CHAPTER 3
WIND ACTIONS

3.1 SCOPE

(1) This Chapter gives rules and methods for calculating wind loads on building structures up to a height of 200m, their components and appendages.

(2) Wind loads shall be calculated for each of the loaded areas under consideration. These may be:

(a) the whole structure
(b) parts of the structure, i.e components, cladding units and their fixings

(3) This Chapter also gives rules for chimneys and other cantilevered structures. Special requirements for lattice towers are not given.

3.2 CLASSIFICATION OF ACTIONS

(1) Wind action are classified as free actions, see Chapter 1.

3.3 DESIGN SITUATIONS

(1) The relevant wind actions shall be determined for each design situation identified in accordance with Chapter 1.

(2) The effect of changes of the form of the construction works which may modify the external and internal wind pressure (such as doors normally closed but left open under storm conditions) shall be considered.

(3) Structures susceptible to dynamic effect shall be designed for fatigue loading.

3.4 REPRESENTATION OF ACTIONS

3.4.1 Expansion of the Wind Actions and the Response of the Structures

(1) Wind actions are fluctuating with time. They act directly on the external surfaces of enclosed structures and, through porosity of the external surface, also act indirectly on the internal surfaces. They may also directly affect the internal surface of open structures. Pressures act on areas of the surface producing forces normal to the surface for the structure or for individual cladding components. Additionally, when large areas of structures are swept by the wind, frictional forces acting tangentially to the surface, may be significant.

To achieve the design aims account shall be taken of:

(a) turbulent wind acting over part or all of the structure (see Section 3.5 and 3.6 respectively)
(b) fluctuating pressures induced by the wake behind the structure (see Section 3.9.4)
(c) fluctuating forces induced by the motion of the structure (see Section 3.9.4).

(2) The total response of structures and their elements may be considered as the superposition of a "background" component, which acts quasi-statically and "resonant" components due to excitation close to natural frequencies. For the majority of structures the resonant components are small and the wind load can be simplified by considering the background component only. Such structures can be calculated by a simplified method. The limits to such structures are set down in Section 3.9.

(3) The dynamic effects are divided into different types according to the physical effect of the wind:

- (a) stochastic and resonant response (alongwind, crosswind and torsional direction) due to turbulence and wake effects
- (b) response due to vortex shedding
- (c) galloping
- (d) interference
- (e) divergence and flutter.

(4) In this Chapter, the wind action is represented by a set of quasi-static pressures or forces whose effects are equivalent to the extreme effects of the wind. Slender structures such as chimneys, observation towers, component elements of open frames and trusses, and in some cases high rise buildings shall be designed to resist the dynamic effect of vortex shedding. General rules for evaluating such situations are provided in Section 3.9.4. Criteria are also given for aeroelastic instability.

3.4.2 Modelling of Wind Actions

(1) The wind action is represented either as a wind pressure or a wind force. The action on the structure caused by the wind pressure is assumed to act normal to the surface except where otherwise specified; e.g. for tangential friction forces.

(2) The following parameters are used several times and are defined below:

- q_{ref} reference mean wind velocity pressure derived from reference wind velocity as defined in Section 3.7.1. It is used as the characteristic value
- $c_e(z)$ exposure coefficient accounting for the terrain and height above ground z given in Section 3.8.5. The coefficient also modifies the mean pressure to a peak pressure allowing for turbulence
- z reference height defined in Appendix A appropriate to the relevant pressure coefficient ($z = z_e$) for external pressure and force coefficient, $z = z_i$ for internal pressure coefficient)
- c_d dynamic coefficient accounting for both correlation and dynamic magnification given in Section 3.9.

3.5 WIND PRESSURE ON SURFACES

3.5.1 Field of Application

(1) The representation of the wind pressure given in this Section is valid for surfaces which are sufficiently rigid to neglect their resonant vibrations caused by the wind, as is normally the case.

(2) If a natural frequency of vibration of the surface is low (i.e. less than 5 Hz), these vibrations may become significant, and they shall be taken into account. These effects are not covered by this Chapter.

3.5.2 External Pressure

(1) The wind pressure acting on the external surfaces of a structure W_e shall be obtained from:

$$W_e = q_{ref}\, c_e(z_e)\, c_{pe} \tag{3.1}$$

where c_{pe} is the external pressure coefficient derived from Appendix A.

3.5.3 Internal Pressure

(1) The wind pressure acting on the internal surfaces of a structure W_i shall be obtained from:

$$W_i = q_{ref}\; c_e(z_i)\; c_{pi} \tag{3.2}$$

where C_{pi} is the internal pressure coefficient obtained from Appendix A.

3.5.4 Net Pressure

(1) The net wind pressure across a wall or an element is the difference of the pressures on each surface taking due account of their signs. (Pressure, directed towards the surface is taken as positive, and suction, directed away from the surface as negative). Examples are given in Figure 3.1.

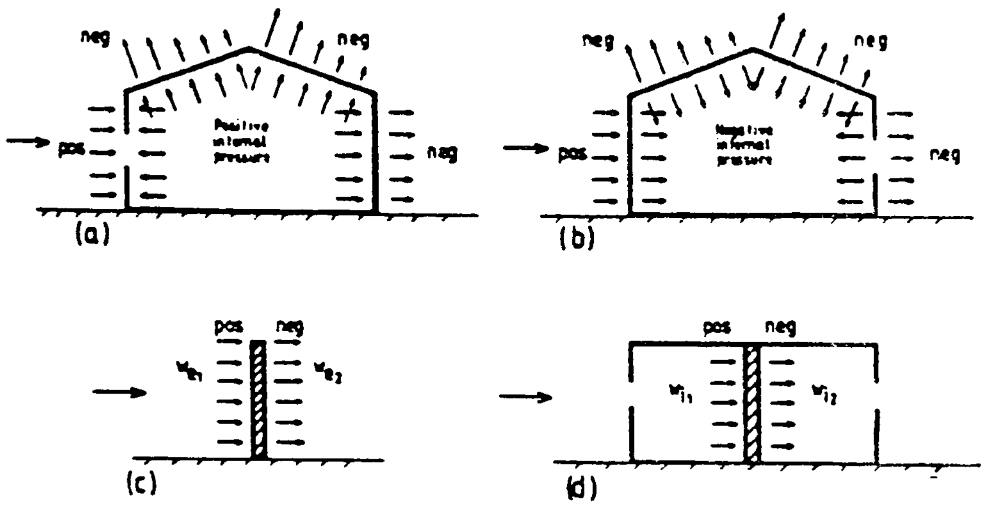

Figure 3.1 Pressure on Surfaces

3.6 WIND FORCES

3.6.1 Wind Forces from Pressures

(1) The wind forces acting on a structure or a structural component may be determined in two ways:

(a) by means of global forces
(b) as a summation of pressures acting on surfaces provided that the structure or the structural component is not sensitive to dynamic response ($C_d < 1.2$ see Section 3.9).

(2) The global force F_w shall be obtained from the following expression:

$$F_w = q_{ref} \; c_e(z_e) \; c_d \; c_f \; A_{ref} \tag{3.3}$$

where c_f is the force coefficient derived from Section 3.10
A_{ref} is the reference area for c_f (generally the projected area of the structure normal to the wind) as defined in Section 3.10

(3) For lattice structures and for vertical cantilevered structures with a slenderness ratio height/width > 2 and with nearly constant cross-section (e.g. tall buildings, chimneys, towers) the force F_{wj} on the incremental area A_j at the height z_j is:

$$F_{wj} = q_{ref} \; c_e(z_j) \; c_d \; c_{fj} \; A_j \tag{3.4}$$

where z_j is the height of the centre of gravity of incremental area A_j
c_{fj} is the force coefficient for incremental area A_j as defined in Section 3.10
A_j is the incremental area

(4) Torsional effects due to inclined or non correlated wind may be represented on non circular nearly symmetric structures by the force F_w acting with the eccentricity e:

$$e = \frac{b}{10} \tag{3.5}$$

where b is the dimension of the cross section transverse to the main axis considered (see Fig.3.2).

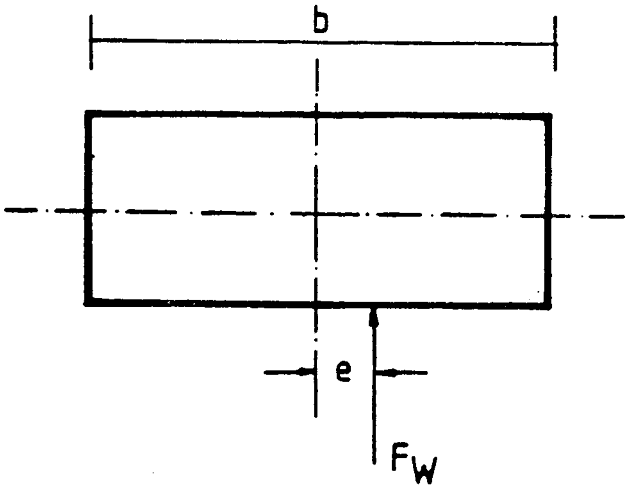

Figure 3.2 Wind Force Acting on Cross Section

(5) More detailed values of the eccentricity for special cross sections are presented in Section 3.10.

3.6.2 Friction Force

(1) For structures with large area swept by the wind (e.g. large free standing roofs), friction forces, F_{fr} may be significant. They shall be obtained from:

$$F_{fr} = q_{ref}\ c_e(z_e)\ c_{fr}\ A_{fr} \qquad (3.6)$$

where c_{fr} is the friction coefficient derived from Section 3.10.13
A_{fr} is the area swept by the wind

3.7 REFERENCE WIND

3.7.1 Reference Wind Pressure

(1) The reference mean wind velocity pressure q_{ref} shall be determined from:

$$q_{ref} = \frac{\rho}{2} V_{ref}^2$$

where V_{ref} is the reference wind velocity as defined in Section 3.7.2
ρ is the air density

The air density is affected by altitude and depends on the temperature and pressure to be expected in the region during wind storms. A temperature of 20°C has been selected as appropriate for Ethiopia and the variation of mean atmospheric pressure with altitude is given in Table 3.1.

Table 3.1 Values of Air Density ρ

Site Altitude(m) Above sea level	ρ(kg/m^3
0	1.20
500	1.12
1000	1.06
1500	1.00
2000	0.94

3.7.2 Reference Wind Velocity

(1) The reference wind velocity v_{ref} is defined as the 10 minute mean wind velocity at 10m above ground of terrain category II (see Table 3.2) having an annual probability of exceedence of 0.02 (commonly referred to as having a mean return period of 50 years).

(2) It shall be determined from:

$$v_{ref} = c_{DIR}\ c_{TEM}\ c_{ALT}\ v_{ref,o} \qquad (3.7)$$

where $v_{ref,o}$ is the basic value of the reference wind velocity to be taken as 22m/sec
v_{DIR} is the direction factor to be taken as 1.0.
c_{TEM} is the temporary (seasonal) factor to be taken as 1.0.
c_{ALT} is the altitude factor to be taken as 1.0.

(3) For temporary structures, which are:

(a) structures during construction (which may require temporary bracing supports
(b) structures whose life time is known and is less than one year

a reduction of the reference wind velocity may be allowed depending upon:

(a) the duration of the situation
(b) the possibilities of protecting or strengthening of the structure during wind storms
(c) the time needed to protect or strengthen the structure
(d) the probability of occurrence of wind storms
(e) the possibilities of forecasting wind storms

Based on Section 3.7.3 and/or on special local climate situation the temporary factor c_{TEM} according to Eq. (3.7) describes this reduction.

(4) Transportable structures which may be dismantled and rebuilt at any time in the year are not considered to be temporary structures.

3.7.3 Annual Probabilities of Exceedence other than 0.02

(1) The reference wind velocity $v_{ref}(p)$ for annual probabilities of exceedence p other than the value of 0.02 (see Section 3.7.2 (1) can be found using the following expression:

$$v_{ref}(p) = v_{ref}\left[\frac{1-K_1\ln[-\ln(1-p)]}{1-K_1\ln(-\ln 0.98)}\right]^n \tag{3.8}$$

where v_{ref} is the reference velocity with an annual probability of exceedence of 0.02 (see Section 3.7.2)

k_1 shape parameter. The representative value $K_1 = 0.2$ can be used.

n exponent. The representative value $n = 0.5$ can be used.

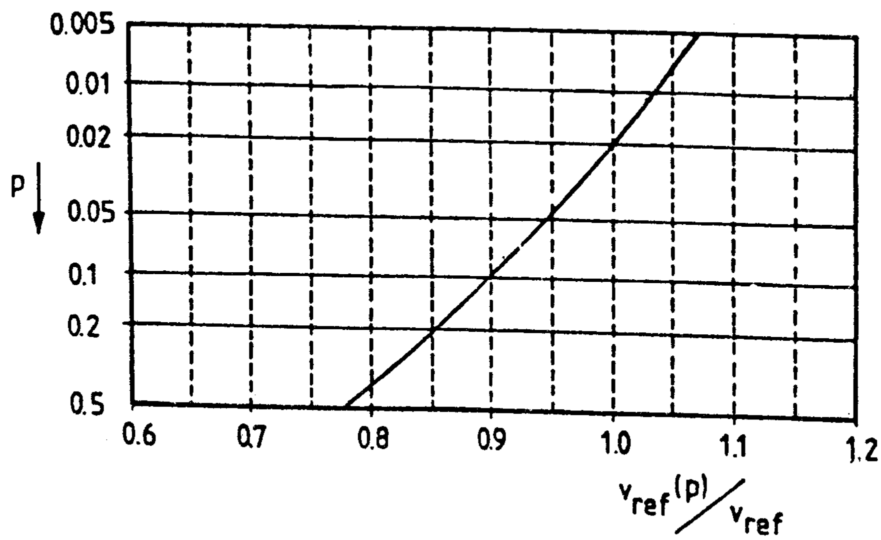

Figure 3.3 Ratio $v_{ref}(p)$ v_{ref} for $k_1 = 0.2$ and $n = 0.5$

3.8 WIND PARAMETER

3.8.1 Mean Wind Velocity

(1) In order to define the Reynolds number in A.8 and the wind coefficients and other parameters of this Chapter, the mean wind velocity $v_m(z)$ is required. It is defined by:

$$v_m(z) = c_r(z)\ c_t(z)\ v_{ref} \tag{3.9}$$

where v_{ref} is the reference wind velocity (Section 3.7.2)
$c_r(z)$ is the roughness coefficient (Section 3.8.2)
$c_t(z)$ is the topography coefficient (Section 3.8.4)

3.8.2 Roughness Coefficient

(1) The roughness coefficient $c_r(z)$ accounts for the variability of mean wind velocity at the site of the structure due to:

(a) the height above ground level
(b) the roughness of the terrain depending on the wind direction.

(2) The roughness coefficient at height z is defined by the logarithmic profile:

$$c_r(z) = k_T\ \ln(z/z_o) \qquad \text{for} \qquad z_{min} \leq z \leq 200\text{m} \tag{3.10}$$

$$c_r(z) = c_r(z_{min}) \qquad \text{for} \qquad z < z_{min} \tag{3.11}$$

where k_T is the terrain factor
z_o is the roughness length
z_{min} is the minimum height

These parameters depend on the terrain category as given in Table 3.2.

(3) At heights more than 200m above ground level specialist advice is recommended.

3.8.3 Terrain Categories

(1) The terrain categories are defined in Table 3.2.

Table 3.2 Terrain Categories and Related Parameters

Terrain Category	k_r	z_o(m)	$z_{min}(m)$
I Lakes with at least 5km fetch upwind and smooth flat country without obstacles	0.17	0.01	2
II Farmland with boundary hedges, occasional small farm structure, houses or trees	0.19	0.05	4
III Suburban or industrial areas and permanent forests	0.22	0.3	8
IV Urban areas in which at least 15% of the surface is covered with buildings and their average height exceeds 15m	0.24	1	16

(2) If the structure is situated near a change of terrain roughness at a distance:

(a) less than 2km from the smoother category I
(b) less than 1km from the smoother categories II and II
the smoother terrain category in the upwind direction should be used.

(3) In the above transition zones small areas of different roughness should be ignored (less than 10% of the area under consideration).

(4) When there is any doubt about the choice between two categories in the definition of a given area, the worse case should be taken.

(5) Table 3.3 gives roughness coefficient $c_r(z)$ for selected values of height z

Table 3.3 Roughness Coefficient c_r

Terrain Category	z(m)							
	2	4	8	16	30	50	100	200
I	0.90	1.02	1.14	1.25	1.36	1.45	1.57	1.68
II	0.83	0.83	0.96	1.10	1.22	1.31	1.44	1.58
III	0.72	0.72	0.72	0.87	1.01	1.13	1.28	1.43
IV	0.67	0.67	0.67	0.67	0.82	0.94	1.11	1.27

3.8.4 Topography Coefficient

(1) The topography coefficient $c_t(z)$ accounts for the increase of mean wind speed over isolated hills and escarpments (not undulating and mountainous regions). It is related to the wind velocity at the base of the hill or escarpment. it shall be considered for locations within the topography affected zone (see Fig. 3.5 and 3.6). It is defined by:

$$
\begin{aligned}
c_t &= 1 && \text{for} \quad \Phi < 0.05 \\
c_t &= 1 + 2\,s\,\Phi && \text{for} \quad 0.05 < \Phi < 0.3 \\
c_t &= 1 + 0.6\,s && \text{for} \quad \Phi > 0.3
\end{aligned}
\qquad (3.12)
$$

Where s is the factor to be obtained by interpolation from the value of $s = 1.0$ at the crest of a hill, ridge or escarpment and the value $s = 0$ at boundary of the topography affected zone. (see figs. 3.5 and 3.6). Interpolation shall be linear with horizontal distance from crest and with height above the local ground level.

Φ is the upwind slope H/L_u in the wind direction (see figs. 3.6 and 3.7)

L_e is the effective length of the upwind slope, defined in Table 3.4

L_u is the actual length of the upwind slope in the wind direction

L_d is the actual length of downwind slope in the wind direction

H is the effective height of the feature

x is the horizontal distance of the site from the top of the crest

z is the vertical distance from the ground level of the site

Table 3.4 Values of L_e

Slope ($\Phi = H/L_u$)	
Shallow ($0.05 < \Phi < 0.3$):	Steep ($\Phi > 0.3$)
$L_e = L_u$	$L_e = H/0.3$

(2) In valleys, $c_t(z)$ may be set to 1.0 if no speed up due to funnelling effects is to be expected. For structures situated within steep-sided valleys care should be taken to account for any increase of wind speed caused by funnelling.

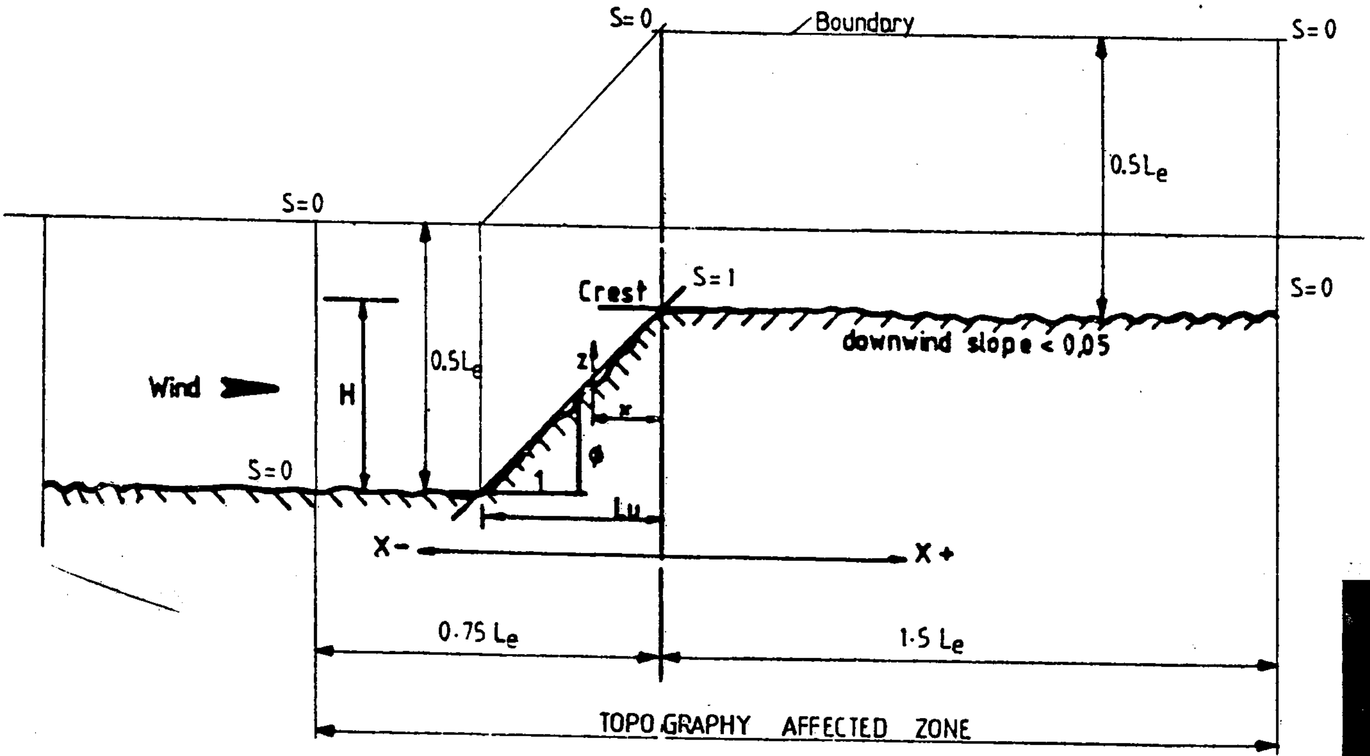

Figure 3.5 Factor s: Cliffs and Escarpments

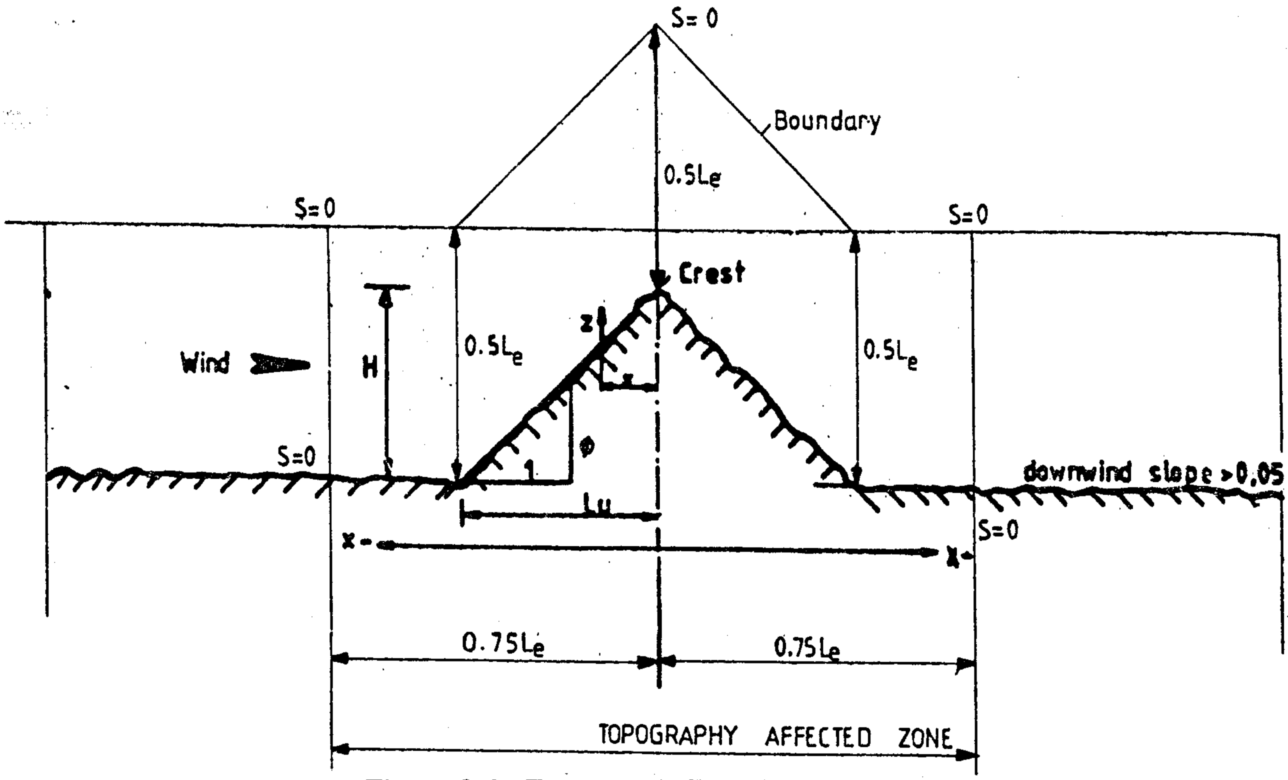

Figure 3.6 Factor *s*: Hills and Ridges

3.8.5 Exposure Coefficient

(1) The exposure coefficient, $c_e(z)$ takes into account the effects of terrain roughness, topography and height above ground on the mean wind speed and turbulence. It is defined by:

$$c_e(z) = c_r^2(z)\ c_t^2\ (z)[1 + 2g\ I_V\ (z)] \tag{3.13}$$

where g is the peak factor
$I_V\ (z)$ is the turbulence intensity, given by:

$$I_v\ (z) = \frac{k_T}{c_r\ (z) \cdot c_t(z)} \tag{3.14}$$

(2) For codification purposes it has been assumed that the quasi-static gust load is determined from:

$$c_e(z) = c_r^2\ (z)\ c_t^2\ (z) \left[1 + \frac{7\ k_T}{c_r(z)\ c_t(z)}\right] \tag{3.15}$$

where k_T is the terrain factor as defined in Section 3.8.2
$c_r(z)$ is the roughness coefficient as defined in Section 3.8.3
$c_t(z)$ is the topography coefficient as defined in Section 3.8.4

(3) The exposure coefficient $c_e(z)$is given in Table 3.5 for each terrain category defined in Section 3.8.2.

(4) For structures which need to be designed by a detailed dynamic analysis method, the simplification in (2) above is not used.

3.9 CHOICE OF PROCEDURES

3.9.1 General

(1) Two procedures for calculating wind loads are required.

(a) the simple procedure of this Code applies to those structures whose structural properties do not make them susceptible to dynamic excitation. This procedure can also be used for the design of mildly dynamic structures by the use of the dynamic coefficient C_d. The value of this coefficient depends upon the type of structure (concrete, steel, composite), the height of the structure and its breadth.

(b) a detailed dynamic analysis procedure is required for those structures which are likely to be susceptible to dynamic excitation and for which the value of the dynamic coefficient C_d is greater than 1.2.

(2) The dynamic coefficient c_d takes into account the reduction effects due to the lack of correlation of pressures over surfaces as well as the magnification effects due to the frequency content of turbulence close to the fundamental frequency of the structure.

(3) Section 3.9.2 defines the field of application of this section, and the criteria for choosing between simple and detailed procedures.

(4) Section 3.9.3 sets down the values of c_d for use with the simple procedure (in-wind response).

(5) Section 3.9.4 gives criteria for vortex shedding and galloping.

3.9.2 Criteria for the Choice

(1) The simple procedure may be used for buildings and chimneys less than 200m tall provided the value of c_d (see Section 3.9.3) is less than 1.2 (in-wind response). In all other cases a detailed dynamic analysis is required in accordance with specialist literature.

3.9.3 Dynamic Coefficient for Gust Wind Response

(1) Values of c_d set out in Figs. 3.7 to 3.13 are based on typical values of the relevant parameters and simplified equations for natural frequencies of structures.

(2) Values of c_d for buildings are set out in Figs.3. 7 to 3.9 depending on the material of construction.

(3) Values of c_d for chimneys are set out in Figs. 3.10 to 3.13 depending on the form of construction.

(4) For values of $1.0 \leq c_d \leq 1.2$ it is recommended that a detailed procedure should be used.

Table 3.5 Exposure Cofficient c_e.

CATEGORY I								
	z(m)							
c_t	2	4	8	16	30	50	100	200
1.0	1.88	2.25	2.64	3.07	3.47	3.82	4.31	4.84
1.1	2.16	2.59	3.05	3.55	4.02	4.43	5.02	5.63
1.2	2.45	2.95	3.48	4.06	4.61	5.09	5.77	6.49
1.3	2.76	3.33	3.94	4.60	5.24	5.78	6.57	7.39
1.4	3.09	3.73	4.42	5.17	5.90	6.52	7.41	8.36
1.5	3.43	4.15	4.93	5.78	6.60	7.30	8.31	9.38
CATEGORY II								
	z(m)							
c_t	2	4	8	16	30	50	100	200
1.0	1.80	1.80	2.21	2.66	3.09	3.47	4.01	4.58
1.1	2.06	2.06	2.54	3.06	3.57	4.00	4.64	5.31
1.2	2.33	2.33	2.88	3.48	4.07	4.58	5.31	6.09
1.3	2.61	2.61	3.24	3.92	4.60	5.18	6.02	6.92
1.4	2.91	2.91	3.62	4.40	5.16	5.82	6.78	7.80
1.5	3.22	3.22	4.02	4.89	5.75	6.49	7.57	8.73
CATEGORY III								
	z(m)							
c_t	2	4	8	16	30	50	100	200
1.0	1.63	1.63	1.63	2.11	2.59	3.00	3.60	4.25
1.1	1.86	1.86	1.86	2.41	2.96	3.44	4.14	4.90
1.2	2.09	2.09	2.09	2.72	3.35	3.90	4.71	5.59
1.3	2.33	2.33	2.33	3.04	3.76	4.39	5.32	6.32
1.4	2.58	2.58	2.58	3.39	4.20	4.91	5.96	7.09
1.5	2.84	2.84	2.84	3.74	4.65	5.45	6.63	7.91
CATEGORY IV								
	z(m)							
c_t	2	4	8	16	30	50	100	200
1.0	1.56	1.56	1.56	1.56	2.04	2.46	3.08	3.75
1.1	1.77	1.77	1.77	1.77	2.31	2.80	3.52	4.31
1.2	1.98	1.98	1.98	1.98	2.61	3.16	3.99	4.89
1.3	2.20	2.20	2.20	2.20	2.91	3.54	4.48	5.51
1.4	2.43	2.43	2.43	2.43	3.23	3.94	4.99	6.16
1.5	2.67	2.67	2.67	2.67	3.56	4.35	5.53	6.84

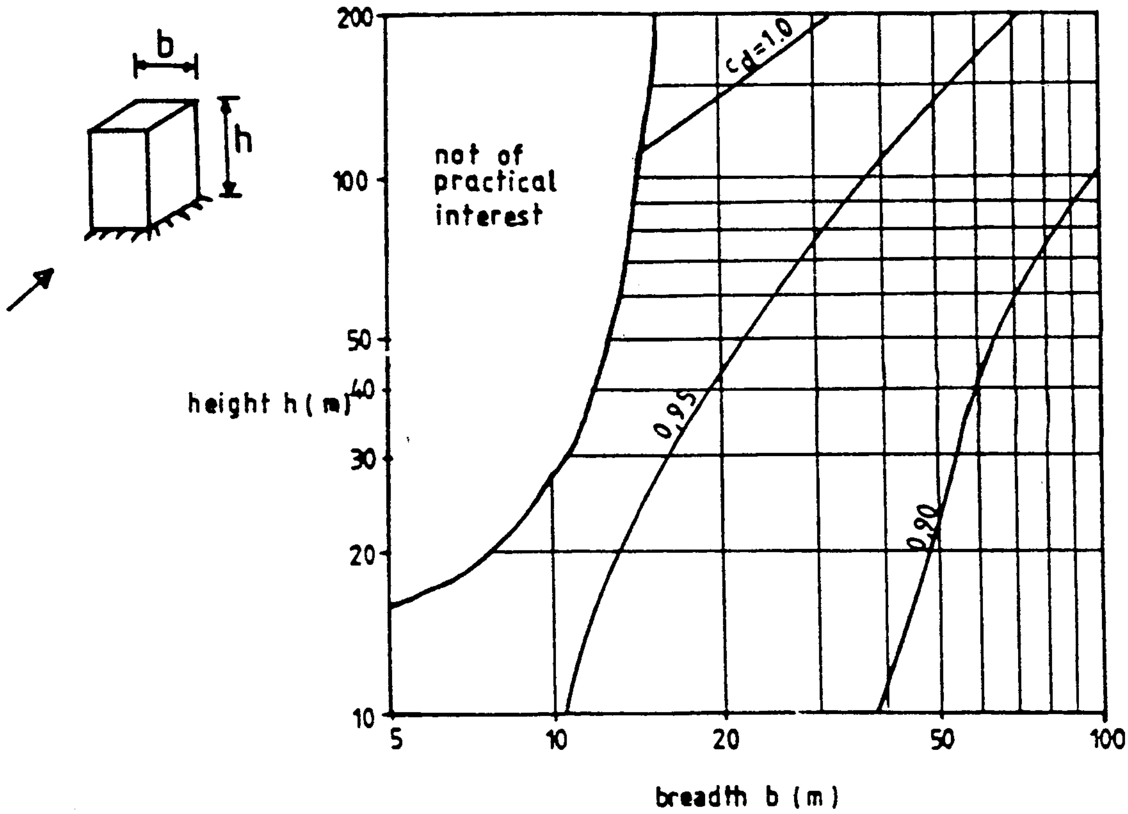

Figure 3.7 C_d Values for Concrete and Masonry Buildings

Note: The criteria set down in this figure do not address comfort conditions at serviceability. If this is likely to be of concern, more detailed procedures should be used.

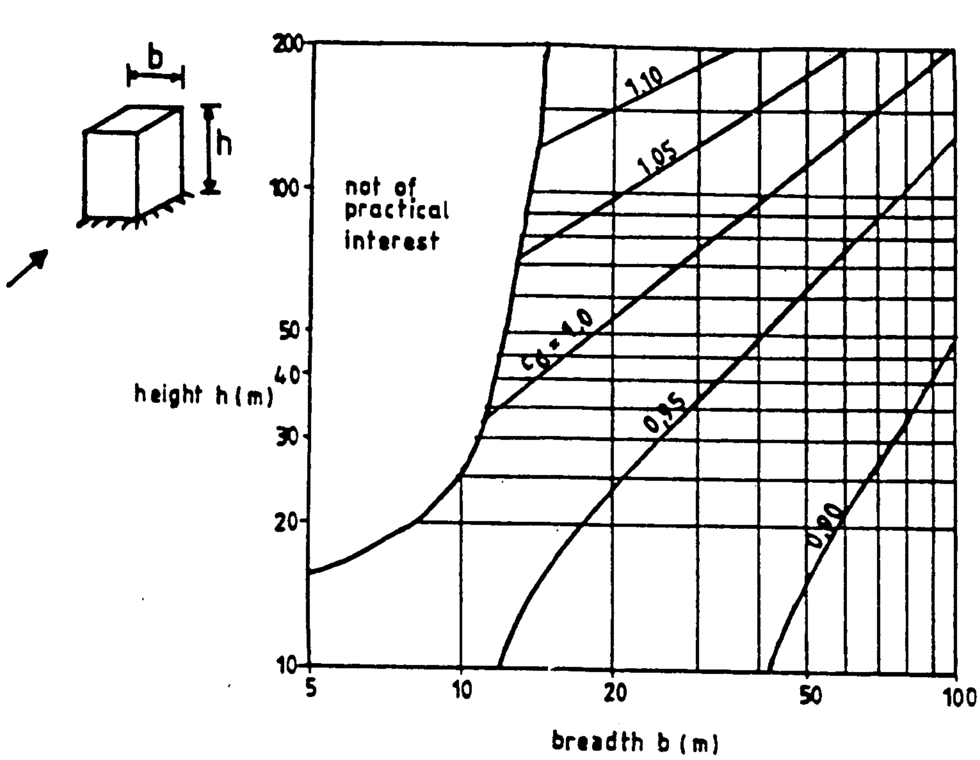

Figure 3.8 C_d Values for Steel Buildings

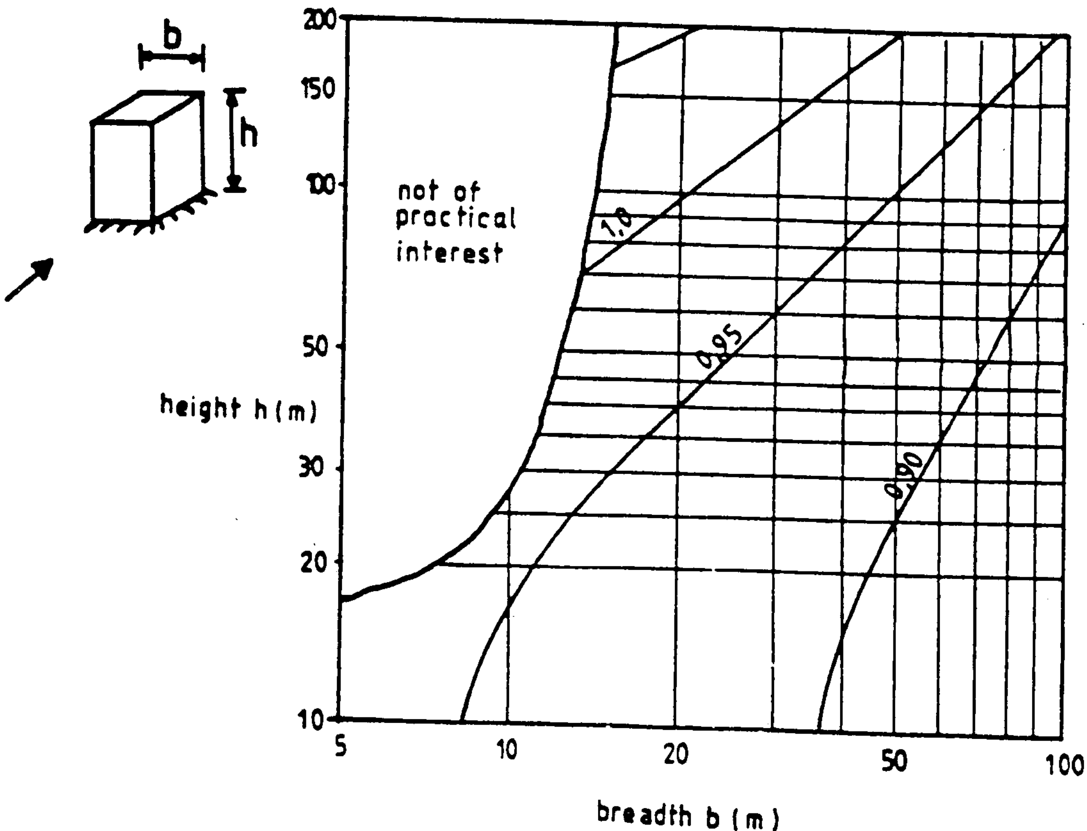

Figure 3.9 C_d Values for Composite (Steel/Concrete) Buildings

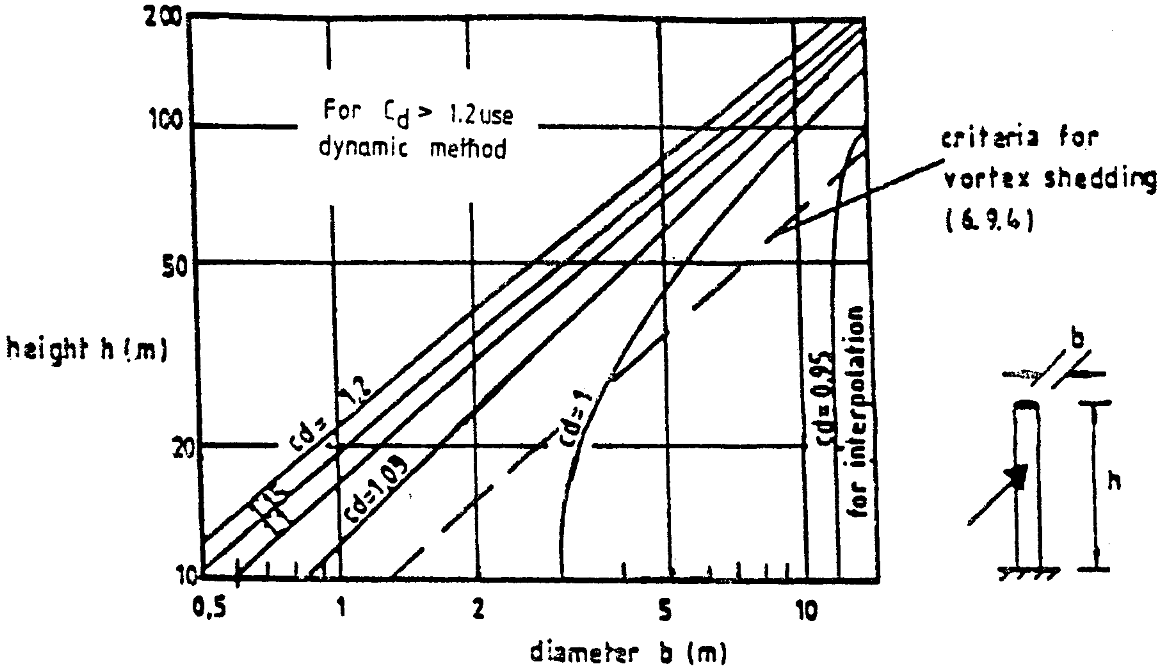

Figure 3.10 C_d Values for Unlined Welded Steel Chimneys

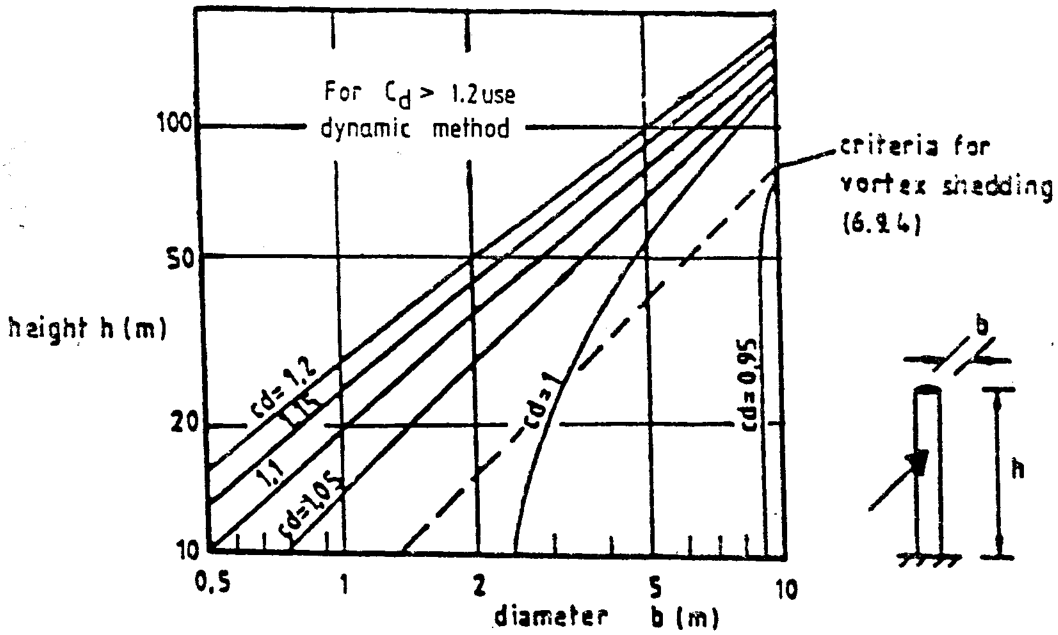

Figure 3.11 C_d Values for Lined Steel Chimneys

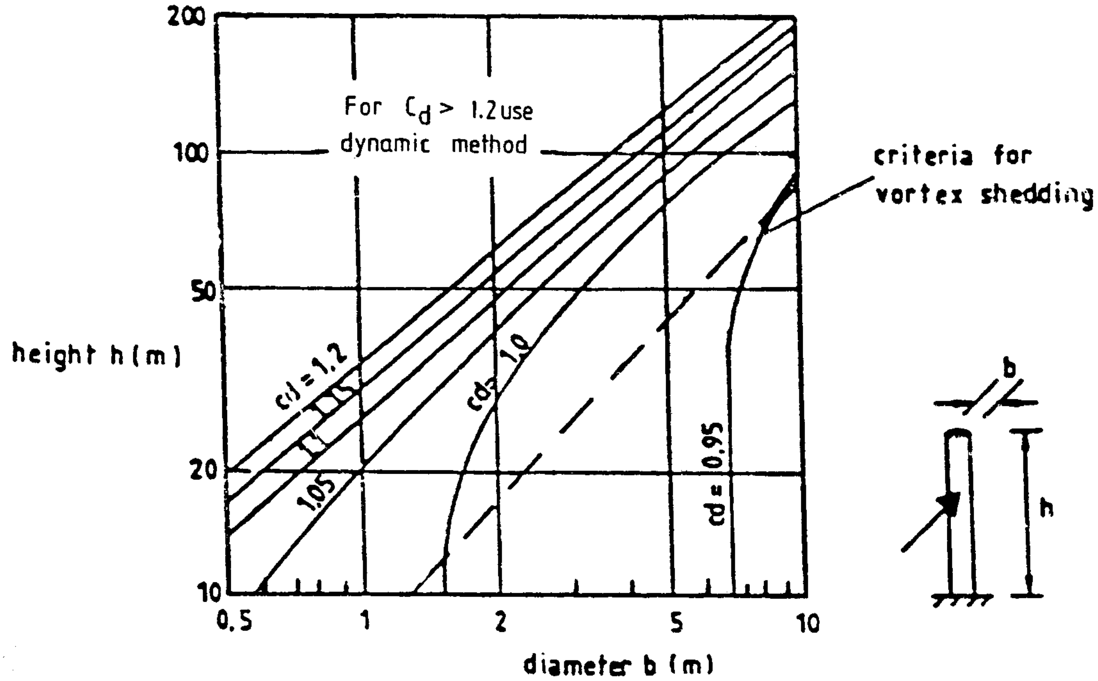

Figure 3.12 C_d Values for Brick Lined Steel Chimney

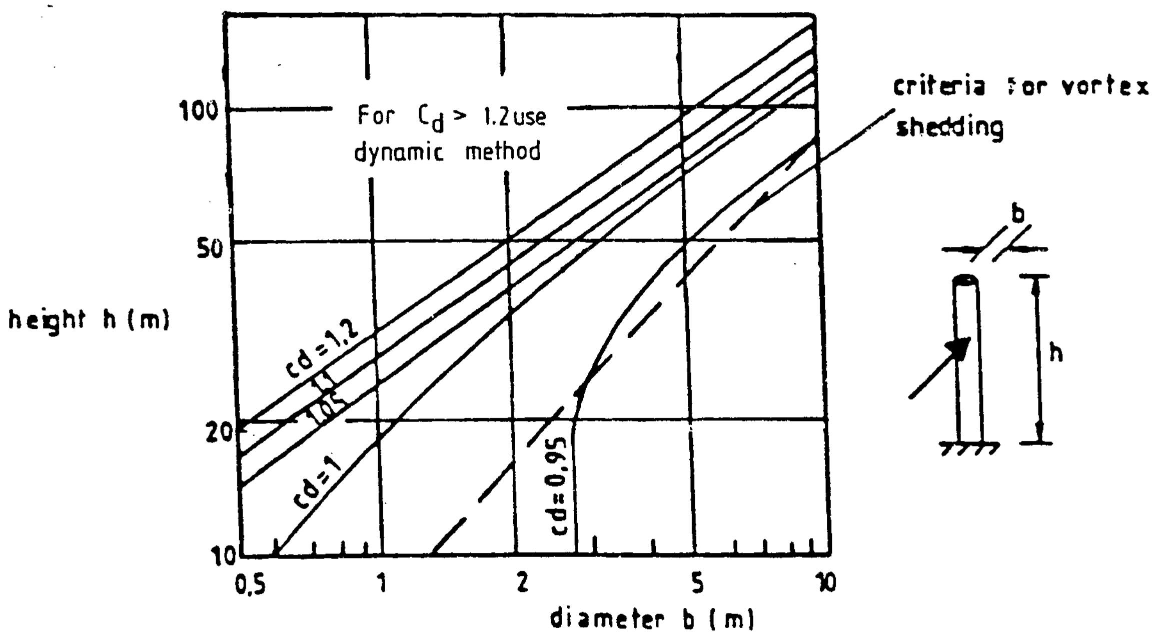

Figure 3.13 C_d Vlaues for Reinforced Concrete Chimney

3.9.4 Vortex Shedding, Aeroelastic Instability and Dynamic Interference Effects

3.9.4.1 *General*

(1) For slender structures the following phenomena of dynamics and instability effects have to be considered:

(a) vortex shedding
(b) galloping
(c) flutter
(d) divergence
(e) interference galloping

(2) Rules for analyzing such phenomena may be obtained from specialist literature.

(3) Criteria for the field of application of vortex shedding and galloping are given in Section 3.9.4.2.

3.9.4.2 *Field of Application*

(1) Buildings whose geometric dimensions satisfy the criteria given in fig. 3.14 need not be checked for vortex shedding and galloping. Buildings which do not satisfy these criteria shall be checked for vortex shedding and galloping.

(2) Elongated structures, such as chimneys, whose geometric dimensions satisfy the criteria given in figs. 3.10 to 3.13 and need not to be checked for vortex shedding, galloping, flutter and interference galloping. Such structures which do not satisfy these criteria shall be checked for these phenomena.

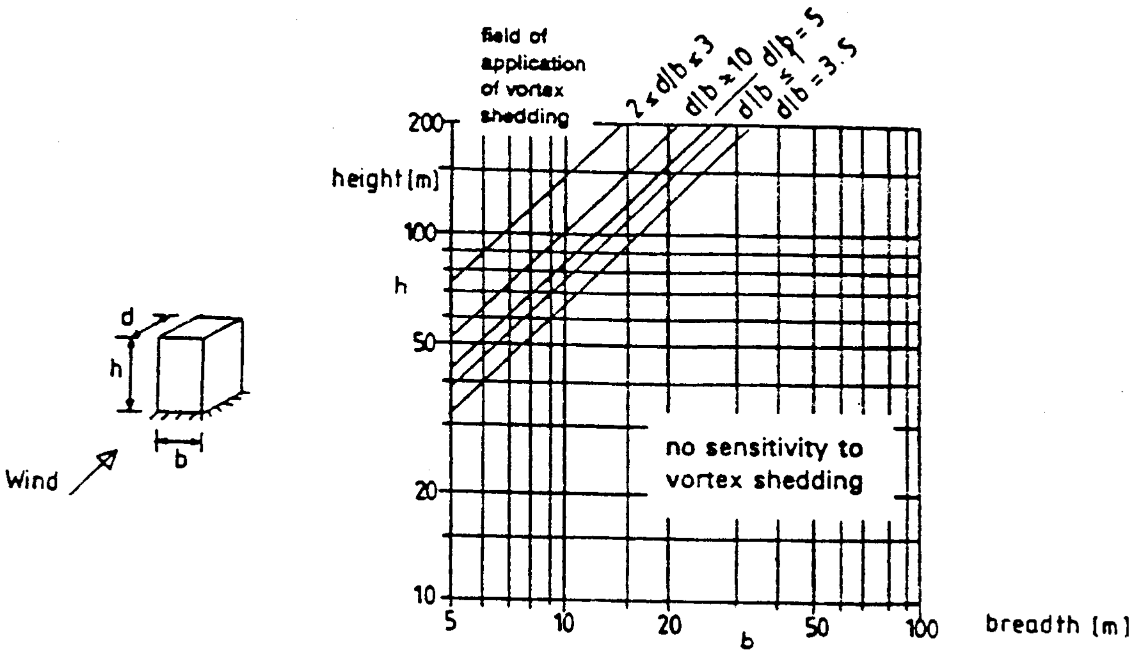

Figure 3.14 Ciriteria for Buildings for Vortex Shedding and Galloping

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