SLOVENSKI STANDARD
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Mnogovodni kotli - 3. del: Konstruiranje in izračun tlačno obremenjenih delov

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

Großwasserraumkessel - Teil 3: Konstruktion und Berechnung für drucktragende Teile

Chaudieres a tubes de fumée - Partie 3: Conception et calcul des parties sous pression

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27.060.30	Grelniki vode in prenosniki toplote	Boilers and heat exchangers

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

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

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

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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.

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

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Contents

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of an identical text or by endorsement, at the latest by November 2002, and conflicting national standards shall be withdrawn at the latest by November 2002.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

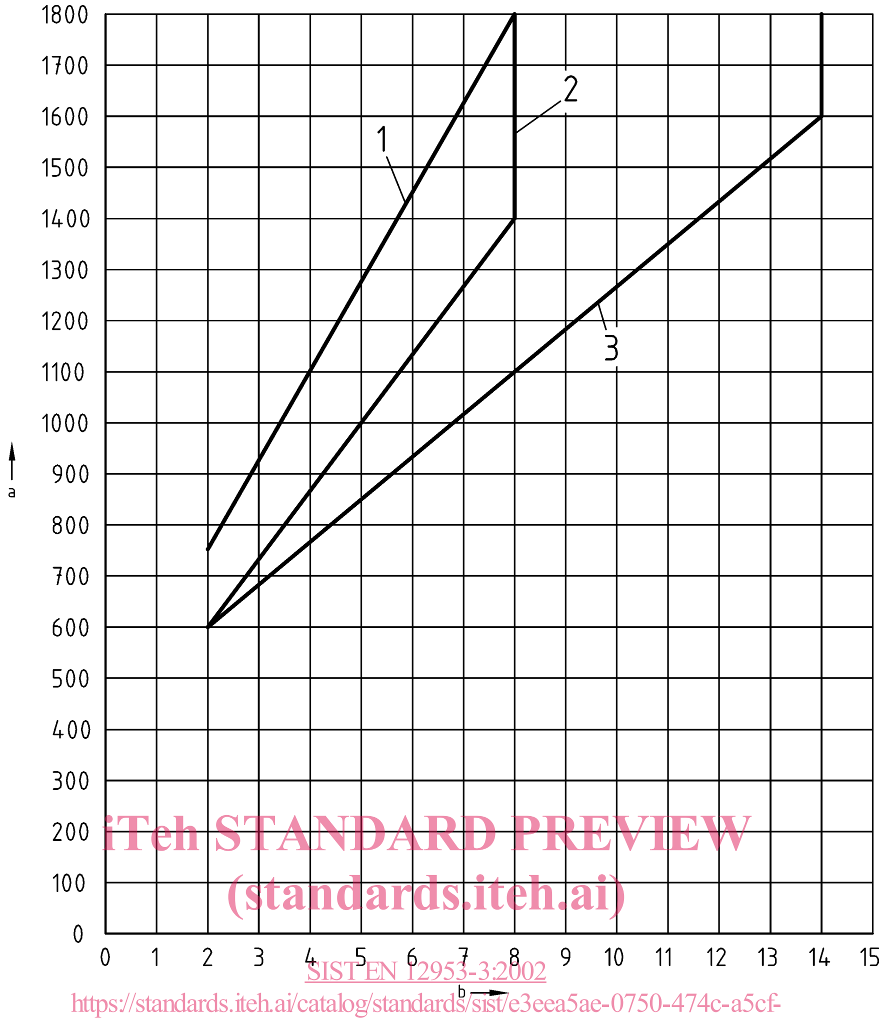
- P295 GH, oil firing: 12,90 MW
- P295 GH, gas firing: 16,77 MW
- P265 GH, oil firing: 8,00 MW
- P265 GH, gas firing: 10,40 MW

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:

$$p_t = 1{,}25 \, p_d \frac{R_{p0,2\ 20}}{R_{p0,2\ tc}} \qquad (5.6\text{-}1)$$

or

$$p_t = 1{,}43 \, p_d \qquad (5.6\text{-}2)$$

which ever is the higher;

where

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

The value of $R_{p0,2\ tc}$ 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;

$\leq$ 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:

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

or

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

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:

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

or

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

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:

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

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:

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

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 °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 ≤ 12 MW

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

2) In the case of furnaces tubes subjected to flame and a heat input > 12 MW

for oil firing

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

for gas firing

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

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

Where it can be shown that the heat flux is lower, e.g. low NOx 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:

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

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

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:

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

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

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

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 ≥ 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:

$$e_{sa} = e_{cs} + c_1 + c_2 \tag{7.1-2}$$

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

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

if d_{is} is given or

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

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 ≤ 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 ≤ 30° (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 surface[1]. 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.

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

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

and for the nozzle with $\Psi \geq 45°$

for external projection

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

for internal projection

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

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

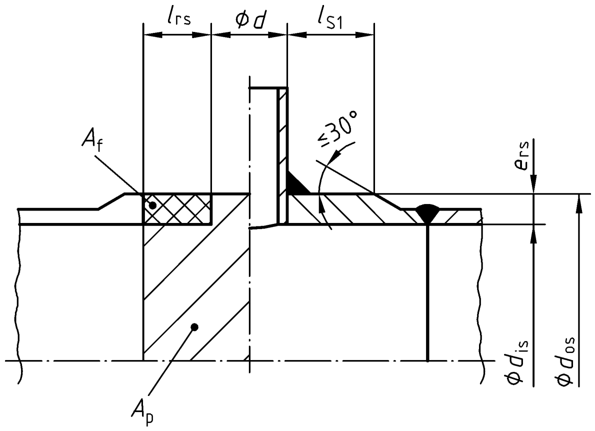


Figure 8.1.1 — Reinforcement by increasing the wall thickness of the main body with opening

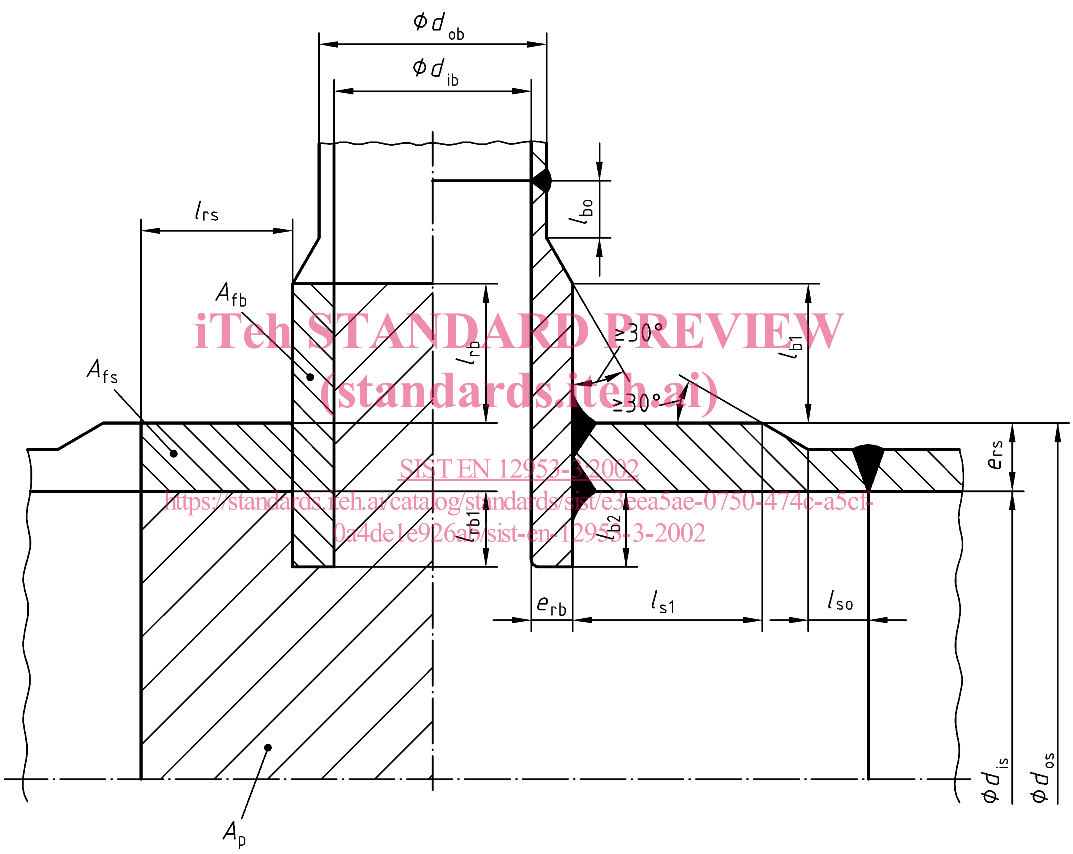


Figure 8.1.2 — Reinforcement by set-through and full penetration welded branch