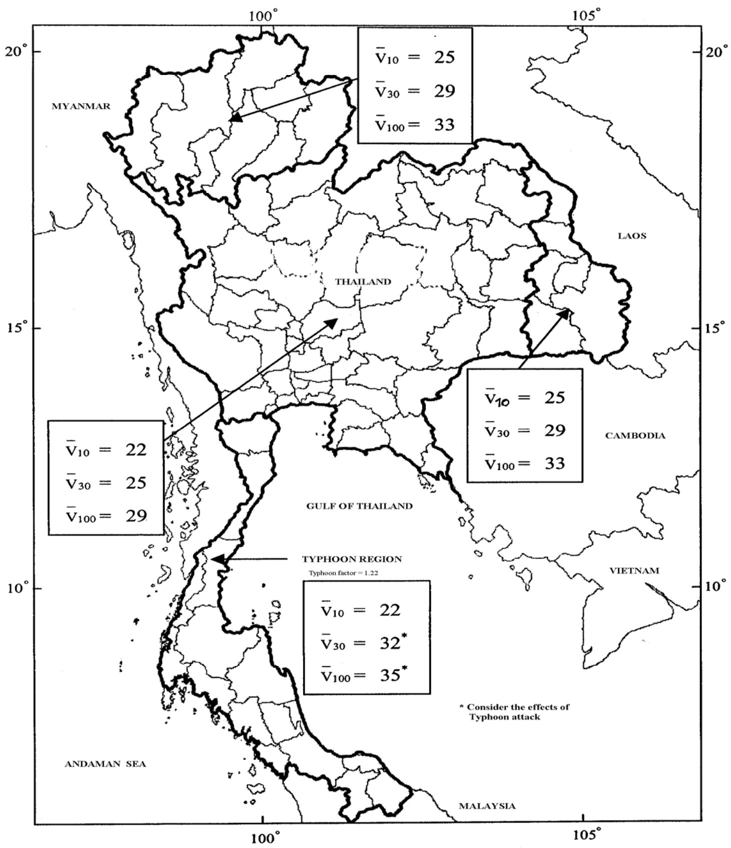

Figure 1. Reference wind speed for return periods of 10, 30 and 100 years for Thailand.

$$q(\text{in kg/m}^2) = \frac{1}{2}\left(\frac{\rho}{g}\right)\overline{V}^2 \quad (3)$$

where

ρ = air density = 1.25 kg/m^3
g = acceleration due to gravity = 9.81 m/s^2

The reference velocity pressure, *q*, is the appropriate value for the following conditions:

a) the reference velocity pressure, *q*, for the design of cladding shall be based on a probability of being exceeded in any one year of 1 in 10,
b) the reference velocity pressure, *q*, for the design of structural members for deflection and vibration shall be based on a probability of being exceeded in any one year of 1 in 10
c) for all buildings, except those listed in Clause (d), the reference velocity pressure, q, for the design of structural members for strength shall be based on a probability of being exceeded in any one year of 1 in 30, and
d) the reference velocity pressure, *q*, for the design of structural members for strength for post-disaster buildings shall be based on a probability of being exceeded in any one year of 1 in 100.

5. EXPOSURE FACTOR

The exposure factor, C_e, reflects changes in wind speed and height, and also the effects of variations in the surrounding terrain and topography. The exposure factor for use with either the simple or detailed procedure are given as follows.

5.1 *Simple procedure*

The exposure factor, C_e, is given in Equation 4 or in Table1.

Table 1
Exposure Factors, C_e

Height, m	Exposure Factor
0 - 6	0.90
6 - 10	1.00
10 - 20	1.15
20 - 30	1.25
30 - 40	1.32
40 - 60	1.43
60 - 80	1.52
80 - 100	1.58
100 - 120	1.64

$$C_e = \left(\frac{Z}{10}\right)^{0.2}, \quad C_e \geq 0.9 \tag{4}$$

where Z is the reference height above ground in metres.

5.2 *Detailed procedure*

For the detailed procedure, the exposure factor, C_e, is based on the mean wind speed profile, which varies considerable depending on the general roughness of the terrain over which the wind has been blowing before it reaches the building. This dependence on terrain is much more significant than is the case for the gust speed profile (variation of gust speed with height) and hence three categories have been established as follows:

Exposure A: (open or standard exposure): open level terrain with only scattered buildings, trees or other obstructions, open water or shorelines thereof. This is the exposure on which the reference wind speeds are based.

$$C_e = \left(\frac{Z}{10}\right)^{0.28}, \quad C_e \geq 1.0 \tag{5}$$

Exposure B: suburban and urban areas, wooded terrain or centres of large towns.

$$C_e = 0.5\left(\frac{Z}{10}\right)^{0.50}, \quad C_e \geq 0.5 \tag{6}$$

Exposure C: centres of large cities with heavy concentrations of tall buildings. At least 50% of the buildings should exceed 4 storeys.

$$C_e = 0.4\left(\frac{Z}{10}\right)^{0.72}, \quad C_e \geq 0.4 \tag{7}$$

In Equations (5) to (7), Z is the height above ground in metres.

Exposure B or C should not be used unless the appropriate terrain roughness persists in the upwind direction for at least 1.5 km, and the exposure factor should be varied according to the terrain if the roughness differs from one direction to another.

6 GUST EFFECT FACTOR

The gust effect factor, C_g, is defined as the ratio of the maximum effect of the loading to the mean effect of the loading. The dynamic response includes the action of

a) random wind gusts action for short durations over all or part of the structure.
b) fluctuating pressures induced by the wake of the structure, including “vortex shedding forces,” and
c) fluctuating forces induced by the motion of the structure itself through the wind.

The gust effect factor for use with either the simple or detailed procedure are given as follows.

6.1 *Simple procedure*

The gust effect factor C_g is one of the following values:

a) 1.0 or 2.0 for internal pressures as appropriate (see code [3]),
b) 2.0 for the building as a whole and main structural members,
c) 2.5 for small elements including cladding

6.2 *Detailed procedure*

The gust effect factor is calculated as

$$C_g = 1 + g_p(\sigma/\mu) \tag{8}$$

where

μ = the mean loading effect,
σ = the "root-mean square" loading effect, and
g_p = a statistical peak factor for the loading effect obtained from figure in the code.

The value of σ/μ can be expressed as

$$\sigma/\mu = \sqrt{\frac{K}{C_{eH}}\left(B + \frac{sF}{\beta}\right)} \tag{9}$$

where

K = a factor related to the surface roughness coefficient of the terrain,
= 0.08 for Exposure *A*,
= 0.10 for Exposure *B*,
= 0.14 for Exposure *C*,
C_{eH} = exposure factor at the top of the building, *H*,
B = background turbulence factor obtained from Figure in the code as a function of *W/H*,
W = width of windward face of the building,
H = height of windward face of the building,
s = size reduction factor obtained from Figure in the code as a function of *W/H* and the reduced frequency n_oH/V_H,
n_o = natural frequency of vibration, *Hz*,
V_H = mean wind speed (m/s) at the top of structure, *H*,
F = gust energy ratio at the natural frequency of the structure obtained from Figure in the code as a function of the wave number, n_o/V_H, and
β = damping ratio.

7 PRESSURE COEFFICIENTS

Pressure coefficients are the non-dimensional ratios of wind-induced pressures on a building to the dynamic pressure (velocity pressure) of the wind speed at the reference height.

Pressures on the surfaces of structures vary considerably with the shape. Wind direction and profile of the wind velocity.

The information on external and internal pressure coefficients given in the code covers requirements for the design of the cladding and the structure as a whole for a variety of simple building geometries.

For rectangular shape building, the pressure coefficients for windward and leeward walls are 0.8 and –0.5, respectively. Reference heights for exposure factor for the calculation of both spatially-averaged and local pressures are as follows. leeward walls use at 0.5 *H*, roof and side walls use at *H*, any area at height *Z* above ground on the windward wall use at *Z*.

8 LATERAL DEFECTION

Lateral deflection of tall buildings under wind loading may require consideration from the standpoints of serviceability or comfort. A maximum lateral deflection limitation of 1/500 of the building height is specified.

9 BUILDING MOTION

While the maximum lateral wind-loading and deflection are generally in the direction parallel with the wind (along-wind direction), the maximum acceleration of a building leading to possible human perception of motion or even discomfort may occur in the direction perpendicular to the wind (across-wind direction)

The peak acceleration in the across-wind direction at the top of the building can be found from the following:

$$a_w = n_w^2 g_p \sqrt{WD} . \frac{78.5x10^{-3}}{\rho_B g \sqrt{\beta_w}} . \left[\frac{V_H}{n_w \sqrt{WD}} \right]^{3.3} \quad (10)$$

The maximum acceleration in the along-wind direction can be found from the expression

$$a_D = 4\pi^2 n_D^2 g_p \sqrt{\frac{KsF}{C_{eH}\beta} . \frac{\Delta}{C_g}} \quad (11)$$

where

W,D = across-wind and along-wind building dimensions, m,

a_W, a_D = peak acceleration in across-wind and along wind directions, m/s^2,

ρ_B = average density of the building, kg/m^3,

β_W, β_D = damping ratio in across-wind and along-wind directions,

n_W, n_D = fundamental natural frequencies in across-wind and along-wind directions, *Hz*.

Δ = maximum wind-induced lateral deflection at the top of the building in along-wind direction, m,

g = acceleration due to gravity = 9.81 m/s^2,

An acceleration limitation of 1.5 to 2 % of gravity once every 10 years is specified for use in conjunction with Equations (10) and (11). The lower value is considered appropriate for apartment buildings, the higher value for office buildings.

10 CONCLUSION

The Wind Loading Code for building Design has been newly published by the Engineering Institute of Thailand since 2003. Three different approaches for determining design wind loads on building are given in the code, namely, the simple procedure for low-rise building, the detailed procedure for high-rise building, and wind-tunnel test procedure. The code includes the calculation of: (1) wind load of the main wind resistant system and cladding; (2) lateral deflection; and (3) building motion in the along-wind and across-wind directions.

The new code by the Engineering Institute of Thailand is much more appropriate and accurate than the existing building code under the Building Control Act 1979.

11 ACKNOWLEDGEMENTS

The authors would like to express their sincere appreciation to Mr. Kumtorn Janesupasaeree, the doctoral student of Thammasat University, for his assistance in preparation of this paper.

12 REFERENCES

1. Lukkunaprasit, P., Pheinsusom, P., and Euasiriwam, N., (1995), Wind Loading for Tall Building Design in Thailand, Proc. of 2nd National Convension on Civil Engineering, Chiangmai, Thailand (in Thai).
2. Boonyapinyo, V., (1998), Comparison between Wind and Earthquake Loads for High-Rise Building Design in Thailand, Proc. of International Seminar on Earthquake Resistant Design of Structures, Chiangmai, Thailand.
3. Engineering Institute of Thailand (2003), E.I.T. Standard 1018-46, Wind Loading Code for Building Design,
4. National Building Code of Canada (1995) issued by the Canadian Commission on Building and Fire Codes, National Research Council of Canada, Ottawa, Canada.
5. International Standard, ISO 4354 (1997) – Wind Actions on Structures, International Organization for Standardization, Switzerland.
6. Mikitiuk, M., Surry, D., Lukkunaprasit, P., and Euasiriwan, N. (1995). Probability Based Wind Loadings for the Design of Transmission Structures, Part A-A Study of The Wind Climate for Thailand. The Boundary Layer Wind Tunnel Laboratory, The University of West Ontario and Chulalongkorn University, Thailand, CU/CE/EVR 1995.001.