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EC 1: Wind Actions

EC 1: Actions du vent

EC 1: Windeinwirkungen

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SUMMARY

A description of the confirmed draft of the European Wind Load Code ENV 1991-2-3 "Wind Actions" is presented. The code includes static actions as well as dynamic actions. For those structures which are less sensitive to dynamic effects, a simplified method is presented. Other structures must be calculated with the detailed method. For the decision between simplified and detailed method, criteria are given which are based on calculations with the detailed method. Some examples are presented.

RÉSUMÉ

On présentera la description du projet de la Norme Européenne (Eurocode) ENV 1991-2-3 "actions du vent" qui a été approuvé par le SC 1. La norme contient les actions statiques et dynamiques du vent. Une méthode de calcul simplifiée sera indiquée pour les structures qui ne sont pas susceptibles de vibrations. Les autres structures doivent être calculées en employant un procédé de calcul détaillé. Afin de faciliter la décision entre les deux procédés, on donnera des critères qui sont basés sur la méthode détaillée. En outre, on présentera quelques exemples de calcul.

ZUSAMMENFASSUNG

Es wird eine Beschreibung des vom SC 1 bestätigten Entwurfs des Eurocodes ENV 1991-2-3 "Windeinwirkungen" vorgestellt. Der Code enthält sowohl die statischen als auch die dynamischen Windeinwirkungen. Für solche Strukturen, die nicht schwinganfällig sind, wird eine vereinfachte Berechnungsmethode angegeben. Die anderen Strukturen müssen nach einem detailierten Berechnungsverfahren berechnet werden. Für die Entscheidung, ob das vereinfachte oder die detaillierte Verfahren angewendet werden muß, sind Kriterien angegeben, die auf der detaillierten Methode beruhen. Es werden einige Berechnungsbeispiele angegeben.

1. PRINCIPLES

The draft of the Eurocode "WIND ACTION" [1, 2], has been started from the ISO T 98 "Wind Action" [3] and it has been developed to a code proposal which can be applied to most of the common buildings and structures. To achieve the design aims of a structure account shall be taken of

- turbulent wind acting over part or all of the structure
- static and fluctuating pressures induced by the wake behind the structure
- fluctuating forces induced by the motion of the structure

The wind load is presented either as a wind pressure or a wind force resp. wind moment. The response of structures due to wind action is divided into the following types:

- static response
- stochastic and resonant response due to turbulence and wake effects
- vortex resonance
- galloping
- interference
- divergence and flutter

Structures of an unusual nature, complexty or size i.e. structures or structural parts higher than 200 m, bridges longer than 200 m, suspended bridges and guyed masts are not yet completely covered by this code and may require special engineering study. Some rules for these structures are incorporated during the ENV period.

2. WIND PRESSURE AND WIND FORCES

2.1. Wind pressure on surfaces, $w_{e,i}$

The wind pressure on surfaces given in this code is valid for surfaces which are sufficiently rigid to neglect their resonant vibration caused by the wind. The pressure is described as an

- external pressure $w_e = q_{ref} \cdot c_e\ (z_e) \cdot c_{pe}$ (1)
- internal pressure $w_i = q_{ref} \cdot c_e\ (z_i) \cdot c_{pi}$ (2)

and the net pressure is

$$w_{net} = w_e - w_i \qquad (3)$$

where: q_{ref} = reference mean wind velocity pressure = $\rho/2\ v_{ref}^2$ (see 3.1)
$c_e\ (z_e, z_i)$ = exposure coefficient (see 3.2.2) which includes the effects of the wind profile and of the topography
$c_{pe,i}$ = external (e) and internal (i) pressure coefficients derived from a coefficient catalogue
$z_{e,i}$ = reference height defined together with the $c_{pe,i}$-values.

2.2. Wind force, F_w

The global force, F_w, which results from the pressure distribution (without friction forces) shall be obtained from the following expression

$$F_w = q_{ref} \cdot c_e(z_e) \cdot c_d \cdot c_f \cdot A_{ref} \qquad (4)$$

where: c_f = force coefficient
A_{ref} = reference area for c_f
c_d = dynamic factor, which takes into account the aerodynamic admission and the resonant gust response and is ≤ 1 for structures which are not sensitive to vibrations
q_{ref}, $c_e\ (z_e)$, z_e defined as before

If not otherwise specfied, the resultant wind force on non circular and nearly symmetric structures, F_w, may be assumed to act with an eccentricity

$$e = b/10 \qquad (5)$$

where: b = largest dimension of the cross section

2.3. Friction force, F_{fr}

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

$$F_{fr} = q_{ref} \cdot c_e(z_e) \cdot c_{fr} \cdot A_{fr} \tag{6}$$

where: c_{fr} = friction coefficient
A_{fr} = area swept by the wind
q_{ref}, $c_e(z_e)$ defined as before.

3. REFERENCE WIND AND WIND COEFFICIENTS

3.1. Reference wind velocity

The reference wind velocity, v_{ref}, is defined as

- the 10 min mean wind velocity
- at 10 m above ground of terrain category II (see Table 1)
- with an annual probability of exceedence of 0,02 (50 year return period). For other annual probabilities of exceedence a calculation formula is given.

3.2. Wind coefficients

3.2.1. Coefficients for the reference wind velocity.

$$v_{ref} = c_{DIR} \cdot c_{TEM} \cdot c_{ALT} \cdot v_{ref,0} \tag{7}$$

where: $v_{ref,0}$ = basic value of the reference wind velocity at 10 m above sea level given in the national wind maps which are presented in an Annex.
c_{DIR} = direction factor, which takes into account the probability of wind speed depending on the wind direction. It is taken as 1,0 unless otherwise specified in the national wind maps.
c_{TEM} = temporary (seasonal) factor which takes into account the probability of wind speed for structures which are
- structures during construction and which may require temporary bracing supports
- structures whose life time is known and less than one year.

Unless otherwise specified in the national wind maps, c_{TEM} is taken as 1,0.
c_{ALT} = altitude factor which takes into account the altitude level of the site and is to be taken as 1,0 unless otherwise specified in the national wind maps.

3.2.2. Coefficients for the mean wind velocity at height z.

The mean wind velocity at height, z, at the site of the structure depends on the roughness of the terrain in the direction from where the wind is blowing and on topographical effects (hills, escarpments etc.). It is given by

$$v_m(z) = c_r(z) \cdot c_t(z) \cdot v_{ref} \tag{8}$$

where: $c_r(z)$ = roughness coefficient at height z
$c_t(z)$ = topography coefficient at height z

The roughness coefficient describes the effect of the terrain roughness and is defined by a logarithmic law (velocity profile). It shall be calculated by

$$c_r(z) = k_r \cdot \ln(z/z_0) \quad \text{for } z_{min} \le z$$
$$c_r(z) = c_r(z_{min}) \quad \text{for } z < z_{min} \tag{9}$$

Four different terrain categories are defined and given in Table 1 together with the parameters

k_r = terrain factor
z_0 = roughness length
z_{min} = minimum height

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

	terrain category	k_r	z_0[m]	z_{min}[m]	ϵ
I	Rough open sea, Lakes with at least 5 km fetch upwind and smooth flat country without obstacles	0,17	0,01	2	0,13
II	Farmland with boundary hedges, occasional small farm structures, houses or trees	0,19	0.05	4	0,26
III	Suburban or industrial areas and permanent forests	0,22	0,3	8	0,37
IV	Urban areas in which at least 15% of the surface is covered with buildings and their average height exceeds 15 m	0,24	1	16	0,46

Table 1: Terrain categories and related parameters (The parameter ϵ is used for the calculation of the integral length scale in the detailed procedure for c_d)

If a structure is situated near a change of terrain roughness, a simple procedure is given in the Code.
Where detailed knowledge of the influence of landscape on the wind profile is available, detailed rules to take into account the transition may be adopted. The topography coefficient, c_t (z), accounts for the increase of mean wind velocity over isolated hills and escarpments and is given in the code by a formula and two diagrams. Otherwise it is set to 1,0.

3.2.3. The exposure coefficient, c_e (z) and the dynamic factor, c_d

The exposure coefficient, c_e (z), takes into account the effects of terrain roughness, topography, turbulence and height above ground on the mean wind speed.
It is developed from the gust response factor, G [4], which itself is not used in its classical expression in the Eurocode. Starting from the basic expression for the quasi static design wind pressure, q(z), in the height, z, above ground:

$$q(z) = q_{ref} \cdot c_r^2(z) \cdot c_t^2(z) \cdot G \qquad (10)$$

$$G = 1 + 2 \cdot g \cdot I_v(z) \cdot \sqrt{Q_o^2 + R_x^2} \qquad (11)$$

where: g = peak factor
$I_v(z)$ = turbulence intensity in the height z above ground
Q_o^2 = background part of the gust response
R_x^2 = resonant part of the gust response
$c_r(z)$, $c_t(z)$, q_{ref} defined as before

and expanding the equation with $(1 + 2 \cdot g \cdot I_v(z))$ we receive the following expression for q(z):

$$q(z) = q_{ref} \cdot c_r^2(z) \cdot c_t^2(z) \cdot (1 + 2 \cdot g \cdot I_v(z)) \frac{1 + 2 \cdot g \cdot I_v(z) \cdot \sqrt{Q_o^2 + Q_x^2}}{1 + 2 \cdot g \cdot I_v(z)}$$

In the first bracket the turbulence intensity $I_v(z)$ is replaced by

$$I_v(z) = \frac{k_r}{c_r(z) \cdot c_t(z)} \qquad (12)$$

thus:

$$q(z) = q_{ref} \cdot \left[c_r^2(z) \cdot c_t^2(z) \cdot \left(1 + 2 \cdot g \frac{k_r}{c_r(z) \cdot c_t(z)}\right)\right] \frac{1 + 2 \cdot g \cdot I_v(z) \cdot \sqrt{Q_o^2 + Q_x^2}}{1 + 2 \cdot g \cdot I_v(z)} \qquad (13)$$

The expression in the first bracket is called "exposure coefficient", $c_e(z)$:

$$c_e(z) = c_r^2(z) \cdot c_t^2(z) \left(1 + 2 \cdot g \frac{k_r}{c_r(z) \cdot c_z(z)}\right) \qquad (14)$$

and the quotient is called "dynamic factor", c_d:

$$c_d = \frac{1 + 2 \cdot g \cdot I_v(z) \cdot \sqrt{Q_o^2 + R_x^2}}{1 + 2 \cdot g \cdot I_v(z)} \tag{15}$$

The dynamic factor, c_d, is described in chapter 5.2 in more detail. The peak factor, g, can be approximated by g = 3.5, thus

$$c_e(z) = c_r^2(z) \cdot c_t^2(z) \left[1 + \frac{7 \cdot k_r}{c_r(z) \cdot c_t(z)} \right] \tag{16}$$

For the most common cases, $c_t(z)=1$, the exposure coefficient is illustrated in Figure 1.

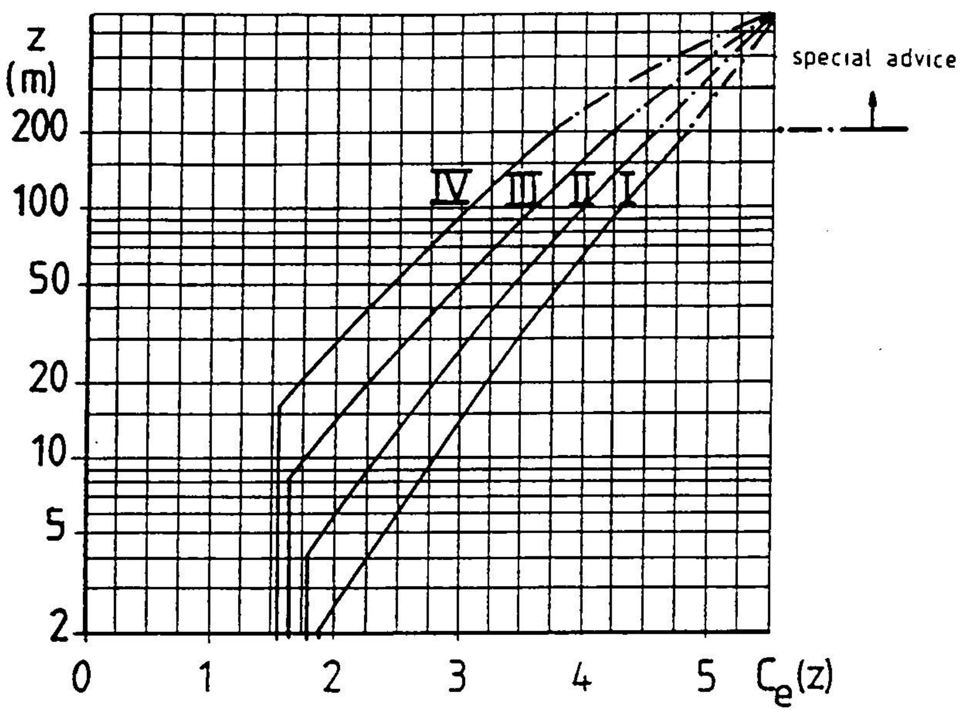


Figure 1: Exposure coefficient $c_e(z)$ as a function of height z above ground and terrain roughness category for $c_t = 1$.

4. AERODYNAMIC COEFFICIENTS

The Eurocode presents aerodynamic coefficients for the following structures, structural elements and components:

- buildings, including building walls, different types of roofs, internal pressure
- canopy roofs and multispan roofs
- free standing boundary walls, fences and signboards
- structural elements with rectangular, sharp edged and regular polygonal section
- circular cylinders and spheres
- lattice structures and scaffoldings
- bridges
- flags
- slenderness effect

Each coefficient is referred to a reference area and a reference height, which are defined for that particular coefficient.
In the following, some explanations are given for some coefficients without presenting the whole coefficient catalogue.

4.1. Buildings, roofs and walls

The wind load for buildings, roofs and walls are presented by pressure coefficients for internal and external pressure [6, 7]. In order to take into account the reduction of the mean value of wind pressure by the integrating effect of a larger loaded area (size effect), the external pressure of the loaded area is given by the following rule:

$$c_{pe} = c_{pe,1} \qquad \text{for } A \le 1 \text{ m}^2$$
$$c_{pe} = c_{pe,1} + (c_{pe,10} - c_{pe,1}) \log_{10} A \qquad \text{for } 1 \text{ m}^2 \le A \le 10 \text{ m}^2$$
$$c_{pe} = c_{pe,10} \qquad \text{for } A \ge 10 \text{ m}^2$$

where:

$c_{pe,1}$ = standard value of the external pressure coefficient corresponding to an area of 1 m²
$c_{pe,10}$ = standard value of the external pressure coefficient corresponding to an area of 10 m²

The values for $c_{pe,10}$ and $c_{pe,1}$ are given for orthogonal wind directions and represent the highest values obtained in the range of wind direction $\pm 45°$ either side.
More detailed information about pressure coefficients for special wind directions may be obtained from the background paper, which is also available.
The internal pressure for buildings is described depending on the ratio of openings in the walls. The values are based on numerous experimental investigations on model and full-scale buildings and on theoretical considerations. The advantage of the presentation in form of the opening ratios is the fact, that the knowledge of the absolute value of the openings must not be known. The presented values for c_{pi} are valid for buildings without partition walls but under specific conditions they can also be applied to buildings with partitions walls if assumptions for the internal openings (i.e. opened doors) can be made. Other critical cases has to be considered which are mentioned in the Eurocode.
The pressure coefficients for free standing walls, fences and signboards include the influence of return corners, the solidity and shelter effects. The wind load for sign boards are described by a force coefficient combined with a slenderness factor.

4.2. Structural elements, circular cylinders and spheres

The wind forces on structural elements as rectangular sharp edged and polygonal sections and circular cylinders are presented by aerodynamic force coefficients depending on the aspect ratio of the cross section (rectangular sections), the corner radii (rectangular and polygonal sections), Reynolds number and surface roughness (circular and polygonal sections and spheres). For circular sections pressure distributions are given for three Reynolds number ranges: subcritical, critical and transcritical range.
The effect of finite slenderness is included by a slenderness factor, where the slenderness is defined for the different application. An indication is given for cylinders and spheres near a plane surface.

4.3. Lattice structures and scaffoldings

Aerodynamic force coefficients for lattice structures based on model tests with full-scale Reynolds numbers, solidity ratios and slenderness are given for plane and spatial elements with members of sharp-edged and circular cross-sections.
The values for scaffoldings are restricted to the worst case of wind direction.

4.4. Bridges

The description of the wind load for bridges is derived in two parts:

(i) For those bridges which are less sensitive to wind, a global boxed[1] value of wind pressure is defined.
(ii) In general, aerodynamic force coefficients are given in alongwind, crosswind and longitudinal direction depending on the aspect ratio of the bridge deck and for different bridge deck types (two groups). A slenderness factor is included into the formula.

The reference area is described in detail, except of the description of the reference area due to traffic. This reference area depends on typical traffic situations and must be defined in the design codes for railway and road bridges.

4.5. Flags and friction force

For free flags a formula for determining the force coefficient is presented. It is based on tests with full-scale flags and describes the wind load including a dynamic factor caused by the fluttering of the flags.

[1] A boxed value means: Each country may define its own value referred to the special situation in that country.

For large areas swept by the wind (i.e. large free standing roofs or long free standing boundary walls) the friction force coefficient is given for three different surface roughnesses.

4.6. Slenderness reduction factor, ψ_λ

The influence of the slenderness is taken into account by a slenderness reduction factor, ψ_λ. It is presented versus the effective slenderness, λ, and the solidity ratio, φ. The effective slenderness, λ, is defined in a table for the different boundary conditions. Worth to mention is, that for vertical structures placed on the ground the wind boundary layer causes flow disturbances at the support and reduces the aerodynamic correlation on the structure. The effective slenderness for those structures is defined by l/d and not by 2 l/d (mirror analogon).

5. DYNAMIC FACTOR FOR GUST RESPONSE

As shown in chapter 3.2.3 the dynamic factor, c_d, takes into account the reduction effect due to the lack of correlation of pressures over surfaces and the magnification effects due to the frequency content of turbulence close to the fundamental frequency of the structure.
In order to evaluate the dynamic factor, c_d, two procedures can be applied:

(i) simple procedure
(ii) detailed procedure.

The simple procedure has been developed for buildings , chimneys and bridges which are less sensitive to dynamic response. The dynamic factor for those structures is less or near 1.
Based on the detailed procedure and with approximations of natural frequencies and damping, criteria have been developed for the field of application of the simplified procedure, which provides conservative results.
In the following chapter the field of application is presented.

5.1. Field of application

In Fig. 2a - c the field of application of the simplified procedure is given for buildings (concrete, steel and mixed material). In order to avoid an abrupt change from one to the other procedure, the c_d-value has been included as a parameter for the range of $0{,}9 \leq c_d \leq 1{,}2$. Most of the common buildings may be calculated with the simplified procedure. Only few extreme buildings must be handled with the detailed procedure. In general it is allowed to use the detailed procedure for all buildings, but it is recommended to do so if $c_d > 1$ or/and the structural data are not close to the data indicated in Figure 2 to 4.
The calculation with the detailed procedure for roadway and railway bridges provides $c_d < 1$. Therefore the simplified procedure may be applied for those bridges of span $l \leq 200$ m. The dynamic factor c_d can be taken from Figure 3.
Figure 4a - d shows the field of application for chimneys. The criterion in Fig. 4 is related to gust wind response. The vortex shedding phenomenon which is important for chimneys is indicated, too, and is described in chapter 6 in more detail.

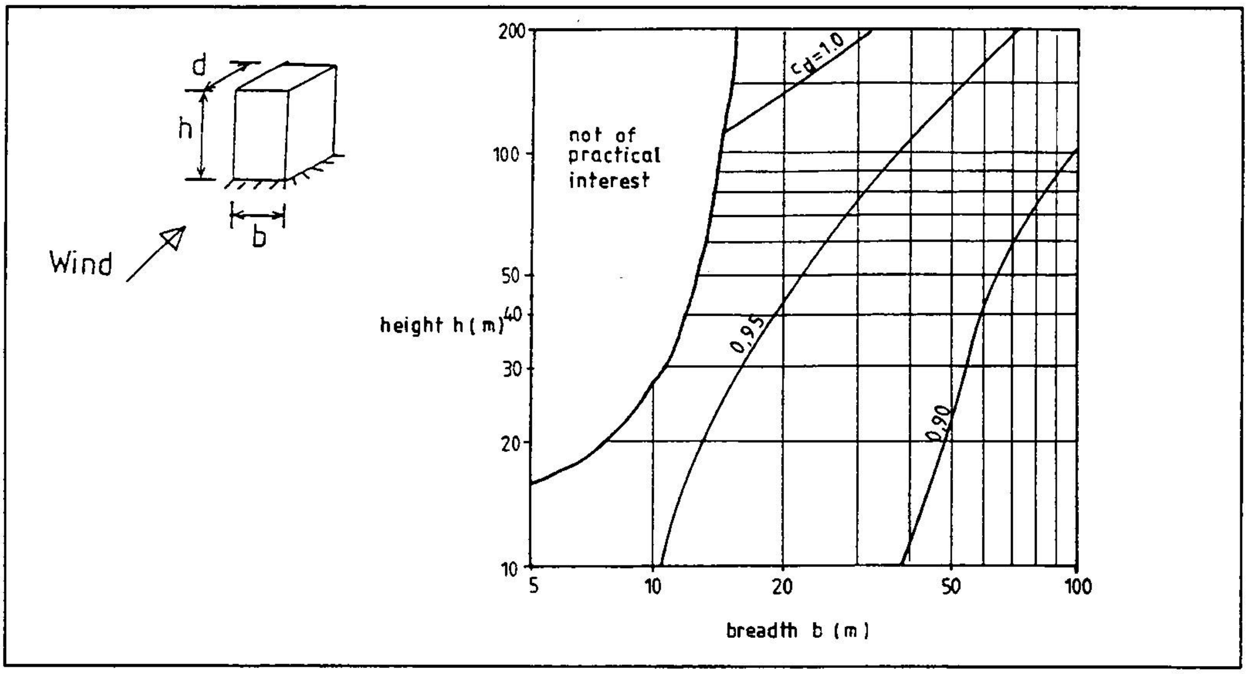


Figure 2a: Concrete structure, $\delta = 0{,}045\, n_1 + 0{,}05$

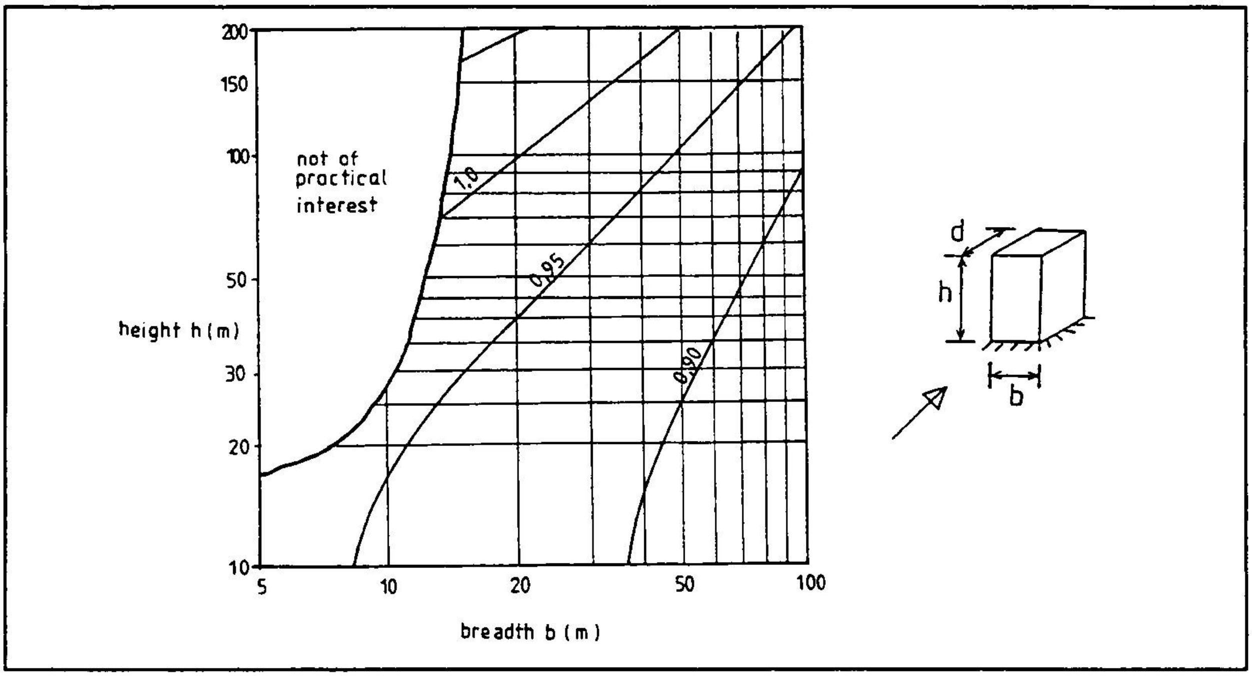


Figure 2b: Mixed structure steel-concrete, $\delta = 0{,}08$ $n_1 > 0{,}08$

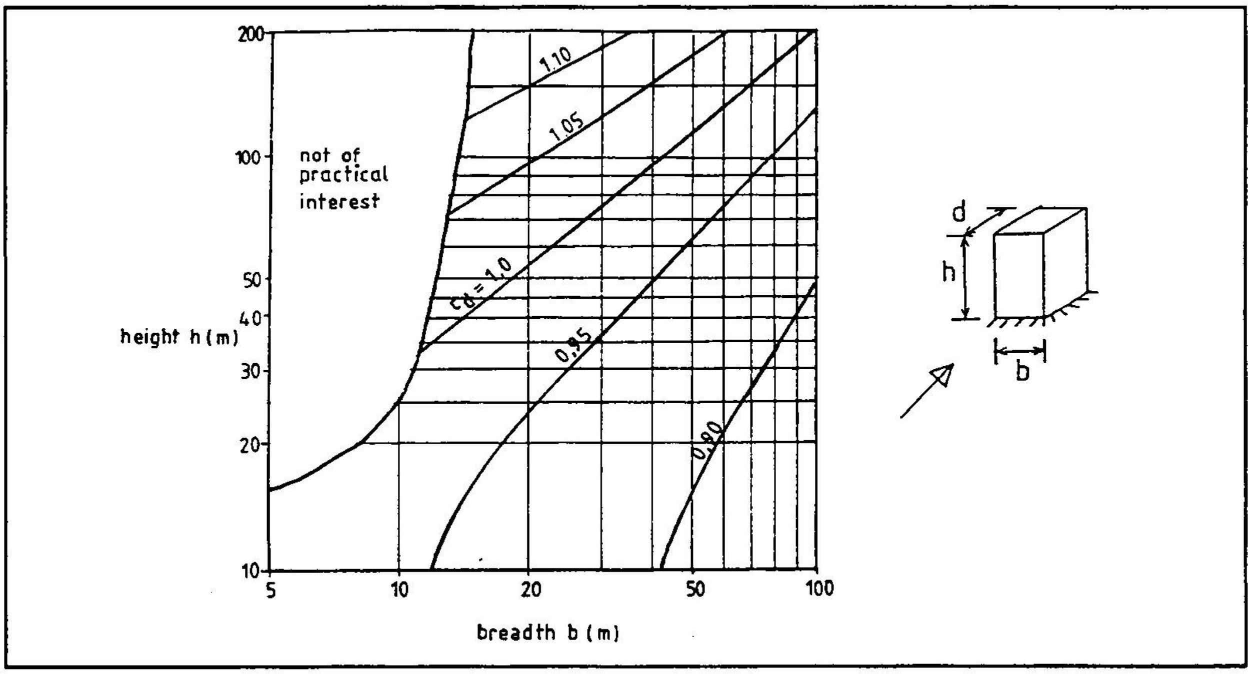


Figure 2c: Steel structure, $\delta = 0{,}045$ $n_1 > 0{,}05$

Figure 2: Field of application for the simplified procedure for buildings. Approximation for the natural frequency: $n_1 = 46/h$ where $[h] = m$

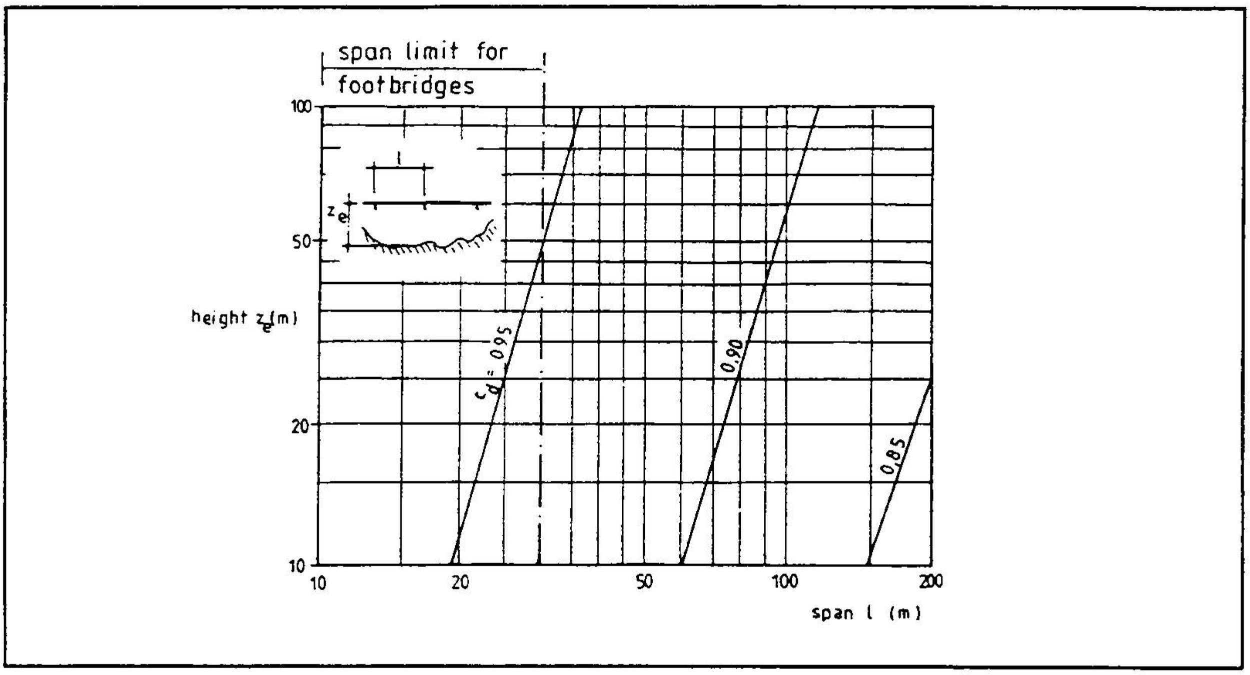


Figure 3: Dynamic factor, c_d, for roadway, railway and footbridges

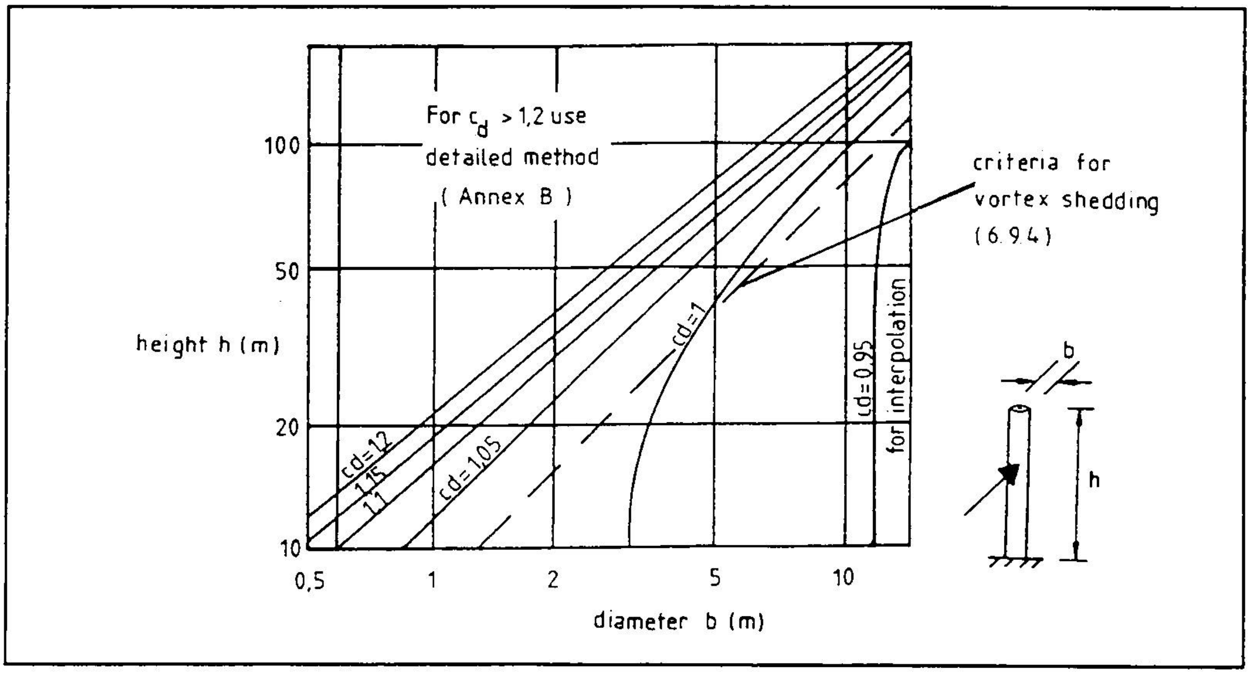


Figure 4a: Field of application for chimneys, values for unlined welded chimneys

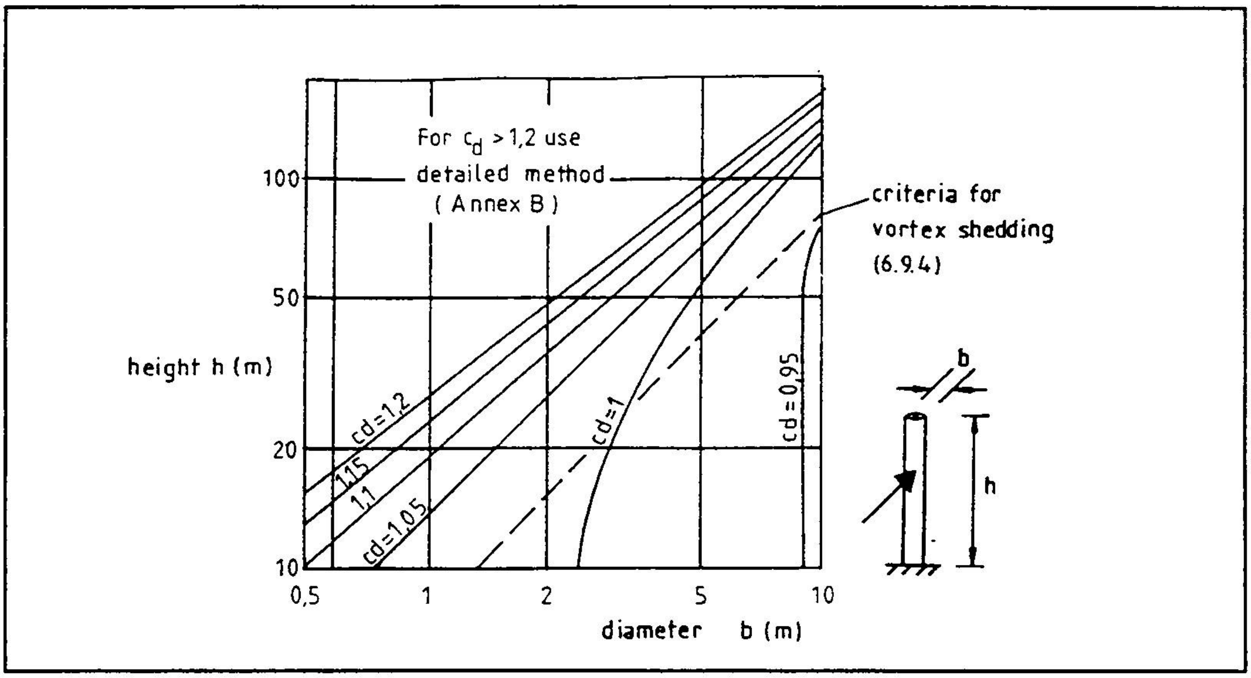


Figure 4b: Field of application for chimneys, values for lined steel chimneys

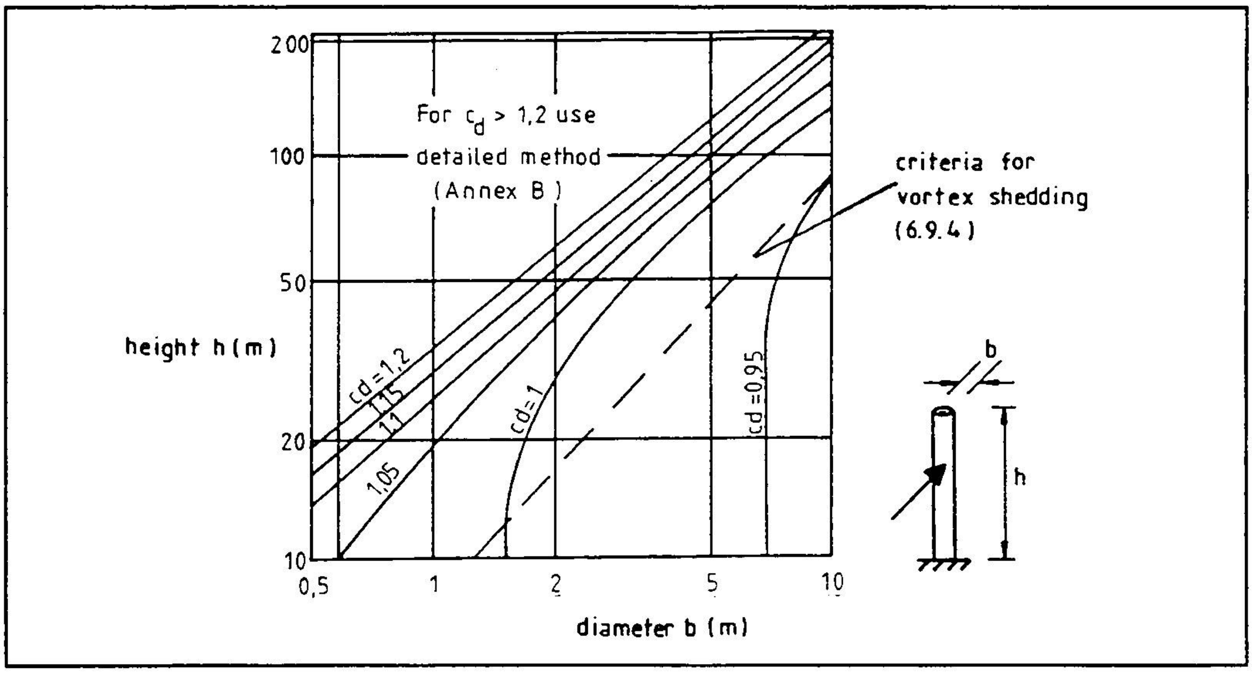


Figure 4c: Field of application for chimneys, values for brick lined steel chimneys

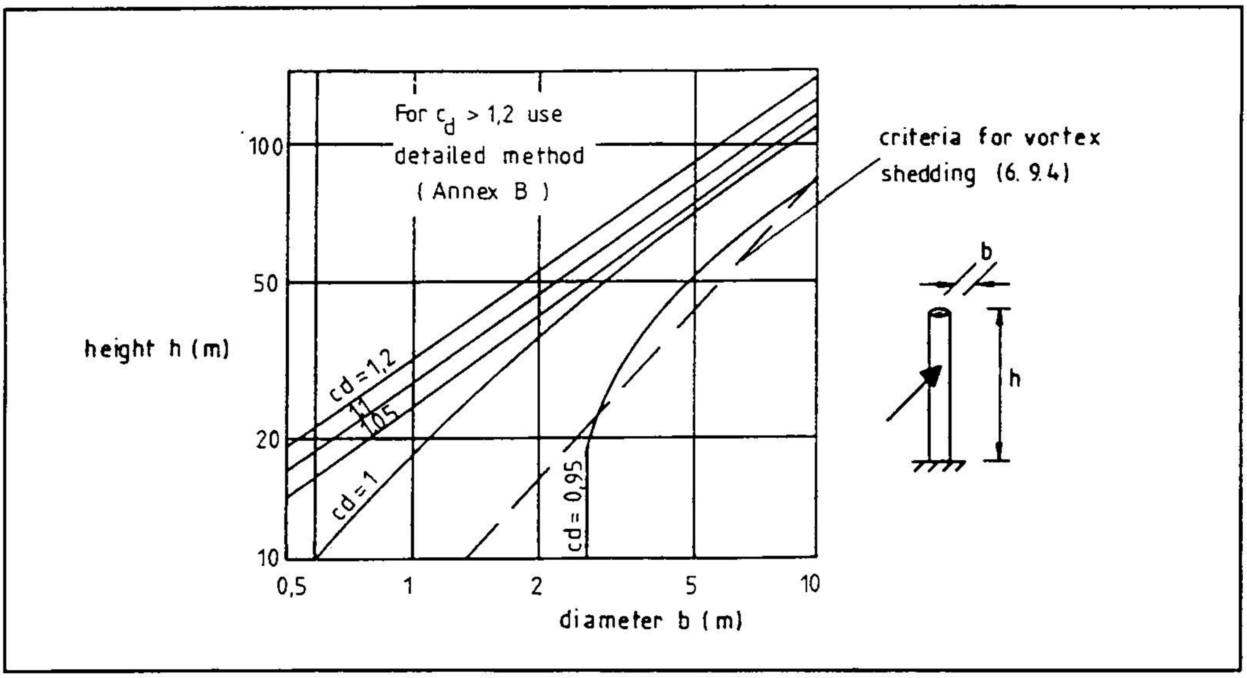


Figure 4d: Field of application for chimneys, values for reinforced concrete chimneys

In Figure 4a to 4d the following values have been used (δ may be used for the vortex resonance calculation):

$$\eta = \frac{\epsilon_1}{h_{eff}^2} \, b \sqrt{\frac{w_s}{w_z}}$$

	Material	δ	ϵ_1
a)	concrete	$0{,}05 \cdot n_1 > 0{,}025$	700
b)	steel or aluminium with brick liner	0,07	1000
c)	Lined steel or aluminium	0,025	1000
d)	Unlined welded steel or aluminium	0,015	1000

b = diameter $\quad w_s$ = weight of the structural part

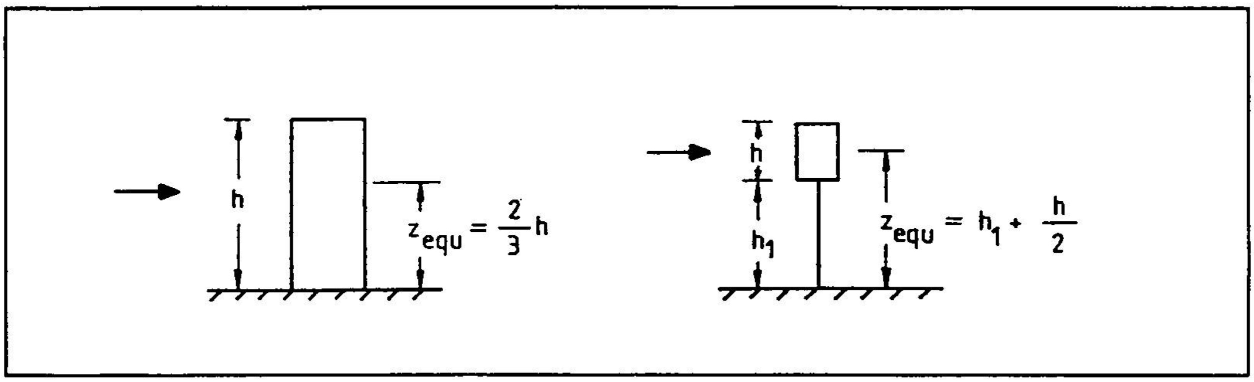
h_{eff} = effective height $\quad w_z$ = total weight

6.2. The detailed procedure for c_d

The dynamic factor, c_d, is defined by

$$c_d = \frac{1 + 2 \cdot g \cdot I_v(z_{equ}) \quad Q_0^2 + R_x^2}{1 + 7 \cdot I_v(z_{equ})} \tag{17}$$

where: z_{equ} = equivalent height of the structure



The quantities

g	=	peak factor
$I_v\ (z_{equ})$	=	turbulence intensity
Q_0	=	background part of the gust response
R_x	=	resonant part of the gust response

are presented by mathematically expressions which allow a numerical calculation with computers. For a quick check and for illustration the parameters are presented in diagrams, too.
In order to evaluate the serviceability of the structure in respect to alongwind vibration an expression is given to calculate the displacements and accelerations.
Finally, interference factors are presented for high-rise buildings in tandem or grouped arrangement effected by wake buffeting.

6. VORTEX SHEDDING

Slender structures such as chimneys, observation towers, component elements of open frames and trusses, bridges and in some cases high rise buildings shall be designed to resist the dynamic effect of vortex shedding. The shedding of vortices from unstiffened cylindrical shells may in addition excite ovalling oscillations. The field of application is given by the criteria in Figure 5 and 6 which implies the limit of

$$v_{crit} \leq 1{,}25\ v_m \tag{18}$$

where v_m = design wind speed (see chapter 3.2.2).

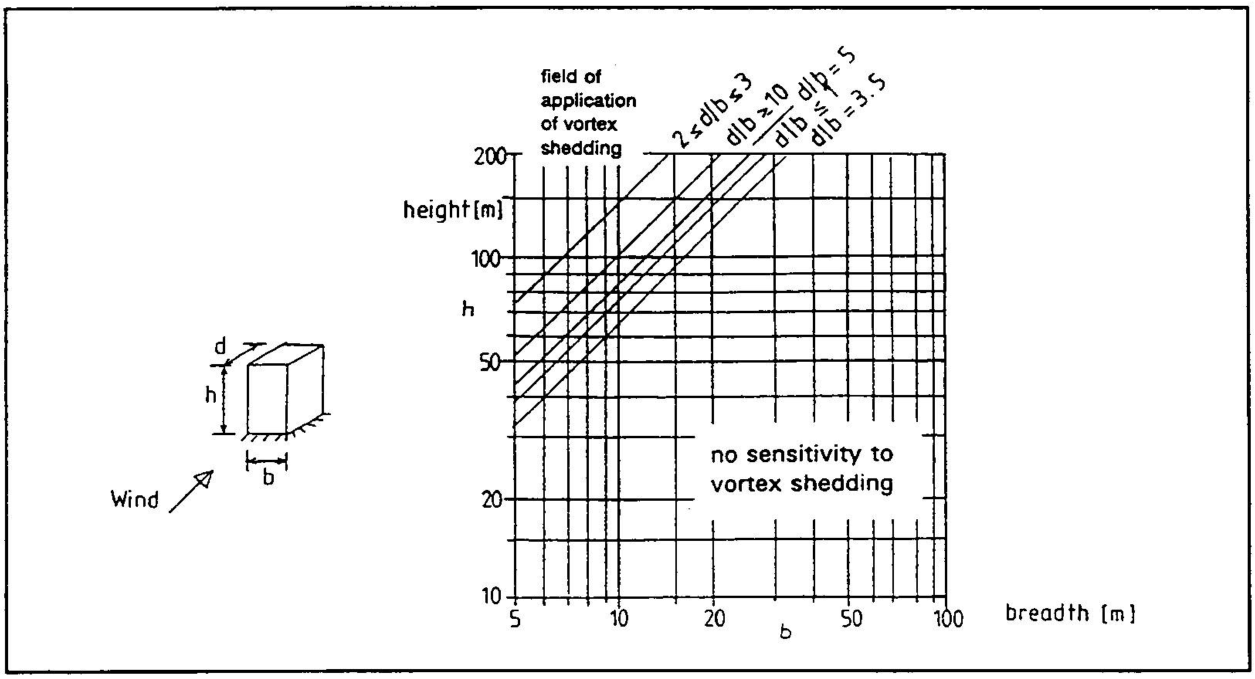
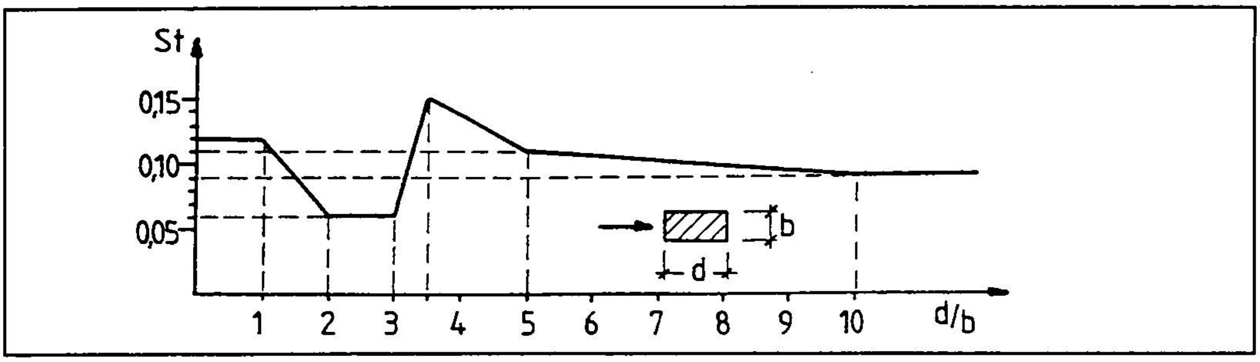


Figure 5: Criteria for the field of application of vortex shedding for buildings

Note: The effect of the d/b ratio is based on the Strouhal number of a rectangular cross section, as shown in the following figure:



Strouhal, St, number for rectangular cross sections with sharp corners

	Criteria satisfied provided:			
Elongated structures like chimneys, posts, towers (h = height, b = diameter	h/b< 8			
Bridges	l ≤ 200m			
Types of supports for horizontal forces		$\frac{d}{b} \leq 5$	$5<\frac{d}{b}<10$	$\frac{d}{b} \geq 10$
	l/b	8	linear interpolation	14
		16		29
		24		44
		32		58

Figure 6: Criteria for the field of application of vortex shedding galloping interference galloping and flutter for elongated structures

In order to calculate the critical wind speed

$$v_{crit} = (b \cdot n_i)/St \tag{19}$$

Strouhal numbers St are given for

- rectangular sections
- circular cylinders
- sharp edged sections
- bridge decks

and the natural frequency n_i may be estimated by using the formulae given in a special Annex (see chapter 8).
For the calculation of the maximum vortex resonance amplitude the correlation length model is presented. This model has been developed including the existing knowledge of that phenomena and to present a stable solution for structures in natural wind. The model has been checked and verified with a lot of full scale measurements during the past 18 years [5]. The maximum amplitude at the top of the chimney is given by equ. (20).

$$\frac{\max y_F}{b} = K_w \cdot K \cdot c_{lat} \frac{1}{St^2} \frac{1}{Sc} \qquad (20)$$

where:
b = reference width of the cross section
K_w = effective correlation length factor $0,1 \le K_w \le 0,6$
K = mode shape factor $0,1 \le K \le 0,14$
c_{lat} = aerodynamic force coefficient, given for the cross sections as listed above
St = Strouhal number
Sc = Scruton number = $2\,m\delta/(\rho b^2)$

The most important point of the correlation length model is the calculation of the effective correlation length factor, K_w which includes the locking-in effect and the type of response (random or harmonic). For large amplitudes ($\max y_F/b > 0,1$) K_w must be calculated by an iterative procedure. Simple formulae are presented for common cases.
The correlation length model cannot only be applied to cantilevered or simple supported structures but also to more complicated structures, like spatial lattice structures, frame structures or guyed masts. The handling for those systems is described in the Eurocode.
Vortex-excited resonance vibrations may cause fatigue problems. Therefore a calculation rule is presented to estimate the stress and the number of stress cycles.

7. AEROELASTIC INSTABILITIES AND INTERFERENCE EFFECTS

The following phenomena are described

- galloping instability
- interference galloping
- bridge flutter
- divergence

Criteria and calculation procedures are presented for the onset velocity resp. divergence velocity for galloping, interference galloping and divergence. Bridge flutter stability should be calculated by solving the flutter equation or with model tests and is not presented in detail. Simplified rules availabe in literature may be used provided that they have been agreed with the relevant authorities.

8. DYNAMIC CHARACTERISTICS

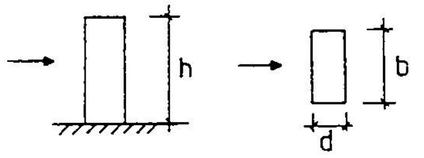
For the calculation of the dynamic effects the natural frequency, the damping, the mode shape and the equivalent mass of the structure must be known. In most cases it is sufficient to have a good approximation of that values. In a special chapter these dynamic characteristics of the most important structures are described. For more complicated structures a modal analysis is recommended.

9. FINAL REMARKS

The new draft of the Eurocode "Wind Action" presents calculation procedures of wind pressure and wind forces for the most common buildings and structures for static loads as well as for dynamic effects. It was the aim to draft a code with includes modern calculation procedures and verified aerodynamic coefficients which produces realistic load values. The most important influcence parameters have been left separated and are not combined together so that the structure of the code enables to add or to reduce values as available and to follow an increase of knowledge and experiences in the field of wind action.
For the description of the wind characteristics a format is given and the regional values are presented in different national wind maps. Every country may introduce simplifications or more sophisticated descriptions of wind parameters, if available.
For structures which are less sensitive to dynamic effects, the calculation procedure becomes simple and is restricted to only a few calculation steps.
All design codes of the Eurocode will refer to this wind action code, so that the wind load will be calculated in an identical manner for all buildings and structures.
During the following ENV period it may happen, that some supplements will be included if the design codes request for it.

10. EXAMPLES

10.1 Steel building of different height



h	=	10 + 200 m
b	=	20 m
d	=	10 m

The building is situated in urban area (category 2) with a reference wind speed of v_{ref} = 27,5 m/s. The force coefficient is set to constant, c_t = 1,3. From the criterion of Fig. 2 the simplified method may be applied up to a height of 50 m. In Fig. 7 the calculated wind force per m², F_w/A_{ref} is plotted against the building height h for the simplified and the detailed method. For h > 50 m the result of simplified method is above the result obtained by the detailed method, while for h > 50 m the detailed method has to be applied because of increasing dynamic response.

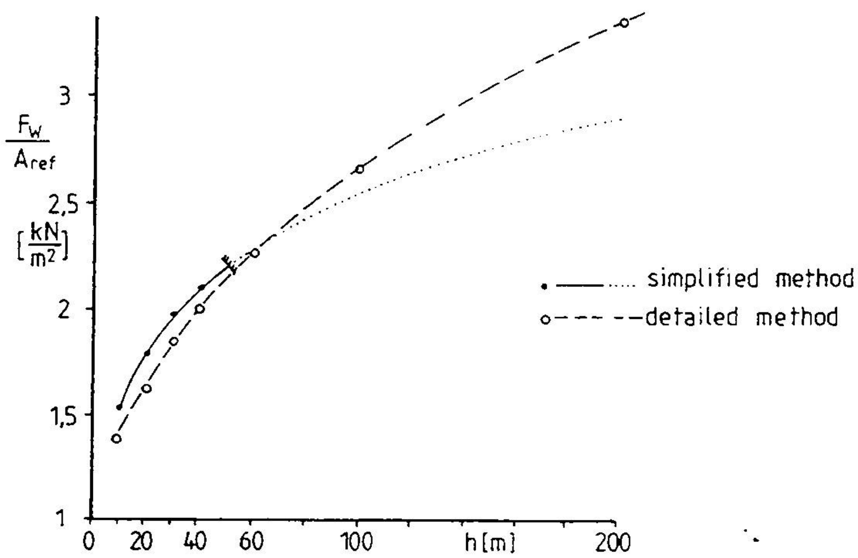
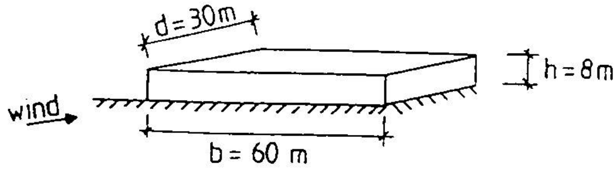


Figure 7: Calculated wind force per m² for the buildings of example 5.1. Comparision of simplified method with detailed method.

10.2 Large low rise steel hall

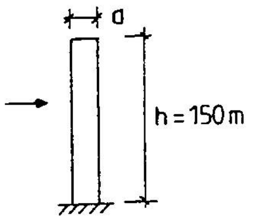


under the same site condition as in example 11.1 we get for the

simplified method: F_w/A_{ref} = 1,40 kN/m²
detailed method: F_w/A_{ref} = 1,19 kN/m²

i.e. the simplified method presents nearly 18 % higher wind loads. The reason for this fact in the neglected size effect in the simplified method.

10.3 Concrete tower



v_{ref} = 27,5 m/s

roughness category 2

10.3.1 Small slenderness, d = 13 m:

$$\lambda = h/d = 11,5 < 12$$

From the criteria for towers and stacks this structures may be calculated with the simplified method. Both calculations, simplified and detailed method come to the same result

$$\frac{F_w}{A_{ref}} = 1,47 \text{ kN/m}^2$$

The reason for the good agreement is that the size effect as well as the dynamic effect may be negligible.

10.3.2 Large slenderness, d = 5 m

$$\lambda = h/d = 30 > 12$$

This structure has to be calculated with the detailed method. The along wind force is

$$\frac{F_w}{A_{ref}} = 2,23 \text{ kN/m}^2$$

and is 52 % above the result which would be received with the simplified method.

11. REFERENCES

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