

Shell boilers —

Part 3: Design and calculation for pressure parts

The European Standard EN 12953-3:2002 has the status of a
British Standard

ICS 27.060.30; 27.100

National foreword

This British Standard is the official English language version of EN 12953-3:2002. It partially supersedes BS 2790:1992 which will be withdrawn on publication of BS EN 12953 Parts 1, 2, 3, 4, 5, 6, 8 and 9.

When the reference to this European Standard has been published in the Official Journal of the European Communities (OJ), compliance with it will confer a presumption of conformity with the essential requirements covered by the standard in respect of the Pressure Equipment Directive.

The UK participation in its preparation was entrusted to Technical Committee PVE/16, Shell boilers, which has the responsibility to:

- aid enquirers to understand the text;
- present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;
- monitor related international and European developments and promulgate them in the UK.

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

Cross-references

The British Standards which implement international or European publications referred to in this document may be found in the *BSI Catalogue* under the section entitled “International Standards Correspondence Index”, or by using the “Search” facility of the *BSI Electronic Catalogue* or of British Standards Online.

This publication does not purport to include all the necessary provisions of a contract. Users of this publication are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

This British Standard, having been prepared under the direction of the Engineering Sector Policy and Strategy Committee, was published under the authority of the Standards Policy and Strategy Committee on 14 June 2002

Summary of pages

This document comprises a front cover, an inside front cover, the EN title page, pages 2 to 90, an inside back cover and a back cover.

The BSI copyright date displayed in this document indicates when the document was last issued.

Amendments issued since publication

Amd. No.	Date	Comments

© BSI 14 June 2002

ISBN 0 580 39851 X

English version

Shell boilers - Part 3: Design and calculation for pressure parts

Chaudières à tubes de fumée - Partie 3: Conception et
calcul des parties sous pression

Großwasserraumkessel - Teil 3: Konstruktion und
Berechnung für drucktragende Teile

This European Standard was approved by CEN on 15 May 2002.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Management Centre or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the Management Centre has the same status as the official versions.

CEN members are the national standards bodies of Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Malta, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.



EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

Management Centre: rue de Stassart, 36 B-1050 Brussels

Contents

	Page
Foreword	4
1 Scope	5
2 Normative references	5
3 Terms and definitions	5
4 Symbols and abbreviations	5
5 General	5
5.1 Boilers	5
5.2 Hot-water generators	5
5.3 Design of principal welds	6
5.4 Thermal design of furnaces tubes	6
5.5 Dimensions of pressure parts	7
5.6 Establishment of pressures	7
5.7 Allowances	8
6 Calculation temperature and nominal design stress	9
6.1 Calculation temperature	9
6.2 Nominal design stress	10
7 Cylindrical shells under internal pressure	10
7.1 Shell thickness	10
7.2 Basic calculation	11
7.3 Boiler support	11
7.4 Reinforcing pads	11
8 Openings and branches in cylindrical shells	11
8.1 General	11
8.2 Efficiency factor, calculation by way of approximation and maximum diameter of an unreinforced opening	17
8.3 Design of openings and branches in cylindrical shells (efficiency and reinforcement)	19
9 Ends	26
9.1 Unstayed dished heads without openings	26
9.2 Flat unstayed removable closures	28
9.3 Flange connections	30
10 Supported flat plates, stays and stiffeners	30
10.1 Breathing spaces for flat plates	30
10.2 Stayed flat surfaces	32
11 Design of isolated openings in shell boiler flat end plates	52
11.1 Unreinforced isolated openings	52
11.2 Branch openings	52
11.3 Manholes, headholes and handholes	53
12 Unpierced tubes and tube plates	54
12.1 Thickness of straight tubes subject to external pressure	54
12.2 Thickness of straight tubes subject to internal pressure	55
12.3 Wall thickness and ovality of elbows and tube bends	55
12.4 Stay tubes	56
12.5 Smoke tubes	58
12.6 Pitch of tubes	58
12.7 Thickness of the tube plates within tube nests	58
13 Furnaces tubes, furnace tube components and reversal chambers of cylindrical form subject to external pressure	58
13.1 Furnaces tubes	58
13.2 Calculation length of composite furnaces tubes	60
13.3 Tolerances of furnaces tubes	61
13.4 Stiffeners	61

14 Access and inspection openings.....64

14.1 General requirements.....64

14.2 Types and minimum dimensions of access and inspection openings.....64

14.3 Minimum gasket bearing width and clearance for access and inspection doors 67

14.4 Access and inspection openings in flat plates.....68

14.5 Inspection requirements 68

14.6 Requirements for entry into boilers with a shell outside diameter greater than 1 400 mm 69

14.7 Accessibility and arrangement of entry and inspection openings.....69

Annex A (normative) Calculation of tube plate temperatures 70

Annex B (informative) Calculation form for "Walker"-type reverse curve sections or corrugations.....87

Annex ZA (informative) Clauses of this European Standard addressing essential requirements or other provisions of the Pressure Equipment Directive 89

Bibliography 90

Foreword

This document (EN 12953-3:2002) has been prepared by Technical Committee CEN/TC 269 "Shell and water-tube boilers", the secretariat of which is held by DIN.

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

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

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 November 2002, and conflicting national standards shall be withdrawn at the latest by November 2002.

This European Standard EN 12953 concerning shell boilers consists of the following Parts:

- *Part 1: General.*
- *Part 2: Materials for pressure parts of boilers and accessories.*
- *Part 3: Design and calculation for pressure parts.*
- *Part 4: Workmanship and construction of pressure parts of the boiler.*
- *Part 5: Inspection during construction, documentation and marking of pressure parts of the boiler.*
- *Part 6: Requirements for equipment for the boiler.*
- *Part 7: Requirements for firing systems for liquid and gaseous fuels for the boiler.*
- *Part 8: Requirements for safeguards against excessive pressure.*
- *Part 9: Requirements for limiting devices, and of the boiler and accessories.*
- *Part 10: Requirements for boiler feedwater and boiler water quality.*
- *Part 11: Acceptance tests.*
- *Part 12: Requirements for firing systems for solid fuels for the boiler.*
- *Part 13: Operational Instructions.*

CR 12953-14: Guidelines for the involvement of an inspection body independent of the manufacturer.

Although these Parts can be obtained separately, it should be recognized that the Parts are inter-dependent. As such, the design and manufacture of shell boilers requires the application of more than one Part in order for the requirements of the standard to be satisfactorily fulfilled.

The Annex A of this European Standard is informative.

The Annex B of this European Standard is normative.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Malta, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

1 Scope

This Part of this European Standard specifies requirements for the design and calculation of pressure parts of shell boilers as defined in EN 12953-1.

2 Normative references

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies (including amendments).

EN 12953-1:2001, *Shell boilers — Part 1: General*.

EN 12953-2, *Shell boilers — Part 2: Materials for pressure parts of boilers and accessories*.

EN 12953-4, *Shell boilers — Part 4: Workmanship and construction of pressure parts of the boiler*.

EN 12953-5:2002, *Shell boilers — Part 5: Inspection during construction, documentation and marking of pressure parts of the boiler*.

EN 12953-8, *Shell boilers — Part 8: Requirements for safeguards against excessive pressure*.

prEN 12953-10, *Shell boilers — Part 10: Requirements for boiler feedwater and boiler water quality*.

EN 13445-3, *Unfired pressure vessels - Part 3: Design*.

3 Terms and definitions

For the purposes of this European Standard the terms and definitions given in EN 12953-1 apply.

4 Symbols and abbreviations

For the purposes of this Part of this European Standard, the symbols given in EN 12953-1:2002, Table 4-1 shall apply. Throughout this standard, additional terminology and symbols have been included where necessary to meet the requirements of the specific text concerned. It should also be noted that in some clauses the same additional symbol is used in different formulae to represent different terms. However, in all such cases, the special meaning of each symbol is indicated for each formula.

5 General

5.1 Boilers

The requirements in this standard shall apply to boilers constructed throughout under the conditions specified herein and which are to be operated under normal operating conditions, with feedwater and boiler water in accordance with prEN 12953-10, and under adequate supervision. Where the risk of abnormal working conditions is foreseen, such as severe cyclic service, the design shall be given special consideration.

5.2 Hot-water generators

For directly fired hot-water generators the difference between the outlet temperature and the inlet temperature should not exceed 50 K. If the difference between these two temperatures is greater than 50 K, either internal or external mixing devices shall be used to limit the differential temperature within the boiler to 50 K.

The difference between the saturation temperature corresponding to the maximum working pressure, and the outlet temperature, should not exceed 80 K. If the difference is greater than 80 K, the distances in accordance with 10.1 shall be increased by 50 %. Furthermore the maximum heat input in accordance with Figure 5.4-1 shall be reduced by 20 %.

The inlet water entering the boiler shall not impinge directly on the furnace tube.

5.3 Design of principal welds

The types of weld employed in the design of the boiler shall be in accordance with EN 12953-4. Welds which are subjected to non-destructive examination (NDE) in accordance with the requirements of EN 12953-5 shall be designed so that the required NDE can be carried out.

The value of the weld factor v used in the calculation for the shell thickness shall be either 0,85 or 1 depending on the extent of NDE to be carried out (see 7.2 and EN 12953-5).

5.4 Thermal design of furnaces tubes

In order to ensure safe burner/boiler combinations, the heat input for a given furnace tube inside diameter shall not exceed the value given in Figure 5.4-1. Burners with a fixed firing rate (also called on/off or single stage burners) shall not be used for heat inputs exceeding 1 MW per furnace tube. Combustion shall be completed in the furnace tube.

NOTE Examples 1 and 2 show how Figure 5.4-1 is used.

EXAMPLE 1 Furnace tube inside diameter required for a given heat input

Oil flow: 0,1 kg/s
Net calorific value: 42,9 MJ/kg
Air flow (with air excess 15 %): 1,76 kg/s
Air temperature (with air preheater): 120 °C
Heat input: $4\,290 + 214 = 4\,504$ kW
Furnace tube steel: P295 GH

- a) Minimum plain furnace tube inside diameter: 810 mm
- b) Minimum Fox 150 × 50 (Table 13.1-1) corrugated furnace tube inside diameter: 760 mm.

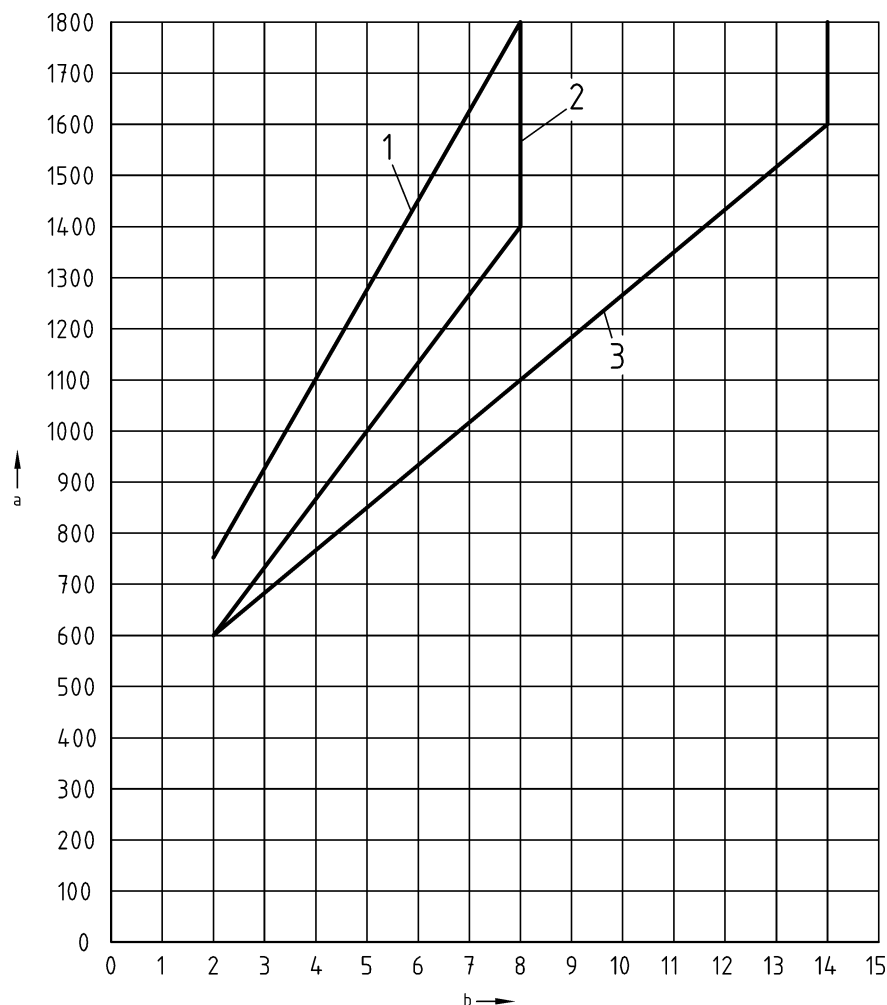
EXAMPLE 2:

Allowable heat input for a given furnace tube inside diameter

- a) Plain furnace tube inside diameter: 1 500 mm
 - P295 GH, oil firing: 12,90 MW
 - P295 GH, gas firing: 16,77 MW
 - P265 GH, oil firing: 8,00 MW
 - P265 GH, gas firing: 10,40 MW
- b) Fox 150 × 50 (Table 13.1-1) corrugated furnace tube inside diameter 1 000 mm
 - P265 GH, gas firing: 7,02 MW.

The length of the refractory should not be larger than one third of the inside furnace tube diameter measured from the end of the burner.

NOTE Attention is drawn to national regulations that for boilers with an inside furnace tube diameter greater than 1 400 mm or a heat input greater than 12 MW a temperature measurement consisting of at least three measurement points in the furnace can be required.



Key

- 1 Coal firing (grate) P 295 GH
- 2 Oil firing P 265 GH
- 3 Oil firing of P 295 GH, P 355 GH

- a Minimum furnace tube inside diameter [mm]
- b Heat input [MW]

NOTE 1 For corrugated furnaces tubes the minimum inside diameter d_i can be reduced by the depth of the corrugation.

NOTE 2 In the case of gas firing the heat input given for oil firing can be increased by 30 %.

NOTE 3 Heat input is the product of the fuel flow rate and the lower calorific value. Air preheating should be taken into account if the air temperature is greater than 100 °C.

Figure 5.4.1 — Relation between heat input and furnace tube inside diameter

5.5 Dimensions of pressure parts

The wall thickness and other dimensions of pressure parts shall be sufficient to withstand the calculation pressure at calculation temperature and shall be determined in accordance with this Part.

5.6 Establishment of pressures

5.6.1 Maximum allowable pressure

The maximum allowable pressure PS is the maximum pressure for which the boiler is designed and shall be measured at the highest point of the shell boiler.

5.6.2 Calculation pressure

The calculation pressure shall be not less than the sum of the maximum allowable pressure and the hydrostatic head. If the latter is less than 3 % of the maximum allowable pressure, the effect of hydrostatic head shall be ignored.

5.6.3 Safety valves set pressure

The safety valve(s) set pressure shall not exceed the maximum allowable pressure (see also EN 12953-8).

5.6.4 Hydrostatic test pressure

The standard hydrostatic test pressure shall be not less than that obtained from the following:

$$p_t = 1,25 p_d \frac{R_{p0,2\ 20}}{R_{p0,2\ t_c}} \quad (5.6-1)$$

or

$$p_t = 1,43 p_d \quad (5.6-2)$$

which ever is the higher;

where

$R_{p0,2\ 20}$ is the minimum value of the yield point at 20 °C.

The value of $R_{p0,2\ t_c}$ shall be taken for the boiler shell or ends at their calculation temperatures.

In the case of boilers with expanded tubes, the values of $p_t = 1,43 p_d$ may be taken.

5.7 Allowances

5.7.1 Allowances for fabrication tolerances

The allowance c_1 is to compensate for negative tolerances, and also any reduction in thickness as a result of the forming process.

5.7.2 Corrosion allowance

For the purpose of design, corrosion allowance c_2 shall also include for erosion and abrasion if these effects are expected to occur.

For components with wall thickness:

> 30 mm and for all flat components, a corrosion allowance of 0 mm may be used;

≤ 30 mm a minimum corrosion allowance of 0,75 mm shall be taken.

In the case of severe corrosion conditions an increased c_2 value shall be chosen accordingly.

6 Calculation temperature and nominal design stress

6.1 Calculation temperature

The calculation temperature t_c shall be the mean metal temperature and shall be determined as specified in a) to e).

- a) For shells, drums and other components not subject to heat transfer, the calculation temperature shall be not less than the saturation temperature corresponding to the maximum allowable pressure or the maximum allowable temperature.
- b) For smoke tubes, the calculation temperature shall be determined in accordance with the following equations:

$$t_c = t_s + 2e_t \quad (6.1-1)$$

or

$$t_c = t_s + 25 \quad (6.1-2)$$

whichever is the greater.

- c) The calculation temperature for areas of plate subject to heat transfer but not swept by flame, or for tube nest areas where the gas entry temperature is not greater than 800 °C, shall be determined in accordance with the following equations:

$$t_c = t_s + 2e_h \quad (6.1-3)$$

or

$$t_c = t_s + 50 \quad (6.1-4)$$

whichever is the greater.

The calculation temperature for flat walls in the flue gas pass with a flue gas temperature $t_G < 400$ °C shall be:

$$t_c = t_s + 20 \quad (6.1-5)$$

- d) For tube plates subject to gas entry temperatures exceeding 800 °C in fired boilers using fossil fuels, including natural gas, the calculation temperature shall be determined in accordance with Annex A, using the true gas entry temperature t_G determined from the following equation:

$$t_G = 51 \left(\frac{H}{A} \right)^{0,25} \quad (6.1-6)$$

For fuels where the true gas entry temperature is higher than that obtained with natural gas, and for waste-heat boilers, the calculation temperature shall be determined in accordance with Annex A.

The maximum metal temperature as determined in accordance with Annex A shall not exceed 420 °C.

The condition for the calculation in accordance with Annex A is good contact between smoke tubes and tube sheet. Where this cannot be ensured, the method of attachment shown in Figure 12.4-1f) may be employed with the following limitations:

- 1) The depth of the connecting weld between smoke tubes and tube sheet shall be greater than or equal to the wall thickness of the smoke tube plus 2 mm;
- 2) The length of the gap, measured from the root of the weld, shall be less than or equal to four times the wall thickness of the smoke tube. If this dimension is exceeded, a cooling groove shall be provided.

If the above requirements are adhered to, the calculated temperature shall be determined in accordance with equation (6.1-4).

For LPB, the calculation temperature for flat walls subject to a flue gas temperature $> 800\text{ }^{\circ}\text{C}$ shall be given by equation (6.1-4).

e) The calculation temperature for furnaces tubes shall be determined by the following equations:

1) In the case of furnaces tubes subjected to the flame and a heat input $\leq 12\text{ MW}$

$$t_c = t_s + 4e + 15 \quad (6.1-7)$$

2) In the case of furnaces tubes subjected to flame and a heat input $> 12\text{ MW}$

for oil firing

$$t_c = t_s + 3,5e + 80 \quad (6.1-8)$$

for gas firing

$$t_c = t_s + 3e + 65 \quad (6.1-9)$$

NOTE Equations (6.1-8) and (6.1-9) are based on a maximum heat flux of $0,3\text{ W/mm}^2$ for oil firing and $0,24\text{ W/mm}^2$ for gas firing, taking into account an allowance of $0,25\text{ mm}$ for the thickness of scale with a conductivity of $1,2\text{ W/m K}$.

Where it can be shown that the heat flux is lower, e.g. low NO_x firing, the calculations can be adjusted accordingly, but the value of t_c should be not less than that given by equation (6.1-7).

3) In the case of furnace tubes without flame the calculation temperature t_c shall taken as being equal to the highest of the two values given by the following equations:

$$t_c = t_s + 25 \quad (6.1-10)$$

$$t_c = t_s + 2e \quad (6.1-11)$$

6.2 Nominal design stress

Unless otherwise stated in this Part of this European Standard, the nominal design stress f shall be the lower of the values obtained from the following ratios:

$$f = \min \left\{ \frac{R_{p0,2\text{ } t_c}}{1,5} ; \frac{R_m}{2,4} \right\} \quad (6.1-12)$$

NOTE The term "nominal design stress", designated by the symbol f , is the stress to be used in the equations herein for the design of pressure parts. The detailed design rules in this Part will maintain the actual maximum stresses within acceptable limits for the type of loading considered.

7 Cylindrical shells under internal pressure

7.1 Shell thickness

7.1.1 Requirements

The shell thickness after deduction of allowances

$$e_{ts} = e_s - c_1 - c_2 \quad (7.1-1)$$

of cylindrical shell shall be at least the greatest of those required by the following:

- a) a minimum of 6 mm for cylindrical shells of outside diameter $\geq 1\,000$ mm except LPB. For outside diameter $< 1\,000$ mm and LPB a minimum of 4 mm shall be required;
- b) the requirements of 7.2;
- c) the requirements of 7.2 by applying 8.2 or 8.3.3 and 8.3.4.

7.1.2 Required wall thickness including allowances

The required wall thickness including allowances shall be derived from:

$$e_{sa} = e_{cs} + c_1 + c_2 \quad (7.1-2)$$

7.2 Basic calculation

The required wall thickness without allowances e_{cs} of a cylindrical shell shall be determined by either of the following equations

$$e_{cs} = \frac{p_c d_{is}}{(2 f_s - p_c) v} \quad (7.2-1)$$

if d_{is} is given or

$$e_{cs} = \frac{p_c d_{os}}{(2 f_s - p_c) v + 2 p_c} \quad (7.2-2)$$

if d_{os} is given.

The equivalent value of the stress in the shell can be calculated by modifying equations (7.2-1) or (7.2-2).

7.3 Boiler support

Experience has shown that it shall not be necessary to carry out strength calculations in regard to boiler supports as fatigue is not normally encountered in this area.

7.4 Reinforcing pads

Reinforcing pads may be used for the reinforcement of openings and branches and for the distribution of load at supports and attachments. Such reinforcing pads shall be designed analogous to the requirements of 8.1.5.1.

8 Openings and branches in cylindrical shells

NOTE This clause specifies the design rules for openings and branches in cylindrical shells. All dimensions exclude allowances c_1 and c_2 for wall thickness.

8.1 General

8.1.1 Requirements for the efficiency of the main body with openings and branches

8.1.1.1 For cylindrical shells with openings the efficiency of the main body shall be satisfied by the following:

- a) by increasing the wall thickness of the main body compared with that of the cylindrical shell without openings. This wall thickness shall be available at least up to the length l_{rs} measured from the edge of the opening (see Figure 8.1-1; and for l_{rs} see 8.1.2). Where there is a branch, the cylindrical length of the main body up to any adjacent butt weld in it shall be $l_{so} \leq e_{rs}$ (see Figures 8.1-2 and 8.1-3).

- b) by branches, measured on a length l_{b1} from the outside surface of the main body wall, which have been provided with a wall thickness in excess of that required on account of the internal pressure, without or in connection with an increase in main body wall thickness (see Figures 8.1-2 and -3). The welded joint between the main body and branch shall be a full-strength weld where in the case of branches in accordance with Figure 8.1-3 a residual gap $\leq 1,5$ mm may be present. A wall thickness ratio of e_{rb}/e_{rs} up to and including 2 shall be permitted for $d_{ib} > 50$ mm. This shall also apply to branches with $d_{ib} > 50$ mm insofar as the diameter ratio $d_{ib}/d_{is} \leq 0,2$. For branches with $d_{ib} > 50$ mm and a diameter ratio $d_{ib}/d_{is} > 0,2$, e_{rb}/e_{rs} shall not exceed unity. These conditions do not apply to access and inspection openings.

Expanded or set-in and seal-welded-only branches (see Figure 8.1-1) or branches attached to the main body by fillet welds with a residual root gap $> 1,5$ mm shall not be regarded as contributing to the reinforcement.

The cylindrical length of branches up to the butt weld between tube and branch shall be $l_{bo} \geq e_{rb}$ (see Figures 8.1-2 and 8.1-3).

For branches with $d_{ib}/d_{is} \geq 0,7$ reference shall be made to 8.3.3.4.

In general, special emphasis shall be placed on smooth wall thickness transitions. Wall thickness transitions shall be made with an angle $\leq 30^\circ$ (see Figure 8.1-2). The reinforcement of openings by inside reinforcing plates or pads shall not be permitted.

- c) reinforcement by reinforcing pads analogous to increasing the wall thickness as in a) (see Figures 8.1-4 to 8.1-5).

8.1.1.2 Where there are elliptical access and inspection openings it shall be assumed that the ratio of major to minor axis does not exceed 1,5. For elliptical or obround openings in cylindrical shells the dimension extending in the direction of the shell axis shall be taken as the diameter for design purposes. (For oblique nozzles, see 8.3.3.3).

The calculation procedure assumes that the transitions shall show a notch-free surface¹⁾. Edges shall be rounded.

Openings shall be located at an adequate distance from the longitudinal and circumferential welds of the main body. The distance shall be considered adequate if the outer edge of a branch or welded-on reinforcement, on a main body with a thickness $e_{rs} \leq 25$ mm is at a distance of $2 e_{rs}$ and on a main with a body thickness $e_{rs} > 25$ mm the distance is at least 50 mm from the weld edge.

8.1.2 Effective lengths l_{rs} for calculation of efficiencies and of compensations

For the calculation of efficiencies by way of approximation as described in 8.2 and the calculation of isolated and adjacent branches described in 8.3, effective lengths l_{rs} are required which shall be used for the main body.

$$l_{rs} = \min \left[\sqrt{(d_{is} + e_{rs})e_{rs}}; l_{s1} \right] \quad (8.1-1)$$

for l_{s1} see Figures 8.1-1 to -3.

and for the nozzle with $\psi \geq 45^\circ$

for external projection

$$l_{rb} = \min \left[\sqrt{(d_{ib} + e_{rb})e_{rb}}; l_{b1} \right] \quad (8.1-2)$$

for internal projection

$$l_{rbi} = \min \left[0,5\sqrt{(d_{ib} + e_{rb})e_{rb}}; l_{b2} \right] \quad (8.1-3)$$

1) Welded joints are considered to be notch-free if they are within the limits given in EN 12952-5.

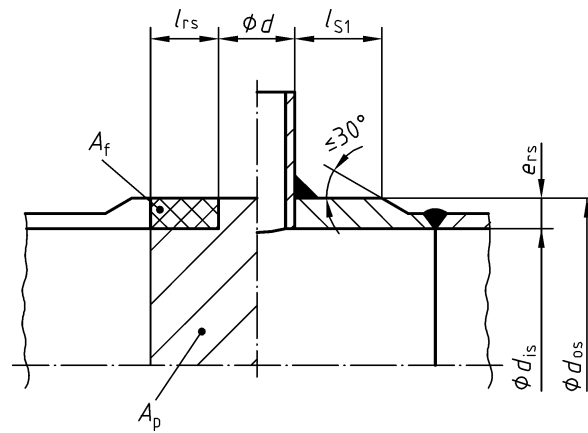


Figure 8.1.1 — Reinforcement by increasing the wall thickness of the main body with opening

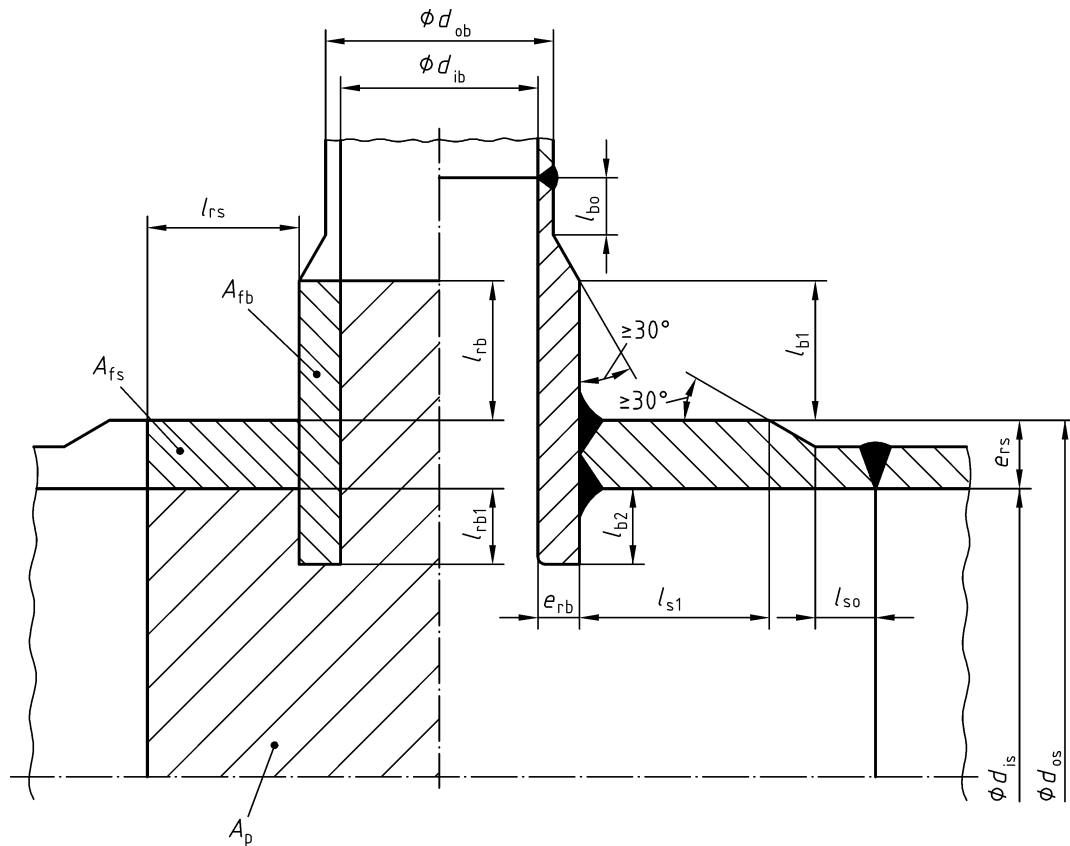


Figure 8.1.2 — Reinforcement by set-through and full penetration welded branch

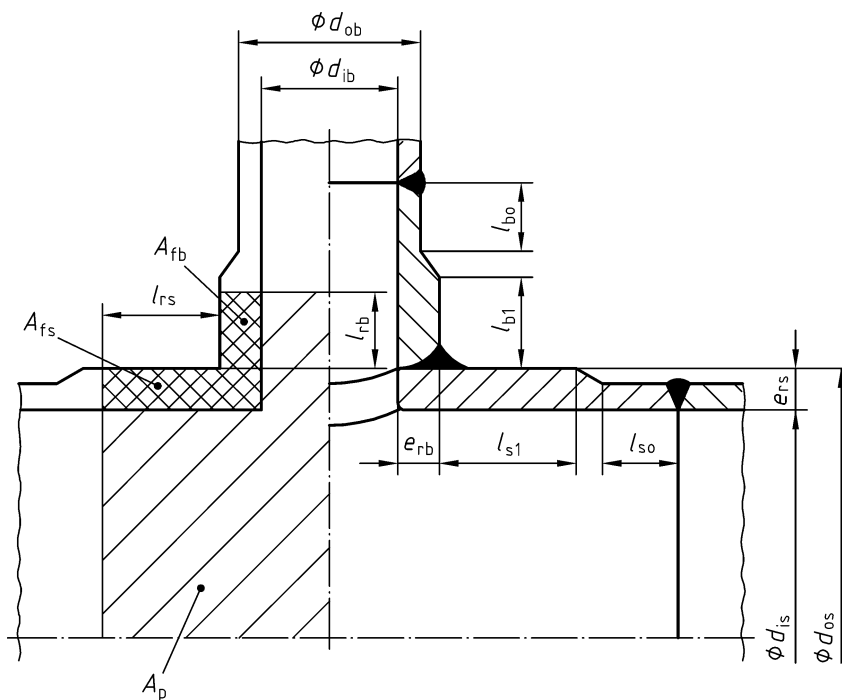


Figure 8.1.3 — Reinforcement by welded-on branch

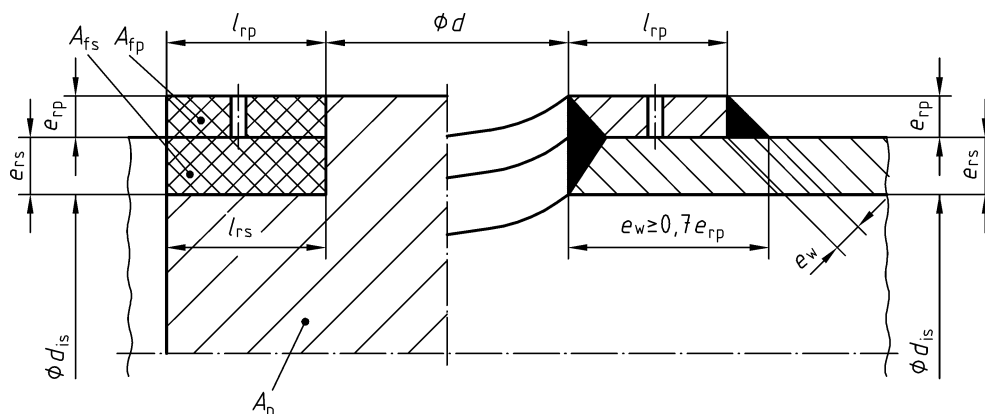
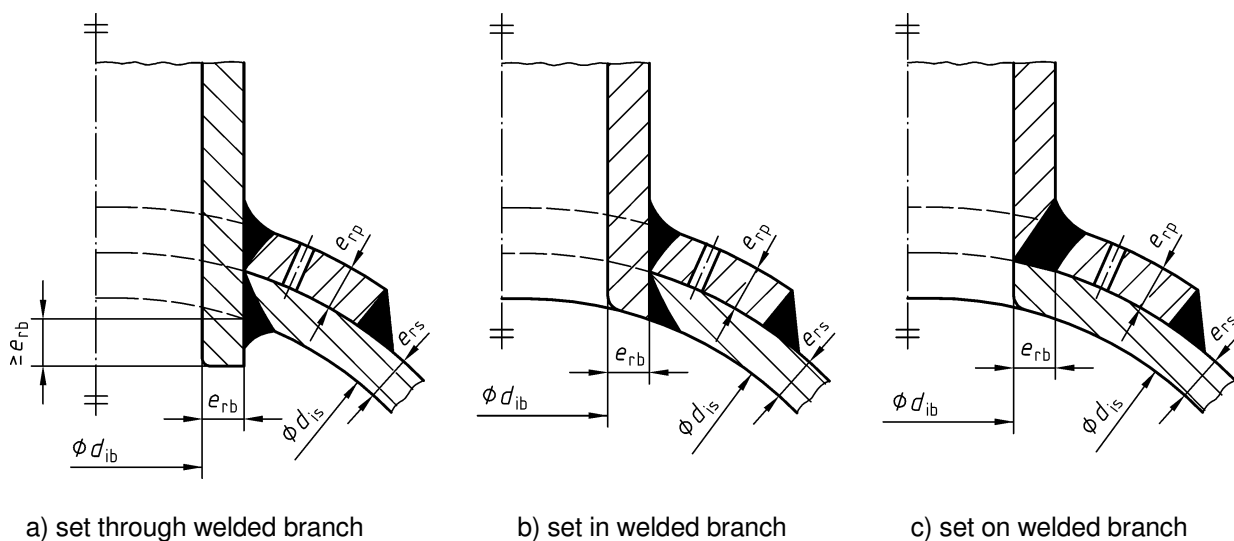


Figure 8.1.4 — Opening with reinforcing pad



a) set through welded branch

b) set in welded branch

c) set on welded branch

Figure 8.1.5 — Opening with reinforcing pad and full penetration branch

8.1.3 Condition of isolated openings

Adjacent openings shall be treated as isolated openings if, for the centre distance P_ϕ in accordance with to Figure 8.3-3, the following condition is satisfied.

$$P_\phi \geq \frac{\left(\frac{d_{ib1}}{2} + e_{rb1}\right)}{\cos \Psi_1} + \frac{\left(\frac{d_{ib2}}{2} + e_{rb2}\right)}{\cos \Psi} + 2\sqrt{(d_{is} + e_{rs})} e_{rs} \quad (8.1-4)$$

For openings without a branch, $e_{rb} = 0$ and $\Psi = 0^\circ$ (for Ψ see Figure 8.3-1).

8.1.4 Requirements for design of branches

8.1.4.1 Main body with lower design stress than the branches

If the main body, the branch and the additional reinforcement consists of materials with different design stresses and the material of the main body has the lowest design stress value f_s , this value shall be used for all materials to calculate the reinforcement of the branch.

8.1.4.2 Branches or reinforcing pads with lower design stress than the main body

If the material used for the branch or the reinforcing pad has a lower design stress f_b or f_p respectively than the main body design stress f_s , this design stress f_b or f_p shall be taken into account when using the equations provided for this case.

8.1.4.3 Special case

The nozzle inside diameter d_{ib} shall be used in the calculation even if the hole diameter d in the main body is less than d_{ib} .

8.1.5 Requirements for design of reinforcing pads

8.1.5.1 General

Reinforcing pads shall be designed in accordance with 8.1.1.1.

Where reinforcing pads are fitted (see Figures 8.1-4 and 8.1-5) they shall have close contact with the main body and shall be provided with tell-tale holes to avoid the trapping of gases, unless experience has shown that it is not necessary.

Reinforcing pads shall not be used where there is a possibility of severe corrosion or oxidation or of large temperature gradients across the thickness of the shell. Reinforcing pads shall not be permitted on the inside of the vessel.

8.1.5.2 Pressure considerations

When reinforcing pads are used for the reinforcement of penetrations or openings, the following conditions shall be observed.

- the ratio d_{ib}/d_{is} of the branch diameter to the cylinder diameter shall be not greater than 1/4 unless the adequacy of the design is demonstrated by experience or by a hydrostatic proof test.
- the sizes L_i of the inner fillet welds by which reinforcing pads are attached to shell plates (see Figure 8.1-6) shall comply with the following relationship:

$$L_i \geq 0,7 e_{cp} \quad (8.1-5)$$

The sizes L_o of the outer peripheral fillet welds by which reinforcing pads (see Figure 8.1-6) are attached to shell plates shall be determined from the following equation, but shall in no case be less than the size of the inner fillet weld:

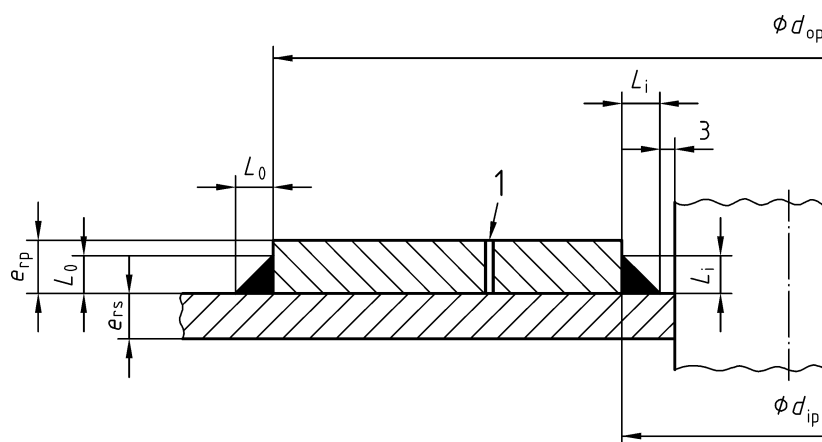
$$L_o = \max \left[\frac{d_{ip} (2 e_{rs} - L_i)}{d_{op}}; L_i \right] \quad (8.1-6)$$

For elliptical reinforcing pads

$$d_{op} = \frac{a_o + b_o}{2} \quad (8.1-7)$$

$$d_{ip} = \frac{a_i + b_i}{2} \quad (8.1-8)$$

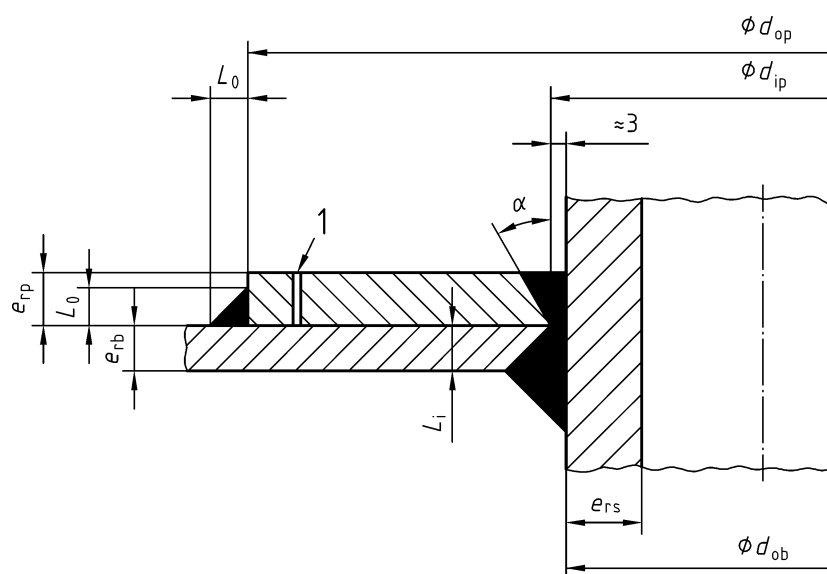
- c) for calculation purposes the thickness of the reinforcing pad shall be not taken greater than the thickness of the shell.

**Key**

1 Tell-tale hole

a Opening in shell

a)

**Key**

1 Tell-tale hole

 α is 30° to 45°

b)

Figure 8.1.6 — Welding of reinforcing pads**8.2 Efficiency factor, calculation by way of approximation and maximum diameter of an unreinforced opening****8.2.1 General**

Exact solutions shall be given by the equations in 8.3.3 and 8.3.4. Application of the equations in 8.2.3 and 8.2.4, except equation (8.2-3), may be conservative as any reinforcement from the branch is not taken into account.

8.2.2 Allowable efficiency and maximum diameter of an unreinforced opening

Rearranging equation (7.2-1) the allowable efficiency v_a shall be calculated for the available wall thickness e_{rs} of a main body as follows:

$$v_a = \frac{p_c d_{is}}{(2 f_s - p_c) e_{rs}} \quad (8.2-1)$$

For this efficiency coefficient the greatest outside diameter d_{ob} of an isolated branch shall be obtained when its wall thickness can only withstand the internal pressure

$$d_{ob \max} = 2 \left(\frac{l_{rs}}{v_a} - l_{rs} \right) \quad (8.2-2)$$

In this case the available average stress f_a shall be equal to the allowable stress f_s of the main body.

8.2.3 Isolated openings

The equations in this clause shall apply to single openings, or if there is more than one opening, only if equation (8.1-4) is satisfied. In the case of more than one opening where equation (8.1-4) is not satisfied, reference shall be made to 8.2.3.

However, isolated unreinforced openings with diameter d in cylindrical shells shall be permitted if they comply with the following equation:

$$d \leq 0,14 l_{rs} \quad (8.2-3)$$

and

$$e_{rs} \leq 0,1 d_{os} \quad (8.2-4)$$

where l_{rs} shall be calculated in accordance with 8.1.2.

This shall also be valid for counter borings and for partial penetration holes even if the equations (8.2-6) or (8.2-9) or the more exact calculations in accordance with 8.3.3 recommend a smaller diameter d as given in equation (8.2-3).

Where a tube with an outside diameter d_{ob} is attached to an opening, as shown in Figure 8.2-1, and the tube is capable of withstanding the internal calculation pressure on account of its wall thickness e_{rb} , the efficiency factor v_b of this opening in the main body shall be calculated by

$$v_b = \frac{2 l_{rs}}{(2 l_{rs} + d_{ob})} \quad (8.2-5)$$

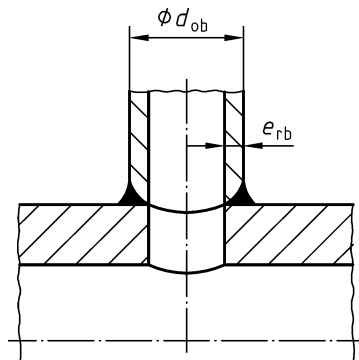


Figure 8.2-1 — Tube attached to main body

If the diameter d_{is} and the wall thickness e_{rs} of the main body have been determined, an isolated hole for a tube with a maximum outside diameter

$$d_{ob} \leq 2l_{rs} \left[\frac{2e_{rs}}{d_{is}} \left(\frac{f_s}{p_c} - \frac{1}{2} \right) - 1 \right] \quad (8.2-6)$$

shall be permitted.

8.2.4 Adjacent openings

Where the condition for the centre distance P_ϕ of adjacent openings given in 8.1.3 is not met, and tubes with an outside diameter d_{ob} are connected to the opening, with the tubes only able to withstand the internal pressure on account of their wall thickness e_{rb} , the efficiency factor of adjacent openings shall be derived as follows:

$$v_m = \frac{2(P_\phi - d_{ob})}{(1 + \cos^2 \Phi)P_\phi} \leq 1 \quad (8.2-7)$$

i.e. for longitudinal pitch P_ϕ with $\Phi = 0$:

$$v_m = \frac{P_\phi - d_{ob}}{P_\phi} \quad (8.2-8)$$

Where the outside diameters of adjacent openings differ from each other, the following shall apply

$$d_{ob} = \frac{d_{ob1} + d_{ob2}}{2} \quad (8.2-9)$$

Instead of the calculation by approximation used in this clause, 8.3.4 may be used.

8.3 Design of openings and branches in cylindrical shells (efficiency and reinforcement)

8.3.1 Symbols and abbreviations

In addition to the symbols given in EN 12953-1:2002, Table 4-1, those shown in Figures 8.3-1 to 8.3-4 shall be used.

8.3.2 Requirements for application

8.3.2.1 Openings

The rules specified in 8.3.3 to 8.3.4 shall apply to circular, elliptical and obround openings and nozzles (including oblique nozzles) arranged singly or in groups, in cylindrical shells, provided that the following conditions are satisfied:

- a) Openings and nozzles non radial to the shell (Figure 8.3-2)

The ratio of the major to minor axes of the opening shall not exceed 2;

- b) Oblique nozzles (Figure 8.3-1)

The nozzle is of circular cross section and the angle between the axis of the nozzle and a line normal to the shell surface shall not exceed 45° ;

- c) All nozzles

No significant external forces and moments shall be applied to the nozzle. If this is not the case, EN 13445-3 shall be used to calculate the resulting stresses.

The nozzle inside diameter d_{ib} shall be used in the calculation even if the hole diameter d in the main body is less than d_{ib} .

Nozzle connections with a residual gap greater than 1,5 mm or set-through and seal-welded-only branches, shall be considered openings without branches. The pressurized area in the tube hole shall be considered except for the case of set-through tubes with an inside seal weld.

8.3.2.2 Minimum thickness of nozzles and branch connections

The thickness of nozzles and branches shall be in accordance with 8.1.1.1b), but the thickness shall be not less than that given by the following equation:

$$e_{cb} = 0,015 d_{ob} + 3,2 \quad (8.3-1)$$

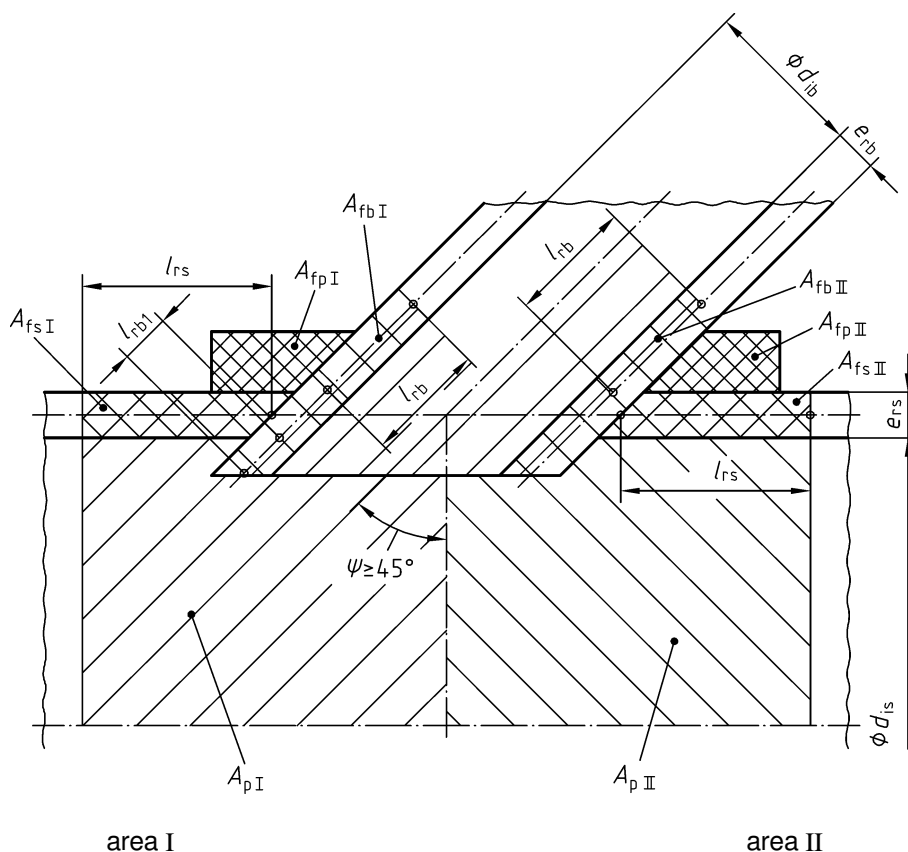


Figure 8.3-1 — Load diagram for cylindrical shell with oblique branch and reinforcing pad

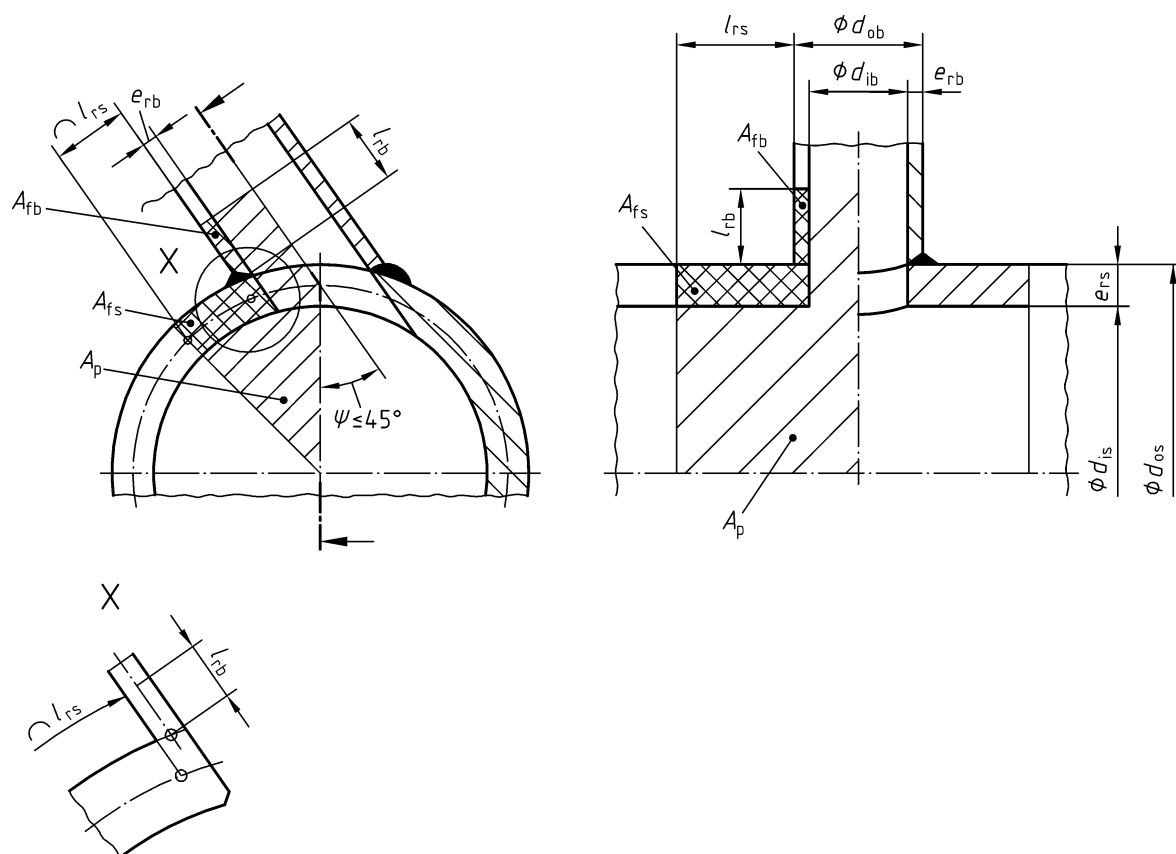
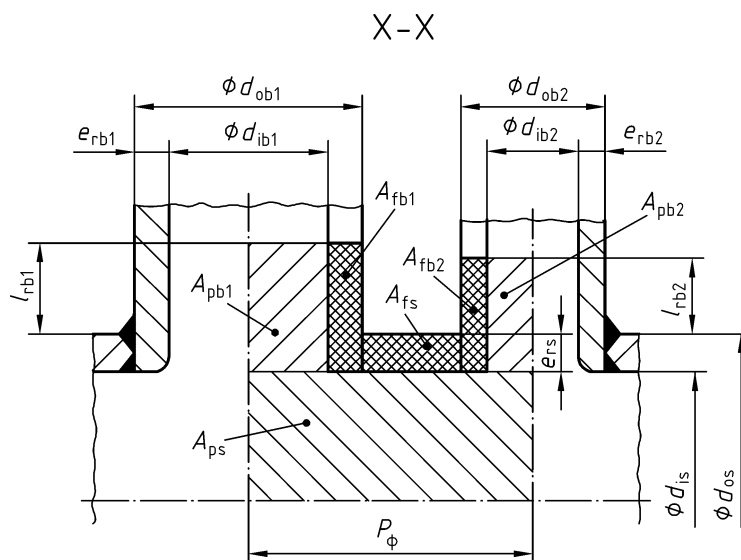
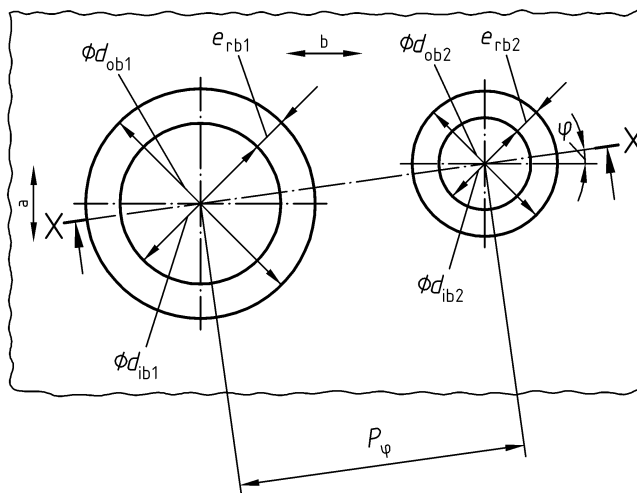


Figure 8.3-2 — Load diagram for cylindrical shell with non-radial branch

a) section view X — X



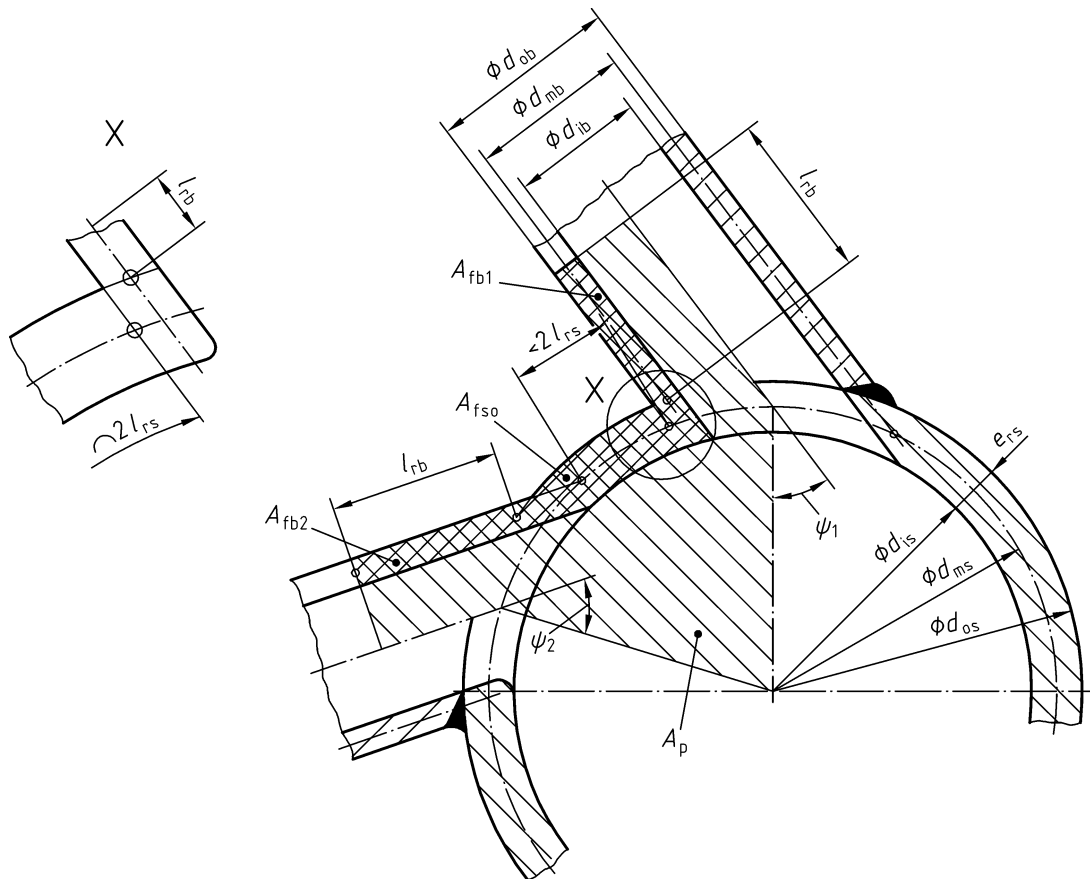
b) plan view



a Circumferential direction

b Longitudinal direction

Figure 8.3-3 — Load diagram for cylindrical shell with adjacent branches, arranged with an angle ϕ to the axis of the shell



with

$$\psi_1 \leq 45^\circ$$

$$\psi_2 \leq 45^\circ$$

Figure 8.3-4 — Load diagram for cylindrical shell with non-radial adjacent branches, arranged on the circumference

8.3.3 Design of isolated openings and branch connections

8.3.3.1 General

The shell thickness e_{rs} and the thickness of a branch connection e_{rb} shall be not less than that calculated for $\nu = 1$ in accordance with 7.2.

8.3.3.2 Isolated opening with a radial branch

8.3.3.2.1 For isolated openings fitted with a radial branch without additional reinforcement 8.3.3.4 and 8.3.3.5 (with $\psi_1 = 0$) shall be additionally taken into account.

8.3.3.2.2 If the design stress of the branch is equal to or greater than that for the main body the following strength condition shall apply:

$$f_a = \min \left[p_c \left(\frac{A_p}{A_{fs} + A_{fb}} + \frac{1}{2} \right); f_s \right] \quad (8.3-2)$$

The efficiency ²⁾ shall be:

$$v_b = \frac{d_{is} (A_{fs} + A_{fb})}{2 e_{rs} A_p} \leq 1 \quad (8.3-3)$$

8.3.3.2.3 If the design stress of the branch is less than that of the main body, the following strength condition shall apply:

$$f_a = \frac{p_c (2 A_p + A_{fs} + A_{fb})}{2 \left(A_{fs} + \frac{f_b}{f_s} A_{fb} \right)} \leq f_s \quad (8.3-4)$$

In this case the efficiency²⁾ shall be:

$$v_b = \frac{d_{is} \left(A_{fs} + \frac{f_b}{f_s} A_{fb} \right)}{e_{rs} \left(2 A_p + A_{fb} - \frac{f_b}{f_s} A_{fb} \right)} \leq 1 \quad (8.3-5)$$

8.3.3.3 Isolated opening with an oblique branch and additional reinforcing pad

8.3.3.3.1 For isolated openings fitted with an oblique branch and additional reinforcing pad in accordance with Figure 8.3-1, the requirements for design of reinforcing pads in 8.1.5 shall be additionally taken into consideration.

8.3.3.3.2 If the design stress of the branch is equal to or greater than that for the main body, the strength condition for area I shall be:

$$f_{a I} = p_c \left(\frac{A_{p I}}{A_{fs I} + A_{fb I} + 0,7 A_{fp I}} + \frac{1}{2} \right) \leq f_s \quad (8.3-6)$$

and for area II

$$f_{a II} = p_c \left(\frac{A_{p II}}{A_{fs II} + A_{fb II} + 0,7 A_{fp II}} + \frac{1}{2} \right) \leq f_s \quad (8.3-7)$$

8.3.3.3.3 If the design stress of the branch material or the material of the additional reinforcing pad is less than that of the main body, the strength condition for area I shall be:

$$\left(f_s - \frac{p_c}{2} \right) A_{fs I} + \left(f_b - \frac{p_c}{2} \right) A_{fb I} + \left(f_p - \frac{p_c}{2} \right) 0,7 A_{fp I} \geq p_c A_{p I} \quad (8.3-8)$$

and for area II.

$$\left(f_s - \frac{p_c}{2} \right) A_{fs II} + \left(f_b - \frac{p_c}{2} \right) A_{fb II} + \left(f_p - \frac{p_c}{2} \right) 0,7 A_{fp II} \geq p_c A_{p II} \quad (8.3-9)$$

8.3.3.4 Cross-section vertical to the main body axis

For branch connections where $d_{ib}/d_{is} \geq 0,7$ and simultaneously $e_{rb}/e_{rs} < d_{ib}/d_{is}$, the following condition shall be met for the main body/branch transition in the cross-section vertical to the main body axis:

2) The approximate calculation in accordance with 8.2 can be used instead of this calculation, in which case the reinforcement effect of the nozzles should not be considered.

$$f_{ab} = \frac{p_c}{1,5} \left(\frac{d_{is} + e_{rs}}{2 e_{rs}} + 0,2 \frac{d_{ib} + e_{rb}}{e_{rb}} \sqrt{\frac{d_{is} + e_{rs}}{e_{rs}}} \right) \leq \min(f_s; f_b) \quad (8.3-10)$$

Where the main body and the branch connection consist of material with differing design stresses, the smaller value shall be used in this calculation.

8.3.3.5 Cylindrical shells with a branch not radially arranged

For cylindrical shells where the branch is not arranged in the radial direction (see Figure 8.3-2), but at an angle ψ , the higher loading can occur in the cross-section of Figure 8.3-2 or in the longitudinal section of Figure 8.3-2. In both cases the strength condition as per equation (8.3-2) shall apply, with the areas A_p , A_{fs} and A_{fb} shown in the respective figures to be used in the calculation. The lengths contributing to the reinforcing pad (effective lengths) shall only be used in the calculation of the main body in accordance with equation (8.1-1) or of the branch connection according to equation (8.1-2) or (8.1-3) respectively.

The wall thickness of the branch e_{rb} shall not exceed the main body wall thickness e_{rs} .

8.3.4 Design of adjacent openings and branch connections

8.3.4.1 General

Adjacent openings shall be calculated additionally as isolated openings.

8.3.4.2 Condition of adjacent openings and branches

The calculation shall only be made if the condition for isolated openings or branch connections laid down in 8.1.3 is not met for adjacent openings or branches.

8.3.4.3 Main body with lower design stress than the branches

For adjacent openings or branch connections, the strength shall be calculated for a cross-section with an angle ϕ for the shell generating line in accordance with Figures 8.3-3. The following strength condition shall apply:

$$f_{a\phi} = \frac{p_c}{2} \frac{2 A_{p0} \frac{1 + \cos^2 \Phi}{2} + 2 A_{p1} + 2 A_{p2}}{A_{fs0} + A_{fb1} + A_{fb2}} + \frac{p_c}{2} \leq f_s \quad (8.3-11)$$

Diagonal or circumferential pitches shall be calculated as a longitudinal pitch in accordance with Figure 8.3-3 with a distance P_ϕ . In this case the pressure area $2 A_{p0}$ shall be corrected by the factor $((1 + \cos^2 \phi)/2)$ in the strength condition in accordance with equation (8.3-14).

The efficiency ²⁾ shall be:

$$v_m = \frac{d_{is}}{e_{rs}} \frac{A_{fs0} + A_{fb1} + A_{fb2}}{2 A_{p0} \frac{1 + \cos^2 \Phi}{2} + 2 A_{p1} + 2 A_{p2}} \leq 1 \quad (8.3-12)$$

8.3.4.4 Branches with equal or lower design stress than the main body

If the design stress of one or both branches is less than that of the main body, the following condition shall apply:

$$f_{a\phi} = \frac{p_c}{2} \frac{2 A_{p0} \frac{1 + \cos^2 \Phi}{2} + 2 A_{p1} + 2 A_{p2} + A_{fs0} + A_{fb1} + A_{fb2}}{A_{fs0} + \frac{f_{b1}}{f_s} A_{fb1} + \frac{f_{b2}}{f_s} A_{fb2}} \leq f_s \quad (8.3-13)$$

In this case, the efficiency ²⁾ shall be:

$$v_m = \frac{d_{is}}{e_{rs}} \frac{A_{fs0} + \frac{f_{b1}}{f_s} A_{fb1} + \frac{f_{b2}}{f_s} A_{fb2}}{2 A_{p0} \frac{1 + \cos^2 \Phi}{2} + 2 A_{p1} + 2 A_{p2} + A_{fb1} + A_{fb2} - \frac{f_{b1}}{f_s} A_{fb1} - \frac{f_{b2}}{f_s} A_{fb2}} \leq 1 \quad (8.3-14)$$

8.3.4.5 Adjacent branches in the circumferential direction

For non-radial adjacent branches arranged on the circumference in accordance with Figure 8.3-4, the calculation procedure shall be analogous to radial branches. In this case the correction factor $((1 + \cos^2 \Phi)/2)$ shall be replaced by the factor 1.

9 Ends

9.1 Unstayed dished heads without openings

9.1.1 Unstayed dished heads under internal pressure

The minimum thickness of unstayed dished heads without openings shall be in accordance with equation

$$e_s = e_{cs} + c + c_1 + c_2 \quad (9.1-1)$$

and the following equation:

$$e_{cs} = \frac{p_e d_o C}{2 f} \quad (9.1-2)$$

In addition, the thickness of a torispherical head shall be not less than that given by equation (9.1-1) and the following equation:

$$e_{cs} = \frac{p_e r_{is}}{2 f - 0,5 p_e} \quad (9.1-3)$$

The shape factor C for unstayed dished heads without openings shall be as given in Figure 9.1-1. However, the limiting conditions given in 9.1.2 shall apply.

9.1.2 Limiting conditions

The limiting conditions shall be for:

a) Hemispherical heads

$$0,005 d_o \leq e_{cs} \leq 0,16 d_o;$$

b) Ellipsoidal heads

$$0,005 d_o \leq e_{cs} \leq 0,08 d_o \text{ and}$$

$$h_c \geq 0,18 d_o;$$

c) Torispherical heads

$$0,005 d_o \leq e_{cs} \leq 0,08 d_o \text{ and}$$

$$r_{ik} \geq 0,1 d_o \text{ and}$$

$$r_{ik} \geq 2 e_{cs} \text{ and}$$

$$r_{is} \leq d_o \text{ and}$$

$$h_c \geq 0,18 d_o;$$

or

$$0,01 d_o \leq e_{cs} \leq 0,03 d_o \text{ and}$$

$$r_{ik} \geq 0,1 d_o \text{ and}$$

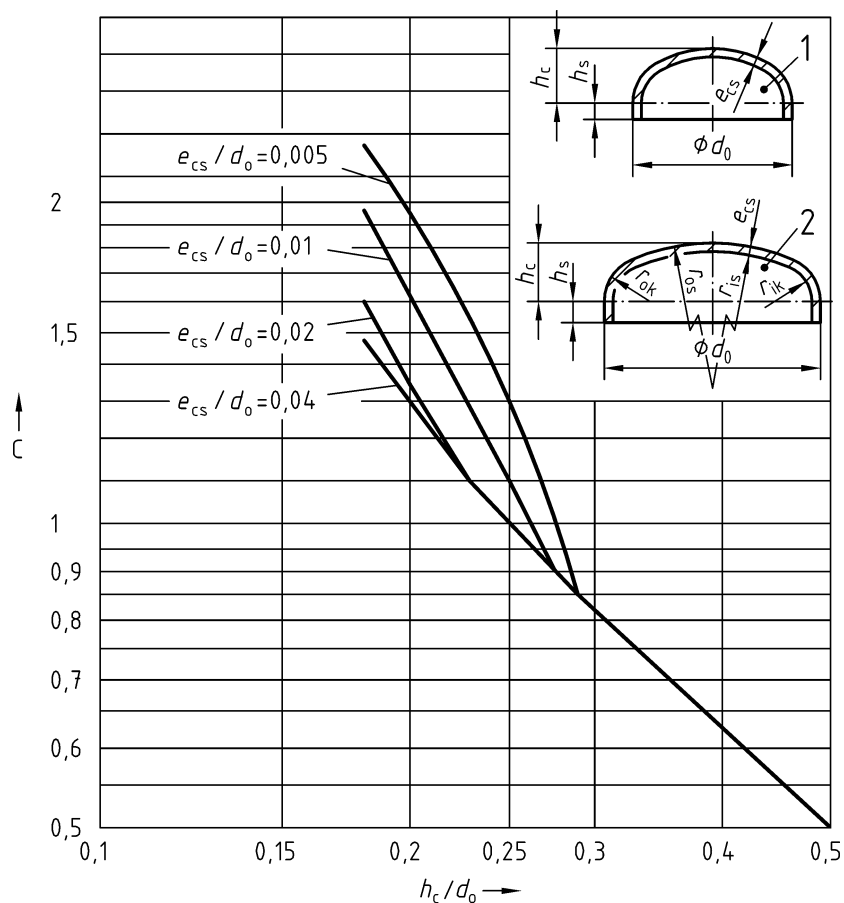
$$h_c \geq 0,18 d_o;$$

or

$$0,02 d_o \leq e_{cs} \leq 0,03 d_o \text{ and}$$

$$r_{ik} \geq 0,1 d_o \text{ and}$$

$$0,18 d_o \leq h_c \leq 0,22 d_o.$$



Key

- 1 Ellipsoidal head
- 2 Torispherical head

Figure 9.1-1 - Shape factor C for unstayed dished heads without openings