INTERNATIONAL STANDARD

**ISO
5730**

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Stationary shell boilers of welded construction (other than water-tube boilers)

Chaudières à tubes de fumée de construction soudée (autres que chaudières aquatubulaires)

Reference number
ISO 5730:1992(E)

Contents

Annexes

Figures

Tables

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 5730 was prepared by Technical Committee ISO/TC 11, *Boilers and pressure vessels*, Sub-Committee SC 5, *Shell boilers*.

Annexes A, B, C, D, E, F, G, H and J of this International Standard are for information only.

Stationary shell boilers of welded construction (other than water-tube boilers)

Section 1:   General

1.1   Scope

1.1.1   This International Standard specifies requirements for both directly fired boilers and waste-heat boilers with a gas-side pressure not exceeding 0,05 N/mm² (0,5 bar)[1], of cylindrical horizontal designs, constructed from carbon or carbon manganese steels by fusion welding and, in the case of directly fired boilers, a design pressure not exceeding 3 N/mm². The boilers covered by this International Standard are intended for land use for providing steam or high-pressure hot water. (Typical examples are shown in figures 1 to 5.) This International Standard does not apply to water-tube boilers, to boilers for railway locomotives, or to marine boilers.

1.1.2   This International Standard applies to the boiler proper, from the feed-water inlet connection to the steam outlet connection and to all other connections, including those required for valves and steam and water fittings. If welded ends are used, the requirements specified herein begin or end at the weld where flanges, if used, would have been fitted.

1.1.3   This International Standard applies to boilers having a capacity of greater than 0,025 m³, a pressure greater than 0,1 N/mm² and a water temperature in excess of 120 °C.

1.1.4   Air preheaters, mechanical stokers, gas- or oil-burning equipment, forced- or induced-draught equipment or other accessories which may be required by the purchaser are not considered as parts of a boiler for the purposes of this International Standard. Superheaters and economizers either integral with or separate from the boiler shall be constructed to the requirements of the future International Standard for water-tube boilers.

1.1.5   This International Standard does not cover brickwork setting, insulation or furnace fittings.

1.1.6   This International Standard does not cover rules of construction since they cannot be written in sufficient detail to ensure good workmanship and construction. Each manufacturer is responsible for taking every necessary step to make sure that the quality of workmanship and construction is such as to ensure compliance with good engineering practice.

1.1.7   Informative references are given in annex J.

1.2   Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

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1)   1 N/mm² = 1 MN/m² = 1 MPa

1 bar = 10⁵ N/m² = 10⁵ Pa

ISO 148:1983, *Steel — Charpy impact test (V-notch).*

ISO 1027:1983, *Radiographic image quality indicators for non-destructive testing — Principles and identification.*

ISO 1106-1:1984, *Recommended practice for radiographic examination of fusion welded joints — Part 1: Fusion welded butt joints in steel plates up to 50 mm thick.*

ISO 1106-2:1985, *Recommended practice for radiographic examination of fusion welded joints — Part 2: Fusion welded butt joints in steel plates thicker than 50 mm and up to and including 200 mm in thickness.*

ISO 1106-3:1984, *Recommended practice for radiographic examination of fusion welded joints — Part 3: Fusion welded circumferential joints in steel pipes of up to 50 mm wall thickness.*

ISO 2504:1973, *Radiography of welds and viewing conditions for films — Utilization of recommended patterns of image quality indicators (I.Q.I.).*

ISO 2604-1:1975, *Steel products for pressure purposes — Quality requirements — Part 1: Forgings.*

ISO 2604-2:1975, *Steel products for pressure purposes — Quality requirements — Part 2: Wrought seamless tubes.*

ISO 2604-3:1975, *Steel products for pressure purposes — Quality requirements — Part 3: Electric resistance and induction-welded tubes.*

ISO 2605-1:1976, *Steel products for pressure purposes — Derivation and verification of elevated temperature properties — Part 1: Yield or proof stress of carbon and low alloy steel products.*

ISO 2605-3:1985, *Steel products for pressure purposes — Derivation and verification of elevated temperature properties — Part 3: An alternative procedure for deriving the elevated temperature yield or proof stress properties when data are limited.*

ISO 4126-1:1991, *Safety valves — Part 1: General requirements.*

ISO 5579:1985, *Non-destructive testing — Radiographic examination of metallic materials by X- and gamma rays — Basic rules.*

ISO 5580:1985, *Non-destructive testing — Industrial radiographic illuminators — Minimum requirements.*

ISO 6947:1990, *Welds — Working positions — Definitions of angles of slope and rotation.*

ISO 9328-1:1991, *Steel plates and strips for pressure purposes — Technical delivery conditions — Part 1: General requirements.*

ISO 9328-2:1991, *Steel plates and strips for pressure purposes — Technical delivery conditions — Part 2: Unalloyed and low-alloyed steels with specified room temperature and elevated temperature properties.*

ISO 10474:1991, *Steel and steel products — Inspection documents.*

1.3 Definitions

For the purposes of this International Standard, the following definitions apply. Throughout this International Standard additional definitions have been included as necessitated by the specific text concerned.

1.3.1 purchaser: Individual or organization who buys the completed boiler from the manufacturer.

1.3.2 designer: Individual or organization who assumes the sole responsibility for the design of the boiler. He/it determines the shape, dimensions and thickness of the boiler, selects the materials and details the methods of construction and testing.

1.3.3 manufacturer: Individual or organization who fabricates or assumes responsibility for the fabrication of the boiler or any component thereof.

1.3.4 material supplier: Individual or organization not being a material producer, who supplies material or prefabricated standardized parts to be used in the construction of the boiler or any component thereof.

1.3.5 producer of the supplied construction material; material producer: Individual or organization who produces materials for the fabrication of the boiler, components or prefabricated standardized parts.

1.3.6 regulating authority: Authority in the country of installation which is legally charged with the enforcement of that country's requirements of the law and regulations relating to boilers.

1.3.7 inspecting authority: That independent body or association, acting on behalf of

a) the purchaser or owner and/or

b) the regulating authority,

which performs the check that the design, materials and construction requirements comply with this International Standard.

1.3.8 inspector: Person employed and trained by an inspecting authority to carry out the functions of that inspecting authority as indicated in 1.3.7 (see also 6.1).

1.3.9 national standard: Specific standard which has proved to be satisfactory in use, which is acceptable to the regulating authority, which is a specification or rule prepared by a national standards *body* or similar authority, and which includes rules prescribed by government authorities and having the force of law.

1.4 Symbols

For the purposes of this International Standard, the general terminology and symbols indicated below shall apply. Throughout this International 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 of section 3 (Design of the parts under pressure) 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.

a	Dimensions indicated in figures 14, 16 to 18, 43 and 47.	mm
a_i	Inner major axis of compensating plate.	mm
a_o	Outer major axis of compensating plate.	mm
A	Effective radiant heating surface (see figures 1 to 5).	m²
A_f	Cross-sectional area effective as compensation without consideration of allowances.	mm²
A_{fb}	Cross-sectional area of branch effective as compensation.	mm²
A_{fp}	Cross-sectional area of reinforcing pad effective as compensation.	mm²
A_{fs}	Cross-sectional area of main body effective as compensation.	mm²
A_p	Pressure-loaded area without consideration of allowances.	mm²
A_{pb}	Pressure-loaded area relative to branch.	mm²
A_{ps}	Pressure-loaded area relative to main body.	mm²
b	Dimensions indicated in figures 14, 16 to 19, 34, 35, 43, 47 and B.1.	mm
b_1	Minor axis of manhole.	mm
b_i	Inner minor axis of compensating plate.	mm
b_o	Outer minor axis of compensating plate.	mm
B_1	Distance from end plate of shell to centre of saddle.	mm
B_2	Width of saddle top plate.	mm
c	Corrosion allowance.	mm
C	Shape factor (figure 7).	
C_1	Constant depending on method of support as given in 3.14.2.4.	
C_2	Effective length of nozzle as given in 3.10.2 and figure 10.	mm
C_3	Factor for the calculation of stress at saddle support.	
d	Diameter of tube hole.	mm
d_i	Internal diameter.	mm
d_{ib}	Internal diameter of branch.	mm
d_{ip}	Diameter of inner periphery of circular pad or compensating plate.	mm
d_{is}	Internal diameter of main body (cylindrical shell, spherical shell or dished head).	mm
d_g	Depth of welded-on girder stay.	mm
d_m	Mean diameter.	mm
d_o	Outside diameter.	mm
d_{ob}	Outside diameter of branch.	mm
d_{op}	Diameter of outer periphery of circular pad or compensating plate.	mm
d_{os}	Outside diameter of main body.	mm

d_s	Diameter of stay.	mm
D_b	Gasket mean diameter.	mm
D_L	Bolt circle diameter.	mm
e	Minimum wall thickness.	mm
e_{cb}	Calculated wall thickness of branch or standpipe.	mm
e_{cf}	Calculated wall thickness of furnace.	mm
e_{cp}	Calculated wall thickness of end plate.	mm
e_{cs}	Calculated wall thickness of main body (cylindrical or spherical shell or dished head).	mm
e_{ct}	Calculated wall thickness of tube.	mm
e_g	Thickness of gusset stay.	mm
e_{rb}	Actual wall thickness of branch or standpipe minus allowances for corrosion and minus tolerances.	mm
e_{rep}	Actual wall thickness of flat end plate.	mm
e_{rf}	Actual wall thickness of furnace.	mm
e_{rp}	Effective wall thickness of reinforcing pad.	mm
e_{rs}	Actual wall thickness of main body (cylindrical or spherical shell or dished head) minus allowances for corrosion and minus tolerances.	mm
e_t	Ordered tube thickness.	mm
E	Young's modulus of elasticity at design temperature.	N/mm²
f	Nominal design stress.	N/mm²
f_a	Existing mean stress.	N/mm²
$f_{a\varphi}$	Existing mean stress between the centres of two openings.	N/mm²
f_b	Allowable stress for the branch material.	N/mm²
f_c	Combined stress at supports.	N/mm²
f_p	Allowable stress for the reinforcing plate material.	N/mm²
f_s	Allowable stress for the material of the main body.	N/mm²
F	Calculation heat flux.	W/m²
g, g_1	Clear height as shown in figure 13.	mm
G	Gas mass flow rate in first pass tubes.	kg/(m²·s)
h	Minimum width of gusset stay.	mm
h_c	Depth of curvature of dished head.	mm
h_f	Height of manhole frame.	mm
h_s	Length of skirt of dished head.	mm
H	Net heat input (burner heat release rate based on the net calorific value of the fuel plus any preheat).	W
I_1	Second moment of area of one complete furnace corrugation about its neutral axis excluding corrosion allowance.	mm⁴
I_2	Second moment of area of stiffeners.	mm⁴
K	Thermal conductivity.	(W·mm)/(m²·K)
l_{rb}	Effective length of branch contributing to reinforcement.	mm
l_{rbi}	Effective length of inward projection of set-through branch contributing to reinforcement.	mm
l_{rp}	Effective width of reinforcing pad.	mm
l_{rs}	Effective length of main body contributing to reinforcement.	mm
L	Distance between two effective points of furnace support.	mm

L_1	Shortest distance from the edge of the access opening to the centre-line of the stay furthest away from the access opening, or, where there is no access opening, half the maximum distance between the centre-lines of the stays.	mm
L_2	Distance between the rear plate of the reversal chamber and the boiler back end plate.	mm
L_b	Length of boiler between end plates.	mm
l_i	Length of leg of fillet weld around inner periphery of pad or compensating plate.	mm
L_g	Length of welded-on girders.	mm
L_h	Heated length of furnace.	mm
L_o	Length of leg of fillet weld around outer periphery of pad or compensating plate.	mm
L_s	Length of shell between end plates.	mm
L_t	Mean pitch of adjacent tubes.	mm
p	Calculation pressure.	N/mm^2
p_b	Centre-to-centre distance of adjacent openings, referred to wall centre, without allowances.	mm
$p_{b\varphi}$	Centre-to-centre distance of adjacent openings, offset by angle φ, referred to wall centre without allowances.	mm
p_c	Pitch of corrugations.	mm
p_t	Hydrostatic test pressure.	N/mm^2
Q	Force on saddle.	N
r_{ik}	Inside radius of knuckle of dished head.	mm
r_{is}	Inside radius of curvature of dished head or spherical shell.	mm
r_{ms}	Mean radius of shell.	mm
r_{ok}	Outside radius of knuckle of dished head.	mm
r_{os}	Outside radius of curvature of dished head or spherical shell.	mm
R_m	Minimum tensile strength for the grade of material concerned at room temperature.	N/mm^2
$R_{p0,2}$	Minimum value of yield point (0,2 % proof stress) for the grade of material concerned at temperature t.	N/mm^2
S	Pitch of welded-on girders.	mm
S_1	Factor of safety.	
S_2	Factor of safety.	
S_o	Original cross-sectional area of test piece subjected to a tensile test.	mm^2
t	Calculation temperature.	°C
t_m	Maximum metal temperature.	°C
t_s	Saturation temperature corresponding to design pressure.	°C
u	Out-of-roundness, or ovality.	%
v	Weld factor.	
w	Depth of corrugations.	mm
W	Force exerted by the pressure on the end plate in the zone assumed to be supported by the gusset.	N
x	Stress reduction factor.	
X_2	Cross-sectional area of longitudinal section of furnace wall of length equal to one pitch and thickness $e_{rf} - c$.	mm^2
y	Factor determined from figure 18 using the ratio b/a.	
φ	Angle of connecting lines between the centres of two openings relative to the axis of the main body.	degree

ψ Angle of inclination of branch relative to the normal to the circumferential line of the main body.   degree

θ Angle subtended by the saddle.   degree

1.5 Information to be supplied by the purchaser and the manufacturer

1.5.1 Information to be supplied by the purchaser

The purchaser shall disclose to the manufacturer at the time of the enquiry

a) the name of the inspecting authority representing the purchaser,

b) the conditions under which the boiler will be required to operate (see 3.1.1 and annex A), and

c) any special statutory or other regulations with which the boiler is required to comply (e.g. boiler laws in countries other than that of manufacture).

See annex A for further information.

1.5.2 Information to be supplied by the manufacturer

Prior to the construction of a boiler or a series of boilers, the manufacturer of the boiler(s) shall supply the inspecting authority with a list of materials, calculations for major design details and fully dimensioned sectional drawings showing in full detail the construction of all the pressure parts of the boiler, including weld details (for further information, see annex B). The manufacturer shall also furnish certificates and documentation in accordance with 7.1.

The boiler manufacturer shall supply the purchaser with operating instructions appropriate to the equipment supplied. Where alternative methods of manufacture or testing are permitted by this International Standard, the manufacturer shall disclose to the purchaser or the inspecting authority, or both, the method selected by him before putting the work in hand.

Section 2:   Materials

2.1   Introduction

The provisions of section 2 cover

a) plates,

b) wrought seamless, electric resistance welded and induction welded tubes,

c) forgings, and

d) weld metal

of carbon and carbon manganese steels for pressure parts of shell boilers covered by this International Standard.

NOTE 1   The word "tube" refers also to "pipe".

2.2   General

2.2.1   Basic materials

2.2.1.1   Shell boilers shall be constructed from steel products selected in accordance with a), b) or c) as follows:

a) steel products of the types listed in table 1, manufactured in accordance with ISO 2604-1, ISO 2604-2, ISO 2604-3 or ISO 9328-2, and which comply in all respects with the minimum requirements of this International Standard;

b) steel products of the types listed in table 1, manufactured in accordance with national standards or specifications, provided that these comply in all respects with the appropriate part of ISO 2604 or ISO 9328 for the steel type concerned and with the minimum requirements of this section;

c) steel products of the types listed in table 1, manufactured in accordance with national standards or specifications which do not comply in all respects with the requirements of the appropriate part of ISO 2604 or ISO 9328, provided that these comply in all respects with the minimum requirements of this section and are agreed between the interested parties.[2]

Subsequent references to ISO 2604 or ISO 9328 throughout this section shall be considered also to

include such non-ISO specifications referred to under b) and c) above.

2.2.1.2   Furnaces with a mean diameter not exceeding 1 400 mm shall be made either from plate to ISO 9328-2 steel types PH 265 or PH 290, or from hot-finished seamless steel tube to ISO 2604-2, TS 9H.

Furnaces with a mean diameter exceeding 1 400 mm shall be made from steel plate with a minimum percentage elongation of 24 % determined with reference to a gauge length of $5,65 \sqrt{S_o}$.

2.2.1.3   Cylindrical shells shall be manufactured from plate material only. Plate cut from strip shall be permitted provided that all the requirements for plate in this section are complied with.

2.2.2   Weld metal

In the absence of International Standards for the composition and properties of weld metal suitable for use with the various grades of steels covered in 2.2.1, the welding process and weld metal (electrodes, filler wire, etc.) to be used shall be agreed between the parties concerned as suitable for the parent metals concerned and for the design conditions of the vessel. This agreement shall take account of successful past service and/or test results on the weld metal. Where relevant national standards or specifications exist, the weld materials shall comply with these. The mechanical properties of the weld metal shall in all cases meet the requirements of 5.2.2 and 5.10 and also such other requirements as may be agreed between the parties.

2.3   Manufacture of the steel

2.3.1   Steel-making process

The steel shall be produced by the open-hearth, electric or one of the basic oxygen processes, or by a combination of these processes. Other processes may be used by agreement between the interested parties, who shall be informed of the steel-making process used.

2.3.2   De-oxidation

Rimming steels and semi-killed steels shall not be permitted.

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2) The circumstances of each instance, including any relevant contractual or regulatory requirements, will determine which of the interested parties (defined in section 1) are concerned in the agreements referred to in section 2.

2.4 Forgings

In the case of forgings, the steel shall be forged by hammering, drop forging, pressing, ring rolling, extruding, upsetting, or by any combination of these processes. Forging reduction shall be carried out under a tool of sufficient power and to an extent that will ensure ample working of the metal throughout its section. The forgings shall be brought, as nearly as practicable, to the finished shape and size by hot working.

2.5 Heat treatment

2.5.1 Plates and forgings shall be supplied in a heat-treated condition appropriate to the steel type as specified in the applicable International Standard, unless otherwise agreed by the interested parties. For plates, the application of controlled temperatures during or after rolling may take the place of normalizing, provided that this is permitted for the steel type concerned in the International material Standard, that the specified material properties would be complied with after an additional normalizing treatment, and that no contrary agreements have been made between the interested parties at the time of enquiry and order.

2.5.2 Unless otherwise agreed between the interested parties, seamless and welded tubes shall be supplied in one of the conditions appropriate to the steel type as specified in the applicable International Standard.

2.6 Chemical composition

2.6.1 For steels intended for welding, the upper limit of the carbon range (in the cast analysis) should, in general, not exceed 0,23 %. For steels with a carbon content higher than 0,23 % and up to a maximum of 0,25 %, which are intended for welding, welding procedures should be specially agreed between the parties concerned at the time of enquiry and order (see also 5.1.1 and 5.8.1).

2.6.2 In the cast analysis, phosphorous and sulfur contents shall not exceed 0,035 % and 0,030 % respectively.

2.6.3 If the interested parties consider that the level of particular residual elements, not already specified in the applicable International Standard, is important in relation to the mechanical and technological properties of the steel, an upper limit of the residual elements should be agreed between the parties concerned and shall be specified in the order.

2.7 Mechanical properties

2.7.1 Values for the mechanical properties used in the design of shell boilers shall be as specified in the applicable International Standard. The values specified shall cover the appropriate range of service temperature.

2.7.2 For all products the mechanical properties at room temperature shall be specified. These are the tensile strength range, the minimum specified yield strength, the minimum percentage elongation after fracture, and for tubes the test category and, where specified, the minimum impact test value (average of three tests).

2.7.2.1 The specified minimum tensile strength shall be not less than that given in table 1 for the corresponding products; the maximum tensile strength shall not exceed the minimum tensile strength by more than 120 N/mm² and shall in no case be higher than 580 N/mm².

2.7.2.2 The specified minimum percentage elongation after fracture referred to a gauge length of $5,65\sqrt{S_0}$ and, where specified, the minimum requirements for the impact, flattening, bend, drift expanding or flanging tests shall be appropriate to the type of steel and comparable to the value given in the International Standard [see 2.2.1.1 a)] for steels with a similar lower limit of the specified tensile strength range.

A minimum impact energy value of 27 J shall be obtained when testing transverse V-notch test pieces.

2.7.3 For all products the minimum 0,2 % proof stress at elevated temperature ($R_{p0,2}$) shall be specified.

2.7.3.1 When a sufficient amount of data is available, the minimum elevated-temperature proof stress values shall be derived in accordance with ISO 2605-1.

2.7.3.2 When only limited amounts of data are available, the minimum elevated-temperature proof stress values shall be derived in accordance with ISO 2605-3.

2.7.3.3 Minimum elevated-temperature proof stress values not derived according to 2.7.3.1 or 2.7.3.2 may also be used provided that

a) they are adopted for an International Standard for products for pressure purposes, or

b) they are listed in a national standard and are verified, where necessary, in accordance with 2.8.

2.8 Verification procedures

2.8.1 The compliance of the steel with the specifications for its chemical composition shall be verified by a cast analysis.

2.8.2 The specified room temperature properties shall be verified by acceptance tests.

For the verification of the yield strength, the upper yield stress R_{eH} or the 0,5 % total elongation proof stress $R_{t0,5}$ shall be measured, and the material specification is complied with in this respect if either value satisfies the specified value of yield strength.

2.8.3 The minimum elevated-temperature proof stress values shall be verified, where necessary, by

a) elevated-temperature acceptance testing in accordance with the appropriate part of ISO 2604, or

b) the procedure given in ISO 2605-1:1976, clause 3, or

c) a verification procedure acknowledged by the interested parties as equivalent to the verification procedure given in ISO 2605-1:1976, clause 3.

2.8.4 Where steel products are manufactured and supplied in accordance with ISO 2604, ISO 9328-2 or an equivalent national standard giving elevated-temperature proof stress values which do not exceed the values specified in ISO 2604 or ISO 9328-2 for a comparable steel, then the proof stress values specified in ISO 2604, ISO 9328-2 or in the equivalent national standard as appropriate, may be used for design purposes without verification.

Elevated-temperature acceptance testing in accordance with 2.8.3 a) shall be carried out only if so specified at the time the steel is ordered.

2.8.5 Where steel products are manufactured and supplied in accordance with a national standard which gives elevated-temperature proof stress values greater than the values specified in ISO 2604 or ISO 9328-2 for a comparable steel, then the values shall be verified in accordance with 2.8.3.

2.9 General rules for carrying out acceptance tests

Acceptance tests shall be carried out in accordance with the general rules given in ISO 2604-1, ISO 2604-2, ISO 2604-3 or ISO 9328-1 as appropriate.

2.10 Number, selection and preparation of samples and test pieces

The number, selection and preparation of samples and test pieces shall be in accordance with the appropriate part of ISO 2604 or with ISO 9328-1 except where otherwise stated in the following subclauses.

2.10.1 The minimum test requirements for tubes are

visual inspection,

hydraulic test,

tensile test, and

flattening or bend test.

Additionally, when tubes are to be expanded or swaged, a drift expanding or flanging test shall be carried out.

2.10.2 Impact tests on tubes are not required.

2.10.3 Every plate, tube and forging shall be inspected visually and appropriate checks shall be made for compliance with the dimensional tolerances.

2.11 Method of testing

2.11.1 The tests shall be made in accordance with the relevant International Standards. If no appropriate International Standard exists, the methods to be used shall be agreed upon between the interested parties and specified at the time of enquiry and order.

2.11.2 For elevated-temperature tests, the testing temperature shall be agreed upon between the interested parties at the time of enquiry and order.

2.12 Retests

Retests shall be carried out in accordance with the corresponding specifications in the appropriate parts of ISO 2604 or in ISO 9328-1.

2.13 Documents

2.13.1 For all steel products, the type of inspection certificate or inspection report (see ISO 10474:1991, section 3) shall be agreed by the interested parties at the time of enquiry and order.

NOTE 2   Use may be made of the model form given in annex E.

2.13.2 For steels with a specified minimum tensile strength of less than 460 N/mm², it may be satisfactory to select inspection certificate 3.1.B in accordance with ISO 10474:1991, namely that inspection and testing shall be carried out by the qualified department of the steel manufacturer's works.

2.13.3 For steels with a specified minimum tensile strength equal to or greater than 460 N/mm², inspection report 3.2 in accordance with ISO 10474:1991 shall be selected except that the inspection and testing shall be carried out in the presence of the inspecting authority.

2.14 Marking

The products shall be marked in accordance with the requirements of ISO 2604-1, ISO 2604-2, ISO 2604-3 or ISO 9328-1 as appropriate.

Table 1 — Internationally standardized steel types for shell boilers

Tensile strength R_m [1]	Steel types			
	Plates	Tubes seamless	Tubes electric resistance or induction welded	Forgings
	in accordance with			
	ISO 9328-2 [2]	ISO 2604-2 [2]	ISO 2604-3 [2]	ISO 2604-1 [2]
320 to 440	—	TS 2 [3]	—	—
360 to 480	—	TS 5	TW 5	—
410 to 530	PH 265	TS 9H	TW 9H	F8, F9
460 to 580	PH 290	—	—	—

[1] The tensile strength values given in this table are for classification purposes only. The governing specifications are those given in the appropriate product standard.

[2] Or in accordance with 2.2.1.1 b) or c).

[3] TS 2 material may be used only for smoke tubes.

Section 3: Design of the parts under pressure

3.1 General

3.1.1 Boilers

The requirements in this International Standard apply to boilers constructed throughout under the conditions specified herein and which are to be operated under normal operating conditions, with good feed-water and boiler water in accordance with annex D, and under adequate supervision. Where risk of abnormal working conditions, such as severe cyclic service, is foreseen, the design shall be given special consideration and shall be made known to the inspecting authority.

3.1.2 Generators

For hot-water generators and superhot-water generators, the difference between the starting temperature (outlet) and the return temperature (inlet) should not exceed 30 °C. If the difference between the flow and return temperature is greater than 30 °C, either internal or external mixing devices shall be used to limit the differential temperature within the boiler to 30 °C.

The difference between the saturation temperature corresponding to the total gauge pressure and the inlet temperature shall not exceed 80 °C. For differences over 60 °C, the breathing spaces given in 3.14.1 shall be increased by 50 %, and the maximum net heat input shall be reduced by at least 20 % to allow for the reduction of the cold-water cooling conditions and the increase in heat input due to the large temperature differences, unless other arrangements are used to the same end.

3.1.3 Design of principal welded seams

3.1.3.1 The types of weld employed in the design of the boiler shall be in accordance with 5.3.2.5. Welds which are subjected to non-destructive testing in accordance with the requirements of this International Standard shall be designed so that the required tests can be properly carried out.

3.1.3.2 The value of the weld factor v used in the calculation for the shell thickness shall be either 0,8 or 1 depending on the extent of testing to be carried out (see 3.7.1, 5.5.5.1 and 5.8.17.1).

3.2 Design pressure

The design pressure is the maximum allowable set pressure of the safety valves.

3.3 Calculation pressure

The calculation pressure shall be taken as the design pressure plus the hydrostatic head where this exceeds 3 % of the design pressure.

3.4 Calculation temperature

The calculation temperature shall be the mean metal temperature and shall be determined as specified in a) to e) below. In no case shall it be less than 150 °C.

a) For shells, drums and other components not designed for heat transfer purposes, the calculation temperature shall be not less than the saturation temperature corresponding to the design pressure.

b) For smoke tubes, the calculation temperature shall be determined in accordance with the following equations:

$$t = (t_s + 2e) \qquad \ldots (3.1)$$

or

$$t = (t_s + 25) \qquad \ldots (3.2)$$

whichever is the greater, with a minimum of 250 °C.

c) The calculation temperature for plain areas of plate 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 equation

$$t = (t_s + 50) \qquad \ldots (3.3)$$

or equation (3.1):

$$t = (t_s + 2e)$$

whichever is the greater, with a minimum of 250 °C. Combustion is to be completed in the furnace.

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 C, using the true gas entry temperature t_G determined from the following equation with a minimum of 250 °C:

$$t_G = 51 \left(\frac{H}{A} \right)^{0,25} \qquad \ldots (3.4)$$

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 C.

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

These requirements are based on good contact between smoke tubes and tube sheet. Where this cannot be ensured, the following limitations apply [see figure 32 f)]:

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.

e) The calculation temperature for furnaces shall be determined in accordance with the following equation

$$t = t_s + 4e + 15 \qquad \ldots (3.5)$$

with a minimum of 250 °C.

Equation (3.5) gives the calculated temperature for the purpose of determining the nominal design stress and does not represent the maximum metal temperature.

3.5 Furnaces

In order to ensure safe burner/boiler combinations, the net heat input for a given furnace tube inside diameter shall not exceed the value given in figure 6. On/off type burners (100 % to 0 %) shall not be used for heat inputs exceeding 1 MW per furnace.

Deviation from the values given in figure 6, and net heat input values greater than 11,5 MW, are permitted by agreement between the interested parties: mainly the boiler manufacturer, the burner manufacturer and the inspecting authority.

The agreement, and all conditions on which it is based, shall be stated in the boiler certificate and made known to the user.

When boilers are designed with net heat input greater than 11,5 MW, special consideration shall be given in the determination of the calculated temperature, maximum heat flux, breathing spaces and possible smoke tube support.

The length of the refractory should not be greater than 400 mm measured from the end of the atomizer.

3.6 Nominal design stress

The nominal design stress f shall be the lower of the values obtained from the following ratios:

$$\frac{R_{p0,2}}{1,5} \quad \text{and} \quad \frac{R_m}{2,4}$$

NOTE 3   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 section 3 will maintain the actual maximum stresses within acceptable limits for the type of loading considered.

3.7 Cylindrical shells under internal pressure

3.7.1 Minimum thickness for pressure loading only

Subject to the conditions specified in 3.7.2, the minimum thickness e for pressure loading only shall be calculated from the following equations:

$$e = e_{cs} + c \qquad \ldots (3.6)$$

where

$c = 0,75$ mm (corrosion allowance);

$$e_{cs} = \frac{pd_o}{2fv + p} \qquad \ldots (3.7)$$

When calculating e, any negative thickness tolerances shall be taken into account.

For boilers having an outside shell diameter greater than 1 000 mm the shell wall shall not be less than 6 mm thick.

For boilers having an outside shell diameter equal to or less than 1 000 mm the shell wall shall not be less than 4 mm or $(e_{cs} + c)$ mm thick, whichever is the greater.

The value of the weld factor v shall depend on the extent of non-destructive testing of the longitudinal welded seam in accordance with 3.1.3.2 and 5.5.5.1.

3.7.2 Conditions of application of formulae (3.6) and (3.7)

Formulae (3.6) and (3.7) (see 3.7.1) shall apply only if the following conditions are fufilled.

a) The ratio of the outside radius to the inside radius does not exceed 1,5.

b) At the welded seams the mid-thickness lines are an extension of each other within the alignment tolerances specified in 5.8.10.

c) A cylindrical shell shall conform to the tolerances specified in 4.3.2.

3.8 Unstayed dished heads without openings

3.8.1 Unstayed dished heads under internal pressure

The minimum thickness of unstayed dished heads without openings shall be in accordance with equation (3.6)

$$e = e_{cs} + c$$

where $c = 0,75$ mm (corrosion allowance), and the following equation:

$$e_{cs} = \frac{pd_o C}{2f} \qquad \ldots (3.8)$$

In addition, the thickness of a torispherical head shall not be less than that given by equation (3.6)

$$e = e_{cs} + c$$

where $c = 0,75$ mm (corrosion allowance), and the following equation:

$$e_{cs} = \frac{pr_{is}}{2f - 0,5p} \qquad \ldots (3.9)$$

The shape factor C for unstayed dished heads without openings shall be as given in figure 7. However, the limiting conditions given in 3.8.2 shall apply.

3.8.2 Limiting conditions

a) Hemispherical heads

$$0,005d_o \leqslant e_{cs} \leqslant 0,16d_o$$

b) Ellipsoidal heads

$$0,005d_o \leqslant e_{cs} \leqslant 0,08d_o$$

$$h_c \geqslant 0,18d_o$$

c) Torispherical heads

$$0,005d_o \leqslant e_{cs} \leqslant 0,08d_o$$

$$r_{ik} \geqslant 0,1d_o$$

$$r_{ik} \geqslant 2e_{cs}$$

$$r_{is} \leqslant d_o$$

$$h_c \geqslant 0,18d_o$$

or

$$0,01d_o \leqslant e_{cs} \leqslant 0,03d_o$$

$$r_{ik} \geqslant 0,1d_o$$

$$h_c = 0,18d_o$$

or

$$0,02d_o \leqslant e_{cs} \leqslant 0,03d_o$$

$$r_{ik} \geqslant 0,1d_o$$

$$0,18d_o \leqslant h_c \leqslant 0,22d_o$$

The two relationships in b) and the three or five relationships in c) shall be fulfilled simultaneously.

3.8.3 Unstayed dished heads under external pressure

The calculation pressure p shall be the lower of the values obtained from the following equations:

$$p = \frac{e_{cs}R_{p0,2}}{1,2r_{os}} \qquad \ldots (3.10)$$

$$p = \frac{0,8E}{9 + 0,006\left(\frac{r_{os}}{e_{cs}}\right)} \times \left(\frac{e_{cs}}{r_{os}}\right)^2 \qquad \ldots (3.11)$$

In addition, the thickness of torispherical and ellipsoidal heads under external pressure shall be not less than 1,2 times the thickness required for a head of the same shape subject to internal pressure (see 3.8.1), with or without openings reinforced according to 3.9.

3.9 Design of openings in cylindrical shells, spherical shells and dished heads

3.9.1 General

3.9.1.1 The design methods specified in 3.9.2 to 3.9.4 shall apply to cylindrical shells, spherical shells and dished heads having circular or elliptical openings, where the assumptions and conditions specified in 3.9.1.2 to 3.9.1.9 have been taken into consideration.

Forces/moments caused by loads arising from sources other than internal pressure are not included when calculating reinforcements.

3.9.1.2 Cylindrical shells, spherical shells and dished heads with openings shall be reinforced where necessary. The reinforcement of the main body can be obtained by the following measures:

a) by an increased wall thickness of the main body compared with that of the shell without openings [see figures 8 a) and 8 b)];

b) by set-on welded compensating plates [see figures 8 c) and 8 d)];

c) by set-in welded pads [see figures 8 e) and 8 f)];

d) by set-on or set-in welded branches [see figures 8 g) and 8 h)];

e) by combinations of the above-mentioned measures [see figures 8 i) and 8 j)].

3.9.1.3 The reinforcement areas of the main body with openings cannot be calculated directly but shall be assumed in the first instance. That assumption may be verified by means of the methods laid down. The applied method is derived from formula (3.7) for cylindrical shells and from formula (3.8) for spherical shells and spherical sections of dished heads respectively and leads to relationships between a pressure-loaded area A_p and a stress-loaded cross-sectional area A_f. Under certain circumstances the calculation may need to be repeated using a corrected assumption of the reinforcement area.

3.9.1.4 Where necessary, sufficient reinforcement shall be provided in all planes through the axis of the opening or branch.

3.9.1.5 For cylindrical shells and spherical shells, the ratio between the internal diameters of the opening or branch and of the main body shall fulfill the condition

$$d_{ib}/d_{is} \leqslant 0.5$$

For dished heads, the openings or branches shall be located within the spherical portion of the head.

3.9.1.6 In the case of elliptical openings, the ratio between the major and the minor axis shall not exceed 1,5. For elliptical openings in cylindrical shells, the axis extending in the direction of the longitudinal axis of the shell shall be taken as the diameter for design purposes. For elliptical openings in spherical shells, the major axis shall be so taken.

3.9.1.7 If the main body and the reinforcement consist of materials with different allowable stresses and if the lowest allowable stress f applies to the material of the main body, that stress governs for the calculation of the entire design, provided that the ductility of the reinforcement is not significantly lower than that of the main body.

3.9.1.8 Set-in or set-on welded branches which are fillet welded without full penetration [see figures 8 n) and 8 o)] shall not be considered as reinforcement and shall be calculated in accordance with 3.9.2.1.

3.9.1.9 Reinforcement of openings by compensating plates is permitted only under the following conditions:

diameter ratio $d_{ib}/d_{is} \leqslant 0.3$

opening temperature $\leqslant 250$ °C

When any part of a compensating plate with an outer diameter $d_{op} > 200$ mm is situated below the boiler water level, any insulation covering the compensating plate shall be capable of being removed for periodic inspection.

3.9.2 Cylindrical shells, spherical shells and dished heads with isolated openings

3.9.2.1 Reinforcement by increased wall thickness

The reinforcement can be attained by an increased wall thickness of the main body, compared with that without openings. This wall thickness shall exist at least up to a distance

$$l_{rs} = \sqrt{(d_{os} - e_{rs})e_{rs}} \qquad \ldots (3.12)$$

measured from the edge of the opening, as shown in figures 8 a) and 8 b).

Furthermore the following condition also applies:

$$f_a = p\left(\frac{A_p}{A_f} + \frac{1}{2}\right) \leqslant f \qquad \ldots (3.13)$$

3.9.2.2 Reinforcement of isolated openings by compensating plates

Compensating plates shall have close contact with the main body.

The width of compensating plates l_{rp} considered as contributing to the reinforcement, and used to determine A_{fp} in formulae (3.16) and (3.17), shall not exceed l_{rs}:

$$l_{rp} \leqslant l_{rs} = \sqrt{(d_{os} - e_{rs})e_{rs}} \qquad \ldots (3.14)$$

according to figures 8 c) and 8 d).

The value of e_{rp} used to determine A_{fp} in formulae (3.16) and (3.17) shall not exceed e_{rs}, and the actual thickness of the compensating plates shall not exceed twice the actual wall thickness of the main body:

$$e_{rp} \leqslant 2e_{rs} \qquad \ldots (3.15)$$

The following conditions shall apply when the allowable stress f_s for the material of the main body is equal to or lower than the allowable stress f_p for the material of the compensating plate:

$$f_a = p\left(\frac{A_p}{A_{fs} + 0{,}7A_{fp}} + \frac{1}{2}\right) \leqslant f \qquad \ldots (3.16)$$

Otherwise the following condition applies:

$$\left(f_s - \frac{p}{2}\right)A_{fs} + \left(f_p - \frac{p}{2}\right)0{,}7A_{fp} \geqslant pA_p \quad \ldots (3.17)$$

3.9.2.3 Reinforcement of isolated openings by pads

Only pads of the set-in welded type in accordance with figures 8 e) and 8 f) shall be used, and when the following width/thickness relationships occur simultaneously, the boiler shall be stress relieved:

$$l_{rp} > 2{,}5e_{rs}$$

$$e_{rp} > 3e_{rs}$$

The width of the pads l_{rp} considered as contributing to the reinforcement, and used to determine A_{fp} in formulae (3.18) and (3.19), shall not exceed l_{rs}:

$$l_{rp} \leqslant l_{rs} = \sqrt{(d_{os} - e_{rs})\,e_{rs}}$$

The value of e_{rp} used to determine A_{fp} in formulae (3.18) and (3.19) shall not exceed twice e_{rs}.

The following conditions shall apply when the allowable stress f_s for the material of the main body is equal to or lower than the allowable stress f_p for the material of the pad:

$$f_a = p\left(\frac{A_p}{A_{fs} + A_{fp}} + \frac{1}{2}\right) \leqslant f \qquad \ldots (3.18)$$

Otherwise the following condition applies:

$$\left(f_s - \frac{p}{2}\right)A_{fs} + \left(f_p - \frac{p}{2}\right)A_{fp} \geqslant pA_p \qquad \ldots (3.19)$$

3.9.2.4 Reinforcement of isolated openings by branches

The wall thickness of branches (nozzles) shall be in excess of the thickness calculated to withstand internal pressure for a length l_{rb} measured from the exterior wall of the main body [see figures 8 g) and 8 h)]. This requirement is independent of any reinforcement provided either by increasing the wall thickness of the main body or by fitting compensating plates [see figures 8 i) and 8 j)].

The maximum value of the branch or nozzle thickness e_{rb} shall be not greater than twice the shell thickness e_{rs} up to a diameter ratio of 0,2:

$$e_{rb} \leqslant 2e_{rs} \text{ for } \frac{d_{ib}}{d_{is}} \leqslant 0{,}2 \qquad \ldots (3.20)$$

The maximum value of the branch or nozzle thickness e_{rb} shall be not greater than the shell thickness e_{rs} for diameter ratios greater than 0,7:

$$e_{rb} \leqslant e_{rs} \text{ for } \frac{d_{ib}}{d_{is}} > 0{,}7 \qquad \ldots (3.21)$$

Between the limits $d_{ib}/d_{is} = 0{,}2$ and 0,7, the maximum value of e_{rb} in terms of e_{rs} shall be determined by linear interpolation [see figure 8 k)].

The above-mentioned conditions governing the wall thickness ratio shall not apply to access and inspection openings.

3.9.2.4.1 Isolated openings with vertically arranged branch connections

3.9.2.4.1.1 The following conditions apply for a vertical branch connection without reinforcing plate

$$f_a = p\left(\frac{A_p}{A_{fs} + A_{fb}} + \frac{1}{2}\right) \leqslant f \qquad \ldots (3.22)$$

and with reinforcing plate

$$f_a = p\left(\frac{A_p}{A_{fs} + A_{fb} + 0{,}7A_{fp}} + \frac{1}{2}\right) \leqslant f \quad \ldots (3.23)$$

The areas A_p, A_{fs}, A_{fb} and A_{fp} shall be determined in accordance with figures 8 g) to 8 j), where the lengths contributing to the reinforcement shall be not more than

$$l_{rs} = \sqrt{(d_{os} - e_{rs})e_{rs}}$$

for the shell, and

$$l_{rb} = 0{,}8\sqrt{(d_{ob} - e_{rb})e_{rb}} \qquad \ldots (3.24)$$

for the branch.

The maximum value to be used in the calculation of the part extending inside, if any, in the case of set-through branches [see figures 8 h) to 8 j)] shall be

$$l_{rbi} = 0{,}5l_{rb} \qquad \ldots (3.25)$$

The dimensions of the reinforcing plate to be used in the calculation shall be

$$e_{rp} \leqslant e_{rs}$$

and

$$l_{rp} \leqslant l_{rs}$$

15

3.9.2.4.1.2 Formulae (3.22) and (3.23) apply only when the allowable stress f_s for the material of the main body is equal to or lower than the allowable stress f_b for the branch and f_p for the reinforcing plate.

3.9.2.4.1.3 When the allowable stress f_b or f_p is lower than the allowable stress f_s of the main body, the following conditions shall apply:

without reinforcing plate

$$\left(f_s - \frac{p}{2}\right)A_{fs} + \left(f_b - \frac{p}{2}\right)A_{fb} \geqslant pA_p \qquad \ldots (3.26)$$

and with reinforcing plate

$$\left(f_s - \frac{p}{2}\right)A_{fs} + \left(f_b - \frac{p}{2}\right)A_{fb} +$$

$$+ \left(f_p - \frac{p}{2}\right)0{,}7A_{fp} \geqslant pA_p \qquad \ldots (3.27)$$

The allowable stresses f_b and f_p to be used in formulae (3.26) and (3.27) shall not exceed the value of f_s.

3.9.2.4.1.4 Formed branches in cylindrical shells, spherical shells and dished heads as shown in figures 8 l) and 8 m) may be calculated in accordance with formula (3.22). The areas A_p and A_f to be used therein shall be determined as shown in figures 8 l) and 8 m) where A_f shall be multiplied by 0,9 to compensate for manufacturing inaccuracies. The lengths l_{rs} and l_{rb} contributing to the reinforcement shall be in accordance with formulae (3.12) and (3.24).

3.9.2.4.2 Isolated openings with non-radial branch connections

3.9.2.4.2.1 Cylindrical shells with a non-radial branch

The following items apply to branches on cylindrical shells lying in a plane perpendicular to the longitudinal axis of the shell and having an angle ψ, formed with the normal, which shall not exceed 50°.

The higher stress may occur in the lateral section or in the longitudinal section [see figure 9 a)]. Formula (3.18) or (3.26) shall apply to both cases with the areas A_p and A_{fs} [as shown in the lateral and longitudinal sections of figure 9 a)] to be used in the calculation.

The maximum length considered as contributing to the reinforcement shall be evaluated for the main body in accordance with formula (3.12), and for the branch in accordance with formula (3.24).

3.9.2.4.2.2 Spherical shells with a non-radial branch

Where branches in spherical shells lie in a plane that contains the axis of the branch and the centre of the spherical shell, using the symbols shown in figure 9 b), spherical shells with a branch not radially arranged shall be calculated in accordance with 3.9.2.4.1.

3.9.3 Cylindrical shells, spherical shells and dished heads with multiple openings and branches

3.9.3.1 Cylindrical shells with multiple openings and branches

3.9.3.1.1 Adjacent openings or branches may be regarded as single openings or single branches, if the centre-to-centre distance $p_{b\varphi}$ as shown in figure 9 c) complies with the relation

$$p_{b\varphi} \geqslant \frac{d_{ob1}}{2} + \frac{d_{ob2}}{2} + 2\sqrt{(d_{os} - e_{rs})e_{rs}} \qquad \ldots (3.28)$$

3.9.3.1.2 Where $p_{b\varphi}$ is smaller, the following strength consideration

$$f_{a\varphi} = p\,\frac{A_{ps}\frac{1}{2}(1 + \cos^2\varphi) + A_{pb1} + A_{pb2}}{A_{fs} + A_{fb1} + A_{fb2}} +$$

$$+ \frac{p}{2} \leqslant f \qquad \ldots (3.29)$$

applies in addition to 3.9.2.4.1.1 to 3.9.2.4.1.3 for the cross-section extending through the adjacent openings or branches at the angle φ with the longitudinal axis of the cylindrical shell in accordance with figure 9 c).

3.9.3.1.3 Where the cylindrical shell, branch and reinforcement consist of materials having different allowable stresses and where the allowable stress of the branch is less than that of the cylindrical shell, the following applies in accordance with figure 9 c):

$$\left(f_s - \frac{p}{2}\right)A_{fs} + \left(f_{b1} - \frac{p}{2}\right)A_{fb1} + \left(f_{b2} - \frac{p}{2}\right)A_{fb2}$$

$$\geqslant \frac{p}{2}\left[A_{ps}(1 + \cos^2\varphi) + 2A_{pb1} + 2A_{pb2}\right] \qquad \ldots (3.30)$$

Where the allowable stress of the material of the cylindrical shell is less than that of the material of the branches, the procedure to be followed shall comply with the appropriate requirements in 3.9.2.4.1.2.

3.9.3.1.4 For adjacent openings or branches with identical diameter, made of materials with identical allowable stress and with smaller centre-to-centre distances $p_{b\varphi}$ than that obtained from formula (3.28),

the following will result according to figure 9 c) at $A_{pb1} = A_{pb2}$ and $A_{fb1} = A_{fb2}$:

$$f_{a\varphi} = p \frac{A_{ps} \frac{1}{2}(1 + \cos^2\varphi) + 2A_{pb1}}{A_{fs} + 2A_{fb1}} +$$

$$+ \frac{p}{2} \leqslant f \qquad \ldots (3.31)$$

Where materials with different allowable stress are used, the procedure to be followed shall be governed by the appropriate requirements given in 3.9.3.1.3 for the use of formula (3.30).

3.9.3.1.5 For groups of holes, the strength consideration shall be conducted for the ligaments extending in longitudinal, circumferential and diagonal directions.

3.9.3.1.6 The requirements of 3.9.3.1.1 to 3.9.3.1.5 shall be permitted to be used for adjacent branches not radially arranged.

3.9.3.2 Spherical shells and dished heads with multiple openings and branches

Adjacent openings or branches may be treated as an isolated opening or an isolated branch, if the length of the arc p_b as per figure 9 d) complies with the relation

$$p_b \geqslant \left\{ \arcsin\left[\frac{(d_{ob1}/2) - e_{rb1}}{r_{os} - (e_{rs}/2)} \right] + \right.$$

$$+ \left. \arcsin\left[\frac{(d_{ob2}/2) - e_{rb2}}{r_{os} - (e_{rs}/2)} \right] \right\} \times$$

$$\times \left(r_{os} - \frac{e_{rs}}{2} \right) + 2\sqrt{(2r_{os} - e_{rs})\,e_{rs}} \quad \ldots (3.32)$$

where the argument of arcsin is in radians.

Where p_b does not comply with formula (3.32), the strength calculation shall be carried out as follows:

$$f_a = p\left(\frac{A_p}{A_{fs} + A_{fb1} + A_{fb2}} + \frac{1}{2} \right) \leqslant f \qquad \ldots (3.33)$$

When the branch material has a higher allowable stress than the material of the spherical shell or dished head, then the appropriate relationships in 3.9.2.4.1.2 shall apply.

If the allowable stress of the branches is lower than that of the dished head or the spherical shell, then the following relationship shall apply:

$$\left(f_s - \frac{p}{2} \right) A_{fs} + \left(f_{b1} - \frac{p}{2} \right) A_{fb1} +$$

$$+ \left(f_{b2} - \frac{p}{2} \right) A_{fb2} \geqslant pA_p \qquad \ldots (3.34)$$

3.9.4 Design of large isolated openings in headers or tubes with vertical branches or nozzles secured by welding

3.9.4.1 These requirements apply to openings for branches or nozzles in headers or tubes with the following relationship:

$$0{,}5 < d_{ib}/d_{is} \leqslant 1$$

The relationships between the ratios e_{rb}/e_{rs} and d_{ib}/d_{is} shall be in accordance with the requirements of 3.9.2.4, and formulae (3.20) and (3.21) as appropriate.

3.9.4.2 The rules for calculation given in 3.9.2.4.1.1 shall be applied where appropriate, provided that the following additional condition is satisfied in the cross-section perpendicular to the axis of the main body (header or tube) in the transition zone of the main body and branch:

$$\frac{p}{1{,}5} \left(\frac{d_{is} + e_{rs}}{2e_{rs}} + 0{,}2\,\frac{d_{ib} + e_{rb}}{e_{rb}} \times \right.$$

$$\left. \times \sqrt{\frac{d_{is} + e_{rs}}{e_{rs}}} \right) \leqslant f \qquad \ldots (3.35)$$

Where the main body and the branch are made from materials having different allowable stresses, the lowest value of f shall be used.

3.10 Design of isolated openings in shell boiler flat end plates

3.10.1 Unreinforced openings

The maximum diameter of an unreinforced opening in a flat end plate shall be determined from the following equation:

$$d_{max} = 8e_{rep}\left(1{,}5\,\frac{e_{rep}^2}{e_{cp}^2} - 1 \right) \qquad \ldots (3.36)$$

3.10.2 Branch openings

Reinforcement for branch openings shall be achieved by taking account of locally disposed material, including the attachment welds, in excess of the minimum requirements for end plate and branch thickness as shown in figure 10. The branch thickness shall be increased where required. Compensation shall be considered adequate when the

compensating area Y is equal to or greater than the area X requiring compensation.

Area X shall be obtained by multiplying 25 % of the inside radius of the branch by the thickness of the flat end plate, calculated from formula (3.43) for the part of the end plate under consideration.

Area Y shall be measured in a plane through the axis of the branch parallel to the surface of the flat end plate, and shall be calculated as follows.

a) For that part of the branch which projects outside the boiler, calculate the full sectional area of the branch up to a distance C_2 from the actual outer surface of the flat end plate and deduct from it the sectional area which the branch would have within the same distance if its thickness were calculated in accordance with formulae (3.6) and (3.7), taking $v = 1$.

b) Add to it the full sectional area of that part of the branch which projects inside the boiler (if any) up to a distance C_2 from the inside surface of the flat end plate.

c) Add to it the sectional area of the fillet welds.

d) Add to it the area obtained by multiplying the difference between the actual flat end plate thickness and its thickness calculated from formula (3.43) for the part of the end plate under consideration by the length D.

e) Add to it the area of the compensating plate (if any) within the limits of reinforcement shown in figure 10.

Where material having a lower allowable stress than that of the flat end plate is taken as compensation, its effective area shall be reduced in the ratio of the allowable stresses at the calculation temperature. No credit shall be taken for the additional strength of material having a higher allowable stress than that of the flat end plate.

Welds attaching branches and compensating plates shall be of sufficient size to transmit the full strength of the reinforcing area and all other loadings to which they may be subjected.

3.10.3 Manholes, headholes and handholes

When elliptical manholes, headholes or handholes are located in flat end plates the openings shall be compensated by flanging the edge of the opening or by the provision of a stiffening ring (see figure 11). The method given in 3.10.2 for calculating the required area of reinforcement shall be used where applicable except that the width of the flange or stiffening ring e_{sr} shall be not less than 19 mm for manholes, 15 mm for headholes and 10 mm for handholes.

Area X shall be obtained by multiplying half the mean of the major and minor semi-axes of the opening by the thickness of the flat end plate, calculated from formula (3.43) for the part of the end plate under consideration.

The full width of the flange or stiffening ring may be used when calculating area Y.

3.11 Fillet welds attaching compensating plates to shells under internal pressure

The sizes L_i of the inner fillet welds by which compensating plates are attached to shell plates (see figure 12) shall comply with the following relationship:

$$L_i \geqslant 0.7 e_{rp} \qquad \ldots (3.37)$$

The sizes L_o of the outer peripheral fillet welds by which compensating plates (see figure 12) 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:

$$L_o = \frac{d_{ip}(2e_{rs} - L_i)}{d_{op}} \qquad \ldots (3.38)$$

For elliptical compensating plates

$$d_{op} = \frac{a_o + b_o}{2} \qquad \ldots (3.39)$$

$$d_{ip} = \frac{a_i + b_i}{2} \qquad \ldots (3.40)$$

3.12 Minimum thickness of nozzles and branch connections

The thickness of nozzles and branches shall be in accordance with 3.15.2, but the thickness shall be not less than given by the following equation:

$$e = (0.015 d_{ob} + 3.2) \geqslant 4 \qquad \ldots (3.41)$$

3.13 Access and inspection openings

3.13.1 General requirements

3.13.1.1 All boilers shall be provided with openings adequate in size and number to allow access for fabrication, cleaning and internal inspection (see the guidelines in 3.13.5.1). The dimensions of the openings shall be in accordance with 3.13.2 to 3.13.4.

3.13.1.2 Boilers with a shell diameter d_o of 1 400 mm or greater shall be designed to permit entry of a person and shall be provided with a manhole for this purpose.

Boilers with a shell diameter d_o less than 1 400 mm, which are capable of being entered by a person, shall be provided with a manhole. Boilers with a shell diameter between 800 mm and 1 400 mm shall be provided with a headhole as a minimum requirement.

3.13.1.3 The number, size and location of access and inspection openings will vary according to the boiler design. The following guidelines are intended to ensure that a good representative visual examination of the welded seams is possible.

3.13.1.4 Detachable ends or covers may replace all the other examination holes if, by their dimensions and position, a general view of the interior is provided which is at least equivalent to that obtained by the examination holes which otherwise would be required.

3.13.2 Types and minimum dimensions of access and inspection openings

Openings shall be elliptical or circular. See figures 11 and 13 a) to 13 i).

a) **Handholes**

A handhole for cleaning shall be not less than 80 mm × 100 mm or shall have an inside diameter of 100 mm.

A handhole for inspection shall be not less than 100 mm × 150 mm or shall have an inside diameter of 120 mm. The height of the neck or ring shall not exceed 65 mm, or 100 mm if the neck or ring is conical.

b) **Headholes**

Headholes shall be not less than 220 mm × 320 mm or shall have an inside diameter of 320 mm. The height of the neck or ring shall not exceed 100 mm, or 120 mm if the neck or ring is conical.

c) **Manholes**

In general, manholes should be not less than 320 mm × 420 mm or should have an inside diameter of 420 mm. The height of the neck or ring shall not exceed 300 mm. If in special cases manholes 300 mm × 400 mm are used, the requirements in the table of figure 13 h) shall be fulfilled.

3.13.3 Minimum gasket bearing width and clearance for access and inspection doors

Access and inspection doors of the type in which the internal pressure forces the door against a flat gas-

ket shall have a minimum gasket bearing width of 15 mm. The total clearance between the door frame and the spigot or recess of such doors shall not exceed 3 mm, i.e. 1,5 mm all round, and the spigot depth shall be sufficient to trap the gasket.

3.13.4 Access and inspection openings in flat plates

Where access and inspection openings are located in flat plates, the openings shall be suitably reinforced. Reinforcement shall be obtained by flanging the edge of the opening, or by the provision of a stiffening ring (see figure 11).

3.13.5 Inspection requirements

3.13.5.1 The efficiency of visual inspection depends in particular on the distance between eye and object and the angle under which the surface of the object is seen. Efficient visual inspection is best achieved by entering the boiler. The guidelines in this subclause are intended to ensure that a good visual examination of representative parts of the various welded seams is possible. It is recognized that it is not practicable to provide access for close visual inspection of every weld after the boiler has been constructed, particularly in the case of small boilers. However, it is also recognized that some parts of boilers are more prone than others to the occurrence of cracking or corrosion. The following inspection categories are arranged in order of relative importance and, for each category, appropriate facilities for the inspection of representative parts shall be provided. Means of achieving various degrees of visual inspection are illustrated in figure 13.

a) **Inspection category 1**

Corner welds (e.g. end plate to shell welds and furnace to end plate welds) except where hidden by tube nests. Attachment welds of stays and stiffeners.

NOTE 4   In the case of category 1 inspection, the representative parts of the welds are those where high bending moments are likely to occur, and would typically include half of the end plate to shell welds and half of the end plate to furnace welds.

b) **Inspection category 2**

All attachment welds not covered under a).

All large components subjected to high heat flux (e.g. furnaces).

Flanged corners where the boiler is not stayed end to end.

All parts where deposits could accumulate.

Parts located in the vicinity of the water inlet or in the area where there are changes in the water level during operation and staybolts are used for anchoring.

c) **Inspection category 3**

All attachment welds not covered under a) and b) which are exposed to low heat flux (flue gas temperature less than or equal to 400 °C) or which are not exposed to flame.

The positions of inspection openings are based on two factors, the size of the opening and the length of the visual ray [see figure 13 g)] appropriate to the inspection category. These positions are shown in figures 13 c) to 13 f).

3.13.5.2 In the case of circumferential corner welds, not more than one single length equal to half the shell outside diameter or a number of lengths totalling one shell outside diameter shall be hidden by tube nests. Where necessary, the tube nest shall have suitable inspection lanes and the shell shall have headholes or handholes in sufficient number.

NOTE 5 In determining the hidden area between tubes and shell, it is assumed that the eye can be brought to within 80 mm of the internal surface.

3.13.5.3 In all cases it shall be possible to inspect the bottom of the shell and the longitudinal welds.

3.13.6 Requirements for entry to boilers with a shell outside diameter greater than 1 400 mm

3.13.6.1 The space available for entry along the length of the boiler shall include at least one cross-section which is comparable with one measuring 600 mm diameter. This requirement may be considered satisfied if the space includes an inscribed circle of at least 500 mm diameter and adjacent wedge-shaped spaces which guarantee sufficient freedom of movement. When entering along the bottom of the boiler (or in similar situations of movement, e.g. above tube assemblies), as well as when climbing in through a bottom manhole, as shown in figure 13 i), or a top manhole, as shown in figure 13 a), a clear height of 400 mm between the boiler shell (manhole surround) and the tube assembly is sufficient, if one width of the entry space (if possible wedge shaped) is at least 600 mm. For smaller spaces, only the upper part of the body need enter as shown in figure 13 c).

3.13.6.2 To pass from one inspection space into another, for instance a lateral space, it is sufficient to have a hole with a height of at least 300 mm at its narrowest point [see figure 13 i)]. Figure 13 i) merely explains the idea of such a "hole". The possible types need not all be available at the same time.

3.13.7 Accessibility and arrangement of entry and inspection openings

All entry and inspection openings shall be accessible or shall be easily made accessible. When installing pumps, valves, preheaters, frame constructions, foundations, etc., this shall be taken into account. In each case, the arrangement of the entry and inspection openings, along or at right angles to the boiler axis, shall be used to make the inspection conditions as favourable as possible.

3.14 Stays, stiffeners and supported surfaces

3.14.1 Breathing spaces

Stays shall give breathing spaces around the furnace connections and tube nests (see figure 14) and equally divide the unstayed areas. Breathing spaces between furnaces and tube nests shall be a minimum of 50 mm or 5 % of the shell outside diameter, whichever is the larger, but need not be more than 100 mm.

Breathing spaces between furnaces and shells shall be as given in table 2 but shall be not less than 50 mm or, for bowling hoop furnaces, not less than 75 mm.

Table 2 — Breathing spaces between furnaces and shells when the thickness of the end plate is 25 mm or less

Design	Length between boiler end plates L_b m	Breathing space	
		percentage of outside diameter	maximum [1] mm
In-serted flat ends	$L_b \leqslant 5,5$	5	100
	$5,5 < L_b \leqslant 6$	5,5	110
	$6 < L_b \leqslant 6,5$	6	120
Flanged ends	any length	5	100

1) But not less than 50 mm or, for bowling hoop furnaces, not less than 75 mm.

Breathing spaces between furnaces shall be not less than 120 mm.

Breathing spaces between gusset or link stays and furnaces shall be not less than 200 mm, except for

— a shell outside diameter greater than 1 800 mm or a furnace length greater than 6 000 mm, in

which case the breathing spaces shall be not less than 250 mm, and

— a shell outside diameter less than 1 400 mm or a furnace length less than 3 000 mm, in which case the breathing spaces shall be not less than 150 mm.

Breathing spaces between gusset or link stays and tube nests shall be not less than 100 mm.

All other breathing spaces shall be a minimum of 50 mm or 3 % of the shell outside diameter whichever is the larger but need not be more than 100 mm.

3.14.2 Stayed flat surfaces

3.14.2.1 Radius of flange

Where flat ends are flanged, the inside radius of flanging shall be at least 1,5 times the thickness of the plate, but not less than 35 mm.

3.14.2.2 Point of support

Where the flange curvature is a point of support, the point of support shall be taken at half the distance between the inside of the shell and the commencement of curvature, or at a line 3,5 times the thickness of the plate measured from the outside of the plate, whichever is nearer to the flange (see figure 15). Where a flat plate is welded directly to a shell or wrapper, the point of support shall be taken at the inside of the shell or wrapper plate.

3.14.2.3 Thickness

The thickness of those portions of flat plates supported by stays shall be determined from the following formulae:

$$e = e_{cp} + c \qquad \ldots (3.42)$$

$$e_{cp} = C_1 by \sqrt{\frac{p}{f}} \qquad \ldots (3.43)$$

The corrosion allowance is

$c = 0,75$ mm for $e_{cp} \leqslant 30$ mm

$c = 0$ mm for $e_{cp} > 30$ mm

For areas enclosed by circles which pass through four or more evenly distributed points of support, y shall be taken as 1.

For areas enclosed by circles which pass through three points of support (such that the centre of a sub-circle which passes through at least two points of support in accordance with figure 16 or 17 with a diameter equal to 0,75 times the diameter of the main circle, lies outside the main circle), y, taken from figure 18, shall be determined using dimensions a and b as indicated in figure 16 or 17. Where the main circle passes through three points of support, not more than two of them shall lie on one side of any diameter. In this case y shall be taken as not less than 1,1.

For unstayed areas of rectangular shape, the dimensions a and b shall be as indicated in figure 14.

3.14.2.4 Values of constant C_1

Where various forms of support apply to the portion of flat plate under consideration, the constant C_1 shall be the mean of the values for the respective methods adopted.

The value of constant C_1 in formula (3.43) shall be as follows.

Freely supported plates with locking devices, e.g. manhole covers	0,45
Inset flat end plates, full penetration welded from one side	0,45
Plates which are bolted along their circumference:	
when ratio $D_L/D_b = 1$	0,45
when ratio $D_L/D_b = 1,3$	0,6
when ratio D_L/D_b is between 1 and 1,3, the values of the constant shall be determined by linear interpolation	
Flanged end plate	0,32
Corner stays or bar stays	0,3
Gusset stays in which the angle θ is greater than 30° (see figure 19)	0,45
Unstayed tube nest with plain tubes welded at both ends	0,3
Plain furnace less than 6 m long	0,3
Corrugated furnace with corrugation depths $\leqslant 50$ mm	0,32
Corrugated furnaces with corrugation depths > 50 mm:	
with a length $\leqslant 4$ m	0,35
with a length > 4 m	0,37
Bowling hoop furnaces	0,35
Isolated plain bar stays (see figure 20) or isolated stay tubes (see figure 21)	0,45
Non-isolated plain bar stays (see figure 20) or non-isolated stay tubes (see figure 21)	0,39
Bar stays or stay tubes shall be considered isolated if there are less than three in a group outside the tube nest.	
Bar stays with washers [see figures 22 a) and 22 b)]	0,35

Bar stays with washers [see figures 22 c) and 22 d)]	0,33
Reversal chamber bar stays (see figure 23)	0,39
Reversal chamber access openings welded from both sides	0,3
Reversal chamber access opening (where not possible to effect back weld) (see figures 39 and B.20)	0,45
Flat unflanged end plates welded to the shell from both sides with the following end plate thickness to shell plate thickness ratios:	
$\leqslant 1,4$	0,33
$> 1,4 \leqslant 1,6$	0,36
$> 1,6 \leqslant 1,8$	0,39
$> 1,8 \leqslant 2$	0,42
Flat surface of reversal chamber reinforced by stiffeners continuously welded above or flush stiffeners equipped with waterways [see figures 24 a) to 24 e)]. For a stiffener height of between six and eight times its thickness	0,4
Portion of unheated end plates containing a manhole with reinforcing ring (see figure 11), when the distance from the edge of the manhole ring to the edge of the furnace, smoke tubes or shell is not more than four times the end plate thickness [see figures 25 a) and 25 b)]: the following single value shall be used	0,27

If the distance exceeds four times the end plate thickness, the manhole is ignored, and the constant C_t shall be determined in the normal manner, from the mean of the values for the respective methods of attachment given above.

3.14.2.5 Stays for wet back reversal chambers

The permissible stress in the stays calculated on the net sectional area shall not exceed 70 N/mm². The diameter of any stay shall be not less than 20 mm.

The stays shall comply with the following rule (see figure 26):

$$\frac{d_s L_1}{L_2^2} \leqslant 2 \qquad \ldots (3.44)$$

3.14.2.6 Longitudinal bar stays

The diameter of each bar stay shall be such that the stress calculated on the least sectional area shall not exceed 70 N/mm². The diameter of any stay at any part shall not be less than 25 mm.

Supports shall be provided for longitudinal bar stays of 5 000 mm in length and longer.

3.14.2.7 Loads on stay tubes and bar stays

Stay tubes and bar stays shall be designed to carry the whole load due to the pressure on the area to be supported, the area being calculated as follows.

a) For a stay tube within the tube nest, the net area to be supported shall be the product of the horizontal and vertical pitches of the stay tubes, in millimetres, less the area of the tube holes embraced. Where the pitch of the stay tubes is irregular, the area shall be taken as the square of the mean pitch of the stay tubes (i.e. the square of one-quarter of the sum of the four sides of any quadrilateral bounded by four adjacent stay tubes) less the area of the tube holes embraced.

b) For a stay tube in the boundary row, or for a bar stay, the net area to be supported shall be the area, in millimetres squared, enclosed by lines through the midpoints of the lines joining the stay and the adjacent point of support, less the area of any tubes or stays embraced as shown in figure 14.

c) For a bar stay where there are no stay tubes in the tube nest, the area to be supported shall extend to the tangential boundary of the tube nest.

3.14.2.8 Gusset and link stays (corner stays)

3.14.2.8.1 Load on each stay

Each gusset or link stay supporting the flat end plate of a boiler shall be designed to carry the whole load due to pressure on the area it supports. The area supported by any one stay shall be obtained by considering the total area to be supported and dividing this area by boundary lines drawn between the stays and the adjacent points of support (furnace, boundary rows of tube nests or the shell). These boundary lines shall be at all points equidistant from the adjacent points of support in the area under consideration (see figure 19).

3.14.2.8.2 Gusset stays

Gusset stays shall be so proportioned that the angle V (see figures 27 and 28) is not less than 60°. The minimum cross-section of the gusset shall be determined in accordance with the following equation:

$$e_g h = \frac{1,33 W}{f \sin V} \qquad \ldots (3.45)$$

where

$e_g \leqslant 1,7 \times$ shell plate thickness

and

$e_g \geqslant 1 \times$ shell plate thickness

$e_g \geqslant 0,7 \times$ end plate thickness

The size and shape of the parts of the end plate supported by each gusset shall be such that the entire surface area of the end plate in each gusset stay zone is supported.

Gusset stays shall be fitted radially and there shall be no sudden changes of contour in the gusset stay profiles.

3.14.2.8.3 Link stays

Link stays shall be so arranged that the angle V (see figure 29) is not less than 60° and the dimensions shall be such that the stress in the stay at its weakest part does not exceed $f/1,67$.

3.14.2.8.4 Anchor plates, angles and link pins, etc.

The strength of anchor plates, angles and link pins calculated at the weakest section shall be as follows.

a) The shear stress in link pins shall not exceed 55 N/mm².

b) Anchor plates or angles shall be so designed that the calculated stress does not exceed $f/1,67$, but in no case shall the thickness be less than 0,875 of the thickness of the shell plate, with a minimum of 12,5 mm.

The part of the anchor plate or angle attached to the end plate shall extend from the inner limit of the breathing space to the outer limit of the furnace or tube breathing space.

c) Links, anchor plates and pins shall be constructed from material having a minimum specified tensile strength of 430 N/mm² and shall be so designed that the compressive stress on the projected area does not exceed 100 N/mm².

3.14.2.8.5 Weld attachments

Where gusset stays are welded to the shell and end plates the attachment shall be by means of full penetration welds in accordance with figure 27.

Where anchor plates or angles are welded to the shell and/or end plates (see figures 28 and 29) the attachment shall be by means of full penetration welds. The welds shall be of such dimensions that the stress calculated on an area equal to the effective length of the weld multiplied by the effective throat thickness shall not exceed that permitted for the parent metal multiplied by the appropriate weld factor given in table 3.

The weld profile shall be free from notches and abrupt changes of contour.

For the purposes of stress calculation, the effective throat thickness of a butt weld shall be taken as the thickness of the gusset or anchor plate. For compound welds, the effective throat thickness shall be the sum of the constituent parts. The effective throat thickness of the fillet weld shall be taken as 0,7 of the fillet size L_o (see figure 12).

Table 3 — Weld attachments

Form of weld	Weld factor	
Single-J or single-bevel butt welds (with or without superimposed fillets)	Without back weld	0,45
	With back weld	0,7
Double-J or double-bevel butt welds (with or without superimposed fillets)		0,8

3.14.2.9 Additional requirements for unflanged flat end plates

3.14.2.9.1 General

In addition to the applicable requirements, especially in respect of acceptable weld details (see section 5 and annex B), and to the general requirements for flat end plates given in 3.14.2.2 to 3.14.2.8, the requirements for welded-on or welded-in unflanged flat end plates given in 3.14.2.9.2 to 3.14.2.9.4 shall be taken into consideration.

3.14.2.9.2 Post-weld heat treatment of steel PH 290

Where steel PH 290 is used for shell or end plates in boilers incorporating flat unflanged end plates, the boiler shall be subjected to post-weld heat treatment in accordance with 5.4 irrespective of the plate thickness.

3.14.2.9.3 Shell plate thickness local to the corner joint

For the determination of the shell plate thickness local to the corner joint equations corresponding to formulae (3.6) and (3.7) shall be used:

$$e = e_{cs} + c$$

where

$c = 0,75$ mm (corrosion allowance);

$$e_{cs} = \frac{pd_o}{2fx + p} \qquad \qquad \ldots (3.46)$$

The stress reduction factor x in formula (3.46) depends on the ratio of the end plate to shell plate thickness as follows:

$$e_{cp}/e_{cs} \geqslant 1,4 \qquad x = 0,8$$
$$e_{cp}/e_{cs} \leqslant 1 \qquad x = 1$$

If the shell thickness e_{cs} is calculated according to formula (3.7) with a weld factor $v = 0,8$ the stress reduction factor x need not be considered.

For values of e_{cp}/e_{cs} between 1 and 1,4 the values of x shall be determined by linear interpolation.

3.14.2.9.4 Design parameters

Unflanged flat end plates shall comply with the parameters given in table 4, and with the requirements given in a) to g) as follows.

a) The wall thickness of the shell shall be calculated in accordance with formula (3.6), including the stress reduction factor x [see formula (3.46)].

b) The actual wall thickness of the end plate shall not exceed 30 mm.

c) When the wall thickness of the shell exceeds 30 mm, the through thickness properties of the material of the shell shall be proved by tests.[3]

d) Shell to end plate, furnace to end plate and reversal chamber end plate to wrapper plate seams shall be completely back welded, except in the case of small boilers as permitted in accordance with 5.3.2.5.2.

e) Both end plates shall be adequately stayed by using plain bar stays, stay tubes or gusset stays. (Stiffening ribs which are not connected to the shell are not permitted.)

f) The breathing spaces between gussets or link stays and furnaces required in accordance with 3.14.1 shall be increased as follows:

    increase 250 mm to 275 mm

    increase 200 mm to 220 mm

    increase 150 mm to 165 mm

    increase 100 mm to 110 mm

g) When the actual thickness of the end plate exceeds 25 mm, the breathing spaces in accordance with table 2 shall be increased in accordance with table 5.

NOTE 6   In order to keep the thickness of the end plate as small as possible it is recommended that an appropriate number of stays be provided.

Table 4 — Design parameters for unflanged flat end plates

Shell outside diameter d_{os} mm	Length between boiler end plates L_b m	Design pressure N/mm²	Ratio of end plate and shell thickness e_{cp}/e_{cs}
$d_{os} \leqslant 1\,500$	$L_b \leqslant 5,5$	$\leqslant 2$	$\leqslant 2$
		> 2	$\leqslant 1,6$
	$5,5 < L_b \leqslant 6,5$	$\leqslant 2$	$\leqslant 1,8$
		> 2	$\leqslant 1,4$
$1\,500 < d_{os} \leqslant 1\,800$	$L_b \leqslant 5,5$	$\leqslant 1,6$	$\leqslant 1,8$
		$> 1,6$	$\leqslant 1,4$
	$5,5 < L_b \leqslant 6,5$	$\leqslant 1,6$	$\leqslant 1,6$
		$> 1,6$	$\leqslant 1,2$
$1\,800 < d_{os} \leqslant 2\,500$	$L_b \leqslant 5,5$	$\leqslant 1,6$	$\leqslant 1,7$
		$> 1,6$	$\leqslant 1,3$
	$5,5 < L_b \leqslant 6,5$	$\leqslant 1,6$	$\leqslant 1,5$
		$> 1,6$	$\leqslant 1,1$
$d_{os} > 2\,500$	$L_b \leqslant 5,5$	$\leqslant 1,6$	$\leqslant 1,6$
		$> 1,6$	$\leqslant 1,2$
	$5,5 < L_b \leqslant 6,5$	$\leqslant 1,6$	$\leqslant 1,4$
		$> 1,6$	$\leqslant 1$

---

3) Test requirements, e.g. minimum elongation 16 %, minimum strength and reduction of area values, will form the subject of a future addendum to this International Standard.

Table 5 — Breathing spaces between furnaces and shells when the thickness of the end plate exceeds 25 mm

Length between boiler end plates L_b m	Breathing space		
	percentage of outside diameter	maximum mm	minimum mm
$L_b \leqslant 5,5$	6,5	130	65
$5,5 < L_b \leqslant 6$	7	140	70
$6 < L_b \leqslant 6,5$	8	150	75

3.14.2.10 Prohibited stiffeners

Reinforcement of flat end plates by stiffeners (fillets, bars or angles) which are not connected to the opposite end plate or to the shell are not permitted.

3.14.2.11 Girder stays supporting the top end plates of reversal chambers

The thickness of welded-on girders in accordance with figures 24 a) to 24 e) shall be calculated in accordance with the following formula, but in no case shall the thickness exceed 35 mm:

$$e = \frac{pL_g^2 S}{1,33 d_g^2 f} \qquad \ldots (3.47)$$

where e is the girder thickness.

3.15 Unpierced tubes and pipes, and tube plates

For the purposes of this International Standard, tubes are cylindrical components used for heat transfer duties.

3.15.1 Thickness of straight tubes subject to external pressure

The thickness of straight tubes up to and including 150 mm outside diameter subject to external pressure shall be not less than that given by the following formulae or 2,9 mm, whichever is the greater. Minus tolerances shall be taken into account.

$$e = e_{ct} + c \qquad \ldots (3.48)$$

where

$c = 0,75$ mm (corrosion allowance);

$$e_{ct} = \frac{pd_o}{1,6f} \qquad \ldots (3.49)$$

3.15.2 Thickness of straight tubes subject to internal pressure

The thickness of straight tubes subject to internal pressure shall be not less than that given by the following formulae or 2,5 mm, whichever is the greater. Minus tolerances shall be taken into account.

$$e = e_{ct} + c$$

where

$c = 0,75$ mm (corrosion allowance);

$$e_{ct} = \frac{pd_o}{2f + p} \qquad \ldots (3.50)$$

3.15.3 Thickness of straight pipes subject to internal pressure

The thickness of straight pipes subject to internal pressure shall be not less than that given by the formulae in 3.15.2 or 4 mm, whichever is the greater. Minus tolerances shall be taken into account.

3.15.4 Wall thickness and ovality of elbows, tube bends and pipe bends (see figure 30)

The wall thickness of elbows, tube bends and pipe bends up to and including 150 mm outside diameter shall be not less than that given by the following formulae:

wall thickness at the intrados

$$e_i = e_{ct} C_i \qquad \ldots (3.51)$$

wall thickness at the extrados

$$e_o = e_{ct} C_o \qquad \ldots (3.52)$$

where e_{ct} is the thickness calculated for a straight tube or pipe in accordance with 3.15.1, 3.15.2 or 3.15.3 as appropriate, and C_i and C_o are factors to be taken from figure 31.

The factors C_i and C_o are valid for elbows, tube bends and pipe bends where the ratio R/d_o is greater than or equal to 1 and less than or equal to 4,5. Bends with R/d_o greater than 4,5 shall be treated as straight tubes or pipes.

Minimum wall thicknesses, corrosion allowances and minus tolerances shall be taken into account in accordance with 3.15.1, 3.15.2 or 3.15.3 as appropriate, except that in no case shall the wall thickness be less than 2,9 mm.

The value of d_m/e shall not exceed 40.

Ovality measured at the end after bending shall not exceed 10 %.

Ovality is defined as

$$u = \frac{d_{o\ max} - d_{o\ min}}{d_o} \times 100 \qquad \ldots (3.53)$$

where

$d_{o\ max}$ is the maximum outside diameter of the tube or pipe measured at the bend apex;

$d_{o\ min}$ is the minimum outside diameter of the tube or pipe measured at the same cross-section as $d_{o\ max}$;

d_o is the outside diameter of the straight tube or pipe.

3.15.5 Stay tubes

Stay tubes are tubes welded in accordance with figure 21 having a weld depth equal to the tube thickness plus 3 mm. These stay tubes are not required within tube nests except when the tube nests comprise tubes which are expanded only [see figure 32 a)].

When the tube nests are comprised of plain tubes which are expanded and beaded, expanded and belled [see figure 32 b)], or expanded and welded in accordance with figures 32 c), 32 d) and 32 e), welded stay tubes in accordance with figure 21 are required in the boundary rows to carry the flat plate loadings.

Where tube nests comprise plain tubes welded in accordance with figure 32 f) or having a weld depth equal to the tube thickness plus 2 mm no stay tubes are required.

Each stay tube shall be designed to carry its due proportion of the load on the plates which it supports. The thickness of stay tubes welded into tube plates shall be such that the axial stress on the thinnest part of the tube does not exceed 70 N/mm².

3.15.6 Pitch of tubes

The spacing of tube holes shall be such that the minimum width, in millimetres, of any ligament between the tube holes shall be not less than

a) for expanded tubes,

     $0,125d + 12,5$ mm

b) for welded tubes,

  1) for gas entry temperatures greater than 800 °C,

      $0,125d + 9$ mm

  2) for gas entry temperatures less than or equal to 800 °C,

      $0,125d + 7$ mm

3.15.7 Thickness of the tube plates within tube nests

The thickness of tube plates shall be calculated from formulae (3.42) and (3.43), except when

a) the tubes are expanded into the tube plate, in which case the minimum thickness of the tube plate shall be 12,5 mm when the diameter of the tube hole does not exceed 50 mm, or 14 mm when the diameter of the tube hole is greater than 50 mm, or

b) the tubes are attached to the tube plates by welding only, in which case the tube plates shall be not less than 6 mm thick for boilers with design pressures less than 0,5 N/mm², and not less than 9 mm thick for boilers with design pressures greater than or equal to 0,5 N/mm².

3.16 Furnaces and wet back reversal chambers of cylindrical form subject to external pressure

3.16.1 Furnaces and wrapper plates

3.16.1.1 Plain furnaces and wrapper plates

The design pressure of plain furnaces and wrapper plates of wet back reversal chambers shall be the lower of the design pressures obtained using the following equations:

$$p = \frac{R_{p0,2}}{S_1} \times \frac{2e_{cf}}{d_m} \times$$

$$\times \frac{1 + 0,1 d_m/L}{1 + (0,03 d_m/e_{cf})\,[u/(1 + 5 d_m/L)]} \qquad \ldots (3.54)$$

$$p = \frac{2,6E}{S_2 L}\left(\frac{e_{cf}}{d_m}\right)^2 \sqrt{d_m e_{cf}} \qquad \ldots (3.55)$$

The preceding equations may be expressed in terms of thickness as shown in formulae (3.56) and (3.58). The greater of the thicknesses obtained shall be used, but the thickness of plain furnaces with diameters less than or equal to 400 mm shall be not less than 6 mm and for diameters greater than 400 mm shall be not less than 7 mm. Bowling hoop furnaces shall have a minimum wall thickness of not less than 10 mm. In no case shall the thickness exceed 22 mm. For wrapper plates the maximum thickness shall not exceed 35 mm.

$$e_{cf} = \frac{B}{2}\left[1 + \sqrt{1 + \frac{0,12 d_m u}{(1 + 5 d_m/L)B}}\,\right] \quad \ldots (3.56)$$

where

$$B = \frac{p d_m S_1}{2 R_{p0,2}\,(1 + 0,1 d_m/L)} \quad \ldots (3.57)$$

$$e_{cf} = d_m^{0,6}(L S_2 p/2,6E)^{0,4} \quad \ldots (3.58)$$

$$e = e_{cf} + c \quad \ldots (3.59)$$

where $c = 0,75$ mm (corrosion allowance).

Formulae (3.54) to (3.59) apply only to furnaces having diameters less than or equal to 1 800 mm.

NOTE 7   Formulae (3.54) and (3.56) are based on considerations of plastic collapse. Formulae (3.55) and (3.58) are based on considerations of elastic instability.

3.16.1.2   Corrugated furnaces

The design pressure of corrugated furnaces shall be determined using the following equation, but the thickness shall be not less than 10 mm nor greater than 22 mm:

$$p = \frac{R_{p0,2}}{S_1} \times \frac{2 X_2}{p_c d_m} \times$$

$$\times \frac{1 + 0,1 d_m/L}{1 + \left[\dfrac{X_2 w d_m}{800 I_1} \times \dfrac{u}{1 + 5 d_m/L(e_{cf}/w)^3}\right]}$$

$$\ldots (3.60)$$

where d_m is the mean diameter.

NOTES

8   For corrugated furnaces the mean diameter is equal to the inside diameter plus the full depth of one corrugation, i.e. inside diameter plus $e_{rf} + w$.

9   Values of X_2 and I_1 for Fox and Morrison corrugations are given in figures 33 a) to 33 g).

3.16.1.3   Safety factors

The value of the safety factor is

$S_1 = 2,5$ for horizontal furnaces exposed to flame

$S_1 = 2$ for furnaces and wrapper plates not exposed to flame

$S_2 = 3$ for all conditions

3.16.2   Tolerances and corrosion allowances on wall thickness

For corrugated furnaces, the calculated wall thickness shall be the minimum thickness of the finished furnace. For plain furnaces and reversal chambers, allowance shall be made to take account of any minus tolerances on the plate thickness.

3.16.3   Out-of-roundness

The out-of-roundness, in per cent, of furnaces and reversal chambers shall be calculated as follows:

$$u = \frac{2(d_{max} - d_{min})}{d_{max} + d_{min}} \times 100 \quad \ldots (3.61)$$

where

d_{max} is the maximum mean diameter of the furnace, in millimetres;

d_{min} is the minimum mean diameter of the furnace, in millimetres.

The maximum allowable out-of-roundness is given in 4.9.2.

3.16.4   Stiffeners

3.16.4.1   General

Stiffeners welded to furnaces with the maximum dimensions in accordance with figures 34 and 35 shall be regarded as fulfilling the requirements of this section and need not be calculated.

Stiffeners not conforming with figures 34 and 35 shall have a second moment of area not less than that given by the following equation:

$$I_2 = \frac{p d_m^3 L}{1,33 \times 10^6} \quad \ldots (3.62)$$

The second moment of area of the stiffener about its neutral axis I_2 shall be related to the stiffener section, including a length of furnace equal to $0,55\sqrt{d_m e_{cf}}$ on either side of the stiffener.

3.16.4.2   Stiffener sections made from bar or plate

Stiffener sections made from bar or plate shall be joined by full penetration welds.

The thickness of the stiffening ring shall be kept to the minimum required by 3.16.4.1. If it exceeds 22 mm or twice the furnace thickness it shall be tapered as shown in figure 35.

Full penetration welds shall be used to attach stiffeners to furnaces.

3.16.4.3 Stiffeners located within the zone of peak heat flux

When stiffeners are welded on to furnaces which are more than 11 mm thick they shall not be located in the zone of peak heat flux, unless the net heat input to the furnace is restricted to not more than H_r in accordance with the following formula:

$$H_r = 130 - 2,7e_{rf} \qquad \ldots (3.63)$$

where H_r is the percentage of the maximum normally permitted net heat input, in watts.

The zone of peak heat flux shall be considered to extend for a length equal to two furnace diameters from the tip of the burner, or to the end of the grate, whichever is applicable.

NOTE 10   The requirements of 3.16.4.3 need not apply to boilers with a net heat input of less than 2 MW.

3.16.4.4 Bowling hoops

Bowling hoops shall be considered effective points of support. The minimum pitch of bowling hoop centres shall be not less than 600 mm. When bowling hoops are used, the furnace thickness shall be calculated in accordance with 3.16.1.1.

In the calculation for furnaces supported by bowling hoops, L shall be taken as 1,5 times the actual length between bowling hoop centres.

The second moment of area of the bowling hoop shall be not less than that required by 3.16.4.1. The length of plain furnace which may be included in the determination of I_2 shall be measured from the outside tangent line and shall not be greater than $0,55\sqrt{d_m e_{cf}}$. The dimensions of bowling hoops shall be in accordance with figures 36 a) to 36 c).

The nominal wall thickness of bowling hoops shall be not less than the calculated wall thickness of the plain furnaces to which they are attached.

The second moment of area of bowling hoops between the outer tangent lines are as given in the tables to figures 36 a) to 36 c).

3.16.4.5 Stiffeners on corrugated furnaces

When corrugated furnaces are equipped with several stiffeners, e.g. one on each corrugation or on each second corrugation, the cross-sectional area and the second moment of area of the stiffeners shall be included when using formula (3.60). A height of not more than six times the furnace thickness shall be used for the calculation.

3.16.5 Calculation length of composite furnaces

When the length of the plain portion of a corrugated furnace exceeds 250 mm, the total length of both sections shall be used for calculating the thickness of the corrugated section, and 1,5 times the length of the plain section shall be used for calculating the thickness of the plain section.

3.17 Boiler supports

3.17.1 Leg supports

For shell diameters of less than 1 500 mm, leg supports or saddle supports with a subtended angle of not less than 60° may be used, provided that the shell thickness has been calculated using a stress reduction factor of $x = 0,8$.

3.17.2 Saddle supports

For shell diameters d_o equal to or greater than 1 500 mm, leg supports are not permitted; only saddle supports may be used with a minimum subtended angle of not less than 90°. The shell thickness shall be such that the combined stress at the inner surface of the shell, obtained from formula (3.64) or (3.65), does not exceed $1,5f$.

If $L_s/r_{ms} > 8$, then

$$f_c = \frac{pr_{ms}}{e_{rs}} - \frac{Q}{4e_{rs}(B_2 + 10e_{rs})} +$$
$$+ \frac{1,5C_3Q}{e_{rs}^2} \qquad \ldots (3.64)$$

If $L_s/r_{ms} \leqslant 8$, then

$$f_c = \frac{pr_{ms}}{e_{rs}} - \frac{Q}{4e_{rs}(B_2 + 10e_{rs})} +$$
$$+ \frac{12C_3Qr_{ms}}{L_s e_{rs}^2} \qquad \ldots (3.65)$$

The width of the saddle top plate B_2 shall be not less than $10e_{rs}$.

The coefficient C_3 is obtained from figure 37.

Section 4:   Workmanship and construction in fabrication other than welding

4.1   Plate identification

In laying out and cutting the plates, the plate identification mark shall be so located as to be clearly visible when the pressure part is completed. Where the plate's identification mark is unavoidably cut out, it shall be transferred by the pressure part manufacturer to another part of this component to the satisfaction of the inspecting authority.

4.2   Cutting of forgings

Forgings should normally be cut to size and shape by machining and/or thermal cutting.

4.3   Cylindrical shells

4.3.1   Each ring shall be formed from not more than two plates, bent to cylindrical form to the extreme ends of the plate. The bending shall be done entirely by machine, and local heating or hammering shall not be used.

The longitudinal seam or seams may be placed in any suitable position(s), but the seams in successive rings should preferably not fall in line. In special cases they may be in line provided that the requirements of 5.3.2.2 are fulfilled.

4.3.2   The shell of completed boilers shall be in accordance with the following requirements.

a) **Straightness**

Unless otherwise shown on the drawing, the maximum deviation of the shell from a straight line shall not exceed 0,3 % both of the total cylindrical length and of any 5 m length. Measurements shall be made to the surface of the parent plate and not to a weld, fitting or other raised part.

b) **Irregularities in profile**

Irregularities in profile (checked by a 20° gauge) shall not exceed 5 % of the minimum plate thickness plus 3 mm. This maximum value may be increased by 25 % if the length of the irregularities does not exceed one-quarter of the length of the shell part between two circumferential seams, with a maximum of 1 m.

c) **Out-of-roundness**

The difference between the maximum and minimum diameter of any section of a shell welded longitudinally shall have a maximum of

$(D + 1\,250)/200$, where D is the nominal internal diameter expressed in millimetres.

Measurements shall be made to the surface of the parent plate and not to a weld, fitting or other raised part.

Shell sections may be measured for out-of-roundness either when laid flat on their sides or when set up on end. When the shell sections are checked when laid flat on either side, each measurement for diameter shall be repeated after turning the shell through 90° about its longitudinal axis. The two measurements for each diameter shall be averaged, and the amount of out-of-roundness calculated from the average values so determined.

Any local departure from circularity shall be gradual.

There shall be no flats or peaking at the longitudinal welded seam.

d) **Cold rolling**

Cold rolling of a welded shell to rectify a small departure from circularity is permitted, provided that non-destructive testing conforming to 5.5 and 5.9.4 is carried out after the departure from circularity has been remedied.

4.4   Tell-tale holes

Reinforcing plates and saddles of nozzles attached to the outside of a boiler shall be provided with at least one tell-tale hole (maximum size G 1/4) that may be tapped for a preliminary leakage test for tightness of welds that seal off the inside of the boiler. These tell-tale holes may be left open or may be plugged when the boiler is in service. If the holes are plugged, the plugging material used shall not be capable of sustaining pressure between the reinforcing plate and the boiler wall.

4.5   End plates and tube plates

4.5.1   Where practicable, flat or dished ends shall be made in one piece except that, where the diameter is so large as to make this impracticable, flat ends may be made from two plates butt welded together (see figure B.19). The weld shall be located preferably between two rows of bar stays or, if there is only one row of bar stays, between this row and the top row of stay tubes. Dishing and peripheral flanging of end plates shall be done by machine. Such flanging should preferably be done in one operation, but where this is impracticable, creep ma-

chine flanging may be permitted provided that the plate is worked at a suitable temperature and heated to an adequate distance beyond the portion under immediate treatment. Care shall be taken to see that the flanges are cylindrical, have a good surface condition, and are free from local irregularities.

End plates and tube plates shall not be flanged cold. The cold dishing of end plates is permitted subject to agreement between the parties concerned and in accordance with an agreed qualified procedure, including normalizing.

Plates which have been dished or flanged at non-uniform temperatures, or which have been locally heated, shall be normalized after forming unless otherwise agreed by the manufacturer and the inspecting authority.

Where flats are pressed (for example, in dished end plates for the attachment of mountings), they shall be formed with an ample radius at the junction of the flat and curved surfaces and be free from sharp corners or tool marks, and the plate shall not be unduly thinned.

On completion of all flanging and machining operations, flat portions of flat end plates shall be flat and free from set or distortion.

4.5.2 Where hemispherical shell end plates are pressed from one plate they shall be pressed to form by machine in progressive stages, without thinning, and shall be normalized on completion except that, when agreed between the parties concerned, normalizing may be omitted in the case of hot-formed ends, when the forming process is completed at temperatures exceeding approximately 850 °C.

4.5.3 Where dished ends are used they shall be flanged for connection to the shell.

4.6 Plain tubes and stay tubes

4.6.1 Tubes may be expanded or welded into the tube plate or secured by a combination of both methods.

4.6.2 Where the tubes are expanded only, the process shall be carried out with roller expanders, and the expanded portion of the tube shall be parallel through the full thickness of the tube plate. In addition to expanding, tubes may be flared, bell-mouthed or beaded.

4.6.3 Where tubes are welded to the tube plate by welds which are not full penetration welds, the unwelded portion of the tube within the tube hole shall be in full contact with the tube plate, except as permitted by 3.4 d).

4.6.4 Stay tubes shall be provided in all cases where the total number of tubes is arranged in more than one nest. Where stay tubes are not provided, the ends of all tubes shall be welded or expanded and beaded at the inlet end, and welded or expanded only at the outlet end.

4.6.5 Examples of stay tube welding attachments are shown in figures 21 a) to 21 e).

4.6.6 Plain tubes may be welded [see figures 32 c) to 32 f)] after stress relief of the boiler.

4.7 Manhole frames and openings

4.7.1 Material

Manhole frames, openings, doors and cover plates shall be of steel complying with the requirements specified in section 2.

4.7.2 Location

Manholes and other openings in shells shall be placed as far as practicable from any seam. Oval openings should preferably be arranged with the minor axis parallel with the longitudinal centre-line of the boilers. In no case shall the major axis of any opening exceed twice the minor axis of the opening.

Where a manhole is located in or in-between tube nests in multitubular boilers, or below the furnaces of twin-furnace boilers, the stay tubes in the boundary rows, or gusset stays, as applicable, shall be arranged as close as practicable to the manhole.

4.7.3 Frames

If the design pressure exceeds 1,8 N/mm^2, raised circular manhole mouthpieces shall not be fitted. In all other cases, where the shell thickness exceeds 14 mm, oval frames or circular mouthpieces may be fitted. Oval frames of the flanged type shall be formed to fit closely to the shell and to provide a flat jointing surface for the door. Where practicable, such frames shall be attached to the inside of the shell, with the minor axis parallel to the longitudinal centre-line of the boiler.

Oval frames and external raised circular openings shall be either formed in one piece without welding, or formed from a suitable rolled section fabricated by fusion welding. Welds in fabricated manhole frames and openings shall be positioned so that they are in a plane at right angles to the longitudinal axis of the boiler.

The joint face of manhole frames shall be not less than 15 mm wide.

Typical forms of manhole frames are shown in figures 11 and 12.

4.7.4 Jointing flanges

The jointing flanges of openings and covers shall be machined on the face and edges and on the bearing surface of the bolt heads and nuts. Bolts and nuts shall be machined where they are in contact with the flanges, and the joints should be formed inside and outside the pitch circle or pitch line of the bolts to preclude the possibility of flange distortion.

4.7.5 Doors

Doors shall be constructed in accordance with the following requirements.

a) Doors shall be formed to fit closely to the internal joint surface and shall be fitted with studs, nuts and cross bars.

b) Doors for openings larger than 250 mm by 175 mm shall have two studs, but for openings of 250 mm by 175 mm or less, only one stud need be fitted. Doors for openings not larger than 125 mm by 90 mm may have the stud forged integrally with the door.

c) Door studs shall be of welding quality steel having a minimum specified tensile strength of 360 N/mm^2, and those for manholes shall be not less than 30 mm diameter. They shall be

   1) screwed through the plate and fillet welded on the inside, or

   2) fillet welded each side of the plate with a leg length of not less than 9,5 mm.

d) The spigot part, or recess, of manhole and sight-hole doors shall be as neat a fit as practicable. In no case, however, shall the clearance all round exceed 1,5 mm.

e) Nuts shall comply with appropriate national standards and shall be faced on the seating surface.

f) Cross bars shall be of steel, forged or cut from plate having a minimum specified tensile strength of 360 N/mm^2. The seating surface shall be faced.

4.8 Seating for mountings

4.8.1 Seatings

Mountings over 25 mm internal diameter, except flanged mountings up to and including 75 mm bore, shall not be attached directly to any boiler plate, but

shall be carried on suitable forged, cast or fabricated steel seatings. These seatings shall take the form of short nozzles, forged pads or pads cut from plate or round bar as may be convenient. Where seatings are fabricated by fusion welding, they shall be stress relieved by heat treatment before attachment unless the whole boiler is to be subjected to heat treatment on completion.

4.8.2 Water gauges

Water gauges and pressure gauge siphons may be attached directly to the plate without the intervention of a pad or standpipe, provided that they are flanged and secured by studs. If the studs are screwed through the plate, nuts of full thickness shall be fitted on the inside of the boiler.

4.8.3 Flanges and pads

Flanges and pads in contact with the boiler shall be formed to fit closely to the plate to which they are to be attached.

4.8.4 Nozzles

Where nozzles are used, the flanges shall be machined or thermal-cut by machine on the edges. The bolting flanges shall be machined on the jointing and bolting surfaces.

4.8.5 Pads

Where pads are used, the jointing surfaces shall be machined. The pads shall have sufficient thickness to allow the drilling of the stud holes for mountings without the inner surface being pierced, and the length of the screwed portion of the stud in the pad shall be not less than the diameter of the stud.

4.8.6 Methods of attachment

The seatings shall be attached to the shell or end plates by one of the following methods.

a) Where the internal diameter of the nozzle does not exceed 25 mm, the nozzle may be screwed through the plate, and either fitted with a nut, or seal welded on the water side. The screwed thread of the nozzle shall have a run-out of thread of not less than three times the pitch of the thread, produced by suitably grinding the cutting die. The threads in the tapped hole in the shell shall be chamfered to produce a corresponding angle of run-out.

b) Where the design pressure does not exceed 1,2 N/mm^2, mountings with screwed ends not exceeding 25 mm diameter may be used. The screwed portion of any such mounting shall be an integral part thereof.

Such mountings may be screwed directly into the plates, nuts being fitted on the water side, or may be screwed into steel distance pieces (see figure 38), the length of the thread engaged being, in no case, less than the bore of the mountings plus 6,5 mm.

The distance pieces shall be made from forged steel or bar complying with the requirements specified in section 2. They shall be screwed into the plate and fitted with nuts on the water side. The walls of the distance pieces shall not be less than 6,5 mm thick at the bottom of the thread.

c) Notwithstanding the requirements in 5.4, in special circumstances, and if approved by the inspecting authority, the seating may be welded to the plate without subsequent heat treatment, where the seating does not exceed 125 mm bore, or where, in the case of a pad, the diameter of the opening in the shell does not exceed 125 mm plus twice the thickness of the plate to which it is to be attached. If these limits are exceeded the method of stress relieving shall be agreed between the manufacturer and the inspecting authority.

Typical methods of attachment are shown in annex B, but other methods of equivalent efficiency may be used subject to agreement between the inspecting authority and the manufacturer.

4.8.7 Bolts and nuts

All bolt and stud holes shall be drilled, and bolts and nuts shall be machined where they are in contact with flanges.

4.9 Cylindrical furnaces

4.9.1 Sections of cylindrical furnaces shall each be made from one plate. Conical furnace sections may be made from not more than two plates. The longitudinal welds shall be at least 120° apart and shall be fusion butt welded in accordance with section 5. Alternatively, furnaces may be made from hot-finished seamless carbon steel tubes to ISO 2604-2, TS 9H, the tensile strength and minus tolerances on thickness being taken into account.

4.9.2 Out-of-roundness, as defined in 3.16.3, shall not exceed 1 % for corrugated furnaces or 1,5 % for plain furnaces with a maximum variation in diameter of any cross-section of 6,5 mm or half the thickness, whichever is the greater. There shall be no flats or peaks, and any departure from circularity shall be gradual.

4.9.3 The longitudinal welds of furnaces shall be placed in such a position that they can be examined from the water side in accordance with 3.13.5.1, category 2. Longitudinal welds in successive sections shall break joint by at least 150 mm.

4.9.4 Where the furnace sections are flanged for circumferential joints, the flanging shall be carried out at one heat by using suitable machinery. When furnace sections are flanged, they shall be normalized unless flanging is carried out above normalizing temperature.

4.9.5 Edges of all furnace flanges shall be machined or thermal-cut by machine.

4.9.6 Flanged circumferential seams shall be arranged so that they do not fall in line with those of the adjacent furnace.

4.9.7 Where stiffeners are required, they shall be attached externally by means of continuous full penetration welding in accordance with figure 34 or 35.

4.9.8 The dimensions of bowling hoops shall be as shown in figure 36 a), 36 b) or 36 c).

4.9.9 Forms of furnace connections to end plates are shown in figures B.17 a) to B.17 c). Where the furnace is inserted into a hole in the end plate, it shall be a good fit around the whole periphery.

4.10 Water-cooled reversal chambers

The attachment of the reversal chamber tube plates and end plates to the wrapper plate shall be in accordance with figures B.16 a) to B.16 e), and where the tube plate or end plate is flanged for connection to the wrapper plate, the weld shall be located between the commencement of curvature of the flange and the first row of stays.

Typical methods of attachment of access opening frames are shown in figure 39.

4.11 Stays

4.11.1 Bar stays

4.11.1.1 All bar stays shall be made from a solid rolled bar without weld in its length, except those attaching them to the plates they support. Bar stays which have been hot worked shall subsequently be normalized where justified by the hot-working procedure or material requirements, and with the agreement of the inspecting authority. It is recommended that when a stay is in position in the boiler, its axis shall be normal to the plate it supports.

It is recommended that a tell-tale hole be drilled along the axis of all bar stays. The diameter of the hole should not exceed 5 mm and the drilling should extend 15 mm min. beyond the water surface of the plate (see figure 20).

4.11.1.2 Bar stays shall be secured to the plates they support by one of the following methods:

a) plain bars passing through clearing holes in the plates and welded thereto (see figure 20);

b) plain bars passing through clearing holes in the plates and fitted with washers on the outside, the stay and washers being welded to the plates in accordance with any one of the methods shown in figures 22 a) to 22 d).

4.11.2 Gusset stays

Gusset stays shall be flat and perpendicular to the end plates.

4.11.3 Girder stays

The attachment of girder stays welded directly to the crown plates shall be by means of full penetration welds, and shall comply with the details shown in figures 24 a) to 24 e). Each girder shall be of sufficient strength to support its due proportion of the load on the top end plate independently of the crown plate, and the attachment welds shall have sufficient cross-sectional area to carry the applied load (see 3.14.2.11).

Section 5: Workmanship and construction in welding

5.1 General

5.1.1 The rules in this section are applicable to boilers and boiler parts that are fabricated by welding and shall be used in conjunction with the specific requirements that pertain to the class of materials used.

The welding and fabrication procedure to be agreed upon when steel containing more than 0,23 % carbon is used shall be appropriate to the grade of steel and shall be based on established International Standards or national standards with a record of reliability. It shall take into account all aspects of fabrication as covered by sections 4 and 5 of this International Standard.

5.1.2 The welding shall be executed in conformity with the qualified welding procedure which is in accordance with the welding procedure specification (see 5.8.3).

5.1.3 The welder shall be qualified in conformity with the welder's competence tests specified (see 5.8.4).

5.1.4 The manufacturer of a boiler or boiler part built in accordance with the requirements of this International Standard is responsible for the welding done for this purpose by his workmen. He shall designate a competent welding supervisor and conduct the tests required to qualify the welding procedure he uses and the competence of the welders who apply this procedure. No production work shall be undertaken until both the welding procedure and the welders or welding operators have been qualified.

5.1.5 The manufacturer shall maintain a record of the results obtained in welding procedure qualifications and competence tests. These records shall be certified by him and give an accurate description of all the particulars of the materials and procedure concerned and shall be accessible to the inspecting authority who shall witness and certify the tests (see the model forms in annex F).

5.1.6 A record shall be kept to show that the welder has been employed on works of the kind covered by his competence tests during the previous 6 months. The records shall contain the results of the welder's competence tests and the identification mark assigned to each welder (see the model forms in annex F) and shall be certified by the manufacturer and be accessible to the inspecting authority.

5.1.7 The welds made by each welder shall be marked with a stamp showing the welder's identity or else some other appropriate record shall be made.

If hard stamping is employed, only low-stress stamps shall be used. (Low-stress stamps are those with radiused edges or those made of a series of dots.)

5.1.8 If, during the construction of a boiler or pressure part, the inspecting authority finds that the work is not satisfactory or is not in accordance with the requirements of this International Standard, the causes should be investigated by the manufacturer and rectified.

5.1.9 If it is proved that the welder is responsible for bad work, a decision should be taken, after consulting the welder's record, as to whether he should be requalified.

5.1.10 This decision should be recorded in the register.

5.2 Materials

5.2.1 The materials shall meet the provisions of section 2.

5.2.2 The welding consumables and flux [see 5.8.3.3 b) and 5.8.4.5.4] shall satisfy the requirements specified herein.

5.3 Design

5.3.1 Introduction

These rules apply to the design of boilers and boiler parts that are manufactured by welding and shall be used in conjunction with section 3 of this International Standard.

5.3.2 Design of welded joints

5.3.2.1 Weld deposition

The design of the welded joints shall be such as to provide adequate access for the deposition of weld metal to meet the requirements laid down in this International Standard.

5.3.2.2 Weld crosses

Joints where more than two welded seams meet shall be avoided. If the design cannot permit this, the appropriate precautions shall be taken into consideration and shall be agreed between manufacturer, purchaser and inspecting authority.

5.3.2.3 Non-pressure parts

Attachment of non-pressure parts by welds which cross or for which the minimum nominal distance between the edge of the attachment weld and the edge of existing main welds or nozzle welds is less than the smaller of twice the thickness of the pressure part or 40 mm shall be avoided.

If such welds cannot be avoided, they shall cross the main weld completely rather than stopping abruptly near the main or nozzle weld, in order to avoid stress concentrations in these areas.

If the design cannot permit this, the appropriate precautions shall be taken into consideration. These precautions shall be agreed between manufacturer, purchaser and inspecting and/or regulating authority.

5.3.2.4 Properties

Connections of nozzles, pads, branches, pipes and tubes, and non-pressure parts, may be welded to pressure parts provided that the properties of the material of all the pressure parts are not influenced adversely.

5.3.2.5 Permissible weld types

Typical examples of acceptable weld details of welded connections are indicated in annex B.

5.3.2.5.1 Full penetration welds

A full penetration weld is one in which the components of the joint are completely fused together through the full depth of the joint and there are no unwelded lands. In some cases the full penetration welds are reinforced by fillet welds.

The following welds shall be of the fully penetrated type:

a) longitudinal and circumferential main seams in cylindrical shells, furnaces and reversal chamber wrapper plates as shown in figures B.18 a) to B.18 d);

b) seams in flat end plates as shown in figures B.19 a) and B.19 b);

c) unflanged flat end plates or tube plates where they are welded

1) to shells as shown in figures B.15 a) to B.15 d),

2) to furnaces as shown in figures B.17 a) and B.17 b),

3) to reversal chamber wrapper plates as shown in figures B.16 b) to B.16 e), and

4) to access tubes as shown in figure B.20;

d) attachment of flanged end plates

1) to reversal chamber wrapper plates as shown in figure B.16 a), and

2) to furnaces as shown in figure B.17 c);

e) compensating plates in accordance with figure 12 b);

f) manhole frames in accordance with figure 11 a);

g) gusset stay attachment welds as shown in figures 27 and 28;

h) stiffener to furnace welds as shown in figures 34 and 35;

i) reversal chamber girders as shown in figures 24 a) to 24 e);

j) reversal chamber stays as shown in figure 23 b);

k) welds of reinforcing branches, nozzles and pads as shown in figures B.3 to B.12.

5.3.2.5.2 Fillet welds (back welding)

When unflanged flat end plates or tube plates are welded to shells, furnaces and reversal chamber wrapper plates, the fillet welds shall be inserted for the full circumference of the seam, except as permitted for small boilers in accordance with table 6.

The above requirements for fillet welds are dictated by consideration of accessibility for welding. Notwithstanding these requirements, the fillet welds shall be inserted for the full circumference of the seam whenever it is possible to provide the requisite quality of finished weld.

The profile of the fillet welds shall be such as to minimize harmful notch effects.

When sections of the fillet welds are omitted in accordance with table 6, special consideration shall be given to the welding technique to ensure sound root conditions, which shall be proved by procedure tests.

Table 6 — Conditions for omitting sections of fillet welds (back welds) from corner joints of flat end plates

Unwelded length mm	Boiler length between end plates L_b mm	Outside diameter of shell d_o mm	Minimum breathing space between furnace and shell	End plate thickness e_{rep} mm	Test pressure p_t	Ratio of end plate to furnace wall thickness e_{rep}/e_{rf}	General requirements for welded sections
⩽ 250	⩽ 3 000	⩽ 1 400	6,5 % of d_o or 65 mm whichever is the greater	⩽ 20	according to 6.3.1.1	⩽ 1,4	The weld shows proper penetration[1]. Thorough inspection of the weld is possible.
> 250	⩽ 2 500	⩽ 1 000	⩾ 65 mm	⩽ 15	⩾ 2,55p		
[2]	⩽ 2 000	⩽ 1 200	⩾ 80 mm	⩽ 20	⩾ 2,1p		The weld is not heated directly.

1) To be proved by special procedure tests. The procedure test piece shall reproduce the geometry of the production weld and shall be sectioned for visual and macro-examination.

2) One length equal to the furnace diameter for the flat end to furnace connection and one length equal to the shell diameter for the flat end to shell connection.

5.3.2.5.3 Welds other than full penetration welds

The following are examples of welds which are not full penetration welds:

a) stay tube to tube plate welds as shown in figures 21 a) to 21 e);

b) plain tube to tube plate welds as shown in figures 32 c) to 32 f);

c) bar stay welds as shown in figures 20, 22 a) to 22 d) and 23 a);

d) fillet welds attaching compensating plates as shown in figures 12 a) and 12 b).

5.3.2.6 Welding grooves

The dimensions and shape of the edges to be joined shall be such as to permit sound welds. [See 5.3.2.1 and 5.8.3.3 c).]

5.3.2.7 Tapered plate edges

If plate edges of unequal thickness are abutted, and if the difference between the surfaces on either side exceeds that specified in 5.8.11, the thicker plate shall be trimmed to a smooth taper for a distance not less than four times the offset including, if so desired, the width of the weld.

5.3.2.8 Welded joints subjected to bending stresses

5.3.2.8.1 Where it is known that local stresses due to geometrical discontinuities are unacceptably high, the weld contours shall be smooth. Where necessary, this may be accomplished by grinding and/or the addition of weld metal.

5.3.2.8.2 Corner joints with fillet welds shall not be used.

5.4 Heat treatment and post-weld heat treatment

5.4.1 Post-weld heat treatment in accordance with 5.8.16.1 shall be carried out after completion of all welding, and prior to the pressure test in the case of boilers where the wall thickness at any welded connection exceeds 30 mm, except as required by 3.14.2.9.2.

When welded repairs have been made to a vessel which has been heat treated, the vessel may again be heat treated. The decision as to whether heat treatment is necessary is left to an agreement between the manufacturer and inspecting and/or regulating authority.

5.4.2 When the welded joint connects parts that are of different thickness, the thicknesses to be considered in applying the limits mentioned in the requirements for post-weld heat treatment shall be the following nominal thicknesses, including corrosion allowance:

a) the thickness of the shell or head plate in nozzle attachment welds;

b) the thickness of the nozzle neck at the joint in nozzle neck to flange connections;

c) the thickness of the pressure part, at the point of attachment, where a non-pressure part is welded to a pressure part;

d) the thinner of two adjacent butt-welded plates including dished end to shell connections;

e) the thickness of the shell in connections to flat plates which are butt welded to the shell;

f) the thickness of flat plates where these are inset into the shell.

5.5 Non-destructive testing

5.5.1 General

For the purposes of this International Standard the term "non-destructive testing" covers the conventional techniques of radiographic, ultrasonic, magnetic particle and/or liquid penetrant testing as specified in 5.5.5, 5.9, annexes G and H, ISO 3452, ISO 3453 and ISO 3059. Percentages given in table 7 relate to each seam.

5.5.2 Procedure and interpretation

Except where otherwise stated in this International Standard, the procedure and interpretation of results shall be agreed upon between manufacturer and inspecting and/or regulating authority.

5.5.3 Non-destructive testing of repairs

On completion of repairs, the re-welded portions shall be examined by all techniques specified for the original weld.

5.5.4 Manufacturing in series

Until the results of future work are available, the amount of non-destructive testing in the case of manufacturing in series shall be subject to agreement between manufacturer and inspecting and/or regulating authority.

5.5.5 Extent of non-destructive testing

5.5.5.1 Shell seams

When the weld factor $v = 0,8$ is employed, 10 % of the length of the longitudinal and circumferential butt-welded seams and all butt-welded intersections shall be non-destructively tested.

When the weld factor $v = 1$ is employed, 100 % of the length of the longitudinal and 25 % of the circumferential butt-welded seams shall be non-destructively tested. When the end plates are fully stayed to each other by bar stays, stay tubes or a combination of bar stays and reversal chamber stays, 10 % of the length of the circumferential seams shall be non-destructively tested. All seam intersections shall be non-destructively tested.

The non-destructive testing techniques employed shall be radiographic and/or ultrasonic.

5.5.5.2 End plate to shell seams and end plate to furnace seams

When the end plates are fully stayed to each other as described in 5.5.5.1, end plate to shell seams of the type shown in figures B.15 a) and B.15 b) shall be non-destructively tested for 10 % of their length, and the end plate to furnace seams of the type shown in figures B.17 a) and B.17 b) shall be non-destructively tested for 25 % of their length.

When the end plates are not fully stayed to each other, 100 % of the end plate to shell and end plate to furnace seams shall be non-destructively tested.

100 % of the length of end plate to shell seams of the type shown in figures B.15 c) and B.15 d) shall be non-destructively tested.

The non-destructive testing technique employed shall be ultrasonic, where practicable, or otherwise the following procedure shall be adopted:

a) visual examination of weld preparation,

b) visual examination after tack welding, and

c) visual examination after initial root run,

unless alternative techniques are acceptable to the inspecting authority.

5.5.5.3 Internal fillet welds

The full length of internal fillet welds (back welds) shall be visually examined to ensure that they are of the correct shape without significant under-cutting (see 5.8.13).

5.5.5.4 Butt-welded seams in end plates

100 % of the length of butt-welded seams in end plates shall be non-destructively tested by radiographic and/or ultrasonic techniques.

Table 7 — Extent of radiographic or ultrasonic testing for butt welds

Com-ponent	Type of weld	Weld location	Figure No.	Testing technique	Notes	Percentage of total length of weld to be tested
Shell	Longitudinal	In shell sections	B.18	Radiographic or ultrasonic	1, 2 and 4	100
	Circumferential	Between shell sections	B.18	Radiographic or ultrasonic	1, 2 and 4	25
	Circumferential	Between shell sections and flanged end plates	B.18	Radiographic or ultrasonic	1, 2, 4 and 5	25
	Circumferential	Between shell sections and set-on end plates	B.15 c) and B.15 d)	Radiographic or ultrasonic	—	100
	T-butt	At junction of shell with set-in end plates	B.15 a) and B.15 b)	Ultrasonic	2 and 3	10
Flat end plates	Butt	Between the two sections in large diameter end plates	B.19	Radiographic or ultrasonic	2	100
Furnaces	Longitudinal	In furnace sections	B.18	Radiographic or ultrasonic	1 and 2	10
	Circumferential	Between furnace sections	B.18	Radiographic or ultrasonic	1 and 2	10
	Circumferential	Between furnace sections and bowling hoops	B.18	Radiographic or ultrasonic	1 and 2	10
	Circumferential	Between furnace sections and flanged end plates	B.17 c)	Radiographic or ultrasonic	1 and 2	10
	T-butt	Between furnace sections and set-in end plates	B.17 a) and B.17 b)	Ultrasonic	2 and 3	25
	T-butt	Furnace to reversal chamber end plate	B17 a) and B.17 b)	Ultrasonic	2 and 3	25
	T-butt	Between furnace sections and cyl-indrical components	B.4, B.5, B.6 and B.7	Ultrasonic	2	25
Reversal cham-bers	Longitudinal	In wrapper plate	B.18	Radiographic or ultrasonic	2	10
	Circumferential	Between wrapper plate and flanged end plate	B.16 a)	Radiographic or ultrasonic	1 and 2	10
	T-butt	Between wrapper plate and set-in end plate	B.16 b) to B.16 e)	Ultrasonic	2 and 3	10

Com-ponent	Type of weld	Weld location	Figure No.	Testing technique	Notes	Percentage of total length of weld to be tested
Reversal chamber access tube	Longitudinal	In access tube	B.18	Radiographic or ultrasonic	2	10
	T-butt	Access tube to boiler and reversal chamber end plates	39 and B.20	Ultrasonic	2 and 3	10

NOTES

1   The tests shall include each intersection of longitudinal and circumferential seams. For each longitudinal and circumferential seam there shall be at least one radiograph, or where ultrasonic testing is specified, at least a 200 mm length shall be examined.

2   In each case the section of weld to be tested shall be selected at random.

3   The position of the tested section of weld shall be marked on the boiler and recorded.

4   See 5.5.5.1.

5   When the flange is thicker than the end plate, the flange shall be machined to a taper and welded in a manner similar to that shown in figure B.19 a).

5.5.5.5   Furnace and reversal chamber seams

10 % of the total length of butt-welded seams (longitudinal and circumferential and intersections) in furnaces and reversal chamber wrapper plates shall be non-destructively tested by radiographic and/or ultrasonic techniques.

5.5.5.6   Branch welds and fillet welds

For branch welds and fillet welds welded to the same procedure, 10 % of the total length of welding shall be non-destructively tested when the thickness of the parts being joined exceeds 30 mm. For branch welds and fillet welds where the parts being joined are less than 30 mm thick, 5 % of the total length of welding shall be so examined.

The location of the weld to be non-destructively tested shall be selected at random by the inspecting authority. If any of the welds of the same type tested are found to be unsatisfactory, the extent of the non-destructive testing shall be increased at the discretion of the inspecting authority.

The non-destructive techniques employed shall be magnetic particle or liquid penetrant except in the case of branch welds when the thickness of the parts being joined exceeds 30 mm, in which case ultrasonic techniques shall be used.

For a given piece of equipment, the branch welds and fillet welds shall be tested as for the main welds (10 % or 100 %) if their diameter is greater than 500 mm.

5.6   Openings in or adjacent to welds

Openings in or adjacent to welded seams should be avoided especially when this seam is not stress relieved. The minimum distance from the centre-line of the welded seam to the nearest point of the weld of the connection, or edge of the opening, should be 60 mm, or four times the shell plate thickness, whichever is the larger.

Where this is not possible, it is recommended that the opening crosses the welded seam completely and in such a manner that the tangent at the point where the axis of the seam meets the edge of the opening makes an angle with this axis as close as possible to 90°. In this case the welded seam shall be non-destructively tested for a length of 60 mm, or four times the shell plate thickness, whichever is the larger, at each side of the opening.

5.7   Fillet welds

5.7.1   Fillet welds may be employed as strength welds for pressure parts within the limitations as indicated in annex B. In order to ensure complete fusion at the root of the fillet welds, particular care shall be taken in the layout of joints with fillet welds.

5.7.2   Corner or T-joints may be made with fillet welds provided that the plates are properly supported independently of such welds, except that independent supports are not required for joints such as lugs for platforms, ladders and other similar attachments.

5.8 Fabrication

5.8.1 General

The weld quality shall be in accordance with the requirements of this International Standard. The methods of welding main seams shall provide full penetration, and it shall be demonstrated by qualification tests that the welding method can produce a weld that is free from significant defects.

Preheating shall be provided in accordance with table 8.

In the case of high carbon steels, and also for thick plates, preheating and inspection for cracks may be necessary (see also 2.6.1).

Table 8 — Recommended preheating temperatures for welding of plates, sections, bars and forgings

Type	Hydrogen controlled weld metal		Non-hydrogen controlled weld metal	
	Material thickness[1]	Minimum preheating temperature	Material thickness[1]	Minimum preheating temperature
	mm	°C	mm	°C
Carbon and carbon manganese steel, ⩽ 0,25 % C	⩽ 30	5	⩽ 20	5
	> 30	100	> 20 ⩽ 50 [2]	100

1) The greatest component thickness at the joint.

2) It is recommended that only hydrogen controlled weld metal is used for thicknesses greater than 50.

5.8.2 Welding processes

Details of welding processes are not defined herein. Any process is acceptable provided that the requirements of the procedure qualification tests are met.

5.8.3 Welding procedure qualification

5.8.3.1 Procedure agreement

The welding procedures used by the manufacturer shall have been certified by the inspector or the inspecting authority in accordance with the requirements of this International Standard. Previous qualification of procedures in accordance with the appropriate national standards may be accepted in lieu by agreement with the inspecting authority.

5.8.3.2 Test welds

All test welds for welding procedure qualifications shall be carried out as butt welds.

If the production welding is to be done in the flat position, the procedure test plate shall also be welded in the flat position. If the production welding is to be done in any other position, the procedure test weld shall be welded in a similar position. All positions falling within the limits of any fundamental welding position as established by ISO 6947 are regarded as similar positions.

For fillet welds, a more representative testing shall be applied, if thought necessary, by agreement between manufacturer, purchaser and inspecting and/or regulating authority.

5.8.3.3 Requirements

Apart from the requirements specified in 5.8.3.1 and 5.8.3.2, procedure qualification test welds for all pressure parts of pressure vessels, including pipes and tubes, shall be made in such a manner that the welds can be considered representative of those made in production, taking into account the following particulars.

a) **Type of base metal**

The procedure qualification test plates or test pipes shall be made from steel with a tensile strength in the same range as that of the steel to be used in the construction, and having a chemical composition approximately corresponding, in so far as practicable, to the most unfavourable analysis from the standpoint of weldability and within the limits of the material specification of the steel concerned.

b) **Electrodes, filler material, flux and arc shielding gas**

Welding filler materials, i.e. electrodes as well as combinations of wire, powder and shielding gas combinations, shall be to the same standard or manufacturing specification, for both the procedure qualification and the production welds.

c) **Type of joint preparation**

Subject to agreement with the inspecting authority, a change of joint preparation for hand welding may be made without further testing. For semi-automatic or automatic processes, any substantial change in plate edge preparation will require a further test.

d) **Welding technique**

A new procedure qualification test is required in the following cases:

1) if in arc welding, the current and speed of welding and, for submerged arc welding, the voltage used, are appreciably changed;

2) if a backing strip is added or omitted;

3) if in machine welding, a change is made from multiple-pass welding per side to single-pass welding per side, or vice versa.

e) **Welding process**

The welding process and, in the case of semi-automatic or automatic welding, the type of welding device, shall be the same for the procedure qualification test and for the production welds.

f) **Preheating and delayed cooling**

The temperature of preheating, any heat treatment immediately following welding, and any control of cooling rate, shall be the same for the procedure qualification test and for the production welds.

However, if the preheat temperature in production work is for practical reasons increased by less than 100 °C, this change will not necessitate a new procedure qualification test.

g) **Subsequent heat treatment**

The subsequent heat treatment, i.e. normalizing, tempering or stress relieving, shall be the same for the welding procedure test and the production welds.

5.8.3.4 Thickness

For metal-arc welding, a procedure qualification shall be valid for thicknesses from 0,75 to 1,5 times the thickness of the procedure qualification test plate.

For oxy-acetylene welding, the plate thickness shall be the maximum thickness for which the procedure qualification shall be valid.

5.8.3.5 Size of test plates

The test plates for procedure qualification for butt welds in plates shall be of sufficient size to provide for the same tests as are required for the testing of production welds. A typical example for the way of taking specimens out of the test plate is shown in figure 40.

5.8.3.6 Special requirements for pipes and tubes

The test plates for procedure qualification for butt welds in pipes and tubes shall consist of two pieces of pipe or tube joined by a circumferential butt weld and shall provide for the number of test specimens given in table 9.

Table 9 — Test specimens to be taken from the test plates for butt-welded pipes and tubes

Outside pipe diameter D	Cross tensile test	Face bend test	Root bend test	Macro-etch	Impact tests for wall thicknesses > 10 mm
≤ 51 mm	2[1]	—	2	1	See 5.8.3.9 b)
> 51 mm	2	1	3	1	

1) The cross tensile test piece for tubes ≤ 51 mm shall be the welded pipe as a whole.

A separate piece of welded pipe or tube shall be required for the preparation of root bend and macro-etch test specimens in the case of tubes or pipes where D ≤ 51 mm.

If a backing strip is used, it shall be left in position in the macro-etch specimen and in the tensile test made on a welded pipe as a whole. The backing strip shall be removed from all other test specimens.

The test plates shall be welded in the position adopted in practice, using, if necessary, the four basic pipe positions

a) horizontal rotating,

b) vertical,

c) horizontal fixed, and

d) inclined at 45° to horizontal — fixed.

Position c) qualifies for position a).

Position d) qualifies for positions a), b) and c).

The manner in which the test specimens shall be taken from test plates is shown in figure 41 a).

The macro-etch test specimen shall be taken from that part of the periphery of the weld which corresponds to what is regarded as the most difficult welding position in the case concerned.

The tensile test specimens shall be made in accordance with 5.8.17.3 except that the minimum width of the curved specimen shall be 20 mm.

The bend test specimens shall have the widths specified in table 10.

Table 10 — Widths of bend test specimens for pipes and tubes

Outside pipe diameter D	Thickness of pipe t	Width of bend test piece W [1]
$\leqslant 51$ mm	t	$t + \dfrac{D}{10}$
> 51 mm	t	$t + \dfrac{D}{20}$
1) With a maximum of 38 mm.		

The bend test specimens shall be cut with the edges parallel as shown in figure 41 b), and shall have the corners rounded or dressed to a radius of approximately 1,5 mm.

The bend test specimens shall be bent without being straightened, after removal of the weld reinforcement down to the level of, but not below, the surface, round a former of diameter $3t$ and through an angle of 90°.

5.8.3.7 Non-destructive testing of test plates

The test plates for procedure qualification shall be subject to non-destructive testing of the weld (see 5.5).

5.8.3.8 Assessment of test pieces

The results of the tests and examination of welding procedure qualification test pieces shall satisfy the requirements for welded production test plates (see 5.10).

5.8.3.9 Selection and results of tests

The welds in test procedure plates shall be subjected to non-destructive testing. If, in a test plate, weld defects which are unacceptable in accordance with this International Standard are revealed by non-destructive examination, a new procedure test plate shall be prepared. Test specimens shall be selected from those parts of the test plate which contain the best quality welding in that test plate.

a) **Tensile and bend specimens**

   When a tensile or a bend test specimen fails to meet the specified requirements, two repeat tests for each failure shall satisfy the requirements of this International Standard.

b) **Impact tests**

   Three test specimens are required.

The test results are acceptable if the mean value is 27 J or more, and at the same time only one of the specimens shows a value not lower than 20 J.

If the required mean value is not met, or if only one of the specimens shows a value below 20 J, then three supplementary test specimens shall be taken and tested.

On the basis of the above, the results shall be considered acceptable if the mean value of all six specimens is 27 J or more and at the same time only two specimens show values below 27 J and only one of these has a value below 20 J.

If one specimen fails due to an obvious defect, the result may be disregarded and one replacement specimen may be taken. However, only one replacement specimen is allowed in a test series.

If the retests are not consistent with the requirements of this International Standard, an investigation of the reason shall be made before the whole procedure is repeated.

5.8.3.10 New welding procedure qualification

A completely new welding procedure qualification is mandatory when a substantial change is made in the essential variables as listed in 5.8.3.1 to 5.8.3.4 inclusive.

5.8.3.11 Acceptance of welded production test plates

Welded production test plates, when accompanied by all the relevant data necessary for a welding procedure test and certified by the inspector or inspecting authority, shall be considered as equivalent to procedure qualification tests.

5.8.3.12 Records of tests

Records of tests shall be kept and shall be available for examination, if required. Suggested model forms for these records are given in annex F.

5.8.4 Welder's competence qualifications

5.8.4.1 General

Each welder shall be qualified in conformity with the welder's competence qualification tests specified in this International Standard. Previous welder's competence qualification tests in accordance with the appropriate national standards may be accepted in lieu by agreement with the inspecting authority.

5.8.4.2 Butt welds on plate and pipe

Test welds of the butt-welded type on plates for welder's competence qualification shall have a length of at least 300 mm and not less than five times the plate thickness. These test welds shall be submitted to visual and radiographic examination (see 5.5) and to macro-etching of a cross-section of the weld.

In the case of welds made by the oxy-acetylene process or by the dip transfer (short arc) process, as many additional root bend tests shall be made as the size of the test coupon permits. These root bend test specimens shall conform to those required for the testing of welded production test plates (see 5.8.17.3.3.2).

For these two processes, test welds of the butt-welded type for welder's competence qualification on pipes or tubes shall be tested by means of bend test pieces of the number, width and conditions of bending in accordance with 5.8.3.6.

5.8.4.3 Fillet welds

Test welds for welder's competence qualification shall be carried out as fillet welds representative of those under consideration; typical test welds are shown in figure 42. These test welds shall be broken and the appearance of the rupture as well as a macro-etching of a cross-section of the weld shall be examined.

When welders are required to requalify (see 5.9.2.2), the fillet weld tests may be omitted with the agreement of the inspecting authority provided that the welder qualifies for butt welding.

5.8.4.4 Conditions of qualification

Test welds for welder's competence qualification shall be carried out in exactly the same way and under the same conditions as laid down for qualification of the welding procedure.

Changes in the welding procedure which entail requalification shall also require requalification of welder's competence, except where these are modified by the essential variables as given in 5.8.4.5.

The relaxations listed in 5.8.4.5 may only be applied provided that for all processes except the oxy-acetylene and dip transfer processes, the welder's competence qualification is judged by means of radiography or ultrasonic examination, supplemented by other non-destructive testing methods where this is considered necessary.

If mechanical testing methods are used to evaluate the competence qualification test welds, the procedure used shall be exactly the same as for the welding procedure test piece. Welder's competence qualification tests in oxy-acetylene or dip transfer processes may be judged by non-destructive testing provided that, in addition, the bend test requirements specified in 5.8.4.2 are also met.

5.8.4.5 Requirements and influence of essential variables for welder's competence qualification

5.8.4.5.1 Base metal

A change in base metal composition shall not entail requalification.

5.8.4.5.2 Position

5.8.4.5.2.1 Plate

A qualification test is required within the limits of each of the four fundamental welding positions (see ISO 6947) in which it is intended to weld in production.

Qualification tests in the fundamental positions cover for intermediate positions.

Qualification on plate shall not qualify for welding pipe or tube.

5.8.4.5.2.2 Pipe and tube

Qualification by means of welding a pipe or tube in the horizontal fixed position shall qualify for welding pipe, tube or plate in all positions, except for circumferential welds in vertical pipes or tubes or for horizontal—vertical welds in plate. Qualification for circumferential welds in vertical pipes or tubes shall necessitate welding in the vertical fixed position and this shall also qualify for horizontal—vertical welds in plate and for intermediate positions. Alternatively a qualification test in the inclined position may be substituted.

5.8.4.5.3 Thickness

The range of validity of thickness shall be within the following limits.

5.8.4.5.3.1 Oxy-acetylene process

A qualification test in the thickness range less than or equal to 4 mm shall qualify for any other thickness in that range. A qualification test in a thickness greater than 4 mm shall qualify for thicknesses of 4 mm and greater, up to and including the nominal thickness of the test plate.

5.8.4.5.3.2 TIG process

A qualification test in the thickness range less than or equal to 4 mm shall qualify for any other thickness in that range. A qualification test in the range

greater than 4 mm and less than or equal to 20 mm shall qualify for any other thickness in that range.

A qualification test in a thickness greater than 20 mm shall qualify for any thickness over 20 mm.

5.8.4.5.3.3 Automatic, semi-automatic or manual electric process

A qualification test on plates of thickness smaller than 12 mm qualifies for any other thickness in the range 0,75 to 1,5 times the thickness of the test plate. A qualification test on plates of thicknesses in the range 12 mm to 15 mm qualifies for all thicknesses exceeding 8 mm.

A qualification test on pipes or tubes of thicknesses smaller than 20 mm qualifies for any other thickness in the range 0,75 to 1,5 times the thickness of the test plate. A qualification test on pipes or tubes of thicknesses over 20 mm qualifies for all thicknesses exceeding 15 mm.

5.8.4.5.3.4 Partially welded seams

When only part of a seam is to be welded by a particular process (for example root runs, etc.), partially welded seams may be subjected to the qualification test. However, the number of runs used in the test weld shall not be less than may be required in production.

5.8.4.5.4 Filler metal and shielding gas

5.8.4.5.4.1 Dip transfer process

Any change in the composition of the filler wire or in the wire manufacturing process or in the composition of the shielding gas which has no effect upon the welding or running characteristics shall not entail requalification.

5.8.4.5.4.2 Metal-arc process

Welder qualification tests made with basic-type coated electrodes qualify also for welding with acid- or rutile-type electrodes but not vice versa.

Welder qualification tests made with cellulosic-type coated electrodes qualify for welding with this type of electrode only.

Furthermore, qualification validity shall, for the flat position, extend to a change in electrode size of plus-or-minus one ISO nominal diameter, but for other positions, the range of qualification validity shall be limited to the electrode size used in testing and one ISO nominal diameter smaller.

5.8.4.5.4.3 TIG process

A change in filler metal within the limits of composition appropriate to this International Standard, or in gas composition which has no effect on the welding or running characteristics, shall not entail requalification.

5.8.4.5.5 Automatic and semi-automatic processes

Qualification validity shall be limited to each individual process. However, a change in flux, in wire size, in the speed of welding, or in the electrical parameters (e.g. voltage, current intensity, AC or DC, etc.) need not entail requalification.

5.8.4.5.6 Joint preparation

A change in the form of joint preparation need not entail requalification provided that the alteration will not adversely affect the ease of welding.

In the case of branch and nozzle welds etc., a change in joint preparation within the range of typical forms recommended herein (see annex B) need not entail requalification.

5.8.4.5.7 Pipes and tubes

Qualification for welding pipes or tubes shall be subject to all the effects of changes in the essential variables as specified herein, and in addition, the validity range shall extend to the following limits:

a) a qualification test done on a pipe or tube with an outside diameter D less than 165 mm qualifies for any other diameter in the range $0,5D$ to $1,5D$;

b) a qualification test done on a pipe or tube having an outside diameter D equal to or greater than 165 mm qualifies for all diameters greater than 80 mm.

5.8.4.5.8 Branches and other openings

Qualification for welding branch, nozzle and similar joints, in all positions, shall be carried out on pipe in accordance with the rules for qualifying pipe or tube welding (see 5.8.4.5.7).

However, qualification for welding such joints in the flat position only may be carried out in accordance with the rules for qualifying plate welding. In this case, the thickness limits (see 5.8.4.5.3) shall refer to the throat thickness of the welds used in production and not to the thickness of the branch, nozzle or shell.

5.8.4.6 Requirements on test welds

The appearance of the test welds, the macro-graphs where required, and the radiographs of these test welds shall conform to the requirements for acceptance of the production welds.

5.8.4.7 Records of test

Records of test shall be kept, and shall be made available for examination if required. Suggested model forms for these records are given in annex F.

5.8.4.8 Validity of the procedure qualification test as welder's competence qualification test

A welder who has successfully carried out a welding procedure qualification is thereby qualified for welder's competence in the procedure concerned.

5.8.4.9 Repetition of tests

The required test shall be repeated if

a) the records of the welder show unsatisfactory production work;

b) a qualified welder has not been employed in the welding of pressure-retaining parts within the scope of the welder's competence qualification test within the previous 6 months, or if his qualification documents are not available.

When access to records is limited, or other special conditions pertain, supplementary tests may be required.

5.8.5 Lowest permissible temperatures for welding

It is recommended that no welding of any kind be done when the temperature of the base metal is lower than − 20 °C. At temperatures between − 20 °C and 0 °C the surface of all areas within approximately 75 mm of the point where a weld is to be started shall be heated to a temperature at least warm to the hand (estimated to be above 15 °C) before welding is started. It is also recommended that no welding be done when surfaces are wet or covered with ice, when snow is falling on the surfaces to be welded, or during periods of high wind, unless the welders or welding operators and the work are properly protected.

5.8.6 Cutting, fitting and alignment

5.8.6.1 Thermal cutting of plate, sections, bars and forgings shall be at a temperature greater than 5 °C.

5.8.6.2 Plates shall be cut to size and shape by thermal cutting and/or machining.

For plates not greater than 15 mm in thickness, cold shearing may be used provided that the edges are examined (visually or otherwise) and found suitable for welding.

5.8.6.3 Plates that are being welded shall be fitted, aligned and retained in position during the welding operation.

Bars, jacks, clamps, tack welds, or other appropriate means may be used to hold the edges to be welded in line. Tack welds shall be removed unless they are completely fused into the weld.

The edges of butt joints shall be held during welding so that the tolerances of 5.8.10 and 5.8.11 are not exceeded in the completed joint. When fitted girth joints have deviations exceeding the permitted tolerances, the head or shell ring, whichever is out-of-true, shall be adjusted until the errors are within the limits specified. Where fillet welds are used, the pieces shall fit closely.

5.8.7 Longitudinal joints

Longitudinal seams in shells, drums and headers may be welded from both sides, or from one side only if the welding procedure test shows acceptable results. If a backing strip is used, it shall be removed after welding and prior to any required non-destructive tests and shall be of such material that it will not adversely influence the weld.

5.8.8 Circumferential joints

If circumferential seams in shells and drums are welded from one side with the use of a backing strip, this backing strip shall be removed after welding and prior to any required non-destructive testing.

The material of a backing strip shall be such that it will not adversely influence the weld.

5.8.9 Surface condition before welding

The surfaces to be welded shall be clean and free from foreign material, such as grease, oil, lubricants, and marking paints, for a distance of at least 25 mm from the welding edge. Detrimental oxide shall be removed from the weld metal contact area. When weld metal is to be deposited over a previously welded surface, all slag shall be removed by a roughing tool, chisel, air chipping hammer, or other suitable means so as to prevent inclusion of impurities in the weld metal.

5.8.10 Middle line alignments (see figure 43)

For longitudinal joints, the middle lines of the plates shall be in alignment within 10 % of the thickness of the thicker plate

$$d_1 \leqslant 0.1b$$

with a maximum of 3 mm.

However, the limits for the alignments of the mid-lines may be exceeded where the design requires that the mid-lines be offset for some technical reasons, these offsets being taken into account in the calculations.

5.8.11 Surface alignment tolerances (see figure 43)

5.8.11.1 Circumferential joints

The maximum misalignment at the surface of the plates shall be as given in table 11. If this misalignment would otherwise be exceeded, the surface of the thicker plate shall be tapered with a slope of 1:4.

Table 11 — Maximum misalignment of plates with circumferential joints

Thicker plate thickness b mm	Maximum misalignment d_2 or d'_2 mm
$b \leqslant 20$	$b/4$
$20 < b \leqslant 40$	5
$40 < b \leqslant 50$	$b/8$
$b > 50$	$b/8$ but not greater than 20

5.8.11.2 Longitudinal joints

The misalignment at the surface of the plates shall not exceed the values given in table 12.

If this misalignment would otherwise be exceeded, the surface of the thicker plate shall be tapered with a slope of 1:4.

Table 12 — Maximum misalignment of plates with longitudinal joints

Thicker plate thickness b mm	Maximum misalignment d_2 or d'_2 mm
$b \leqslant 12$	$b/4$
$12 < b \leqslant 48$	3
$b > 48$	$b/16$ but not greater than 10

5.8.12 Finished longitudinal and circumferential joints (see figure 43)

All welds shall have a smooth finish without valleys and shall merge into the plates without significant[4] under-cutting or abrupt irregularity.

To ensure that the weld grooves are completely filled so that the surface of the weld metal at any point does not fall below the surface of the adjoining plate, weld metal may be built up as reinforcement on each side of the plate. This reinforcement shall not exceed the thicknesses given in table 13.

The reinforcement need not be removed except to the extent that it exceeds the permissible thickness, or if required by 5.8.14.4, 5.9.4.2.1 and G.4.

Table 13 — Maximum reinforced thickness for finished longitudinal and circumferential joints in plates

Thicker plate thickness b mm	Maximum reinforcement thickness r or r' mm
$b \leqslant 12$	2,5
$12 < b \leqslant 25$	3
$b > 25$	5

5.8.13 Fillet welds

All fillet welds shall be made in such a way that there is no significant[4] under-cutting or other harmful effects. For strength fillet welds, the weld metal shall be deposited in such a way that adequate penetration into the base metal at the root of the weld is secured, and sufficient weld metal shall be deposited to meet the calculated requirements.

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4) Under-cutting is regarded as significant if it is approximately 0,5 mm deep.

5.8.14 Miscellaneous welding requirements

5.8.14.1 Double-sided welds

The reverse side of double-welded joints shall be cleaned back to sound metal before applying weld metal from the reverse side. This requirement is not intended to apply to any process of welding by which proper fusion and penetration are otherwise obtained and by which the base of the weld remains free from impurities.

5.8.14.2 Restart

If the welding is stopped for any reason, extra care shall be taken on restarting to obtain the required penetration and fusion.

For submerged arc welding, chipping out a groove in the crater is recommended.

5.8.14.3 Single-sided welds

Where single-welded joints are used, particular care shall be taken in aligning and separating the components to be joined so that there will be complete penetration and fusion at the bottom of the joint for its full length.

5.8.14.4 Plates welded prior to hot or cold forming

When necessary, plates may be butt welded together prior to hot forming, provided that the welded joint is non-destructively tested after hot forming and a test plate of the weld (subjected to the same heat treatment) is examined.

Cold forming of welded plates is allowed under the following conditions.

a) Forming precautions

Before cold forming, the weld reinforcement shall be ground smooth, and the manufacturer shall take precautions, where necessary, in order to avoid crack formation in weld metal or the heat-affected zone.

b) Limiting thicknesses

The limiting thicknesses are as follows:

1) up to 20 mm thickness for coarse-grained steels;

2) up to 25 mm thickness for fine-grained steels.

c) Forming

If the inside radius of curvature after forming is less than 10 times the thickness, an appropriate heat treatment shall be applied, as agreed between purchaser, manufacturer and inspecting and/or regulating authority.

d) Control

After cold forming, the welded joints shall be visually examined and non-destructively tested throughout their length. Joints of any thickness which have been cold formed to an inside radius less than that specified in c) shall be inspected for cracks by magnetic or penetrant methods or by other agreed methods. The method to be used shall be agreed by the purchaser and the inspecting and/or regulating authority.

5.8.14.5 Re-rolling

Cold rolling of a welded shell to rectify a small departure from circularity is permitted.

5.8.14.6 Heat treatment

In cases where heat treatment is mandatory under the requirements of this International Standard, the attachment of nozzles, pads, branches, pipes and tubes, and non-pressure parts by welding shall be done before final heat treatment.

However, exceptions are permitted when agreed between the manufacturer, purchaser and inspecting and/or regulating authority, taking into account the working conditions of the boiler and the materials used. In this instance, local preheating and non-destructive testing (crack detection) is necessary.

5.8.14.7 Attachments

5.8.14.7.1 Lugs, brackets, stiffeners, and other attachments shall conform reasonably to the curvature of the shell or other surface to which they are to be attached.

5.8.14.7.2 Temporary attachments welded to the pressure parts shall be kept to a practical minimum.

5.8.14.7.3 Temporary attachments shall be removed prior to the first pressurization unless they have been designed to the same standard as permanent attachments.

5.8.14.7.4 The welding of all attachments shall be carried out by approved welders and according to an approved procedure.

5.8.14.7.5 Welds of permanent major load-carrying attachments to pressure parts shall be examined by appropriate non-destructive testing.

5.8.14.8 Removal of attachments

5.8.14.8.1 Where construction attachments are to be removed, the technique used shall be such as to avoid impairing the pressure part proper. Such removal shall be by chipping, grinding, or thermal cutting followed by chipping or grinding.

5.8.14.8.2 The areas from which temporary attachments have been removed shall be dressed smooth and be examined by an appropriate non-destructive test.

5.8.15 Repair of weld defects

Any repair to a weld carried out by the manufacturer shall be reported to the inspecting authority. If the repair is made as a consequence of a radiographic examination, the films of the original defects shall be made available (see 5.9.1).

It is the responsibility of the manufacturer, after due consideration of the importance and number of defects to be removed, to decide whether to carry out a number of local repairs, or to produce a new complete joint after cutting or grinding of the weld concerned.

The welding procedures for local or complete repairs shall be approved. If the defects being repaired do not require the use of a welding procedure different from that already approved for use by the manufacturer, and if the manufacturer decides to use this procedure for the above-mentioned repair, no approval test shall be necessary. The repair shall be carried out by an approved welder.

In the case of a difficult repair the manufacturer shall inform the inspecting authority.

In the case of recurring unacceptable defects, the cause shall be investigated and the inspecting authority informed.

5.8.16 Heat treatment

5.8.16.1 Post-weld heat treatment

The temperature to which plain carbon and carbon manganese steels shall be heated for stress-relief purposes shall be within the range of 550 °C minimum to 620 °C maximum. The holding time within this temperature range shall be 2 min/mm, with a minimum of 30 min and a maximum of 120 min.

The procedures in 5.8.16.1.1 to 5.8.16.1.7 shall be adopted for application of the heat treatment.

5.8.16.1.1 The temperature of the furnace, at the time the boiler is placed in it, shall not exceed 300 °C, depending on the boiler involved.

5.8.16.1.2 The rate of heating above 300 °C shall not exceed the rates given in table 14.

Table 14 — Rate of heating above 300 °C during post-weld heat treatment

Shell or end plate thickness	Rate of heating
$e \leqslant 25$ mm	220 °C/h
$e > 25$ mm	5 500/e °C/h or 55 °C/h, whichever is the greater

5.8.16.1.3 During the heating period, the temperature variation between points 4,5 m apart shall not exceed 150 °C, and when at the holding temperature, the temperature throughout the portion of the boiler being heated shall be within the range 550 °C minimum to 620 °C maximum as specified in 5.8.16.1.

5.8.16.1.4 During the heating and holding periods, the furnace atmosphere shall be so controlled as to avoid excessive oxidation of the surface of the boiler. There shall be no direct impingement of the flame on the boiler.

5.8.16.1.5 The boiler shall be cooled in the furnace to 300 °C at a rate not exceeding the rates given in table 15.

Table 15 — Rate of cooling to 300 °C during post-weld heat treatment

Shell or end plate thickness	Rate of cooling
$e \leqslant 25$ mm	275 °C/h
$e > 25$ mm	6 875/e °C/h or 55 °C/h, whichever is the greater

5.8.16.1.6 Below 300 °C, the boiler may be cooled in still air.

5.8.16.1.7 The temperatures specified shall be the actual temperatures of any part of the boiler and shall be determined using thermocouples in contact with the boiler.

5.8.16.1.8 A sufficient number of temperatures shall be recorded continuously and automatically. Several thermocouples shall be applied to ensure that the whole boiler, or the part of the boiler being heat treated, is within the range specified, and additional pyrometers shall be utilized to check that undesirable thermal gradients do not occur.

5.8.16.2 Other heat treatments

If a normalizing heat treatment has to be carried out, the part to be normalized shall be brought up to the required temperature slowly and held at that temperature for a period just sufficient to soak the part thoroughly through. If the geometry of the part causes insufficiently homogeneous cooling, a stress-relieving heat treatment shall be applied after the normalizing heat treatment.

5.8.16.3 Heat treatment of test plates

Where a welded production test plate is required, it shall be placed inside the pressure part it represents during heat treatment, or, where this is impracticable, the test plate may be placed alongside the pressure part it represents, in the furnace, in such a position that it will receive similar heat treatment.

The test plate may be heated separately from the pressure part, provided that means are adopted to ensure that the following factors are the same for the test plate and for the pressure part:

a) rate of heating, maximum temperature;

b) time held at temperature;

c) condition of cooling.

Heat treatment temperatures of separately heated test plates shall be recorded.

5.8.17 Production testing

5.8.17.1 Weld production test plates

5.8.17.1.1 Where shell boilers or parts thereof are welded with a weld factor of $v = 1$, production tests shall be performed to prove the quality of the products delivered.

Production test plates shall be provided at the rate of one for each 10 m of welding, with at least one for each shell welded to the same procedure, in the case of longitudinal welds, and one for each 30 m of welding to the same procedure, in the case of circumferential welds.

If the circumferential welds are made to the same procedure as the longitudinal welds no test plates need be provided for the circumferential seams.

5.8.17.1.2 Where shell boilers or parts thereof are welded with a weld factor of $v = 0,8$, production test plates shall be provided at the rate of one for each 100 m of welding to the same procedure, in the case of longitudinal welds, and one for each 300 m of welding to the same procedure, in the case of circumferential welds.

If the circumferential welds are made to the same procedure as the longitudinal welds no test plates need be provided for the circumferential seams.

5.8.17.1.3 When boilers with a weld factor of $v = 0,8$ are manufactured along with boilers with a weld factor of $v = 1$, and are welded to the same procedure, destructive tests are not required for the boilers with a weld factor of $v = 0,8$, provided that sufficient test plates are produced to cover the total length of welding involved.

5.8.17.1.4 Production test plates for longitudinal seams shall be welded as a continuation of a longitudinal seam. For a weld factor of $v = 1$, the material for the production test plates shall be from the same batch as the shell, and for a weld factor of $v = 0,8$, the material for the production test plates shall be to the same specification as plates local to the seam represented.

5.8.17.1.5 The tests on weld production test plates shall comprise

a) one reduced section tensile test, transverse to the weld,

b) one all-weld-metal tensile test (only required for plate 20 mm thick and over),

c) one face bend test,

d) one reverse bend test,

e) three impact tests — V-notch of the weld metal (only required for plate 10 mm thick and over), and

f) one macro-test.

The results of all the tests shall be recorded. If any test specimen shows an unsatisfactory result the reason for the failure shall be investigated and two retest specimens shall be prepared and tested. If it can be shown that the failure has resulted from a local or accidental defect and the retest results are satisfactory the retest results shall be accepted.

5.8.17.1.6 If so desired, weld test plates may be provided at both ends of a longitudinal seam, in which case the dimensions of the test plates shall be sufficient to take the required test specimens out

of one of them, and the specimens for any necessary retesting out of the other.

5.8.17.1.7 The test plates shall be supported or reinforced during welding in order to prevent undue warping.

The test plates shall be subjected to the same heat treatment as required for the work piece to which they belong.

Test plates which have warped during welding may be straightened at a temperature below the temperature of heat treatment of the shell to which they belong. Straightening shall be done before final heat treatment.

5.8.17.2 Non-destructive testing of test welds

The test welds shall be subjected to non-destructive testing by the same technique as the production welds represented, and if unacceptable defects are revealed, the whole of the production welds represented by the test plates shall be subjected to non-destructive testing for 100 % of their length.

If any defects in the weld of a test plate are revealed by non-destructive testing, their position shall be clearly marked on the plate and test specimens shall be selected from such other parts of the test plate as may be agreed upon between the manufacturer and the inspecting authority.

The cause of such defects in the production test plate shall be ascertained.

5.8.17.3 Test specimens and dimensions

Production weld test plates shall make provision for the test specimens specified in 5.8.17.3.1 to 5.8.17.3.5.

5.8.17.3.1 Reduced section tensile test specimen

One reduced section tensile test specimen cut transversely to the weld, or as many specimens as are necessary to investigate the tensile strength over the whole thickness of the joint, shall be taken.

The dimensions of the reduced section tensile test specimen shall be those shown in figure 44.

The width of the reduced section shall be at least 25 mm.

If the plate thickness exceeds 30 mm the tensile test may be carried out on several reduced section specimens, each having a thickness of at least 30 mm and a width at the effective cross-section of at least 25 mm.

These specimens shall be taken out of the test plate in such a way that the tensile test covers the whole

thickness of the welded joint as shown in figure 45. In this case, the result of the test of every test specimen concerned shall meet the requirements specified in 5.10.1.

5.8.17.3.2 All-weld-metal test specimen

The dimensions of the all-weld-metal tensile test specimen shall be those shown in figure 46.

The diameter d_o shall be the maximum possible consistent with the cross-section of the weld, but in no case more than 20 mm.

The gauge length shall be equal to five times the diameter.

Two all-weld-metal test specimens, one above the other, shall be taken if the thickness of the plate is greater than 70 mm.

5.8.17.3.3 Bend test specimens

5.8.17.3.3.1 General

Two bend test specimens, one for direct and one for reverse bending, shall be taken transversely to the weld. Where the thickness of the plate permits, one shall be above the other.

When the thickness of the plate exceeds 20 mm, face bend and root bend tests may be substituted by side bend tests. When welds are made from one side only, one bend test may be a side bend test, but at least one shall be a normal bend test with the root of the weld in tension.

5.8.17.3.3.2 Face and root bend tests

5.8.17.3.3.2.1 The bend test specimens shall be rectangular in section so as to have a width equal to 1,5 times the thickness of the specimen, but not less than 30 mm.

The surface of the specimen shall be machined just enough to remove the surface irregularities of the plate and the weld.

The corners of the specimens shall be rounded to a radius not exceeding 10 % of the thickness of the specimen.

5.8.17.3.3.2.2 Where the plate thickness does not exceed 30 mm, the thickness of the specimen shall be equal to the full thickness of the test plate.

5.8.17.3.3.2.3 Where the plate thickness exceeds 30 mm, the specimen shall in all cases have a thickness of at least 30 mm. The specimen to be tested with the outer surface of the weld in tension shall be prepared by cutting to waste the metal local to the inner surface of the weld so that the desired specimen thickness is obtained.

5.8.17.3.3.2.4 The specimen to be tested with the inner surface of the weld in tension shall be prepared by cutting to waste the metal local to the outer surface of the weld so that the desired specimen thickness is obtained.

5.8.17.3.3 Side bend test specimen

5.8.17.3.3.1 The side bend test specimen shall be rectangular in section in accordance with figure 47. The diameter D of the former shall be such that the maximum width of the weld is always contained within the limits of the diameter of the former. The thickness of the specimen shall be at least 10 mm and proportional to the diameter of the former according to the type of steel (see 5.10.3).

5.8.17.3.3.3.2 For plate thicknesses between 30 mm and 40 mm, the width b of the test specimen shall be the full thickness of the plate, and the upper and lower surfaces of the weld shall be dressed flush with the original surfaces of the material.

5.8.17.3.3.3.3 When the plate thickness exceeds 40 mm, it is allowed, if necessary, to substitute a full-thickness specimen by two or more specimens of equal width cut from the plate thickness, provided that the width of the specimens is not less than 30 mm.

5.8.17.3.4 Impact test specimen — V-notch

Three V-notched bar impact test specimens shall be taken transversely to the weld as near as possible to the face side of the last pass of the weld.

The V-notched bar impact test specimens shall be of the type and dimensions shown in figure 48 and ISO 148.

The notch shall be contained in the weld metal at approximately the axis of the weld, and the axis of the notch shall be perpendicular to the surface of the plate.

The machining of the bottom of the notch shall be done very carefully.

The impact tests shall be made on the specimen at a maximum temperature of 22 °C.

5.8.17.3.5 Macro-test specimen

One macro-test specimen shall be provided for. The macro-test specimen shall contain a macro-etch of a complete cross-section of the weld.

5.9 Inspection and tests

5.9.1 Check of welding procedure

The inspector shall satisfy himself that the welding procedure employed in the construction of a boiler has been qualified under the requirements of 5.8.

Welding production tests, when accompanied by all the relevant data necessary for a welding procedure test and certified by the inspecting authority, shall be considered as equivalent to procedure qualification tests.

Records of tests shall be kept, and shall be made available for examination if required.

5.9.2 Check of welder and welding operator qualifications

5.9.2.1 The manufacturer shall certify that the welding on a vessel has been done only by welders and welding operators who have been qualified under the requirements of 5.8.4, and the inspector shall satisfy himself that only qualified welders and welding operators have been used.

5.9.2.2 The manufacturer shall make available to the inspector a certified copy of the record of the qualification tests of each welder and welding operator. The inspector shall have the right at any time to request and witness tests of the welding procedure or the ability of any welder and welding operator.

The inspector has the right to witness the competence test of any welder and welding operator. Subsequently, in case of doubt, he has the right to request requalification of any welder.

5.9.3 Check of post-weld heat treatment

The inspector shall satisfy himself that all post-weld heat treatment has been correctly performed and that the temperature readings conform to the requirements.

5.9.4 Non-destructive testing of welded joints — Techniques and acceptability of imperfections

All welded joints which are to be subjected to non-destructive testing shall be prepared so as to be suitable for the non-destructive test method to be used.

5.9.4.1 Visual examination of butt welds

All butt-welded joints shall be visually examined for profile defects and shall comply with the requirements of table 16.

Table 16 — Acceptance levels of profile defects in butt welds found by visual examination

Defect type	Acceptance level
Undercut	Continuous undercut not permitted. Local undercut with depth greater than 0,5 mm not permitted.
Shrinkage grooves and root concavity	As for undercut, except that depth shall not exceed 1,5 mm.
Reinforcement shape	The reinforcement shall blend smoothly with the parent metal and dressing is not normally required provided that the shape does not interfere with the specified non-destructive testing techniques.
Excess reinforcement and excess penetration	The maximum reinforcement given in 5.8.12 shall not be exceeded (see figure 43).
Overlap	Not permitted.
Linear misalignment	The maximum misalignment given in 5.8.11 shall not be exceeded (see figure 43).
Surface-breaking cavities	Not permitted.

NOTE — Attention is drawn to the project in ISO/TC 44/SC 10, *Unification of requirements in the field of metal welding,* concerning the drafting of a future International Standard on "Quality assurance of welding operations: Fusion-welded joints in steel, requirements, assessment groups".

5.9.4.2 Radiography

5.9.4.2.1 Techniques

5.9.4.2.1.1 All welded joints to be radiographed shall be prepared as follows.

The weld ripples or weld surface irregularities on both the inside and the outside shall, when necessary, be removed by any suitable mechanical process to such a degree that the resulting radiographic image due to any irregularities cannot mask or be confused with the image of any objectionable defect. If so required, the weld reinforcement as stated in 5.8.12 may be reduced to the thicknesses given in table 17.

Table 17 — Permitted reinforcement

Thickness b	Reinforcement thickness
mm	mm
$b \leqslant 12$	1,5
$12 < b \leqslant 25$	2,5
$25 < b \leqslant 52$	3
$b > 52$	4

5.9.4.2.1.2 The welds shall be radiographed in accordance with ISO 1106 using at least class B techniques, ISO 2504 and ISO 5579.

5.9.4.2.1.3 The boiler shall be marked alongside the welds so that each radiograph may be identified with its proper location (see also 5.1.7).

5.9.4.2.1.4 The radiographs shall be identified by means of lead characters to indicate the following:

a) the particular boiler to which the radiographs apply by a serial or order number;

b) the location of the welded seam using appropriate letters for the different seams with a numeral to indicate whether the seam was the first, second, third, etc.;

c) the region of the welded seam covered by the radiograph;

d) an indication that repair welding has been carried out in the length of welded joints represented by the radiographs.

5.9.4.2.1.5 The image quality indicator (I.Q.I.) shall comply with the requirements of ISO 1027.

5.9.4.2.1.6 The use of I.Q.I.s shall be in accordance with the recommendations of ISO 2504.

5.9.4.2.1.7 The examination of the radiographs of welds shall be made on the original film using a viewing device complying with the requirements of ISO 5580.

5.9.4.2.2 Acceptance level of defects in butt welds

The acceptance level of defects in butt welds shall be as stated in table 18.

5.9.4.2.3 Radiographs

A complete set of radiographs for each job shall be retained by the manufacturer and kept on file for a period of at least 5 years.

5.9.4.3 Ultrasonic testing

5.9.4.3.1 Techniques

Guidance on weld preparation and technique in the case of ultrasonic testing is given in annex G.

5.9.4.3.2 Acceptance levels of defects in butt welds

Any of the following defects shall be judged unacceptable:

a) rounded and elongated discontinuities of any diameter or length, if the amplitude of the associated echo exceeds the reference level (see annex G);

Table 18 — Acceptance levels of defects in butt welds found by radiography

Defect type[1]		Acceptance level[2] [3]
Planar defects	Cracks Lack of fusion or penetration[4]	Not permitted
Rounded defects	Slag inclusions Single pores Uniformly distributed porosity	$\varnothing \leqslant 3$ mm $\varnothing \leqslant 0{,}25e$ $\leqslant 2\ \%$ by area[5]
	Localized porosity[4]	$\varnothing \leqslant 2$ mm $\varnothing \leqslant 0{,}2e$ $\leqslant 4\ \%$ by area[5]
	Tungsten inclusions	As porosity
Elongated defects	Slag inclusions[6] Isolated wormholes	$l \leqslant 0{,}5e$ } for $e \leqslant 18$ mm $l \leqslant 6$ mm } $l \leqslant 0{,}33e$ for $e > 18$ mm
	Aligned slag inclusions[6] Wormholes[4]	Total length $\leqslant e$ in any length of $12e$
Interactive defects	Elongated or localized	$d \geqslant 6l_{max}$

1) General reference should be made to ISO 6520.

2) Defect dimensions and percentages refer to the projected area on the film.

3) The symbols used have the following meanings.

   $\varnothing$ is the diameter of the defect.

   e is the parent material thickness (in the case of dissimilar thicknesses, e applies to the thinner component).

   l is the length of the defect.

   d is the distance between defects.

   l_{max} is the length of the longest defect (for clusters it is the overall length of the cluster).

4) Aligned wormholes and linear porosity parallel to the axis of the weld may indicate lack of fusion or penetration, and are therefore not permitted.

5) The area to be considered is the product of the length and width of an envelope enclosing the projection of the affected volume of weld metal.

6) Slag inclusions are not permitted where welds cross within a distance $L = 2e$, up to a maximum of 20 mm (see figure 49).

b) elongated discontinuities, if the amplitude of the associated echo exceeds 50 % of the reference level and the length of the discontinuities exceeds the limits given in table 18 for elongated defects: the requirements in table 18 for interactive defects shall also be taken into account;

c) discontinuities which are interpreted to be cracks, lack of fusion or lack of penetration, except as defined in 5.9.4.3.3, regardless of length or associated echo amplitude.

5.9.4.3.3 Acceptance levels of defects in T-butt welds

The acceptance levels for T-butt welds apply to shell to end plate welds of the types shown in figures B.15 a) and B.15 b), furnace to end plate and reversal chamber welds as shown in figures B.17 a) and B.17 b) and reversal chamber end plate to wrapper plate welds as shown in figures B.16 b) to B.16 e).

The requirements of 5.9.4.3.2 for acceptance levels of defects found by ultrasonic examination shall apply, except as follows.

a) **Welds with a second side fillet weld (back welded)**

For welds with a second side fillet weld, full penetration is desirable, but lack of penetration at the root is permitted within the following limits:

$e_{rs}/e_{rep} < 1,25$

$l = 200$ mm

$h = 3$ mm maximum

where l is the length and h is the height of the defect.

Surface defects due to incomplete penetration which are revealed by visual inspection or surface crack detection, preferably by the magnetic particle method, are unacceptable and shall be ground out to sound metal and repaired.

b) **Welds with no second side fillet weld**

In the case of welds with no second side fillet weld, it is important that every effort should be made to achieve full penetration, especially in those parts of the seam located in the narrow water space. To this end, special attention shall be paid to the fit up in these areas, and it is recommended that the height of the nose should not exceed 1,5 mm.

5.9.4.4 Magnetic particle and liquid penetrant testing

5.9.4.4.1 Techniques

Guidance on weld preparation and technique in the case of magnetic particle and liquid penetrant testing is given in annex H, ISO 3452, ISO 3453 and ISO 3059. In general the magnetic particle test is to be preferred.

5.9.4.4.2 Unacceptable imperfections in welds

In the magnetic particle or the liquid penetrant test, the following defects shall be judged unacceptable:

discontinuities which are interpreted to be cracks, lack of fusion or penetration, regardless of the length.

Sub-superficial defects revealed by magnetic particle testing according to the procedures indicated in annex H shall be investigated, and repaired if necessary.

5.9.5 Methods of non-destructive testing for branches, studded connections and couplings, flanges, tube to tube plate connections and tube plate to shell connections

The methods of non-destructive testing for connections etc. are listed in table 19.

The possible methods refer primarily to radiographic and ultrasonic testing. Both methods are mentioned if radiographic testing alone does not give enough information.

Magnetic particle and/or liquid penetrant testing are recommended to be applied in all cases, either when these are the only methods practicable or to provide additional information. However, the application or use of these methods is a mandatory requirement where these test methods are indicated in table 19 as the only possibility or as additional to radiography and/or ultrasonic testing.

Table 19 — Methods of non-destructive testing for connections etc.

Figure No.	Radiographic examination	Ultrasonic examination	Magnetic particle/liquid penetrant test	Note
Branches without compensation rings				
B.3 a)	—	Yes	Yes	1)
B.3 b)	—	Yes	Yes	1)
B.4 a)	—	Yes	Yes	
B.4 b)	—	Yes	Yes	
B.5 a)	—	Yes	Yes	
B.5 b)	—	Yes	Yes	
B.6 a)	—	Yes	Yes	
B.6 b)	—	Yes	Yes	
B.7 a)	—	Yes	Yes	1)
B.7 b)	—	Yes	Yes	1)
B.8	Yes	Yes	Yes	1)2)
B.9 a)	Yes	Yes	Yes	1)2)
B.9 b)	Yes	Yes	Yes	1)2)
Branches with compensation rings				
B.10	Yes	Yes	Yes	3)
B.11	Yes	Yes	Yes	3)
Studded connections and couplings				
B.12 a)	—	Yes	Yes	
B.12 b)	—	Yes	Yes	
B.12 c)	Yes	Yes	Yes	
Flanges				
B.13 a)	—	—	Yes	
B.13 b)	—	—	Yes	
B.14	Yes	Yes	Yes	4)
End plate or tube plate connections to shell				
B.15 a)	—	Yes	Yes	
B.15 b)	—	Yes	Yes	
B.15 c)	—	Yes	Yes	
B.15 d)	—	Yes	Yes	
End plate or tube plate connections to reversal chambers				
B.16 a)	Yes	Yes	Yes	
B.16 b)	—	Yes	Yes	
B.16 c)	—	Yes	Yes	
B.16 d)	—	Yes	Yes	
B.16 e)	—	Yes	Yes	
End plate or tube plate connections to furnaces				
B.17 a)	—	Yes	Yes	
B.17 b)	—	Yes	Yes	
B.17 c)	Yes	Yes	Yes	
Inspection opening compensating plates				
12 a)	—	—	Yes	
12 b)	—	—	Yes	

Figure No.	Radiographic examination	Ultrasonic examination	Magnetic particle/liquid penetrant test	Note
Stay connections				
22 a)	—	—	Yes	
22 b)	—	—	Yes	
22 c)	—	—	Yes	
22 d)	—	—	Yes	
23 a)	—	—	Yes	
23 b)	—	—	Yes	
Stiffeners for furnaces				
34	—	Yes	Yes	
35	—	Yes	Yes	
Butt-welded longitudinal and circumferential seams				
B.18 a)	Yes	Yes	Yes	
B.18 b)	Yes	Yes	Yes	
B.18 c)	Yes	Yes	Yes	
B.18 d)	Yes	Yes	Yes	
Cross seams in end plates				
B.19 a)	Yes	Yes	Yes	
B.19 b)	Yes	Yes	Yes	
Attachment of access tube to end plate				
B.20 a)	—	Yes	Yes	
B.20 b)	—	Yes	Yes	

1) After removing the root reinforcement to flush.

2) If the forged branch connection is high enough.

3) A tell-tale hole in the compensating ring for leak testing of the welds by the soap-bubble test is necessary in all cases.

4) For wall thicknesses greater than or equal to 15 mm, ultrasonic testing is preferred.

5.10 Requirements of test results of welded production test plates

5.10.1 Reduced section tensile test

The tensile strength obtained shall be at least equal to the specified minimum tensile strength of the plate material.

When the design is not based on the ultimate tensile strength of the material, it is permissible, when the fracture occurs in the weld metal, to accept a reduction of the tensile strength by 19,6 N/mm² lower than the limit specified for the plate material, provided that the yield point of the weld metal as determined by the all-weld-metal test piece is equal to or higher than the specified minimum yield point of the plate.

5.10.2 All-weld-metal test

The values of the mechanical properties shall be equal to or greater than the specified minimum val-

ues of the base material. However, where the minimum tensile strength of the plate is over 490 N/mm², the tensile strength of the all-weld-metal test piece can be a maximum of 19,6 N/mm² lower than the limit specified for the plate, provided that the yield point of the weld metal is higher than the yield point of the plate.

5.10.3 Bend tests

The specimen shall be mounted in such a way that the axis of the former is in the middle of the weld, and on roller supports, the faces of which are separated by a distance determined by the thickness of the specimen (see figure 47).

The test specimen shall be pushed through the supports by a former having a diameter also determined by the thickness of the specimen.

The requirements of table 20, in which a is the thickness of the test specimen, shall apply.

Table 20 — Bend test requirements

Steels	Diameter of former	Free space between supports
Carbon steels $R_m < 431$ N/mm^2	$2a$	$4,2a$
Carbon steels $R_m = 431$ N/mm^2 to 530 N/mm^2	$3a$	$5,2a$
Required bending angle of test specimen: 180°.		

On completion of the test, the length of the greatest defect in any direction shall not exceed 3 mm.

Premature failure at the corners of the specimen shall not be considered as a cause for rejection.

5.10.4 Notched bar impact tests

The minimum results to be obtained from the impact test pieces, as shown in figure 48, shall be as follows, and shall not be less than the requirements for the parent material. Three test specimens are required.

The test results are acceptable if the mean value is 27 J or more, and at the same time only one of the specimens shows a value not lower than 20 J.

If the required mean value is not met, or if only one of the specimens shows a value below 20 J, then three supplementary test specimens shall be taken and tested.

On the basis of the above, the results shall be considered acceptable if the mean value of all six specimens is 27 J or more and at the same time

only two specimens show values below 27 J and only one of these has a value below 20 J.

If one specimen fails due to an obvious defect, the result may be disregarded and one replacement specimen may be taken. However, only one replacement specimen is allowed in a test series.

If the retests are not consistent with the requirements of this International Standard, an investigation of the reason shall be made before the whole procedure is repeated.

5.10.5 Macro-test

The macro-etching of a complete cross-section of the weld shall show a good penetration and absence of lack of fusion, significant inclusions, and other defects.

In case of doubt, a micro-etching of the doubtful zone shall be investigated.

5.10.6 Non-destructive tests

Non-destructive testing techniques and results of non-destructive tests shall conform to the provisions of 5.9.4.

5.10.7 Actions to be taken in the event of unsatisfactory test results

If the results of the tests on welded production test plates are unsatisfactory, the causes shall be investigated, making use in particular of the results of new tests.

If the unsatisfactory results of the original tests are proved to have been caused by local or accidental defects, the results of the repeated new tests shall be decisive.

Section 6: Inspection and testing

6.1 Qualification of inspectors

Inspectors mentioned herein shall be persons employed and trained as inspectors by inspection organizations which are recognized as the inspecting authority in the country of manufacture and/or installation.

In countries where the certification of inspectors is required by statute, the term inspector herein shall mean a person who has qualified for such certification.

The inspector, for the purpose of inspecting and/or certification of boilers under the requirements of this International Standard, shall be independent of the manufacturer and the puchaser, and shall not be in the employ of either.

6.2 Inspection during construction

6.2.1 General

6.2.1.1 Each boiler shall be inspected during construction by inspectors as defined in 1.3.8 and 6.1. Sufficient inspections shall be made to ensure that the materials, construction and testing conform in all respects to the requirements of this International Standard.

6.2.1.2 The inspecting authority shall have access to the works of the manufacturer at all times during which work is in progress, and shall be at liberty to inspect the manufacture at any stage and to reject any part not conforming to this International Standard. The inspecting authority shall check the design and have the right to require evidence that the design conforms to the requirements of this International Standard.

6.2.1.3 The inspecting authority shall notify the manufacturer before construction commences of the stages of the construction at which special examinations of materials will be made, and the manufacturer shall give reasonable notice to the authority when such stages will be reached, but this shall not preclude the inspecting authority from making examinations at any other stages, or from rejecting material or workmanship whenever they may be found defective.

6.2.2 Inspection

6.2.2.1 Manufacturers' personnel may perform the functions indicated in 6.2.2 b), c) and e) by agreement between the manufacturer and the inspector, but the inspector shall satisfy himself by random checks that the required functions are properly carried out.

6.2.2.2 Except as indicated in 6.2.2.1 the inspector shall make examinations at least at the following stages:

a) when plates have been received at the manufacturer's works, to compare identification markings with those recorded on the platemaker's certificates and to check the reported results of mechanical and chemical properties against the specification. The inspector shall carry out spot-check measurements of material wall thicknesses;

b) when shell plates and end plates have been formed, with the plate edges prepared for welding, and when test plates are attached;

c) during various stages of welding, if appropriate to the welding technique. When the first run has been deposited along the principal seams and the test plates, when these seams have been completed on one side and prepared for welding on the other side, and on completion of welding. Radiographic films and/or ultrasonic test reports shall be examined;

d) when weld test specimens have been prepared from the test plate previously selected, to witness the required tests;

e) when openings have been prepared, and when branches and similar connections have been tack welded in position, and subsequently on completion;

f) dimensional check of the boiler on completion of manufacture, during hydraulic testing and again after testing, and inspection internally and externally;

g) the marking of the boiler, e.g. nameplate;

h) the marking of the welds by spot-checks;

i) the appropriate function of important safety equipment during commissioning of the boiler.

6.3 Pressure tests

6.3.1 After all heat treatment, but before applying refractory and insulation, each completed boiler shall be subjected to an acceptance pressure test. An inspector shall be present during this test and he shall certify the results.

If any repairs are found to be necessary as a result of the acceptance pressure test, the boiler shall again be subjected to the acceptance pressure test after the repairs and any heat treatment.

6.3.1.1 Standard pressure acceptance test

The standard pressure acceptance test shall be a hydraulic test and the test pressure p_t shall be not less than that given by the following equation:

$$p_t = 1,5 \times p$$

where

p is the calculation pressure defined in 3.3;

p_t is the test pressure;

and p and p_t have consistent units.

6.3.1.2 Non-standard pressure acceptance test

When it is necessary to test boilers hydraulically to pressures greater than $1,5 \times p$ (see 5.3.2.5.2,

table 6), the design shall be checked to ensure that the membrane stress in any part of the boiler under test does not exceed 90 % of the room temperature 0,2 % proof stress of the material. In cases where 90 % of the room temperature 0,2 % proof stress would be exceeded, the design of the boiler shall be changed to ensure that this does not occur.

6.3.2 The acceptance test pressure shall be applied and maintained for a sufficient length of time to permit a visual examination to be made of all surfaces and joints, but in any case for not less than 30 min. The boiler shall exhibit no sign of general plastic deformation or leakage. It is recommended that before the boiler is approached for close examination, the pressure should be reduced to not less than 1,1 times the design pressure and not more than 0,9 times the test pressure.

NOTE 11   It is important, in the interests of safety, that the boiler should be properly vented so as to prevent the formation of air pockets before the test pressure is applied. It is recommended that during the test the temperature of the water be such as to prevent brittle fracture.

6.3.3 After installation, the boiler shall be hydraulically tested to the same pressure as in the acceptance test and held for a period of 20 min. The tube plates shall be visually checked for evidence of tube end leakage. It is not necessary to remove insulation in order to check visually main seams and nozzle welds unless damage is suspected.

Section 7: Documentation, certification and stamping

7.1 Design specification, drawings and data sheets

The manufacturer shall allow the inspecting authority full access to all drawings and calculations necessary for checking dimensions of parts during manufacture. He shall also supply to the inspecting authority and to the purchaser, by drawings, documents, or data sheets, full information as to the design specification of the boiler with particulars of the materials of which it is constructed. Where erection on site is not undertaken by the manufacturer, he shall supply full information to permit the proper erection of the boiler.

Results of inspections during fabrication, including radiographic films, shall be kept on file for a period of 5 years from the date of completion of the boiler and shall be made available to the inspecting authority at any time during this period, if requested.

The manufacturer shall issue a certificate that the boiler has been designed, constructed, and tested in every respect in accordance with the requirements of this International Standard, and this certificate shall be countersigned by the inspecting authority that it has been so constructed and tested. Where erection is inspected by a second inspecting authority, each inspecting authority shall sign the certificate in respect of the work it has supervized. The countersigned certificate shall be furnished to the purchaser, and a copy to the regulating authority if required.

7.2 Documents to be submitted to the inspector

The following documents shall be submitted to the inspector:

a) constructional drawings and specifications of the completed boiler;

b) quality certification of the materials used;

c) reports of dimensional checks carried out on the boiler;

d) reports, where applicable, of welding procedure qualifications, welder's competence qualifications, production weld tests, non-destructive tests and post-weld heat treatment.

7.3 Stamping

Each boiler shall be legibly stamped by visible marking on the boiler or on a permanently attached nameplate.

The marking shall show the following:

a) the number of this International Standard;

b) the name and location of the manufacturer;

c) the manufacturer's serial number of the boiler;

d) the design pressure (gauge);

e) the following information, as appropriate:

Label nomenclature	Boiler type
Maximum water flow temperature	Hot water boiler
Maximum steam temperature	Superheater
Maximum heat input (MW)	All boilers

f) the hydraulic test pressure;

g) the year of manufacture;

h) the identifying mark of the inspecting authority;

i) any statutory marking required.

Section 8: Safety valves, fittings and mountings[5]

8.1 Safety valves

8.1.1 General

8.1.1.1 Every boiler shall have at least two safety valves except in the case of boilers where the design pressure in bar[6] times the total volume in litres is not more than 10 000, when at least one safety valve shall be fitted. Agreement of the inspecting authority of the country of installation shall be obtained.

Every superheater shall have at least one safety valve on the outlet side.

8.1.1.2 When a boiler is provided with an integral superheater without an intervening stop valve, the safety valves fitted on the superheater may be considered as forming part of the safety valve capacity of the boiler.

8.1.1.3 There shall be no intervening valves between the boiler and its protective safety valves or between the safety valves and their points of discharge.

8.1.1.4 Where a superheater is fitted with a valve intervening between it and the boiler, it shall be fitted with safety valves which shall not be counted as forming part of the safety valve capacity of the boiler.

8.1.1.5 Safety valve seats of inside diameter smaller than 20 mm shall not be used.

8.1.1.6 In cases where sub-atmospheric pressure may occur and the boiler is incapable of withstanding such conditions, a vacuum break device shall be fitted.

8.1.1.7 The safety valves shall comply with the requirements of ISO 4126-1.

8.1.1.8 Notwithstanding the requirements for safety valves herein, the safety valves fitted to any boiler (and integral superheater) shall be capable of discharging all the steam which can be generated without causing a pressure rise to a value more than 10 % in excess of the design pressure of the boiler.

8.1.2 Types of safety valves

Safety valves used for the protection of shell boilers and their superheaters shall be as defined in ISO 4126-1, and shall be, in principle, direct-loaded safety valves.

The safety valves shall be loaded by springs, except that the use of dead-weight or lever-and-weight safety valves is permissible where specifically accepted by the regulating authority.

8.1.3 Construction

8.1.3.1 The moving parts of valves shall be efficiently guided and shall have adequate clearance under all conditions of service. Means shall be provided to prevent their lifting out of their guides. Spindles should not be fitted with stuffing boxes or glands.

8.1.3.2 The design of safety valves and the choice of materials of construction shall take into consideration the possible effect of differential expansion and contraction. They shall be so constructed that the breakage of any part will not obstruct the free and full discharge of steam under pressure.

8.1.3.3 The materials used in the construction of safety valves shall be suitable for the pressure, temperature and other relevant conditions. Safety valve discs and seats should be of corrosion- and erosion-resistant material.

8.1.3.4 Bearings of levers should allow full movement. Where a lever is mounted on pin bearings, it should be bushed with corrosion-resistant metal or the pins should be of corrosion-resistant metal.

8.1.3.5 Where the loading is applied by lever and weight, the force exerted by the valve disc should not exceed 6 000 N with single-lever valves, nor 10 000 N with double-lever valves or with single-lever valves designed so that side forces cannot occur. The loading weight of every safety valve shall be in one piece, and the weight shall be efficiently secured on the lever to prevent inadvertent movement of the weight.

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5) Attention is called to legislation covering the use of boilers in some countries where the regulations are stricter or more detailed than those contained in this International Standard.

Materials, design and construction of all valves, fittings and mountings referred to in this section should be in accordance with national standards.

6) 1 bar = 10^5 N/m^2 = 10^5 Pa

8.1.3.6 Where the loading is applied by a coil spring, the springs shall be so made that all coils still have a clear space of half the wire diameter or 1 mm at the necessary lift at full discharge.

8.1.3.7 Easing gear shall be provided and the gear shall be arranged so that the valves can be lifted positively off their seats when under pressure. The easing gear shall be such that it cannot lock or hold the valve off its seat when the external lifting force is released.

8.1.3.8 Safety valves may have seats at any angle between 45° and 90° with the axis of the valve.

8.1.4 Integrity testing of all safety valves

All safety valves shall be subjected to a hydraulic test in the safety valve manufacturer's works as required by ISO 4126-1:1991, subclause 5.3.

8.1.5 Operating and flow characteristics for safety valves

Copies of the records of the tests previously made in the presence of the independent authority defined in ISO 4126-1, on safety valves representative of the valves used for the boiler, shall be furnished on request to all the parties concerned.

The tests shall be made to meet the requirements of ISO 4126-1:1991, subclauses 6.2 (operating characteristics) and 6.3 (flow characteristics).

The coefficient of discharge shall be calculated in accordance with ISO 4126-1:1991, subclauses 7.1 and 7.2.

8.1.6 Certified capacity

8.1.6.1 For each valve, the certified capacity shall be 90 % of the theoretical capacity times the coefficient of discharge (see ISO 4126-1:1991, subclause 6.5).

8.1.6.2 The rated discharge capacity of a safety valve which discharges superheated steam shall be calculated in accordance with ISO 4126-1.

8.1.7 Set pressures

The safety valves provided by ISO 4126-1 shall be set to lift at a pressure no higher than the design pressure of the boiler (see 3.2).

Where multiple safety valves are provided lower set pressures may be chosen to provide for progressive opening, provided that the requirements of 8.1.1.8 are met.

It is desirable that there should be an adequate margin between the actual pressure at which the boiler generates and delivers steam and the lowest pressure at which any of the safety valves is set to lift, to prevent the unnecessary lifting of the safety valves.

8.1.8 Marking

Every safety valve shall be marked, on its body or on an identification plate, with the minimum information stated in ISO 4126-1:1991, subclauses 9.1 and 9.2.

8.1.9 Attachment to the boiler

Safety valves should be mounted without any intervening valves on robust pads or nozzles used for no other purpose, and having a cross-sectional area at least equal to the sum of the areas of the orifices of all the safety valves mounted on them. The inlet of the safety valve shall have a bore nominally equal to that of the pad or nozzle to which it is connected. The pads or nozzles shall be not less than 25 mm in internal diameter. If nozzles are used they should be as short as possible. The pressure loss between the boiler and the safety valve inlet shall not exceed 3 % of the set pressure of the valve at certified capacity.

8.1.10 Discharge lines

The areas of steam discharge pipes should be sufficient to prevent a back pressure interfering with the operation of the valve.

Safety valves should discharge to atmosphere, in a space normally inaccessible to personnel. Discharge lines should be nearly vertical and so arranged that there will be no accumulation of deposit or condensed water to restrict the flow of steam. Their supports and anchorages shall be so designed and constructed that reactions are resisted without excessive forces being transmitted to the safety valve.

8.2 Water gauges

8.2.1 Each steam boiler shall have at least two independent means of indicating the water level, one of which shall be a gauge of transparent material which is directly connected to the boiler shell. It is recommended that the other should be a gauge of transparent material, but, if national regulations permit, it may be a remote water level indicator or alternative device.

8.2.2 The gauge(s) of transparent material shall be mounted so that the water level is visible in the gauge glass at the lowest alarm level, i.e. at the lowest permissible water level, and this level shall

be at least 100 mm above the highest heated surface.

8.2.3 Pipes and fittings connecting a water gauge to a boiler should be as short as possible, and so constructed that no undrained pocket is formed between the boiler and the gauge, and there should be no outlet therefrom except for damper regulators, feed-water regulators, steam gauges, drains, or other similar apparatus which does not permit the escape of an appreciable amount of steam.

Pipes connecting a water level gauge to the boiler shall be not less than 25 mm bore. Where the water gauge is fitted to the chamber of a safety control or alarm device, the connecting pipes to the boiler shall have a bore of not less than 40 mm.

8.2.4 The lowest permissible water level of the boiler shall be permanently and legibly marked.

8.2.5 Cylindrical water gauge glasses shall be fitted with protectors.

8.3 Steam pressure gauges

8.3.1 Each boiler shall have a steam pressure gauge, with a minimum dial diameter of 100 mm, connected to the steam space either directly or through the water gauge column or its steam connections.

8.3.2 The steam pressure gauge shall be connected to a siphon or similar device of sufficient capacity to keep the gauge tube filled with water. The pipe shall be of sufficient size and have provision for blowing out, if possible.

8.3.3 Steam pressure gauge connections shall be made suitable for the design working pressure of the boiler and for the steam temperature.

8.3.4 Pressure gauges shall be graduated in the proper units and, where practicable, to approximately twice the working pressure, but shall not in any case be graduated to less than 50 % in excess of the working pressure. The maximum permissible working pressure shall be clearly indicated on the scale.

8.3.5 Each boiler shall be provided with a valved connection for the special purpose of attaching a test gauge when the boiler is in service so that the accuracy of the boiler steam gauge can be ascertained.

8.4 Blowdown mountings

8.4.1 Each boiler, integral economizer, and water wall or screen, shall be fitted with a suitable blowdown valve or cock placed at, or as near as practicable to, the lowest point of the apparatus.

8.4.2 Blowdown valves or cocks shall be attached to the apparatus by heavy gauge pipes as short as practicable in view of the construction of the apparatus.

8.4.3 Where blowdowns from two or more boilers are connected to a common discharge, two valves shall be fitted to each blowdown, one being of a non-return type to prevent the contents of one boiler passing to another.

8.4.4 The blowdown pipe between the apparatus and the blowdown valve or cock shall, if exposed to furnace heat, be protected by brickwork or other heat-resisting material so arranged that the pipe may be inspected and is not constrained against expansion.

8.4.5 Blowdown cocks fitted with taper plugs shall be of the bolted cover type with separately packed glands, and shall not be used with design pressures over 1,3 N/mm^2.

8.5 Valves for connections

8.5.1 Steam outlets

Each outlet, except for safety valves and superheater inlet and reheater inlet and outlet, shall be fitted with a stop valve located at an accessible point in the steam delivery line as near to the boiler as convenient and practicable.

NOTE 12   The valve should preferably be of a type which positively indicates whether it is open or closed.

Where more than one boiler is connected to a common header or steam manifold, the steam connections for each boiler shall be provided with two stop valves with a free blowing drain between them, or some similar safety method should be provided.

NOTE 13   It is preferable that the valve nearest the boiler be a non-return type.

8.5.2 Feed connections

Each feed pipe to any boiler shall be provided with a check valve and a separate stop valve near the boiler. Where there is an integral economizer, the foregoing fittings shall be placed at the inlet to the economizer. The internal feed pipe shall be so arranged that the boiler cannot empty itself to a level

less than 70 mm above the highest point of the heating surface containing gases at a temperature of more than 400 °C.

8.6 Materials for valves and fittings

NOTE 14   Where temperature limits are imposed, the temperature of saturated steam at the design working pressure of the boiler, or the final superheat temperature being used in the case of fittings on superheaters, should be considered.

8.6.1 Cast iron

Cast iron shall not be used for blowdown mountings or other water duties including hot-water boilers. In other cases, cast iron shall not be used for pressures exceeding 1,3 N/mm^2, or for temperatures exceeding 220 °C, or for parts with a diameter exceeding 200 mm.

8.6.2 Brass, bronze and gun metal

Brass, bronze and gun metal shall not be used for temperatures exceeding 220 °C, except where spe-

cially approved by the inspecting authority in cases of special alloys for high temperature.

8.6.3 Steel castings

Steel castings shall be the subject of agreement between the interested parties.

8.7 Flanges and bolting

8.7.1   Flanges and bolting in accordance with any nationally accepted specification shall be deemed to be acceptable.

8.7.2   For the purpose of determining dimensions within the above-mentioned specifications, the design working pressure of the boiler shall be considered as the working pressure for all mountings including blowdown mountings.

8.8 Automatic controls

National rules concerning the use of automatic controls shall apply until a new section covering boiler management and equipment has been accepted and incorporated in this International Standard.

Unflanged front tube plate

Reversal chamber tube plate

Unflanged rear tube plate

Wet back rear plate

Wet back reversal chamber

Plain furnace tube
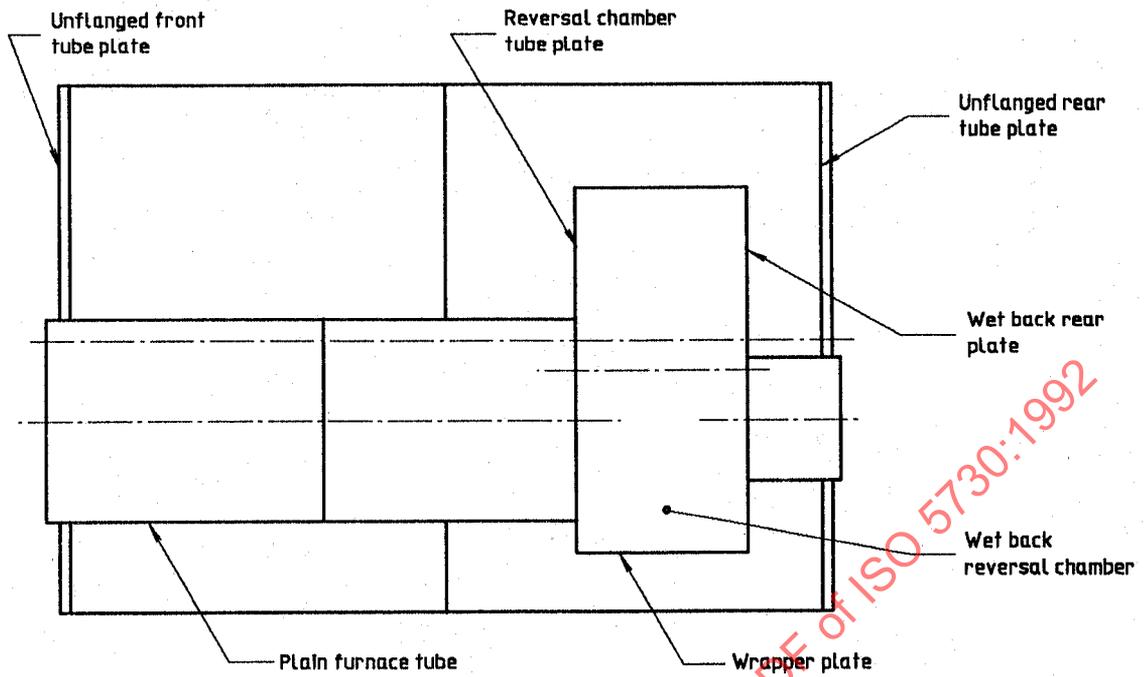
Wrapper plate

NOTE — The effective radiant heating surface comprises the furnace tube, wrapper plate and wet back.

Figure 1 — Wet back boiler

Flanged front tube plate

Flanged rear tube plate

Water-cooled reversal chamber

Tube wall

Corrugated furnace tube

Header
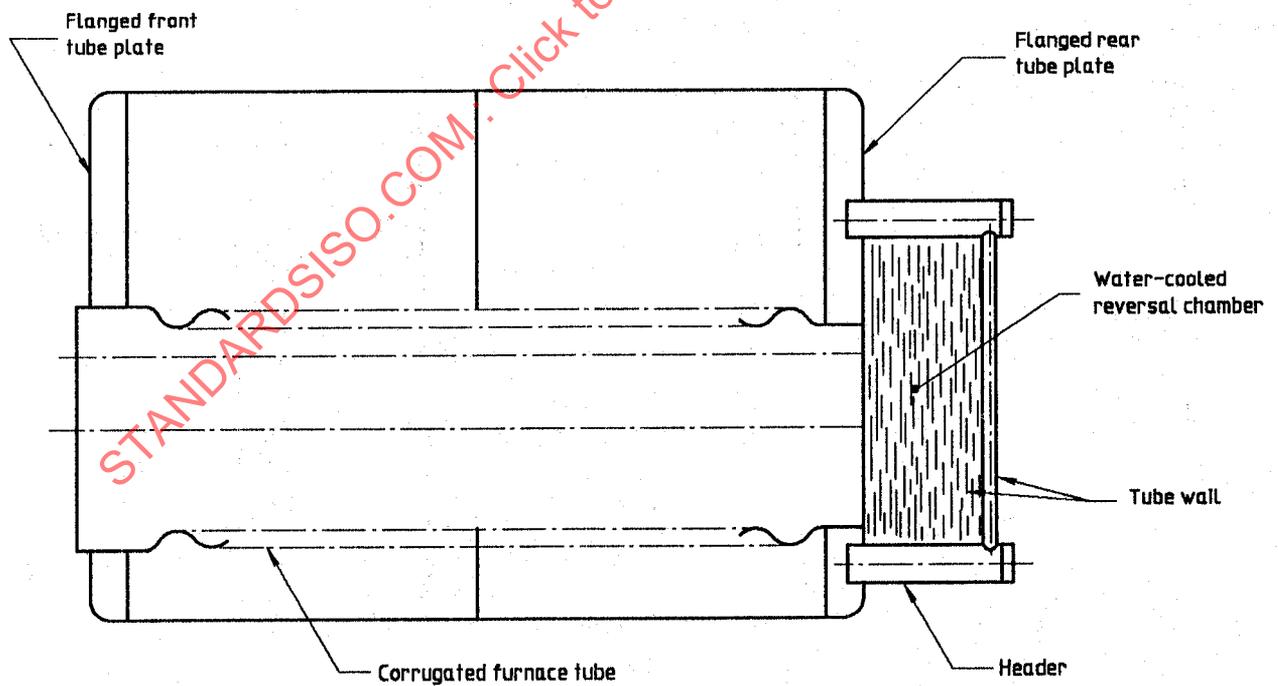
NOTE — The effective radiant heating surface comprises the furnace tube and complete surface of the reversal chamber.

Figure 2 — Wet back boiler
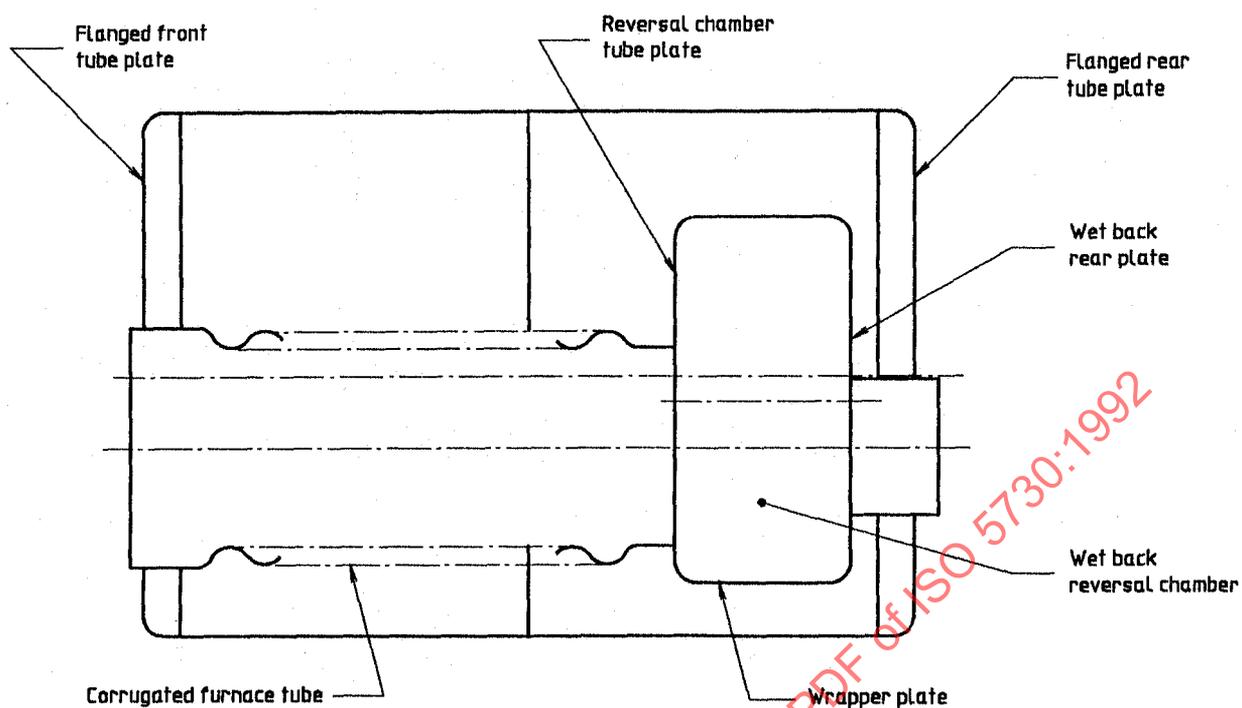
NOTE — The effective radiant heating surface comprises the furnace tube, wrapper plate and wet back.

Figure 3 — Wet back boiler
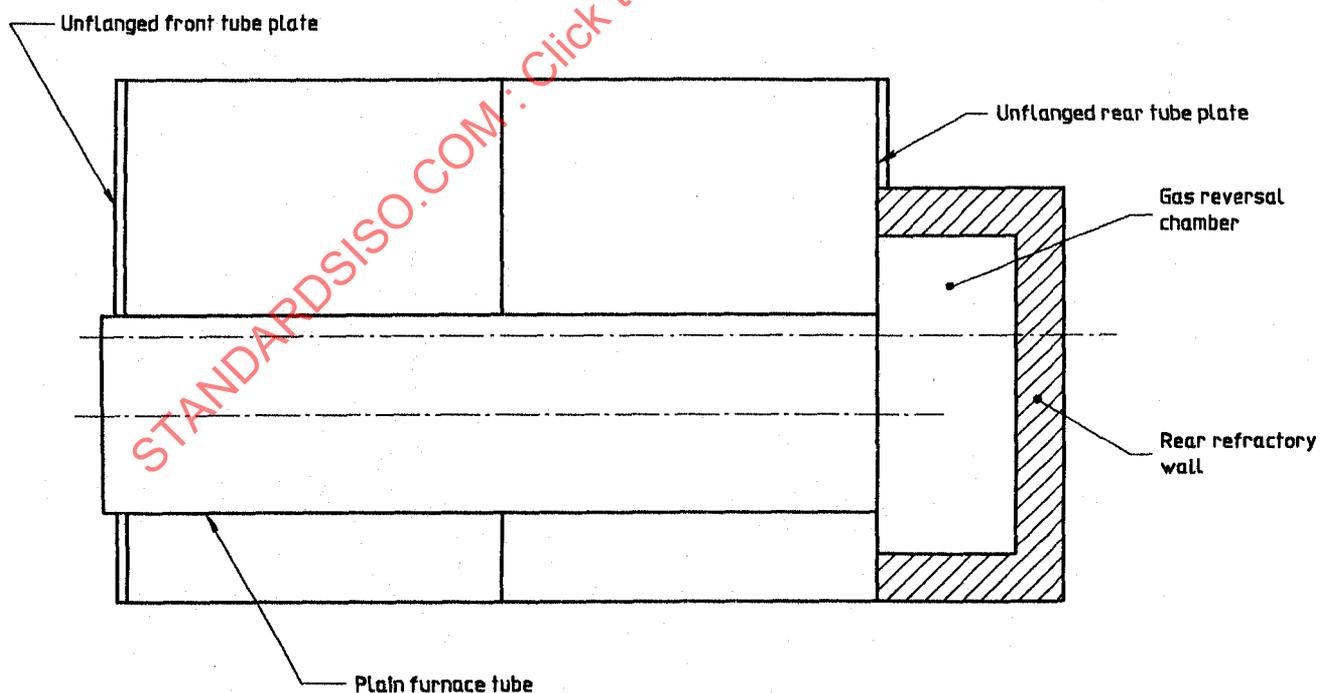
NOTE — The effective radiant heating surface comprises the furnace tube.

Figure 4 — Dry back boiler
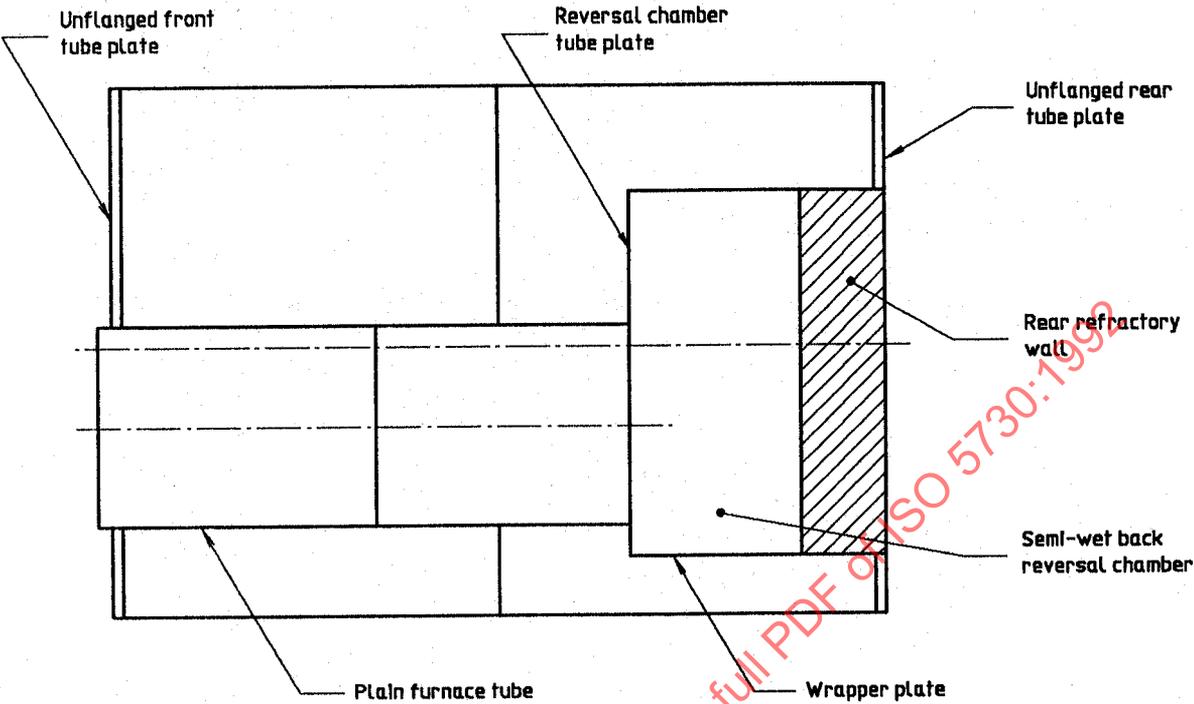
NOTE — The effective radiant heating surface comprises the furnace tube and wrapper plate.

Figure 5 — Semi-wet back boiler

The axes of the figure: vertical axis labelled "Minimum furnace tube inside diameter[1] (mm)" with values 500, 1 000, 1 400[2], 1 500; horizontal axis labelled "Net heat input (MW)" with values 0, 5, 10.

Labels within graph:
- PH 290 / PH 265 with e × 1,25[3]
- Coal with grate firing
- PH 265
- > 1,8 N/mm²
- ≤ 1,8 N/mm²
- PH 290 / PH 265 with e × 1,25[3]
- Oil, gas and pulverized coal firing
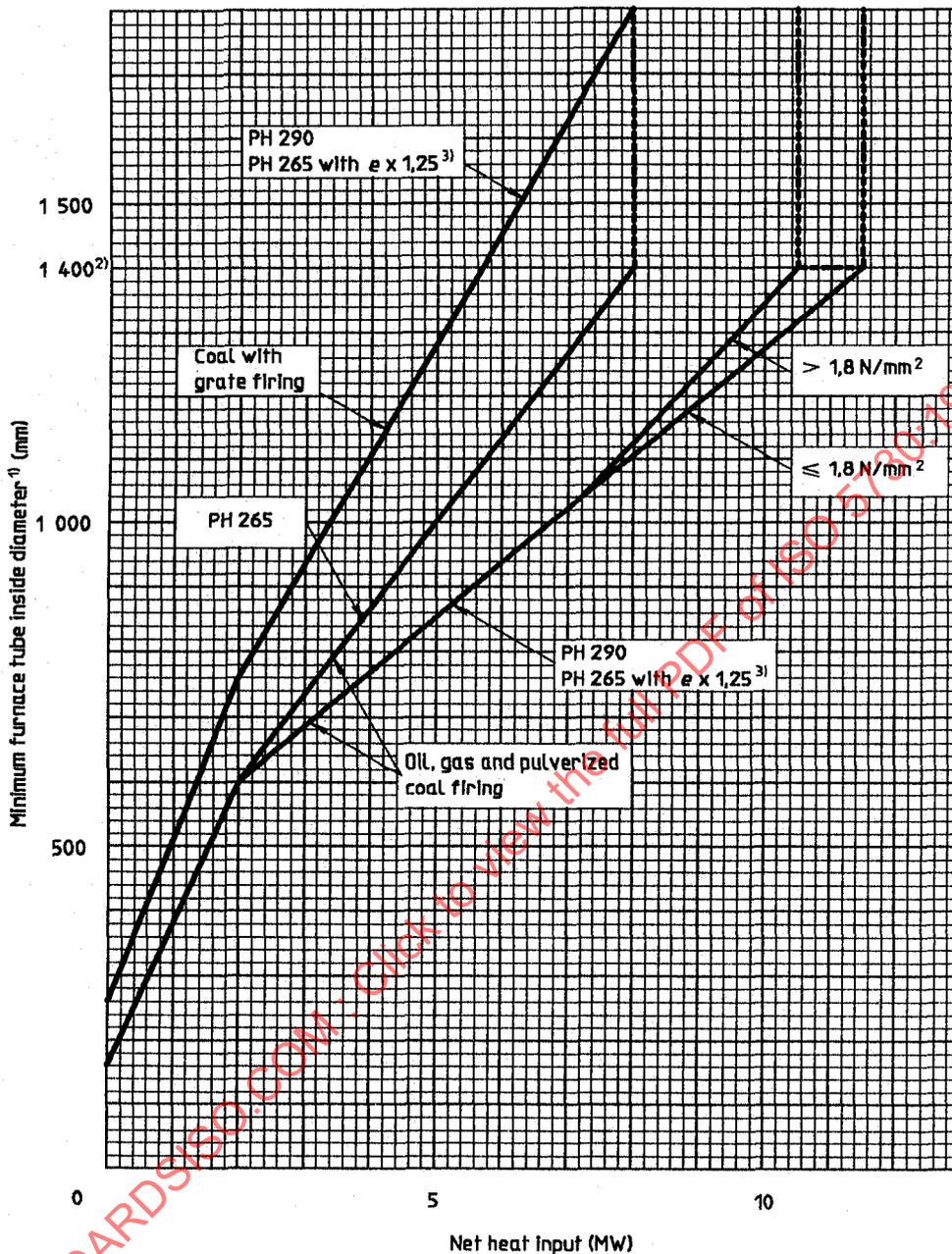
1) In the case of reverse-flame boilers, the furnace diameter indicated on the graph shall be increased by 40 %.
2) If the chosen furnace diameter for oil, gas or pulverized coal firing is greater than 1 400 mm, the minimum elongation of material of furnaces shall be 24 %.
3) In the case of PH 265 materials, the calculated thickness shall be increased by 25 %.

Figure 6 — Relation between heat input and furnace tube inside diameter
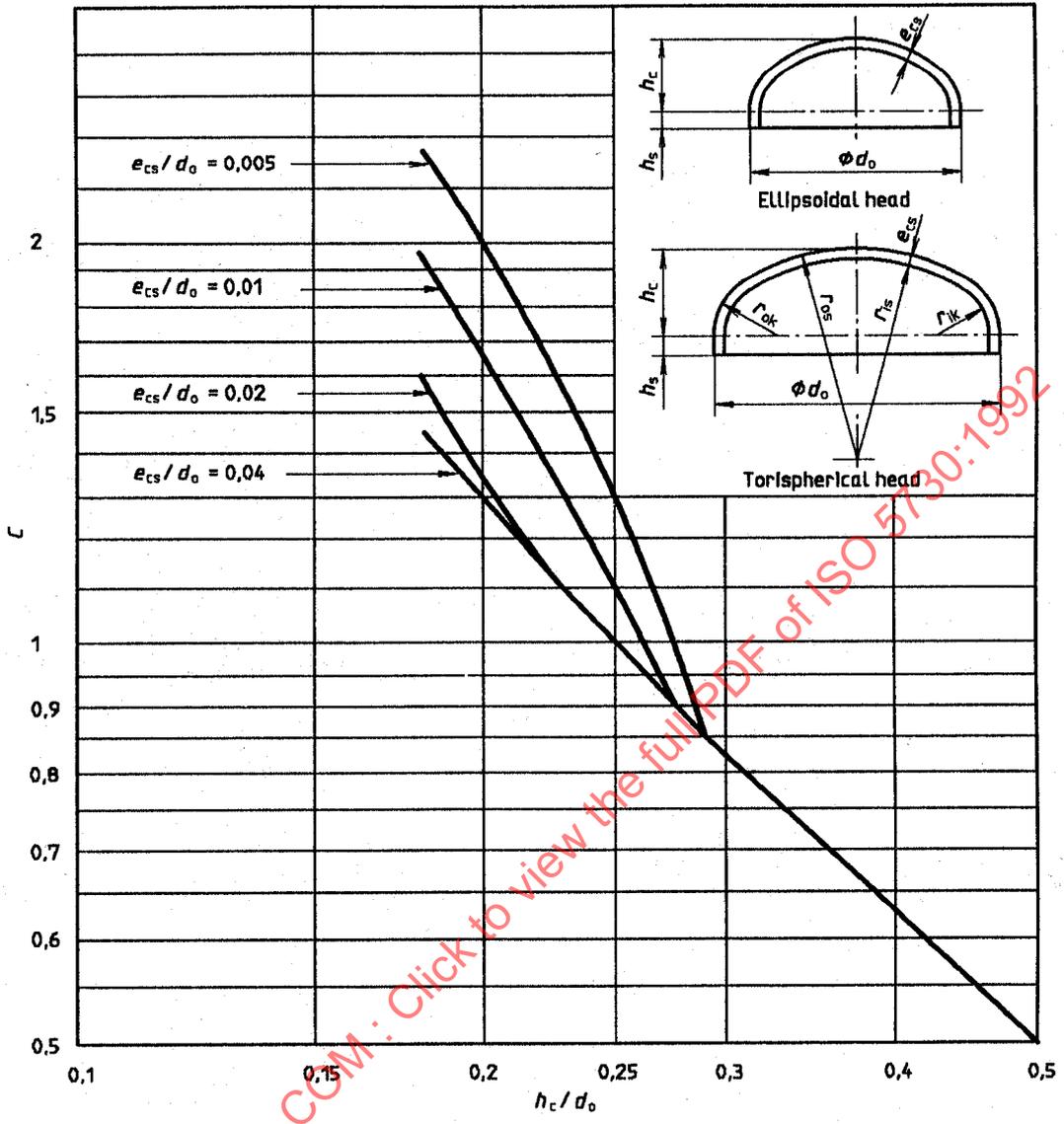
Figure 7 — Shape factor C for unstayed dished heads without openings
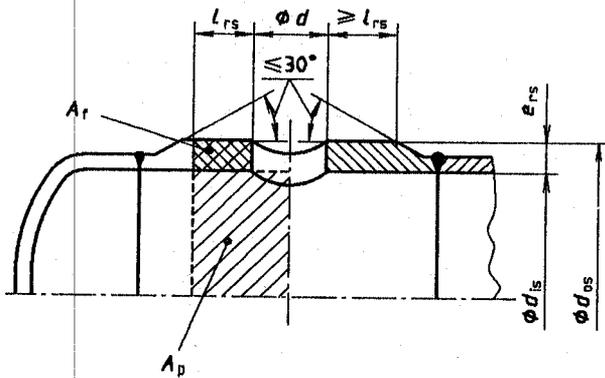
8a) Cylindrical shells with isolated openings –
Reinforcement by increased wall thickness
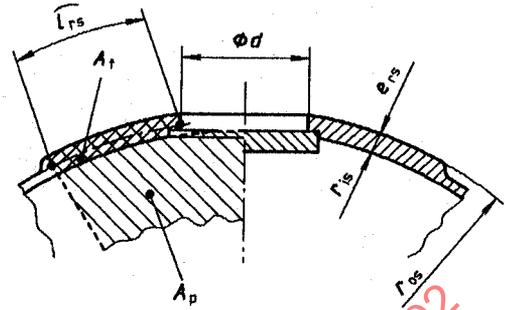
8b) Spherical shells and dished heads with isolated
openings – Reinforcement by increased wall thickness
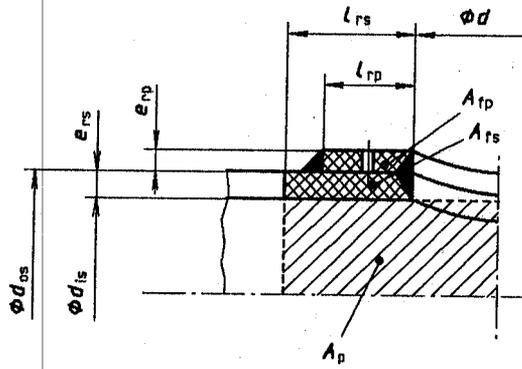
8c) Cylindrical shells with isolated openings –
Reinforcement by compensating plates
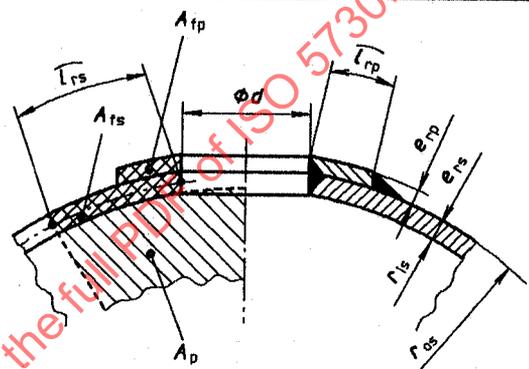
8d) Spherical shells and dished heads with isolated
openings – Reinforcement by compensating plates
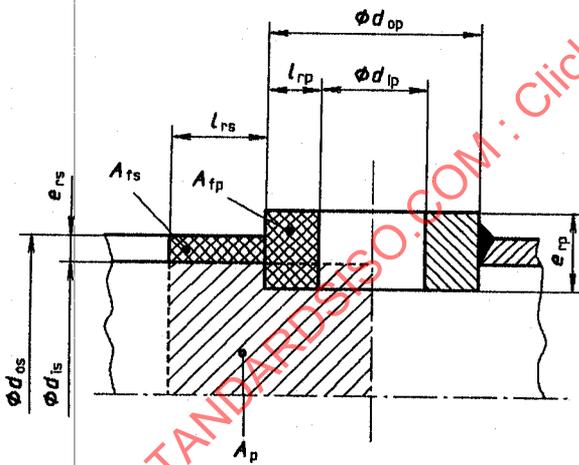
8e) Cylindrical shells with isolated
openings – Reinforcement by pads
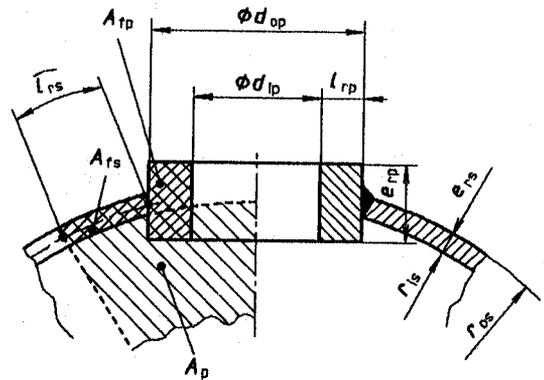
8f) Spherical shells and dished heads with
isolated openings – Reinforcement by pads

Figure 8 — Reinforcement of openings and branches
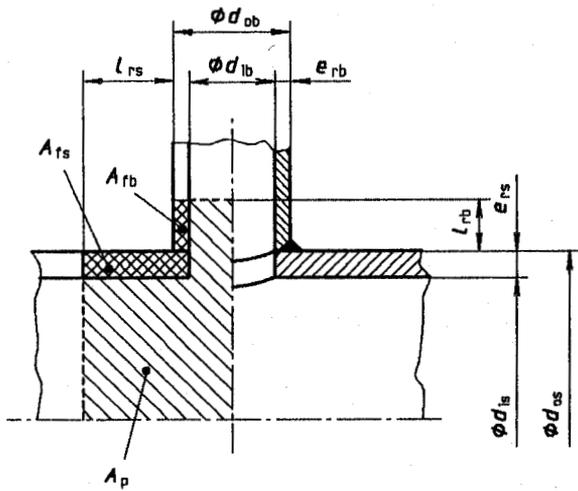
8g) Cylindrical shells with isolated openings – Reinforcement by branches
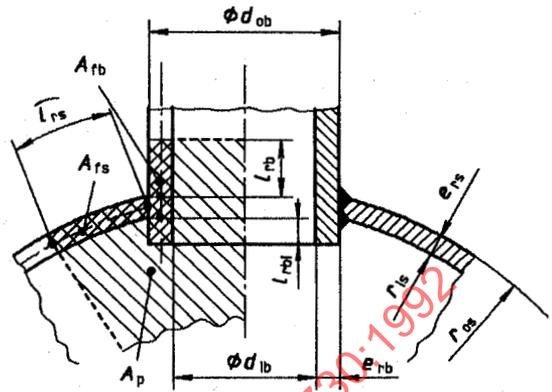
8h) Spherical shells and dished heads with isolated openings – Reinforcement by branches
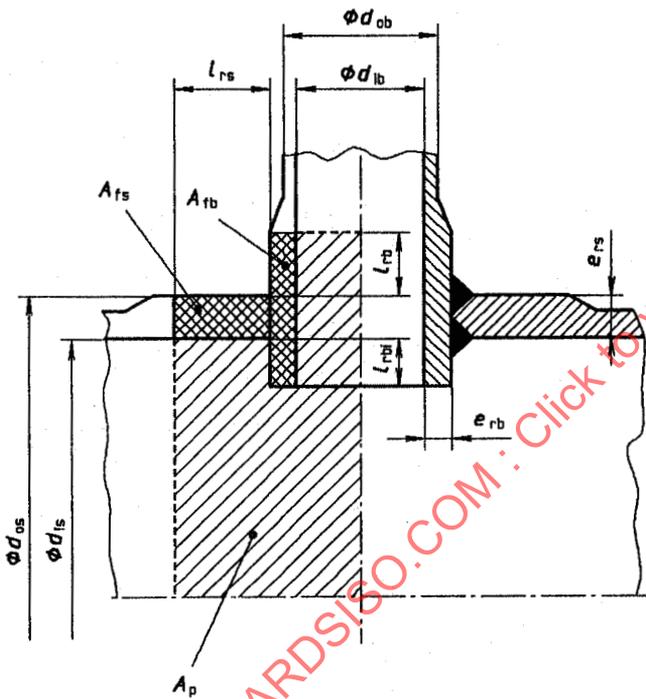
8i) Cylindrical shells with isolated openings – Combined reinforcement
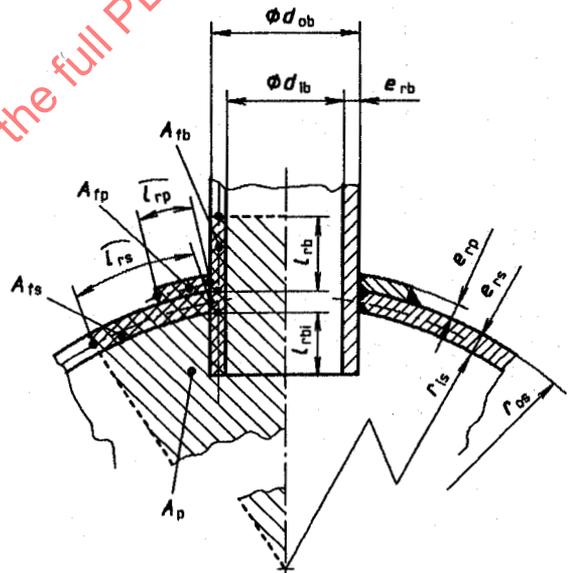
8j) Spherical shells and dished heads with isolated openings – Combined reinforcement

Figure 8 — Reinforcement of openings and branches (continued)
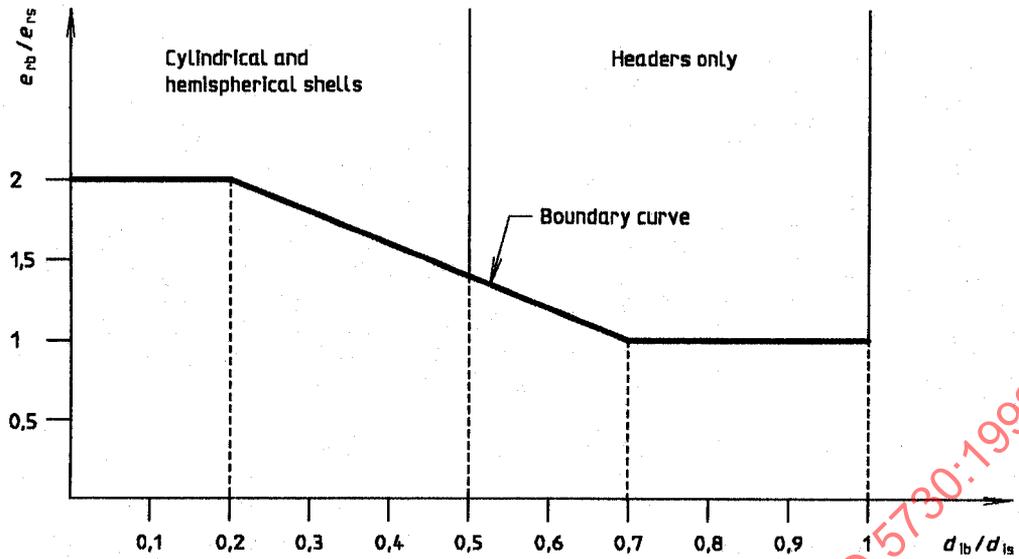
8k) Wall thickness ratio for branches
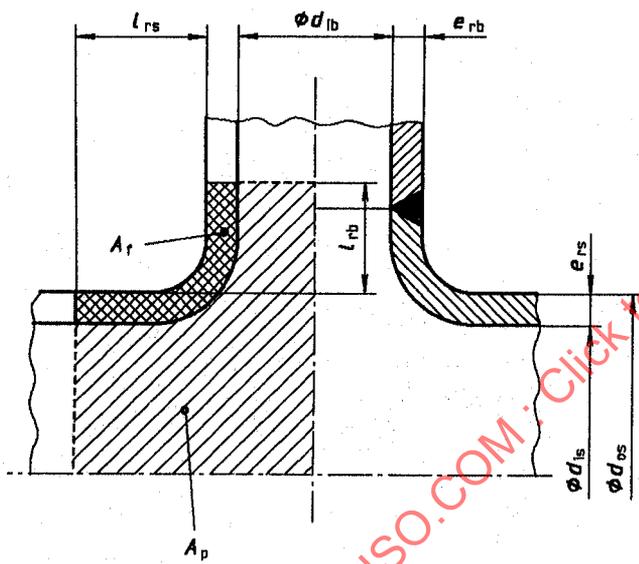
8L) Extruded branch in a cylindrical shell
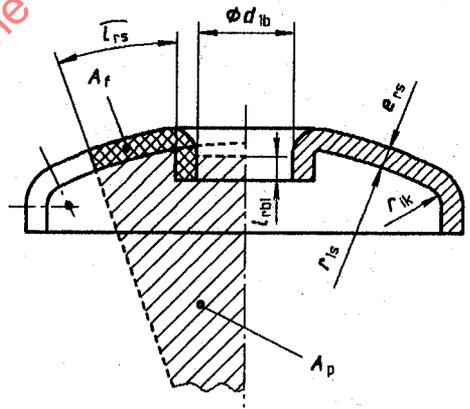
8m) Intruded branch in a dished head

Figure 8 — Reinforcement of openings and branches (continued)
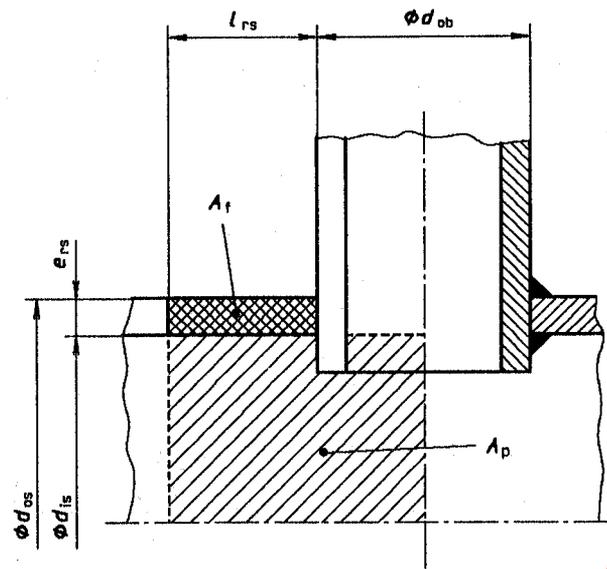
8n) Cylindrical shell with a set-in welded branch without full penetration welds
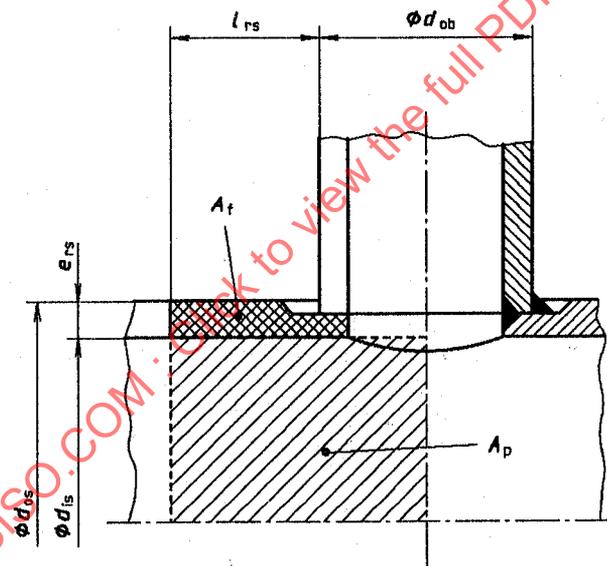
8o) Cylindrical shell with a set-on welded branch without full penetration welds

Figure 8 — Reinforcement of openings and branches *(concluded)*

NOTE – Hatching and weld details omitted for clarity.
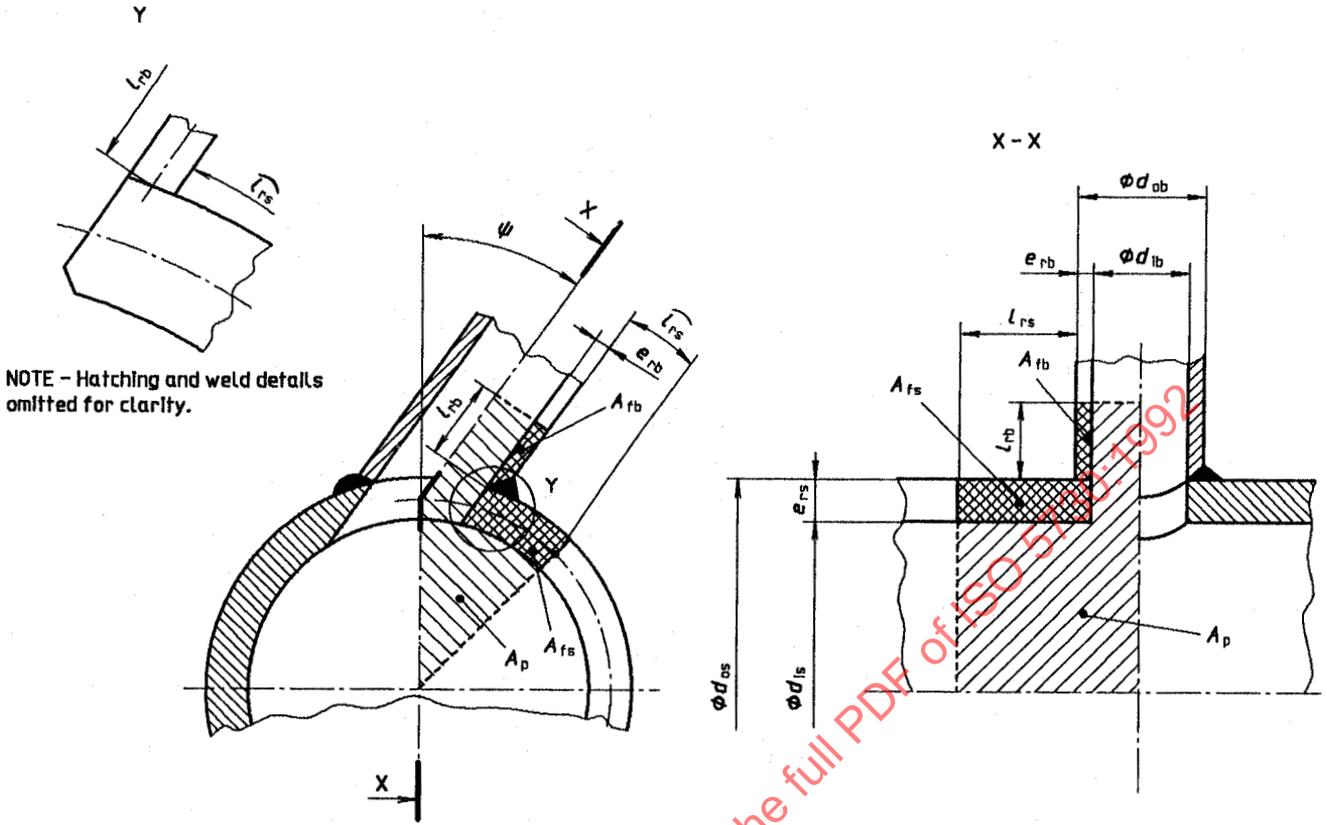
9a) Cylindrical shell with a branch not radially arranged
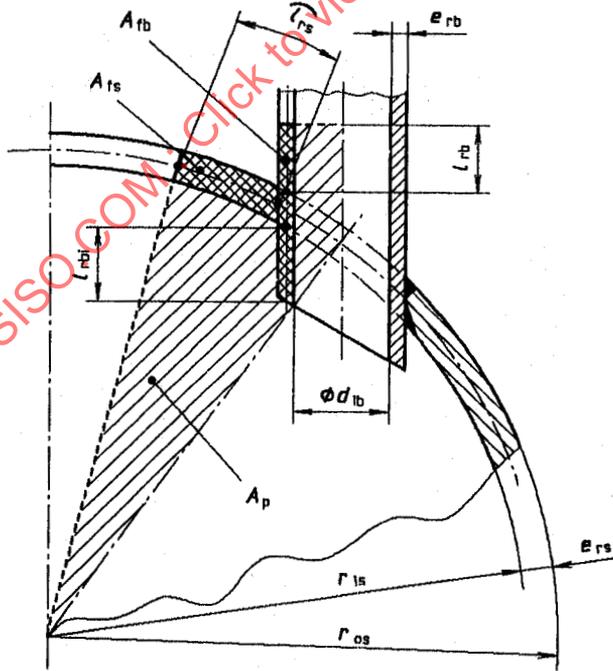
9b) Spherical shell with a branch not radially arranged

Figure 9 — Non-radial branches and adjacent branches
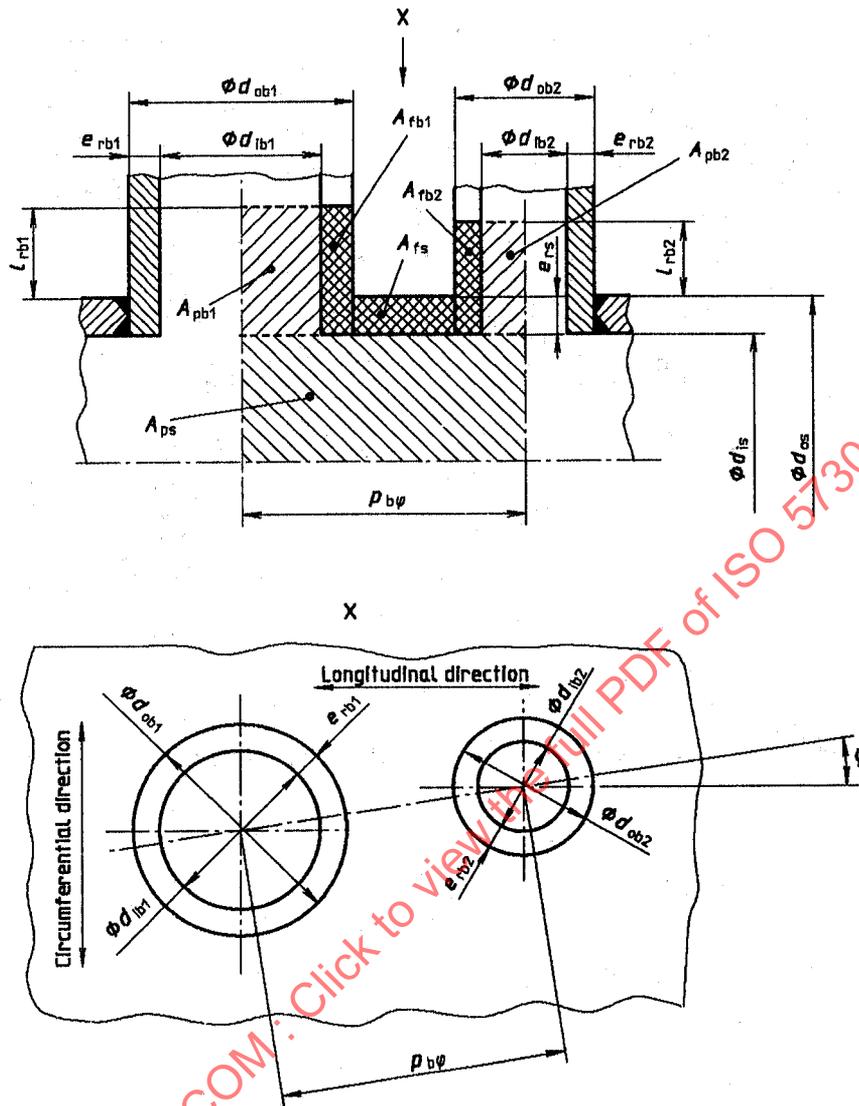
9c) Adjacent branches in a cylindrical shell

Figure 9 — Non-radial branches and adjacent branches *(continued)*
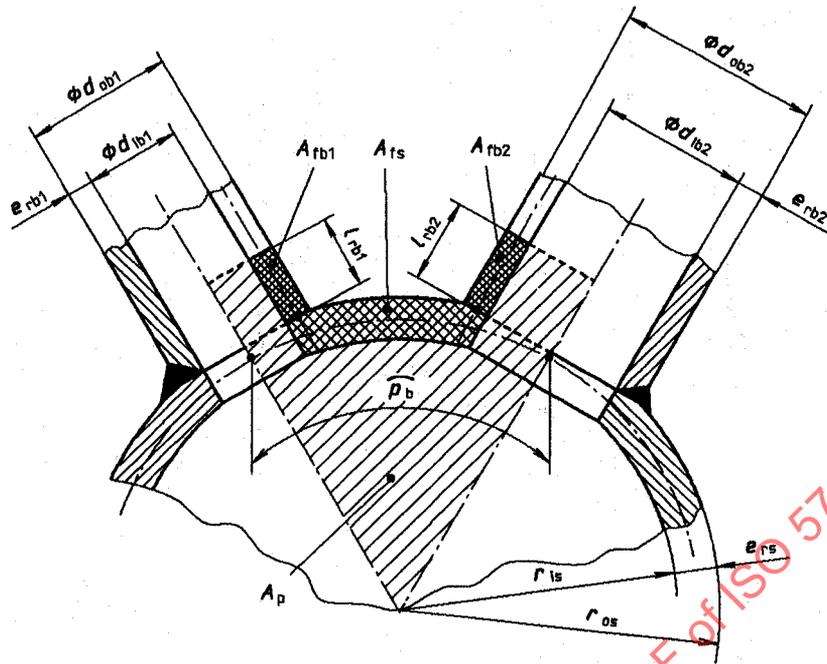
9d) Adjacent branches in a spherical shell

Figure 9 — Non-radial branches and adjacent branches *(concluded)*

Dimensions in millimetres
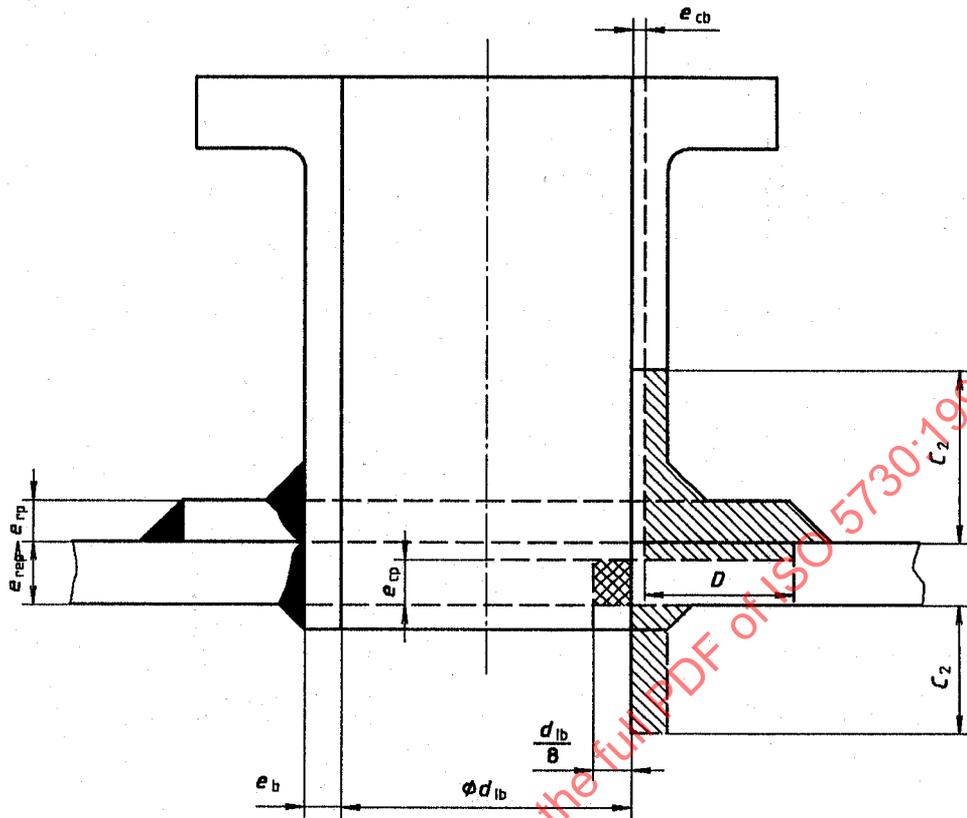
Area X ▨   Area Y ▨

e_{cp} is the thickness calculated in accordance with formula (3.43) for the part under consideration.

e_{cb} is the thickness calculated in accordance with formula (3.7), taking $v = 1$.

C_2 is the smaller of the two values $2{,}5\, e_{rep}$ and $(2{,}5\, e_b + e_{rp})$.

D is the greater of the two values $(e_{rep} + 75)$ and $(d_{lb} + 4)$.

Area Y shall not be less than area X.

NOTE — The compensating plate is required only in cases where area Y would otherwise be less than area X.

Figure 10 — Compensation for branch in flat end plate

Dimensions in millimetres

11a)

11b)

Area X (cross-hatched)   Area Y (diagonal)

e_{cp} is the thickness calculated in accordance with formula (3.43) for the part under consideration.

d_{lo} is half the mean of the major and minor semi-axes of the opening.

D is the greater of the two values $(e_{rep} + 75)$ and d_{lo}.

e_{sr} shall be not less than 19 for manholes, 15 for headholes and 10 for handholes.

Area Y shall not be less than area X.

Figure 11 — Compensation for elliptical manholes or inspection openings in flat end plates

Dimensions in millimetres
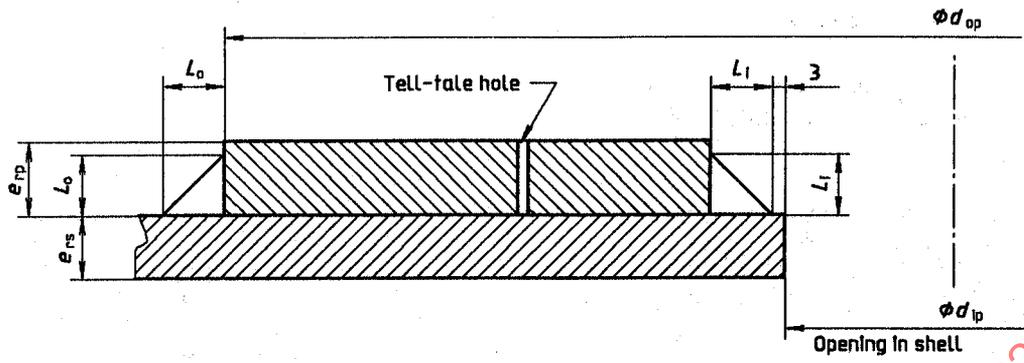
12a)
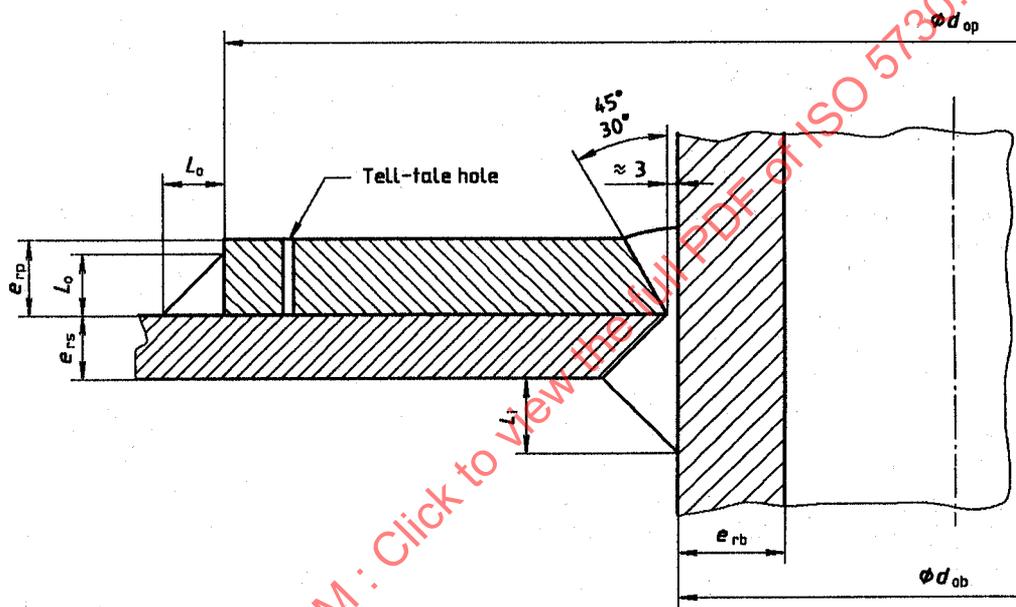
12b)

Figure 12 — Welding of compensating plates

79

Dimensions in millimetres

NOTE – For the size of manhole and dimension g, see the table in 13h).

13a)

Headhole
220 x 320

350

13b)

Inspection category

Plane of eye

Centre of manhole
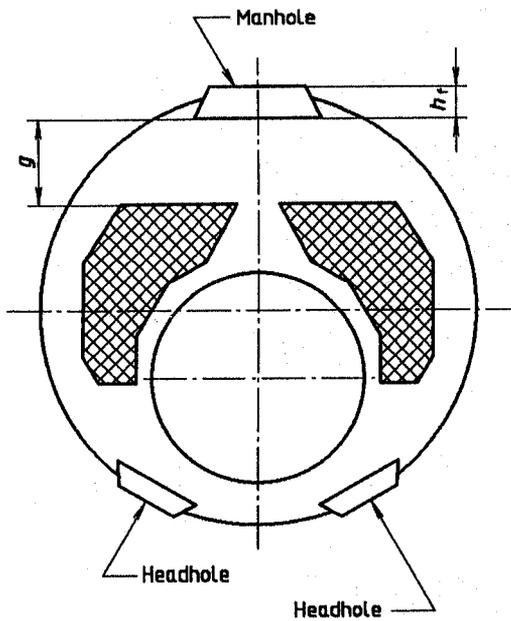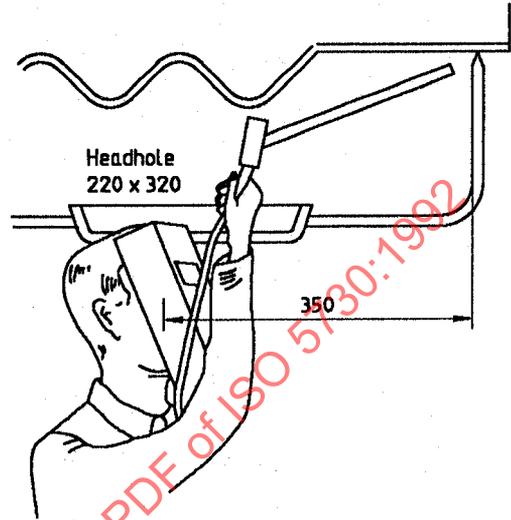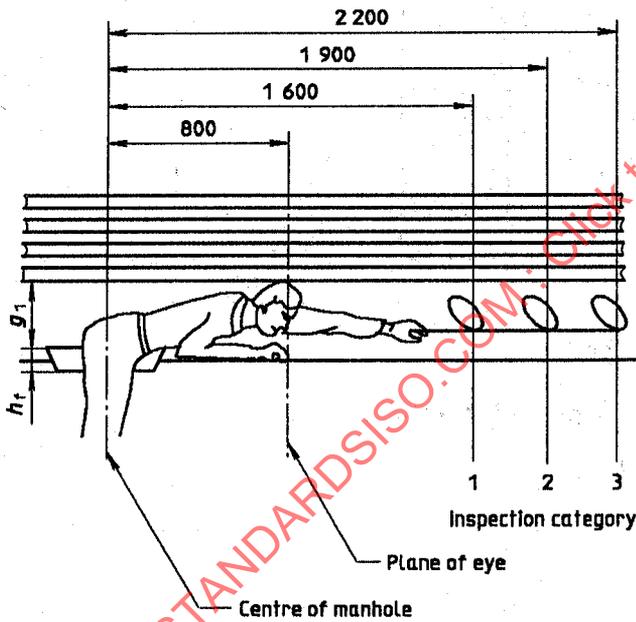
NOTES

1 For the size of manhole and dimension g_1, see the table in 13h).

2 Visual ray, see 13g).

13c)

Inspection category

Plane of eye

Centre of headhole
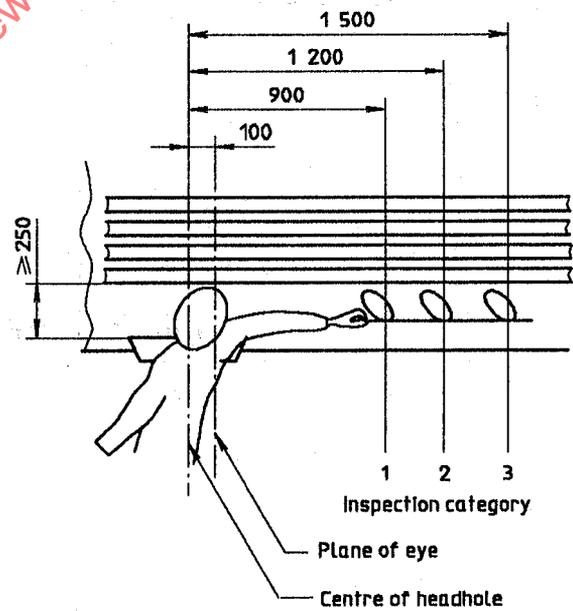
NOTE – Visual ray, see 13g).

13d)

Figure 13 — Openings for access and inspection

Dimensions in millimetres

1 000
750
500
100
≥ 150
≥ 250

1 2 3
Inspection category

Plane of eye

Centre of headhole

NOTE – Visual ray, see 13g).

13e)

800
600
400
≥ 150

1 2 3
Inspection category

Centre of handhole
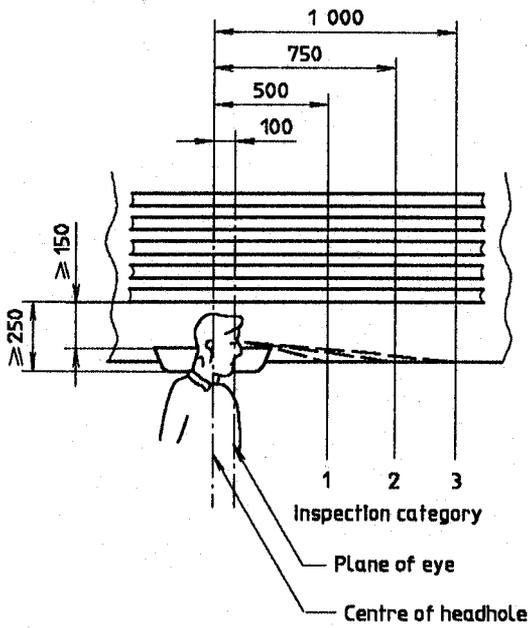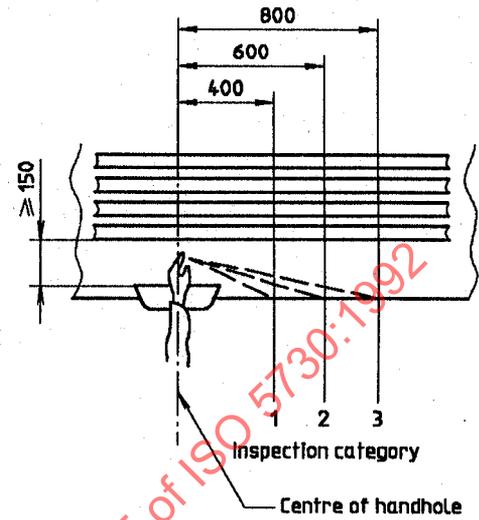
NOTE – Visual ray, see 13g).

13f)

r
q
q
q
r
r
Mirrors

13g)
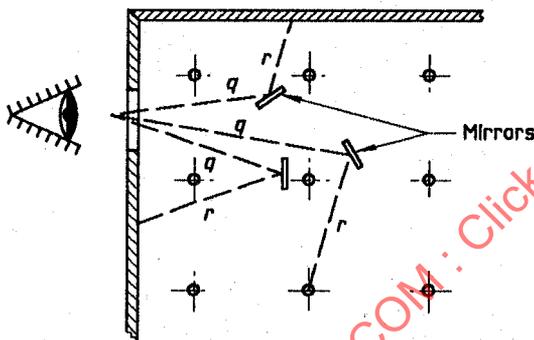
Inspection category	Visual ray $s = q + r$
1	1 000
2	1 300
3	1 600

Manhole

g
h_f

Depth of pit ≥ 500

≥ 750
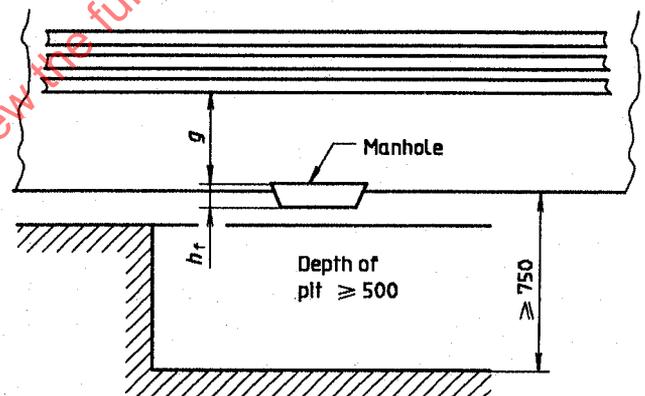
Size of manhole	h_f	g [1]	g_1 [2]
320 x 420	≤ 300	≥ 400	≥ 320
300 x 400	≤ 150	≥ 450	≥ 370

1) For dimension g, see also 13a) and 13l).
2) For dimension g_1, see 13c).

13h)

Figure 13 — Openings for access and inspection *(continued)*
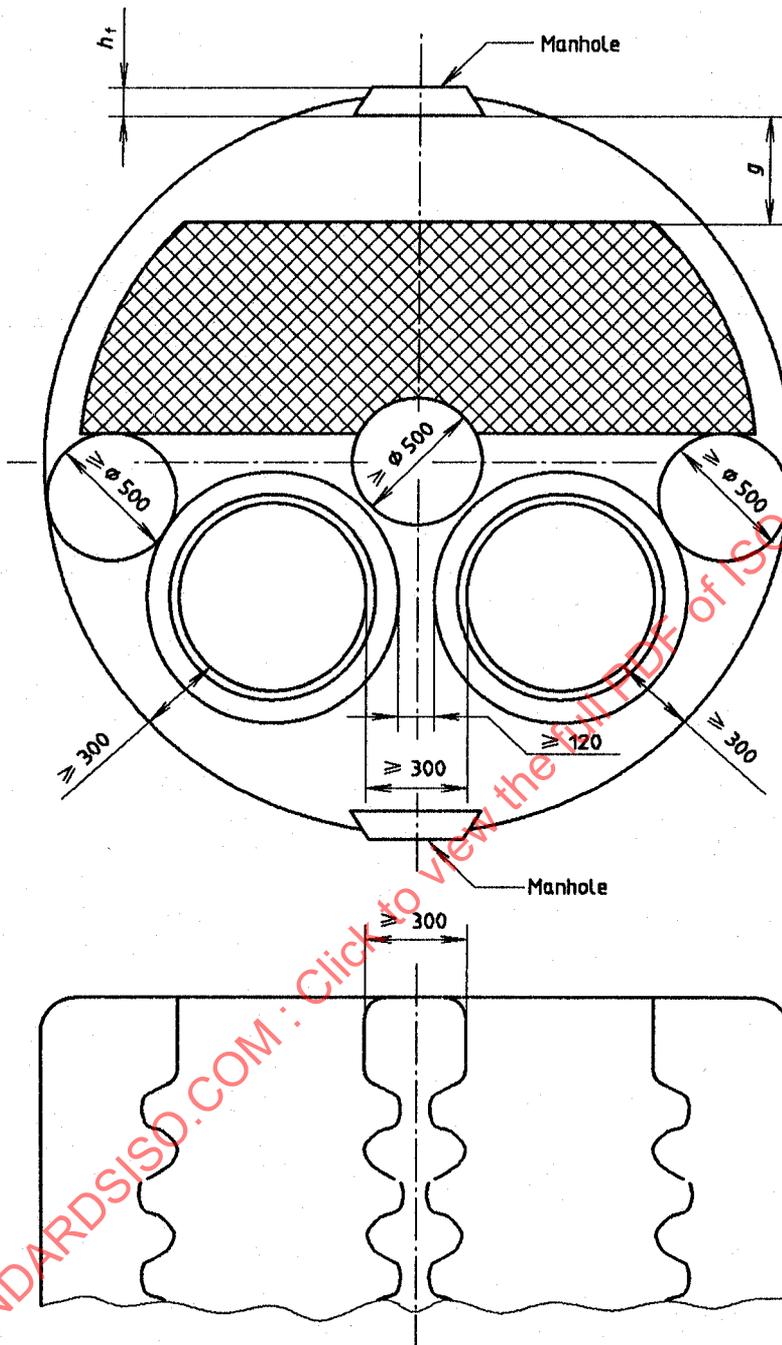
Dimensions in millimetres

NOTE – For the size of manhole and dimension *g*, see the table in 13h).

13l)

Figure 13 — Openings for access and inspection *(concluded)*

To establish the area supported by bar stays or stay tubes in boundary rows, the boundary of the loaded area should terminate at the centre of the associated main circle

Boundaries of areas supported by individual stays [see 3.14.2.7b)]

Unstayed rectangular area (see 3.14.2.3)

Main circles (see 3.14.2)

Bar stays

Stay tubes

90°

∅ b

b

∅ b

a

Breathing spaces (see 3.14.1)

Termination of boundary areas where stay tubes are situated in the boundary rows only (see 3.15.5)
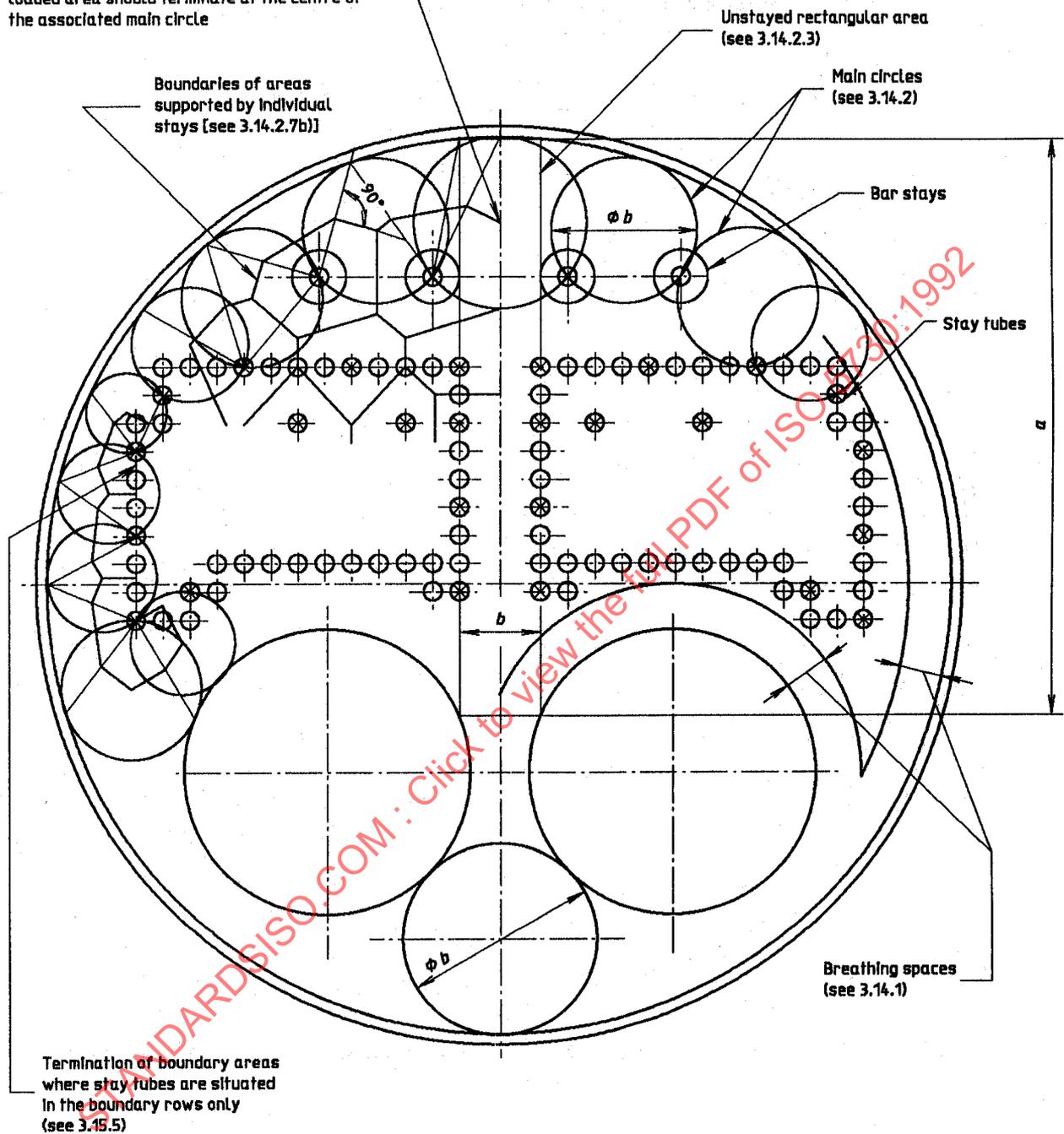
NOTE — See also figure 15.

Figure 14 — Typical arrangement of end plate in a multitubular boiler

The point of support shall be taken at half the distance between the inside of the shell and the commencement of curvature, or at a line 3,5 times the thickness of the plate measured from the outside of the plate, whichever is nearer to the flange (see 3.14.2.2)

Main circle

Sub-circle

Outer limit
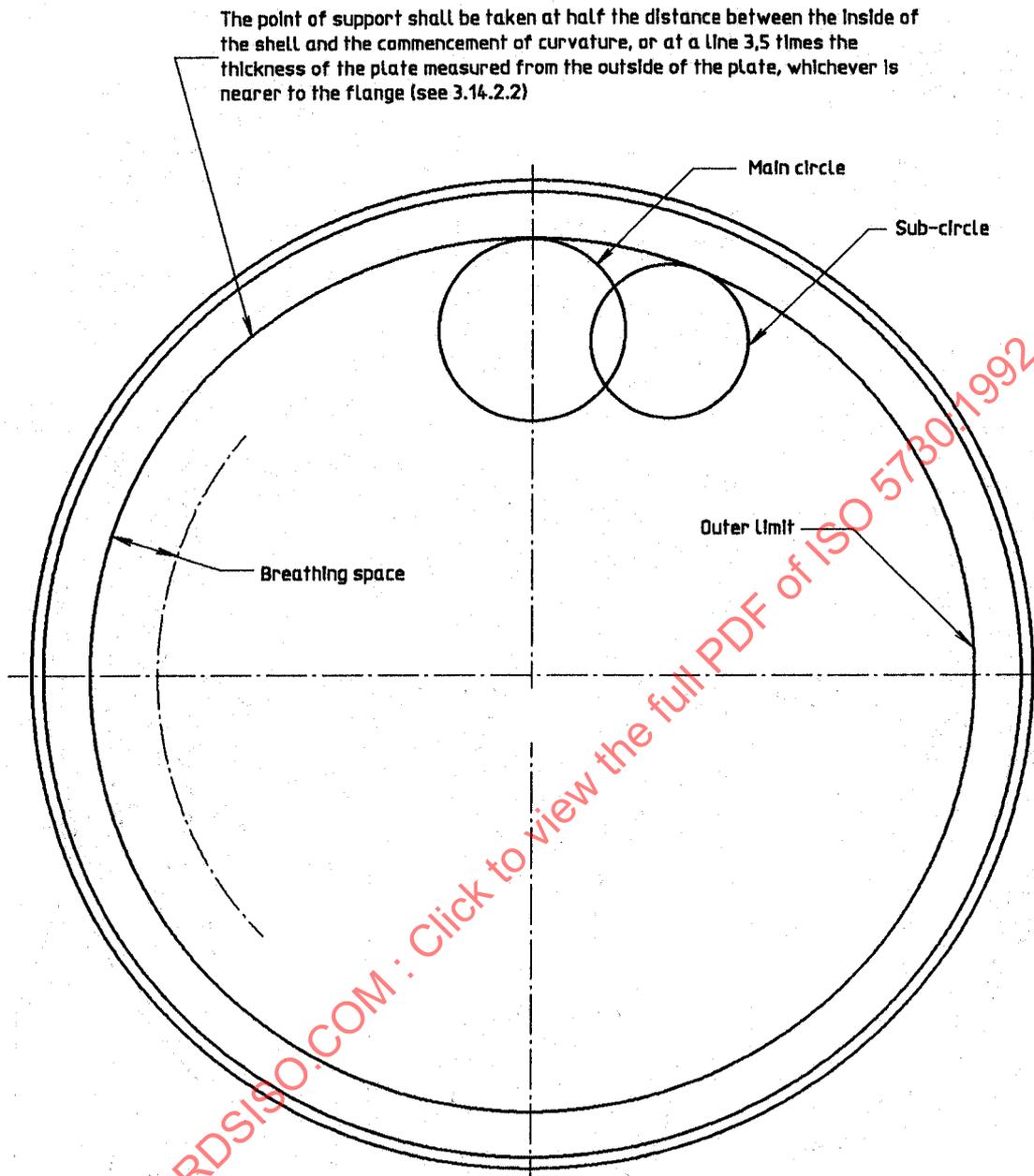
Breathing space

Figure 15 — Outer limits for supported areas, breathing spaces, main circles and sub-circles in flanged end plates
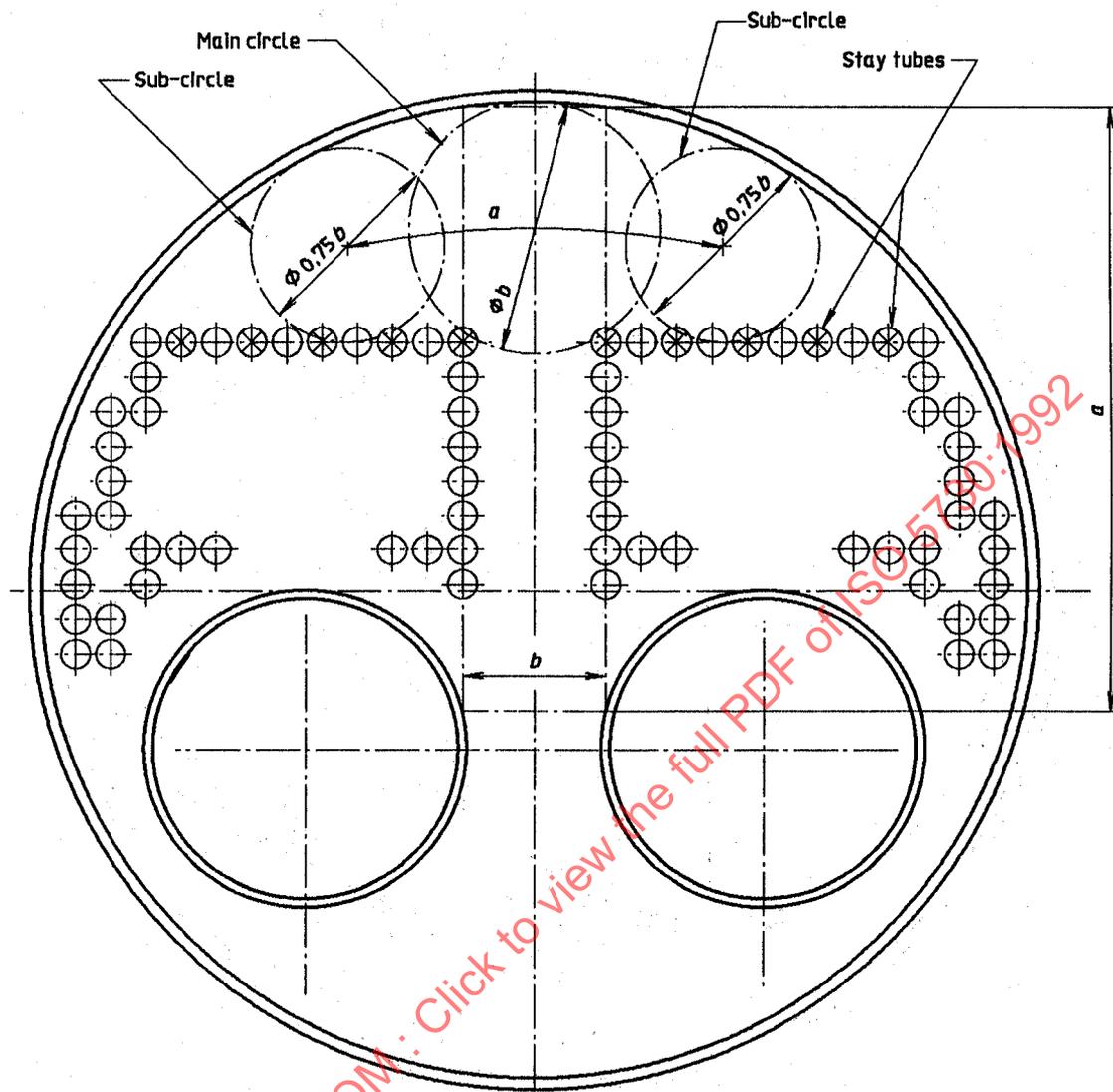
NOTE — See also figure 15.

Figure 16 — Use of sub-circles (twin furnace)

Sub-circle

Main circles

Ø 0.75 b

Ø b

a

Sub-circle

Main circle

Two or three adjacent stay tubes may
be considered as one point of support,
in which case the circle shall pass
through the geometric centre of the
stay tube
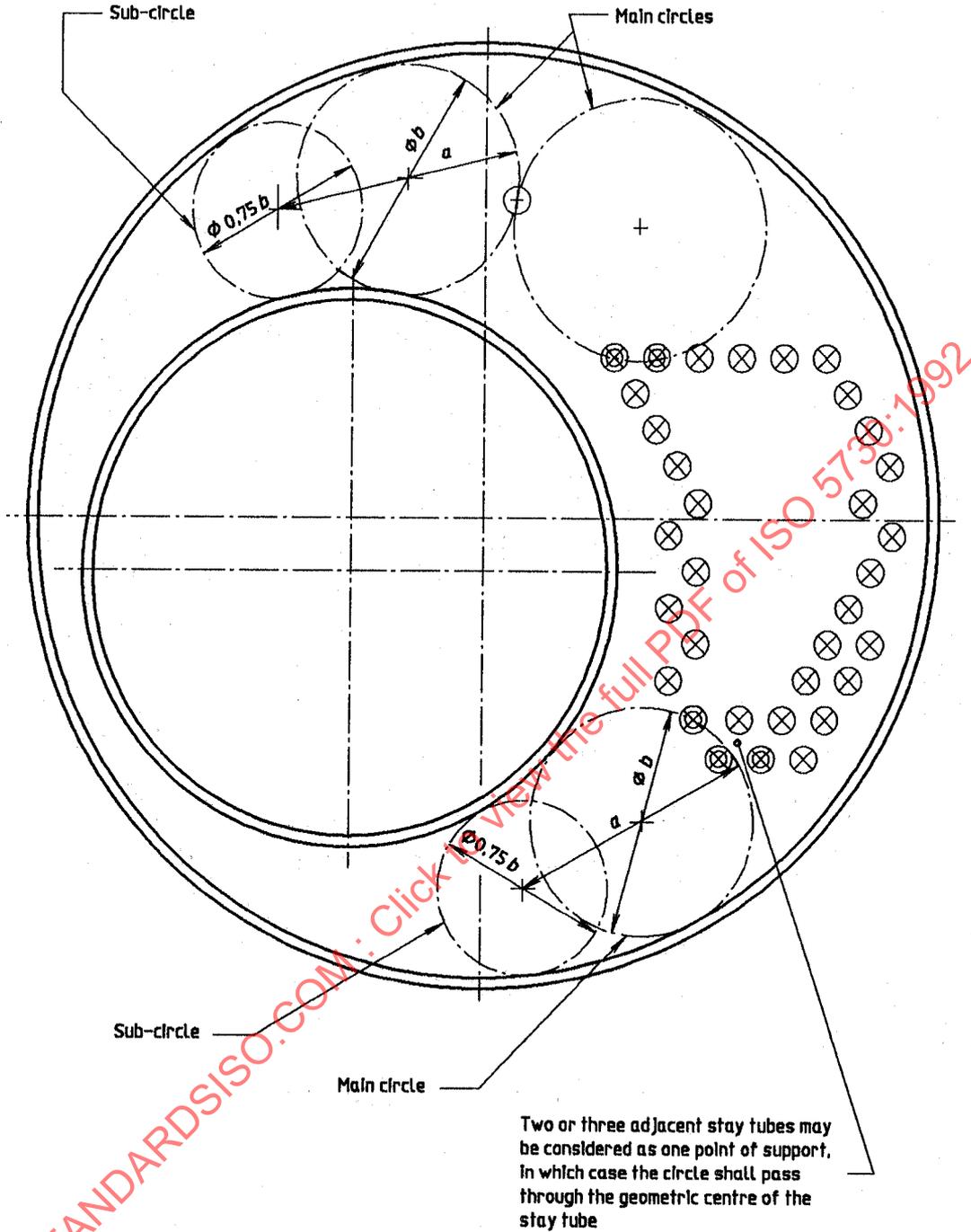
NOTE — See also figure 15.

Figure 17 — Use of sub-circles (single furnace)
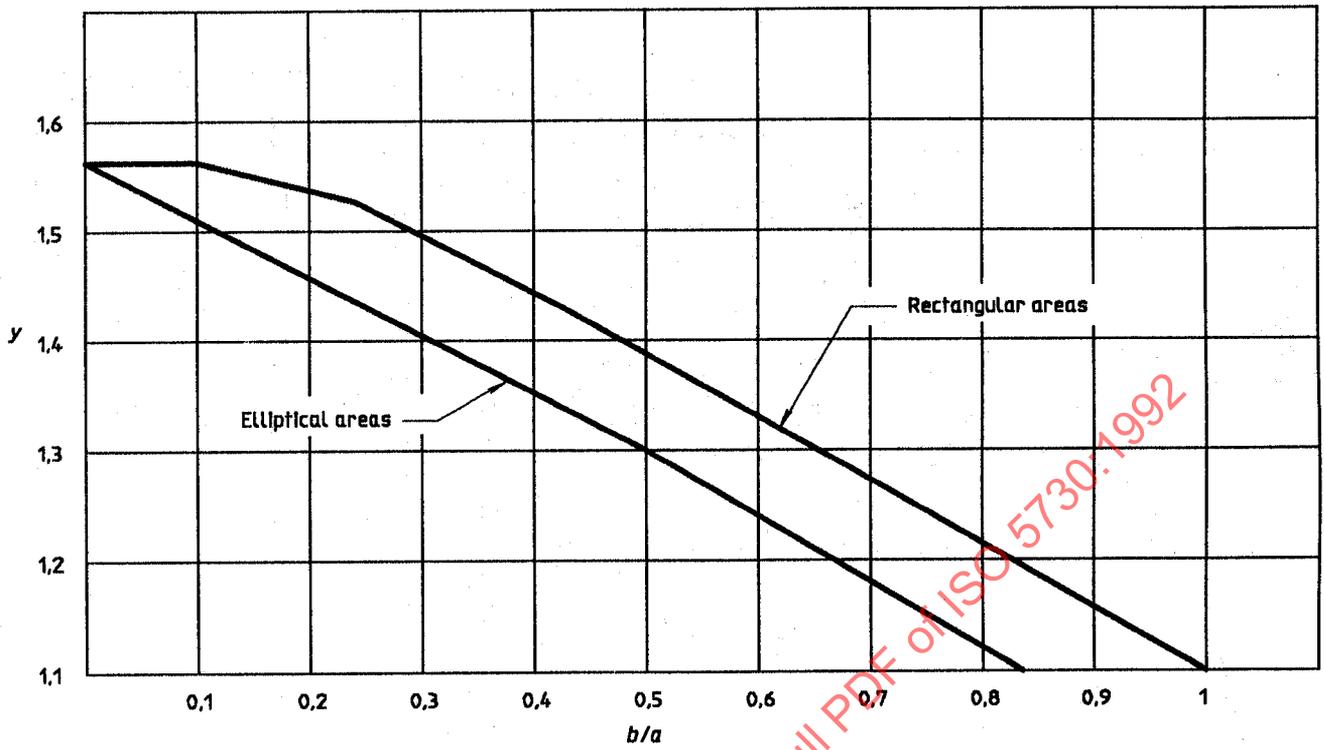
Figure 18 — Determination of factor y

Main circles

Gusset stays

Tangent to inner
or lower circle
(see 3.14.2.4)

$\emptyset b$

β

90°
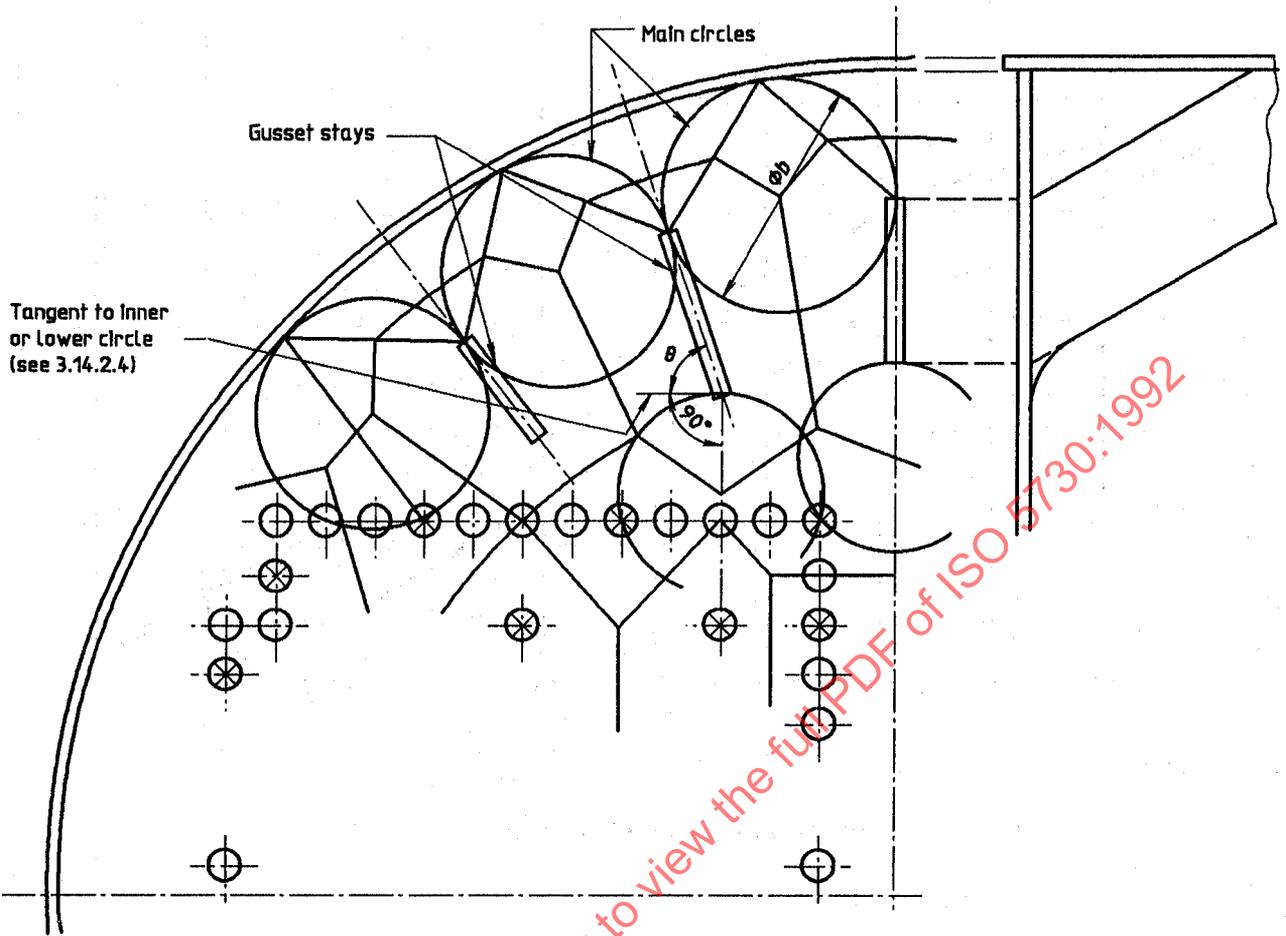
Figure 19 — Example of gusset stays

Figure 20 — Permitted weld details of plain bar stay

Dimensions in millimetres
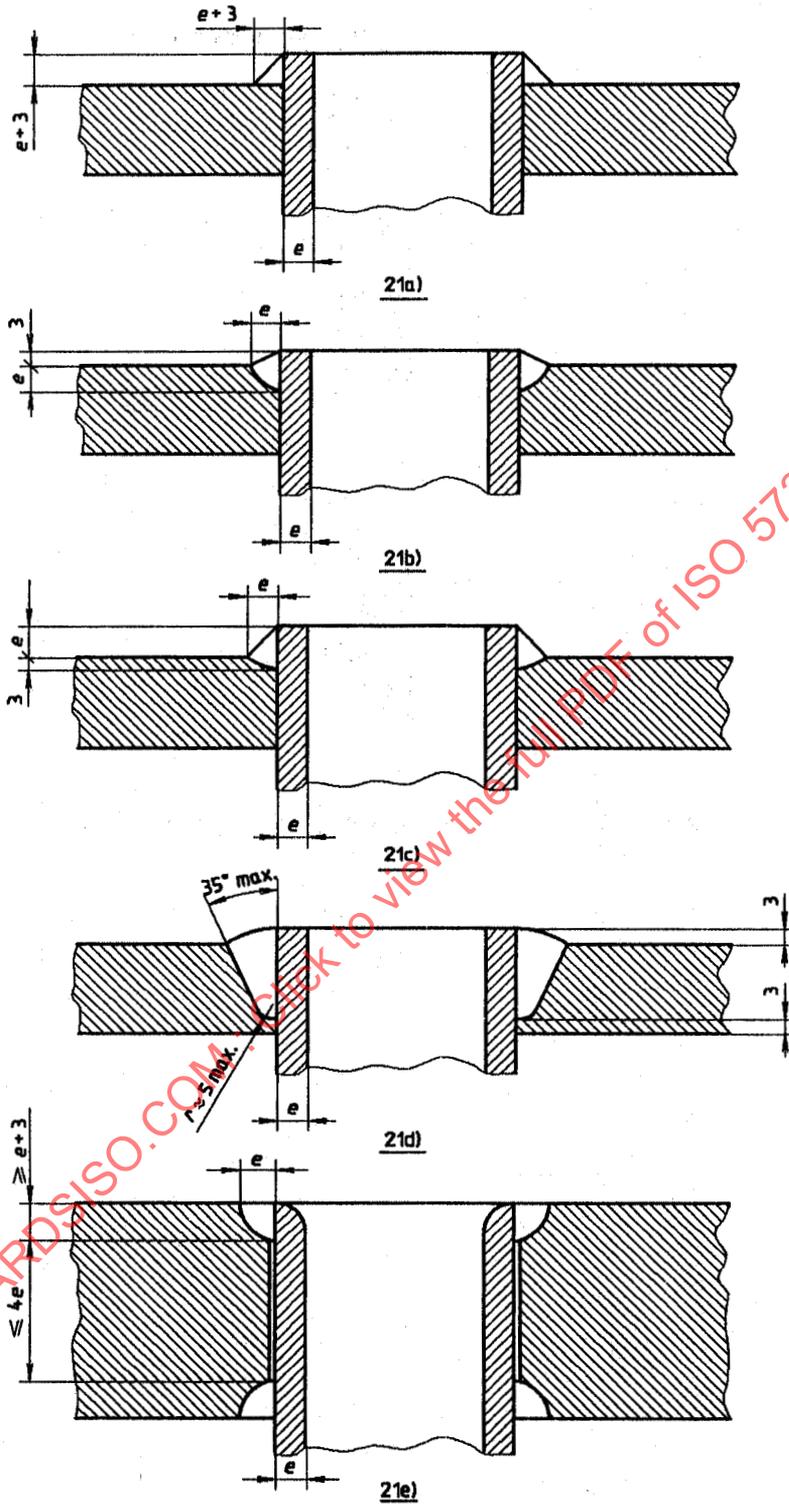
NOTE — The ends of the tubes shall be dressed flush with the welds when exposed to temperatures above 600 °C. When exposed to lower temperatures, the ends of the tubes may extend to a maximum of 10 beyond the weld.

Figure 21 — Permitted weld details of stay tubes

Dimensions in millimetres

NOTE : $e_w = \frac{2}{3}e$

22a)
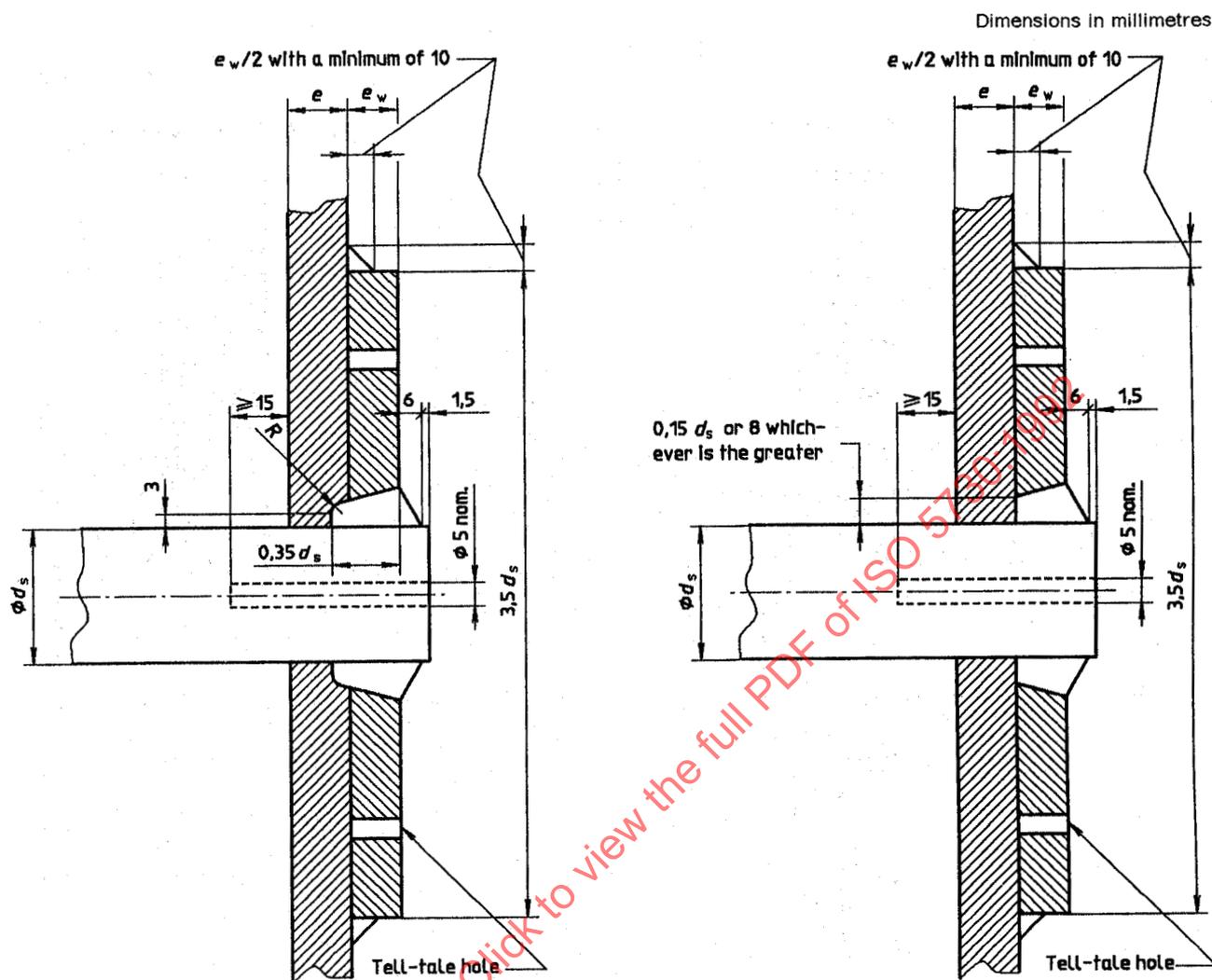
NOTES

1 $e_w = \frac{2}{3}e$

2 Where e_w is less than 0,35 d_s, the form of construction shown in 22a) shall be used.

22b)

Figure 22 — Permitted weld details of bar stays with washers

Dimensions in millimetres
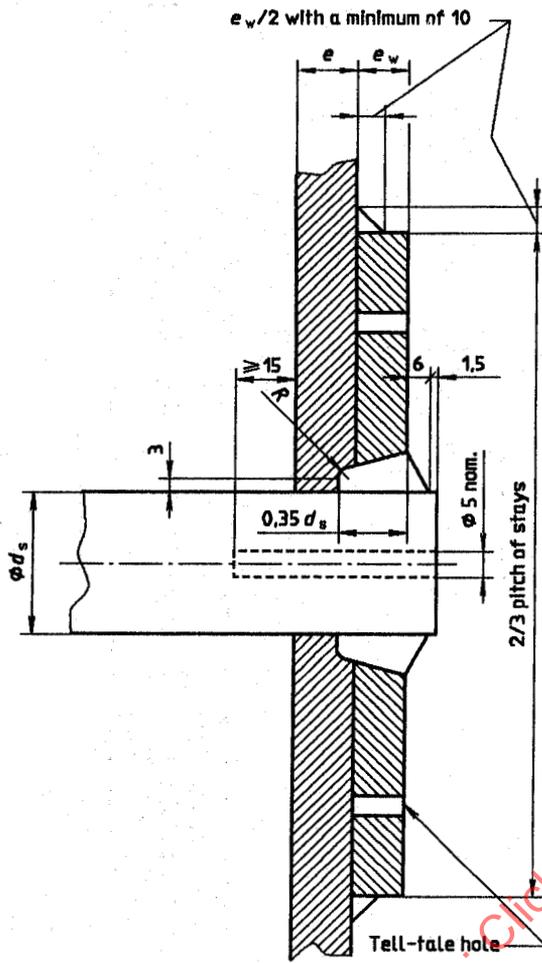
NOTE: $e_w = \frac{2}{3}e$

22c)
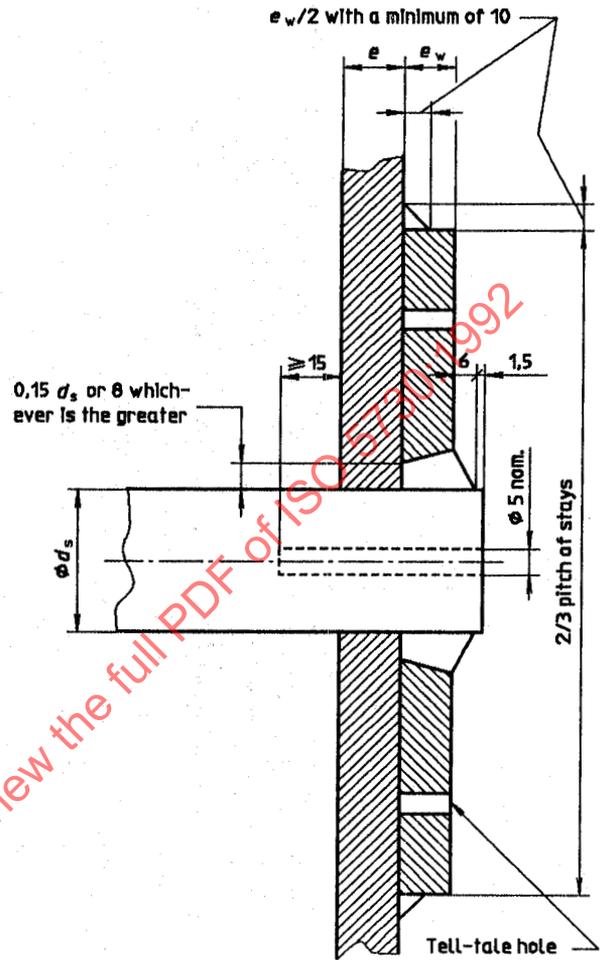
NOTES

1 $e_w = \frac{2}{3}e$

2 Where e_w is less than 0,35 d_s, the form of construction shown in 22c) shall be used.

22d)

Figure 22 — Permitted weld details of bar stays with washers *(concluded)*
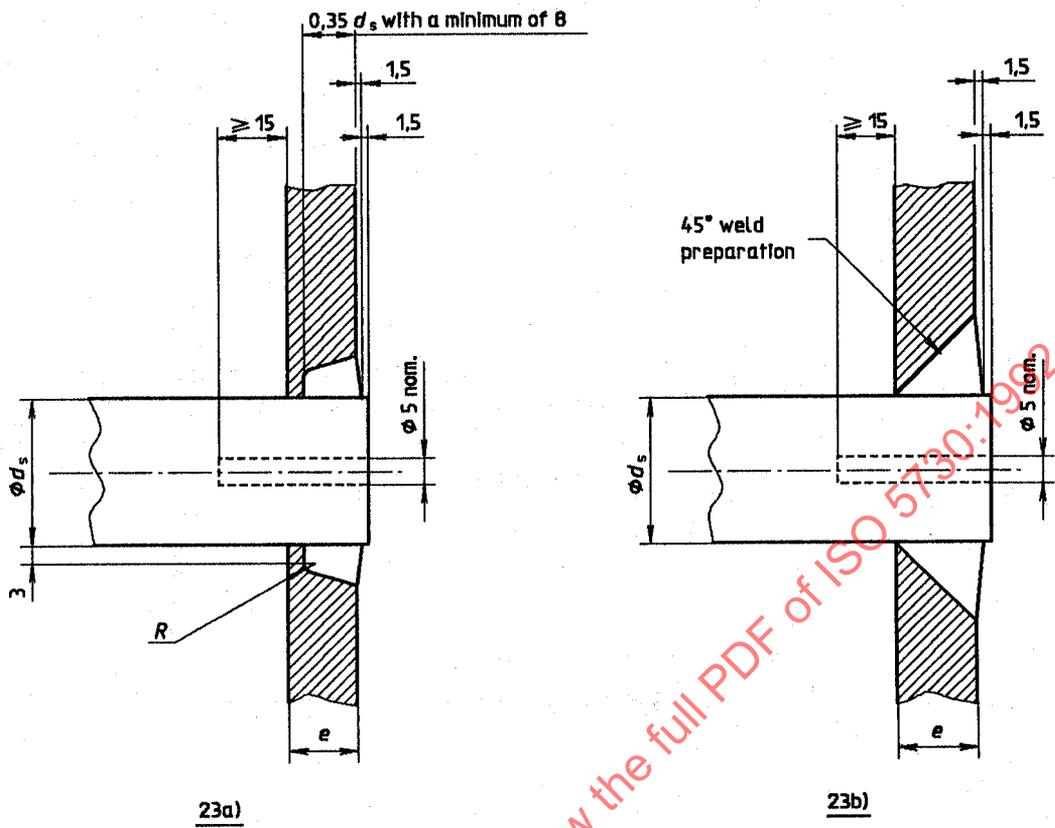
Figure 23 — Permitted weld details of reversal chamber bar stays

Dimensions in millimetres

Alternative shape of girder (see the note)

May be welded for fixed attachment

38

Width of waterway
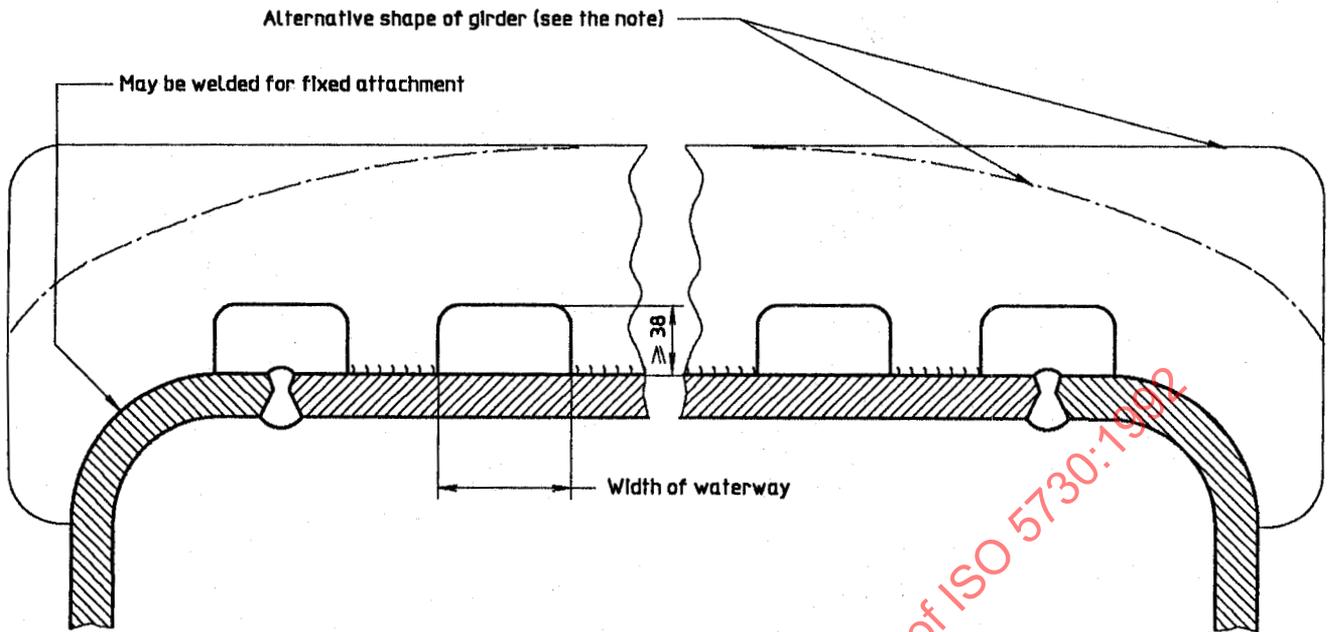
NOTE – Girders may be shaped to either the full or the thin chain line shown.

24a) Method of welding girder to a reversal chamber with flanged ends

38

Width of waterway

Girders may be carried over the ends of the reversal chamber
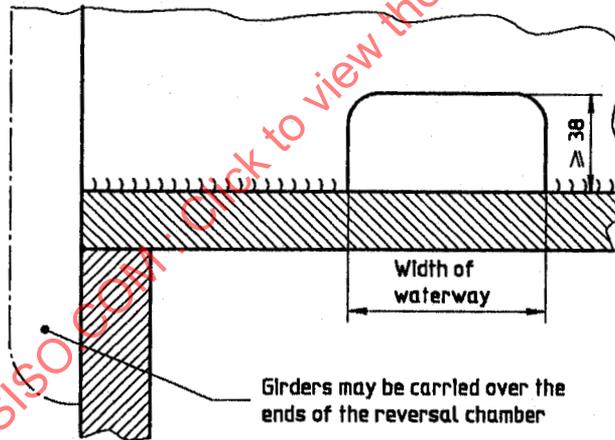
24b) Method of welding girder to a reversal chamber with flat ends

Figure 24 — Typical methods of welding girder stays to reversal chambers

Alternative shape of girder (see the note) ⎯
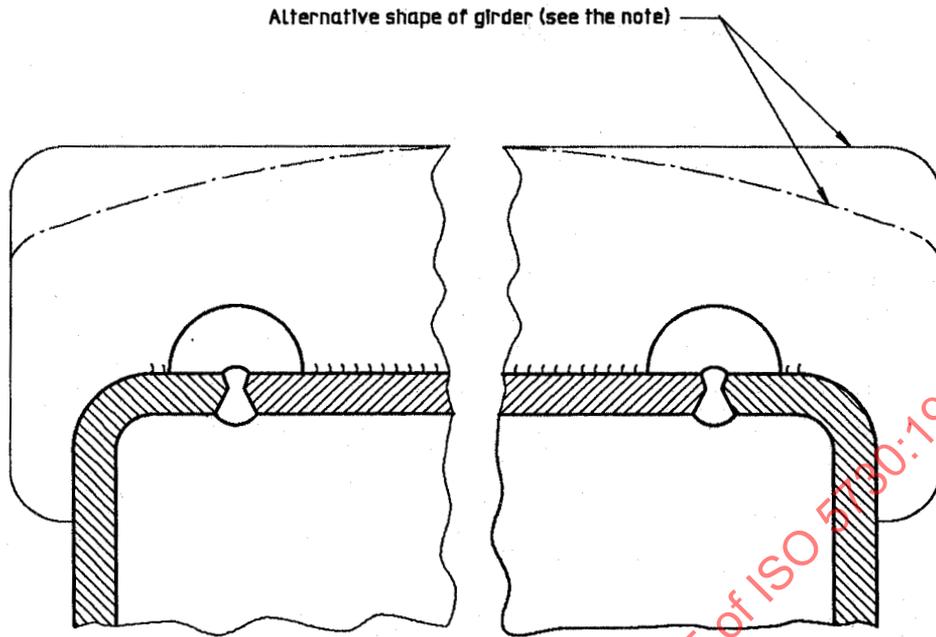
NOTE – Girders may be shaped to either the full or the thin chain line shown.

24c) Welded-on girder to a reversal chamber having flanged tube plate and back plate

Figure 24 — Typical methods of welding girder stays to reversal chambers *(continued)*

Alternative shape of girder (see the note)
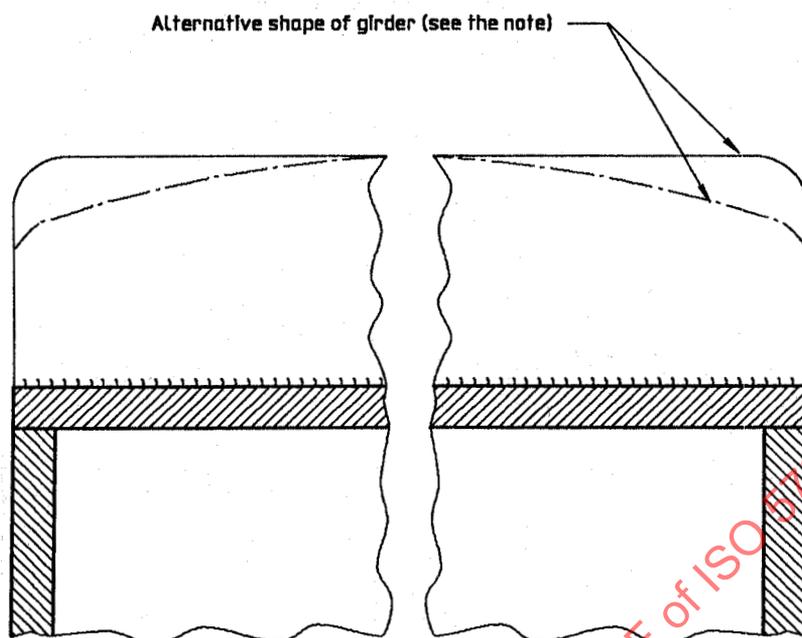
NOTE – Girders may be shaped to either the full or the thin chain line shown.

24d) Welded–on girder to a reversal chamber having square corners
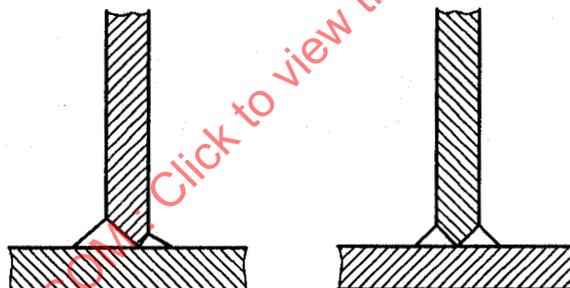
24e) Alternative methods of welding girders to the reversal chamber top

Figure 24 — Typical methods of welding girders to reversal chambers (concluded)
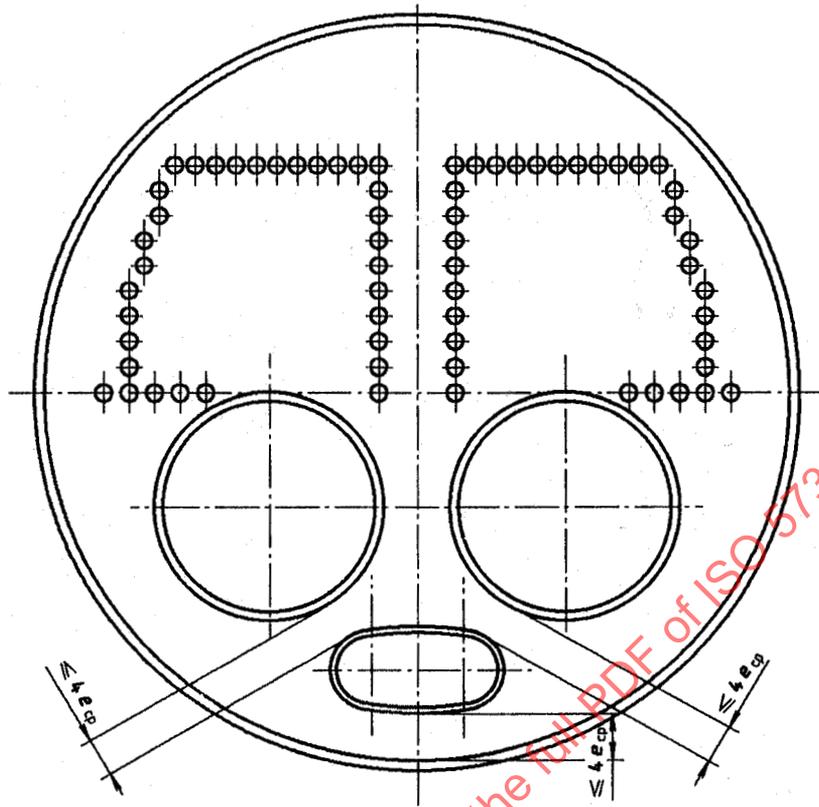
25a) Distances between manhole reinforcing ring, furnaces and shell
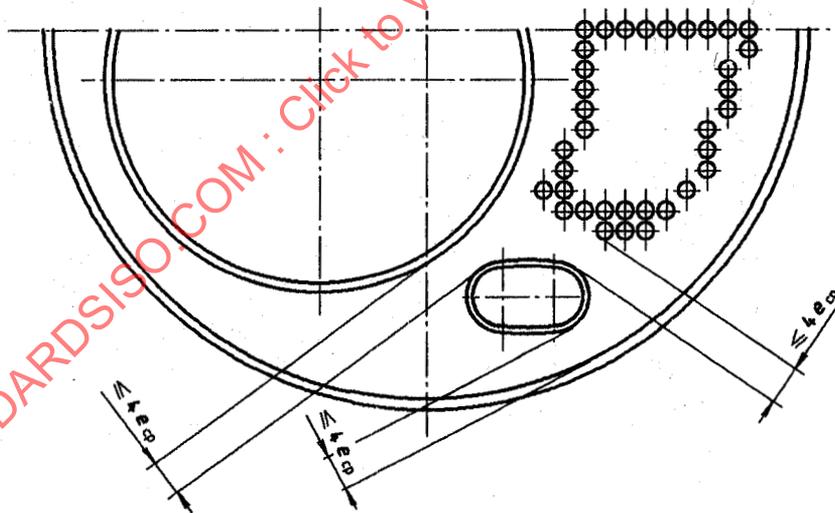
25b) Distances between manhole reinforcing ring, furnace, shell and tube nest

NOTE — See 3.14.2.4.

Figure 25 — Distances from manhole reinforcing ring

26a)

26b)
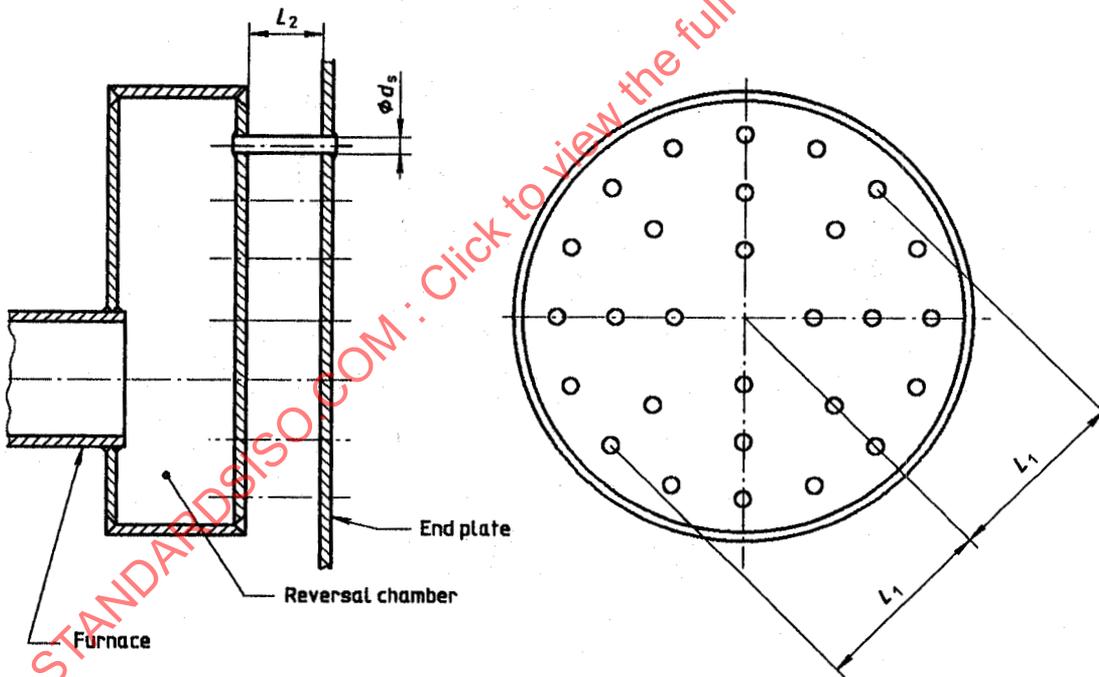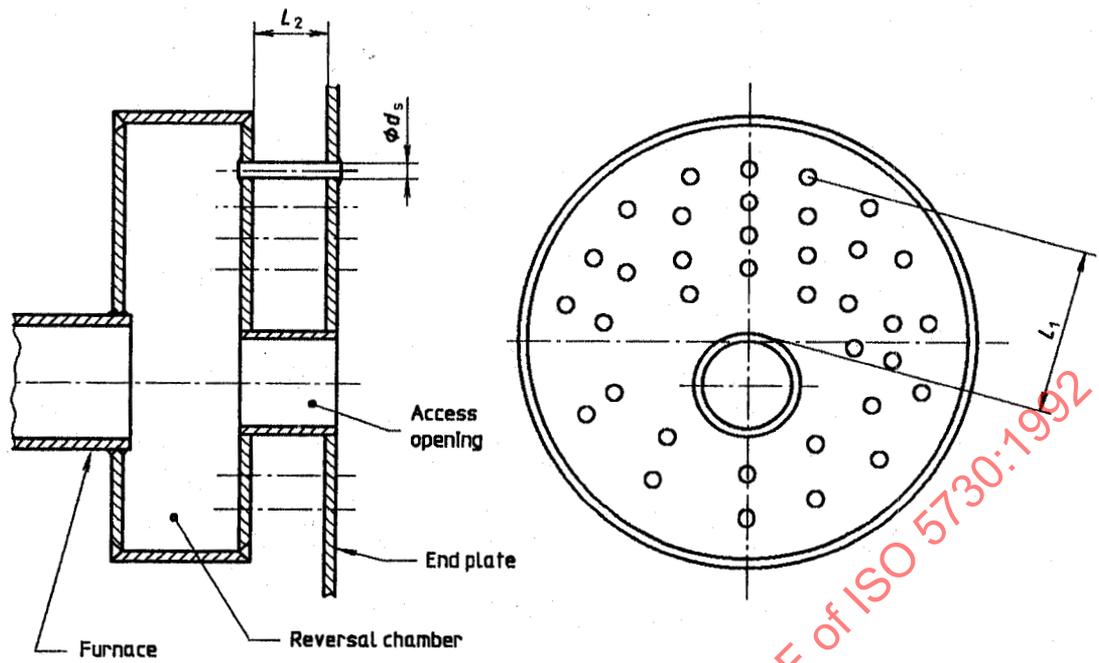
Figure 26 — Location of stays in reversal chamber back plates

Dimensions in millimetres
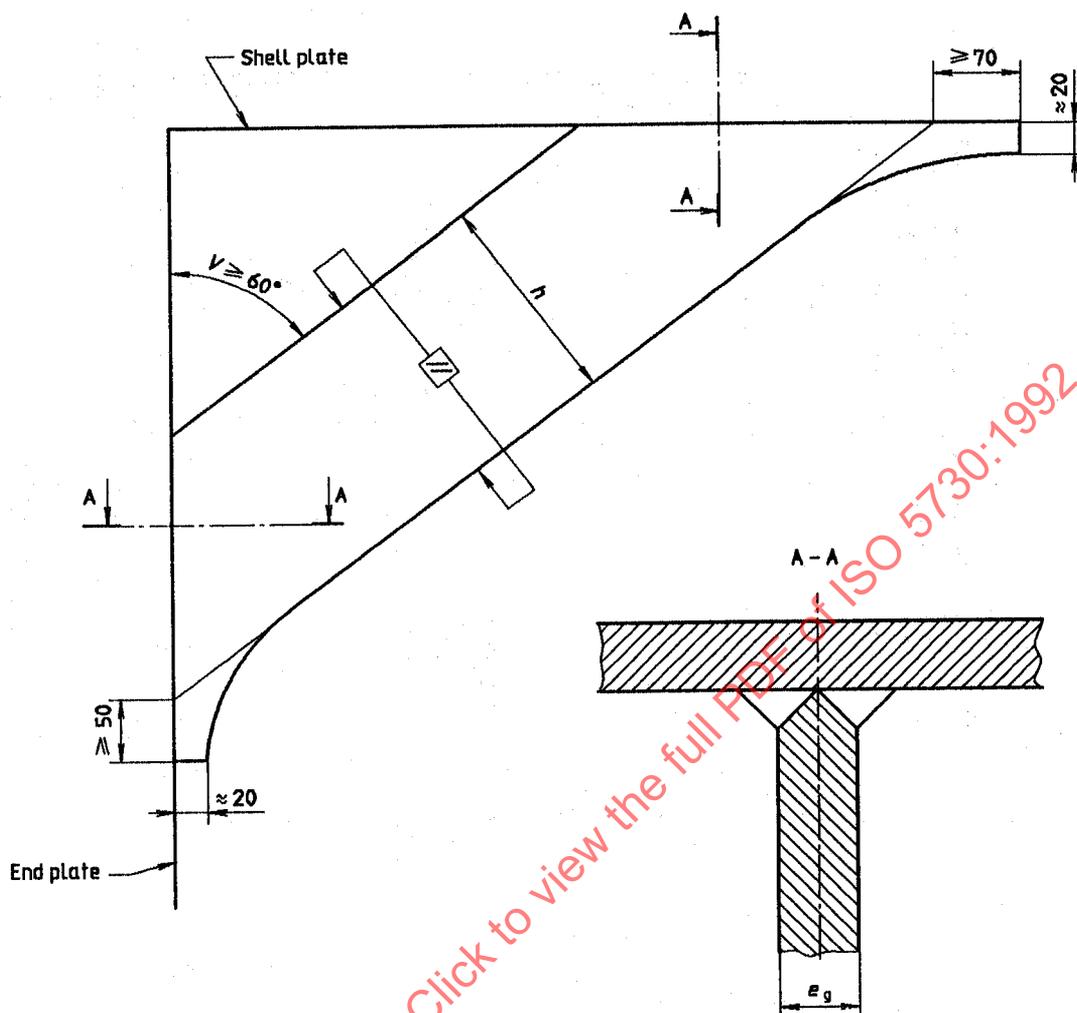
Figure 27 — Details of welded gusset stays
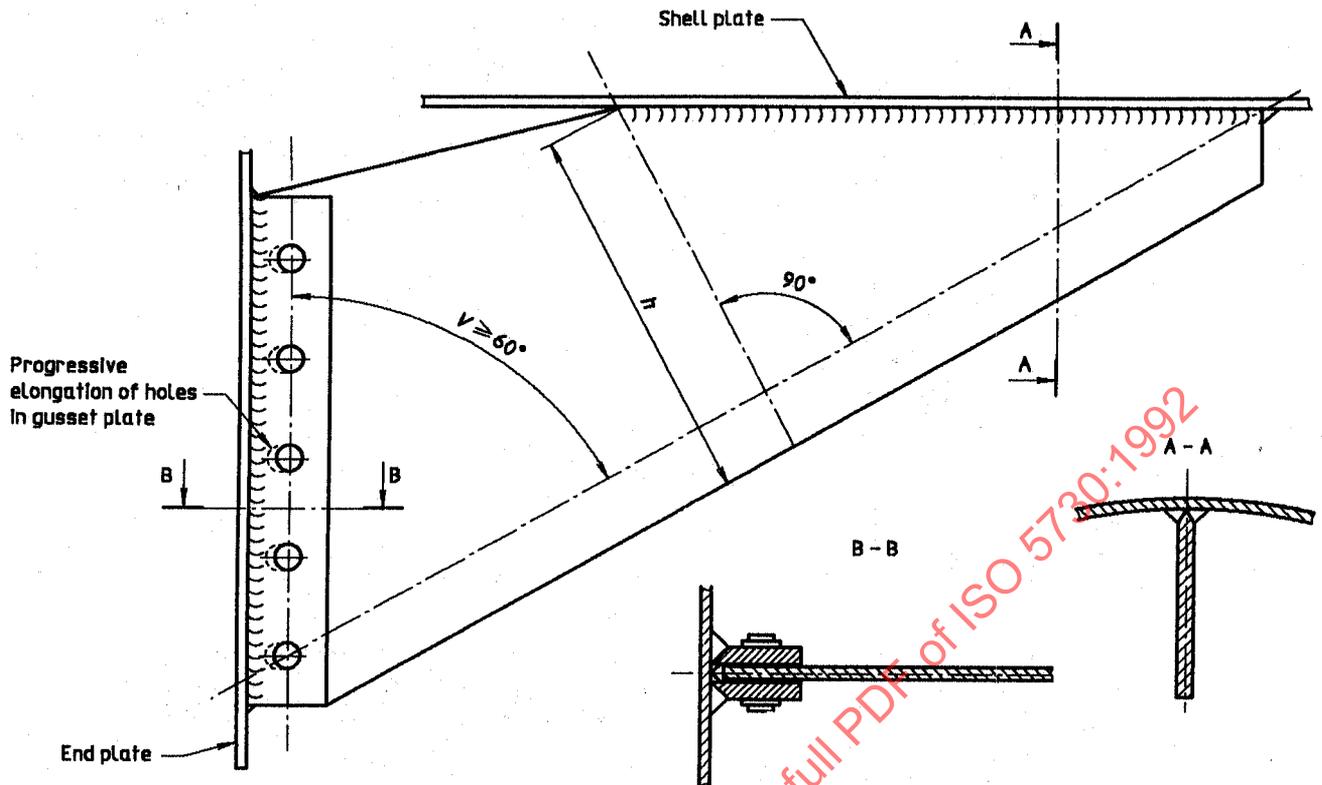
Figure 28 — Details for welded and pinned gusset stays

Figure 29 — Details for diagonal link stays
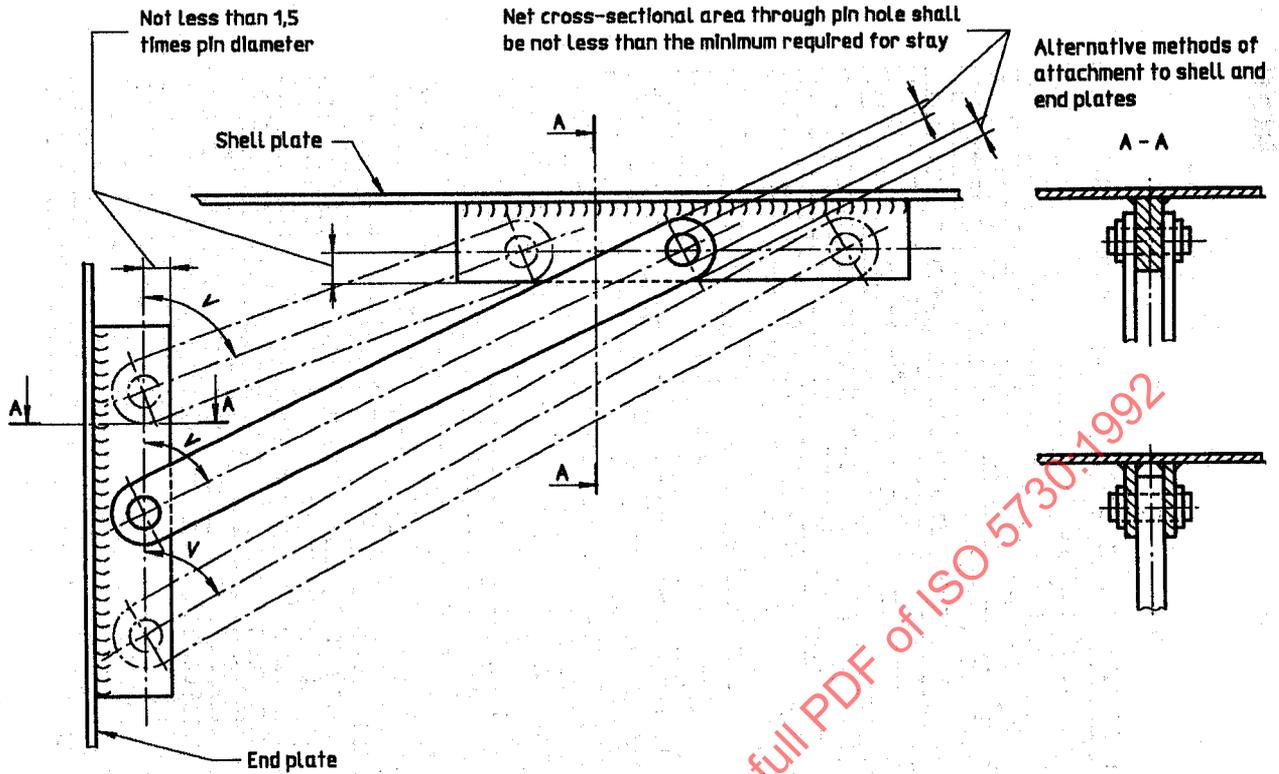
NOTES

1 $V \geqslant 60°$.

2 The thin chain lines indicate stays with multiple links.
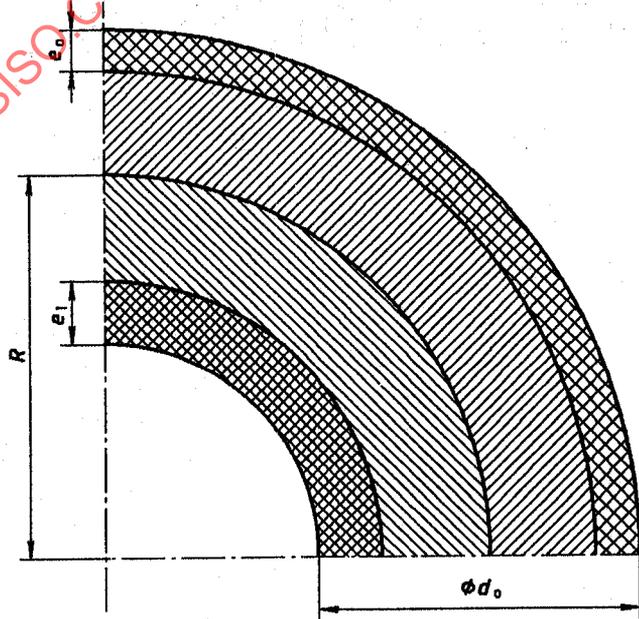
Figure 30 — Notation used for tube bends
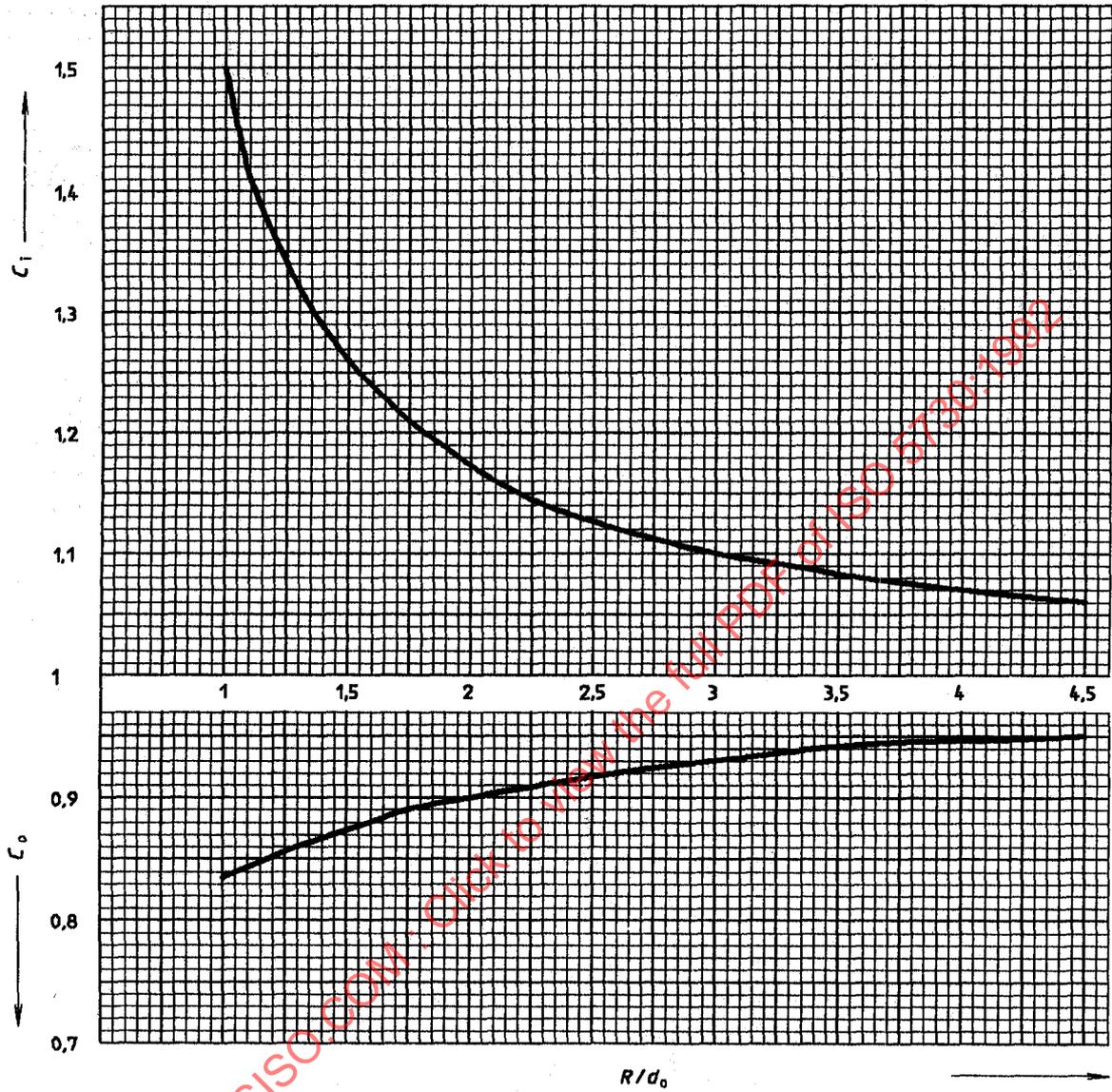
Figure 31 — Design factors C_i and C_o

Dimensions in millimetres

NOTE : $g \geqslant e$
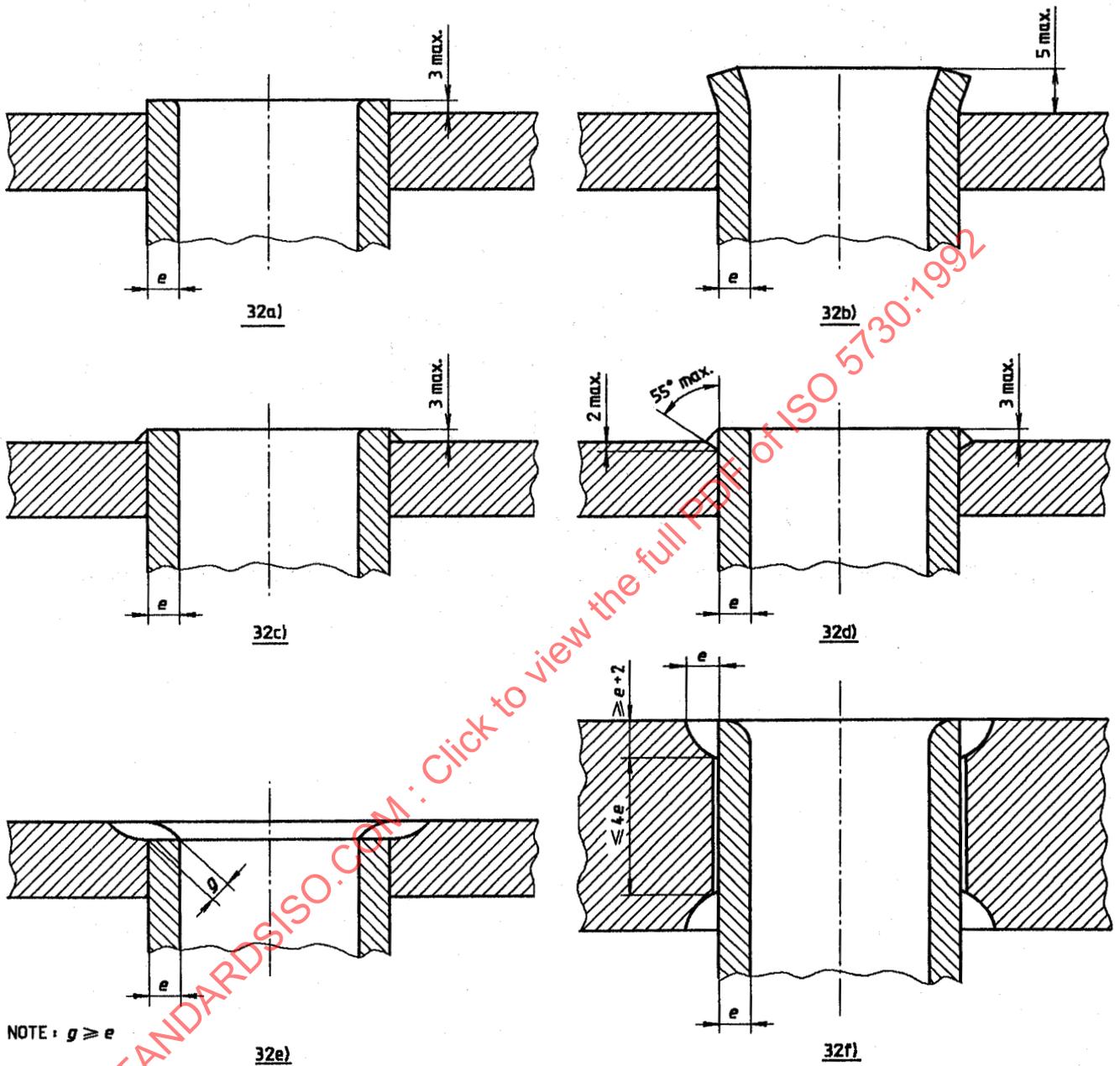
NOTE — For plain tubes exposed to flame or gas temperatures exceeding 600 °C, the ends of welded tubes shall be dressed flush with the welds, and the ends of expanded tubes shall be as shown in 32 a) and 32 b). If not so exposed, the ends of welded tubes shall extend a maximum of 10 beyond the weld or, in the case of expanded tubes, the tube shall project beyond the tube plate up to a maximum of 15.

Figure 32 — Permitted methods of attaching plain tubes

Dimensions in millimetres
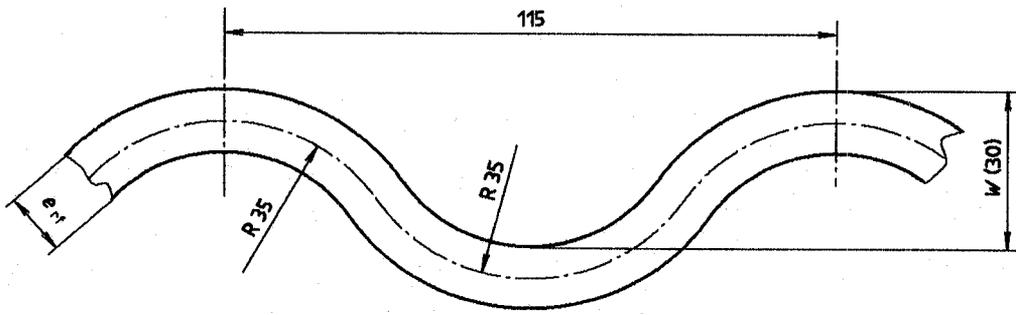
$e_{rf} - c$	I_1	x_2
	$mm^4 \times 10^4$	$mm^2 \times 10^2$
8,25	13,9	11,1
9,25	15,8	12,5
10,25	17,8	13,8
11,25	19,9	15,2
12,25	22,1	16,5
13,25	24,4	17,9

33a) Fox type furnaces (115 corrugation and 30 depth)

Figure 33 — Second moments of area and cross-sectional area for Fox and Morrison type furnaces
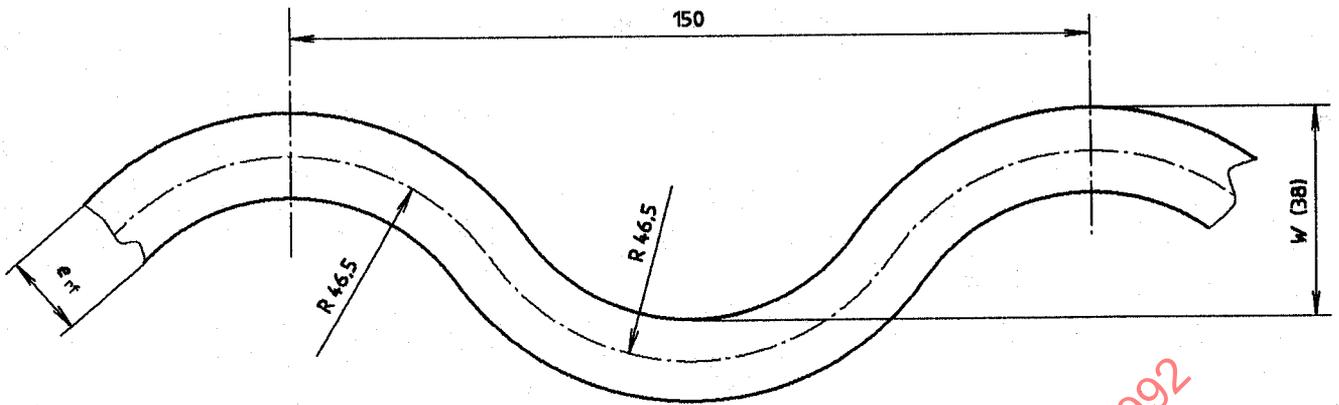
$e_{rt} - c$	I_1	X_2
	$mm^4 \times 10^4$	$mm^2 \times 10^2$
9,25	31,9	16,1
10,25	35,7	17,9
11,25	39,6	19,6
12,25	43,6	21,4
13,25	47,8	23,1
14,25	52,1	24,9
15,25	56,6	26,6
16,25	61,2	28,4
17,25	66,0	30,1
18,25	71,0	31,8
19,25	76,2	33,6
20,25	81,6	35,3
21,25	87,3	37,1

33b) Fox type furnaces (150 corrugation and 38 depth)

Figure 33 — Second moments of area and cross-sectional area for Fox and Morrison type furnaces
(continued)

Dimensions in millimetres
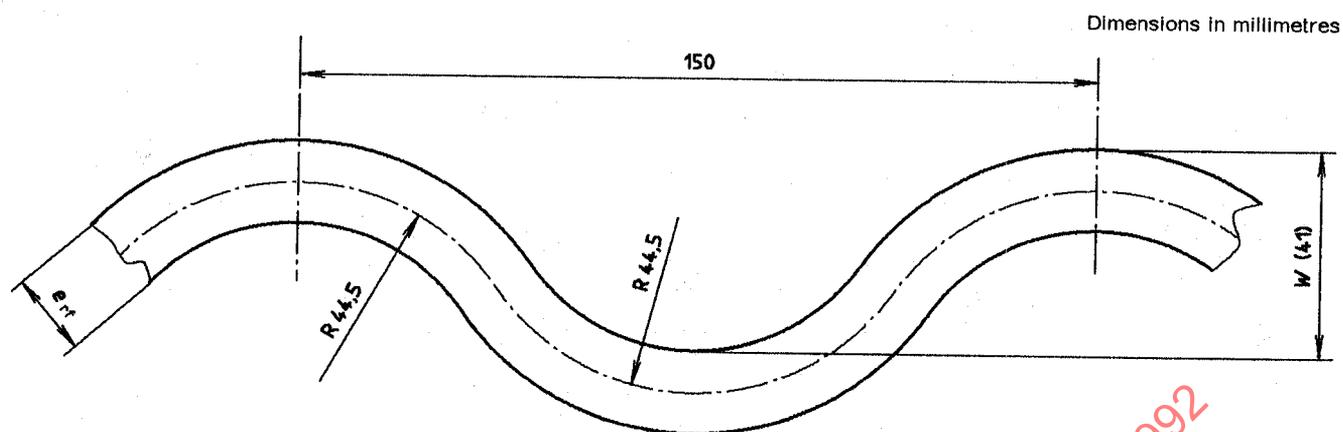
$e_{rf} - c$	I_1 mm^4 x 10^4	X_2 mm^2 x 10^2
9,25	37,7	16,5
10,25	42,2	18,3
11,25	46,8	20,1
12,25	51,5	21,9
13,25	56,3	23,6
14,25	61,3	25,4
15,25	66,4	27,2
16,25	71,8	29,0
17,25	77,3	30,8
18,25	83,0	32,6
19,25	88,9	34,3
20,25	95,0	36,1
21,25	101,4	37,9

33c) Fox type furnaces (150 corrugation and 41 depth)

Figure 33 — Second moments of area and cross-sectional area for Fox and Morrison type furnaces
(continued)

Dimensions in millimetres
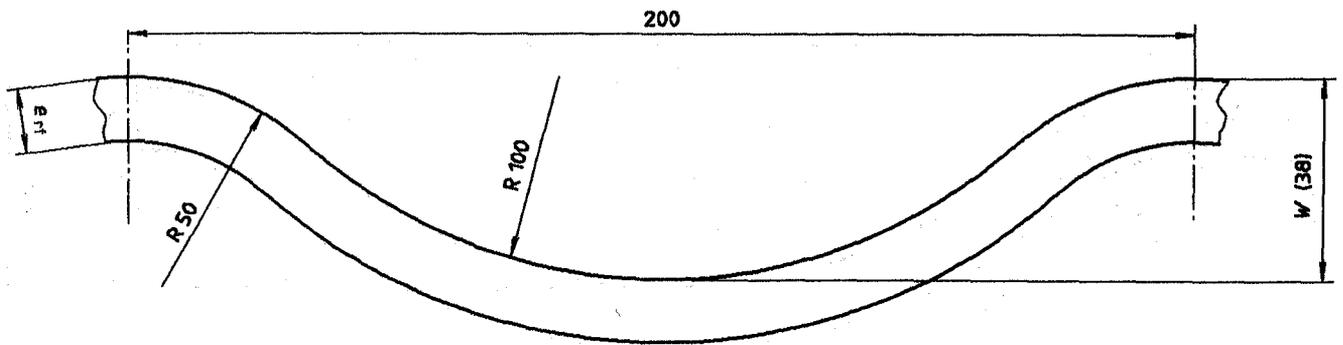
$e_{rf} - c$	I_1 mm^4 x 10^4	X_2 mm^2 x 10^2
9,25	38,6	20,2
10,25	43,2	22,4
11,25	47,8	24,6
12,25	52,6	26,8
13,25	57,5	29,0
14,25	62,6	31,2
15,25	67,8	33,4
16,25	73,2	35,6
17,25	78,8	37,8
18,25	84,6	40,0
19,25	90,6	42,1
20,25	96,8	44,3
21,25	103,3	46,5

33d) Morrison type furnaces (200 corrugation and 38 depth)

Figure 33 — Second moments of area and cross-sectional area for Fox and Morrison type furnaces
(continued)

107

Dimensions in millimetres
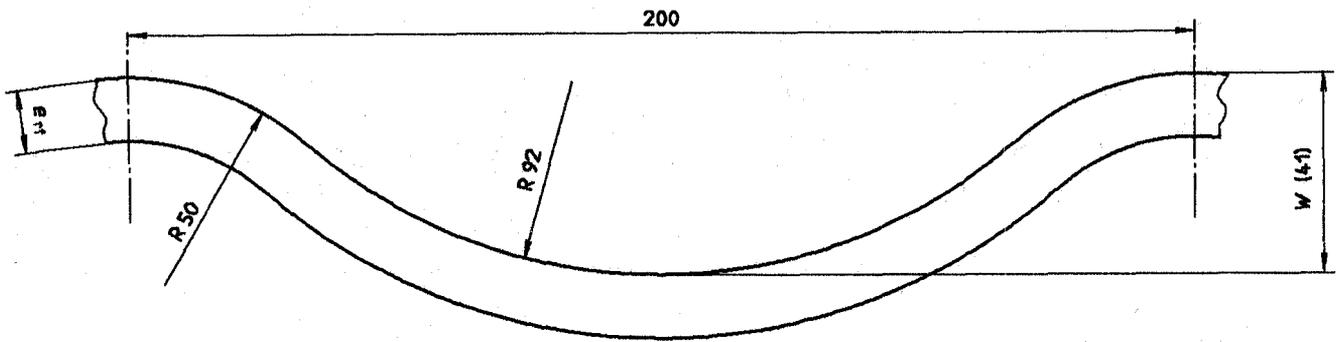
$e_{nf} - c$	I_1 mm^4 x 10^4	X_2 mm^2 x 10^2
9,25	45,6	20,5
10,25	50,9	22,7
11,25	56,3	25,0
12,25	61,8	27,2
13,25	67,5	29,4
14,25	73,3	31,6
15,25	79,3	33,8
16,25	85,5	36,1
17,25	91,8	38,3
18,25	98,4	40,5
19,25	105,2	42,7
20,25	112,2	44,9
21,25	119,5	47,2

33e) Morrison type furnaces (200 corrugation and 41 depth)

Figure 33 — Second moments of area and cross-sectional area for Fox and Morrison type furnaces
(continued)

Dimensions in millimetres
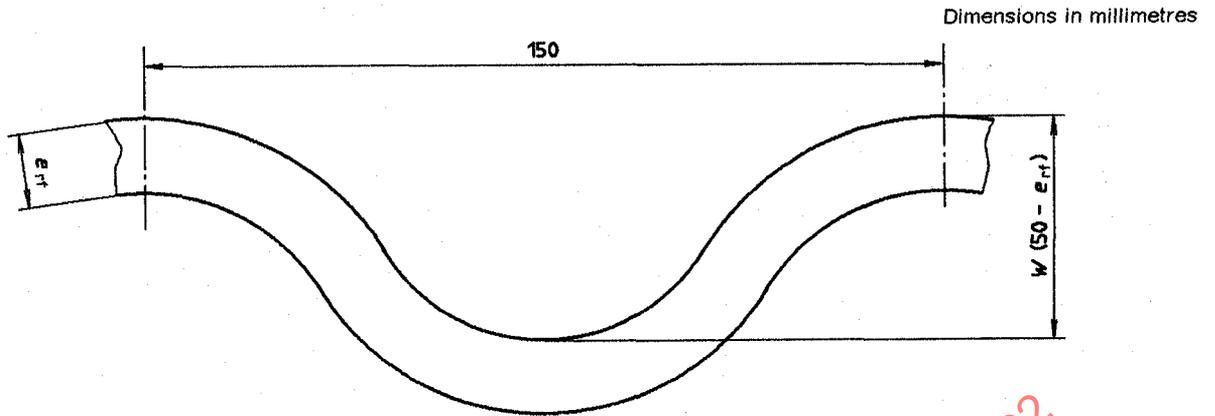
$e_{rf} - c$	I_1 mm^4 x 10^4	X_2 mm^2 x 10^2
9,25	35,6	16,4
10,25	37,7	18,0
11,25	39,6	19,6
12,25	41,2	21,2
13,25	42,7	22,8
14,25	44,1	24,4
15,25	45,3	25,9
16,25	46,4	27,4
17,25	47,4	28,9
18,25	48,3	30,4
19,25	49,2	31,9
20,25	50,1	33,3
21,25	51,0	34,8

33f) Fox type furnaces (150 corrugation and 50 total depth)

Figure 33 — Second moments of area and cross-sectional area for Fox and Morrison type furnaces
(continued)

Dimensions in millimetres
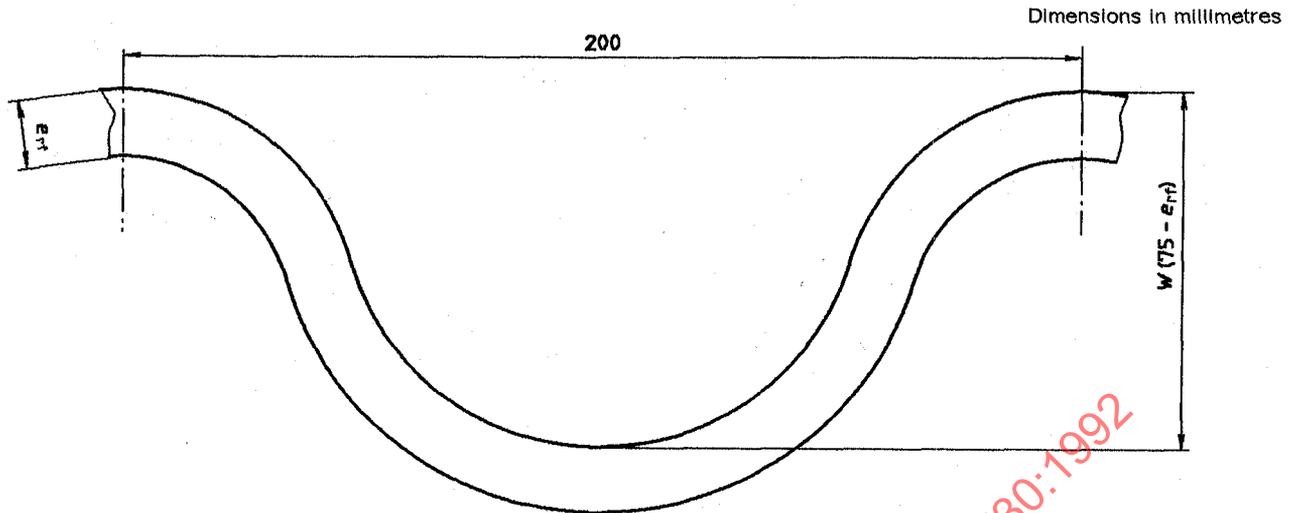
$e_{rf} - c$	I_1 mm^4 x 10^4	X_2 mm^2 x 10^2
9,25	129,4	23,3
10,25	138,9	25,7
11,25	147,7	28,0
12,25	155,9	30,4
13,25	163,5	32,6
14,25	170,5	34,9
15,25	177,0	37,1
16,25	183,0	39,4
17,25	188,5	41,5
18,25	193,6	43,7
19,25	198,4	45,8
20,25	202,8	48,0
21,25	206,9	50,0

33g) Fox type furnaces (200 corrugation and 75 total depth)

Figure 33 — Second moments of area and cross-sectional area for Fox and Morrison type furnaces *(concluded)*

Dimensions in millimetres

$2e \leqslant b \leqslant 22$
$5e \leqslant h \leqslant 6b$

Continuous full
penetration weld
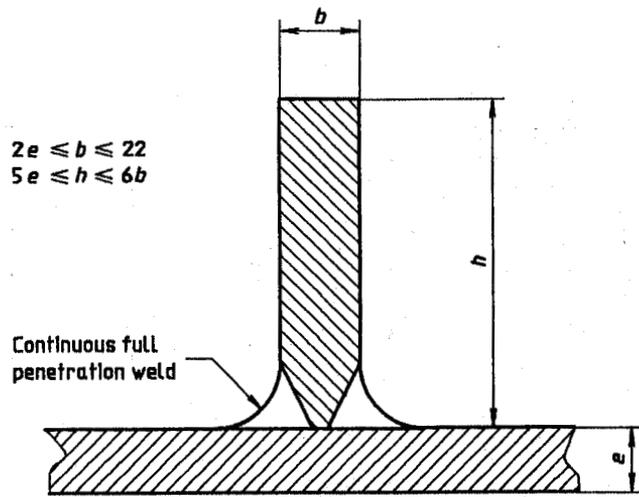
Figure 34 — Furnace stiffeners up to and including 22 mm thick for plain and corrugated sections

Dimensions in millimetres

$2e \leqslant b > 22$
$5e \leqslant h \leqslant 6b$

Continuous full
penetration weld

22 max.
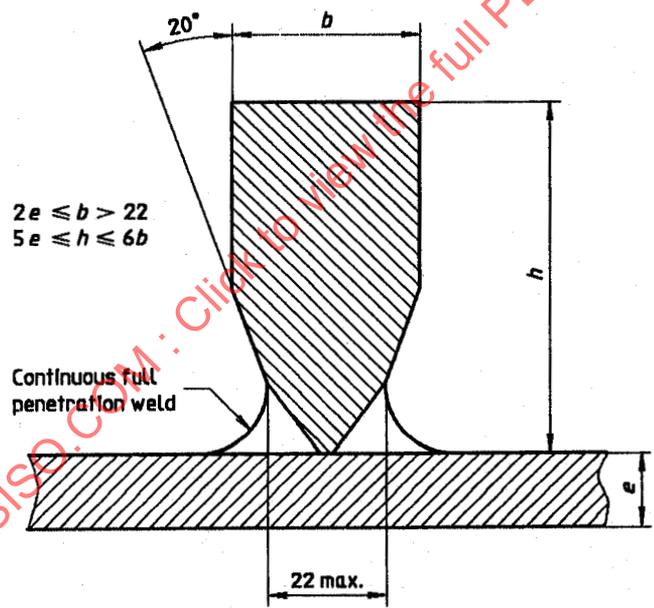
Figure 35 — Furnace stiffeners thicker than 22 mm for plain and corrugated sections

Dimensions in millimetres
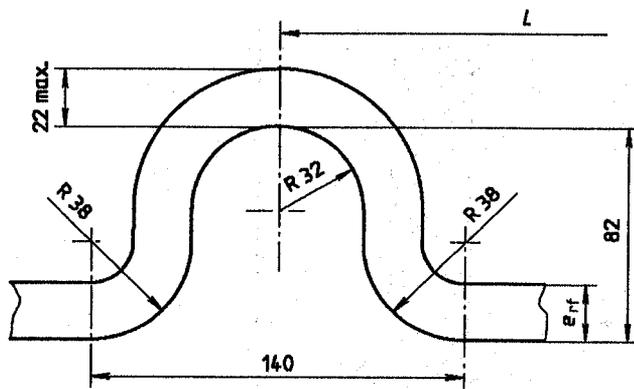
$e_{rf} - c$	I_2 mm^4 x 10^6
9,25	1,90
10,25	2,11
11,25	2,32
12,25	2,53
13,25	2,74
14,25	2,96
15,25	3,18
16,25	3,40
17,25	3,62
18,25	3,85
19,25	4,08
20,25	4,31
21,25	4,55

36a)
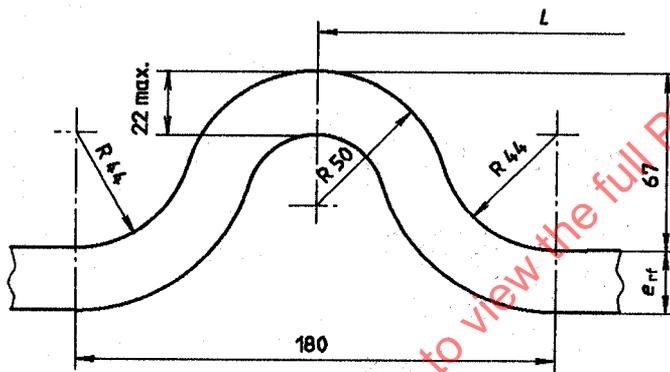
$e_{rf} - c$	I_2 mm^4 x 10^6
9,25	1,30
10,25	1,44
11,25	1,59
12,25	1,74
13,25	1,90
14,25	2,04
15,25	2,20
16,25	2,36
17,25	2,52
18,25	2,68
19,25	2,84
20,25	3,01
21,25	3,18

36b)

$e_{rf} - c$	I_2 mm^4 x 10^6
9,25	1,14
10,25	1,28
11,25	1,41
12,25	1,55
13,25	1,70
14,25	1,86
15,25	2,04
16,25	2,22
17,25	2,41
18,25	2,60
19,25	2,80
20,25	3,01
21,25	3,22
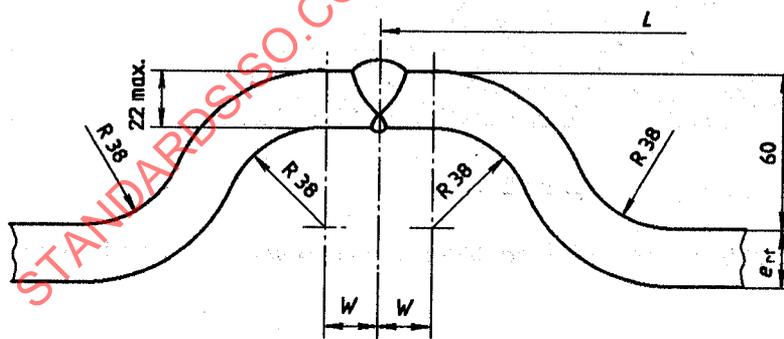
NOTE : $W = e_{rf} - c$, but not less than 13.

36c)

Figure 36 — Bowling hoops
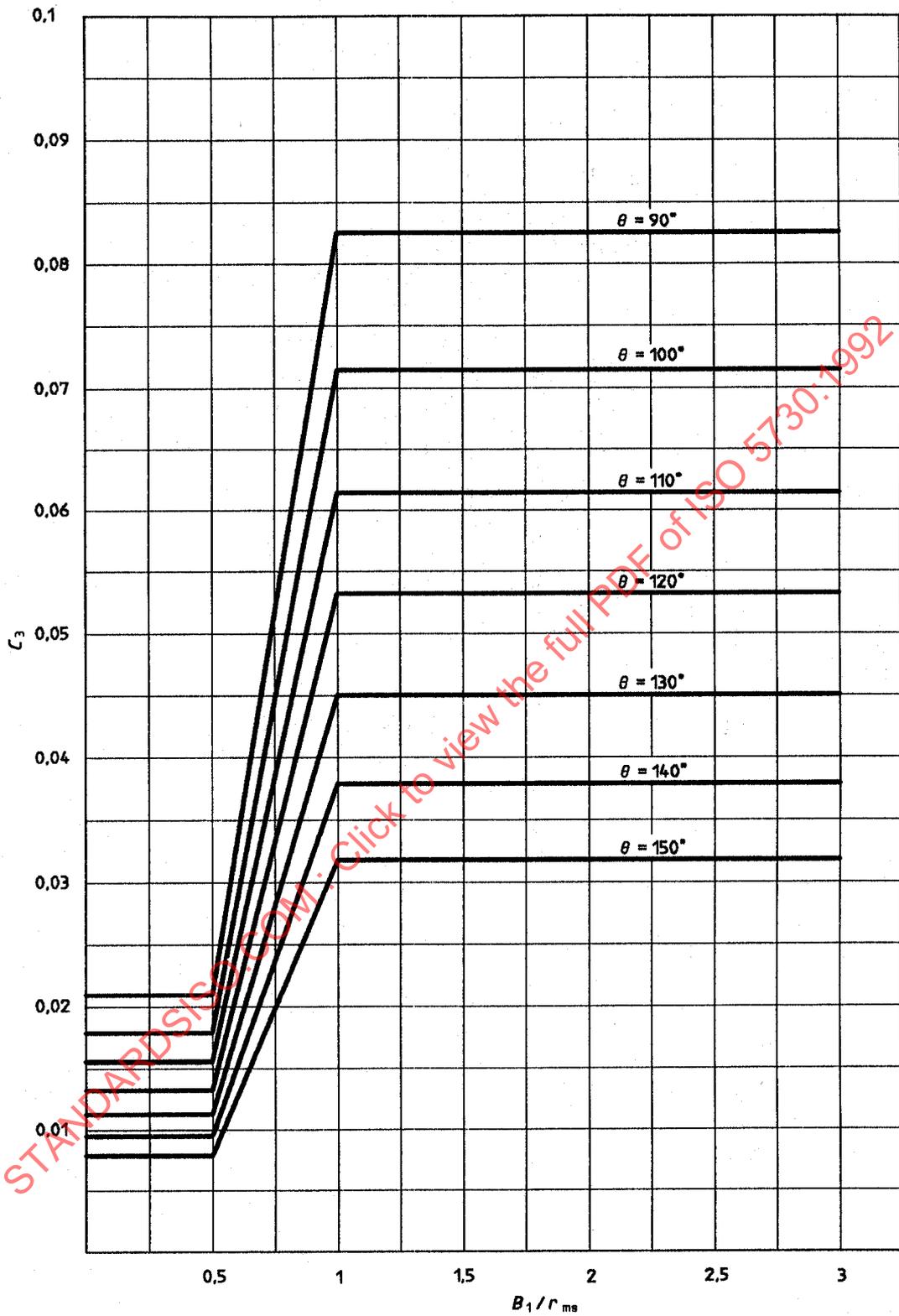
Figure 37 — Coefficient for calculation of stress at saddle supports

Dimensions in millimetres
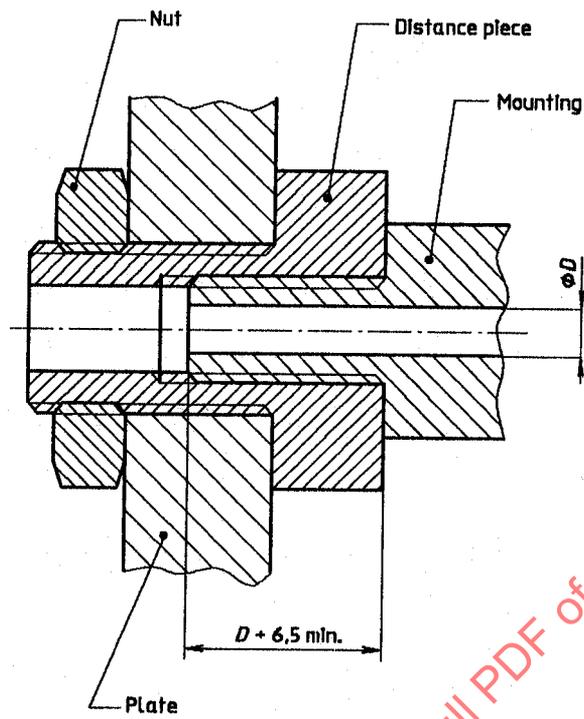
NOTE — See 4.8.6 b).

Figure 38 — Mounting screwed into steel distance piece
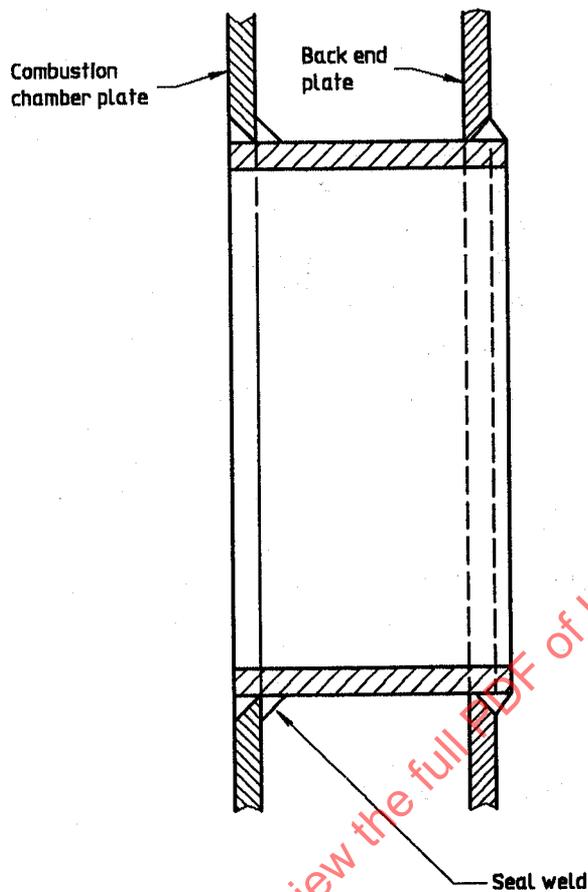
Figure 39 — Access opening for wet back boilers

Dimensions in millimetres
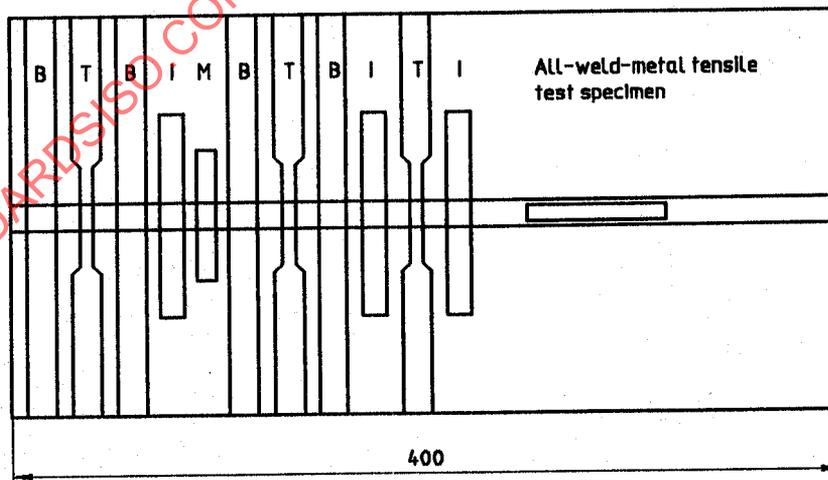
B Bend test specimen
T Reduced section tensile test specimen
I Impact test specimen
M Macro-test specimen

Figure 40 — Cutting up the test plate

Dimensions in millimetres

1 Tensile
2 Face bend
3 Root bend
M Macro-etch

41a)

41b)
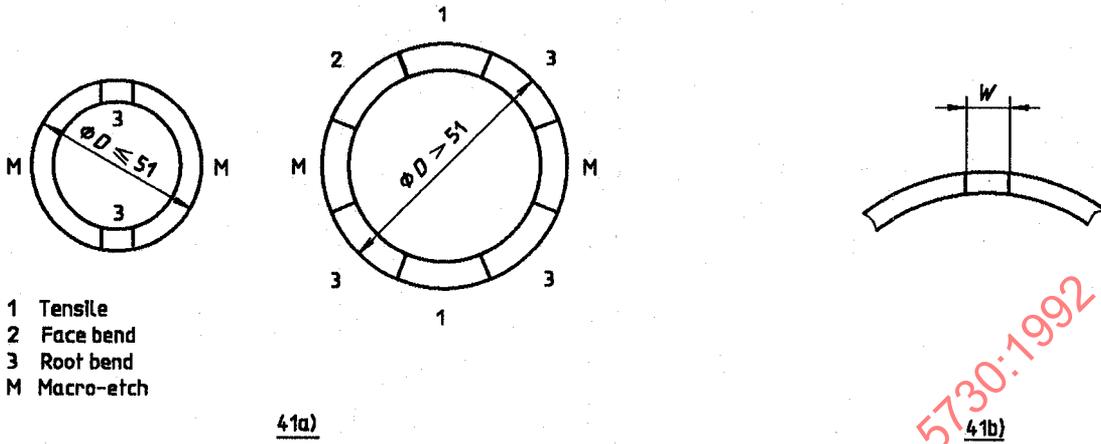
Figure 41 — Bend test specimens for pipes and tubes

Dimensions in millimetres

42a) Lapped test plate for sheet and plate welders on e = 1,5 to 2

42b) Wedge test piece for sheet and plate welders on e ≥ 4

42c) Test piece with fillet weld at lap joint for pipe welders on e ≥ 4

42d) Angled test piece for sheet and plate welders on e ≥ 4
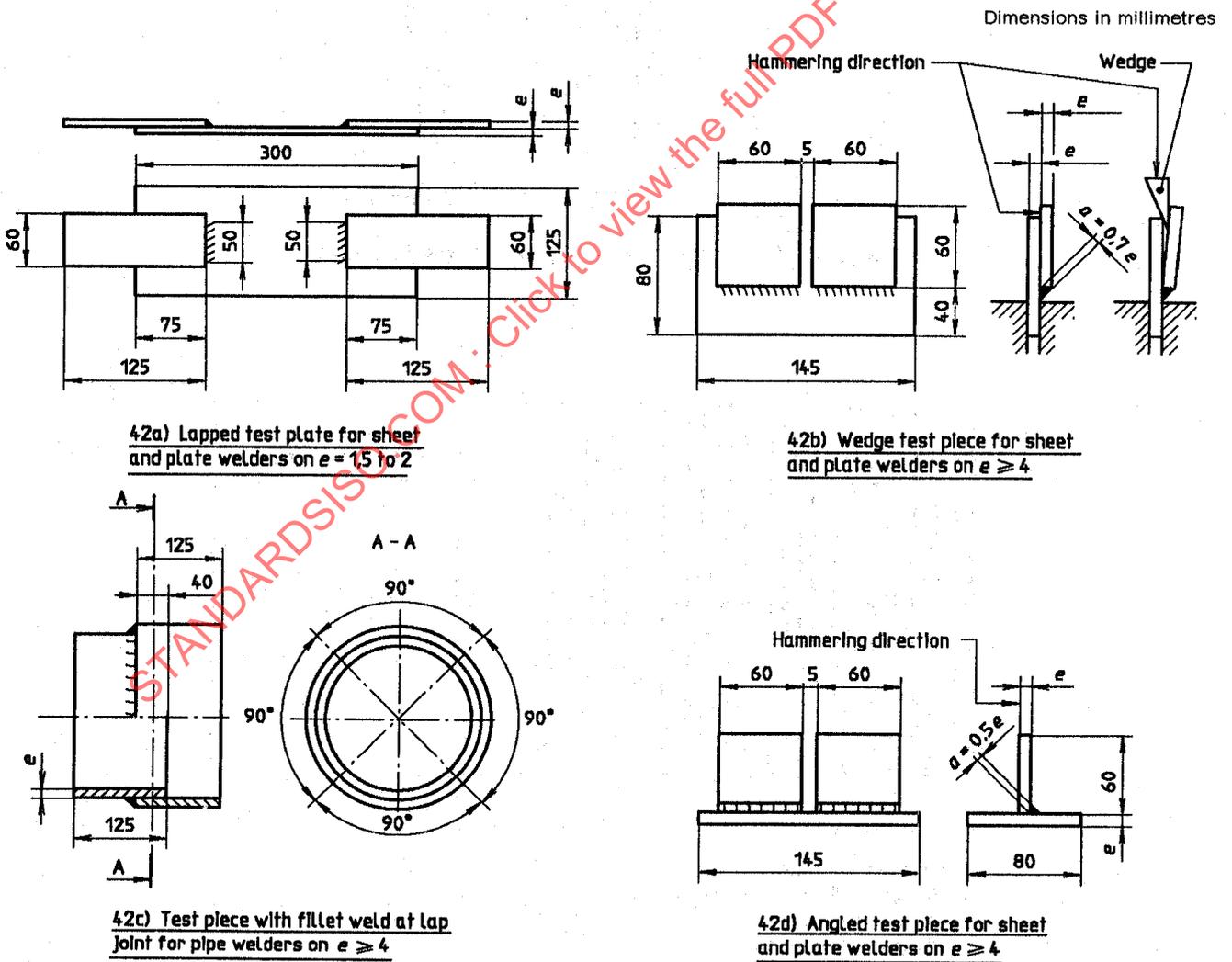
Figure 42 — Test pieces for fillet welds

Dimensions in millimetres
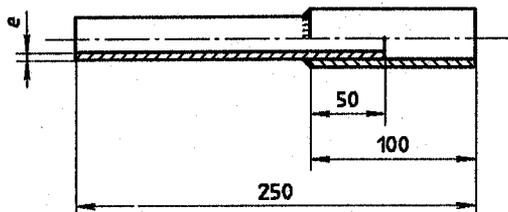
42e) Test piece with fillet weld at lap
joint for pipe welders on *e* = 1,5 to 2
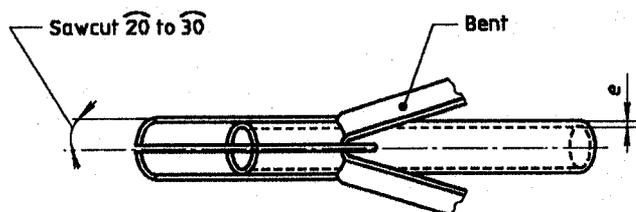
42f) Pipe bend test specimen for
pipe welders on *e* = 1,5 to 2
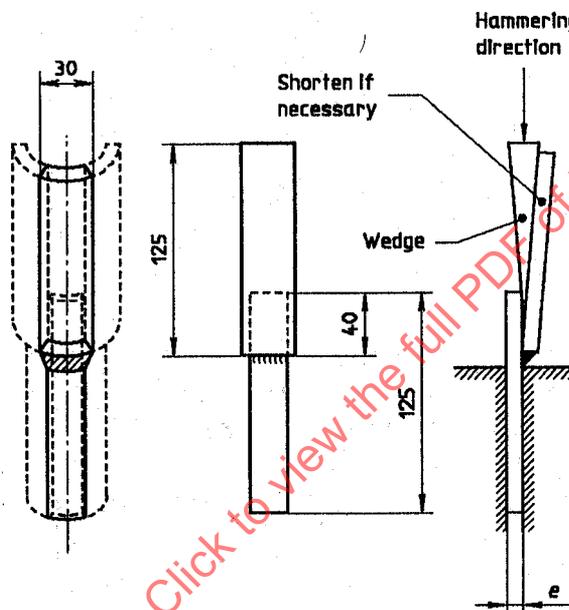
42g) Pipe wedge test specimen for fillet welds
at lap joint for pipe welders on *e* ≥ 4

Figure 42 — Test pieces for fillet welds *(concluded)*
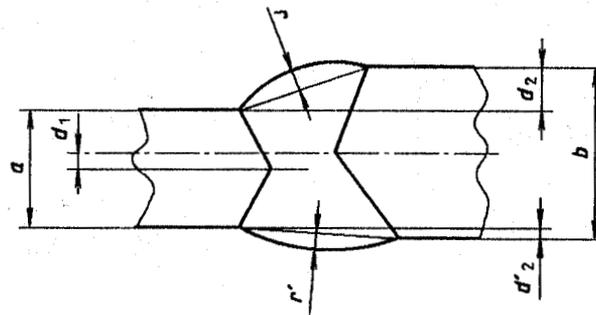
43a)
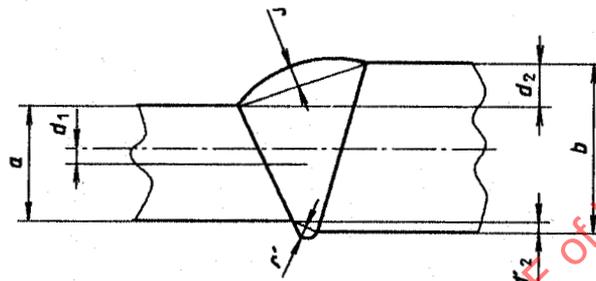
43b)
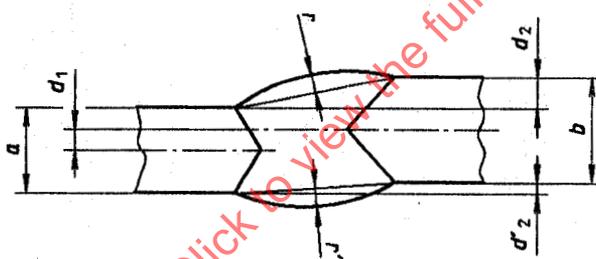
43c)

NOTE — See 5.8.10 and 5.8.11 for maximum permissible misalignments.

Figure 43 — Plate alignment

Dimensions in millimetres

Dimensions in millimetres
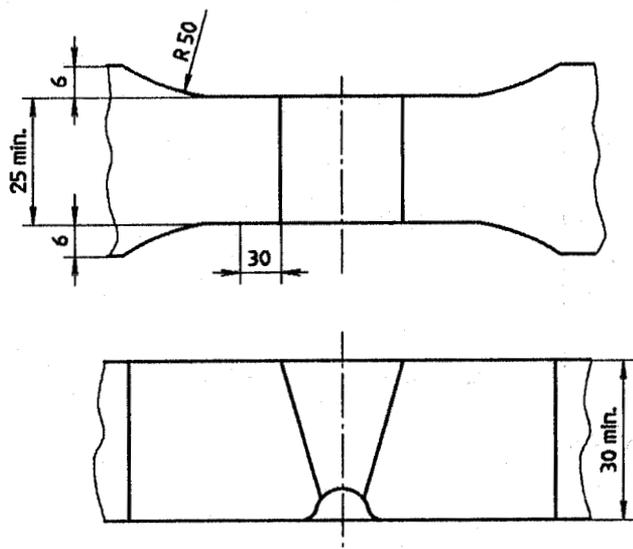
Figure 44 — Reduced section tensile test specimen

Figure 45 — Selection of reduced section tensile test specimens in a thick plate
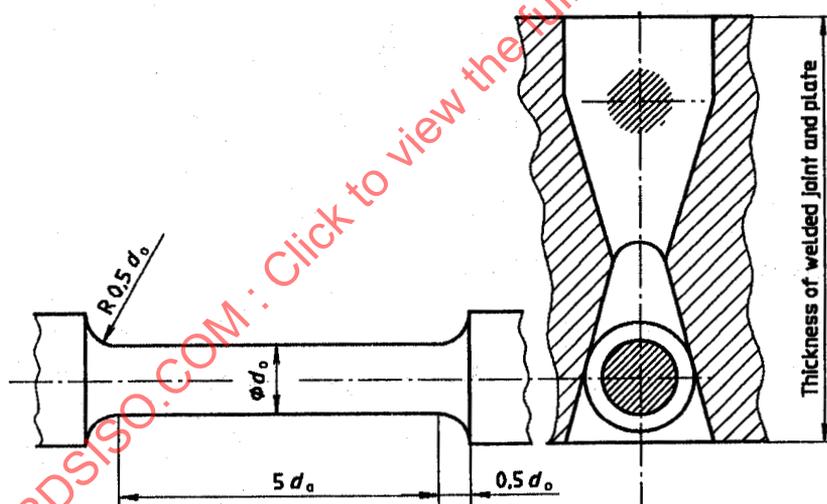
Figure 46 — All-weld-metal tensile test specimen

Dimensions in millimetres
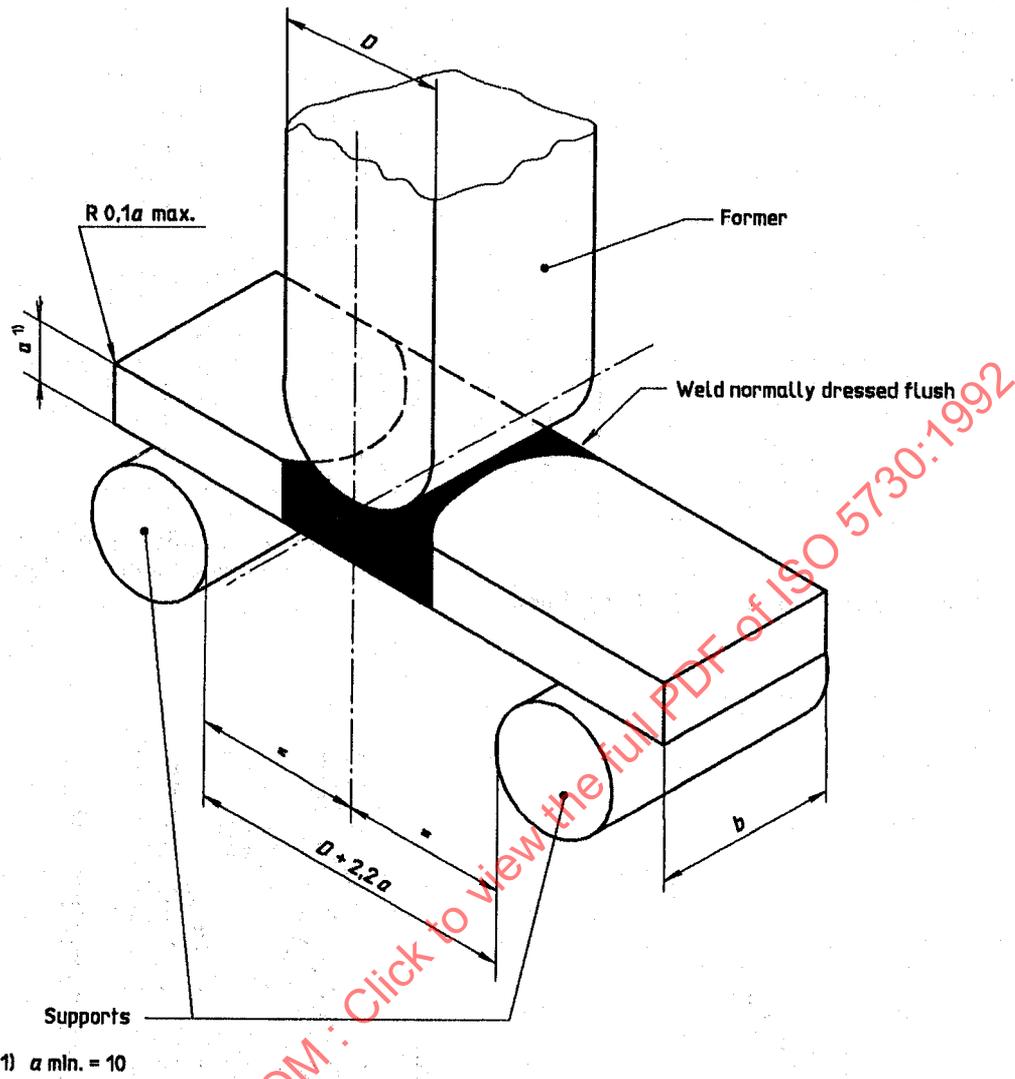
Figure 47 — Side bend test specimen

1) *a* min. = 10
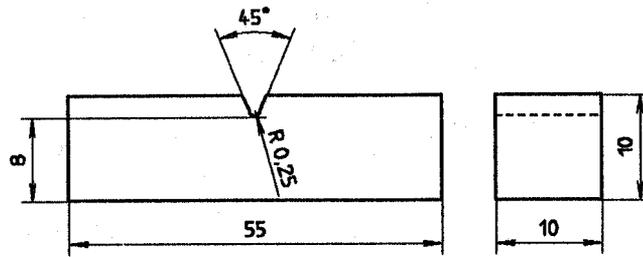
Figure 48 — Impact test specimen — V-notch
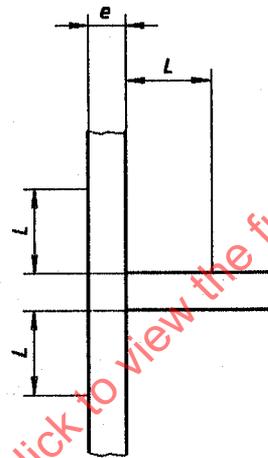
NOTE: $L = 2e$ or 20 max.

Figure 49 — Crossing weld zones where weld imperfections are not permitted

Annex A
(informative)

Information to be supplied by the purchaser to the manufacturer

The following is typical of the minimum information which is required by the manufacturer and which shall be supplied to him by the purchaser at the time of the enquiry.

A.1 For saturated steam boilers

a) Steam capacity, in tonnes per hour, actual

b) Working pressure, in bar[7] (gauge)

c) Feed-water inlet temperature, in degrees Celsius

A.2 For superheated steam boilers

a) Steam capacity, in tonnes per hour, actual

b) Working pressure at the superheater outlet, in bar[7] (gauge)

c) Superheated steam temperature at actual steam capacity, in degrees Celsius

d) Feed-water inlet temperature, in degrees Celsius

A.3 For hot-water boilers

a) Heat capacity, in kilowatts, actual

b) Working pressure, in bar[7] (gauge)

c) Hot-water return temperature, in degrees Celsius

d) Hot-water flow temperature, in degrees Celsius

e) Method of pressurization

f) Switching method of the hot-water circuit

A.4 Fuels

A.4.1 Liquid fuels

a) Type and origin.

b) Specification and analysis.

c) Gross and net calorific values.

A.4.2 Gaseous fuels

a) Type and origin.

b) Specification and analysis.

c) Gross and net calorific values.

d) Available gas pressure at installation.

A.4.3 Solid fuels and waste

a) Type and origin (e.g. country, district, mine, manufacturer, industrial undertaking, community).

b) Specification and analysis (e.g. state of material as supplied, gross and net calorific values, size of granule, ash-fusion point).

A.4.4 Mixed fuels

The proportion of the various fuels and the method of combustion. (This requires agreement between purchaser and manufacturer.)

A.5 General information

A.5.1 The limits of certain characteristic values on which the guarantees shall be based. (This requires agreement between purchaser and manufacturer.)

A.5.2 Electrical power supply specification, e.g. voltage, frequency, number of phases, number of wires and any limitations for the direct starting of motors.

A.5.3 Erection height above sea level and climatic conditions.

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7) 1 bar = 10^5 N/m^2 = 10^5 Pa

Annex B

(informative)

Typical examples of acceptable weld details

B.1 General

The drawings given in this annex are intended to convey recommendations in regard to connections welded manually by the metal-arc process in carbon steel boilers with a shell thickness of not less than 6 mm. The following types of connections are covered.

	Figures
Standard weld preparation details	B.1
Weld preparation details for set-in branches	B.2
Branches without added compensation rings	
a) Set-on branches	B.3
b) Set-in branches	B.4 to B.7
c) Forged branch connections	B.8 and B.9
Branches with added compensation rings	
a) Set-on branches	B.10
b) Set-in branches	B.11
Butt-welded studded connections	B.12
Flanges	B.13 and B.14
End plates or tube plates to shell	B.15
End plates or tube plates to wrapper plates	B.16
Furnaces to tube or end plates	B.17
Plate preparation for butt-welded seams	B.18
Cross seams in end plates	B.19
Access tube to end plate	B.20

B.2 Purpose

The purpose of this annex is to exemplify sound and commonly accepted practice and not to promote the standardization of connections that may be regarded as mandatory or to restrict development in any way. A number of connections have been excluded which, whilst perfectly sound, are restricted in their use to certain applications, firms, or localities. Furthermore, the future desirability is appreciated of introducing amendments and additions to reflect improvements in welding procedures and techniques as they develop.

B.3 Selection of detail

The connections recommended are not, of course, considered to be equally suitable for all service conditions, nor is the order in which they are shown indicative of their relative mechanical characteristics. In selecting the appropriate detail to use from the several alternatives shown for each type of connection, consideration must be given to the manufacture and service conditions that pertain.

B.4 Weld profiles and size

The limitations quoted in weld profiles and sizes are based on commonly accepted sound practice, but they may be subject to modifications dictated by special welding techniques or design conditions.

B.4.1 Weld profiles

The weld profiles (e.g. bevel angles, root radii, and root faces) recommended are indicated by underlined letters and numbers, which refer to the profiles shown in figure B.1. They are designed to provide correct conditions for welding and to facilitate the deposition of sound weld metal in the root of the joint. This is particularly important in the case of single-bevel and single-J welds, and, where these are given as alternatives, it is recommended in general that preference be given to the latter, where the depth or throat thickness of the weld exceeds about 15 mm.

B.4.2 Butt joints

In cases where full penetration butt joints are indicated, it is intended that they should be back chipped or gouged and back welded, or alternatively that the welding procedure shall be such as to ensure sound positive root penetration.

B.4.3 Weld sizes

The sizes of the welds, i.e. throat thicknesses, have been proportioned to develop the full strength of the parts joined.

B.4.4 Modifications

Cases may well arise where sound modifications may be made with advantage

a) to the weld profiles to suit special welding techniques, or

b) to the weld sizes to suit design and service conditions.

It is recommended, however, that such modifications be approved by a competent engineer.

B.5 Notes applicable to the various types of connections as specified in figures B.3 to B.15

B.5.1 The dimensions and shape of the detail chosen can influence the feasibility and/or efficiency of ultrasonic examination. This may also be a function of the equipment and time available. Where ultrasonic examination is specified, these factors should be given due consideration.

B.5.2 When welds are made from one side only, the penetration bead shall have a smooth contour and be flat or slightly convex.

B.5.3 The use of ring-type compensation is not suitable for cases where there are severe temperature gradients.

B.5.4 When ring-type reinforcement is used, the material used for the ring shall be of the same nominal strength as that of the shell.

B.5.5 When partial penetration joints are used, root defects may be present and these cannot always be detected or interpreted by means of non-destructive testing. The use of partial penetration joints is not suitable for cases where there are severe temperature gradients, especially when these are of fluctuating nature.

B.5.6 In addition to the necessity for care in selecting weld details for tube to tube plate connections, special attention must be given to the choice of the welding and inspection techniques used.

B.5.7 When the root spigot is not produced by means of forging, attention is drawn to the necessity of ensuring that the through thickness properties are adequate for the design.

B.5.8 When ultrasonic inspection is required, it may be necessary to examine the welded connection between the branch and shell prior to fitting the compensation ring.

B.6 Notes applicable to branches in figures B.3 to B.12

B.6.1 Weld sizes

The sizes of the welds have been proportioned to develop the full strength of the parts joined. See also B.4.3 and B.4.4, as well as B.7.2.1.

B.6.2 Weld profiles

While both single-bevel and single-J welds have been shown as acceptable in the smaller sizes, in general the latter are to be preferred because of the sounder root conditions obtained, and it is recommended that single-bevel welds be limited in size to about 15 mm in depth. See also B.4.1 and B.4.4.

B.7 Notes applicable to branches without compensation rings in figures B.3 to B.7

B.7.1 Set-on branches

Consideration should be given to the necessity for examining the shell plate for laminations around the branch hole when set-on branches are used.

B.7.2 Set-in branches

B.7.2.1 Weld sizes

The type of branch to shell connections and the sizes of welds employed may be influenced by several factors in the operational conditions for which the boiler is designed. For general guidance in this annex, weld sizes have been shown for the various connections recommended, based on the concept that the welded joints should develop the full strength in tension of the branch radial to the shell as indicated in figures B.2 a) and B.2 b). In general, it should therefore be unnecessary to apply larger welds than those shown.

The simple, though approximate, assumption has been accepted that the total throat thickness of the welds should equal twice the branch thickness. It has also been assumed that the welds should be reasonably symmetrical about the full thickness of the connection.

It is further recommended that, when the branch thickness exceeds half the thickness of the shell, full penetration joints should be used with fillet welds equal in total throat thickness to 20 % of the shell thickness as shown in figures B.2 c) and B.2 d). This additional throat thickness is recommended to compensate for the relative practical difficulty of applying perfectly sound welds in nozzle connections and of applying non-destructive tests for their exam-

ination. These additional fillet welds are also intended to provide a reasonable geometric profile, and for practical reasons a minimum dimension of 6 mm has been applied to the fillet weld size.

There may be service conditions for which smaller welds are adequate. In such cases, when subject to study by a competent engineer, the weld sizes may be reduced.

B.7.2.2 Gap between branch and shell

It is recommended that the gap between the branch and the shell should not exceed 3 mm. Wider gaps increase the tendency to spontaneous cracking during welding, particularly as the thickness of the parts joined increases.

B.7.2.3 Removal of internal sharp edge in branch bore

It will be noted that the internal edges in the bores of set-in branches are shown radiused, because a stress concentration occurs at this point. This precaution is recommended when the branch connection is fully stressed or subjected to fatigue, but may not be necessary where these conditions do not obtain.

B.7.2.4 Preparation of hole in shell

In the case of set-in branches of the types shown in figures B.4 to B.7 inclusive, the hole in the shell may be cut and profiled in two ways as follows.

a) The depth of the grooves B and D may be constant around the hole as shown in figure B.2 e). This, the normal case, is the concept upon which the drawings have been prepared [see, for example, figure B.6 b)].

b) The roots of the weld grooves may be in one plane, as, for example, when they are machine bored, in which case the depths of the grooves will vary around the hole as shown in figure B.2 f).

B.8 Notes applicable to branches with added compensation rings in figures B.10 and B.11

B.8.1 General

Compensation rings should be a close fit to the shell and tell-tale holes should be provided in them.

B.8.2 Set-in branches

It is recommended that the gap between the branch and the shell should not exceed 3 mm. Wider gaps increase the tendency to spontaneous cracking during welding, particularly as the thickness of the parts joined increases.

B.9 Notes applicable to tube and to tube plate connections

B.9.1 Tubes are welded to tube plates by several processes other than manual metal-arc welding to which this International Standard primarily refers (see B.1). These include the oxy-acetylene gas and atomic hydrogen processes where appropriate and the TIG process, both manual and automatic, whose application in recent years has extended widely. The connections recommended do not apply only to metal-arc welding in this sphere of application, and selection of the connection to use must be largely influenced by the welding process to be employed.

B.9.2 It is advisable to examine the tube plate for laminations before machining.

B.9.3 Tubes should be a close fit in their holes and this may be achieved, for example, by light drifting.

B.9.4 Care should be taken to ensure that the tube ends and tube plate holes are clean before welding.

B.9.5 The sharp edge on the inside of the tube plate hole should be removed where there is a risk of damage to the tube by fretting in service.
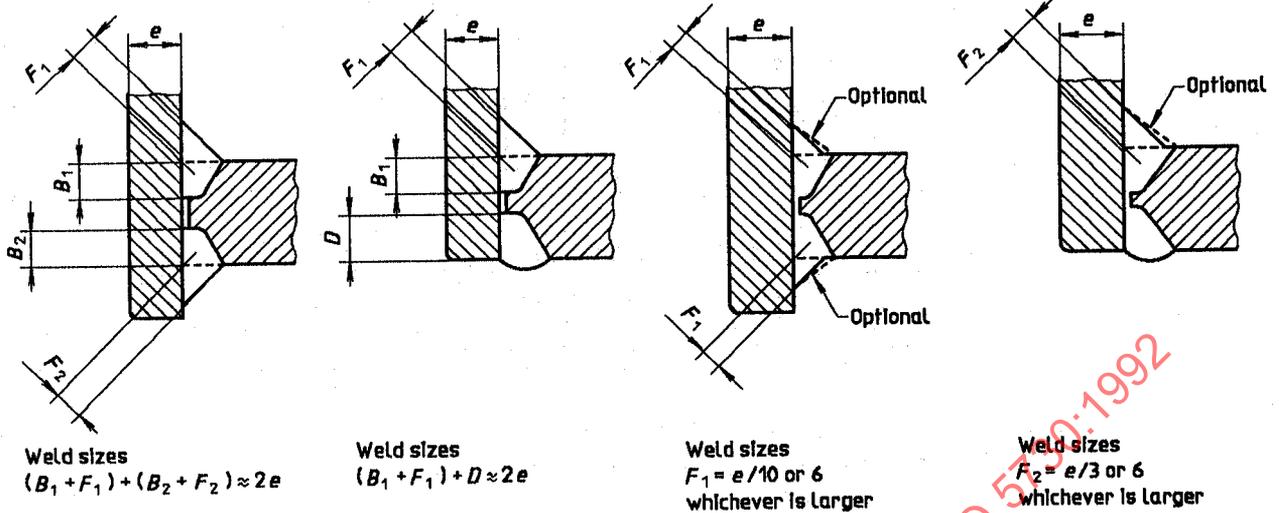
Dimensions in millimetres

$$\alpha = 45° \text{ min.}$$
$$s_1 = 1,5 \text{ to } 2,5 \qquad g_1 = \begin{vmatrix} 1,5 \text{ to } 2,5 \text{ when } e_{rb} < 9,5 \\ 2,5 \text{ to } 4 \text{ when } e_{rb} \geqslant 9,5 \end{vmatrix}$$
$$s_2 = 0 \text{ to } 3 \qquad g_2 \text{ (see note 2)}$$

$$\alpha = 15° \text{ to } 35° \qquad g_1 = 1,5 \text{ to } 3 \qquad b = 0 \text{ to } 3$$
$$s_1 = 2 \text{ to } 3 \qquad g_2 \text{ (see note 2)} \qquad r = 6 \text{ to } 13$$
$$s_2 = 2 \text{ to } 3$$
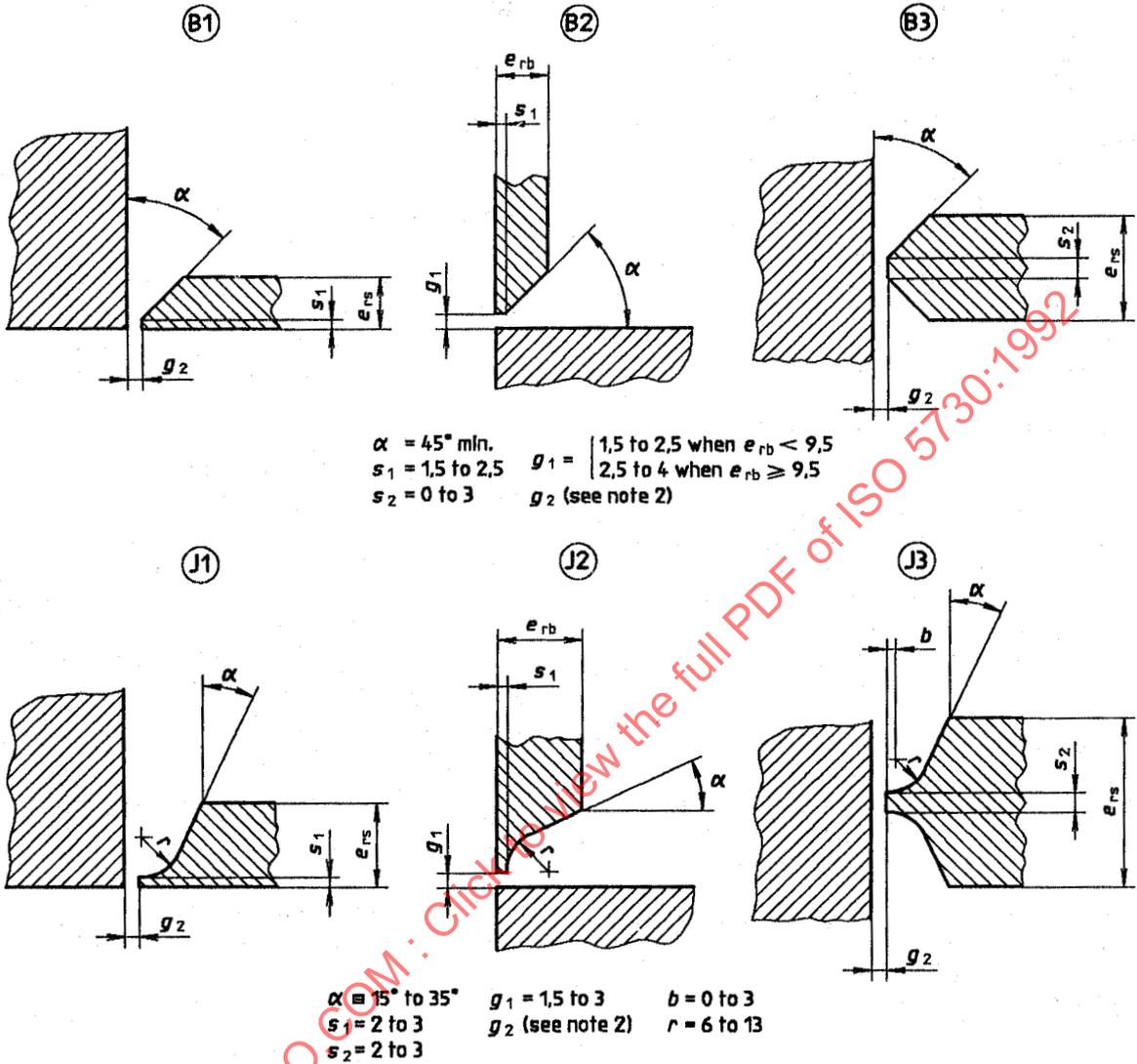
NOTES

1   These recommendations have been included for general guidance. Discretion must be used in applying the maximum and minimum dimensions quoted which are subject to variation according to the welding procedure employed (for example, size and type of electrodes) and also to the position in which the welding is carried out.

2   It is recommended that in no case should the gap between the branch and shell exceed 3. Wider gaps increase the tendency to spontaneous cracking during welding, particularly as the thickness of the parts joined increases.

Figure B.1 — Standard weld preparation details

Dimensions in millimetres

Weld sizes
$(B_1 + F_1) + (B_2 + F_2) \approx 2e$

B.2a)

Weld sizes
$(B_1 + F_1) + D \approx 2e$

B.2b)

Weld sizes
$F_1 = e/10$ or 6
whichever is larger

B.2c)

Weld sizes
$F_2 = e/3$ or 6
whichever is larger

B.2d)
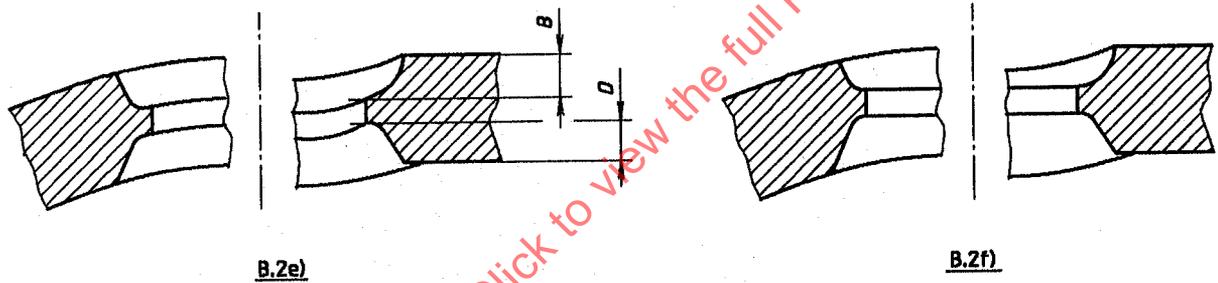
B.2e)

B.2f)

Figure B.2 — Weld preparation details for set-in branches

Dimensions in millimetres
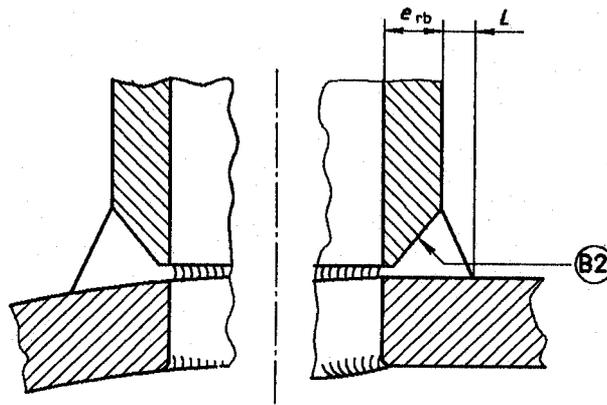
$$L = \frac{e_{rb}}{3} \text{ min., but not less than 6}$$

NOTE – Preference should be given to the detail shown in B.3b) If e_{rb} exceeds about 16.

B.3a)
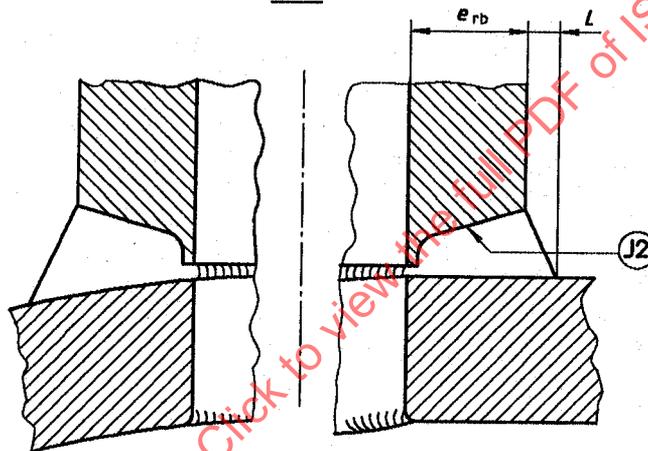
$$L = \frac{e_{rb}}{3} \text{ min., but not less than 6}$$

B.3b)

NOTE — For details (B2) and (J2), see figure B.1.

Figure B.3 — Set-on branches
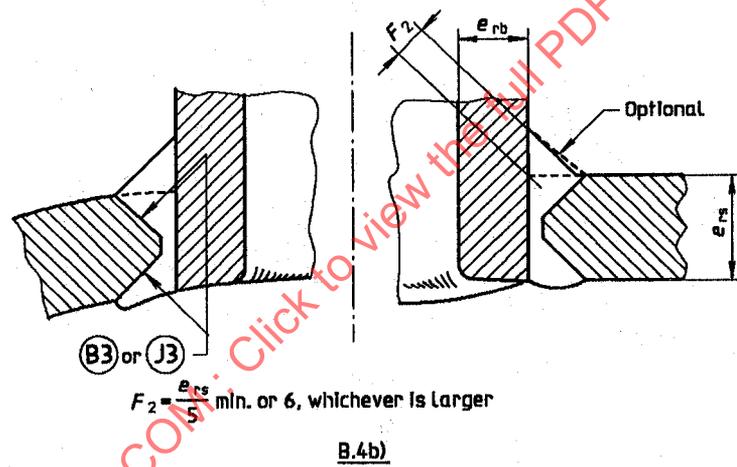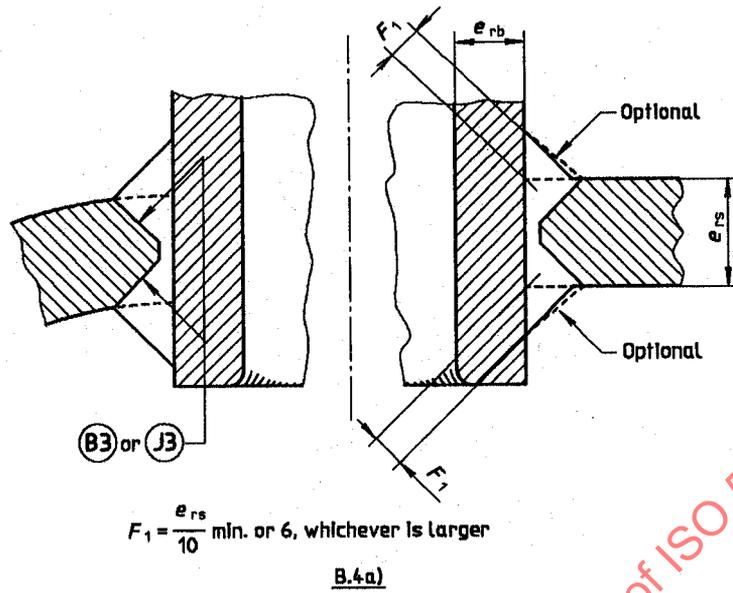
$$F_1 = \frac{e_{rs}}{10} \text{ min. or 6, whichever is larger}$$

<u>B.4a)</u>

$$F_2 = \frac{e_{rs}}{5} \text{ min. or 6, whichever is larger}$$

<u>B.4b)</u>

NOTES

1   Full penetration connections. Generally used when e_{rb} is greater than $e_{rs}/2$.

2   For details ⑬ and ⑬, see figure B.1.

Figure B.4 — Set-in branches

$$F_1 = \frac{e_{rs}}{10} \text{ min. or 6, whichever is larger}$$

B.5a)

$$F_2 = \frac{e_{rs}}{5} \text{ min. or 6, whichever is larger}$$
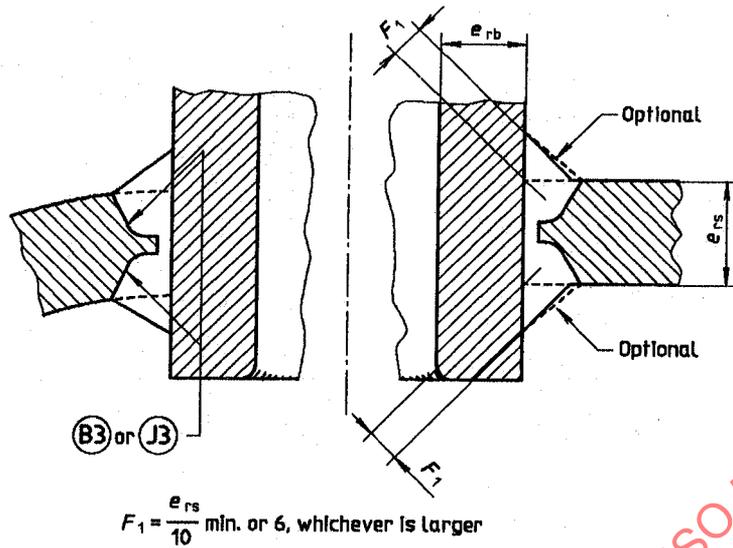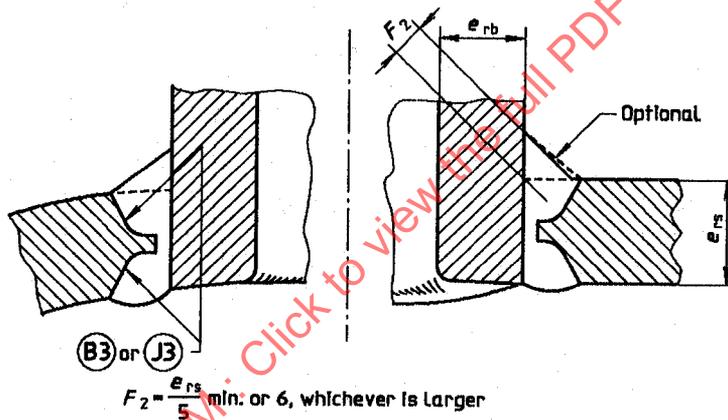
B.5b)

NOTES

1 Full penetration connections. Generally used when e_{rb} is greater than $e_{rs}/2$.

2 For details B3 and J3, see figure B.1.

Figure B.5 — Set-in branches

Dimensions in millimetres

B.6a)

$s = 1,5$ to $2,5$

$F_1 = \dfrac{e_{rs}}{10}$ min. or 6, whichever is larger

B.6b)

$s = 1,5$ to $2,5$

$F_2 = \dfrac{e_{rs}}{5}$ min. or 6, whichever is larger
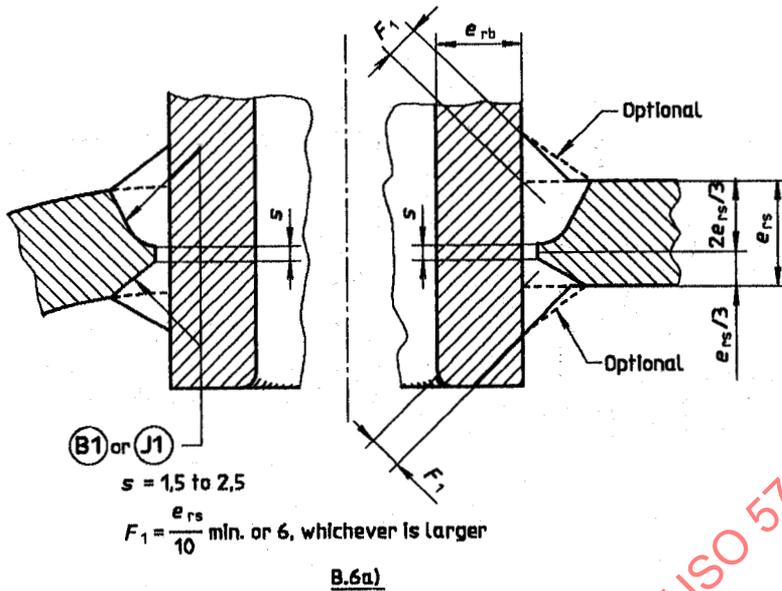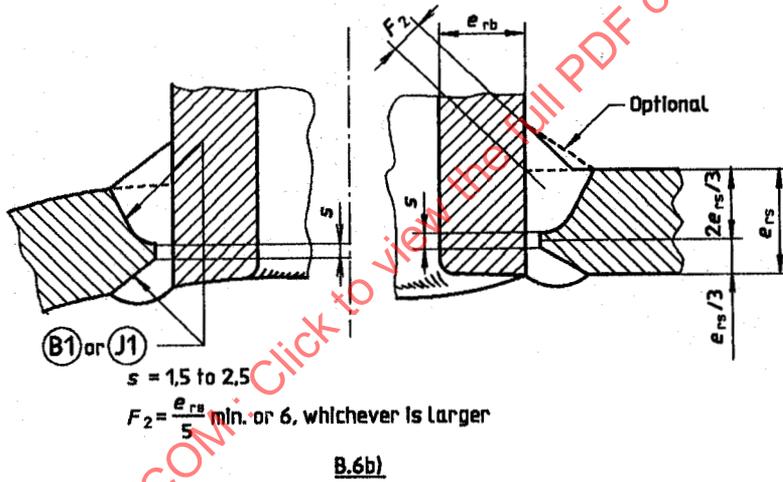
NOTES

1   Full penetration connections with asymmetrical butt joints.

2   For details B1 and J1, see figure B.1.

Figure B.6 — Set-in branches

131

Dimensions in millimetres

$L = \frac{e_{rb}}{3}$ min., but not less than 6

$e_{rs} = 16$ max.

B.7a)

$L = \frac{e_{rb}}{3}$ min., but not less than 6

$e_{rs} = 25$ max.

B.7b)
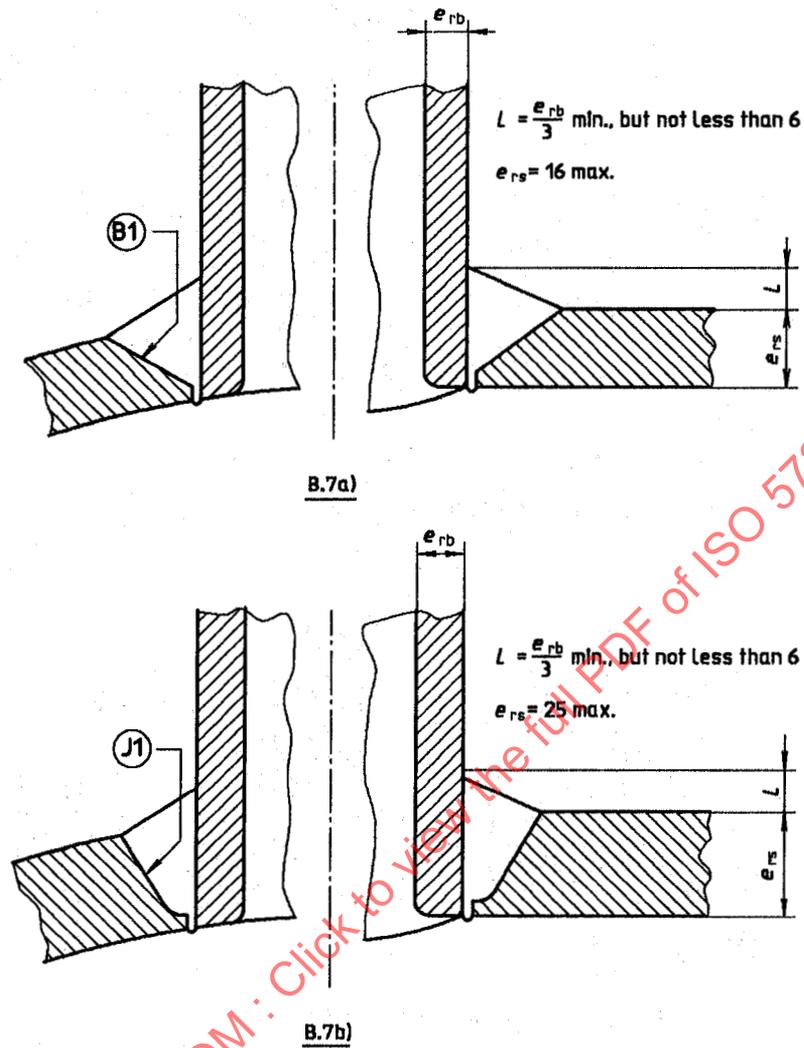
NOTES

1   Full penetration connections welded from one side only.

2   For details (B1) and (J1), see figure B.1.

3   As a general recommendation, all set-in branches should be welded on the inside of the shell as shown in figures B.4 to B.6 if they are accessible for the purpose; otherwise preference should be given to set-on branch connections as shown in figure B.3. However, the connections shown above in figures B.7 a) and B.7 b) are considered to be acceptable, but only if assurance can be provided that the welding procedure employed will ensure sound and consistent root conditions with uniform penetration.

Figure B.7 — Set-in branches

Conventional butt joint

See B.5.1 and B.5.2
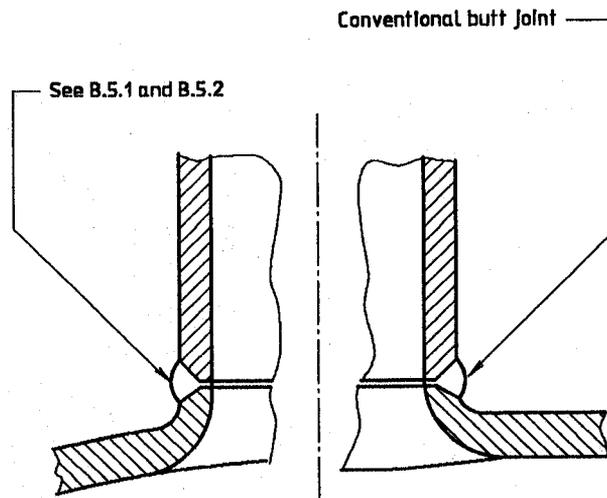
NOTE — Forging should be to good practice and within the correct range of temperature for the material used.

Figure B.8 — Forged branch connections

Conventional butt joints

See B.5.1 and B.5.2

B.9a)

See B.5.1 and B.5.2

The parallel portion should be sufficiently long to permit satisfactory radiographic examination when required

e_{rs}

B.9b)
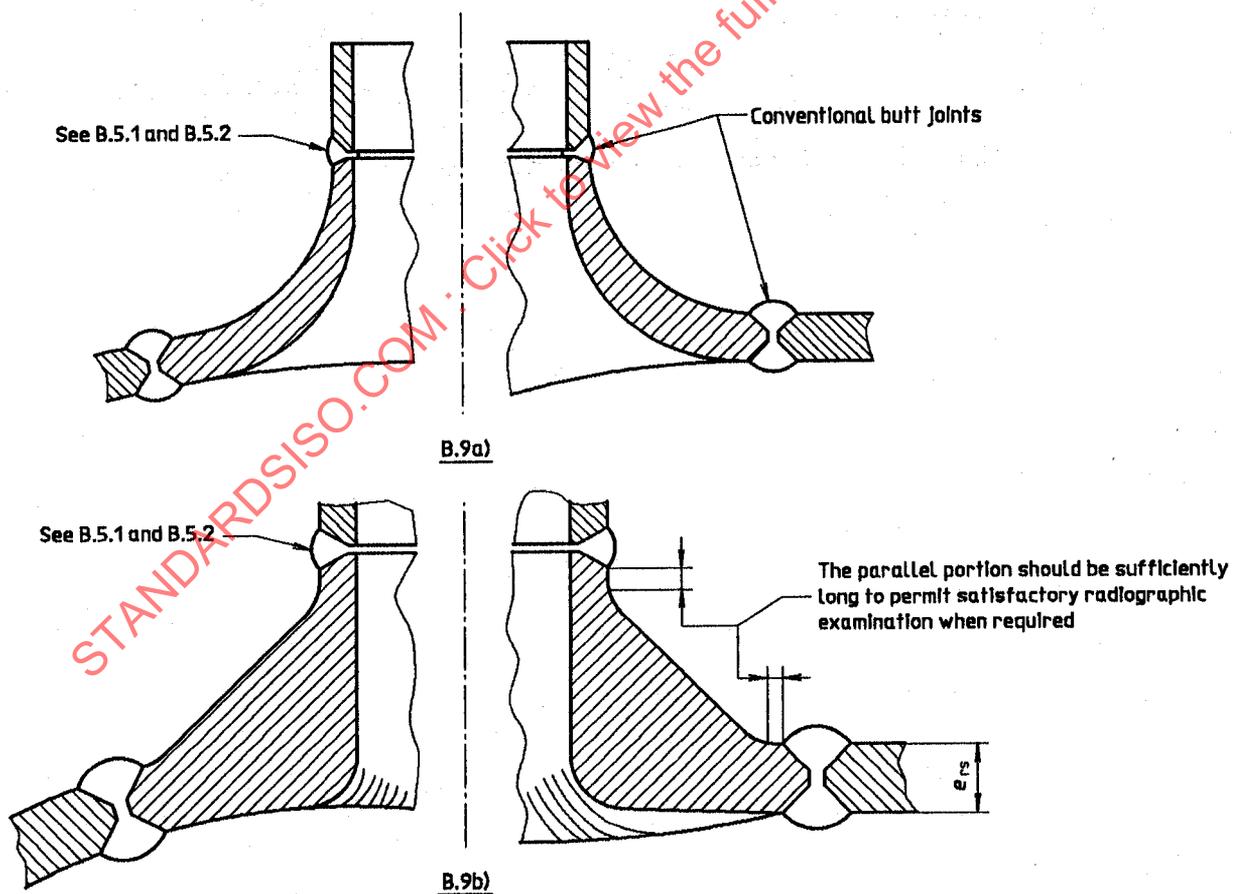
NOTE — Conventional butt joints are used to connect the forging to the shell and may not necessarily be of the form shown. See also B.4.1 and B.4.2. These forgings, connecting branches to shells, are used with various forms of profile.

Figure B.9 — Forged branch connections

Dimensions in millimetres

E = 10 min.

$L = \dfrac{e_{rb}}{3}$ min., but not less than 6

Tell-tale hole

15° min.

e_{rb}

For shell-to-branch connection, see figure B.3

Consideration may be given to this detail as the required weld size is increased

B2 or J2
(See B.4.1)
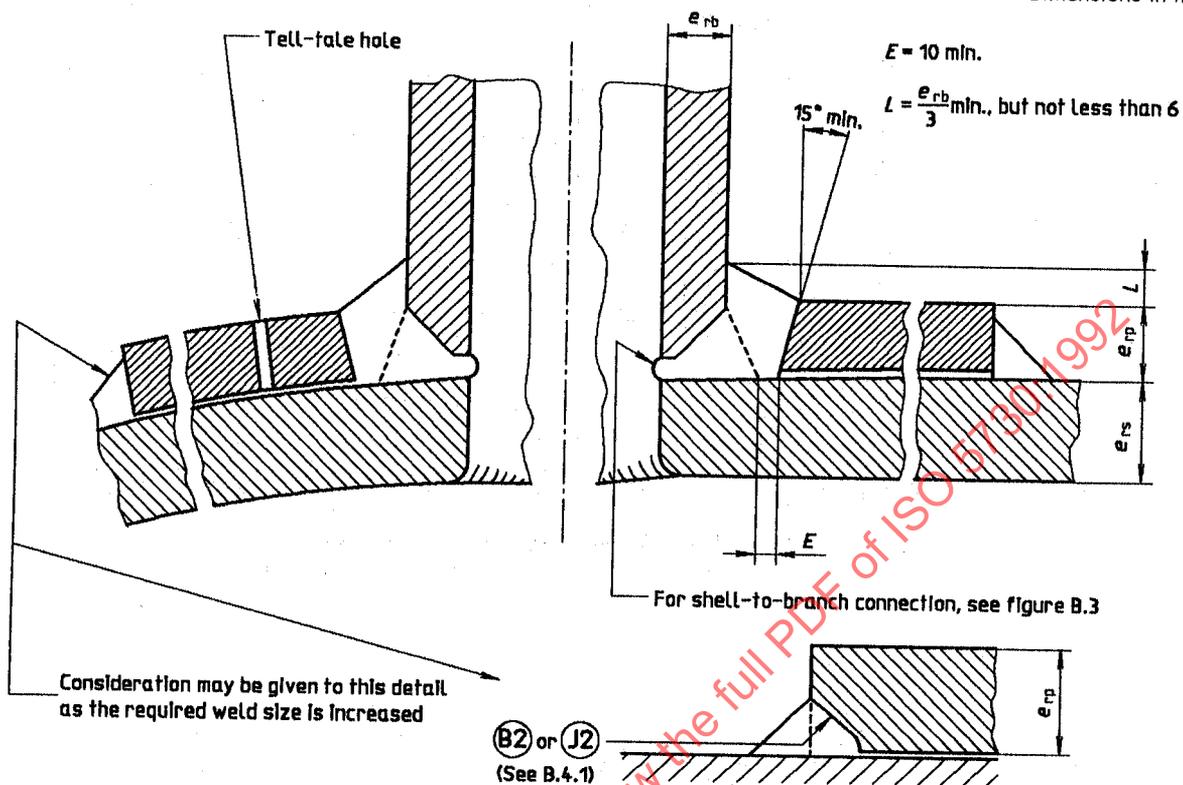
Figure B.10 — Set-on branches with added compensation rings

Dimensions in millimetres

Tell-tale hole

e_{rb} E

$E = 10$ min.

$L = \dfrac{e_{rb}}{3}$ min., but not less than 6

15° min.

For shell-to-branch joints, see figures B.4 to B.6

Consideration may be given to this detail as the required weld size increases

e_{rp}

(B2) or (J2)
(See B.4.1)
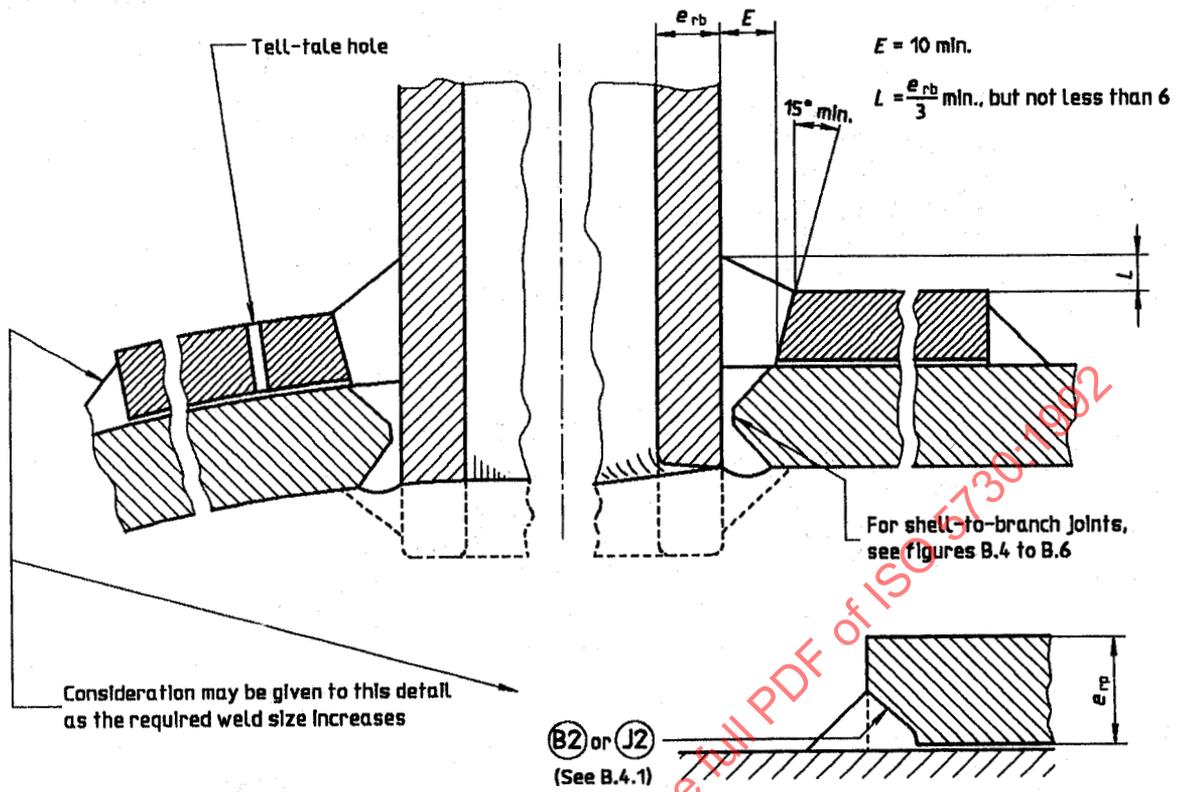
Figure B.11 — Set-in branches with added compensation rings

Dimensions in millimetres

B.12a)

B.12b)

Conventional
butt joint

See B.4.2
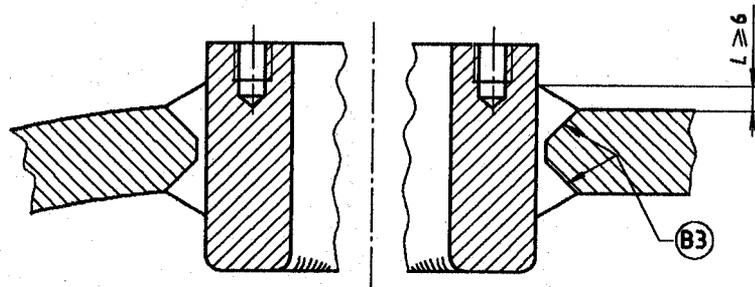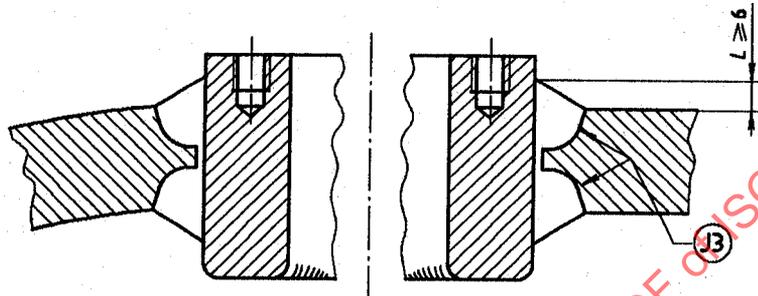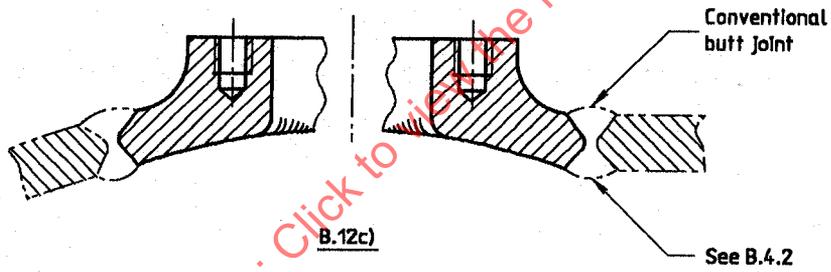
B.12c)

NOTE — For details B3 and J3, see figure B.1.

Figure B.12 — Butt-welded studded connections

Dimensions in millimetres

Generally machined after welding

Weld sizes
$C = e_{rb}$
$B = e_{rb}$
$A = e_{rb}$ min., after machining
flange to final thickness

(J2)

See B.5.5

e_{rb}

A   B   C

To project when assembled for welding
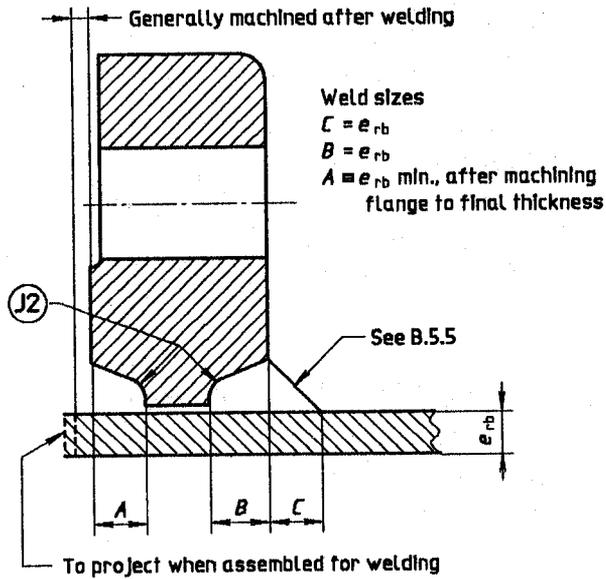
B.13a) Face and back welded flange

Generally machined after welding

Weld sizes
$C = e_{rb}$
$B = e_{rb}$
$A = e_{rb}/2$ but 5 min., after machining
flange to final thickness

(J2)

See B.5.5

e_{rb}

A   B   C
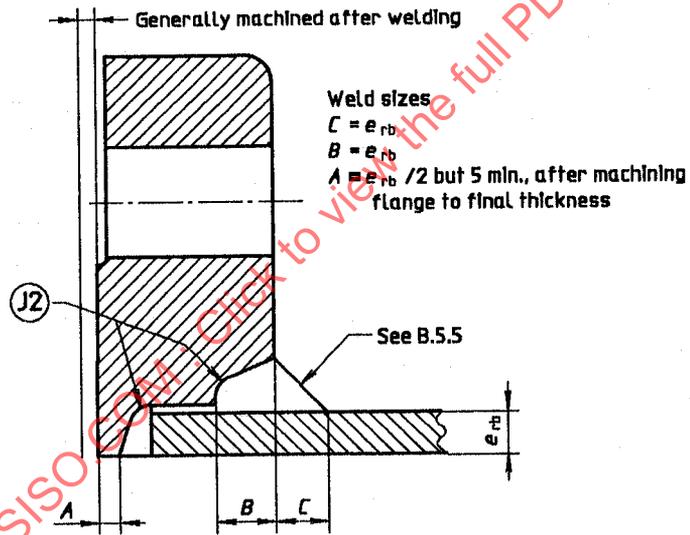
B.13b) Bore and neck welded flange

NOTE — The clearance between the bore of the flange and the outside diameter of the vessel should not exceed 3 at any point and the sum of the clearances diametrically opposite should not exceed 5.

Figure B.13 — Flanges
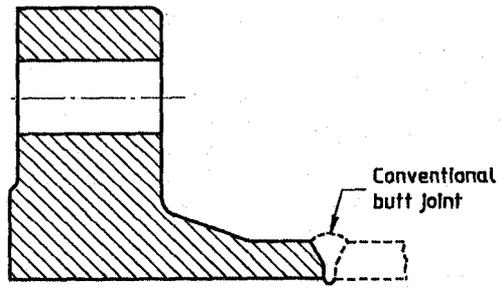
NOTE — See B.5.2.

Figure B.14 — Weld neck flange

Dimensions in millimetres
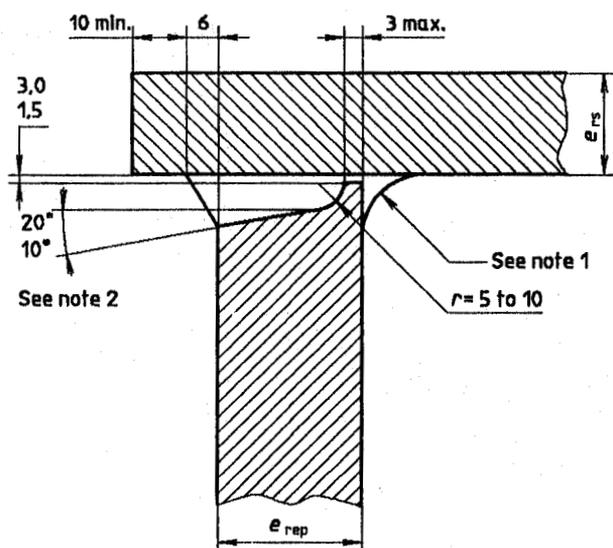
B.15a) Construction for set-in end plates
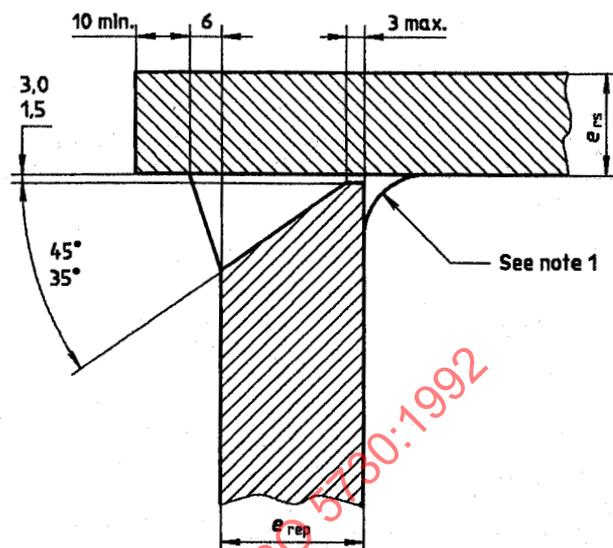
B.15b) Alternative construction for set-in end plates

NOTES

1 The shape of the internal fillet weld should be concave. The ratio of the leg lengths, shell to end plate, should be approximately 4:3 and the minimum throat thickness should be related to the shell thickness as follows:

Shell thickness, e_{rs}	Minimum throat thickness
$e_{rs} < 12$	4
$12 \leqslant e_{rs} \leqslant 16$	5
$e_{rs} > 16$	6

2 The use of the minimum angle should be associated with the maximum radius r of 10. Conversely, the maximum angle should be associated with the minimum radius r of 5.

Figure B.15 — Attachment of unflanged flat end plates or tube plates to shell

Dimensions in millimetres
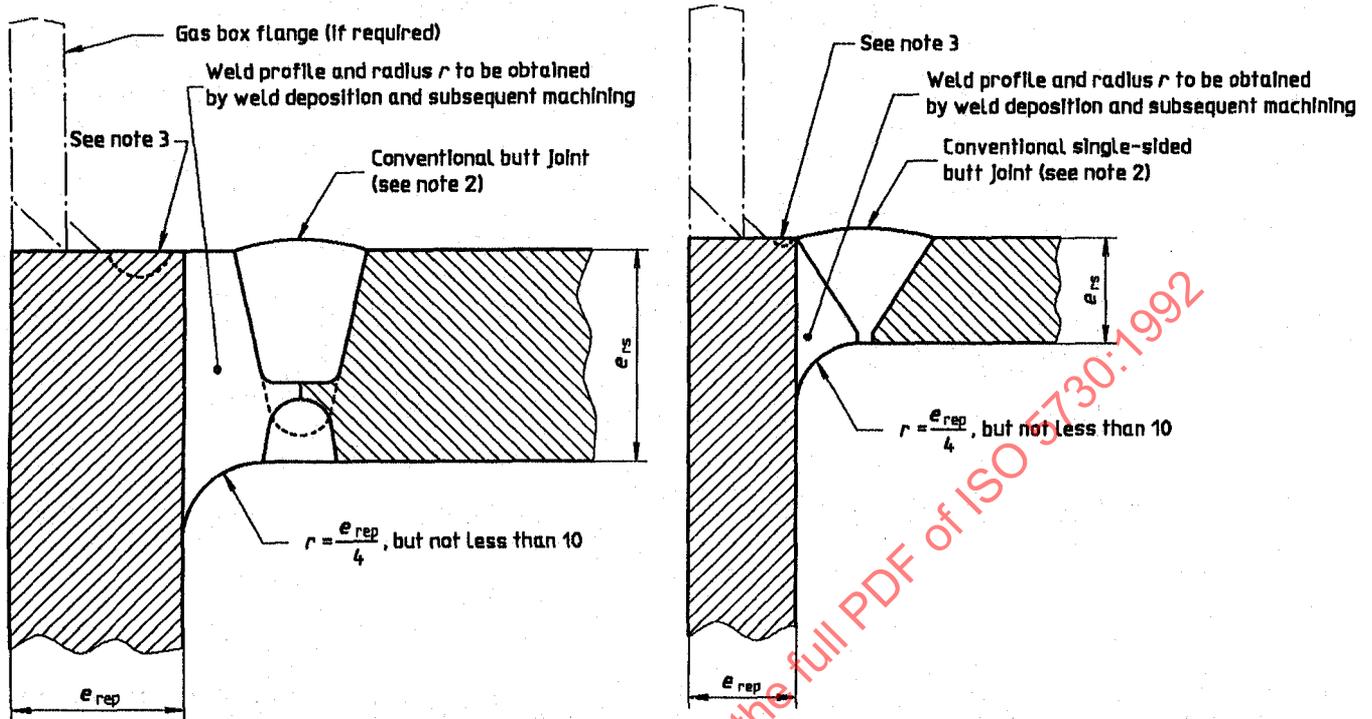
B.15c) Construction for set-on end plates (see notes 1, 2, 3 and 4)

B.15d) Construction for set-on end plates where internal access is limited (see notes 1, 2, 3 and 5)
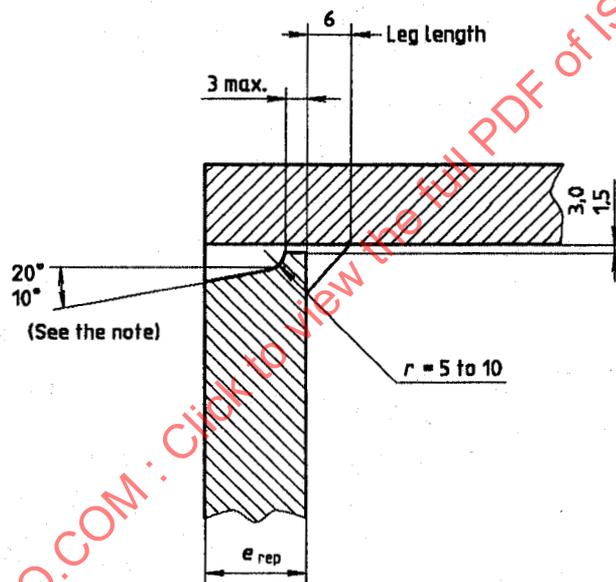
NOTES

1   Figures B.15c) and B.15d) are for attachment of end plates to shell in waste-heat boilers when there is danger of lamellar tearing of the shell plate.

2   Conventional butt joints are used and may not necessarily be of the form shown.

3   When a gas box flange is attached by welding as shown, a machined groove to reduce stress concentration is preferred.

4   Taking into account the stress conditions, the junctions of the internal welded seams with the surface of the plates shall be such as to avoid any notch effects.

5   The welding procedure shall ensure sound and consistent root conditions and uniform penetration.

Figure B.15 — Attachment of unflanged flat end plates or tube plates to shell *(concluded)*
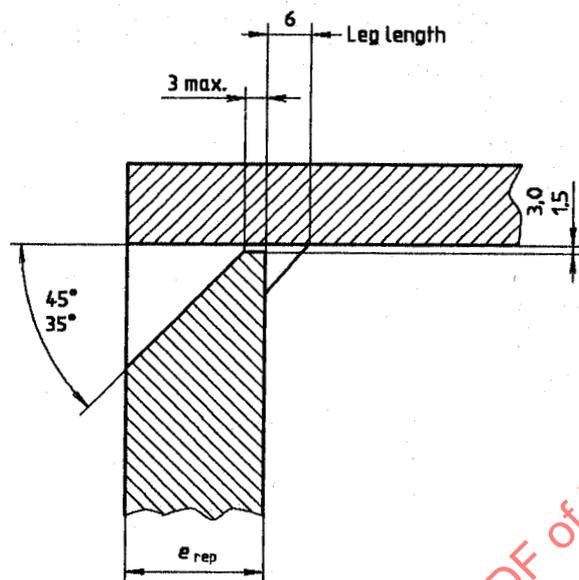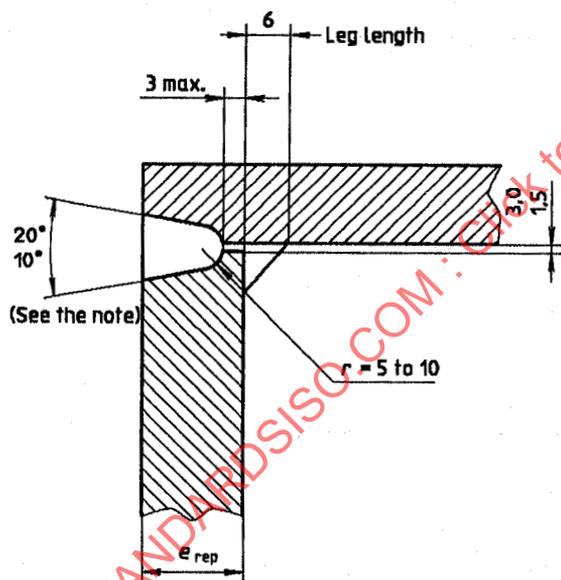
Dimensions in millimetres

B.16a)

NOTE – The use of the minimum angle should be associated with the maximum radius r of 10. Conversely, the maximum angle should be associated with the minimum radius r of 5.
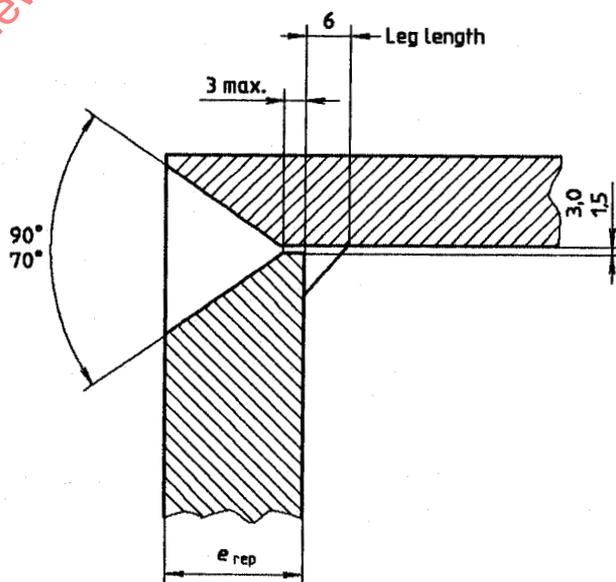
B.16b)

Figure B.16 — Attachment of end plates or tube plates to reversal chamber wrapper plates

141

Dimensions in millimetres

Figure B.16 — Attachment of end plates or tube plates to reversal chamber wrapper plates *(concluded)*

NOTE – The use of the minimum angle should be associated with the maximum radius *r* of 10. Conversely, the maximum angle should be associated with the minimum radius *r* of 5.

Dimensions in millimetres

B.17a)


B.17b)

B.17c)
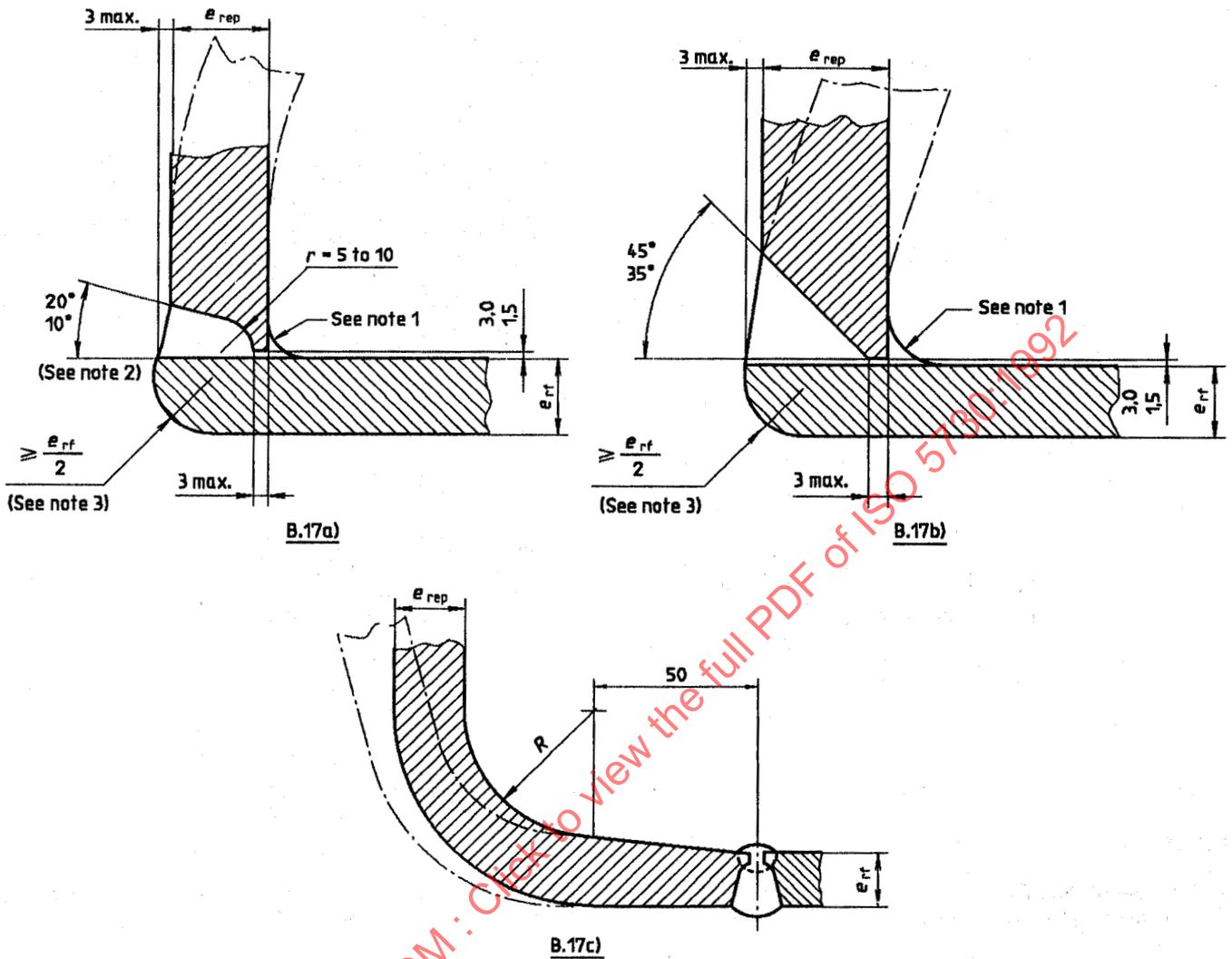
NOTES

1   The shape of the internal fillet weld should be concave. The ratio of the leg lengths, furnace to tube plate or end plate, should be approximately 4:3 and the minimum throat thickness should be related to the furnace thickness as follows:

Furnace plate thickness, e_{rf}	Minimum throat thickness
$e_{rf} < 12$	4
$12 \leqslant e_{rf} \leqslant 16$	5
$e_{rf} > 16$	6

2   The use of the minimum angle should be associated with the maximum radius r of 10. Conversely, the maximum angle should be associated with the minimum radius r of 5.

3   The plate edge radius of not less than $e_{rf}/2$ is only required when the furnace end is exposed to flame or comparably high temperature.

Figure B.17 — Attachment of furnaces to tube plates or end plates (dished or flat)

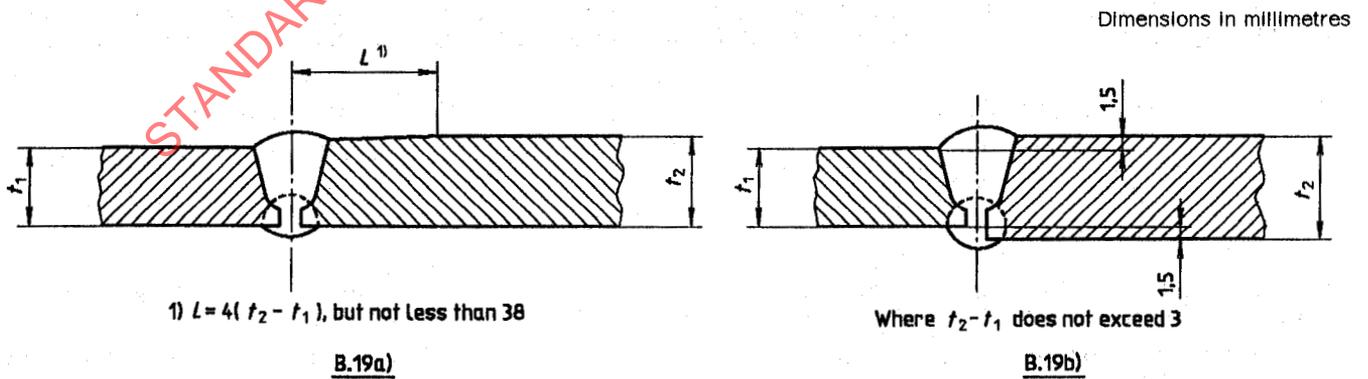Dimensions in millimetres

B.18a)

B.18b)

B.18c)

B.18d)
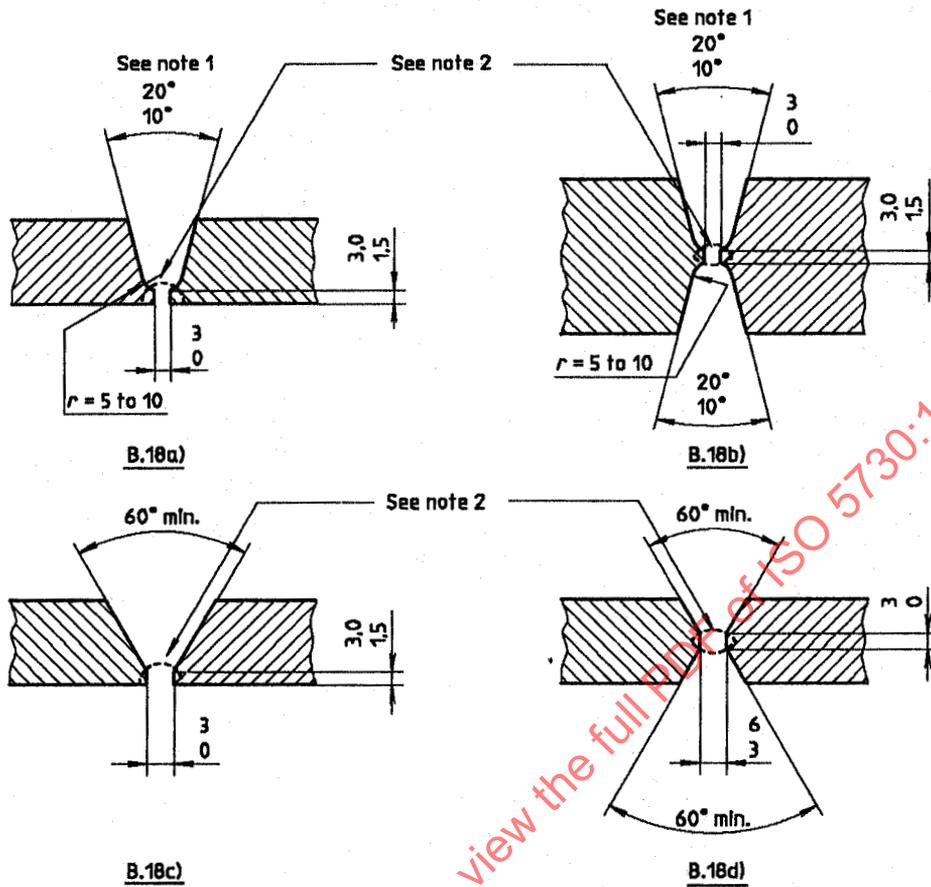
NOTES

1   The use of the minimum gap and the minimum angle should be associated with the maximum radius r of 10. Conversely, the maximum gap and the maximum angle should be associated with the minimum radius r of 5.

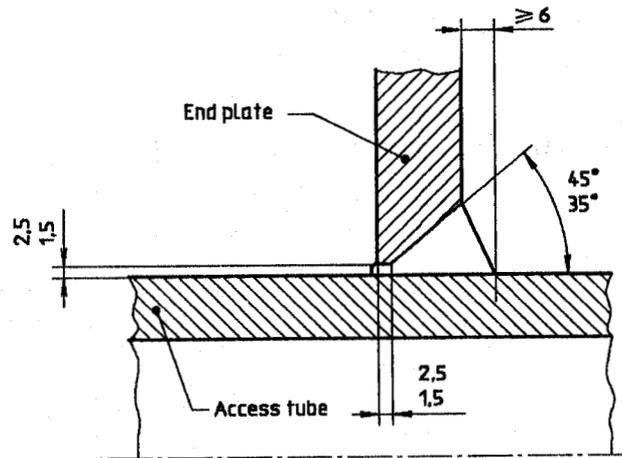2   Gouge out before applying weld from the second side.

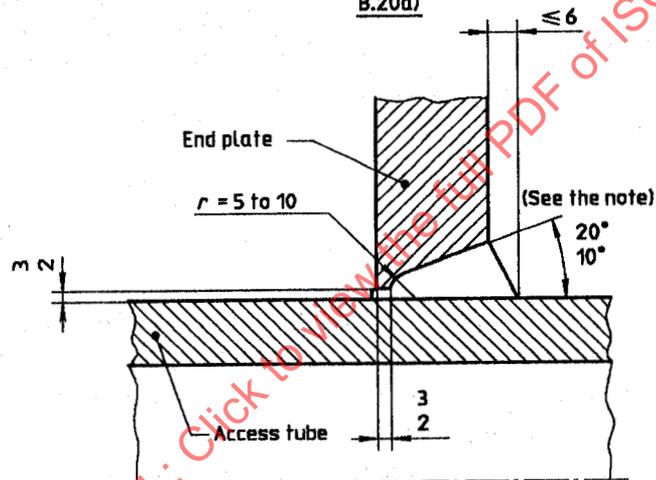**Figure B.18 — Plate preparation for butt-welded longitudinal and circumferential seams**

Dimensions in millimetres

1) $L = 4(t_2 - t_1)$, but not less than 38

B.19a)

Where $t_2 - t_1$ does not exceed 3

B.19b)

NOTE — V-preparation may be used as an alternative.

Figure B.19 — Cross seams in end plates

Dimensions in millimetres

NOTE – The use of the minimum angle should be associated with the maximum radius *r* of 10. Conversely, the maximum angle should be associated with the minimum radius *r* of 5.

B.20b)

Figure B.20 — Attachment of access tube to end plate

Annex C

(informative)

Calculation of tube plate temperatures

C.1 General

This annex provides a method for the calculation of the hot-face metal temperature and the average (design) temperature of tube plates within the tube nest.

The calculation takes into account the effects under steady conditions of heat transfer

a) from the hot gas to the tube plate face and tube inside surfaces by convection, including the tube entrance effect, and radiation, including radiation interchange in the reversal chamber,

b) by thermal conduction through the tube plate and tube walls from the tube plate face and tube inside surfaces to the water side surfaces, assuming adequate thermal contact between tube and plate, and

c) by nucleate boiling from the water side surfaces.

The method and design curves have been developed from published heat transfer data and contain some simplifying approximations which tend to be self-compensating. Calculated and measured temperatures have shown good agreement where complete data are available.

C.2 Symbols

a	Heat input area to the tube plate element from the tube plate face (see figure C.8).	mm²
A	Heat input area to the tube plate element from the tube inside surfaces (see figure C.7).	mm²
A_C	Total effective water-cooled surface area in the reversal chamber.	mm²
A_R	Total refractory surface area in the reversal chamber.	mm²
C	Correction factor for tube to tube plate contact thermal resistance.	
d	Inside diameter of the convection tube.	mm
D	Reversal chamber inside diameter (for cylindrical chambers).	mm
e	Tube plate thickness.	mm
F	Overall exchange factor for radiation interchange in the reversal chamber (see figure C.2).	
G	Tube specific gas flow rate.	kg/(m²·s)
h_{CE}	Tube entrance convection coefficient (see figure C.6).	W/(m²·K)
h_{CO}	Corrected basis convection coefficient (see figure C.5).	W/(m²·K)
h'_{CO}	Hypothetical basis convection coefficient (see figure C.4).	W/(m²·K)
h_m	Tube plate thermal conductance.	W/(m²·K)
h_R	Radiation coefficient for the tube plate face.	W/(m²·K)
h'_R	Radiation coefficient for black exchange (see figure C.1).	W/(m²·K)
h_t	Weighted average heat transfer coefficient.	W/(m²·K)
L	Reversal chamber inside length (for cylindrical chambers).	mm
L_B	Reversal chamber radiation beam length.	mm
N	Water side constant, $= 4\,000$.	W/(m²·K)
p	Average pitch between the tube centres.	mm
t	Tube plate average (design) temperature.	°C
t_C	Initial estimate of t_M.	°C

t_G	True gas temperature at the tube entrance.	°C
t_M	Tube plate hot-face metal temperature.	°C
t_S	Boiler water temperature.	°C
β	Tube plate average temperature factor (see figure C.12).	
η	Heat transfer factor for the tube plate element (see figure C.10).	
λ	Tube plate thermal conductivity:	W·mm/(m²·K)
	for steel grades 460 and 490, = 40 000;	
	for steel grades 400 and 430, = 45 000.	
φ	Tube plate hot-face temperature factor (see figure C.11).	

C.3 Calculation method

C.3.1 Radiation coefficients

Determine the radiation coefficient h'_R for black exchange, i.e. emissivity = 1, F = 1, from figure C.1. The gas temperature t_G at tube entry shall be the true value as would be measured by a multishield high-velocity suction pyrometer. (An ordinary thermocouple will always read low; the error may be up to 300 °C.) Assume an initial value t_C for the tube plate hot-face metal temperature. Typical values shown on figure C.1 will usually avoid the neccessity for reiteration.

The emissivity of the gas is dependent on the gas analysis, temperature, partial pressures and the beam length in the reversal chamber. The curves in figure C.2 are based on the excess air normally used in directly fired boilers. For products of coal combustion, it is recommended that the natural gas curve be used to allow for particle radiation. For other gas mixtures, the gas emissivity should be determined from a text on radiant heat transfer, e.g. [1].

The radiation beam length for a cylindrical reversal chamber is given by the following formula:

$$L_B = \frac{0,83 L}{L/D + 0,5}$$

For chambers which are not cylindrical, the radiation beam length is given by the following formula:

$$L_B = 3,3 \frac{V_C}{A_{CS}}$$

where

V_C is the chamber volume;

A_{CS} is the chamber surface area.

In calculating the chamber surface area no reduction shall be made for tube holes or the furnace opening.

For chambers containing refractory linings A_R/A_C is the ratio of the total effective (reflecting) refractory surface area to the effective cooled (absorbing) surface area in the chamber.

A_C includes the total area enclosed within the tube plate perimeter, i.e. no reduction for tube holes or the furnace opening.

A_R/A_C for cylindrical chambers may be obtained from figure C.3.

For fully water-cooled chambers A_R/A_C = 0.

Determine the overall exchange factor F from figure C.2, then the radiation coefficient for the tube plate face is given by the following formula:

$$h_R = F h'_R$$

Radiation to the tube inside surfaces is taken into account by use of the coefficient $0,5 h_R$ in the equation for the weighted average heat transfer coefficient h_t (see C.3.3).

C.3.2 Convection coefficients

The hypothetical basis convection coefficient h'_{CO} is dependent on the specific gas flow rate G in the convection tubes and on the tube inside diameter d. For the products of combustion of oil fuels, natural gas and coal, determine h'_{CO} from figure C.4. Determine the correction factor h_{CO}/h'_{CO} for the tube entry gas temperature from figure C.5. Then the corrected basis convection coefficient for fully developed tube flow at temperature t_G is given by the following formula:

$$h_{CO} = h'_{CO} \left(\frac{h_{CO}}{h'_{CO}} \right)$$

For other gases where the values of specific heat, thermal conductivity or viscosity are different from those for the products of combustion of oil or natural gas, the value of h_{CO} may be deduced from the equation for fully developed flow inside tubes as follows:

$$Nu = 0,023 Re^{0,8} Pr^{0,33}$$

147

where

Nu is the Nusselt number, based on the tube inside diameter d;

Re is the Reynolds number, based on the tube inside diameter d;

Pr is the Prandtl number;

(see, for example, [1]).

Determine the correction factor h_{CE}/h_{CO} for the tube entrance region from figure C.6. Then the average convection coefficient, h_{CE}, for the tube inside surface over the effective length for heat input to the tube plate, is given by the following formula:

$$h_{CE} = h_{CO}\left(\frac{h_{CE}}{h_{CO}}\right)$$

Convective heat transfer to the tube plate face is taken into account by the use of the coefficient h_{CO} in the equation for the weighted average heat transfer coefficient h_t (see C.3.3).

C.3.3   Weighted average gas-side heat transfer coefficient

For the tube plate element, bounded by tube inside surfaces and planes containing tube centre-lines, the heat input areas A (tube inside surfaces) and a (tube plate face) are determined from figures C.7 and C.8.

The weighted average heat transfer coefficient is then calculated as follows:

$$h_t = \frac{\dfrac{CA}{d^2}(h_{CE} + 0,5h_R) + \dfrac{a}{d^2}(h_{CO} + h_R)}{\left(\dfrac{A}{d^2} + \dfrac{a}{d^2}\right)}$$

where

$C = 0,9$ for tubes expanded only;

$C = 0,95$ for tubes expanded and welded;

$C = 1$ for tubes full penetration welded.

C.3.4   Tube plate thermal conductance

The tube plate thermal conductance is given by the following formula:

$$h_m = \frac{\lambda}{e}$$

C.3.5   Water side heat transfer

Heat transfer conditions at the water side surfaces are taken into account in the equations for the tube plate metal temperatures by use of the constant N.

C.3.6   Tube plate temperatures

The following equations for the tube plate hot-face and average metal temperatures are based on equations developed by Gardner [2]:

$$t_M = t_S + 15 + (t_G - t_S)\left[1 - \frac{\varphi}{1 + (\eta h_t/N)}\right]$$

$$t = t_S + 15 + (t_G - t_S)\left[1 - \frac{\beta}{1 + (\eta h_t/N)}\right]$$

The factors η, φ and β are dependent on A/a (from figure C.9) and on h_t/h_m and are obtained from figures C.10 to C.12.

C.4   Example of a calculation carried out using the method given in C.3

C.4.1   Design data assumed

Fuel: natural gas

Boiler: multitubular waste heat with refractory-lined hot-gas chamber

Specified inlet gas temperature: 900 °C

Boiler design pressure: 1,1 N/mm2

Saturation temperature: $t_S = 188$ °C

Boiler tubes:

inside diameter $d = 56,3$ mm

pitch, triangular $p = 88$ mm

gas flow rate $G = 11$ kg/(m2·s)

Tubeplate:

thickness $e = 22$ mm

material 430 grade

Tube end attachment: expanded and welded

Inlet gas chamber:

cylindrical, refractory lined on wrapper and back plates

inside diameter $D = 1\,800$ mm

inside length $L = 1\,000$ mm

C.4.2 Calculation of radiation coefficient

The calculation of the radiation coefficient h_R is carried out as described in C.3.1.

From figure C.1, using an assumed value of $t_C = 350$ °C indicated by the typical dry back curve, $h'_R = 185$ W/(m²·K).

Radiation beam length

$$L_B = \frac{0,83 \times 1\,000}{(1\,000/1\,800) + 0,5} = 786 \text{ mm}$$

From figure C.3, $A_R/A_C = 3,15$ where $L/D = 0,555$.

From figure C.2, $F = 0,58$.

Therefore,

$$h_R = 0,58 \times 185 = 107,3 \text{ W/(m²·K)}$$

C.4.3 Calculation of convection coefficients

The calculation of convection coefficients h_{CO} and h_{CE} is carried out as described in C.3.2.

From figure C.4, $h'_{CO} = 61$ W/(m²·K).

From figure C.5, $h_{CO}/h'_{CO} = 0,952$.

Therefore,

$$h_{CO} = 61 \times 0,952 = 58,1 \text{ W/(m²·K)}$$

From figure C.6, $h_{CE}/h_{CO} = 2,9$, where $e/d = 22/56,3 = 0,391$.

Therefore,

$$h_{CE} = 58,1 \times 2,9 = 168,5 \text{ W/(m²·K)}$$

C.4.4 Calculation of weighted average gas-side heat transfer coefficient

The calculation of the weighted average gas-side heat transfer coeficient h_t is carried out as described in C.3.3.

From figure C.7, $A/d^2 = 0,6$, where $e/d = 0,391$, triangular pitch.

From figure C.8, $a/d^2 = 0,67$, where $p/d = 88/56,3 = 1,563$.

For tubes expanded and welded $C = 0,95$.

Therefore,

$$h_t = \frac{0,95[0,6(168,5 + 0,5 \times 107,3)] + 0,67(58,1 + 107,3)}{0,6 + 0,67}$$

$$= 187 \text{ W/(m²·K)}$$

C.4.5 Calculation of tube plate thermal conductance

The calculation of the tube plate thermal conductance h_m is carried out as described in C.3.4.

For 430 grade steel $\lambda = 45\,000$ W·mm/(m²·K) (see C.2). Therefore,

$$h_m = \frac{45\,000}{22} = 2\,045 \text{ W/(m²·K)}$$

C.4.6 Calculation of tube plate temperatures

The calculation of tube plate temperatures t and t_M is carried out as described in C.3.6.

$$\frac{h_t}{h_m} = \frac{187}{2\,045} = 0,091\,44$$

From figure C.9, $A/a = 0,9$.

From figures C.10, C.11 and C.12,

$$\eta = 1,72$$
$$\varphi = 0,885$$
$$\beta = 0,935$$

Therefore, the tube plate hot-face metal temperature is given by

$$t_M = 188 + 15 + (900 - 188) \times$$
$$\times \left[1 - \frac{0,885}{1 + (1,72 \times 187)/4\,000} \right] = 332 \text{ °C}$$

This is below the limit given in 3.4 and is therefore satisfactory.

The tube plate average (design) metal temperature is given by

$$t = 188 + 15 + (900 - 188) \times$$
$$\times \left[1 - \frac{0,935}{1 + (1,72 \times 187)/4\,000} \right] = 299 \text{ °C}$$

C.5 Bibliography

[1] McAdams, W.H. *Heat Transmission*, McGraw-Hill, 1954.

[2] Gardner, K.A. Heat Exchanger Tube Sheet Temperatures. *Refiner and Natural Gasoline Manufacturer,* March 1942, Vol. 21, No. 3, pp. 71-77.

C.6 Further reading

[3] Lucas, D.M. and Lockett, A.A. Mathematical Modelling of Heat Flux and Temperature Distribution in Shell Boilers. *Proc. 4th Symp. on Flames and Industry,* 1972, BFRC - Inst. Fuel.

[4] Kern, D.Q. *Process Heat Transfer,* McGraw-Hill, 1950.

[5] Gore, W.H., Gunn, D.C. and Horsler, A.G. *Natural Gas Firing of Shell Boilers,* Inst. Fuel, March 1972.

[6] *VDI-Wärmeatlas*.

[7] Jakob, M. *Heat Transfer*, John Wiley, 1949.

[8] Eckert, E.R.G. and Drake, R.M. *Heat and Mass Transfer*, McGraw-Hill, 1959.

[9] Fraas, A.P. and Ozisik, M.N. *Heat Exchanger Design*, John Wiley, 1965.

[10] Perry, K.P. Heat Transfer by Convection from a Hot Gas Jet to a Plane Surface. *Proc. I. Mech. E.,* 1954, Vol. 168, pp. 775-784.
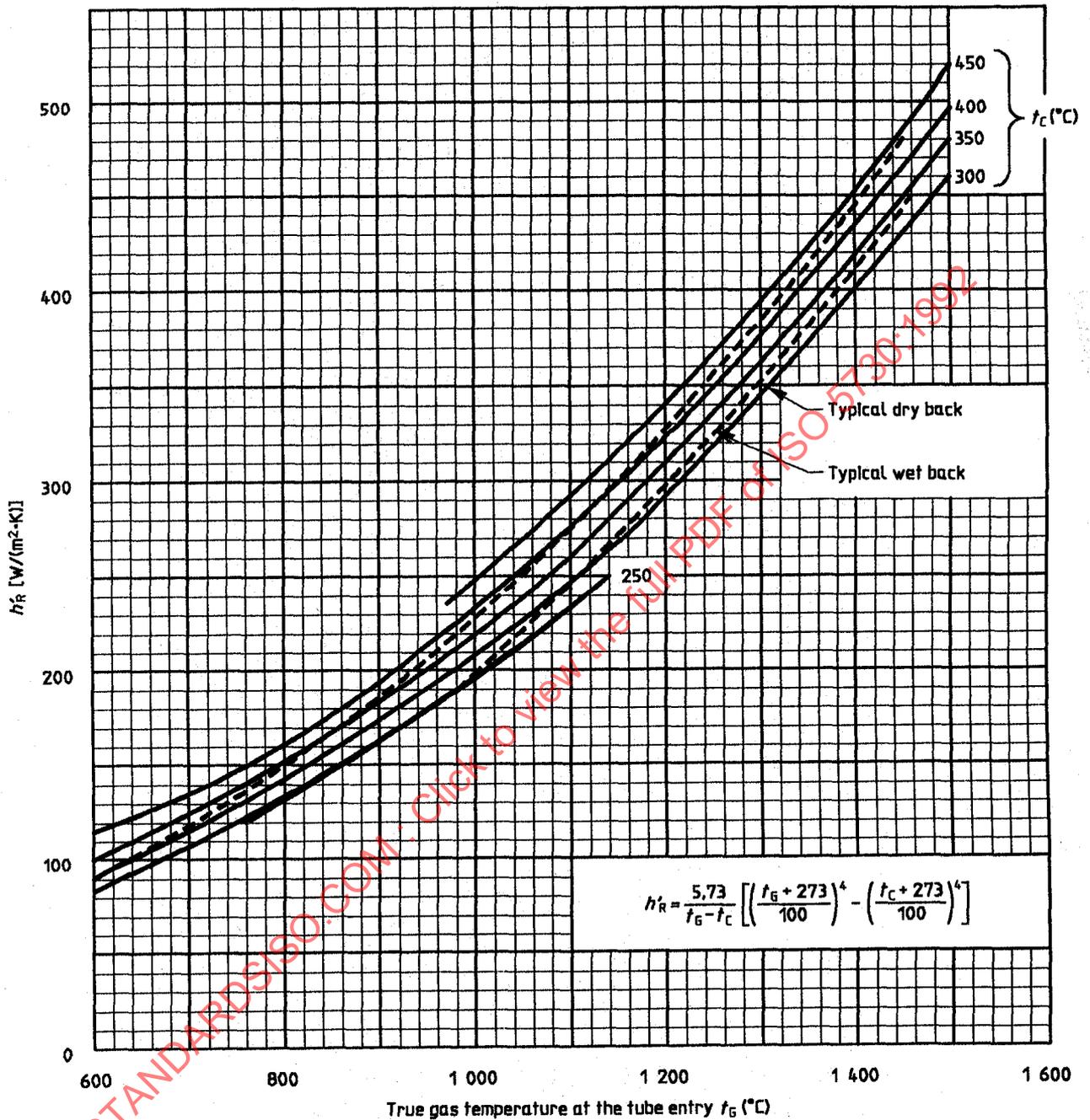
Figure C.1 — Radiation coefficient h'_R for black exchange ($F = 1$)

$$h'_R = \frac{5{,}73}{t_G - t_C}\left[\left(\frac{t_G + 273}{100}\right)^4 - \left(\frac{t_C + 273}{100}\right)^4\right]$$
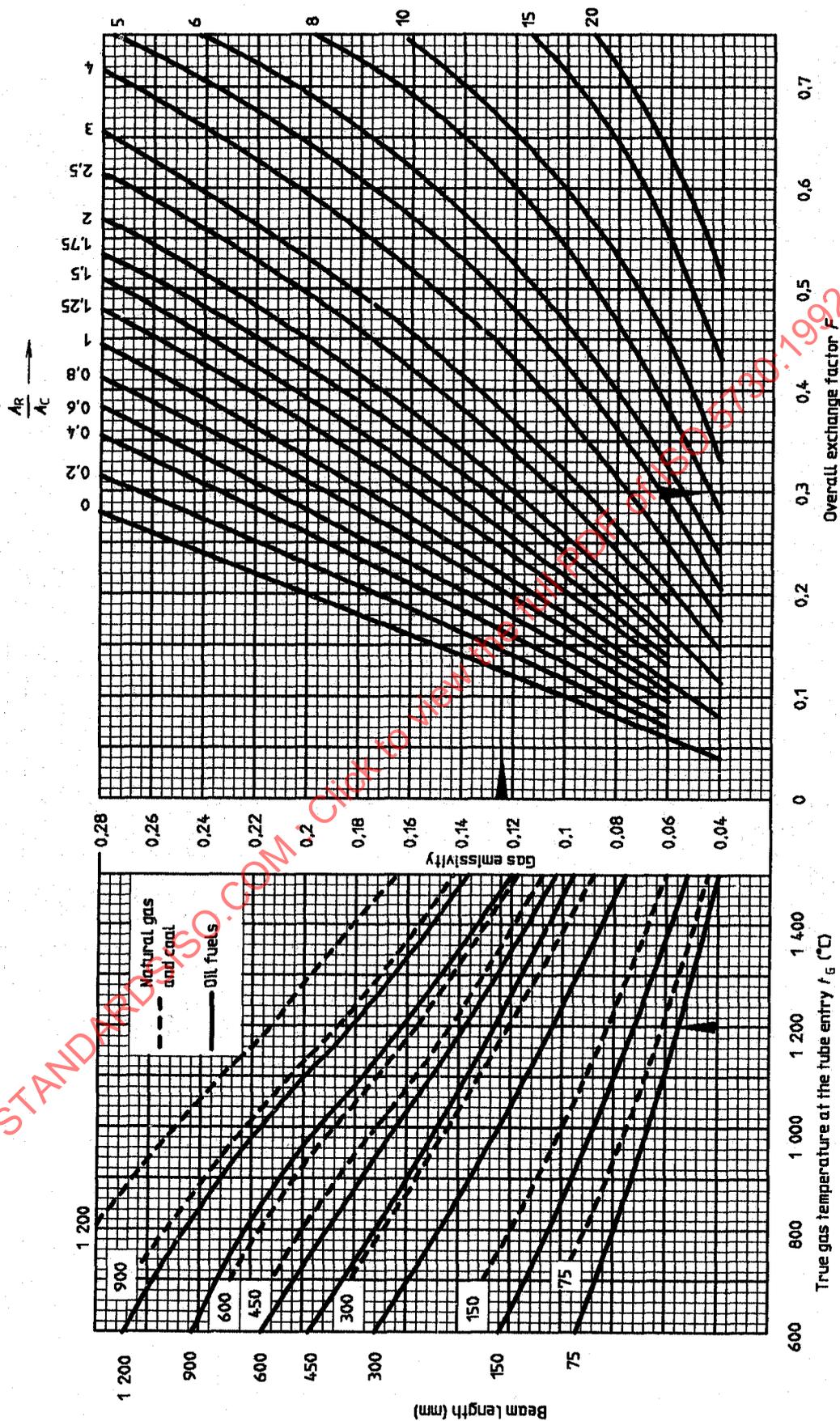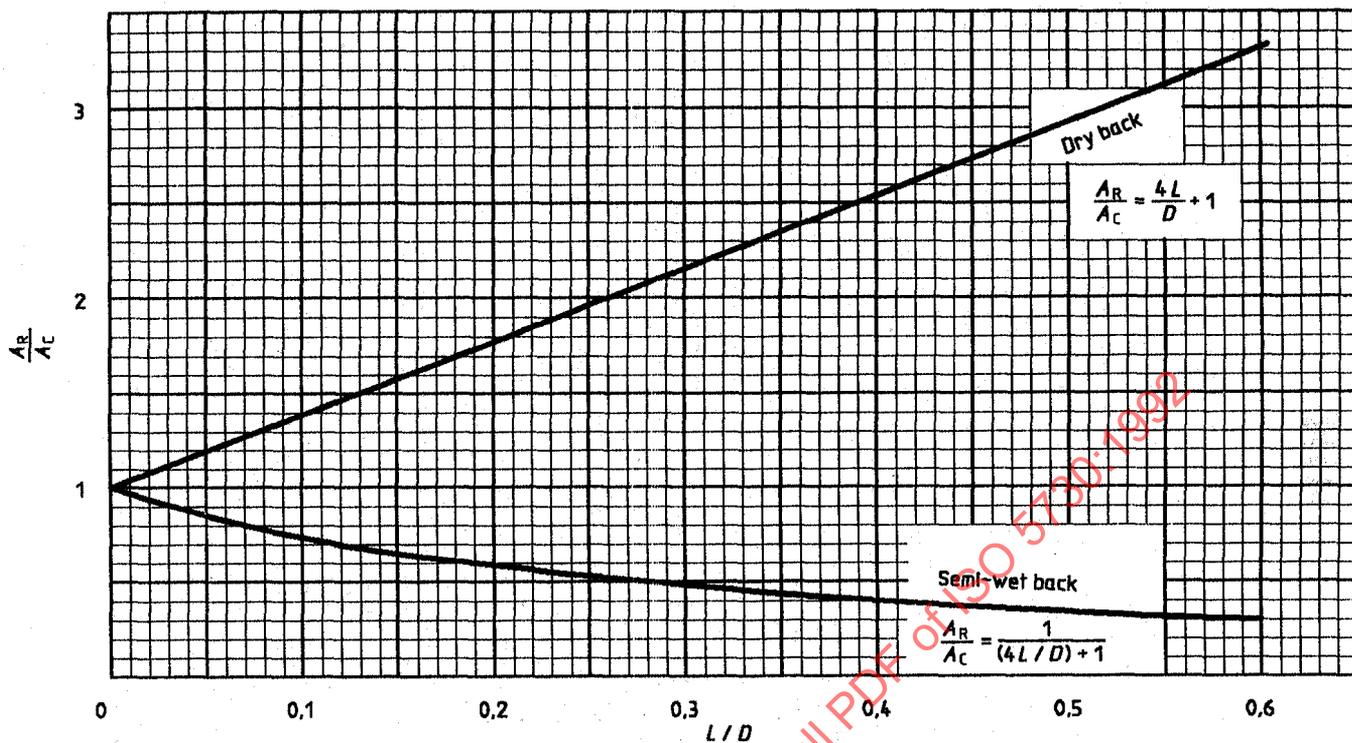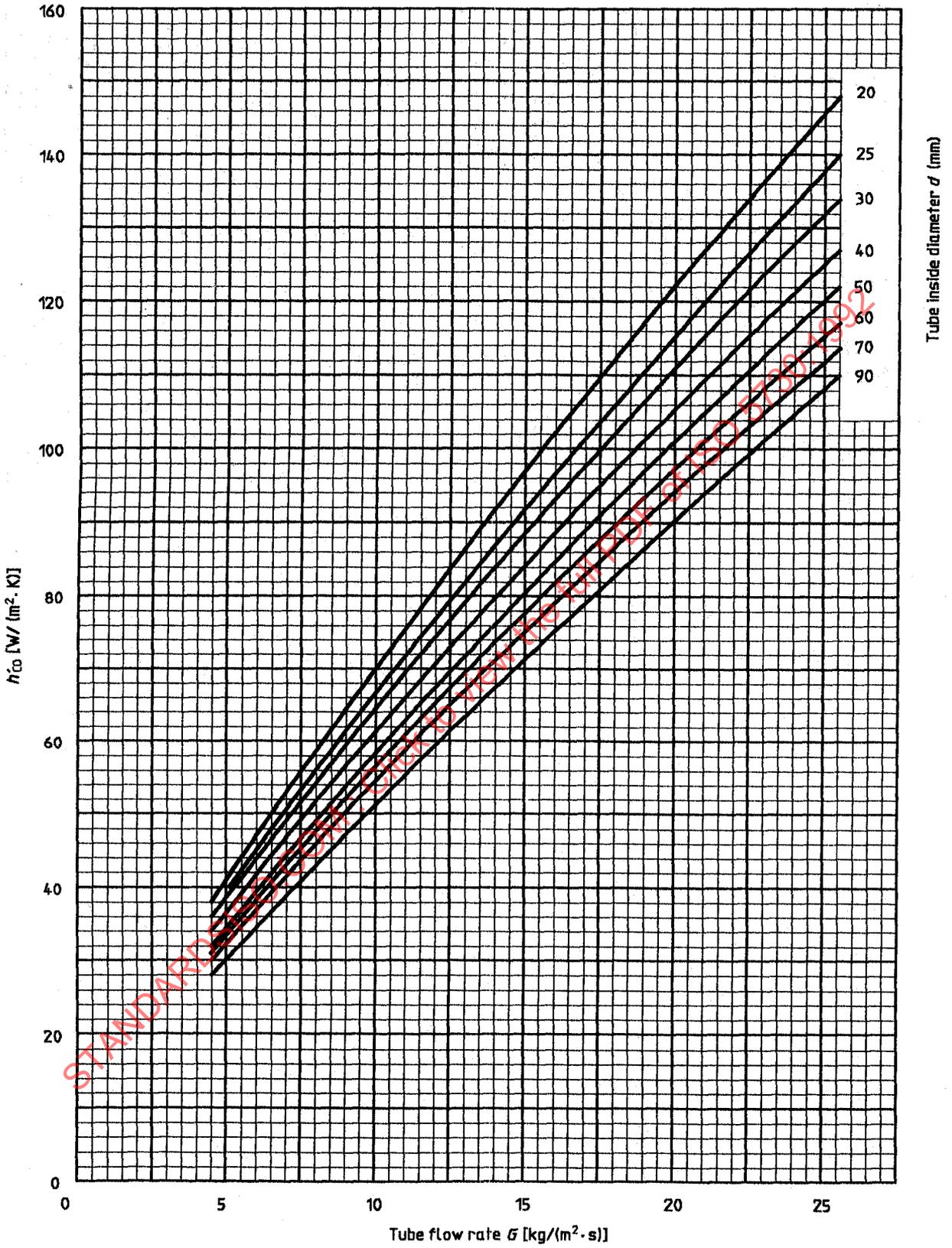
Figure C.2 — Determination of overall exchange factor F

NOTE — For a non-cylindrical chamber, include the total superficial area of the tube plate in A_C (no reduction for tube holes or furnace openings).

Figure C.3 — A_R/A_C for a cylindrical chamber with diameter D and length L

NOTE: $h'_{CO} = 20{,}2 \dfrac{G^{0,8}}{d^{0,2}}$

Figure C.4 — Basis convection coefficient h'_{CO}

$$\frac{h_{CO}}{h'_{CO}} = 0.87 + 0.000\ 28\ (t_G - 600)$$

$$\frac{h_{CO}}{h'_{CO}} = 0.855 + 0.000\ 27\ (t_G - 600)$$

Natural gas
Oil fuels and coal

Factor $\dfrac{h_{CO}}{h'_{CO}}$

True gas temperature at tube entry t_G (°C)
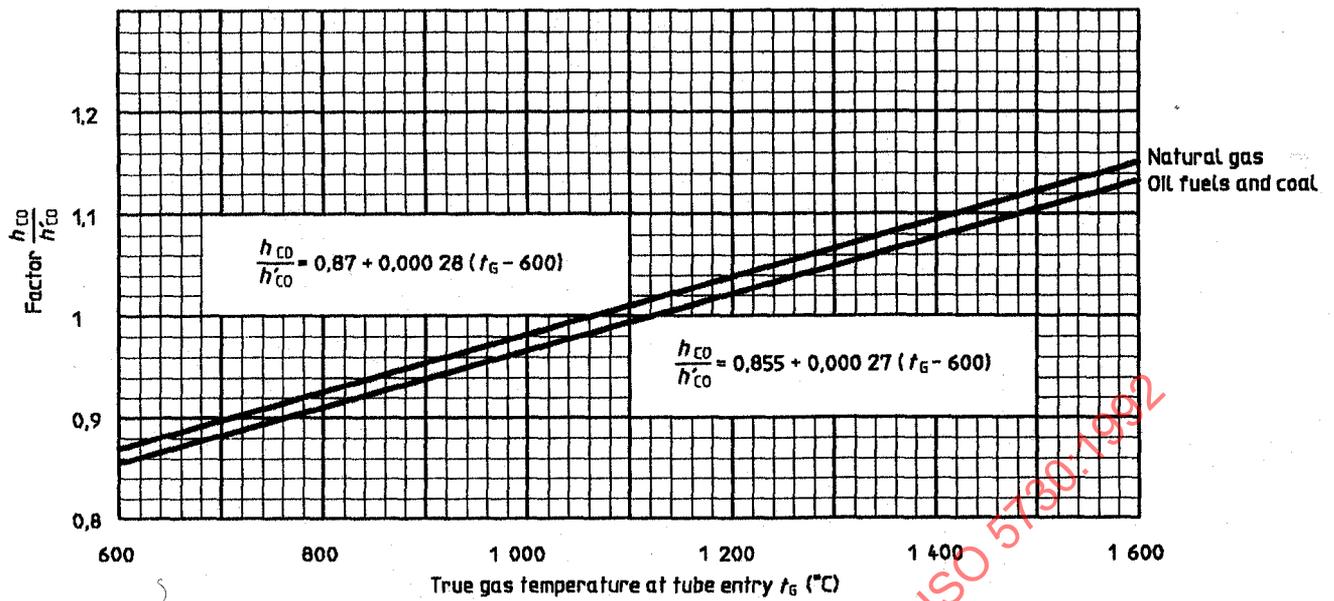
Figure C.5 — Determination of correction factor h_{CO}/h'_{CO}

$$\frac{h_{CE}}{h_{CO}} = 1 + \left(\frac{1}{e/d}\right)^{0.7}$$

Factor $\dfrac{h_{CE}}{h_{CO}}$

e/d
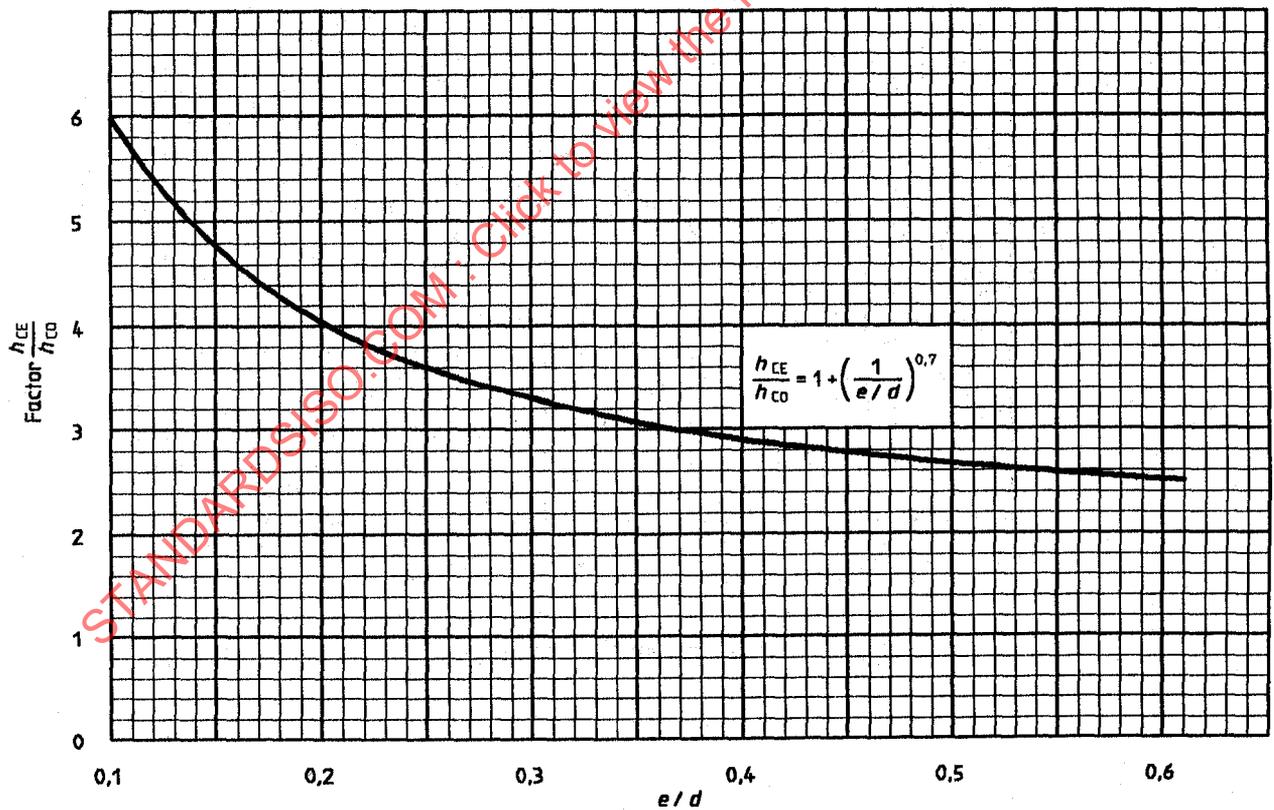
Figure C.6 — Determination of correction factor h_{CE}/h_{CO}
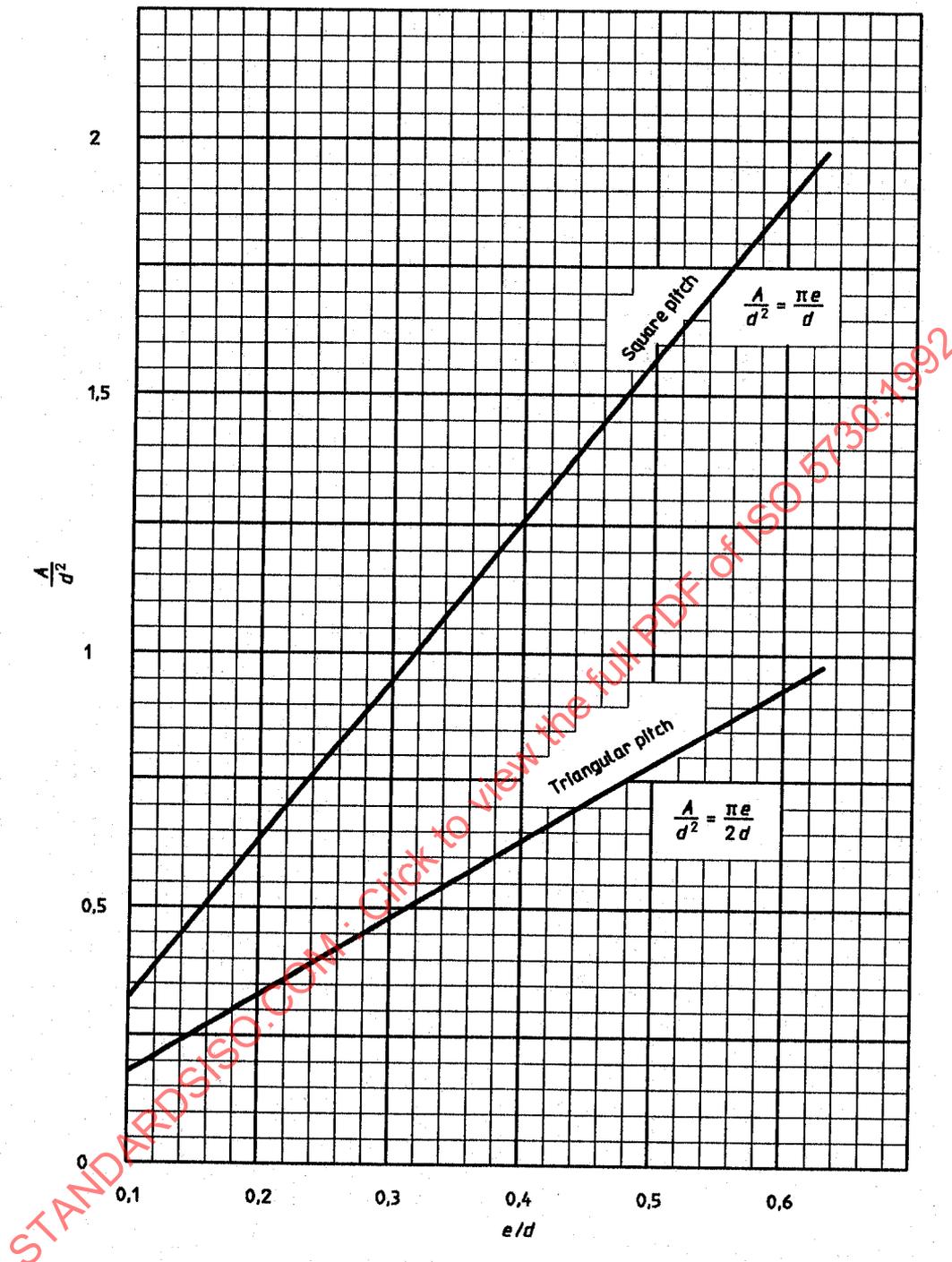
Figure C.7 — Non-dimensional tube area
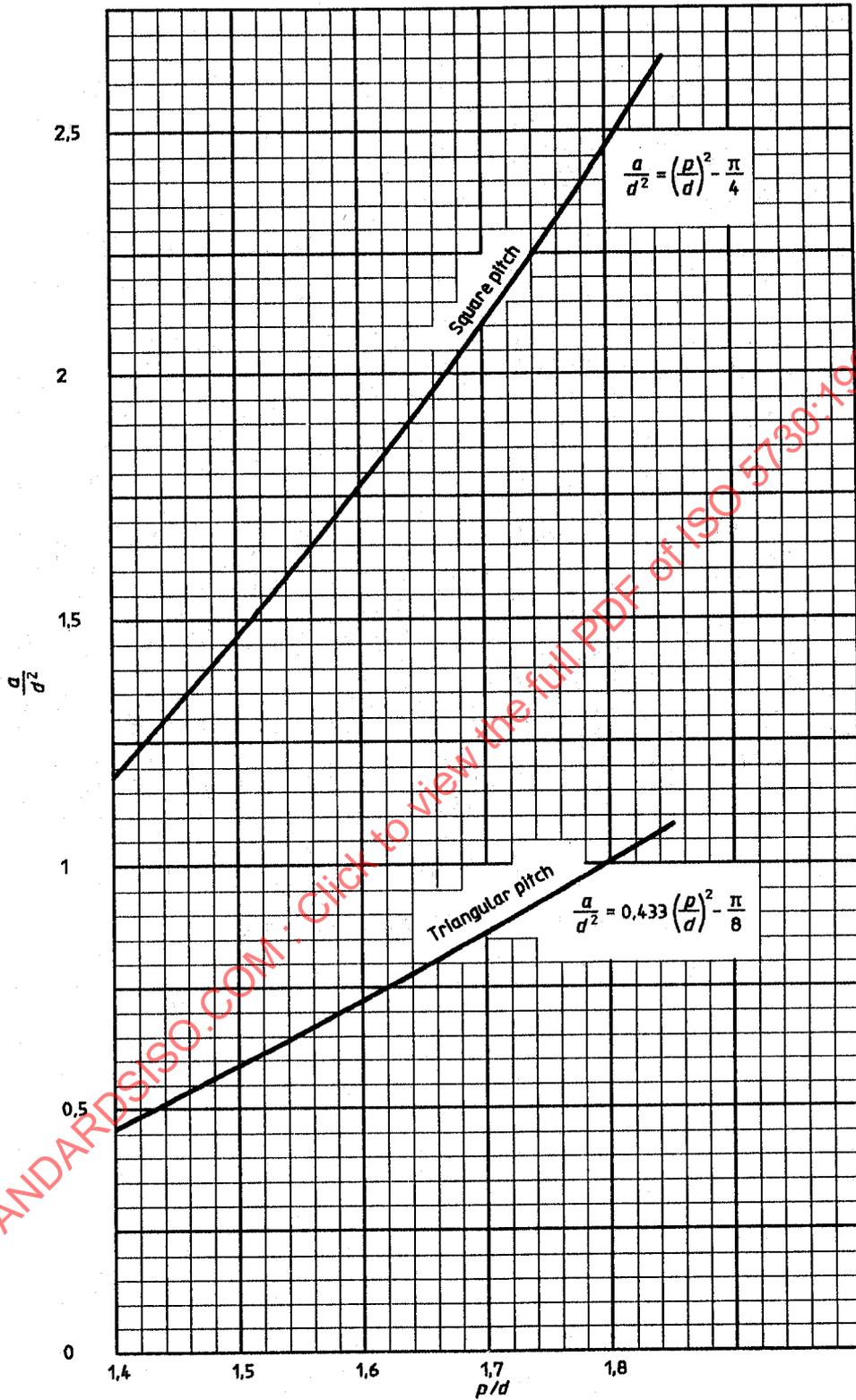
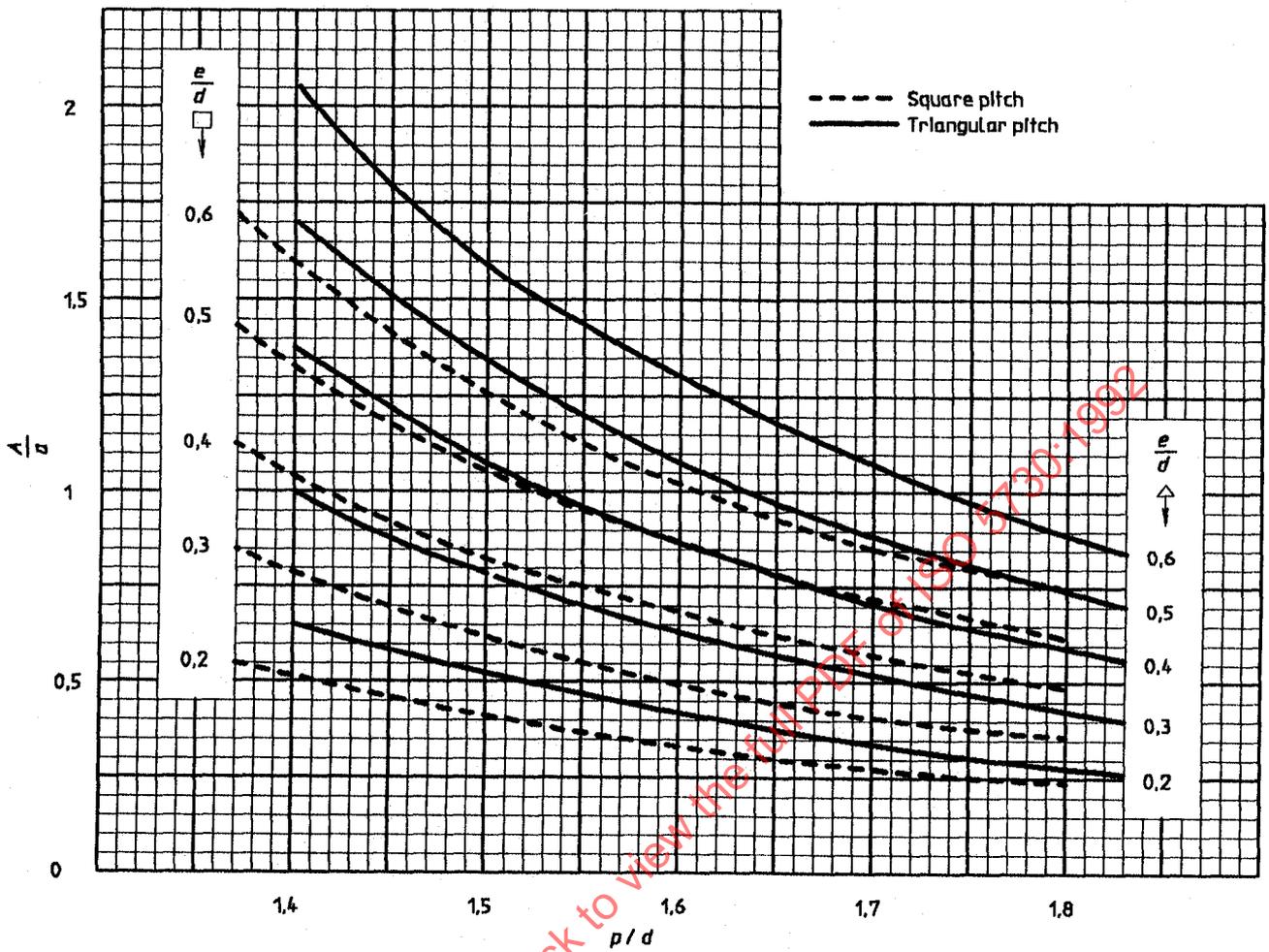**Figure C.8 — Non-dimensional plate area**

Figure C.9 — Tube/plate area ratio
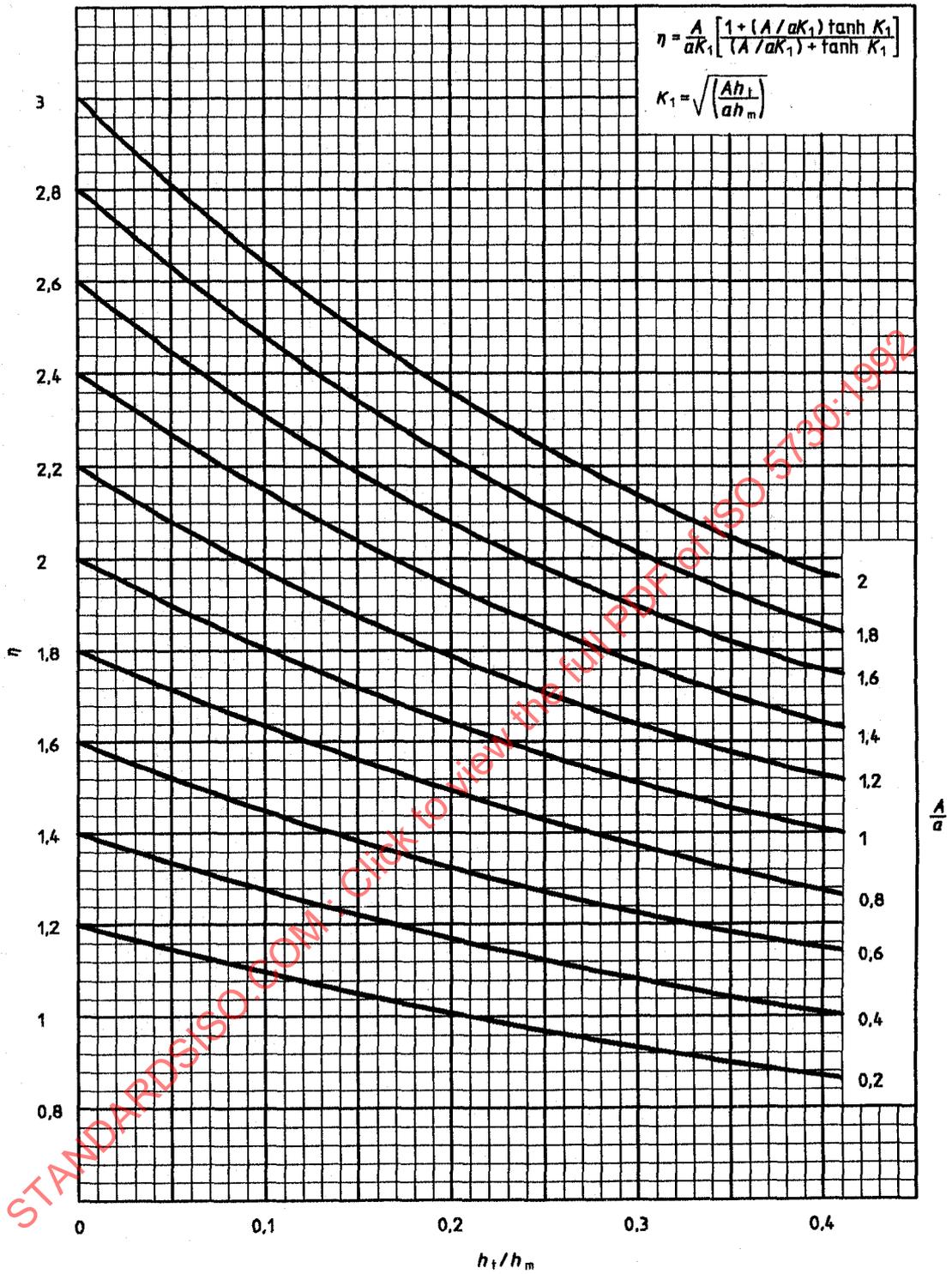
$$\eta = \frac{A}{aK_1}\left[\frac{1+(A/aK_1)\tanh K_1}{(A/aK_1)+\tanh K_1}\right]$$

$$K_1 = \sqrt{\left(\frac{Ah_t}{ah_m}\right)}$$

Figure C.10 — Factor η

$$\varphi = \frac{1}{\cosh K_1 + (K_1 a / A)\sinh K_1}$$

$$K_1 = \sqrt{\left(\frac{A h_t}{a h_m}\right)}$$
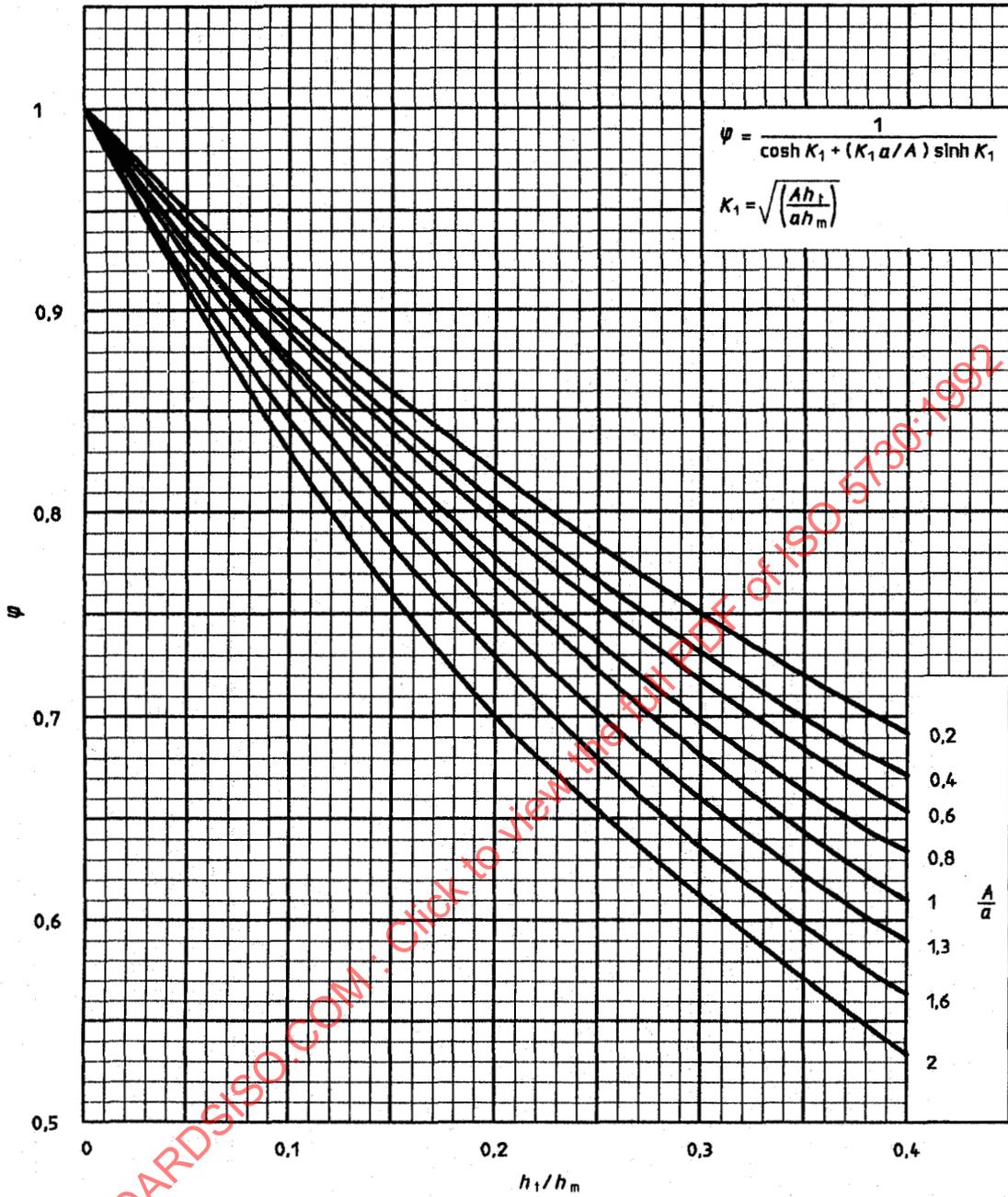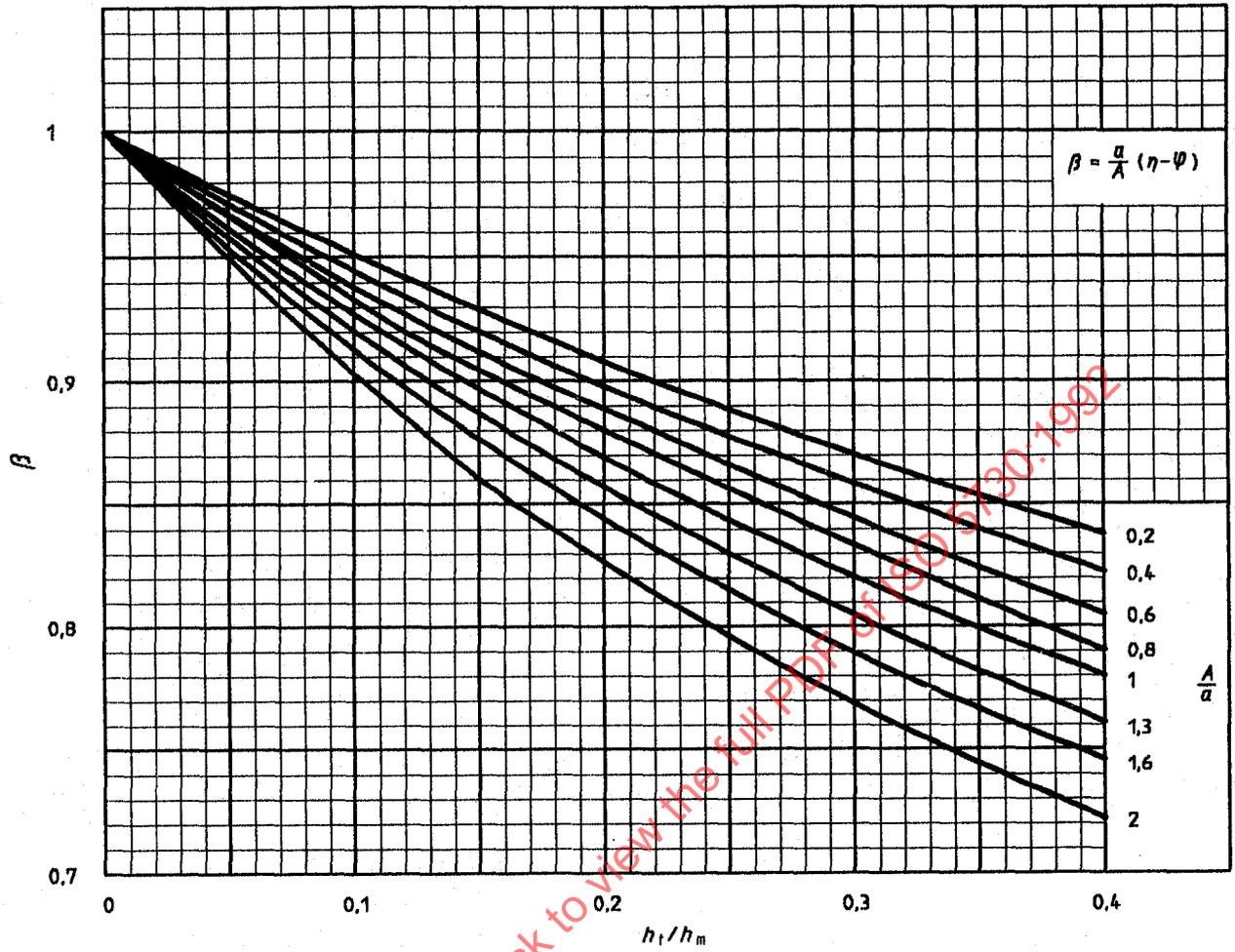
Figure C.11 — Factor φ

Figure C.12 — Factor β

Annex D

(informative)

Feed-water and boiler water quality

D.1 Introduction

D.1.1 This annex gives guidance on the feed-water and boiler water quality necessary for steam generators with a design pressure of greater than 0,1 N/mm² and less than or equal to 3 N/mm². It applies to the zone between the water inlet and the steam outlet of the steam generator.

D.1.2 The feed-water and boiler water of steam generators should meet certain minimum requirements. In principle, the feed-water and boiler water should be clear, colourless and free from suspended substances and conditioned to prevent corrosion. When the guidance conditions for feed-water and boiler water given in tables D.1 to D.3 are adhered to, the essential prerequisites for safe and trouble-free operation of the steam generator should exist. As well as the basic ideas relating to safety engineering aspects, economic aspects have also been taken into consideration.

The guidance conditions apply to new plant. However, application of these conditions to plant already in operation is also advised if trouble due to water chemistry is likely to impair the operational safety and reliability of the plant.

D.1.3 The observance of the necessary water quality should be controlled according to works or factory instructions and the results of water measurements should be recorded.

D.2 Factors to be considered

D.2.1 General

In shell boilers, all substances, except those volatile in steam, which are fed into the boiler with the feed-water, remain in the boiler and are concentrated. There is, therefore, a direct relationship between feed-water and boiler water quality.

The concentration of substances in the boiler water, especially when demineralization is not practised, leads to high concentrations of dissolved solids which can, however, be reduced by blowdown.

The substances contained in the boiler water will affect the corrosive properties of the water and the

formation of deposits both in the boiler and in the superheater (if any). Since the solubility of certain salts (e.g. sulfates, phosphates) decreases with rising temperature, thus favouring deposits from supersaturated solutions, concentration should be limited (see tables D.2 and D.3).

D.2.2 Corrosion

The material predominantly used in steam boiler plants is steel and this is attacked by both water and steam. However, under suitable conditions, the attack will lead to the formation of a protective layer adherent to the metal, i.e. a magnetite layer which impedes further attack by water and steam, thus effecting self-inhibition of the corrosive action. Magnetite protective layers, as well as other comparable layers on other materials, are indispensable to avoid corrosion.

D.2.3 Deposits

Corrosion products lower the quality of the feed-water or boiler water because they form deposits. Deposits may result from the crystallization of dissolved substances from supersaturated solutions or the precipitation of suspended solids. Owing to the deposition of deposits of a certain morphology, electrolytes dissolved in the water may reach such a high concentration that, depending on the thermal load, the boiler material is damaged by corrosion.

D.2.4 Suspended solids and emulsified or dissolved substances

Suspended solids and emulsified or dissolved organic substances increase the tendency of the boiler to foam, especially in the alkaline range, contribute to the impurity of saturated steam and lead to deposits, for example in superheaters.

Organic substances can comprise a variety of substances which, according to their composition and behaviour under the operating conditions of a steam generator, cannot be controlled. In the boiler they may decompose to form acidic substances thereby reducing the alkalinity of the boiler water which may, in turn, lead to corrosion.

Oil alone or together with suspended substances, e.g. corrosion products, undissolved calcium and