

Industrial valves — Shell design strength

Part 2: Calculation method for steel valve shells

National foreword

This British Standard is the UK implementation of EN 12516-2:2014+A1:2021. It supersedes BS EN 12516-2:2014, which is withdrawn.

The start and finish of text introduced or altered by amendment is indicated in the text by tags. Tags indicating changes to CEN text carry the number of the CEN amendment. For example, text altered by CEN amendment A1 is indicated by A1 A1.

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A list of organizations represented on this committee can be obtained on request to its committee manager.

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Date	Text affected
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enveloppes d'appareils de robinetterie en acier

Industriearmaturen - Gehäusefestigkeit - Teil 2:
Berechnungsverfahren für drucktragende Gehäuse von
Armaturen aus Stahl

This European Standard was approved by CEN on 9 August 2014 and includes Amendment 1 approved by CEN on 6 September 2021.

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European foreword

This document (EN 12516-2:2014+A1:2021) has been prepared by Technical Committee CEN/TC 69 “Industrial valves”, the secretariat of which is held by AFNOR.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by April 2022, and conflicting national standards shall be withdrawn at the latest by April 2022.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN shall not be held responsible for identifying any or all such patent rights.

This document includes Amendment 1 approved by CEN on 6 September 2021.

This document supersedes A1 EN 12516-2:2014 A1.

The start and finish of text introduced or altered by amendment is indicated in the text by tags A1 A1.

This document has been prepared under a Standardization Request given to CEN by the European Commission and the European Free Trade Association, and supports essential requirements of EU Directive(s) / Regulation(s).

For relationship with EU Directive(s) / Regulation(s), see informative Annex ZA, which is an integral part of this document.

A1 In comparison with the previous edition EN 12516-2:2004, the following significant changes have been made in the new edition EN 12516-2:2014: A1

- a) the normative references were updated;
- b) all formulae and figures have been renumbered; in particular 10.6 “Design temperature” became 10.5 “Calculation of the bolt diameter”;
- c) some formulae were changed:
 - 1) Formulae (3) to (6) for calculated wall thickness have been added;
 - 2) Formulae (9) and (10) for calculation of e_c in case of $d_o / d_i > 1,7$ have been added;
 - 3) Formulae (17) and (20) for conical bodies or branches have been added;
- d) the figures were changed and/or updated:
 - 1) a new Figure 1 “Composition of section thickness and tolerance allowances” has been added;
 - 2) Figure 2 “Cone calculation coefficient” has been over-worked;
 - 3) former Figures 6a and 6b are now combined in Figure 7 “Calculation coefficient B_n for rectangular cross-sections”;
 - 4) Figures 23, 24, and 25 used to establish the calculation coefficients C_x , C_y and C_z were moved to 8.2.1;

- 5) the new Figure 46 “Types of flange connections” has been added;
- e) tables were updated:
 - 1) Table 1 giving the symbols characteristics and units has been revised;
 - 2) a column for test conditions in Table 2 “Nominal design stresses (allowable stresses)” has been added;
 - 3) Table 5 “Flat circular plates and annular plates — Bending moments as a function of load cases and clamping conditions” has been revised;
 - 4) Table 7 “Lever arms of the forces in the moment formulae” has been revised;
- f) Clause 6 “Nominal design stresses for pressure parts other than bolts” now contains references to PED 97/23/EC;
- g) Clause 7 “Calculation methods for the wall thickness of valve bodies” has been restructured; and 7.1 now contains information on calculation of the surface-comparison;
- h) Subclauses 8.2.2 and 8.2.3 now draw a distinction between “direct loading” and “not subjected to direct loading”; and 8.2.3 now contains a warning regarding the mean support diameter d_{mA} ;
- i) there is a new Subclause 8.3.3.5 regarding the diameter of centre of gravity;
- j) Clause 10 “Calculation methods for flanges” has been over-worked;
- k) the former informative Annex A “Allowable stresses” has been deleted;
- l) the Annex “Characteristic values of gaskets and joints” has been over-worked;
- m) Annex ZA has been updated.

EN 12516, *Industrial valves — Shell design strength*, consists of four parts:

- *Part 1: Tabulation method for steel valve shells*;
- *Part 2: Calculation method for steel valve shells* (the present document);
- *Part 3: Experimental method*;
- *Part 4: Calculation method for valve shells manufactured in metallic materials other than steel*.

Any feedback and questions on this document should be directed to the users’ national standards body. A complete listing of these bodies can be found on the CEN website.

According to the CEN-CENELEC Internal Regulations, the national standards organisations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Republic of North Macedonia, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

Introduction

EN 12516, *Industrial valves — Shell design strength*, is composed of four parts. EN 12516-1 and EN 12516-2 specify methods for determining the thickness of steel valve shells by tabulation and calculation methods respectively. EN 12516-3 establishes an experimental method for assessing the strength of valve shells in steel, cast iron and copper alloy by applying an elevated hydrostatic pressure at ambient temperature. EN 12516-4 specifies methods for calculating the thickness for valve shells in metallic materials other than steel.

The calculation method, EN 12516-2, is similar in approach to the former DIN 3840 where the designer is required to calculate the wall thickness for each point on the pressure temperature curve using the allowable stress at that temperature for the material he has chosen (see Bibliography, reference [1]). The allowable stress is calculated from the material properties using safety factors that are defined in EN 12516-2. The formulae in EN 12516-2 consider the valve as a pressure vessel and ensure that there will be no excessive deformation or plastic instability.

The tabulation method, EN 12516-1, is similar in approach to ASME B16.34 (see Bibliography, reference [2]) in that the designer can look up the required minimum wall thickness dimension of the valve body from a table. The internal diameter of the inlet bore of the valve gives the reference dimension from which the tabulated wall thickness of the body is calculated.

The tabulated thicknesses in EN 12516-1 are calculated using the thin cylinder formula that is also used in EN 12516-2. The allowable stress used in the formula is equal to 120,7 MPa and the operating pressure, p_c , in MPa, varies for each PN and Class designation. EN 12516-1 gives these p_c values for all the tabulated PN and Class designations.

EN 12516-1 specifies PN, Standard Class and Special Class pressure temperature ratings for valve shells with bodies having the tabulated thickness. These tabulated pressure temperature ratings are applicable to a group of materials and are calculated using a selected stress, which is determined from the material properties representative of the group, using safety factors defined in EN 12516-1.

Each tabulated pressure temperature rating is given a reference pressure designation to identify it.

The tabulation method gives one thickness for the body for each PN (see EN 12516-1:2014, 3.1 PN (Body)) or Class designation depending only on the inside diameter, D_i , of the body at the point where the thickness is to be determined.

The calculated pressure is limited by the ceiling pressure which sets up an upper boundary for high strength materials and limits the deflection.

A merit of the tabulation method, which has a fixed set of shell dimensions irrespective of the material of the shell, is that it is possible to have common patterns and forging dies. The allowable pressure temperature rating for each material group varies proportionally to the selected stresses of the material group to which the material belongs, using the simple rules above.

A merit of the calculation method is that it allows the most efficient design for a specific application using the allowable stresses for the actual material selected for the application.

The two methods are based on different assumptions, and as a consequence the detail of the analysis is different (see Bibliography, reference [3]). Both methods offer a safe and proven method of designing pressure-bearing components for valve shells.

1 Scope

This European Standard specifies the method for the strength calculation of the shell with respect to internal pressure of the valve.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 19:2016, *Industrial valves — Marking of metallic valves* 

EN 1092-1:2018, *Flanges and their joints — Circular flanges for pipes, valves, fittings and accessories, PN designated — Part 1: Steel flanges* 

EN 1591-1:2013, *Flanges and their joints — Design rules for gasketed circular flange connections — Part 1: Calculation*

EN 10269:2013, *Steels and nickel alloys for fasteners with specified elevated and/or low temperature properties*

EN 12266-1:2012, *Industrial valves — Testing of metallic valves — Part 1: Pressure tests, test procedures and acceptance criteria — Mandatory requirements*

EN 12266-2:2012, *Industrial valves — Testing of metallic valves — Part 2: Tests, test procedures and acceptance criteria — Supplementary requirements*

EN 13445-3:2014,¹ *Unfired pressure vessels — Part 3: Design* 

EN 16668:2016+A1:2018, *Industrial valves — Requirements and testing for metallic valves as pressure accessories* 

EN ISO 3506-1:2020, *Fasteners — Mechanical properties of corrosion-resistant stainless steel fasteners — Part 1: Bolts, screws and studs with specified grades and property classes (ISO 3506 1:2020)* 

3 Symbols and units

The following symbols are used:

 **Table 1 — Symbols and units**

Symbol	Unit	Description
a_H	mm	lever arm for horizontal force
a_S	mm	lever arm for bolt force
a_V	mm	lever arm for vertical force
B	—	calculation coefficient to determine the thickness of the flange
$B_{1...3}$	—	calculation coefficient for oval and rectangular cross-sections

¹ As impacted by EN 13445-3:2014/A1:2015, EN 13445-3:2014/A2:2016, EN 13445-3:2014/A3:2017, EN 13445-3:2014/A4:2018, EN 13445-3:2014/A5:2018, EN 13445-3:2014/A6:2019, EN 13445-3:2014/A7:2019 and EN 13445-3:2014/A8:2019.

Symbol	Unit	Description
B_5	—	correction factor for oval flanges
B_{FI}, B_{FII}	—	calculation coefficient for flat circular plates
B_h	—	calculation coefficient to determine the thickness of the flange
B_{MI}, B_{MII}	—	calculation coefficient for flat circular plates
B_{PI}, B_{PII}	—	calculation coefficient for flat circular plates
b	mm	double flange width
b_1	mm	minor width in oval and rectangular cross section
b_2	mm	major width in oval and rectangular cross section
b_{D1}, b_{D2}	mm	width of the seal
b'_1	mm	width in oval and rectangular cross section
b_D	mm	width of the seal
b_s	mm	effective width for reinforcement
C_x, C_y, C_z	—	calculation coefficient for covers made of flat plates
C	—	calculation coefficient for lens-shaped gaskets
c	mm	design allowance for bolts
c_1	mm	fabrication tolerance
c_2	mm	standardized corrosion and erosion allowance
d_o	mm	outside diameter
d_0, d'_0	mm	diameter in base body
d_{01}, d_{02}	mm	diameter for self-sealing closure
d_1	mm	diameter in branch
d_2	mm	diameter in further branch
d_4	mm	outside diameter of collar flange
d_A	mm	outside diameter of the plate/cover
d_a	mm	outside flange diameter
d_i	mm	inside diameter
d_f	mm	diameter of the biggest inscribed circle
d_k	mm	diameter in knuckle
d_K	mm	diameter in corner welds
d_L	mm	hole diameter

Symbol	Unit	Description
d'_L	mm	reduced bolt hole diameter
d_m	mm	mean diameter of the plate/cover
d_{mA}	mm	mean diameter of the face (see Figure 28)
d'_m	mm	mean diameter
d_D	mm	mean diameter of the seal
d_s	mm	required bolt diameter
d_t	mm	bold circle diameter/reference circle diameter
d_p	mm	diameter of centre of gravity
d_{ast}	mm	stuffing box outside diameter
d_{ist}	mm	stuffing box inside diameter
d_{S0}	mm	calculated bolt diameter without design allowance
d_V	mm	diameter of the vertical force at the cone
E	MPa	modulus of elasticity
E_D	MPa	modulus of elasticity for material of the seal
e_n	mm	wall thickness
e_{an}	mm	wall thickness (final/actual)
e_{acn}	mm	actual wall thickness less c_1 and c_2
e_{acF}	mm	thickness of flange neck
e_{cn}	mm	calculated theoretical minimum wall thickness, without c_1 and c_2
F_{DV}	N	minimum bolt force for the assembly condition
F_F	N	flange force
F_H	N	horizontal component force
F_S	N	bolt force for operating conditions
F_{SB}	N	minimum bolt force
F_{S0}	N	bolt force for assembly conditions
F_T	N	tensile force
F_V	N	vertical force at the cone
F_Z	N	additional force
f	MPa	nominal design stress
f_d	MPa	maximum value of the nominal design stress for normal operating load

Symbol	Unit	Description
		cases
f_d/t	MPa	nominal design stress for design conditions at temperature t °C
g_1, g_2	mm	welding throat depth
h	mm	plate thickness
h_0	mm	minimum height for the seating shoulder
h_1	mm	minimum height of the inserted ring
h_D	mm	minimum depth of the sealing ledge
h_r	mm	plate thickness
h_A	mm	height of flange hub
h_c	mm	plate thickness
h_F	mm	thickness of flange
h_N	mm	reduced plate thickness
k_c	—	welding factor
l	mm	length
$l_{0...3}$	mm	effective length for cylindrical bodies
l'	mm	length which is influenced by the entry nozzle
l'_0	mm	length for calculating body shapes in cross section II
$l/3$	mm	length for calculating body shapes in cross section II
M	Nm	external moment
M_i	Nm	summary of moments M_P, M_F, M_M
M_a	Nm	external moment
M_{a0}	Nm	moment for assembly condition
M_{aB}	Nm	moment for operation condition
M_F	Nm	single force (point force)
$M_{\max}$	Nm	maximum bending moment
M_M	Nm	rim moment
M_P	Nm	resulting moment from internal pressure
M_r	Nm	bending moment in radial direction
M_t	Nm	bending moment in tangential direction
m	—	gasket coefficient
n	—	number of bolts

Symbol	Unit	Description
n_1	—	load carrying factor
p	MPa	pressure
p_c	MPa	calculation pressure
p_d	MPa	design pressure
p_F	MPa	contact pressure
PS	MPa	maximum allowable pressure
R	mm	radius for calculating load cases
R_{eH}	MPa	upper yield strength
R_{eH}/t	MPa	upper yield strength at temperature t °C
R_i	mm	inner Radius of spherical cap
R_m	MPa	tensile strength
R_m/t	MPa	tensile strength at temperature t °C
$R_m/T/t$	MPa	creep rupture strength for T hours at temperature t °C
$R_{p0,2}$	MPa	0,2 % - proof strength
$R_{p0,2}/t$	MPa	0,2 % - proof strength at temperature t °C
$R_{p0,2}/t$ Test	MPa	0,2 % - proof strength at test temperature t °C
$R_{p1,0}/t$ Test	MPa	1,0 % - proof strength at test temperature t °C
$R_{p1,0}$	MPa	1,0 % - proof strength
$R_{p1,0}/t$	MPa	1,0 % - proof strength at temperature t °C
$R_{p1,0}/T/t$	MPa	1,0 % - creep proof strength for T hours at temperature t °C
r	mm	radius
r_0	mm	radius for calculating load cases
r_1	mm	radius for calculating load cases
r_o	mm	outside radius
r_i	mm	inside radius
r_D	mm	radius to the middle of the support plate for the seal
r_F	mm	radius to F_1
S_D	—	safety factor for gasket value
SF	—	safety factor
s	mm	distance of the centre of gravity of the half circular ring from the centreline

Symbol	Unit	Description
s_N	mm	thickness of weld
S_S	mm	centre of gravity
S_1, S_2	—	centre of gravity
s_1, s_2	mm	distance of the centre of gravity or distance
s_3	mm	distance
T	h	time
t	°C	temperature
t_d	°C	design temperature
U_D	mm	mean circumference
V	—	correction factor of bolt hole diameter
W, W_I, W_{II}, W_{III}	mm ³	flange resistance
W_{avI}, W_{avII}	mm ³	flange resistance in cross-section
W_{req1}	mm ³	flange resistance in operating condition
W_{req2}	mm ³	flange resistance in assembly condition
X	mm	distance variable
Y	mm	distance variable
Z		coefficient
Z_1	mm ³	coefficient
γ	°	angle of lenticular gasket
α	—	form factor
β	—	calculation factor = α/δ
η	—	machining quality factor
μ	—	Poisson's ratio
δ	—	ratio of bolt forces against pressure forces
δ_1	—	proof stress ratio
φ	°	angle for corner welds
φ_k	°	angle in knuckle area
Φ	°	angle of body branch
Φ_A	°	angle for valve bodies with oblique branch
χ	—	calculation factor depending on the gasket material
σ	MPa	stress in the cross sections or branches

Symbol	Unit	Description
σ_{VU}	MPa	minimum sealing constant assembly state
σ_{VO}	MPa	maximum sealing constant assembly state
σ_{BO}	MPa	maximum sealing constant operating state
$\sigma_I, \sigma_{II}, \sigma_{III}$	MPa	stress in the cross section I, II, III

A1

4 General conditions for strength calculation

Formulae (1) and (2) apply to mainly static internal pressure stressing. The extent to which these formulae can also be applied to pulsating internal pressure stressing is described in Clause 12.

The total wall thickness is found by adding the following allowances:

$$e_0 = e_{c0} + c_1 + c_2 \quad (1)$$

$$e_1 = e_{c1} + c_1 + c_2 \quad (2)$$

$$e_{a0} \geq e_0 \quad (3)$$

$$e_{a1} \geq e_1 \quad (4)$$

where

e_{c0}, e_{c1} are the calculated wall thicknesses in accordance with the rules given in this standard at different locations on the valve shell (see Figures 1a and 2);

c_1 is a manufacturer tolerance allowance;

c_2 is a standardized corrosion and erosion allowance.

The values of the corrosion allowance are:

$c_2 = 1$ mm for ferritic and ferritic-martensitic steels;

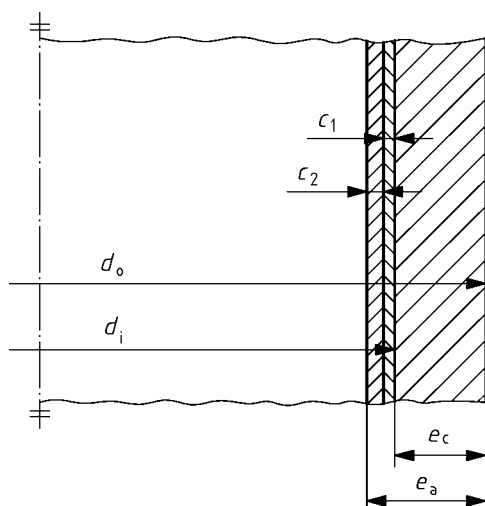
$c_2 = 0$ mm for all other steels;

$c_2 = 0$ mm if $e_{c0} \geq 30$ mm or if $e_{c1} \geq 30$ mm.

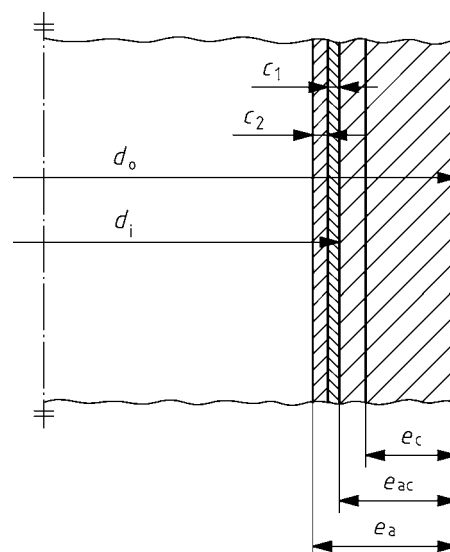
When checking the wall thickness of existing pressure retaining shells these allowances shall be subtracted from the actual wall thickness.

$$e_{ac0} = e_{a0} - c_1 - c_2 \quad (5)$$

$$e_{ac1} = e_{a1} - c_1 - c_2 \quad (6)$$



a) for new design



b) for verification of existing wall thickness

A1

Key e wall thickness d diameter a actual c calculated i inner o outer

$$e_{ac} \geq e_c$$

$$e_a \geq e_c + c_1 + c_2$$

 c_1 fabrication tolerance c_2 corrosion allowance e_c calculated wall thickness e_{ac} actual minimum wall thickness less c_1 and c_2 e_a actual wall thickness

A1

Figure 1 — Composition of section thickness and tolerance allowances**5 Design pressure**

All reasonably foreseeable conditions shall be taken into account, which occur during operation and standby. Therefore the design pressure p_d shall not be less than the maximum allowable pressure PS . In formulae, p_d is shortly written as p .

6 Nominal design stresses for pressure parts other than bolts**6.1 General**

A1 deleted text A1

The calculation of the test conditions is optional.

Table 2 — Nominal design stresses (allowable stresses)

Material	Design conditions	Creep conditions	Test and assembly conditions ^b
Steel as defined in 6.2	$f = \min (R_{p0,2/t} / 1,5 ; R_{m/20} / 2,4)$	$f = R_{m/100\,000/t} / 1,5$	$f = R_{p0,2/t_{Test}} / 1,05$
Austenitic steel and austenitic cast steel as defined in 6.2	$f = \min (R_{p1,0/t} / 1,5 ; R_{m/20} / 2,4)$	$f = R_{m/100\,000/t} / 1,5$	$f = R_{p1,0/t_{Test}} / 1,05$
Austenitic steel and austenitic cast steel as defined in 6.3 with rupture elongation > 30 %	$f = R_{p1,0/t} / 1,5$	$f = R_{m/100\,000/t} / 1,5$	$f = R_{p1,0/t_{Test}} / 1,05$
Austenitic steel and austenitic cast steel as defined in 6.4 with rupture elongation > 35 %	$f = \max [R_{p1,0/t} / 1,5 ; \min (R_{p1,0/t} / 1,2 ; R_{m/t} / 3,0)]$	$f = R_{m/100\,000/t} / 1,5$	$f = R_{p1,0/t_{Test}} / 1,05$
Cast steel as defined in 6.5	$f = \min (R_{p0,2/t} / 1,9 ; R_{m/20} / 3,0)$	$f = R_{m/100\,000/t} / 1,9$	$f = R_{p0,2/t_{Test}} / 1,33$
Weld-on ends on cast steel as defined in 6.2	$f = \min (R_{p0,2/t} / 1,5 ; R_{m/20} / 2,4)$ ^a	$f = R_{m/100\,000/t} / 1,5$	$f = R_{p0,2/t_{Test}} / 1,05$
^a The transition zone situated immediately outside the effective length l_0 or l_1 may be calculated with this higher nominal design strength if the length of the transition zone $\geq 3 \cdot e_c$, however = 50 mm min. and the angle of the transition $\leq 30^\circ$. ^b For the calculation of the test pressure, EN 12266-1 or EN 12266-2 shall be used.			

A1

A1 For the selection of the material, the relevant requirements outlined in EN 16668 shall be applied. When using shell materials conforming a minimum rupture elongation of $\geq 14\%$ and a minimum impact energy measured on a Charpy-V-notch impact test specimen of $\geq 27\text{ J}$, the nominal design stresses (allowable stresses) shall be calculated in accordance with Table 2. If a shell material is considered which satisfies lower elongation values and/or lower values for a Charpy-V-notch impact test, appropriate measures shall be taken to compensate for these lower values and the specific requirements shall be verifiable. **A1**

A1

NOTE The nominal design stresses of this clause are in accordance with the European Legislation for Pressure Equipment. The term “nominal design stress” means the “permissible general membrane stress” in the context of this European Legislation for Pressure Equipment. **A1**

6.2 Steels and cast steels other than defined in 6.3, 6.4 or 6.5

The maximum value of the nominal design stress for normal operating load cases f_d shall not exceed the smaller of the following two values:

- the yield strength $R_{eH/t}$ or 0,2 % proof strength $R_{p0,2/t}$ at calculation temperature, as given in the material standard, divided by the safety factor $SF = 1,5$. For austenitic steels and cast steels with a rupture elongation less than 30 % and with a relationship at 20 °C between proof and tensile strength less than or equal 0,5 the 1,0 % proof strength $R_{p1,0/t}$ can be used, divided by the safety factor $SF = 1,5$;
- the minimum tensile strength R_m at 20 °C as given in the material standard, divided by the safety factor $SF = 2,4$.

6.3 Austenitic steel and austenitic cast steel with a minimum rupture elongation > 30 %

The maximum value of the nominal design stress for normal operating load cases f_d shall not exceed the 1,0 % proof strength $R_{p1,0/t}$ at calculation temperature, as given in the material standard, divided by the safety factor $SF = 1,5$.

6.4 Austenitic steel and austenitic cast steel with a minimum rupture elongation > 35 %

The maximum value of the nominal design stress for normal operating load cases f_d shall not exceed the greater of the following two values:

- a) the 1,0 % proof strength $R_{p1,0/t}$ at calculation temperature, as given in the material standard, divided by the safety factor $SF = 1,5$;
- b) the smaller of the two values:
 - 1) the 1,0 % proof strength $R_{p1,0/t}$ at calculation temperature, as given in the material standard, divided by the safety factor $SF = 1,2$;
 - 2) the minimum tensile strength $R_{m/t}$ at calculation temperature divided by the safety factor $SF = 3,0$.

6.5 Ferritic and martensitic cast steel

The maximum value of the nominal design stress for normal operating load cases f_d shall not exceed the smaller of the following two values:

- the yield strength $R_{eH/t}$ or 0,2 % proof strength $R_{p0,2/t}$ at calculation temperature, as given in the material standard, divided by the safety factor $SF = 1,9$;
- the minimum tensile strength R_m at 20 °C as given in the material standard, divided by the safety factor $SF = 3,0$.

6.6 Creep conditions

The maximum value of the nominal design stress for normal operating load cases shall not exceed the average creep rupture strength at calculation temperature $R_{m/T/t}$ divided by the safety factor $SF = 1,5$ for the $T = 100\,000$ h value.

The nominal design stress calculated in 6.2 to 6.5 shall be compared with the nominal design stress calculated in this clause and the lower value shall be used.

For cast steel defined in 6.5 the safety factor $SF = 1,9$ for the $T = 100\,000$ h value.

For limited operating times and in certain justified cases, creep rupture strength values for shorter times may be used for calculations but not less than $T = 10\,000$ h.

7 Calculation methods for the wall thickness of valve bodies

7.1 General

Valve bodies are considered to be hollow bodies penetrating each other with different angles, i.e. basic bodies with branches.

Basic bodies and branches can be tubes, balls or conical hollow parts with cylindrical, spherical, elliptical or rectangular cross-sections.

In special cases the body consists only of a basic body.

The basic body-part is the part of the body with the larger diameter or cross-section, with the symbol d_0 . For the branches, the symbols are for example, d_1 , d_2 .

It follows that: $d_0 \geq d_1$; $b_2 \geq d_1$, see Figure 9 a) and Figure 9 b).

For the calculation of the surface-comparison, the completed wall thickness shall apply, c_1 and c_2 shall be stripped from the side in contact with the operating medium according to Figure 1 b).

ⓘ The calculation needs two steps:

- the calculation of the wall thickness of the basic body and the branches outside of the intersection or crotch area, see 7.2;
- the calculation of the wall thickness in the crotch area, see 7.3.

A check of the wall thickness of the crotch area is necessary by considering the equilibrium of forces, see 7.3. ⓘ

7.2 Wall thickness of bodies and branches outside crotch area

7.2.1 General

Outside the intersection or crotch area means that the calculated hollow body is without openings or cutaways in this zone (e.g. a smooth tube).

The welding factor k_c in the following formulae is a calculation factor dependent on the level of destructive and non-destructive testing to which the weld or series of welds is subject.

ⓘ The values of the welding factor k_c shall not exceed:

- 1 for equipment subject to destructive and non-destructive testing which confirms that the whole series of joints show no significant imperfections;
- 0,85 for equipment subject to random non-destructive testing;
- 0,7 for equipment not subject to non-destructive testing other than visual inspection. ⓘ

All the calculated wall thicknesses are wall thicknesses excluding allowances.

- d_i = inside diameter
- r_i = inside radius
- d_o = outside diameter
- r_o = outside radius

7.2.2 Cylindrical bodies or branches

$$d_o / d_i \leq 1,7$$

If this condition is not met, the procedure shall be according to 7.4.5, Figure 20.

$$e_c = \frac{d_i \cdot p}{(2 \cdot f - p) \cdot k_c} \quad (7)$$

or

$$e_c = \frac{d_o \cdot p}{(2 \cdot f - p) \cdot k_c + 2 \cdot p} \quad (8)$$

$$d_o / d_i > 1,7$$

$$e_c = \frac{d_i}{2} \left(\sqrt{\frac{f \cdot k_c + p}{f \cdot k_c - p}} - 1 \right) \quad (9)$$

or

$$e_c = \frac{d_o}{2} \left(1 - \sqrt{\frac{f \cdot k_c - p}{f \cdot k_c + p}} \right) \quad (10)$$

Ⓐ Formulae (7) and (8) respectively (9) and (10) are equivalent when $d_i = d_o - 2 \cdot e_c$. Ⓐ

7.2.3 Spherical bodies or branches

$$d_o / d_i \leq 1,2$$

$$e_c = \frac{r_i \cdot p}{(2 \cdot f - p) \cdot k_c} \quad (11)$$

or

$$e_c = \frac{r_o \cdot p}{(2 \cdot f - p) \cdot k_c + p} \quad (12)$$

$$1,2 < d_o / d_i \leq 1,5$$

$$e_c = r_i \cdot \left[\sqrt{1 + \frac{2 \cdot p}{(2 \cdot f - p) \cdot k_c}} - 1 \right] \quad (13)$$

or

$$e_c = r_o \cdot \frac{\sqrt{1 + \frac{2 \cdot p}{(2 \cdot f - p) \cdot k_c}} - 1}{\sqrt{1 + \frac{2 \cdot p}{(2 \cdot f - p) \cdot k_c}}} \quad (14)$$

Ⓐ Formulae (11) and (12) respectively (13) and (14) are equivalent when $r_i = r_o - e_c$. Ⓐ

7.2.4 Conical bodies or branches

$$e_a / d_o > 0,005 \quad (15)$$

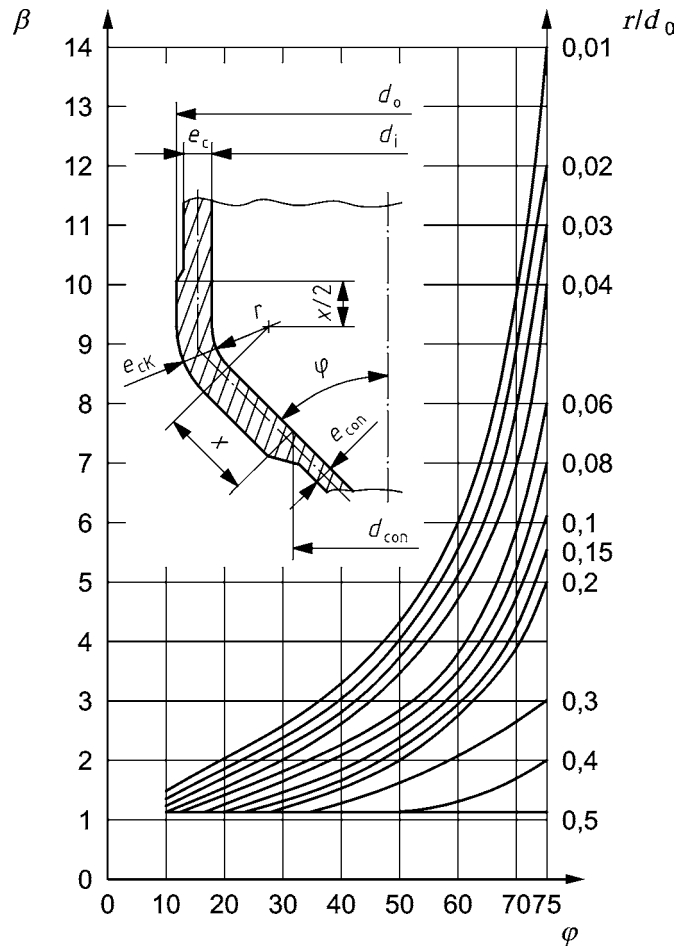


Figure 2 — Cone calculation coefficient

$$e_{\text{con}} = \frac{p \cdot d_{\text{con}}}{(2 \cdot f - p) \cdot k_c} \cdot \frac{1}{\cos(\varphi)} \quad (16)$$

$$d_{\text{con}} = d_o - 2(e_{\text{cK}} + r(1 - \cos \varphi) + x \sin \varphi) \quad (17)$$

Wall thickness in the knuckle or in a corner weld:

$$e_{\text{cK}} = \frac{d_o \cdot p \cdot \beta}{4 \cdot f \cdot k_c} \quad (18)$$

e_{cK} is also required in the zone x and $\frac{x}{2}$

$$x = \sqrt{d_o \cdot e_{\text{ac}}} \quad (19)$$

$$e_{\text{ac}} \leq e_a - c_1 - c_2 \quad (20)$$

k_c is now a factor for a weld situated in the knuckle or in the influence zone of the knuckle running in meridian direction.

In cases of corner welds which are admissible for angles $\varphi \leq 30^\circ$, $e_{\text{cK}} \leq 20$ mm and double joint weld, β shall be read off Figure 2 by taking for the ratio $r / d_o = 0,01$.

For corner welds, diameter d_{con} is equal to the inside diameter of the wide end.

In case of flat cones with a knuckle and $\varphi > 70^\circ$:

$$e_{\text{con}} = 0,3 \cdot (d_o - r) \cdot \frac{\varphi}{90} \cdot \sqrt{\frac{p}{f \cdot k_c}}$$

(21)

Table 3 — Cone calculation coefficient

Angle φ	β for the ratio r / d_o												cos φ
	0,01	0,02	0,03	0,04	0,06	0,08	0,10	0,15	0,20	0,30	0,40	0,50	
10	1,4	1,3	1,2	1,2	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	0,985
20	2,0	1,8	1,7	1,6	1,4	1,3	1,2	1,1	1,1	1,1	1,1	1,1	0,940
30	2,7	2,4	2,2	2,0	1,8	1,7	1,6	1,4	1,3	1,1	1,1	1,1	0,866
45	4,1	3,7	3,3	3,0	2,6	2,4	2,2	1,9	1,8	1,4	1,1	1,1	0,707
60	6,4	5,7	5,1	4,7	4,0	3,5	3,2	2,8	2,5	2,0	1,4	1,1	0,500
75	13,6	11,7	10,7	9,5	7,7	7,0	6,3	5,4	4,8	3,1	2,0	1,1	0,259

If two conical shells with different taper angles are joined together, the angle φ arising between the conical portion with the more pronounced taper and that with the less pronounced taper shall be determined for the value of β .

7.2.5 Bodies or branches with oval or rectangular cross-sections

7.2.5.1 General

The following calculation rules apply to oval or rectangular valve bodies with a wall thickness/diameter ratio $e_{ac} / b_2 \leq 0,15$ and a ratio $b_1 / b_2 \geq 0,4$.

For ratios $e_{ac} / b_2 \leq 0,06$, these rules are applicable for $b_1 / b_2 \geq 0,25$ (see Bibliography, reference [3]).

In the case of oval shaped cross-sections (see Figure 3 a) and Figure 3 b)) and of rectangular shapes with or without radiusing of the corners (see Figure 3 c) and Figure 3 d)), the additional bending stresses, which arise in the walls or in the corners, shall be taken into consideration.

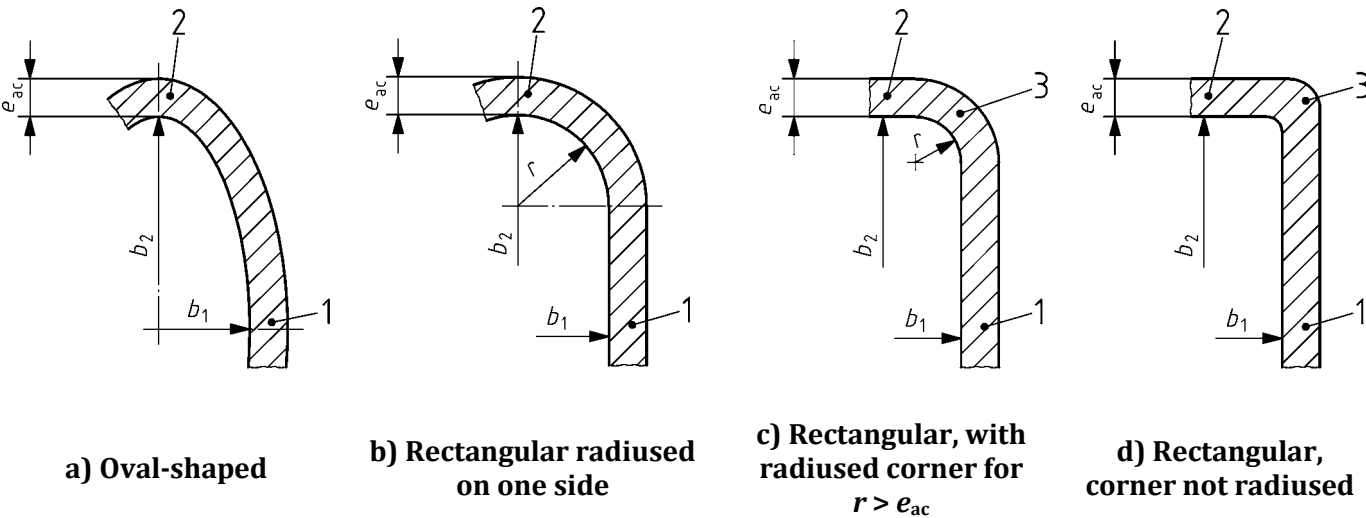


Figure 3 — Cross-sections

The theoretical minimum wall thickness of such bodies under internal pressure stressing can be calculated by means of the formula below, without any allowance for edge effects:

Ⓐ

$$e_{cn} = \frac{p \cdot b_2}{2 \cdot f \cdot k_c} \cdot \sqrt{B_{0n}^2 + \frac{4 \cdot f \cdot k_c}{p} \cdot B_n} \quad (22)$$

Ⓐ

Ⓐ

NOTE 1 e_{c0} is the maximum of e_{cn} with $n = 1, 2$ and 3 . Ⓐ

The calculation shall be carried out in respect of locations 1 and 2 (designated in Figure 3 a) and Figure 3 b) for oval-shaped cross-sections), and in respect of locations 1 and 3 (designated in Figure 3 c) and Figure 3 d) for rectangular cross-sections), because the bending moments, which have a predominant influence on the strength behaviour, exhibit their maximum values at the above locations. In exceptional cases (e.g. a low b_1 / b_2 ratio) a check calculation for location 2 may also be necessary for square cross-sections.

The calculation coefficient B_{0n} , which is a function of the normal forces, shall be:

$$B_{01} = b_1 / b_2 \text{ for location 1} \quad (23)$$

$$B_{02} = 1 \text{ for location 2} \quad (24)$$

For Location 3, B_{03} can be obtained from Figure 4 as a function of the sides ratio b_1 / b_2 and of the corner radii ratio r / b_2 , or it can be calculated in accordance with Formula (25):

$$B_{03} = \left[1 - \frac{2r}{b_2} (1 - \sin \varphi_k) \right] \sin \varphi_k + \left[\frac{b_1}{b_2} - \frac{2r}{b_2} (1 - \cos \varphi_k) \right] \cos \varphi_k \quad (25)$$

$$\text{with } \tan \varphi_k = \frac{1 - 2r/b_2}{\frac{b_1}{b_2} - \frac{2r}{b_2}} \quad (26)$$

NOTE Ⓐ 2 Ⓐ In case of Figure 3 b) ($b_1 = 2r$): $\varphi_k = 90^\circ$ and $B_{03} = 1$.

7.2.5.2 Oval-shaped cross sections

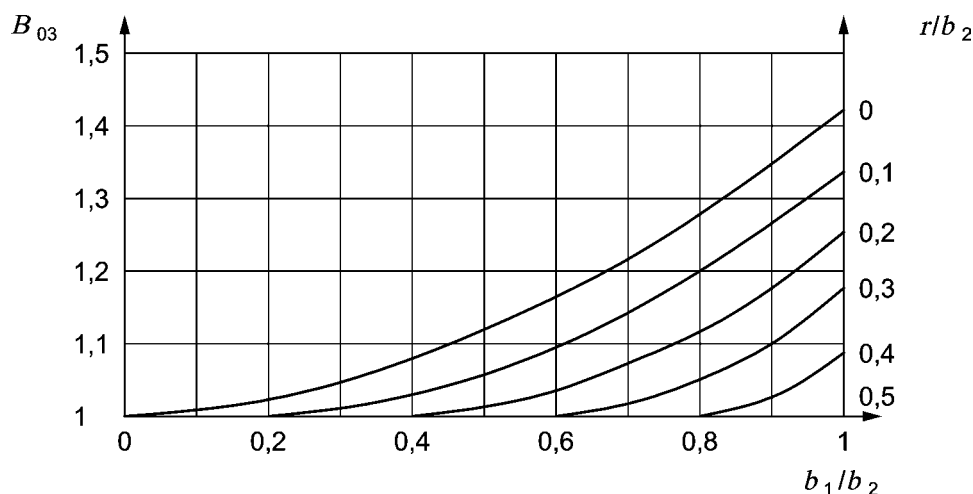


Figure 4 — Calculation coefficient B_{03} for location 3

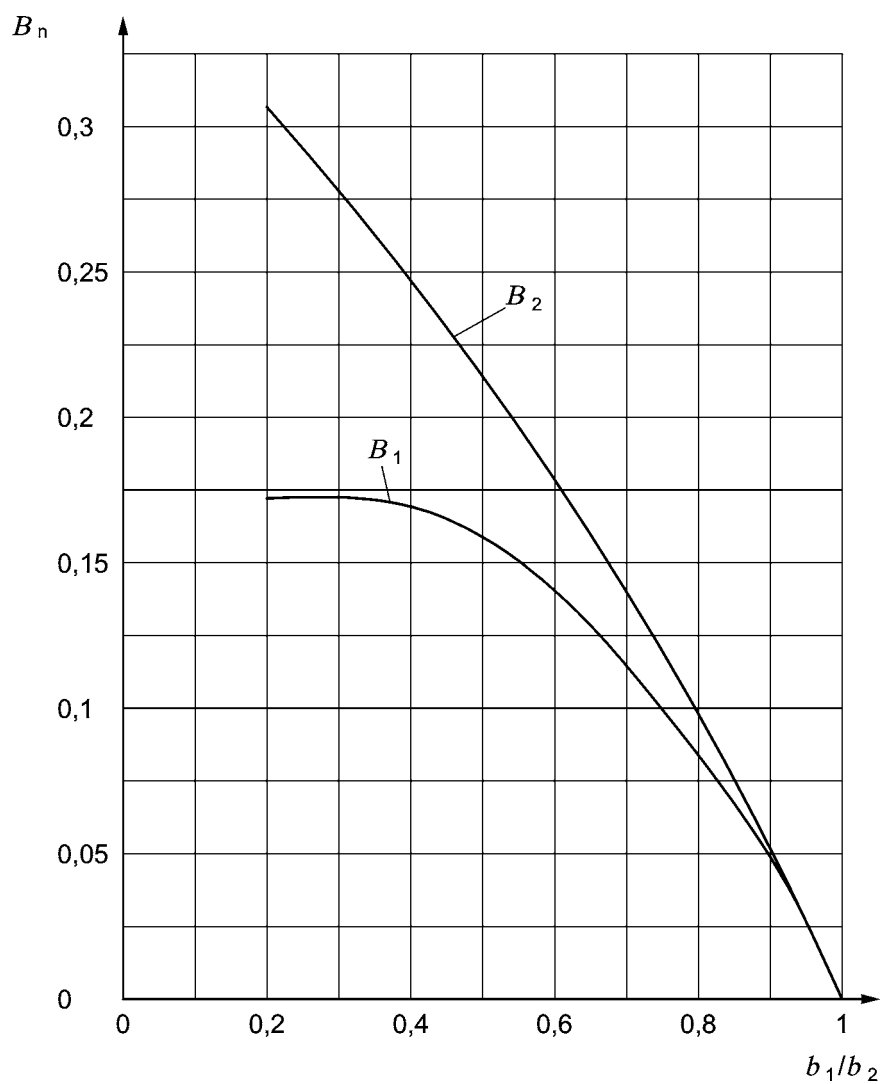


Figure 5 — Calculation coefficient B_n for oval-shaped cross-sections

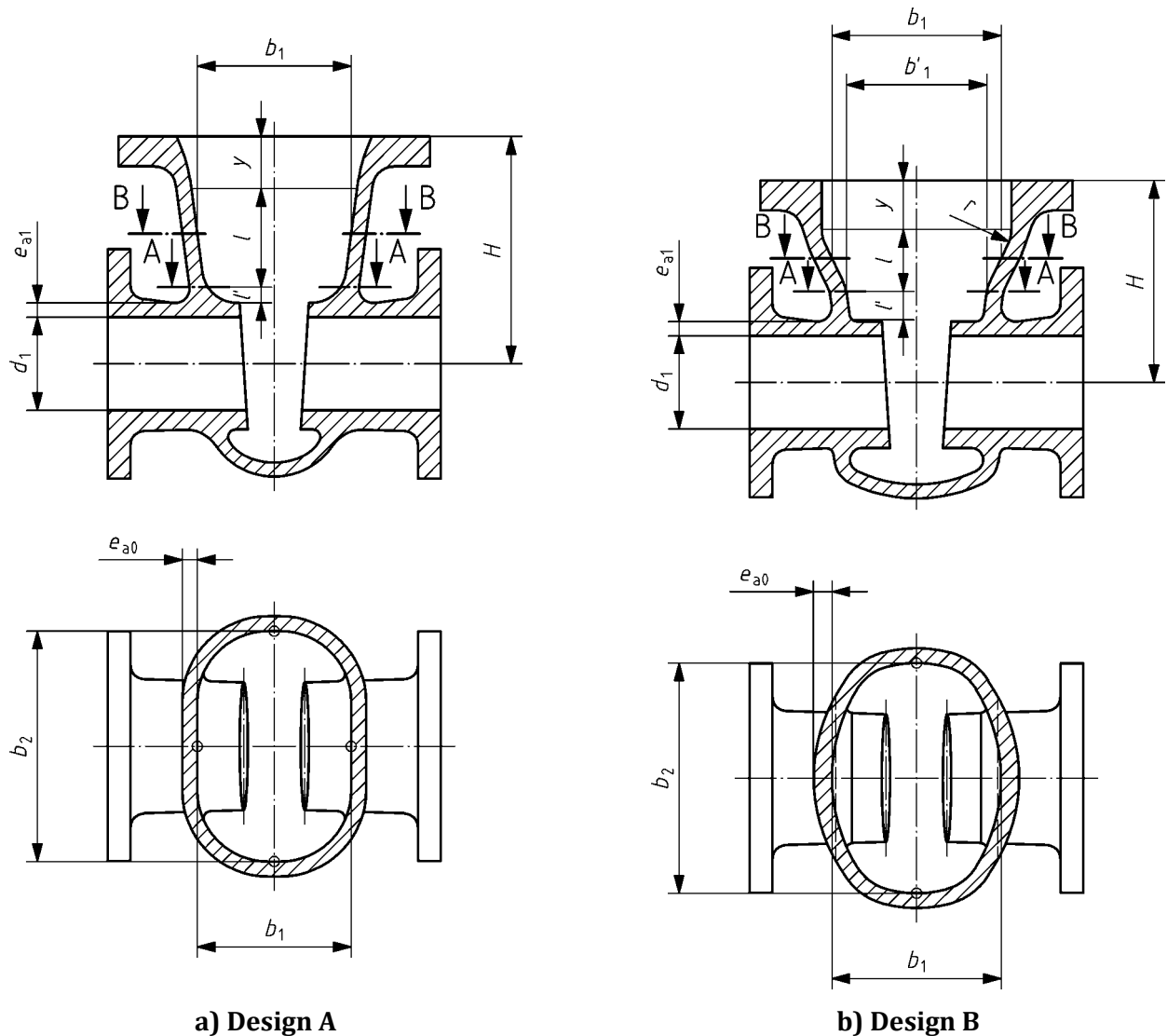


Figure 6 — Examples of changes in cross-section B - B in oval basic bodies

The calculation coefficients B_n which are dependent on the bending moments plotted in Figure 5 as a function of ratio b_1 / b_2 for oval-shaped cross-sections for locations 1 and 2. These curves correspond to the formulae below:

$$B_1 = \frac{1 - k_E^2}{6} \cdot \frac{K'}{E'} - \frac{1 - 2k_E^2}{6} \quad (27)$$

$$B_2 = \frac{1 + k_E^2}{6} - \frac{1 - k_E^2}{6} \cdot \frac{K'}{E'} \quad (28)$$

$$\text{with } k_E^2 = 1 - \left(\frac{b_1}{b_2} \right)^2 \quad (29)$$

These values result from the analytical solution of the formulae of equilibrium for a curved shaped beam. The values of K' , E' , are explained in Reference [4] of the Bibliography.

For determination of the calculation coefficients the following approximation formulae may also be used for $b_1 / b_2 \geq 0,5$:

$$B_1 = \left(1 - \frac{b_1}{b_2}\right) \left(0,625 - 0,435 \cdot \sqrt{1 - \frac{b_1}{b_2}}\right) \quad (30)$$

$$B_2 = \left(1 - \frac{b_1}{b_2}\right) \left[0,5 - 0,125 \cdot \left(1 - \frac{b_1}{b_2}\right)\right] \quad (31)$$

The calculation coefficients are also valid for changes in cross-section in oval basic bodies (e.g. for gate valves in accordance with Figure 6, design A and design B), on these valves, the lateral length b_1 increases from the apex zone of the entry nozzle (flattened oval) to value length b_2 (circular shape) over length l . In this case, value b_1 in cross-section B-B up to $l/2$ is determining for the determination of B_n . l is obtained from:

$$l = H - y - \left(\frac{d_1}{2} + e_{ac1}\right) - l' \quad (32)$$

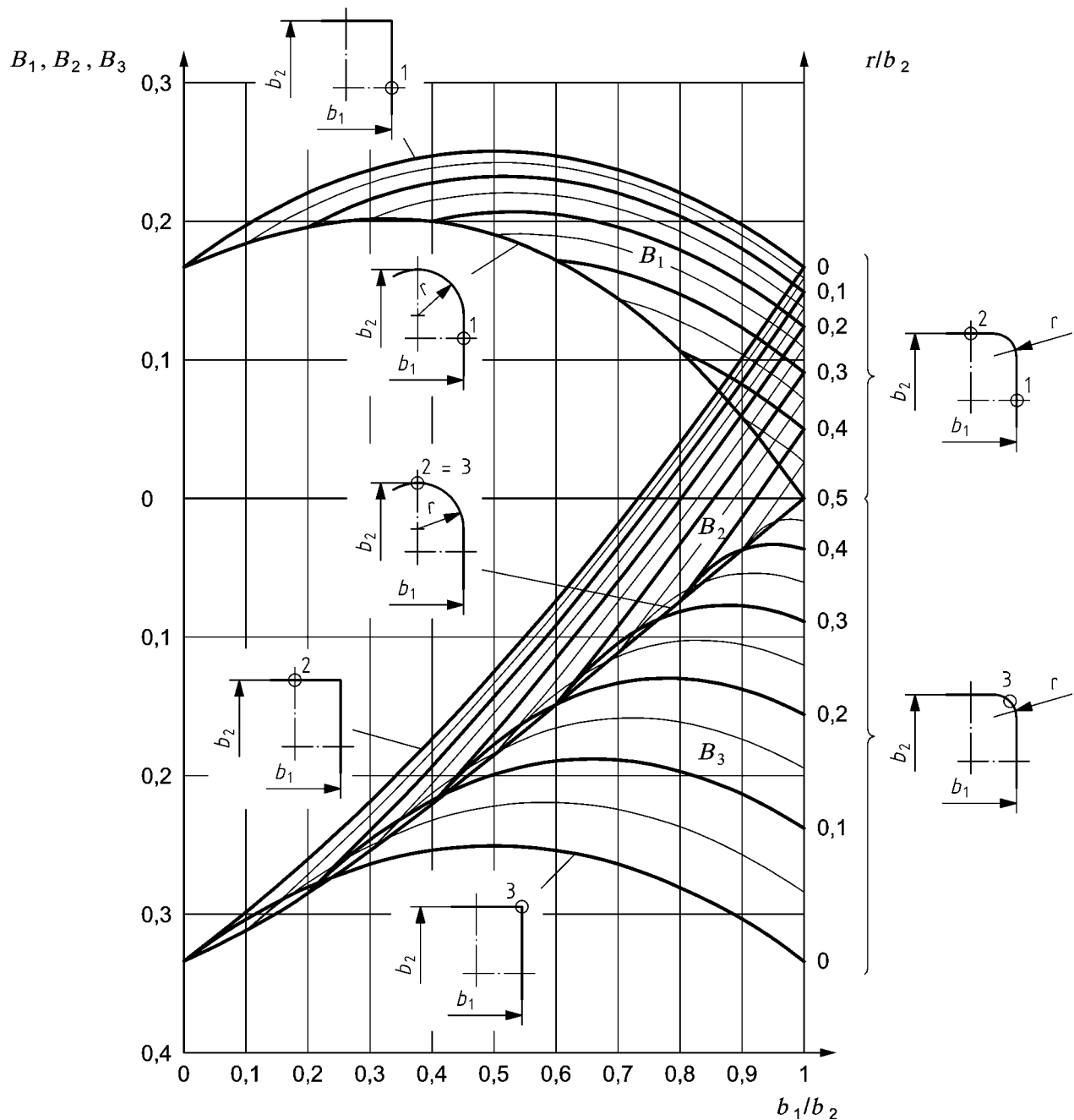
and length l' which is influenced by the entry nozzle is obtained from:

$$l' = 1,25 \cdot \sqrt{d'_m \cdot e_{ac0}} \quad (33)$$

$$\text{with } d'_m = \frac{b'_1 + b_2}{2} \quad (34)$$

where b'_1 and b_2 shall be determined at the cross-section A-A at a distance l' from the entry nozzle. The wall thickness at that location is e_{a0} .

7.2.5.3 Rectangular cross sections

Figure 7 — Calculation coefficient B_n for rectangular cross-sections

The calculation coefficients B_n for rectangular cross-sections are plotted in Figure 7 as a function of the ratio b_1 / b_2 for locations 1 to 3 under consideration. The calculation coefficients B_n shall always be entered in Formula (22) as positive values.

The curves for B_n can also be determined analytically with the aid of the following formulae:

$$B_1 = \frac{1}{6} \cdot \frac{1 - 2 \cdot \left(\frac{b_1}{b_2}\right)^3 + 3 \cdot \left(\frac{b_1}{b_2}\right) - 3 \cdot \frac{2r}{b_2} \cdot \left(2 - \frac{\pi}{2}\right) - 3 \cdot \left(\frac{2r}{b_2}\right)^2 \cdot \left(1 + \frac{b_1}{b_2}\right) \cdot (\pi - 3) + \left(\frac{2r}{b_2}\right)^3 \cdot \left(\frac{9}{2} \pi - 14\right)}{1 + \frac{b_1}{b_2} - \frac{2r}{b_2} \cdot \left(2 - \frac{\pi}{2}\right)} \quad (35)$$

$$B_2 = B_1 - \frac{1}{2} \left[1 - \left(\frac{b_1}{b_2} \right)^2 \right] \quad (36)$$

$$B_3 = \frac{1}{2} \left[1 - 2 \frac{2r}{b_2} \cdot (1 - \sin \varphi_k) + \frac{4r^2}{b_2^2} \cdot (3 - 2 \sin \varphi_k - 2 \cos \varphi_k) - 2 \cdot \frac{b_1}{b_2} \cdot \frac{2r}{b_2} \cdot (1 - \cos \varphi_k) \right] - B_1 \quad (37)$$

where Formula (26) shall apply to the angle of the maximum moment.

For short valve bodies (e.g. design A or B of Figure 6) with the undisturbed length l corresponding to the calculation geometry, the supporting action of the components adjoining the ends (e.g. flanges, bottoms, covers) can be taken into account in the calculation. In this case the required minimum wall thickness in accordance with Formula (22) becomes:

$$e_c = e_{c0} \cdot k \quad (38)$$

[A1] The correction factor k is obtained from Formula (39) below, by analogy to the damping behaviour of the stresses in cylindrical shells, taking into consideration the experimental investigation results on non-circular casings: **[A1]**

$$k = 0,48 \cdot \sqrt[3]{\frac{l^2}{d_m \cdot e_{c0}}} \quad (39)$$

$$\text{with } 0,6 \leq k \leq 1 \quad (40)$$

This function is plotted in Figure 8 as a function of $l^2 / d_m \cdot e_{c0}$.

d_m shall be entered in the formula at a value $d_m = (b_1 + b_2) / 2$, and e_{c0} corresponds to Formula (22). In the case of changes in cross-section over length l , (e.g. in accordance with Figure 6, design A or B), dimensions b_1 and b_2 shall be taken at cross-section B-B (for $l / 2$). Local deviations from the shape of the casing body, whether they be of convex or concave nature, can as a general rule be ignored.

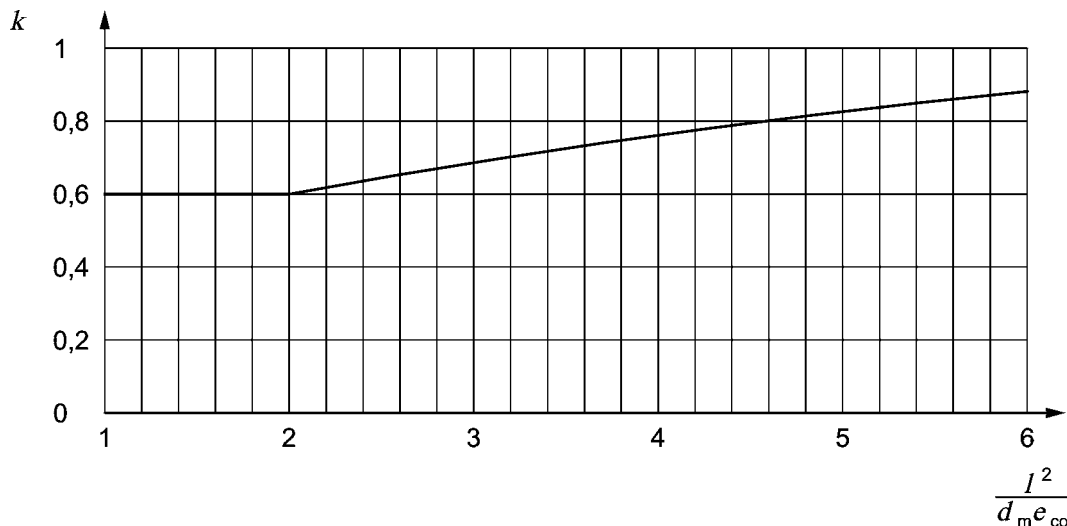


Figure 8 — Correction factor k for short casing bodies

The strength conditions can be deemed to be satisfied if the required wall thickness is attained locally, on the precondition that wall thickness transitions are gradual and gentle.

Should a finished design not meet the strength condition in accordance with Formula (22) or Formula (38), a local reinforcement, e.g. in the form of ribs, may be provided, and this will require a separate verification of the strength for the design.

7.3 Wall thickness in the crotch area

A direct calculation of the wall thickness in this area is not possible.

As a first step a wall thickness in this area shall be assumed; this assumption can also be derived from the wall thickness calculation in 7.2.2.

This assumed wall thickness shall be checked by considering the equilibrium of forces. The crotch area here is limited by the distances l , see Figures 9 to 20.

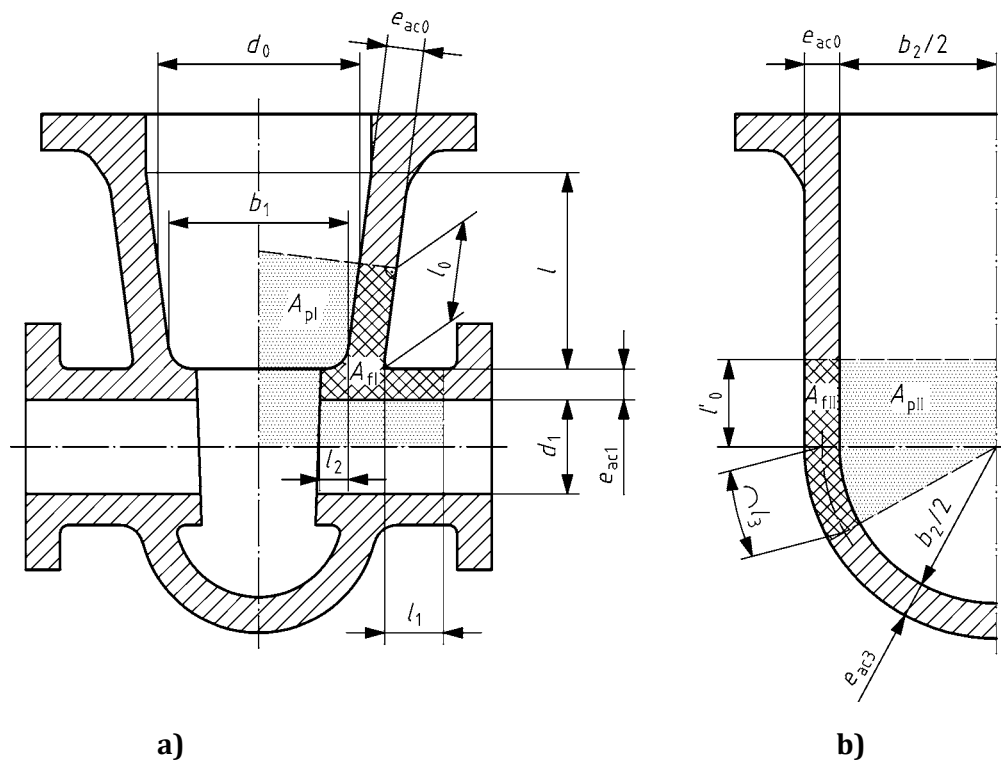


Figure 9 — Calculation procedure in the crotch area

ⓘ According to Figure 9 the equilibrium of forces corresponds to Formula (41):

$$p \cdot A_p = f \cdot A_f \cdot k_c \quad (41)$$

where

- A_p I or A_p II is the pressure loading area;
- A_f I or A_f II is the metal cross-sectional area effective as compensation;
- k_c is the welding factor.

The areas A_p and A_f are determined by the centrelines of the bonnet and the flow passage and by the distances l , see Figure 9 to Figure 20. ⓘ

For the allowable value of f , see Clause 6.

Table 4 shows the formulae for f , depending on the body shape.

Condition: e_{a0} body $\geq e_{a1}$ branches, if this is not possible: e_{a1} branches = e_{a0} body in the whole A_f region including the distances l .

Table 4 — Calculation formulae

circular cross-section	Diameter ratio $d_1 / d_0 < 0,7$ $p \cdot \left[\frac{A_{pI}}{A_{fI} \cdot k_c} + \frac{1}{2} \right] \leq f$	(42)
non-circular cross-section	$p \cdot \left[\frac{A_{pI}}{A_{fI} \cdot k_c} + \frac{1}{2} \right] \leq f / 1,2$	(43)
	$p \cdot \left[\frac{A_{pII}}{A_{fII} \cdot k_c} + \frac{1}{2} \right] \leq f / 1,2$	(44)
circular cross-section	Diameter ratio $d_1 / d_0 \geq 0,7$ $p \cdot \left[\frac{A_{pI}}{A_{fI} \cdot k_c} + \frac{1}{2} \right] \leq f$	(45)
	$p \cdot \left[\frac{A_{pII}}{A_{fII} \cdot k_c} + \frac{1}{2} \right] \leq f$	(46)
circular cross-section	Diameter ratio $d_1 / d_0 \geq 0,7$ and $e_{a1} / e_{a0} < d_1 / d_0$ — Formula (45) — Formula (46) — additional for Section II: (Figure 9b) $p \cdot \left[\frac{d_0 + e_{ac0}}{2 \cdot e_{ac0}} + 0,2 \cdot \frac{d_1 + e_{ac1}}{e_{ac1}} \cdot \sqrt{\frac{d_0 + e_{ac0}}{e_{ac0}}} \right] \leq 1,5 \cdot f$	(47)
non-circular cross-section	— Formula (43) — Formula (44) — additional for Section II: $p \cdot \left[\frac{b_2 + e_{ac0}}{2 \cdot e_{ac0}} + 0,25 \cdot \frac{d_1 + e_{ac1}}{e_{ac1}} \cdot \sqrt{\frac{b_2 + e_{ac0}}{e_{ac0}}} \right] \leq 1,5 \cdot f$	(48)

7.4 Examples of pressure-loaded areas A_p and metallic cross-sectional areas A_f

7.4.1 General

The pressure-containing areas A_p and the effective cross-sectional areas A_f shall be determined by calculation or from CAD drawings. The effective lengths shall be determined from the following relations.

For determination of the pressure-containing area A_p , the limitation inside the valve body is circumscribed by the geometrical centrelines of the basic body and the branch (see Figures 10 to 20). Reduced seats such as shown in Figure 10 shall not be taken into account. Due to the complicated geometrical shapes of bodies in accordance with Figures 10 to 14, the effective lengths l_0 and l_1 are indicated in the drawing as running parallel to the outside contour of the casing starting from the tangent point of the normal to the contour to the circle formed by the transition radius between the basic body and the branch (see examples in Figure 10). For small transition radii, it is sufficient to start from the intersection of the linearly extended contours of the bodies (see Figure 14). At the terminal point, the perpendicular is drawn to the relevant centreline.

Any material of the basic body or branch protruding inwards can be included in the effective cross-sectional area A_f up to a maximum length of $l_0 / 2$ or $l_1 / 2$ with the limitation thus determined representing also the boundary of the pressure-loaded area (see for example Figures 9, 10 and 17). For penetration welds which can be tested, welded-in seat rings inside the valve body can be included in the calculation.

Abrupt wall thickness transitions shall be avoided (chamfer angle $\leq 30^\circ$).

For branch/valve body diameter ratios $d_1 / d_0 > 0,8$, the factor preceding the square root shall be 1 in all subsequent formulae for effective lengths.

For all valve body shapes in cross-section II (Figure 9 b)) it is:

$$l'_0 = 1,25 \cdot \sqrt{(b_2 + e_{ac0}) \cdot e_{ac0}} \quad (49)$$

$$l_3 = \sqrt{(b_2 + e_{ac3}) \cdot e_{ac3}} \quad (50)$$

7.4.2 Cylindrical valve bodies

The effective lengths for cylindrical bodies e.g. in accordance with Figure 10 are:

$$l_0 = \sqrt{(d_0 + e_{ac0}) \cdot e_{ac0}} \quad (51)$$

$$l_1 = 1,25 \cdot \sqrt{(d_1 + e_{ac1}) \cdot e_{ac1}} \quad (52)$$

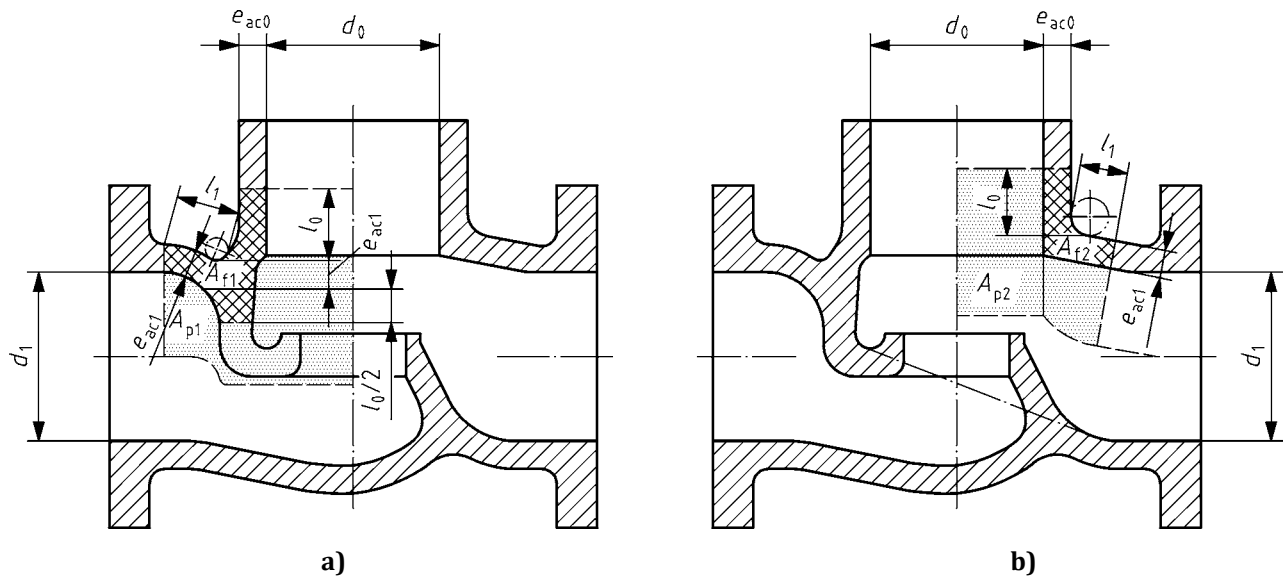


Figure 10 — Cylindrical valve body