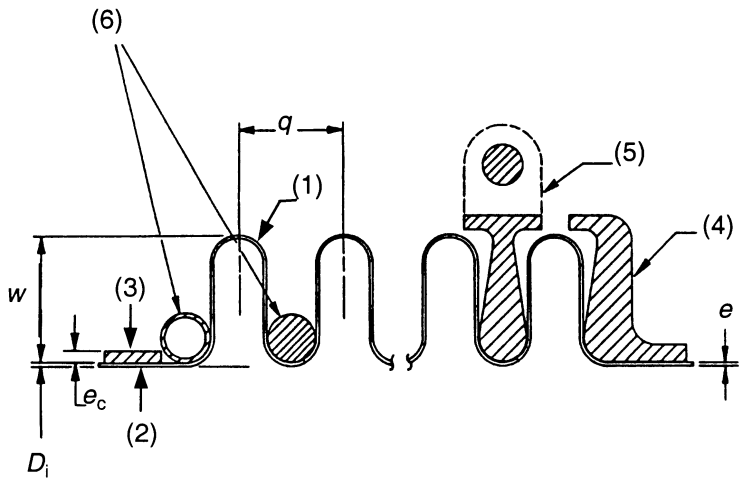
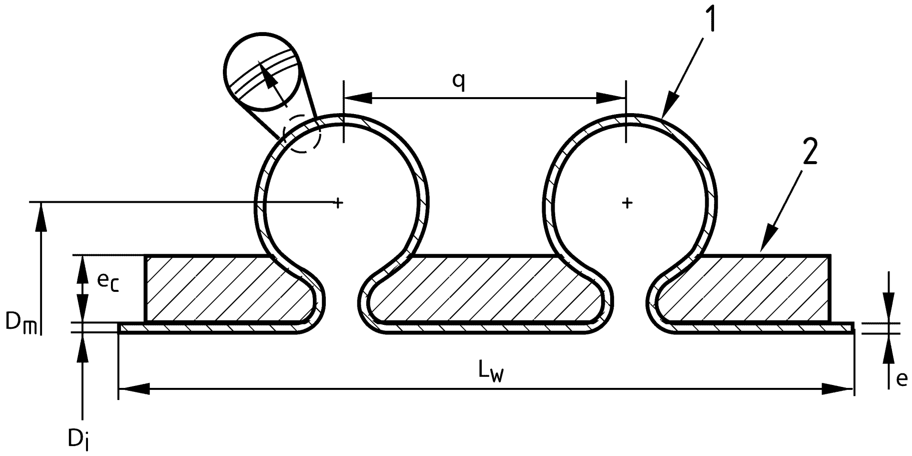


(1) convolution
(2) end tangent
(3) reinforcing collar
(4) end equalizing ring
(5) equalizing ring
(6) reinforcing rings

b) Reinforced U-shaped bellows



Key

(1) convolution

(2) renforcing collar

c) Toroidal bellows

Figure 14.1-1 — Three types of expansion bellows

14.3 Specific symbols and abbreviations

The following symbols apply in addition to those listed in clause 4.

A is the cross sectional metal area of one convolution, given by Formula (14.5.2-7) or (14.6.3-7);

c_p, c_f, c_d are coefficients used for U-shaped convolutions, see Figures 14.5.2-1, 2 and 3;

c_1 and c_2 are coefficients given by Formulae (14.5.2-8) and (14.5.2-9) or (14.6.3-8) and (14.6.3-9), used to determine the coefficients c_p, c_f, c_d;

D_c is the mean diameter of collar, given by Formula (14.5.2-2) or (14.6.3-2) or (14.7.3-2);

D_i	is the inside diameter of bellows convolution and end tangents, see Figure 14.1-1;
D_m	is the mean diameter of bellows convolution, given by Formula (14.5.2-3) or (14.6.3-3) or (14.7.3-3);
E_b	is the modulus of elasticity of bellows material at design temperature;
E_c	is the modulus of elasticity of collar material at design temperature;
E_o	is the modulus of elasticity of bellows material at room temperature;
e	is the bellows nominal thickness, given by Formula (14.5.2-1) or (14.6.3-1) or (14.7.3-1);
	For single ply bellows: $e = e_p$;
e_c	is the collar thickness, see Figure 14.1-1;
e_p	is the nominal thickness of one ply;
e^*	is the bellows thickness, corrected for thinning during forming, given by Formula (14.5.2-5) or (14.6.3-5) or (14.7.3-5);
e_p^*	is the thickness of one ply, corrected for thinning during forming, given by Formula (14.5.2-4) or (14.6.3-4) or (14.7.3-4);
f	is the nominal design stress of bellows material at design temperature;
f_c	is the nominal design stress of collar material at design temperature;
K_b	is the bellows axial rigidity, given by Formula (14.5.7-1, 14.6.8-1 or 14.7.8-1);
k	is the factor considering the stiffening effect of the attachment weld and the end convolution on the pressure capacity of the end tangent, given by Formula (14.5.2-6) or (14.6.3-6);
L_c	is the collar length, see Figure 14.1-1;

L_t is the end tangent length, see Figure 14.1-1;

N is the number of convolutions;

N_{alw} is the allowable number of fatigue cycles;

N_{spe} is the specified number of fatigue cycles;

n_p is the number of plies;

P is the calculation pressure;

q is the convolution pitch, given by Formula (14.5.2-10);

r_i is the internal radius of torus at the crest and root of U-shaped convolutions, see Figure 14.5.1-1;

s_d is the strain caused by deformation during manufacturing, see 14.5.2.2;

w is the convolution height, see Figure 14.1-1;

α is the in-plane instability stress interaction factor, given by Formula (14.5.2-12);

δ is the in-plane stress instability stress ratio, given by Formula (14.5.2-11);

Δq is the total equivalent axial displacement range per convolution, given by 14.10.5;

ν_b is the Poisson's ratio of the bellows material;

$\sigma(P)$ is a stress depending on P;

$\sigma(\Delta q)$ is a stress depending on Δq ;

σ_{eq} is the total stress range due to cyclic displacement;

Main subscripts:

b for bellows

c for collar

m for membrane or meridional

p for ply

r for reinforced

t for end tangent

θ for circumferential

No subscript is used for the bellows convolutions.

14.4 Conditions of applicability

14.4.1 Geometry

14.4.1.1 An expansion bellows comprises one or more identical convolutions. Each convolution is axisymmetric.

14.4.1.2 Each convolution may have one or more plies of equal thickness and made of same material.

14.4.1.3 Bellows including a cylindrical end tangent of length L_t, with or without collar (see Figure 14.1-1): if the thickness of the tangent is less than the cylindrical shell to which the bellows is welded, L_t shall be such that:

$$L_t - L_c \leq 0{,}5\sqrt{e \cdot D_i}$$

In this formula, $L_c = 0$ if the bellow is without collar.

14.4.1.4 The number of plies shall be such that:

$$n_p \leq 5$$

14.4.2 Loading

This clause provides rules for bellows subjected to constant internal pressure, and cyclic axial displacements. In addition:

— bellows subjected to lateral or angular displacement, shall be calculated as per 14.10,

— specific rules are given to cover external pressure (see 14.5.5),

— other loads (e.g. weight, vibration, wind, or thermal shock) shall be given special consideration.

14.4.3 Temperature

This clause applies only at material temperatures below the creep range, as stated in the relevant European material standard. In the absence of such specification:

— design temperature shall be less than 500 °C for austenitic steel and similar materials quoted in 14.5.6.3.2,

— design temperature shall be less than 380 °C for ferritic steel.

14.4.4 Materials

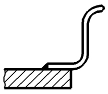
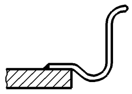
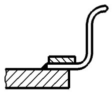
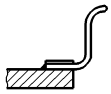
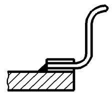
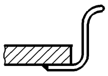
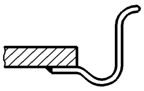
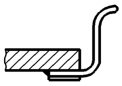
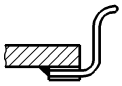
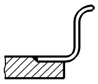
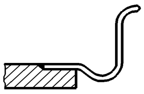
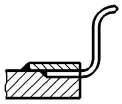
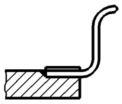
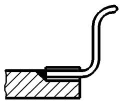
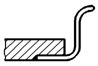
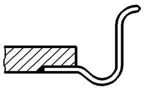
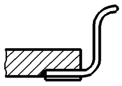
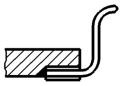
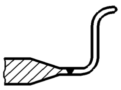
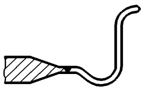
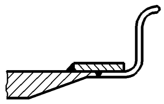
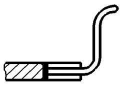
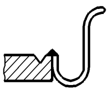
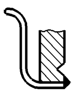
These rules apply to ferritic steel, austenitic steel and nickel-chromium-iron, nickel-iron-chromium alloys.

14.4.5 Welding seams

Expansion bellows may include one or several longitudinal welds. U-shaped unreinforced bellows may also have circumferential welds (see 14.5.9).

The circumferential attachment welds of single and multi-ply expansion bellows shall be designed according to the sketches given in Table 14.4.5-1.

Table 14.4.5-1 — Typical bellows attachment welds

Weld type		Variants (combinations of A to D are permitted)			
N°	General design	A	B	C	D
		Increased neck	Reinforcing collar	assisting collar Single	double
1.1	1)  outside lap joint/filled weld		2) 3) 		
1.2	1)  inside lap joints/fillet weld				
2.1	 outside lap joint/groove weld				
2.2	 inside lap joint/groove weld				
3.0	4)  butt weld	4) 			
4.1	5)  radial edge weld (inside or outside)				
4.2	 axial edge weld (inside or outside)				

Fittings and reinforcing collars opposite to the pressure bearing side of the bellows shall have a radius or a bevel at the edge in contact with the bellows and tangent.

NOTE These sketches are not exhaustive. Other configurations can be used, provided they lead to an equivalent level of safety.

1) In the case of fillet welds, the weld thickness "a" shall fulfil following formula: $a \geq 0{,}7 e_s$

where e_s is the nominal thickness of the connecting shell.

2) A reinforcing collar is advisable, if the cylindrical end tangent of bellows L_t exceeds:

$$L_t \geq 0{,}5 \sqrt{e_s D_i}$$

3) The reinforcing collar shall be fixed axially by welding or mechanical devices.

4) In the case of butt welds, special tools are necessary for welding of multi-ply bellows.

5) The diameter of the weld shall not exceed the mean diameter of bellows D_m by more than 20 % of the convolution height w.

14.4.6 Installation

The expansion bellows shall be provided with bars or other suitable members for maintaining the proper overall length dimension during shipment and installation. Bellows shall not be extended, compressed, rotated, or laterally offset to accommodate connecting parts which are not properly aligned, unless the design considers such movements.

In all vessels with expansion bellows, the hydrostatic end force caused by pressure and/or the bellows spring force shall be resisted by adequate restraint elements (e.g. exchanger tubes or shell, external restraints, anchors). The stress in these elements shall not exceed the nominal design stress at the design temperature.

14.5 U-shaped unreinforced bellows

14.5.1 General

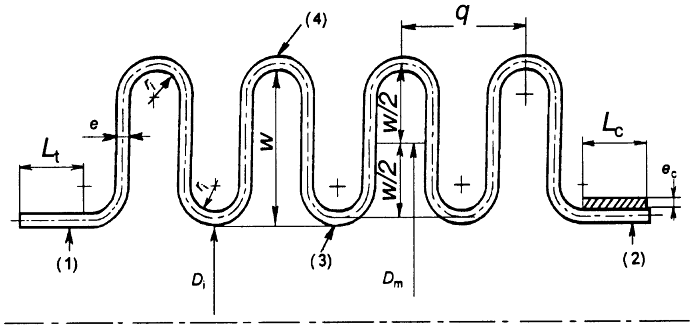
14.5.1.1 Scope

This subclause applies to two types of unreinforced bellows having nominally U-shaped convolutions:

— Those shown in Figure 14.5.1-1 are generally manufactured by a forming process (e.g. hydraulic forming, roll forming) without any circumferential welding in the convolutions. This type of bellows is covered by subclauses 14.5.2 to 14.5.7.

— Those shown in Figure 14.5.8-1 are of single ply construction where the convolutions have circumferential welds at their roots and crests. This type of bellows shall comply with the additional requirements of 14.5.8.

Each convolution consists of a sidewall and two tori of nearly the same radius (at the crest and root of the convolution), in the neutral position, so that the convolution profile presents a smooth geometrical shape as shown in Figure 14.5.1-1.



Key

(1) end tangent without reinforcing collar
(2) end tangent with reinforcing collar
(3) convolution root
(4) convolution crest

Figure 14.5.1-1 — U-shaped unreinforced bellows

14.5.1.2 Conditions of applicability

The following conditions of applicability apply in addition to those listed in 14.4.

a) A variation of 10 % between the crest convolution radius r_{ic} and the root convolution radius r_{ir} is permitted (see Figure 14.5.1 -2 for definitions of r_{ic} and r_{ir}).

b) The torus radius shall be such that:

$$r_i \geq 3\, e_p\,,$$

where

$$r_i = \frac{r_{ic} + r_{ir}}{2}\,.$$

c) The off-set angle of the sidewalls, α, in the neutral position shall be such that:

$-15 \leq \alpha \leq +15$ degrees (see Figure 14.5.1-2).

d) The convolution height shall be such that: $w \leq \dfrac{D_i}{3}$.

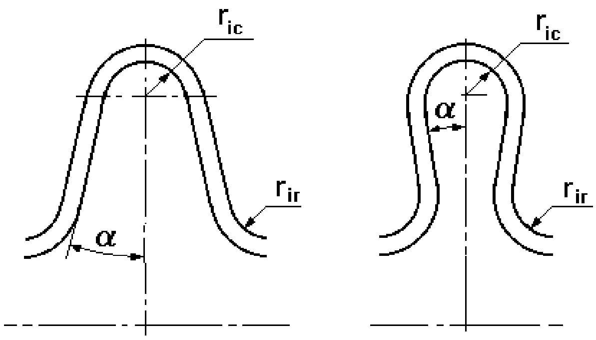


Figure 14.5.1-2 — Possible configuration shapes in the neutral position

14.5.2 Determination of intermediate quantities

14.5.2.1 General

The following formulae are used in the determination of the intermediate factors.

$$e = n_p \cdot e_p \tag{14.5.2-1}$$

$$D_c = D_i + 2\,e + e_c \tag{14.5.2-2}$$

$$D_m = D_i + w + e \tag{14.5.2-3}$$

$$e_p^* = e_p \sqrt{\frac{D_i}{D_m}} \tag{14.5.2-4}$$

$$e^* = n_p \cdot e_p^* \tag{14.5.2-5}$$

$$k = \min\left[\left(\frac{L_t}{1{,}5\sqrt{D_i \cdot e_p}}\right); (1{,}0)\right] \quad (14.5.2\text{-}6)$$

$$A = \left[\left(\frac{\pi - 2}{2}\right) q + 2w\right] e^* \quad (14.5.2\text{-}7)$$

$$C_1 = \frac{q}{2w} \quad (14.5.2\text{-}8)$$

$$C_2 = \frac{q}{2{,}2\sqrt{D_m \cdot e_p^*}} \quad (14.5.2\text{-}9)$$

$$q = 4r_i + 2e \quad (14.5.2\text{-}10)$$

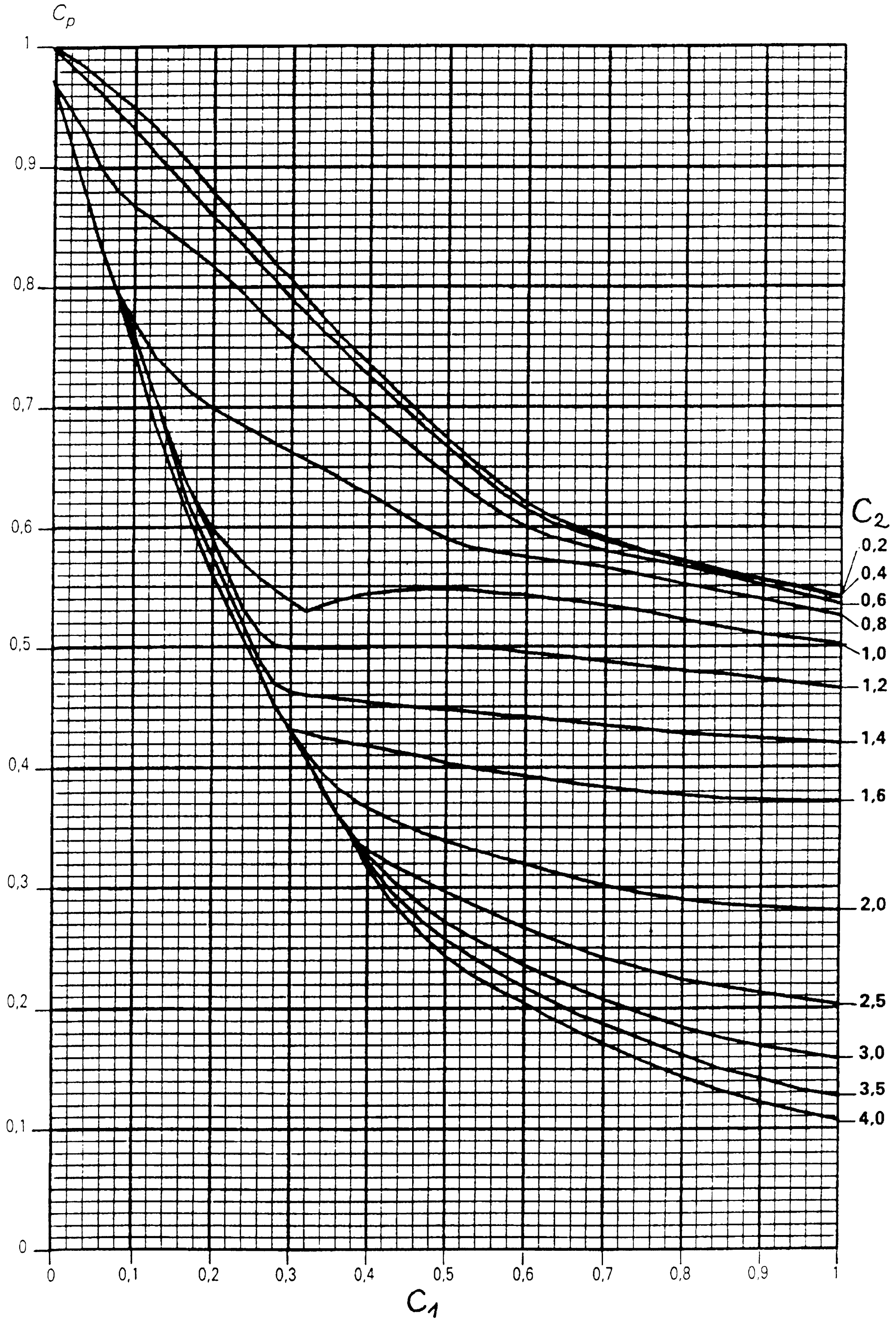
NOTE Formula (14.5.2-10) applies in the case of parallel walls. Otherwise, the actual pitch has to be used.

$$\delta = \frac{\sigma_{m,b}}{3\sigma_{\theta,I}} \quad (14.5.2\text{-}11)$$

Where $\sigma_{m,b}$ and $\sigma_{\theta,I}$ are defined in 14.5.3.3.

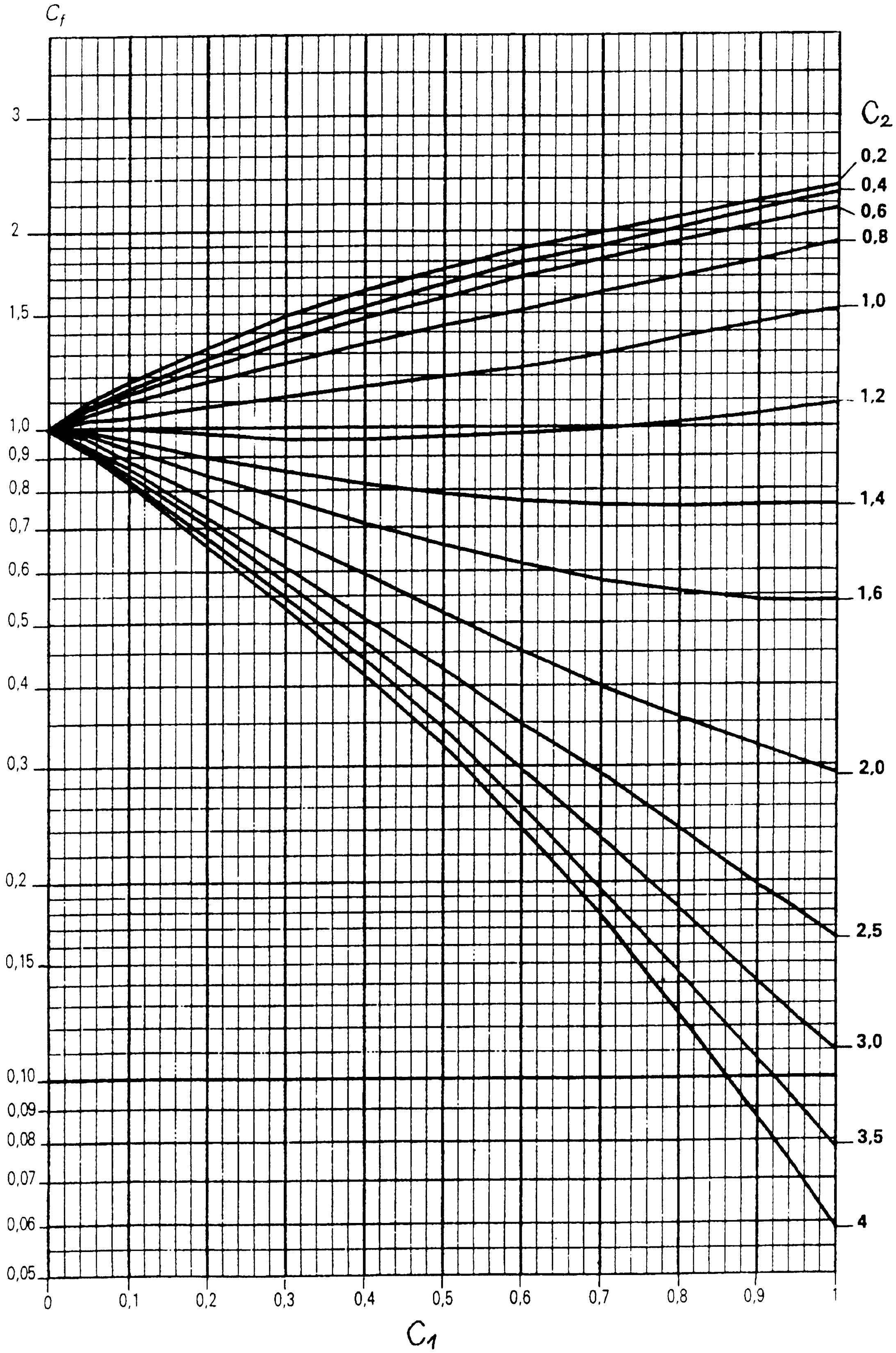
$$\alpha = 1 + 2\delta^2 + \sqrt{\left(1 - 2\delta^2 + 4\delta^4\right)} \quad (14.5.2\text{-}12)$$

For coefficient C_p, C_f and C_d, see Figures 14.5.2-1 to 14.5.2-3.



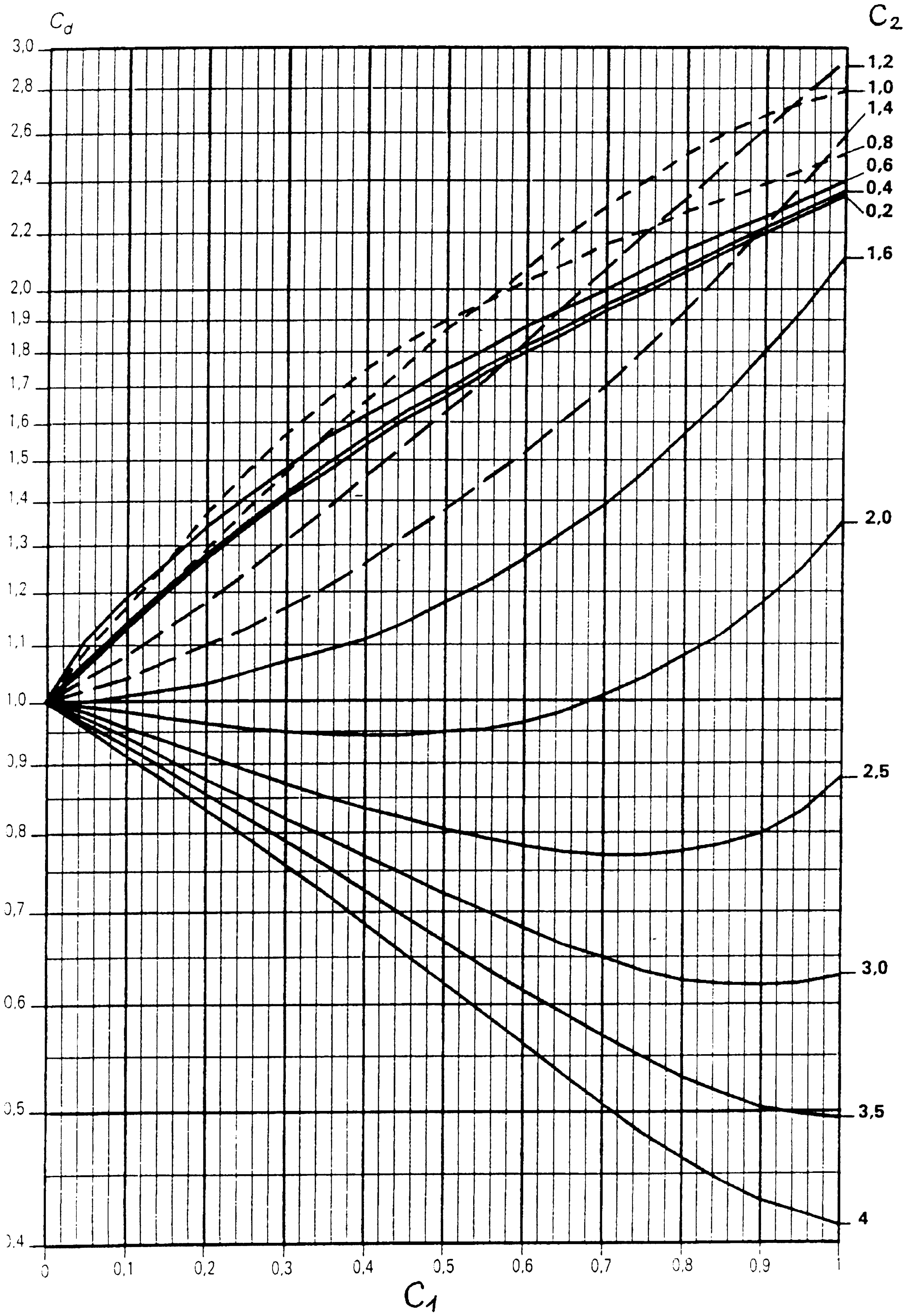
NOTE Clause K.2 gives polynomial approximations for these curves.

Figure 14.5.2-1 — Coefficient c_p



NOTE Clause K.2 gives polynomial approximations for these curves.

Figure 14.5.2-2 — Coefficient c_f



NOTE Clause K.2 gives polynomial approximations for these curves.

Figure 14.5.2-3 — Coefficient c_d