CHAPTER 2

WIND EFFECT ON BUILDINGS

2.1 Specified Wind Load

Specific external pressure on surface of building can be calculated by using National Building Code of Canada [NBC 1995] as

$$P = qC_eC_gC_p \tag{2.1}$$

where P is the equivalent static wind pressure profile impacting on the high-rise building (kg/m^2). Physical meaning of P is shown in Fig. 2.1. In this study, the specified wind load is calculated by using EXCEL computer program as shown in Appendixes D.

2.1.1 Reference velocity pressure q

$q = \frac{1}{2}\rho\,\overline{V}^2$, $\overline{V}$ is the reference wind speed determined by extreme value analysis of meteorological observation of hourly mean wind speeds, taken at sites chosen in most cases to be representative of the height of 10 m in an open exposure. The procedure to determine reference wind speed is shown in Fig. 2.2 and Thailand map of reference mean wind speed in one hour at height of 10 m in an open exposure for 50 years returned period is applied as proposed by Lukkunaprasit et al (1995) and is shown in Fig. 2.3.

$C = \frac{1}{2}\rho$ where ρ is the density of the air around the building which depends on atmospheric pressure and the air temperature. The atmospheric pressure in turn is influenced mainly by elevation above sea level, but also varied somewhat changes in the weather.

$$C = 650 * 10^{-6} \qquad \text{for } \overline{V} \text{ unit in m/sec and } q \text{ in kPa} \tag{2.2}$$

2.1.2 Exposure factor C_e

The exposure factor, C_e, is based on the mean wind speed profile, which varies considerably 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 important than is the case for the gust speed profile (variation gust speed with height) and hence three categories has been established as follow:

1. **Exposure A;** (Open of 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.

$$C_e = \left(\frac{Z}{10}\right)^{0.28}, C_e \geq 1.0 \quad (2.3)$$

2. **Exposure B;** suburban and urban area, wood terrain or centers of large town.

$$C_e = 0.5\left(\frac{Z}{10}\right)^{0.5}, C_e \geq 0.5 \quad (2.4)$$

3. **Exposure C;** centers of large cities with heavy concentration of tall buildings. At least 50 percent of building should be exceeding 4 storeys.

$$C_e = 0.4\left(\frac{Z}{10}\right)^{0.72}, C_e \geq 0.4 \quad (2.5)$$

In equation (2.3) to (2.5), Z is the height above the ground in meters. For the leeward side Z is equal to the half of the height of building. It is strict that $C_e \leq 2.6$. Alternatively, value C_e can be determined directly from Fig. 2.4.

2.1.3 Gust effect factor C_g

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

1. Random wind gust acting for short durations over all or part of the structure,
2. Fluctuating pressures induced by the wake of the structure, including "*vortex shedding force*", and
3. Fluctuation forces induced by the motion of the structure itself through the wind

These forces act on the external surfaces of the structure as a whole or on cladding components and may also affect internal surfaces. They may act longitudinally, laterally of torsionally and further they may be amplified by resonance of structure at one or other of its natural frequencies.

All structures are affected to some degree by these forces. The total response may be considered as a superposition of a "*background component*," which acts quasi-statically without any structural dynamic magnification, and a " *resonant* " component due to excitation close to a natural frequency. For the majority of structures, the resonant component is small and the dynamic factor can be simplified by considering the background component only and treated using normal static methods. For structures that are particularly tall, long, slender, lightweight, flexible of lightly damped, the resonant component may be dominant.

The majority of structures can be treated using the "*simple procedure*".

C_g is defined as

$$C_g = 1 + g_p\left(\frac{\sigma}{\mu}\right) \tag{2.6}$$

g_p is called Statistic peak factor for the loading effect or the meaning as the standard deviation of peak load effect.

$$g_p = \sqrt{2\ln T\nu} + \frac{0.577}{\sqrt{2\ln T\nu}} \tag{2.7}$$

Alternatively, g_p can be directly determined from Fig. 2.5.

$$\nu = n_o\sqrt{\frac{sF}{sF + B\beta}} \tag{2.8}$$

where $T = 3600$ sec ; n_o is the natural frequency of building; β is defined as critical damping ratio.

Size reduction factor s is the function of width and height ratio $\frac{W}{H}$ and reduced frequency $\frac{n_o H}{V_H}$ as

$$s = \frac{\pi}{3}\left[\frac{1}{1 + \frac{8n_o H}{3V_H}}\right]\left[\frac{1}{1 + \frac{10n_o W}{V_H}}\right] \tag{2.9}$$

where W is the width of water; H is the height of building; $V_H = \bar{V}\sqrt{C_{eH}}$; C_{eH} is the Exposure factor at the height of building H. Alternatively, s can be directly determined from Fig. 2.6.

F is the gust energy ratio at the natural frequency of the structure which can express in the term of the function of the wave number $\frac{n_o}{V_H}$ as

$$F = \frac{x_o^2}{\left(1 + X_0^2\right)^{4/3}}, X_0 = \frac{1220 \times n_o}{V_H} \tag{2.10}$$

Alternatively, F can be directly determined from Fig. 2.7.

B is the back ground turbulence factor which is the function of the ratio of width and height $\frac{W}{H}$. B can be expressed as

$$B=\frac{4}{3}\int_{0}^{914/H}\left[\frac{1}{1+\frac{ZH}{457}}\right]\left[\frac{1}{1+\frac{ZW}{122}}\right]\left[\frac{Z}{\left(1+Z^2\right)^{4/3}}\right]dz \tag{2.11}$$

Alternatively, value of B can be directly determined from Fig. 2.8.

The ratio of the root mean square loading effect and the mean loading effect $\frac{\sigma}{\mu}$ can be generated in the detail equation as

$$\frac{\sigma}{\mu}=\sqrt{\frac{K}{C_{eH}}}\left(B+\frac{sF}{\beta}\right) \tag{2.12}$$

where K is a factor related to the surface roughness coefficient of the terrain, which equal to 0.08 for Exposure A, 0.1 for Exposure B, 0.14 for Exposure C.

2.1.4 Pressure coefficient C_p

Pressure coefficients are the non-dimensional ratios of wind induced pressures on a building to dynamic pressure (velocity pressures) 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. Pressure coefficients are usually determined from wind tunnel experiments on small-scale models, although in a few recent instances measurements on full-scale building have been used directly. In most cases, this pressure must be measured in a wind tunnel in which the natural velocity profile and turbulence are simulated: experiments in uniform flow can be highly misleading. In this thesis, flat-roofed buildings which have the height greater than the width are considered. From NBC code, the pressure coefficients are equal to 0.8 for the windward side and 0.5 for the leeward side.

2.2 Wind Induced Building Motion

For the case of the slender of both axes $\frac{\sqrt{WD}}{H}$ less than one third the acceleration of the across wind is higher than along wind, where W and D is the across wind and along wind dimensions.

Although treatment of this subject is somewhat tentative, the following guidelines may be of assistance. A wide range of turbulent boundary layer wind tunnel studied, have demonstrated that the peak across wind acceleration can be written as

$$a_W = n_W^2 g_p \sqrt{WD}\left(\frac{a_r}{\rho_B g \sqrt{\beta_W}}\right) \tag{2.13}$$

where D is the depth of building; β_W is the damping ratio for the across wind direction of building; n_W is the natural frequency of across wind direction of building; ρ_B is the density of building.

g_p is the Statistic peak factor for the loading effect of the across wind direction which the natural frequency and the critical damping ratio is different from the along wind direction.

$$\mathrm{a}_r = 78.5 * 10^{-3}\left[V_H / \left(n_W \sqrt{WD}\right)\right]^{3.3}, Pa, \tag{2.14}$$

Along wind speed can be expressed as

$$a_D = 4\pi^2 n_D^2 g_p \sqrt{\frac{KsF}{C_e \beta_D}\frac{\Delta}{C_g}} \tag{2.15}$$

where n_D is natural frequency of along wind direction of building; β_D is the damping ratio of along wind direction of building.

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

$$\Delta = \frac{3\int_0^H ZP(Z)dz}{4\pi^2 n_D^2 D \rho_B H^2} \tag{2.16}$$

One possible expression for $P(Z)$ assumes a power law variation with a maximum at the top of $qC_e C_g C_p$

$$\int_0^H ZP(Z)dZ = \left(\frac{H^2}{2+\alpha}\right) qC_e C_g C_p \tag{2.17}$$

where α is the appropriate exponent from Eq. (2.3) - Eq. (2.5). The peak across-wind displacement may be approximated by $a_w / (2\pi n_w)^2$.

By assuming linear vibration mode and uniform distribution of the building mass, the first modal mass can be computed as

$$m_s = \int_0^H \rho_B WD\left(\frac{Z}{H}\right)^2 dZ = \rho_B WD\frac{H}{3} \tag{2.18}$$

2.3 Allowance of Response

Base on the NBC recommendation, the lateral deflection limitation of H/500 and the acceleration of 1 to 3% of gravity once every 10 years should be used. The lower value of acceleration might be considered approximately for apartment building, the higher value for office building.

2.4 Vibration Controller Application

Because the high-rise building is mostly vibrated higher than the allowance response of NBC code so the application of vibration controller is needed to behave as if increasing the damping ratio of the total system. Physical meaning of equivalent damping ratio is shown in Fig. 2.9.

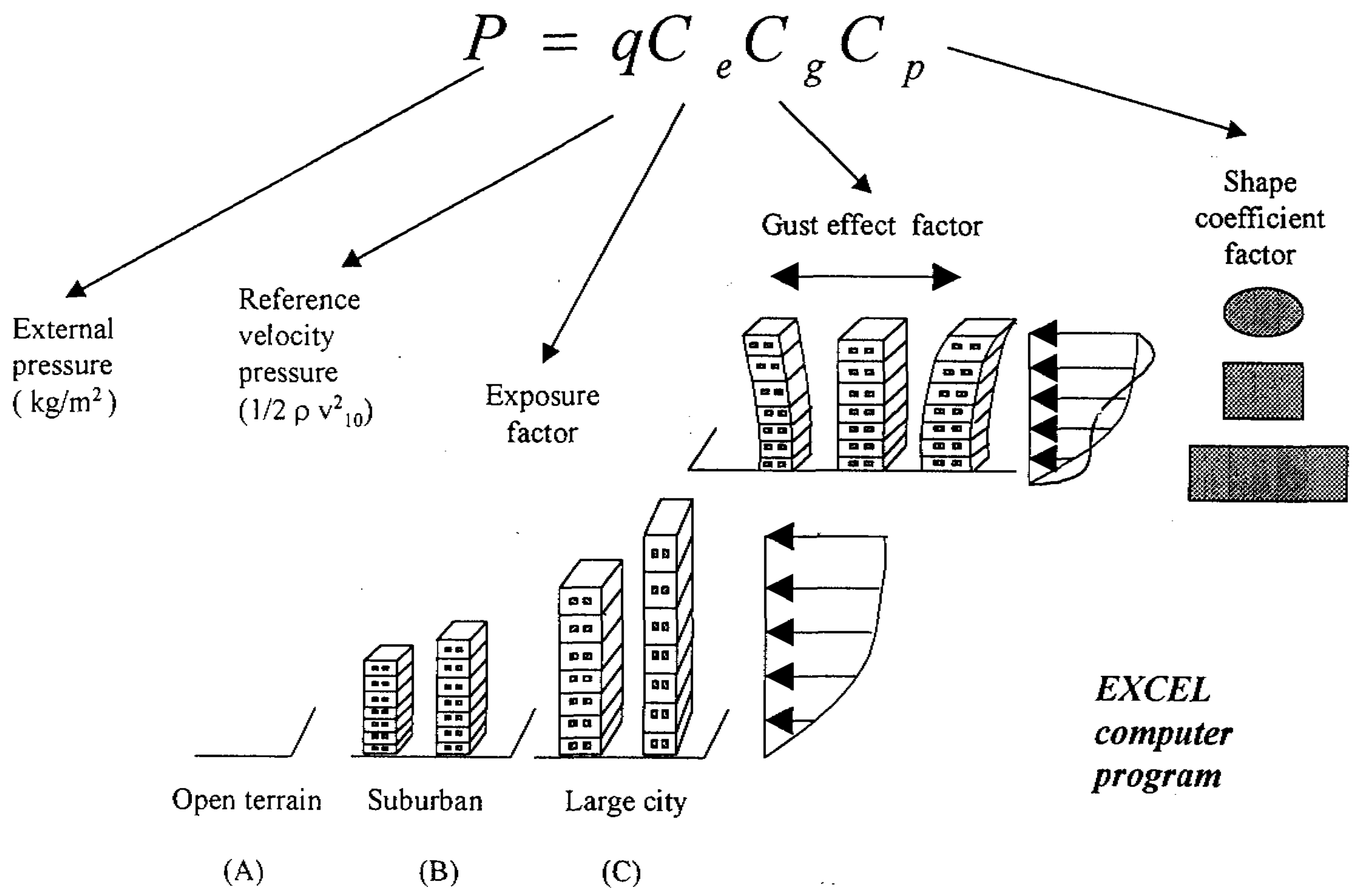

Fig. 2.1 Equivalent static pressure (NBC code)

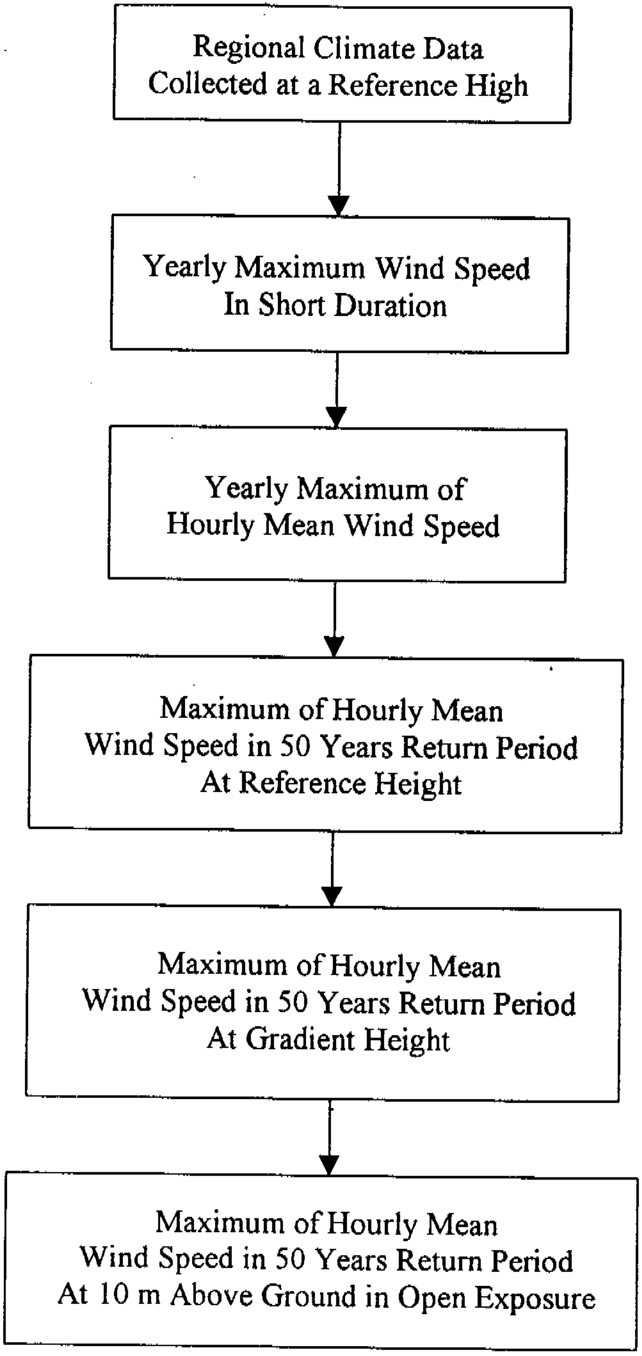

Fig. 2.2 Procedure to determine reference wind speed

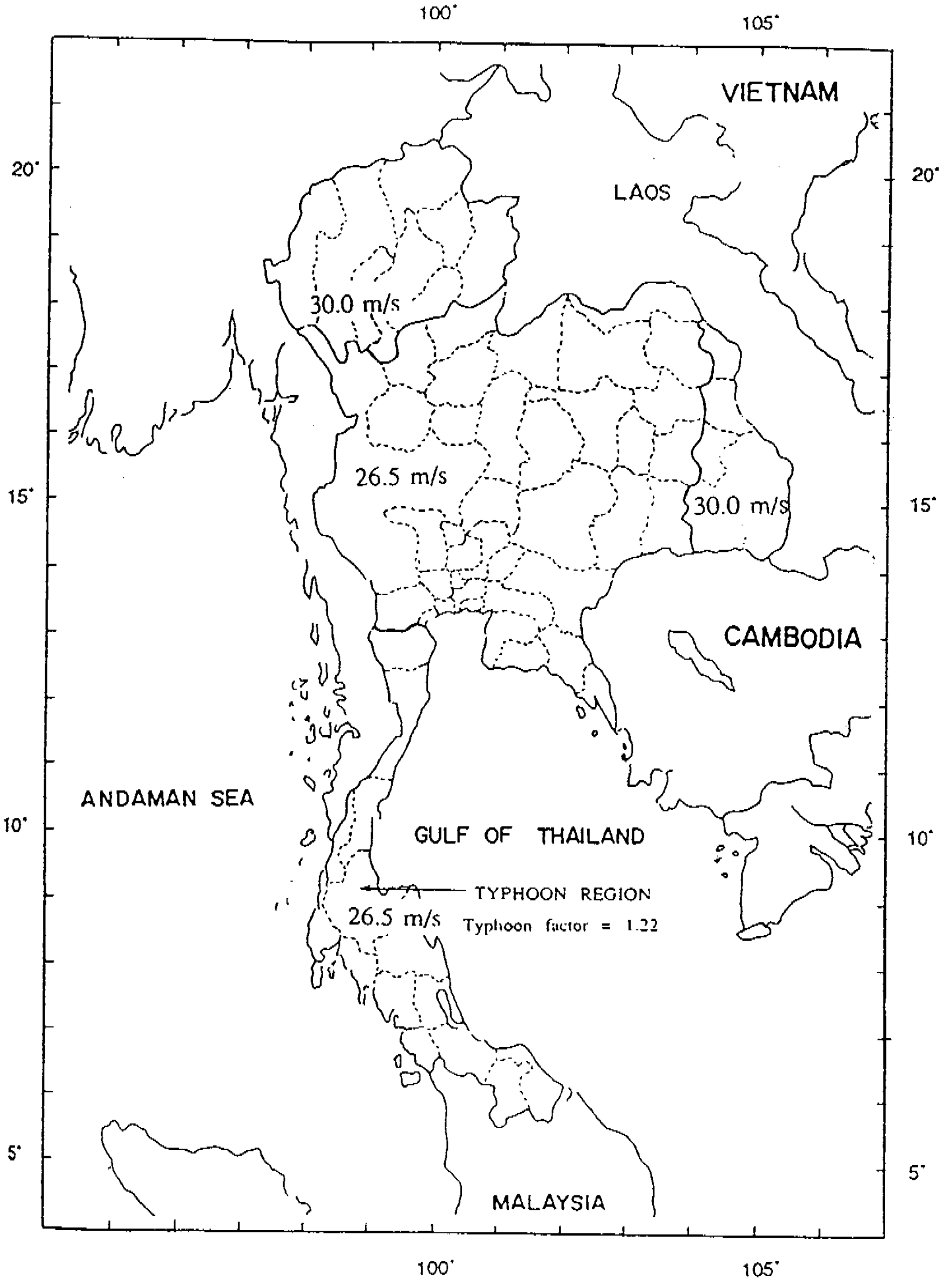

Fig. 2.3 Thailand map of reference mean wind speed in one hour at height of 10 m in an open exposure for 50 years returned period (Lukkunaprasit 1995)

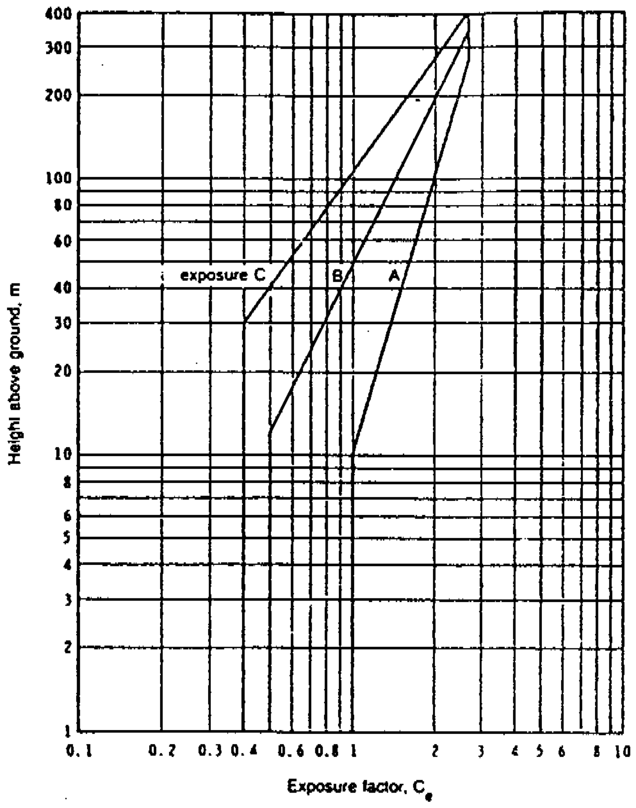

Fig. 2.4 Exposure factor as a function of terrain roughness and height above ground

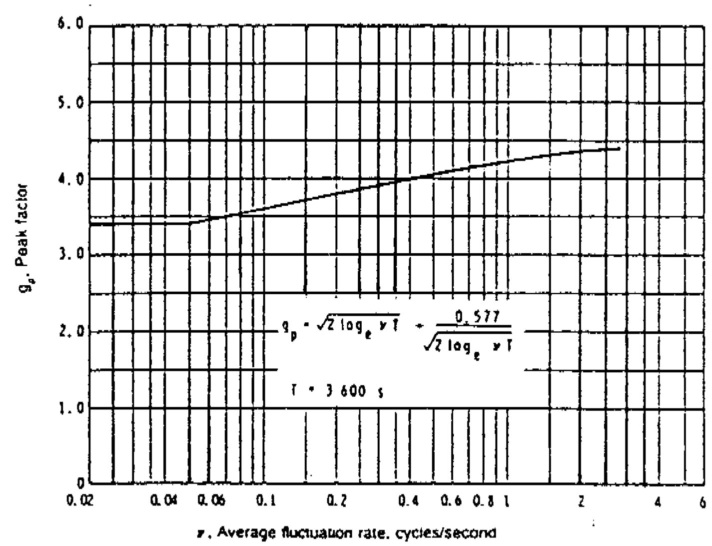

Fig. 2.5 Peak factor as a function of average fluctuation rate

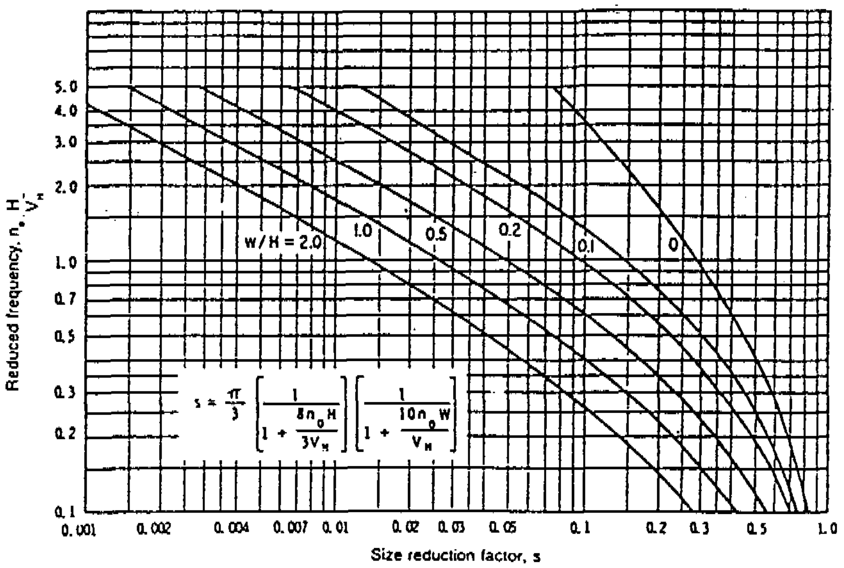

Fig. 2.6 Size reduction factor as a function of width, height and reduced frequency of structure

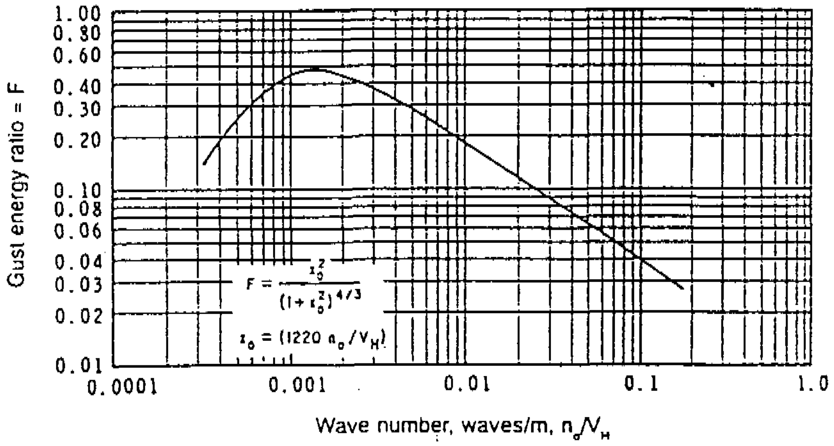

Fig. 2.7 Gust energy ratio as a function of wave number

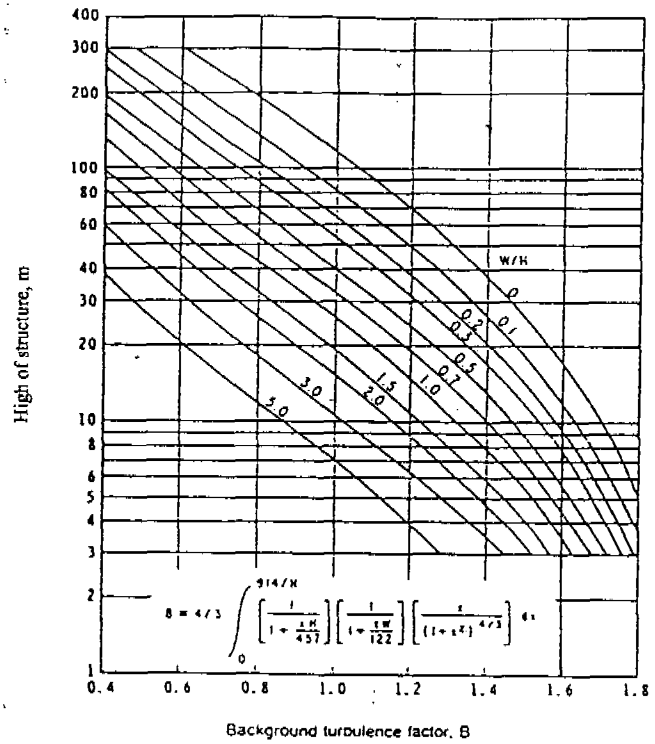

Fig. 2.8 Background turbulence factor as a function of width and height of structure

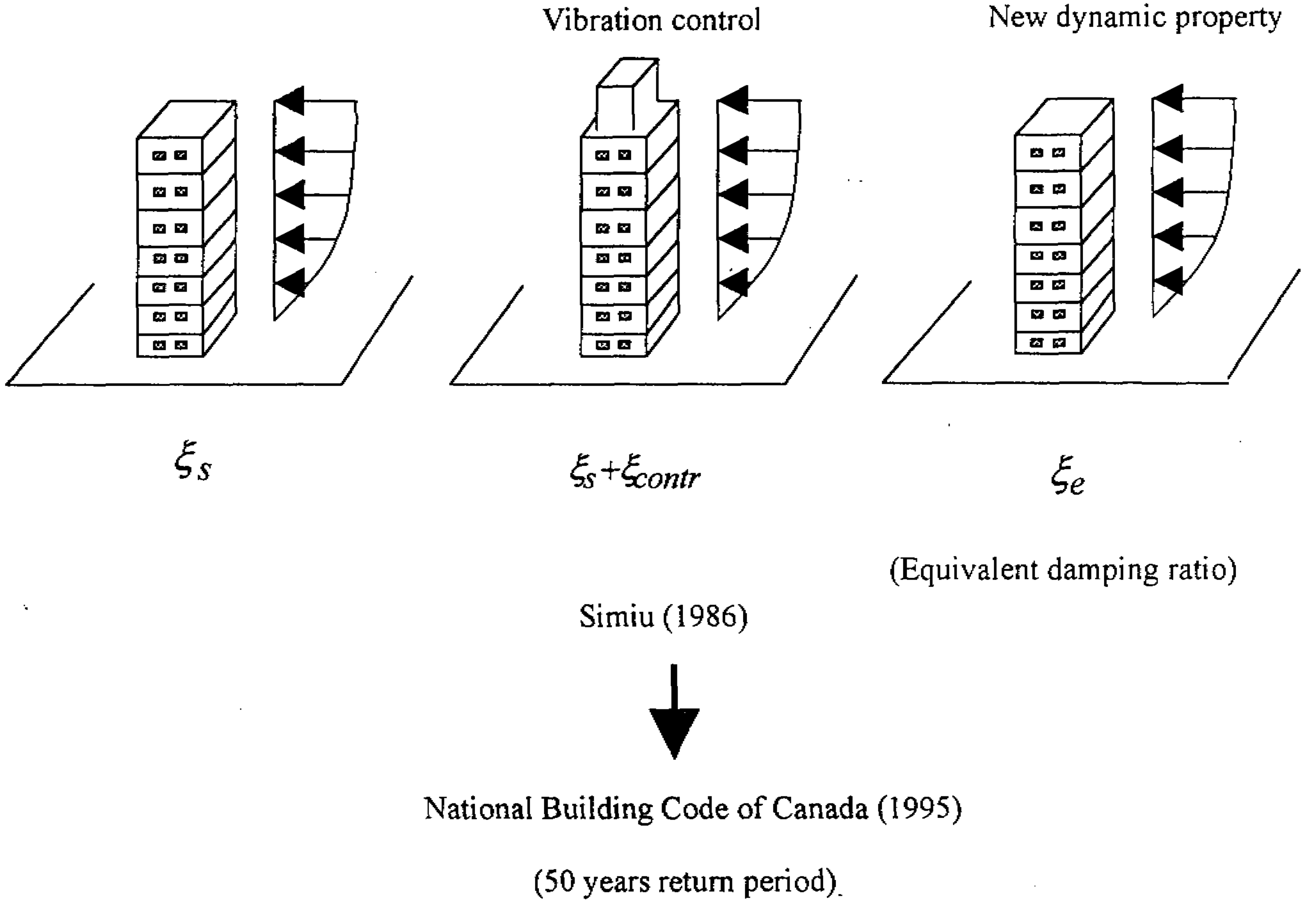

Fig. 2.9 Principle of applying vibration control on high-rise building