

# Simple unfired pressure vessels designed to contain air or nitrogen —

## Part 1: Pressure vessels for general purposes

The European Standard EN 286-1:1998, incorporating amendments A1:2002 and A2:2005, has the status of a British Standard

ICS 23.020.30

## National foreword

This British Standard is the UK implementation of EN 286-1:1998, incorporating amendments A1:2002 and A2:2005 and corrigendum July 2002. It supersedes BS EN 286-1:1991 and BS 5169:1992, which are withdrawn.

Amendment No. 1, 14014 implements CEN amendment A1:2002 and CEN corrigendum July 2002.

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

The start and finish of text introduced or altered by corrigendum is indicated in the text by tags **AC** **AC**. Text altered by CEN corrigendum July 2002 is indicated in the text by **AC1** **AC1**.

The UK participation in its preparation was entrusted to Technical Committee PVE/17, Air receivers — General.

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

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

**Compliance with a British Standard cannot confer immunity from legal obligations.**

### Amendments issued since publication

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14014	12 December 2002	Implementation of CEN amendment A1:2002
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English version

# Simple unfired pressure vessels designed to contain air or nitrogen — Part 1: Pressure vessels for general purposes

Réipients à pression simples, non soumis à la  
flamme, destinés à contenir de l'air ou de l'azote —  
Partie 1: Réipients pour usage général

Einfache unbefeuerte Druckbehälter für Luft oder  
Stickstoff —  
Teil 1: Druckbehälter für allgemeine Zwecke

This European Standard was approved by CEN on 30 November 1997.

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

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

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

## CEN

European Committee for Standardization  
Comité Européen de Normalisation  
Europäisches Komitee für Normung

Central Secretariat: rue de Stassart 36, B-1050 Brussels

## Foreword

This European Standard has been prepared by Technical Committee CEN/TC 54, Unfired pressure vessels, the secretariat of which is held by BSI.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by August 1998, and conflicting national standards shall be withdrawn at the latest by August 1998.

It is the revision of the standard adopted by CEN in 1991. Main changes concern:

- scope;
- materials;
- weld joint design;
- calculations coefficient;
- flange calculations;
- reinforcement of openings;
- supports;
- testing and inspection;
- instruction and marking;
- corrosion allowance.

Although the requirements of this standard support the essential safety requirements of the Simple pressure vessel Directive 87/404/EEC, that directive does not make compliance with this standard mandatory. This standard includes an interpretation of the conformity assessment requirements of the directive and thus the national implementing legislation. These interpretations cannot be taken as having any formal status and carry the risk of misinterpretation. Users of this standard should, therefore, refer to the applicable national legislation for the definitive conformity assessment requirements. A further revision of this standard is being prepared to remove any misleading provisions.

This standard is one of four within the series *Simple unfired pressure vessels designed to contain air or nitrogen*. The other standards are:

*Part 2: Pressure vessels for air braking equipment and auxiliary systems for motor vehicles and their trailers;*

*Part 3: Steel pressure vessels designed for air braking equipment and auxiliary pneumatic equipment for railway rolling stock;*

*Part 4: Aluminium alloy pressure vessels designed for air braking equipment and auxiliary pneumatic equipment for railway rolling stock.*

This Part of this European Standard has been prepared for use in conjunction with the informative Annex G of this European Standard.

No rules of construction can 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. Aspects of quality assurance are dealt with in various clauses and annexes of this standard; for example in Clause 10, Testing; and in Annex A, Verification; Annex B, Declaration of conformity — Surveillance; Annex C, Design and manufacturing schedule; Annex D, Type examination; Annex E, Content of the manufacturing record, all of which form part of this standard. These are minimum requirements, having taken into account EN ISO 9002 *Quality systems — Model for quality assurance in production, installation and servicing* and EN ISO 9003 *Quality systems — Model for quality assurance in final inspection and test*, but it is not implied that a quality system in accordance with EN ISO 9002 and EN ISO 9003 is necessary.

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

The general layout of the standard was not changed and accordingly is not in full conformity with the recent CEN rules for harmonized standards.

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

## Foreword to amendment A1

This document (EN 286-1:1998/A1:2002) has been prepared by Technical Committee CEN/TC 54, Unfired pressure vessels, the Secretariat of which is held by BSI.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by January 2003, and conflicting national standards shall be withdrawn at the latest by January 2003.

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

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

## Foreword to amendment A2

This European Standard (EN 286-1:1998/A2:2005) has been prepared by Technical Committee CEN/TC 54 "Unfired pressure vessels", the secretariat of which is held by BSI.

This Amendment to the European Standard EN 286-1:1998 shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by April 2006, and conflicting national standards shall be withdrawn at the latest by April 2006.

This amendment incorporates requirements for peaking in a new Annex H.

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

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## 1 Scope

**1.1** This part of this European Standard applies to the design and manufacture of welded, simple unfired pressure vessels manufactured in series, with a single compartment, hereinafter referred to as vessels, the essential safety requirements of which are given in Annex G.

It only applies to vessels that:

- a) include fabrication by welding, but some designs can entail the use of bolts;
- b) have a simple geometry enabling simple-to-use production procedures; this is achieved by either:
  - 1) a cylindrical part of circular cross-section closed by outwardly dished and/or flat ends which revolve around the same axis as the cylindrical part; or
  - 2) two outwardly dished ends revolving around the same axis;
- c) have branches not larger in diameter than 0,5 of the diameter of the cylinder to which they are welded.

**1.2** It applies to vessels which are intended to contain air or nitrogen which are not intended to be fired and which operate within the following constraints:

- a) subjected to an internal gauge pressure greater than 0,5 bar;
- b) the parts and assemblies contributing to the strength of the vessel under pressure to be made either of non-alloy quality steel or of non-alloy aluminium or non-age-hardening aluminium alloys;

NOTE In this part of the standard, the term "aluminium" covers non-alloy aluminium and aluminium alloys.

- c) the maximum working pressure is not greater than 30 bar. The product of the maximum working pressure and the capacity of the vessel ( $PS \times V$ ) is greater than 50 bar·l but does not exceed 10 000 bar·l. Below 50 bar·l, use of this standard is considered to fulfil the requirements of sound engineering practice;
- d) the minimum working temperature is not lower than  $-50\text{ °C}$ , and the maximum working temperature is not higher than  $300\text{ °C}$  for steel and  $100\text{ °C}$  for aluminium or aluminium alloy vessels.

It does not apply to vessels specifically designed for nuclear use, to vessels specifically intended for installation in, or the propulsion of, ships and aircraft, nor to fire extinguishers.

The standard does not apply to transportation vessels nor to vessels which also contain substances other than air or nitrogen which could adversely affect their safety. For vessels designed to contain compressed air for the braking systems of road vehicles and their trailers, see also EN 286-2. For vessels designed to contain compressed air for the braking systems of rail-mounted vehicles, see also EN 286-3 and EN 286-4.

**1.3** It applies to the vessel proper, from the inlet connection to the outlet connection and to all other connections required for valves and fittings. If bosses/pipes are used, the requirements specified herein begin or end at the weld where flanges, if used, would have been fitted.

**1.4** For the purposes of calculations required to be made in accordance with this standard, dimensions are in millimetres, pressures are in bars (except where otherwise specified), stresses are in newtons per square millimetre and temperatures are in degrees Celsius.

## 2 Normative references

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

EN 287-1, *Approval testing of welders: Fusion welding — Part 1: Steels.*

EN 287-2, *Approval testing of welders: Fusion welding — Part 2: Aluminium and aluminium alloys.*

EN 288-2, *Specification and approval of welding procedures for metallic materials — Part 2: Welding procedure specification for arc welding.*

EN 288-3, *Specification and approval of welding procedures for metallic materials — Part 3: Welding procedure tests for arc welding of steels.*

- EN 288-4, *Specification and approval of welding procedures for metallic materials — Part 4: Welding procedure tests for arc welding of aluminium and its alloys.*
- EN 473, *Qualification and certification of NDT personnel — General principles.*
- EN 485-2, *Aluminium and aluminium alloys — Sheet, strip and plates — Part 4: Tolerances on shape and dimensions for cold rolled products.*
- EN 573-3, *Aluminium and aluminium alloys — Chemical composition and form of wrought products — Part 3: Chemical composition.*
- EN 573-4, *Aluminium and aluminium alloys — Chemical composition and form of wrought products — Part 4: Forms of products.*
- EN 754-2, *Aluminium and aluminium alloys — Wrought products — Cold drawn rod/bar and tubes — Part 2: Mechanical properties.*
- EN 755-2, *Aluminium and aluminium alloys — Wrought products — Extruded rod/bar, tube and profile — Part 2: Mechanical properties.*
- EN 875, *Welding — Welded joints in metallic materials — Specimen location and notch orientation for impact tests.*
- EN 910, *Welding — Welded butt joints in metallic materials — Bend tests.*
- EN 1418, *Welding personnel — Approval testing of welding personnel for fully mechanized and automatic welding of metallic materials.*
- EN 1435, *Non-destructive examination of welds — Radiographic examination of welded joints.*
- EN 10002-1, *Metallic materials — Tensile testing — Part 1: Method of test (at ambient temperature).*
- EN 10028-2, *Flat products made of steels for pressure purposes — Part 2: Non-alloy and alloy steels with specified elevated temperature properties.*
- EN 10204, *Metallic products — Types of inspection documents.*
- EN 10207, *Steels for simple pressure vessels — Technical delivery requirements for plates, strips and bars.*
- EN 10216-1, *Seamless steel tubes for pressure purposes — Technical delivery conditions — Part 1: Non-alloy steels with specified room temperature properties.*  
(based on ISO 9329-1)
- EN 10217-2, *Welded steel tubes for pressure purposes — Technical delivery conditions — Part 2: Unalloyed and alloyed steels with specified elevated temperature properties.*  
(based on ISO 9330-2)
- EN 10222-4, *Steel forgings for pressure purposes — Part 4: Weldable fine grain steel with high proof strength.*
- EN 10226-1, *Pipe threads where pressure tight joints are made on the thread — Part 1: Designation, Dimensions and tolerances.*
- EN 20898-1, *Mechanical properties of fasteners — Part 1: Bolts, screws and studs.*
- EN 20898-2, *Mechanical properties of fasteners — Part 2: Nuts with specified proof load values.*
- EN 25817, *Arc-welded joints in steel — Guidance on quality level for imperfections.*
- EN 30042, *Arc-welded joints in aluminium and its weldable alloys — Guidance on quality levels for imperfections.*
- EN ISO 2409:1994, *Paints and varnishes — Cross-cut test.*
- ISO 228-1, *Pipe threads where pressure tight joints are not made on the threads — Part 1: Designation, dimensions and tolerances.*
- ISO 3057, *Non-destructive testing — Metallographic replica techniques of surface examination.*
- ISO 7005-1, *Metallic flanges — Part 1: Steel flanges.*
- ISO 7253:1996, *Paints and varnishes — Determination of resistance to neutral salt spray.*



## 3 Definitions, symbols and units

### 3.1

#### Definitions

For the purposes of this standard the following definitions apply.

#### 3.1.1

##### automatic welding

welding in which all the welding parameters are automatically controlled; some of these parameters may be adjusted to a limited amount (manually or automatically by mechanical or electronic devices) during welding to maintain the specified welding conditions

#### 3.1.2

##### non-automatic welding

all types of welding other than that defined in 3.1.1

#### 3.1.3

##### batch

a batch of vessels consists at the most of 3 000 vessels of the same type

#### 3.1.4

##### type of vessel

vessels are of the same type if the five following conditions are met:

- they have similar geometrical form (i.e. shell rings and ends, or only ends; in both cases, ends of the same shape);
- they belong to the same class (see Clause 4);
- they have wall material and thickness within the limit of validity of the weld procedure, including those for branches, nozzles and inspection opening;
- they have the same type of inspection opening; (sightholes, handholes, headholes and manholes are examples of different types of inspection opening);
- they have the same design temperature limitations.

#### 3.1.5

##### declaration of conformity

the procedure whereby the manufacturer certifies vessels to be in conformity with this European Standard (see Annex B)

#### 3.1.6

##### verification

the procedure adopted to check and certify that vessels manufactured comply with this European Standard (see Annex A)

#### 3.1.7

##### surveillance

the procedure carried out by an approved inspection body during manufacture to ensure that the manufacturer duly fulfils the requirements of this European Standard (see B.3.2)

#### 3.1.8

##### type examination

the procedure by which an approved inspection body ascertains and certifies that a specimen of a vessel satisfies the provisions of this European Standard (see Annex D)

#### 3.1.9

##### design and manufacturing schedule

a schedule, issued by the manufacturer, the purpose of which is to describe the construction, material and fabrication including the certificates (see Annex C)

**3.1.10**

**manufacturing record**

a record, kept by the manufacturer, of all the relevant information on the vessels manufactured to this standard

**3.1.11 Design temperature**

**3.1.11.1**

**maximum design temperature**

the temperature that is used in the design calculations, and which is never less than the maximum working temperature

**3.1.11.2**

**minimum design temperature**

the lowest temperature used in the selection of materials, and which is never greater than the minimum working temperature

**3.1.12**

**minimum working temperature,  $T_{\min}$**

the lowest stabilized temperature in the wall of the vessel under normal conditions of use

**3.1.13**

**maximum working temperature,  $T_{\max}$**

the highest stabilized temperature which the wall of the vessel can attain under normal conditions of use

**3.1.14**

**design pressure,  $P$**

the pressure used in design calculations, and which is never less than the maximum working pressure  $PS$

**3.1.15**

**maximum working pressure,  $PS$**

the maximum gauge pressure which may be exerted under normal conditions of use

(the set pressure of the pressure relief device is never greater than  $PS$ , but after pressure relief has commenced, the pressure can exceed  $PS$  by 10 % maximum)

**3.1.16**

**manufacturer's inspector**

person(s) employed and authorized by the manufacturer, but independent from the production personnel, qualified and responsible for inspections, examinations and tests to be carried out by him on vessels

qualification means technical competency on the different inspections, examinations and tests to be carried out under the manufacturer's responsibility, as well as necessary experience. It is the responsibility of the manufacturer to ascertain that the inspector is competent

**3.1.17**

**report on the examinations and tests**

a report of the examinations and tests carried out by the manufacturer

**3.1.18**

**test report**

document in which the manufacturer certifies that the products supplied comply with the requirements of the order, and in which he supplies test results based on non-specific inspection and testing

[2.2 in EN 10204]

NOTE 1 This corresponds to "inspection slip" defined in the Directive.

NOTE 2 In this definition, "manufacturer" means material manufacturer.

**3.1.19**

**series manufacture**

more than one vessel of the same type manufactured during a given period by a continuous manufacturing process, in accordance with a common design and using the same manufacturing process

**3.1.20****main body**

main body means main shell and/or ends

**3.2 General symbols and units**

International System (SI) units are used in the standard, as follows:

— dimensions (thickness, diameter, length, ...):	mm
— areas:	mm <sup>2</sup>
— loads, forces:	N
— moments:	N·mm
— pressures:	bar or N/mm <sup>2</sup> (see note)
— stresses, yield strength, tensile strength:	N/mm <sup>2</sup>

NOTE Concerning the design pressure  $P$ , the unit N/mm<sup>2</sup> is used throughout 6.4 in order to have a coherent system of units for the formula. The unit bar is used throughout the other clauses in order to meet the terminology of the Directive.

The following general symbols are used (specific symbols are defined in the relevant clauses):

$A$	elongation after rupture
$D_i$	inside diameter of main body
$D_o$	outside diameter of main body
$d$	diameter of openings
$d_{ib}$	internal diameter of branch
$d_{ob}$	external diameter of branch
$d_{ip}$	internal diameter of pad
$d_{op}$	external diameter of pad
$d_{is}$	internal diameter of shell
$e$	nominal thickness of wall
$e_s$	nominal thickness of shell
$e_b$	nominal thickness of branch
$e_p$	nominal thickness of compensating plate or of pad
$e_c$	calculated thickness
$e_a$	actual thickness
$e_{as}$	actual thickness of shell
$e_{ab}$	actual thickness of branch
$e_{am}$	actual thickness of main body
$e_{ap}$	actual thickness of compensating plate or of pad
$f$	nominal design stress at design temperature
$K_c$	calculation coefficient, which depends on the welding process (see 6.4.2)
$K_s$	shell coefficient, which depends on the extent of testing (see 6.4.2)
$KCV$	impact energy
$l_b$	effective length of branch contributing to reinforcement
$l_{bi}$	effective length for inside part of set-through branch
$l_m$	effective length of main body, contributing to reinforcement
$l_p$	width of compensating plate
$l_{rp}$	width of pad minus corrosion allowance and tolerances
$P$	design pressure (never less than $PS$ ), in bars or in newtons per square millimetre (see note at the beginning of 3.2)
$PS$	maximum working pressure
$R_{eT}$	value at the maximum working temperature, $T_{max}$ , of: <ul style="list-style-type: none"> <li>— the upper yield point <math>R_{eH}</math>, for a material with both a lower and upper yield point;</li> <li>— the proof stress <math>R_{p0.2}</math>;</li> <li>— or the proof stress <math>R_{p1.0}</math> in the case of non-alloy aluminium.</li> </ul>
$R_m$	minimum value of tensile strength at room temperature specified in the material standard

## 4 Classifications and certification procedures

This standard specifies three classes of vessels, for which the applicable certification procedures are shown in Table 4.1.

Table 4.1 — Classification of vessels

Classification	$PS \times V$ bar·l	Certification procedure <sup>a</sup>	
		Design stage	Fabrication stage
Class 1	Above 3 000, up to and including 10 000	At manufacturer's choice: type examination (see Annex D) or design and manufacturing schedules approval (see Annex C.2)	Verification (see Annex A)
Class 2	Above 200, up to and including 3 000		At manufacturer's choice: verification <sup>b</sup> (see Annex A) or declaration of conformity and surveillance (see Annex B), and special documents
Class 3	Above 50, up to and including 200		At manufacturer's choice: verification <sup>b</sup> (see Annex A) or declaration of conformity (see Annex B), and special documents
—	Below or equal to 50	See note	

<sup>a</sup> This requirement is not part of the EC Directive and therefore is not part of the harmonized standard.  
<sup>b</sup> For those vessels subject to verification, the identification of the approved inspection body shall be stamped on the data plate (see Clause 12).

NOTE Use of this standard is considered to fulfil the requirements of sound engineering practice. It is the responsibility of the manufacturer to comply with the rules of this standard and to mark the vessel in accordance with Clause 12, with the exception of the CE marking and of the approved inspection body mark.

## 5 Materials

### 5.1 Main pressurized parts (see also 5.2)

#### 5.1.1 General

The essential requirements for materials are given in Annex G.

The materials shall be delivered with at least a test report (type 2.2 in accordance with EN 10204). Inspection certificates of types 3.1.A, 3.1.B or 3.1.C are also acceptable.

#### 5.1.2 Steel vessels

The following materials should be used:

- plate, strip and bar: steel grades P235S, P265S, and P275SL in accordance with EN 10207; steel grades P275N, P275NH, P275NL1 and P275NL2 in accordance with EN 10028-2;
- tubes: steel grades P235T2 and P265T2 in accordance with EN 10216-1 and EN 10217-2;
- forgings: steel grade P285QH in accordance with EN 10222-4.

### 5.1.3 Aluminium vessels

The materials stated in Table 5.2, in accordance with EN 573-4, should be used:

- a) plates in accordance with EN 485-2;
- b) bars in accordance with EN 755-2.

**Table 5.2 — Aluminium materials in accordance with EN 573-4**

Material designation		Maximum working temperature °C
Numerical	Chemical symbol	
EN AW-1080A	EN AW-Al 99,8(A)	100
EN AW-1070A	EN AW-Al 99,7	100
EN AW-1050A	EN AW-Al 99,5	100
EN AW-5005	EN AW-Al Mg1(B)	100
EN AW-5251	EN AW-Al Mg2	100
EN AW-5049	EN AW-Al Mg2Mn0,8	100
EN AW-5052	EN AW-Al Mg2,5	100
EN AW-5754	EN AW-Al Mg3	100
EN AW-5454	EN AW-Al Mg3Mn	100
EN AW-5154A	EN AW-Al Mg3,5(A)	100
EN AW-5086	EN AW-Al Mg4	65
EN AW-5083	EN AW-Al Mg4,5Mn0,7	65
EN AW-3103	EN AW-Al Mn1	100
EN AW-3105	EN AW-Al Mn0,5Mg0,5	100

### 5.1.4 Other standard materials

Any material not included in 5.1.2 and 5.1.3, which is manufactured in accordance with a national or International Standard for quality steels, aluminium or aluminium alloy, will be acceptable, subject to approval by an approved inspection body.

## 5.2 Accessories contributing towards the strength of vessels

These accessories (bolts, nuts, pipes, tubes, bosses etc.) shall be made from steel, aluminium or aluminium alloy which is compatible with materials used for the manufacture of the main pressurized parts. They shall have an elongation after rupture, *A*, on longitudinally oriented test-pieces of at least 14 % (see EN 10002-1).

Bolts and screws in accordance with EN 20898-1, property classes 5.6 or 8.8, and nuts to EN 20898-2, property classes 5 or 8, but with an elongation of at least 12 %, are considered to be suitable.

Steel bolts for working temperatures colder than  $-10\text{ }^{\circ}\text{C}$  shall have an average impact strength, *KCV*, for three longitudinal test-pieces, at the minimum working temperature, of not less than  $35\text{ J/cm}^2$ . Not more than one of the three values may be less than  $35\text{ J/cm}^2$ , with a minimum of  $25\text{ J/cm}^2$ . The corresponding material shall be delivered with at least a test report (type 2.2 in accordance with EN 10204). Inspection certificates of types 3.1.A, 3.1.B or 3.1.C are also acceptable.

### 5.3 Non-pressurized parts

All non-pressurized parts of welded vessels shall be of materials that are compatible with those of the components to which they are welded.

To this end, supports and accessories fitted by welding on the shell of steel vessels shall be made of killed non-alloy steel which meets the following requirements:

$$C \leq 0,25 \% ; S \leq 0,05 \% ; P \leq 0,05 \% ;$$

$$\text{and } R_{m \max} < 580 \text{ N/mm}^2$$

Aluminium and aluminium alloys shall be as given in 5.1.3.

### 5.4 Welding consumables

The welding consumables used to manufacture the welds on or of the vessel shall be appropriate to and compatible with the materials to be welded, and shall comply with available European Standards.

## 6 Design

### 6.1 General

When designing the vessel, the manufacturer shall define the use to which it will be put, and shall select:

- the minimum working temperature,  $T_{\min}$ ;
- the maximum working temperature,  $T_{\max}$ ;
- the maximum working pressure,  $PS$ .

When the intended use of the vessel implies additional loads or fatigue, this shall be taken into account in the design.

**A2** Requirements for peaking (out-of-roundness caused by misalignment of (welded) joints or local irregularities in vessel profile) are given in Annex H. **A2**

### 6.2 Weld joint design

**6.2.1** Welds of partial penetration type are not permitted, except in the case of branches, flat ends and flanges which are fixed to the main shell by means of two welds of adequate thickness, see 6.2.5. The type of edge preparation is dependent on the welding procedures used.

Where full penetration welds are not used for branches, welds shall be as shown in Figure 6.2-1a to Figure 6.2-1d, with each weld having a throat thickness,  $g$ , of at least 0,7 times the thickness of the thinnest part.

Branches may be considered as reinforcement of the main body if the weld joints are made as shown in Figure 6.2-1a to Figure 6.2-1d, Figure 6.2-2a and Figure 6.2-2b.

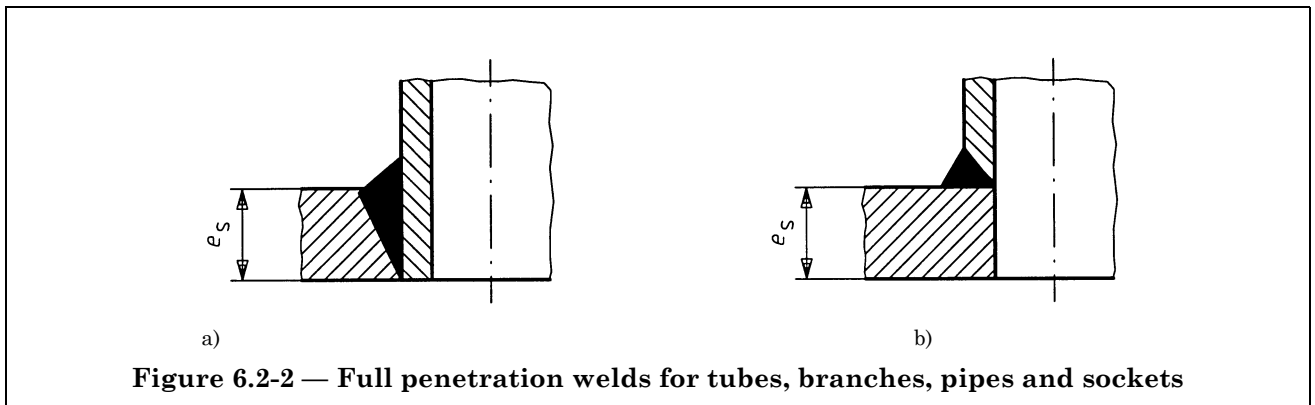
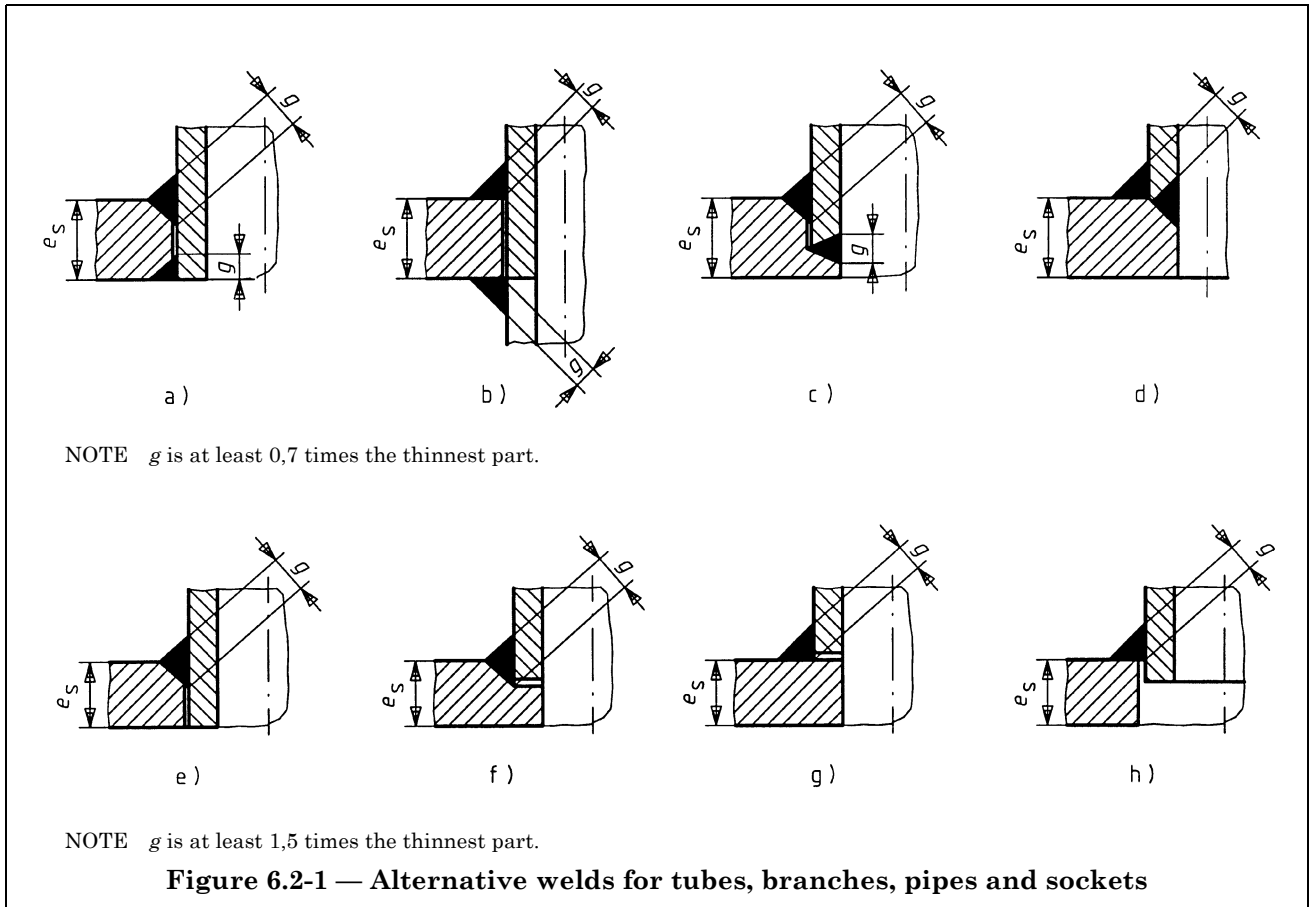
**6.2.2** A single partial penetration weld is permitted in the case of branch pipes and sockets whose outside diameter does not exceed 65 mm. The throat thickness,  $g$ , of the weld shall be at least 1,5 times the thickness of the thinnest part (see Figure 6.2-1e, Figure 6.2-1f, Figure 6.2-1g and Figure 6.2-1h).

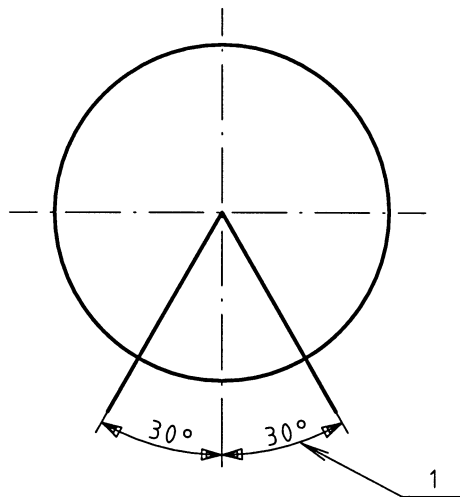
Branches shall not be considered as reinforcement if the weld joints are made as shown in Figure 6.2-1e to Figure 6.2-1h and the thickness of the main body to which the branch is attached is greater than 6 mm.

**6.2.3** If a shell is manufactured from more than one ring, the alignment between the centre-lines of the longitudinal welds shall be as far apart as possible but not less than 50 mm.

For horizontally mounted vessels, longitudinal welds shall not be closer than  $30^\circ$  to the lowest line along the surface of the vessel parallel to its centre-line (see Figure 6.2.3-1).

**6.2.4** Openings in cylindrical shells and end plates shall be placed as far as practical from any welded seam, but in no instance shall the seam in the shell be pierced. The distance between any two welds taken from the extremity of the edge preparation shall not be less than 4 times the actual shell thickness,  $e_{as}$ , and in no case shall the distance to any circumferential seam be less than  $0,5\sqrt{D_o e_s}$ .



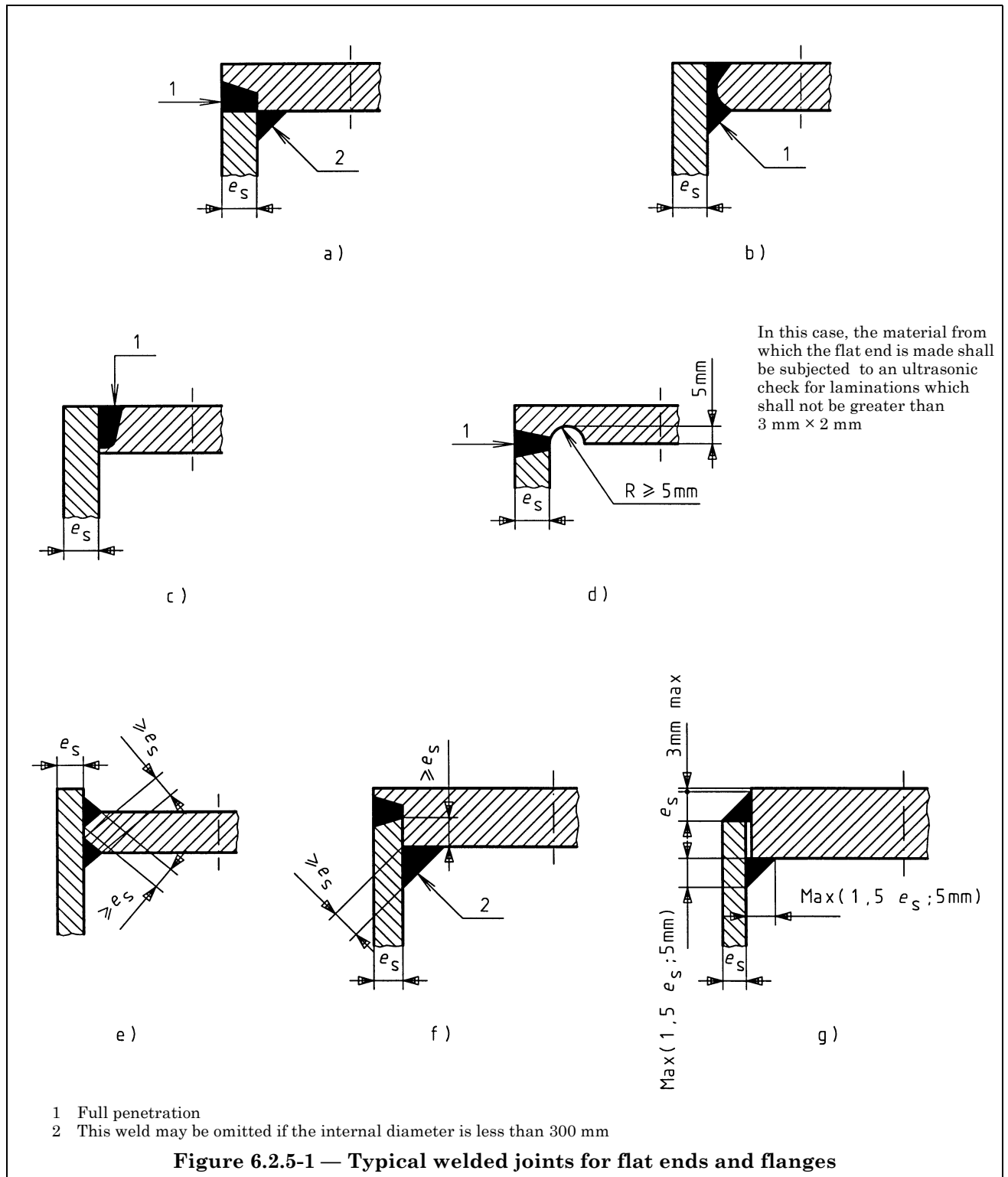


1 No longitudinal welds in this area

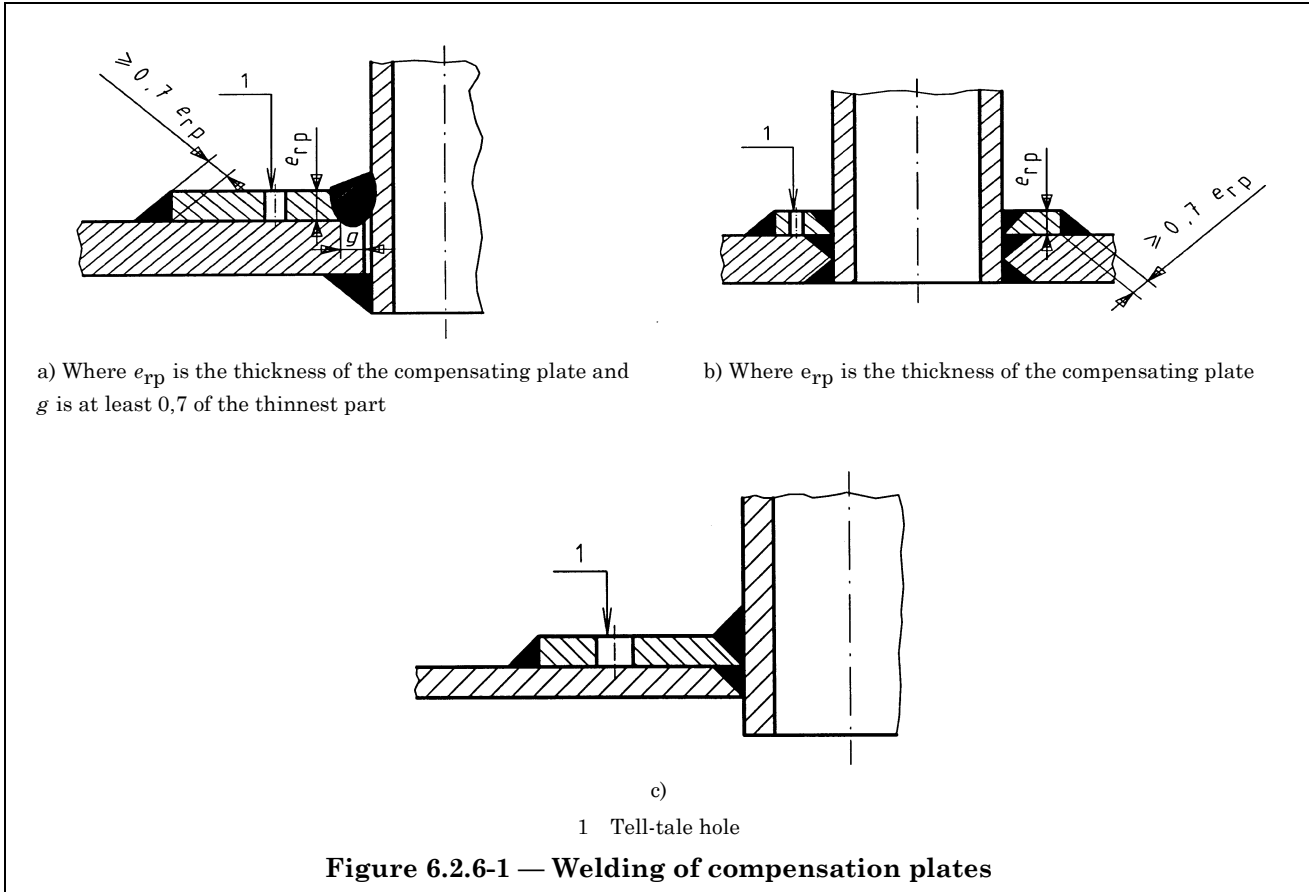
**Figure 6.2.3-1 — Positioning of longitudinal welds**



6.2.5 Welded joints for flat ends and flanges shall be of the types shown in Figure 6.2.5-1.



6.2.6 Welding of compensation plates shall be as shown in Figure 6.2.6-1.



### 6.3 Determination of wall thicknesses

#### 6.3.1 Choice of the method

The wall thicknesses shall be determined, in the corroded conditions, using the calculation method (see 6.4) or the experimental method (see 6.5), at the manufacturer's choice, in accordance with the following criteria.

- If the product of  $PS$  and  $V$  is more than 3 000 bar·l, or if the maximum working temperature exceeds 100 °C, the calculation method shall be used.
- If the product of  $PS$  and  $V$  is not more than 3 000 bar·l, or if the maximum working temperature does not exceed 100 °C, the calculation method or the experimental method may be used, at manufacturer's choice.

#### 6.3.2 Actual wall thicknesses

The actual wall thickness  $e_a$  of a component (shell, head or flange) is the nominal thickness of the component corrected for tolerance, thinning and corrosion (see Figure 6.3.2-1):

$$e_a = e - t - m - c \tag{6.3.2-1}$$

where

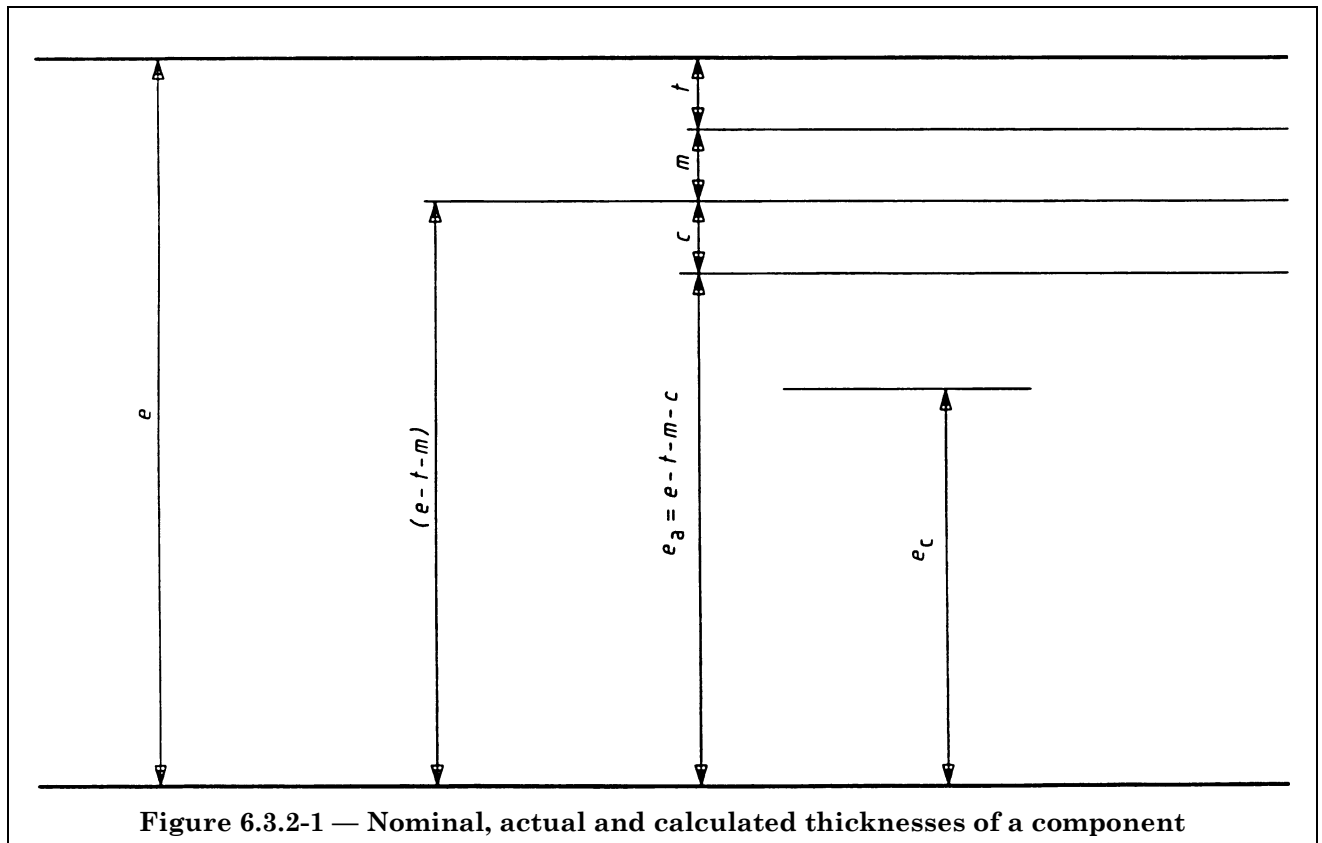
- $e$  is the nominal thickness of the component;
- $c$  is the corrosion allowance (see 6.3.3);
- $t$  is the absolute value of the negative tolerance taken from the material standard;
- $m$  is the thinning during the manufacturing process.

The actual wall thickness of the shell and ends shall not be less than 2 mm in the case of steel vessels and not less than 3 mm in the case of aluminium vessels:

$$e_a \geq 2 \text{ mm for steel vessels} \quad (6.3.2-2)$$

$$e_a \geq 3 \text{ mm for aluminium vessels} \quad (6.3.2-3)$$

The wall thickness of the shell to be indicated on the data plate (see Clause 12) is the actual thickness  $e_a$ .



### 6.3.3 Corrosion allowance

Bearing in mind their prescribed use, the vessels shall be adequately protected against corrosion.

#### 6.3.3.1 Steel vessels are adequately protected against corrosion if either:

- a reliable and durable internal coating is present, which shall be tested in accordance with Annex F and checked by the approved inspection body, who shall indicate its acceptability by stamping “F” on the data plate (see Clause 12); or
- an adequate corrosion allowance is specified, which shall not be less than 0,5 mm;

unless no corrosion risk is to be expected during the lifetime of the vessel.

The adopted corrosion allowance shall be indicated on the data plate (see Clause 12).

#### 6.3.3.2 Aluminium vessels do not require protection against corrosion, nor a corrosion allowance.

## 6.4 Calculation method

### 6.4.1 General

6.4.1.1 The nominal design stress,  $f$ , shall not exceed the lower value of  $0,6 R_{eT}$  or  $0,3 R_m$ .

6.4.1.2 All calculations shall be made for the vessel in the corroded condition.

6.4.1.3 For the purposes of this clause, pressure  $P$  is in newtons per square millimetre.

**6.4.1.4** The actual thickness  $e_a$  of the shell, ends and flanges shall not be less than the calculated thickness of the component:

$$e_a \geq e_c \quad (6.4.1.4-1)$$

where  $e_c$  is the calculated thickness.

**6.4.2 Calculated thickness of shells,  $e_{cs}$**

$$e_{cs} = \frac{PD_o}{2f+P} K_c K_s \quad (6.4.2-1)$$

where

$K_c$  is the calculation coefficient depending on the welding process:

$K_c = 1$  for welds made by automatic welding process (see Table 10.2.1-1 and Table 10.2.1-3);

$K_c = 1,15$  for welds made by non-automatic welding process (see Table 10.2.1-2 and Table 10.2.1-4);

$K_s$  is the shell coefficient depending on the amount of testing:

$K_s = 1$  for normal amount of testing (see Table 10.2.1-1 and Table 10.2.1-3);

$K_s = 1,25$  for alternative amount of testing (see Table 10.2.1-2 and Table 10.2.1-4).

**6.4.3 Calculated thickness of dished ends,  $e_{ce}$**

Dished ends shall fulfil the following limitations:

a) hemispherical ends:

$$0,002 D_o \leq e_a \leq 0,16 D_o \quad (6.4.3-a1)$$

b) elliptical ends:

$$0,002 D_o \leq e_a \leq 0,08 D_o \quad (6.4.3-b1)$$

$$h \geq 0,18 D_o \quad (6.4.3-b2)$$

c) torispherical ends:

$$0,002 D_o \leq e_a \leq 0,08 D_o \quad (6.4.3-c1)$$

$$r \geq 0,06 D_o \quad (6.4.3-c2)$$

$$r \geq 3e_a \quad (6.4.3-c3)$$

$$R \leq D_o \quad (6.4.3-c4)$$

where

$h$  is the outside height of the end;

$r$  is the inside knuckle radius, for torispherical ends;

$R$  is the inside spherical radius, for torispherical ends.

(see Figure 6.4.3-1)

The two relationships in 6.4.3b or the four relationships in 6.4.3c shall be fulfilled simultaneously.

In no case shall the thickness of the cylindrical or straight flange (see Figure 6.4.3-1a and Figure 6.4.3-1b) of a dished end be less than the thickness of a seamless unpierced cylindrical shell of the same diameter and material for the same design pressure and temperature.

**6.4.3.1 Hemispherical ends**

The thickness of hemispherical ends shall be determined using equation:

$$e_{ce} = \frac{PD_0}{4f + P} \quad (6.4.3.1-1)$$

NOTE When two hemispherical ends are welded together without a straight flange, the formula is multiplied by the appropriate  $K_f$  factor (this being the calculation coefficient shown in Table 10.2.1-1 to Table 10.2.1-4).

**6.4.3.2 Elliptical and torispherical ends**

Typical configurations are shown on Figure 6.4.3-1.

The thickness of elliptical and torispherical ends shall be determined using the following procedure.

a) Calculate  $P/f$ .

b) Enter Figure 6.4.3.2-1 with this value, read up to the appropriate  $h_e/D_0$  line for the proposed end shape and then across to the  $e_{ce}/D_0$  axis for the corresponding  $e_{ce}/D_0$  value, where  $h_e$  is the design height of the end:

$$h_e = \min \left[ (h); \left( \frac{D_0^2}{4(R + e_a)} \right); \left( \sqrt{\frac{D_0(r + e_a)}{2}} \right) \right] \quad (6.4.3.2-b1)$$

NOTE For elliptical ends, use:

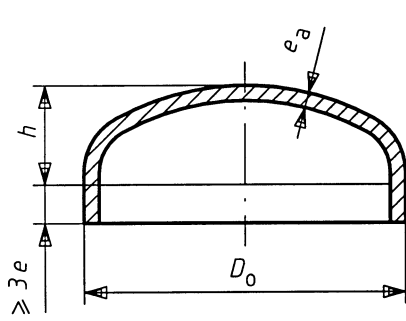
$$h_e = h \quad (6.4.3.2-b2)$$

c) Multiply by  $D_0$  to obtain the calculated end thickness.

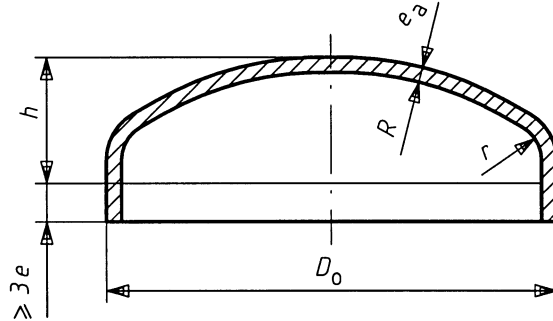
Numerical values of Table 6.4.3.2-1 may be used instead of curves of Figure 6.4.3.2-1.

Interpolation between  $h_e/D_0$  curves is permissible, or, alternatively, values may be read from the next higher  $h_e/D_0$  curve.

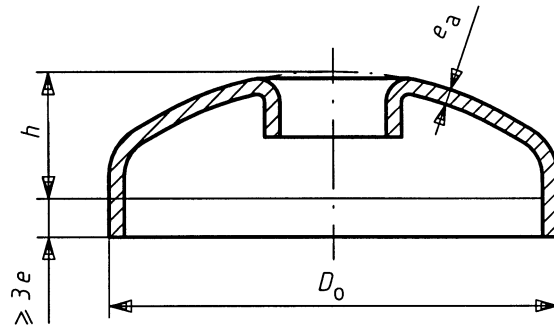
NOTE Figure 6.4.3.2-1 may be used with values of  $h_e$  and  $D_0$  based on internal dimensions, provided that  $h_e/D_0 < 0,27$ ; beyond this value, external dimensions are to be used.



a) Elliptical end



b) Torispherical end



c) End with manhole (elliptical torispherical)

**Figure 6.4.3-1 — Dished ends**

AC1

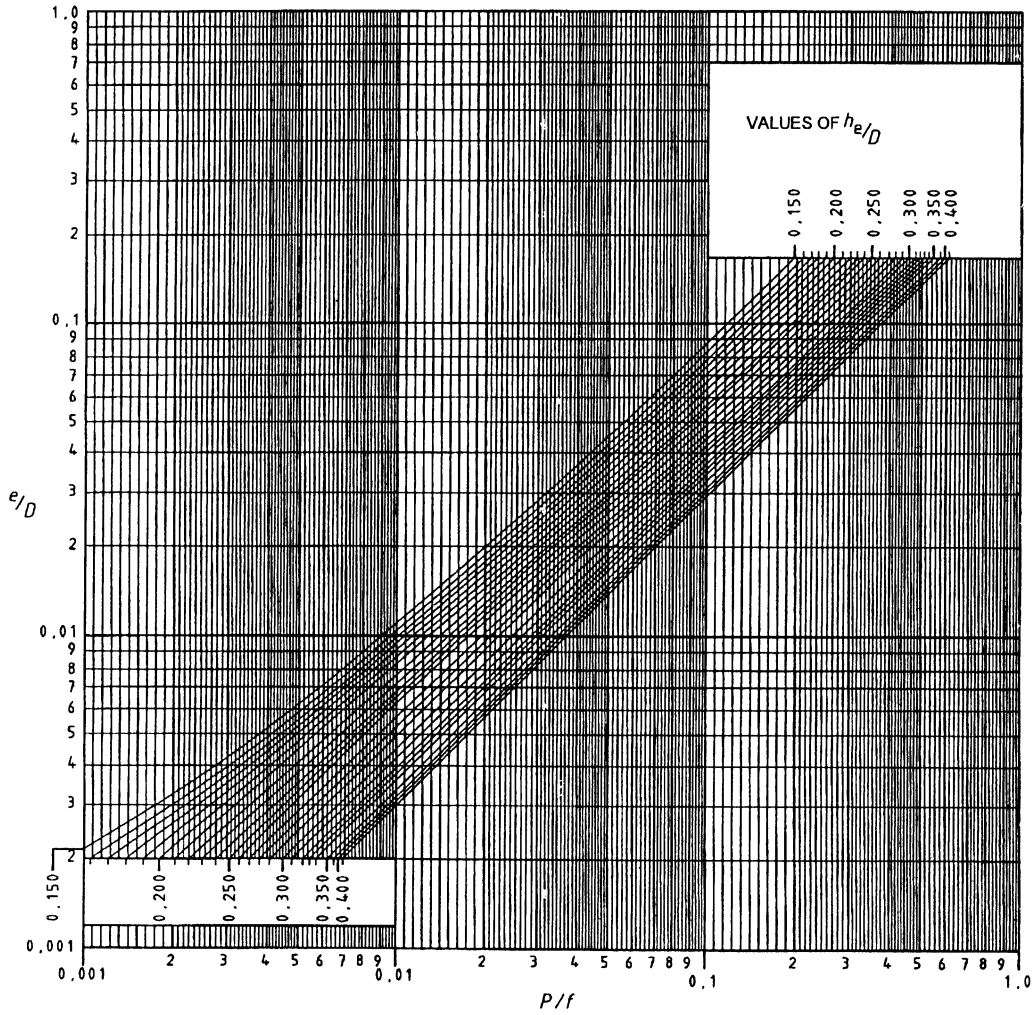


Figure 6.4.3.2-1 — Design curves for elliptical and torispherical ends

AC1

**Table 6.4.3.2-1 — Values of  $e_{ce}/D_o \times 10^3$  for unpierced elliptical and torispherical ends in terms of  $h_e/D_o$  and  $P/f$**

$\frac{h_e}{D_o}$	$P/f$									
	0,001	0,0015	0,0025	0,004	0,006	0,010	0,015	0,025	0,050	Greater values
0,15	2,13	2,70	3,73	5,22	7,20	10,9	15,4	24,0	44,5	$880 \times P/f$
0,16	(1,95)	2,50	3,50	4,90	6,70	10,2	14,3	22,2	41,5	$810 \times P/f$
0,17	(1,80)	2,30	3,24	4,58	6,30	9,6	13,5	21,0	39,2	$770 \times P/f$
0,18	(1,65)	2,11	2,99	4,23	5,80	8,8	12,6	19,7	37,0	$730 \times P/f$
0,19	—	(1,95)	2,77	3,95	5,43	8,3	11,8	18,5	35,0	$695 \times P/f$
0,20	—	(1,80)	2,55	3,64	5,00	7,7	11,0	17,3	33,0	$650 \times P/f$
0,21	—	(1,65)	2,39	3,42	4,75	7,3	10,4	16,2	$620 \times P/f$	—
0,22	—	(1,52)	2,22	3,20	4,45	6,84	9,7	15,4	$585 \times P/f$	—
0,23	—	(1,40)	2,08	2,95	4,12	6,30	9,1	14,5	$555 \times P/f$	—
0,24	—	—	(1,92)	2,76	3,83	5,90	8,5	13,6	$530 \times P/f$	—
0,25	—	—	(1,75)	2,58	3,56	5,50	7,8	$500 \times P/f$	—	—
0,26	—	—	(1,64)	2,40	3,34	5,15	7,35	$475 \times P/f$	—	—
0,27	—	—	(1,52)	2,25	3,12	4,80	6,80	$445 \times P/f$	—	—
0,28	—	—	(1,41)	2,12	2,93	4,50	6,45	$425 \times P/f$	—	—
0,29	—	—	—	(2,00)	2,73	4,20	$405 \times P/f$	—	—	—
0,30	—	—	—	(1,86)	2,54	3,95	$385 \times P/f$	—	—	—
0,31	—	—	—	(1,71)	2,41	3,80	$370 \times P/f$	—	—	—
0,32	—	—	—	(1,61)	2,30	3,65	$358 \times P/f$	—	—	—
0,33	—	—	—	(1,52)	2,20	3,50	$345 \times P/f$	—	—	—
0,34	—	—	—	(1,45)	2,10	$335 \times P/f$	—	—	—	—
0,35	—	—	—	—	$325 \times P/f$	—	—	—	—	—
0,36	—	—	—	—	$319 \times P/f$	—	—	—	—	—
0,38	—	—	—	—	$307 \times P/f$	—	—	—	—	—
0,40	—	—	—	—	$295 \times P/f$	—	—	—	—	—

NOTE 1 This table is not valid for values of  $e_{ce}/D_o \times 10^3 < 2,00$ .  
 NOTE 2 Intermediate values may be obtained by logarithmic interpolation.  
 NOTE 3 Values in parentheses are provided for purposes of interpolation.

**6.4.4 Calculated thickness of flat ends and covers**

**6.4.4.1 Flat ends without openings**

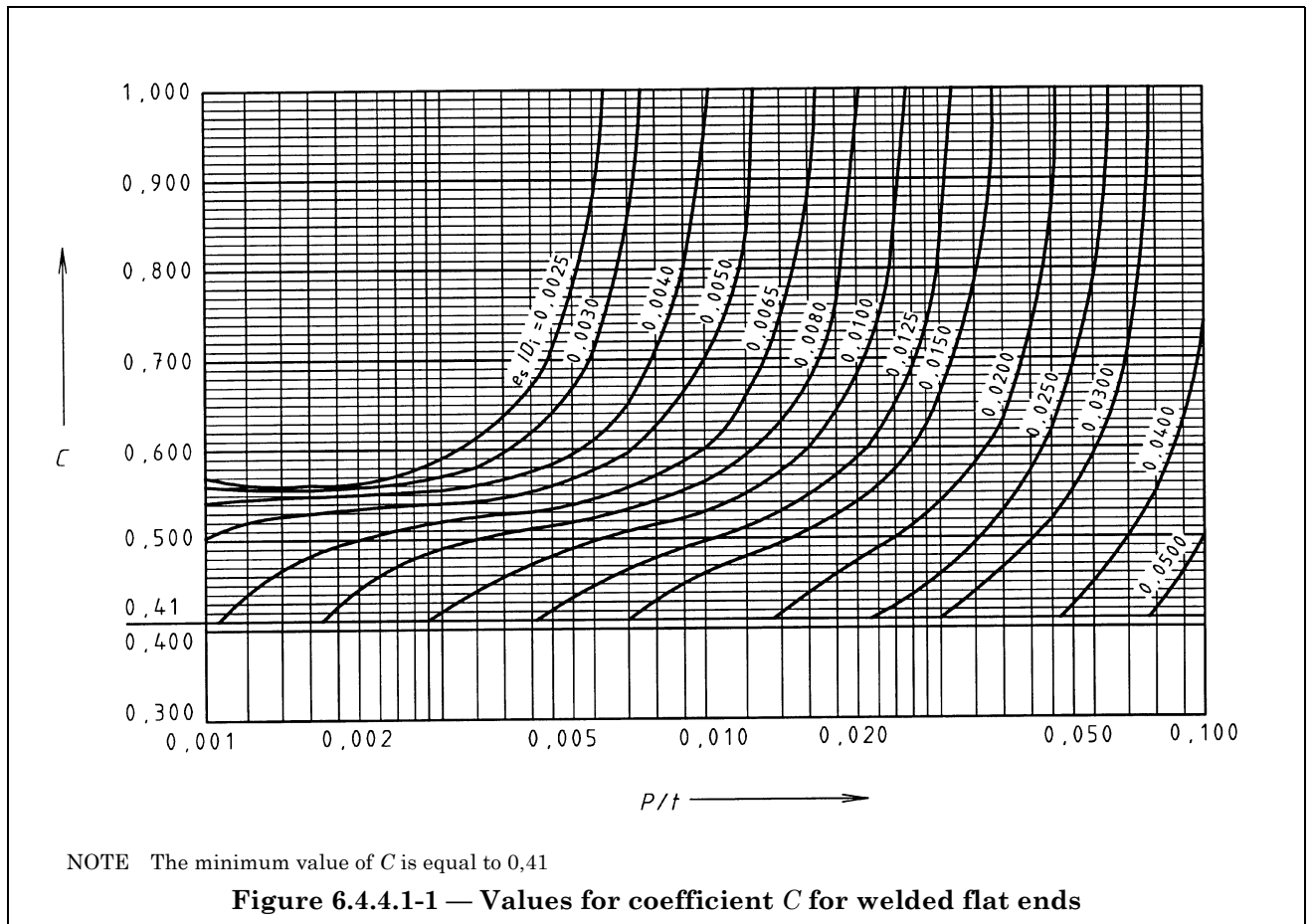
The calculated thickness of a flat end is given by the following equation:

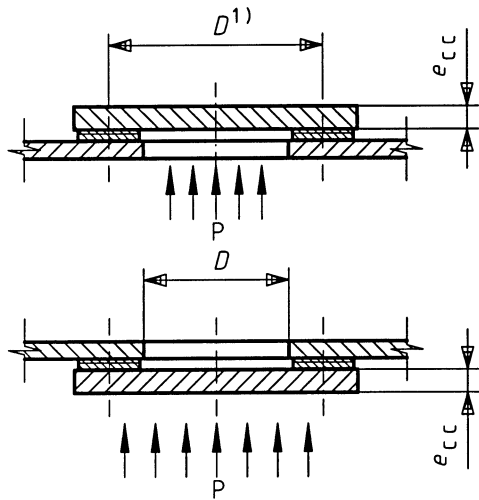
$$e_{ce} = CD_i \sqrt{\frac{P}{f}} \tag{6.4.4.1-1}$$

where

- $C$  is obtained from Figure 6.4.4.1-1;
- $D_i$  is the internal diameter of the end (see Figure 6.4.4.1-2c).

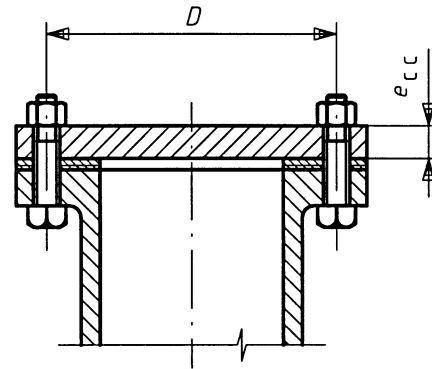




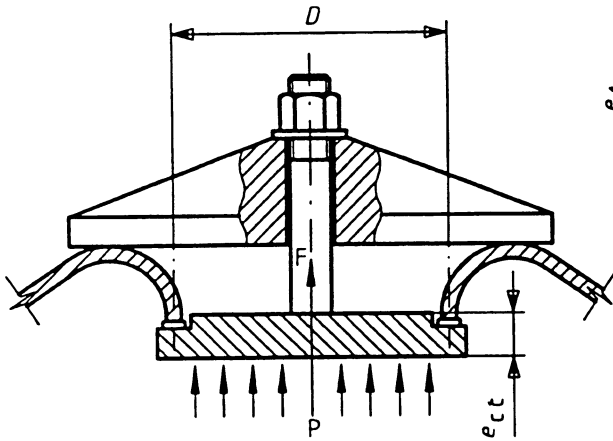


<sup>1)</sup>  $D$  is the mean gasket diameter.

a1) Flat cover with a full-faced gasket,  $C = 0,41$

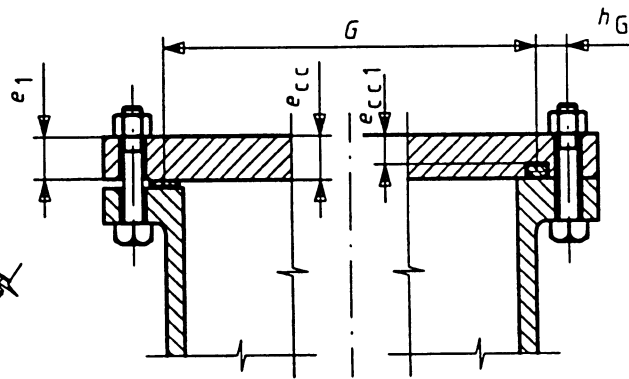


a2) Cover with a full-faced  $C = 0,41$

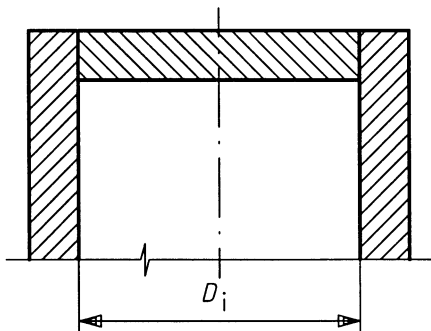


This configuration to be used in connection with configuration 6.4.3.1c and 6.4.6.3-11

a3) Cover with self-sealing joint



b) Cover with gasket entirely within the bolt circle



NOTE 1 See Figure 6.2.5-1 for details of welded joints.

c) Welded flat end

**Figure 6.4.4.1-2 — Typical flat ends and covers**

#### 6.4.4.2 Covers without opening

The calculated thickness of a cover is calculated from the appropriate following equation.

- a) For covers with full-faced gasket or with self-sealing joint (Figure 6.4.4.1-2a1, Figure 6.4.4.1-2a2 and Figure 6.4.4.1-2a3):

$$e_{cc} = CD \sqrt{\frac{P}{f}} \quad (6.4.4.2-a1)$$

where

$D$  is the design diameter shown in Figure 6.4.4.1-2a1, Figure 6.4.4.1-2a2 and Figure 6.4.4.1-2a3;

$C = 0,41$  for full-faced gasket covers (Figure 6.4.4.1-2a1 and Figure 6.4.4.1-2a2);

$$c = \sqrt{0,17 + 0,75 \frac{F}{H}} \text{ for self-sealing joint (Figure 6.4.4.1-2a3)} \quad (6.4.4.2-a2);$$

where

$F$  is the total bolt load;

$H$  is the total hydrostatic end load.

- b) For covers with gasket entirely within the bolt circle (Figure 6.4.4.1-2b):

- 1) For circular covers the following equations apply:

$$e_{cc} = \max \left[ \left( \sqrt{\frac{0,3 G^2 P}{f_{F,op}} + \frac{1,91 W_{m,op} h_G}{G f_{F,op}}} \right); \left( \sqrt{\frac{1,91 W h_G}{G f_{F,b}}} \right) \right] \quad (6.4.4.2-b1-1)$$

$$e_{cc1} = \max \left[ \left( \sqrt{\frac{1,91 W_{m,op} h_G}{G f_{F,op}}} \right); \left( \sqrt{\frac{1,91 W h_G}{G f_{F,b}}} \right) \right] \quad (6.4.4.2-b1-2)$$

where

$e_{cc}$  and  $e_{cc1}$  are shown in Figure 6.4.4.1-2b;

$W$ ,  $W_{m,op}$ ,  $h_G$ ,  $G$  are given in 6.4.5.1.1;

$f_{F,op}$ ,  $f_{F,b}$  are the nominal design stress of the cover for operating conditions or bolting-up condition.

- 2) For non-circular covers the following equations apply:

$$e_{cc} = \max \left[ \left( \sqrt{\frac{0,3 G^2 P Z_0^2}{f_{F,op}} + \frac{6 W_{m,op} h_G}{n p f_{F,op}}} \right); \left( \sqrt{\frac{6 W h_G}{n p f_{F,b}}} \right) \right] \quad (6.4.4.2-b2-1)$$

$$e_{cc1} = \max \left[ \left( \sqrt{\frac{6 W_{m,op} h_G}{n p f_{F,op}}} \right); \left( \sqrt{\frac{6 W h_G}{n p f_{F,b}}} \right) \right] \quad (6.4.4.2-b2-2)$$

where

- $e_{cc}$  and  $e_{cc1}$  are shown in Figure 6.4.4.1-2b;
- $W, W_{m,op}, h_G, G$  are given in 6.4.5.1.1;
- $f_{F,op}, f_{F,b}$  are the nominal design stress of the cover for operating conditions or bolting-up condition;
- $G$  is measured along the shorter axis;
- $p$  is the minimum bolt spacing;
- $n$  is the number of bolts;
- $Z_o$  is obtained from Figure 6.4.4.2-1, in terms of  $b_{min}$  and  $b_{max}$  (see Figure 6.4.4.2-2).

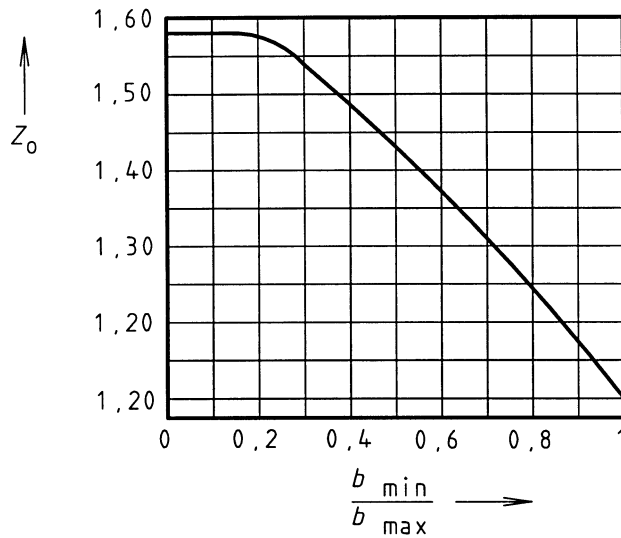


Figure 6.4.4.2-1 — Values of coefficient  $Z_o$  for non-circular covers

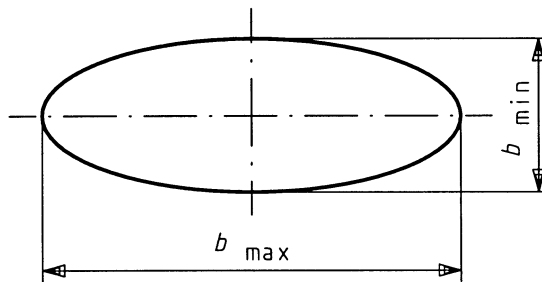


Figure 6.4.4.2-2 — Definition of  $b_{min}$  and  $b_{max}$

**6.4.4.3 Openings in flat ends and covers**

Flat ends or covers with openings where diameter  $d$  is greater than  $D/2$  shall be calculated by using the appropriate equation in **6.4.5**.

Openings with  $d \leq D/2$  shall be provided with reinforcement as given in **6.4.7**.

**6.4.5 Flange calculations**

The following calculations apply to the following four classes of flanges:

- narrow-faced gasket flanges, treated in **6.4.5.1** (see Figure 6.4.5.1-1);
- full-faced gasket flanges, treated in **6.4.5.2** (see Figure 6.4.5.2-1);
- reverse narrow-faced gasket flanges, treated in **6.4.5.3** (see Figure 6.4.5.3-1);
- reverse full-faced gasket flanges, treated in **6.4.5.4** (see Figure 6.4.5.4-1).

For the purpose of calculation, flanges shall be classified in two types:

- integral-type flanges, in which account is taken of support from the shell. Figure 6.4.5-1 shows the three configurations a, b, c permitted for integral flanges;
- loose-type flanges, in which the flange is assumed to get no support from the shell. Figure 6.4.5-1 shows the three configurations d, e, f permitted for loose flanges.

NOTE Figure 6.4.5-1, which shows narrow-faced gasket flanges, can also be used for the three other classes of flange mentioned above.




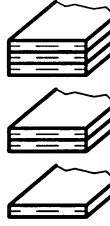


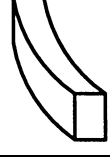

Subclause **6.4.5.1** for narrow gasket flanges gives the complete basic calculation method. The three other classes of flange refer to this basic method, with modifications mentioned in the three relevant subclauses, **6.4.5.2**, **6.4.5.3** and **6.4.5.4**.

All calculations shall be made for both the operating conditions (more than one operating condition may require consideration) and the bolting-up condition.

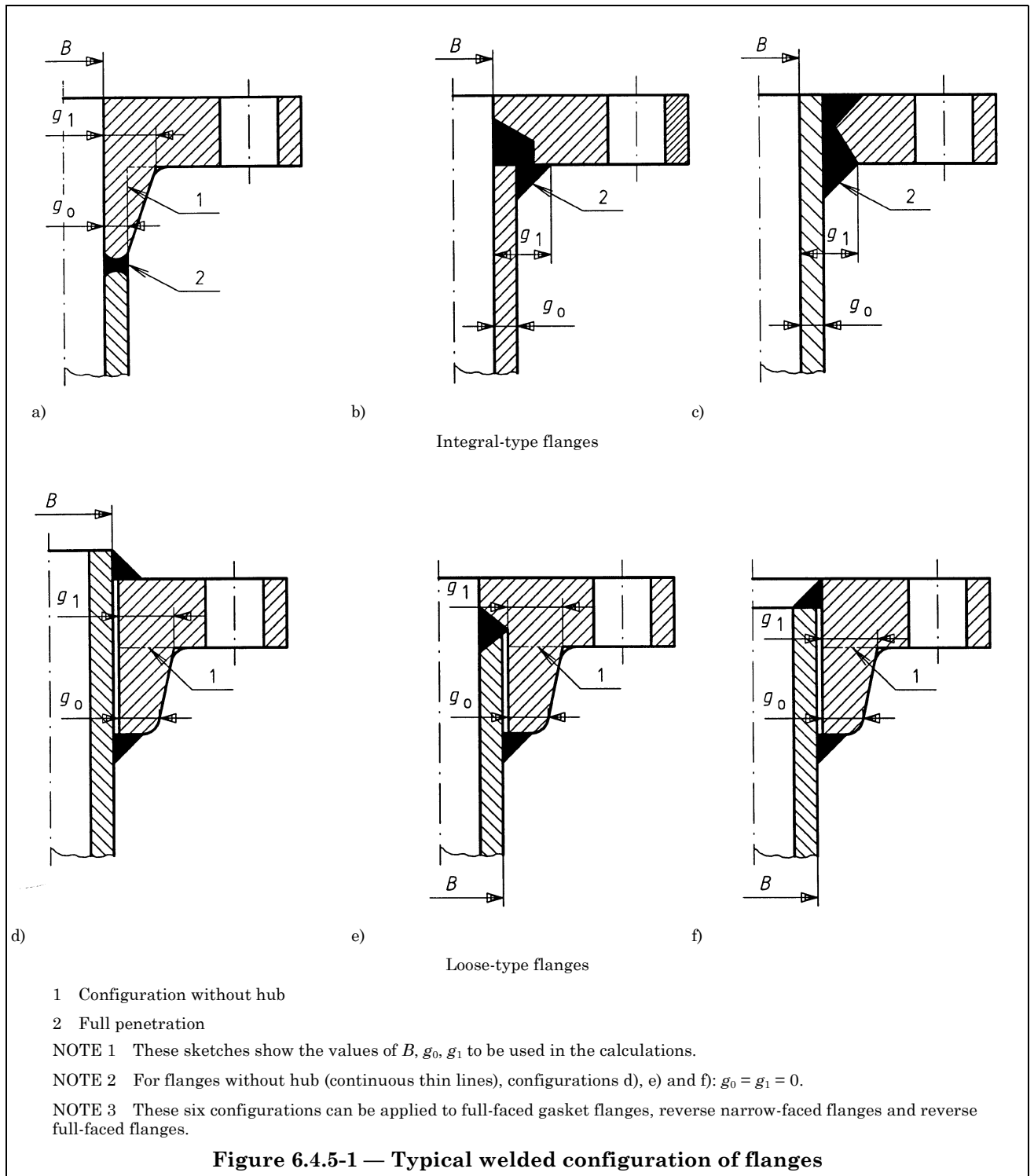
Recommended values for the gasket factors  $m$  and  $y$  are given in Table 6.4.5-1 for various gaskets.

If standard flanges of up to 250 mm diameter in accordance with ISO 7005-1 are used, the calculation of the flange is not mandatory.

**Table 6.4.5-1 — Recommended gasket factors ( $m$ ) for operating conditions and minimum design seating stress ( $y$ )**

Gasket material	Gasket factor $m$	Minimum design seating stress $y$ N/mm <sup>2</sup>	Sketches
Rubber without fabric or high percentage of fibre: — below 75° IRH — 75° IRH or higher	0,50 1,00	0 1,4	
Compressed fibre binder with a suitable binder for the operating conditions: — 3,2 mm thick — 1,6 mm thick — 0,8 mm thick	2,0 2,75 3,50	11,0 25,5 44,8	
Rubber with cotton fabric insertion	1,25		
Rubber with fabric insertion, with or without wire reinforcement: — 3-ply — 2-ply — 1-ply	2,25 2,50 2,75	15,2 20,0 25,5	
Vegetable fibre	1,75	7,6	
Rubber O-rings: — below 75° IRH — between 75° and 85° IRH	0 0,25	0,7 1,4	
Rubber square-section rings: — below 75° IRH — between 75° and 85° IRH	0 0,25	1,0 2,8	
Rubber T-section rings: — below 75° IRH — between 75° and 85° IRH	0 0,25	1,0 2,8	

NOTE The use of asbestos is prohibited in several countries.



6.4.5.1 Narrow-faced gasket flanges

Hereafter, calculations apply to narrow-faced gasket flanges as represented in Figure 6.4.5.1-1. Figure 6.4.5-1 shows typical configurations of integral flanges (configurations a, b, c) and of loose-type flanges (configurations d, e, f).

The rule applies to circular flanges. However, it can be extended to non-circular flanges, as shown in Figure 6.4.5.1-2, if the inside diameter is less than 80 mm (Figure 6.4.5.1-2a) or 120 mm (Figure 6.4.5.1-2b). The outside diameter  $A$ , to be used in the calculations, is represented in Figure 6.4.5.1-2.

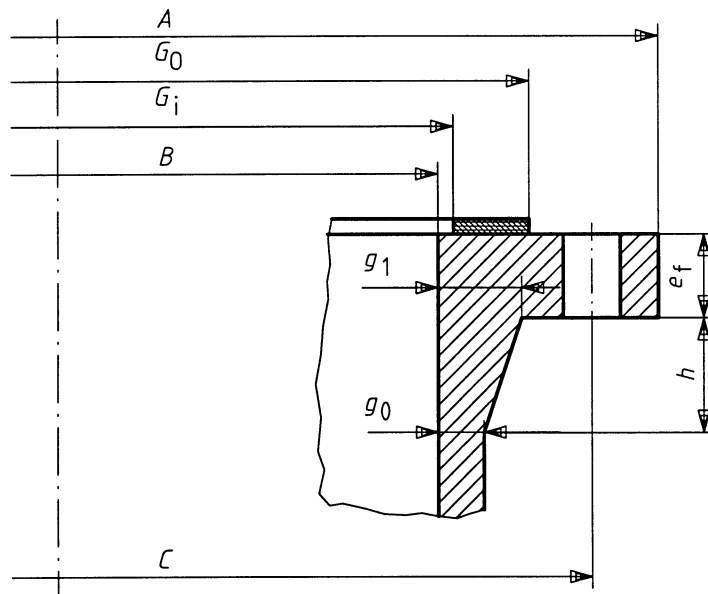
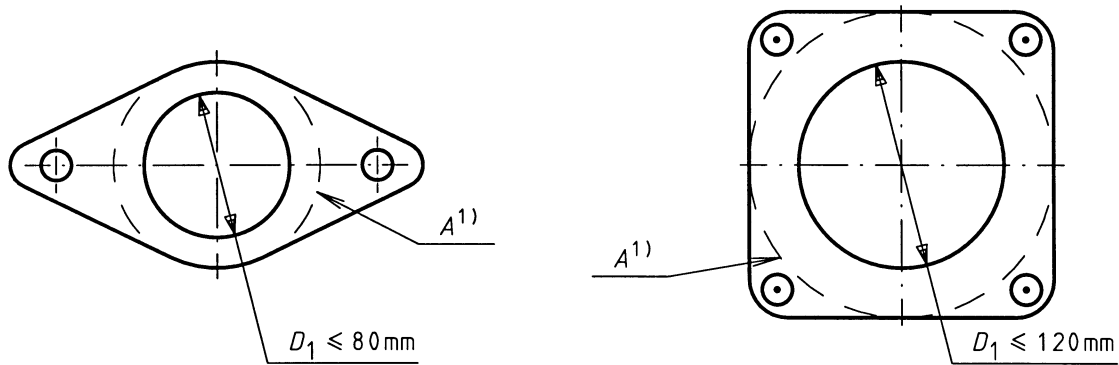


Figure 6.4.5.1-1 — Narrow-faced gasket flange



<sup>1)</sup>  $A$  is the diameter to be used in the calculations.

Figure 6.4.5.1-2 — Non-circular flanges



### 6.4.5.1.1 Symbols

For the purposes of the calculations, the following symbols are used in addition to those given in 3.2. All dimensions are in the corroded condition.

NOTE Further modified symbols are given in 6.4.5.2, 6.4.5.3 and 6.4.5.4.

$A$	outside diameter of flange	
$A_m$	total required cross-sectional area of bolts	
$A_{m,op}$	total cross-sectional area of bolts required for operation conditions	
$A_{m,b}$	total cross-sectional area of bolts required for bolting-up condition	
$b$	effective gasket seating width $\overline{AC_1}$ :	
	$b = \frac{G_o - G_i}{4}$	(6.4.5.1.1-1) $\overline{AC_1}$
$B$	inside diameter of flange, in millimetres (mm) (see Figure 6.4.5-1a, Figure 6.4.5-1b, Figure 6.4.5-1c for integral-type, and Figure 6.4.5-1d, Figure 6.4.5-1e, Figure 6.4.5-1f for loose-type)	
$C$	bolt circle diameter	
$e_f$	flange thickness, at the thinnest section	
$f_{op}$	nominal design stress of bolts at operating temperature	
$f_b$	nominal design stress of bolts at bolting-up temperature	
$f_{F,op}$	nominal design stress of flange material at operating temperature	
$f_{F,b}$	nominal design stress of flange material at bolting-up temperature	
$g_o$	thickness of hub at small end	
$g_i$	thickness of hub at back of flange	
$G$	mean diameter of gasket contact surface:	
	$G = \frac{G_i + G_o}{2}$	(6.4.5.1.1-2)
$G_i$	inside diameter of gasket contact surface	
$G_o$	outside diameter of gasket contact surface	
$h_o = \sqrt{B g_o}$		(6.4.5.1.1-3)
$h$	hub length	
$h_D$	radial distance from bolt circle to circle on which $H_D$ acts	
$h_T$	radial distance from bolt circle to circle on which $H_T$ acts	
$h_G$	radial distance from gasket load reaction to bolt circle	
$H_D$	hydrostatic end force applied via shell to flange	
$H_T$	hydrostatic end force due to pressure on flange face	
$H_G$	compression load on gasket	
$K = \frac{A}{B}$		(6.4.5.1.1-4)
$m$	gasket factor obtained from Table 6.4.5-1, or from gasket supplier	
$M_{op}$	total moment acting upon the flange for operating conditions	
$M_b$	total moment acting upon the flange for bolting-up condition	
$T = \frac{K^2 (1 + 8,55246 \log_{10} K) - 1}{(1,0472 + 1,9448 K^2) (K - 1)}$		(6.4.5.1.1-5)

$$U = \frac{K^2 (1 + 8,55246 \log_{10} K) - 1}{1,36136 (K^2 - 1)(K - 1)} \quad (6.4.5.1.1-6)$$

$W$  flange design bolt load  
 $W_{m,op}$  minimum required bolt load for operating conditions  
 $W_{m,b}$  minimum required bolt load for bolting-up condition  
 $y$  gasket seating stress from Table 6.4.5-1, or from gasket supplier

$$Y = \frac{1}{K-1} \left( 0,66845 + 5,71690 \frac{K^2 \log_{10} K}{K^2 - 1} \right) \quad (6.4.5.1.1-7)$$

$$Z = \frac{K^2 + 1}{K^2 - 1} \quad (6.4.5.1.1-8)$$

**6.4.5.1.2 Bolt loads and areas**

It is recommended that bolts and studs have a nominal diameter of not less than 12 mm, but in no case less than 8 mm.

The nominal design stress of the bolt shall not be greater than  $0,6R_{eT}$  or  $0,3R_m$ . Table 6.4.5.1.2-1 gives values for nominal design stress values in cases where the bolt standard used does not give  $R_{eT}$  and  $R_m$  values.

**Table 6.4.5.1.2-1 — Nominal design stress values for flange bolting material**

Material	References EN 20898 property class	Recommended nominal design stress N/mm <sup>2</sup>				
		50 °C	100 °C	200 °C	250 °C	300 °C
Carbon steel	8.8	192	174	139	129	119
Carbon steel	5.6	150	125	105	95	80

The pitch between bolt/stud centres should not be greater than:

$$2 d_b + \frac{6e}{m + 0,5} \quad (6.4.5.1.2-1)$$

where

$d_b$  is the nominal diameter of bolts;  
 $e$  is the nominal flange thickness.

The minimum bolt loads and areas are given by:

— for the operating conditions:

$$W_{m,op} = H_D + H_T + H_G \quad (6.4.5.1.2-2)$$

$$A_{m,op} = \frac{W_{m,op}}{f_{op}} \quad (6.4.5.1.2-3)$$

— for the bolting-up condition:

$$W_{m,b} = \pi b G y \quad (6.4.5.1.2-4)$$

$$A_{m,b} = \frac{W_{m,b}}{f_b} \quad (6.4.5.1.2-5)$$

The actual bolt area  $A_{\text{act}}$  shall not be less than  $A_{\text{m}}$ :

$$A_{\text{act}} \geq A_{\text{m}} \quad (6.4.5.1.2-6)$$

where

$$A_{\text{m}} = \max [(A_{\text{m,op}}); (A_{\text{m,b}})] \quad (6.4.5.1.2-7)$$

#### 6.4.5.1.3 Flange loads and moments

For the operating conditions, Table 6.4.5.1.3-1 states loads, lever arms and moments.

For the bolting-up condition:

$$W_{\text{b}} = \frac{A_{\text{m}} + A_{\text{act}}}{2} \times f_{\text{b}} \quad (6.4.5.1.3-8)$$

$$M_{\text{b}} = W_{\text{b}} h_{\text{G}} \quad (6.4.5.1.3-9)$$

**Table 6.4.5.1.3-1 — Loads, lever arms and moments for operating conditions**

Loads		Lever arms	
$H_{\text{D}} = \frac{\pi}{4} B^2 P$	(6.4.5.1.3-1)	$h_{\text{D}} = \frac{C - B - g_1}{2}$	(6.4.5.1.3-2)
$H_{\text{T}} = \frac{\pi}{4} (G^2 - B^2) P$	(6.4.5.1.3-3)	$h_{\text{T}} = \frac{2C - B - G}{4}$	(6.4.5.1.3-4)
$H_{\text{G}} = \pi (2b) G m P$	(6.4.5.1.3-5)	$h_{\text{G}} = \frac{C - G}{2}$	(6.4.5.1.3-6)
$M_{\text{op}} = H_{\text{D}} h_{\text{D}} + H_{\text{T}} h_{\text{T}} + H_{\text{G}} h_{\text{G}}$		(6.4.5.1.3-7)	
NOTE For loose-type flanges: $g_1 = 0$ in equation 6.4.5.1.3-2.			

#### 6.4.5.1.4 Flange stresses

The moment  $M$  is equal to:

— for operating conditions:

$$M = \frac{M_{\text{op}}}{B} \quad (6.4.5.1.4-1)$$

— for the bolting-up condition:

$$\frac{M}{B} = \frac{M_{\text{b}}}{B} \quad (6.4.5.1.4-2)$$

The flange stresses shall be determined as follows.

a) For integral-type flanges, the maximum stresses are given by:

— longitudinal hub stress:

$$\sigma_{\text{H}} = \frac{f_{\text{I}}}{\lambda I g_1^2} \times M \quad (6.4.5.1.4-a1)$$

— radial flange stress:

$$\sigma_{\text{R}} = \frac{\frac{4}{3} \times \frac{F_1}{h_o} \times e_{\text{f}} + 1}{\lambda_{\text{I}} e_{\text{f}}^2} \times M \quad (6.4.5.1.4-a2)$$

— tangential flange stress:

$$\sigma_{\text{T}} = \frac{Y}{e_{\text{f}}^2} \times M - Z \times \sigma_{\text{R}} \quad (6.4.5.1.4-a3)$$

where

$$\lambda_I = \frac{\frac{F_I}{h_o} \times e_f + 1}{T} + \frac{V_I}{U} \times \frac{e_f^3}{h_o g_o^2} \quad (6.4.5.1.4-a4)$$

$F_I$ ,  $V_I$ ,  $f_I$  are integral flange factors given in Figure 6.4.5.1.4-1, Figure 6.4.5.1.4-2 and Figure 6.4.5.1.4-3 respectively.

b) For loose-type flanges, the maximum stresses are given by:

— longitudinal hub stress:

$$\sigma_H = \frac{1}{\lambda_L g_1^2} \times M \quad (6.4.5.1.4-b1)$$

— radial flange stress:

$$\sigma_R = \frac{\frac{4}{3} \times \frac{F_L}{h_o} \times e_f + 1}{\lambda_L e_f^2} \times M \quad (6.4.5.1.4-b2)$$

— tangential flange stress:

$$\sigma_T = \frac{Y}{e_f^2} \times M - Z \sigma_R \quad (6.4.5.1.4-b3)$$

where

$$\lambda_L = \frac{\frac{F_L}{h_o} \times e_f + 1}{T} + \frac{V_L}{U} \times \frac{e_f^3}{h_o g_o^2} \quad (6.4.5.1.4-b4)$$

$F_L$  and  $V_L$  are loose flange factors given in Figure 6.4.5.1.4-4 and Figure 6.4.5.1.4-5 respectively.

NOTE If there is no hub:

$$\sigma_H = 0 \quad (6.4.5.1.4-b5)$$

$$\sigma_R = 0 \quad (6.4.5.1.4-b6)$$

$$\sigma_T = \frac{Y}{e_f^2} \times M \quad (6.4.5.1.4-b7)$$

c) For integral and loose-type flanges, these maximum stresses are limited as follows:

$$\sigma_H \leq 1,5 f_F \quad (6.4.5.1.4-c1)$$

$$\sigma_R \leq f_F \quad (6.4.5.1.4-c2)$$

$$\sigma_T \leq f_F \quad (6.4.5.1.4-c3)$$

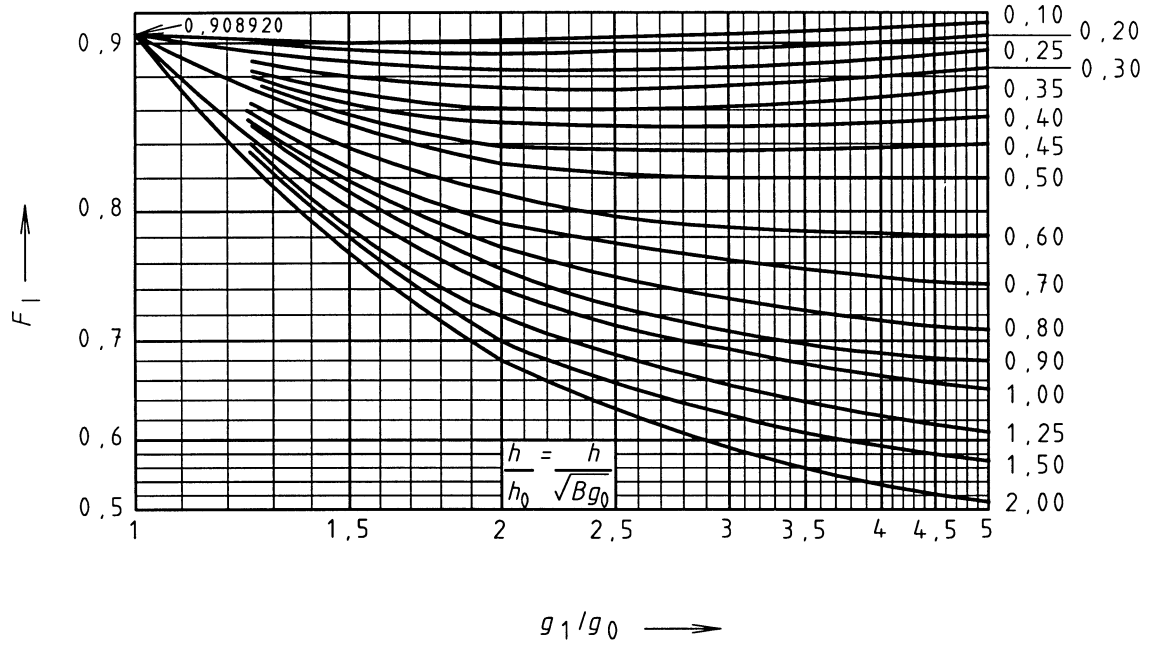
$$\frac{\sigma_H + \sigma_R}{2} \leq f \quad (6.4.5.1.4-c4)$$

$$\frac{\sigma_H + \sigma_T}{2} \leq f \quad (6.4.5.1.4-c5)$$

where

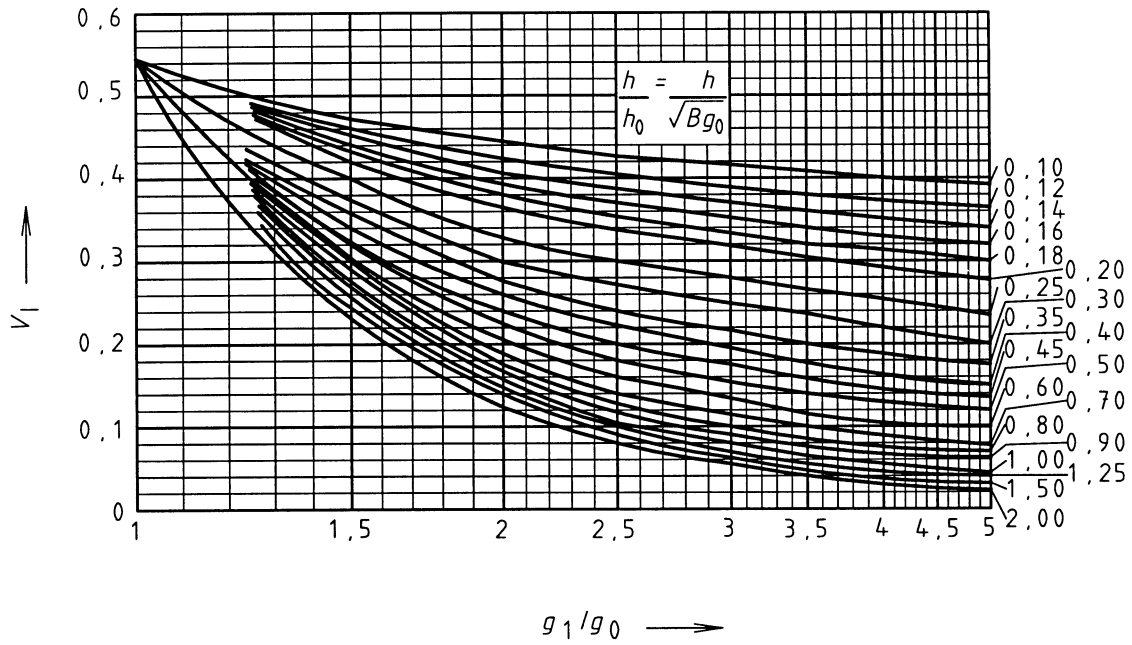
$$f_F = f_{F,op} \text{ when considering the operating conditions} \quad (6.4.5.1.4-c6)$$

$$f_F = f_{Fb} \text{ when considering the bolting-up conditions} \quad (6.4.5.1.4-c7)$$



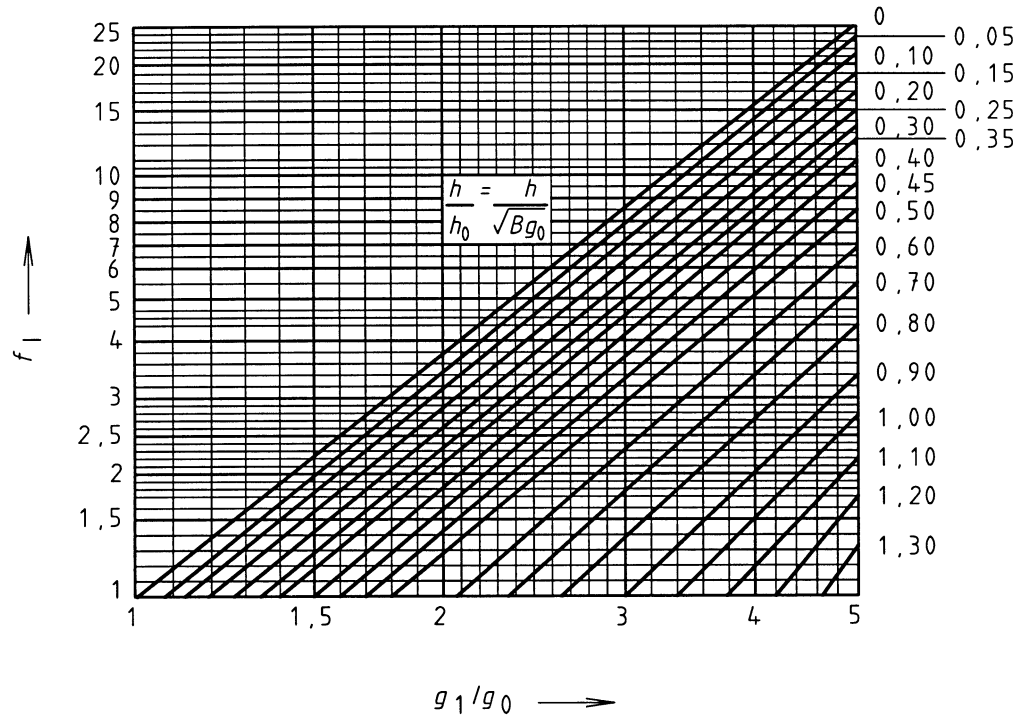
NOTE Use  $\frac{g_1}{g_0} = 1$  when there is no hub.

**Figure 6.4.5.1.4-1 — Values of  $F_1$  applicable to integral-type hub flanges (Figure 6.4.5-1a, 6.4.5-1b and 6.4.5-1c)**



NOTE Use  $\frac{g_1}{g_0} =$  when there is no hub.

**Figure 6.4.5.1.4-2 — Values of  $V_1$  applicable to integral-type hub flanges (Figures 6.4.5-1a, 6.4.5-1b, 6.4.5-1c)**



NOTE 1  $f = 1$  for hubs of uniform thickness ( $\frac{g_1}{g_0} = 1$ ).

NOTE 2 Use  $\frac{g_1}{g_0} = 1$  when there is no hub.

**Figure 6.4.5.1.4-3 — Values of  $f_I$  applicable to integral-type hub flanges  
(Figures 6.4.5-1a, 6.4.5-1b, 6.4.5-1c)**

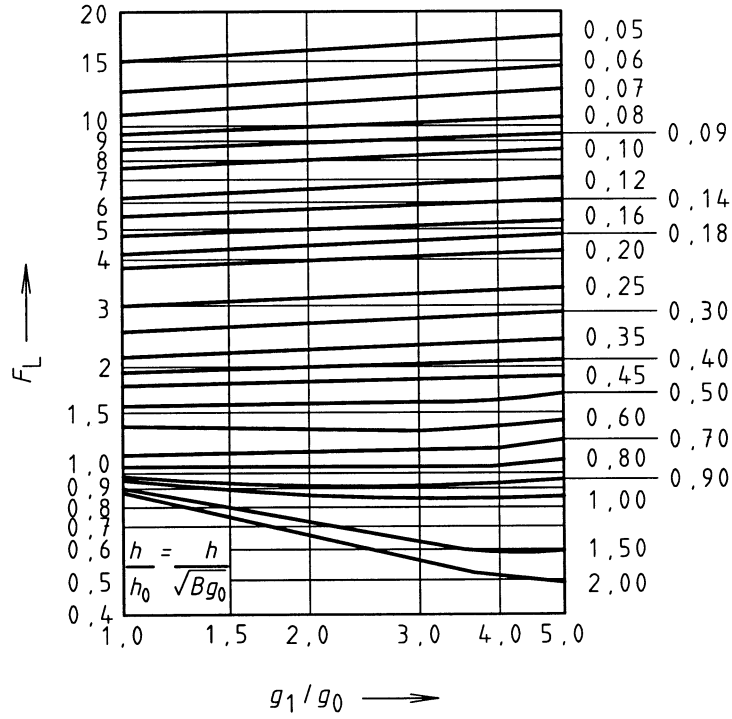


Figure 6.4.5.1.4-4 — Values of  $F_L$  applicable to loose-type hub flanges (Figures 6.4.5-1d, 6.4.5-1e, 6.4.5-1f)

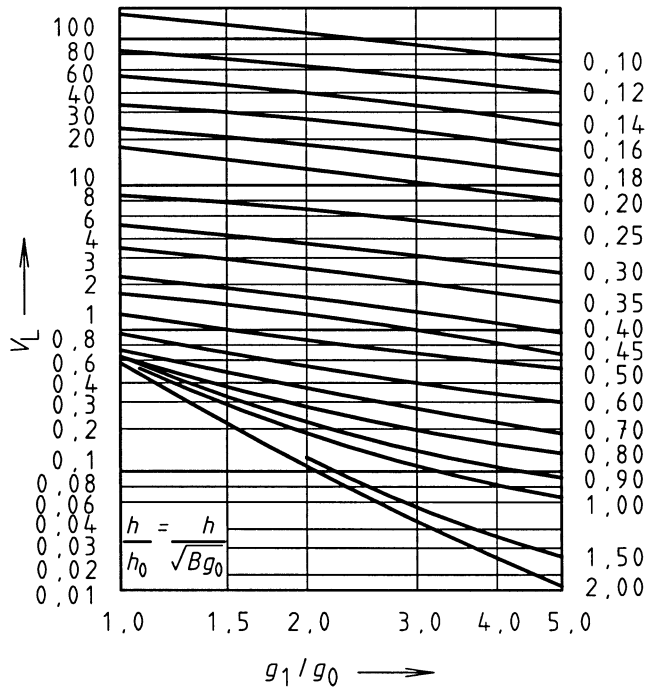
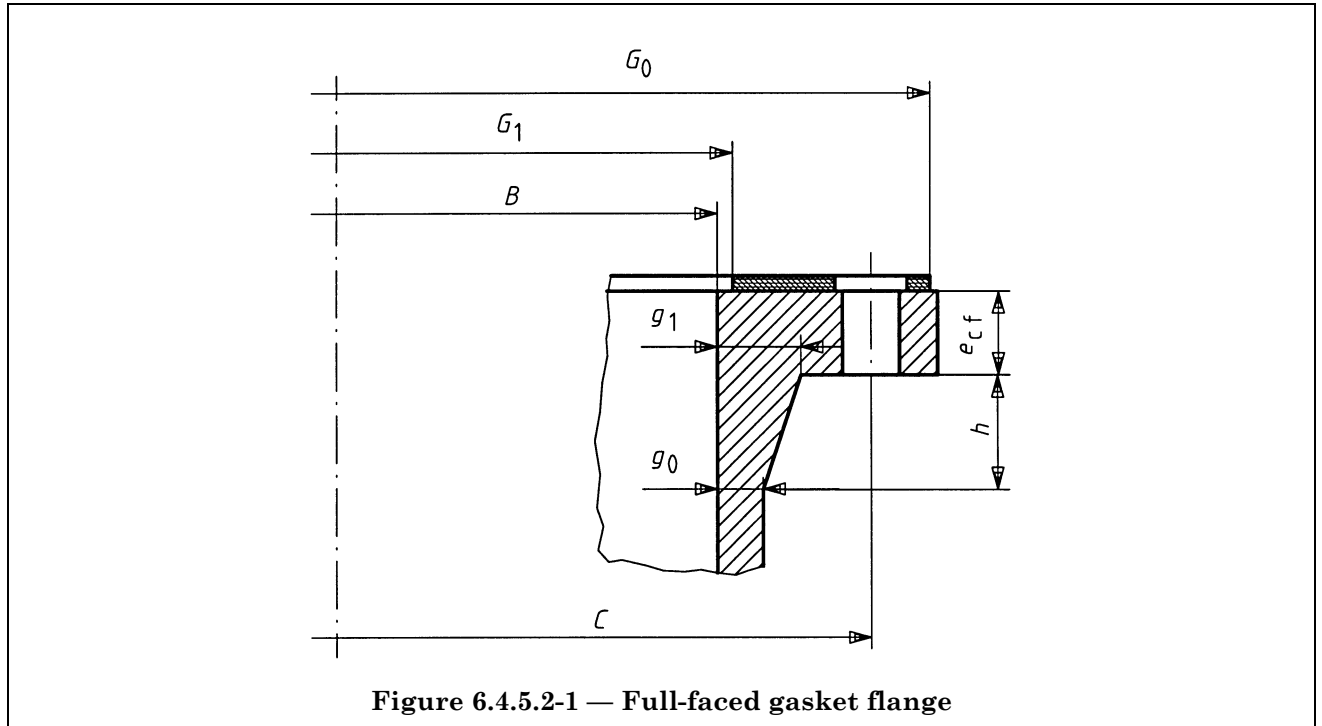


Figure 6.4.5.1.4-5 — Values of  $V_L$  applicable to loose-type hub flanges (Figures 6.4.5-1d, 6.4.5-1e, 6.4.5-1f)



#### 6.4.5.2 Full-faced gasket flanges

Hereafter, calculations apply to full-faced flanges with non-metallic gaskets not less than 1,5 mm thick and extending beyond the bolt circle, as shown in Figure 6.4.5.2-1. Configurations of flanges represented in Figure 6.4.5-1 are accepted.



6.4.5.2.1 Symbols

For the purpose of the calculations, the following symbols are additional to, or modify, those given in 3.2 and 6.4.5.1.1.

- $b'$  effective gasket seating width:  

$$b' = 4\sqrt{G_o - C} \tag{6.4.5.2.1-1}$$
- $2b''$  effective gasket pressure width:  

$$2b'' = 5 \text{ mm} \tag{6.4.5.2.1-2}$$
- $d_h$  diameter of bolt holes
- $e_{cf}$  calculated thickness of flange
- $G$  diameter at location of gasket load reaction:  

$$G = C - d_h - 2b'' \tag{6.4.5.2.1-3}$$
- $H_R$  balancing reaction force outside bolt circle in opposition to moments due to loads inside bolt circle
- $h_R$  radial distance from bolt circle to circle on which  $H_R$  acts
- $n$  number of bolts

6.4.5.2.2 Bolt loads and areas

Bolts shall be calculated in accordance with 6.4.5.1.2, with the following modifications:

$$W_{m,op} = H_D + H_T + H_G + H_R \tag{6.4.5.2.2-1}$$

$$W_{m,b} = \pi b' C y \tag{6.4.5.2.2-2}$$

6.4.5.2.3 Flange loads and moments

Loads, lever arms and moments shall be calculated in accordance with 6.4.5.1.3, with the modifications stated in Table 6.4.5.2.3-1.

Table 6.4.5.2.3-1 — Loads and lever arms for operating conditions

Loads		Lever arms	
$H_T = \frac{\pi}{4} - (G^2 - B^2) \times P$ (unchanged)	(6.4.5.2.3-1)	$h_T = \frac{C + d_h + 2b'' - B}{4}$	(6.4.5.2.3-2)
$H_G = \pi (2b'') G m P$	(6.4.5.2.3-3)	$h_G = \frac{d_h + 2b''}{2}$	(6.4.5.2.3-4)
$H_R = \frac{M_{op}}{h_R}$	(6.4.5.2.3-5)	$h_R = \frac{G_o - C + d_h}{4}$	(6.4.5.2.3-6)

6.4.5.2.4 Flange thickness

The flange thickness is given by the formula:

$$e_{cf} = \sqrt{\frac{6M_{op}}{f_{F,op} (\pi C - n d_h)}} \tag{6.4.5.2.4-1}$$

### 6.4.5.3 Reverse narrow-faced gasket flanges

Ⓐ) Hereafter, calculations apply to reverse flanges with narrow gaskets shown in Figure 6.4.5.3-1. Ⓐ) Configurations of flanges represented in Figure 6.4.5-1 are accepted.

If the inside shell diameter  $D_i$  is less than 300 mm, the configuration shown in Figure 6.4.5-1e can be used without back fillet weld (see Figure 6.4.5.3-1). In such a case the flange thickness  $e_f$ , shown in Figure 6.4.5.3-2, shall be used in the calculations.

#### 6.4.5.3.1 Symbols

For the purpose of the calculations, the following symbols are additional to, or modify, those given in 3.2 and 6.4.5.1.1.

$A$  inside diameter of flange

$B$  outside diameter of flange

$D_i$  inside diameter of shell:

$$D_i = B - 2g_0 \quad \text{for integral-type} \quad (6.4.5.3.1-1)$$

$$D_i = B \quad \text{for loose-type} \quad (6.4.5.3.1-2)$$

$$K = \frac{B}{A} \quad (6.4.5.3.1-3)$$

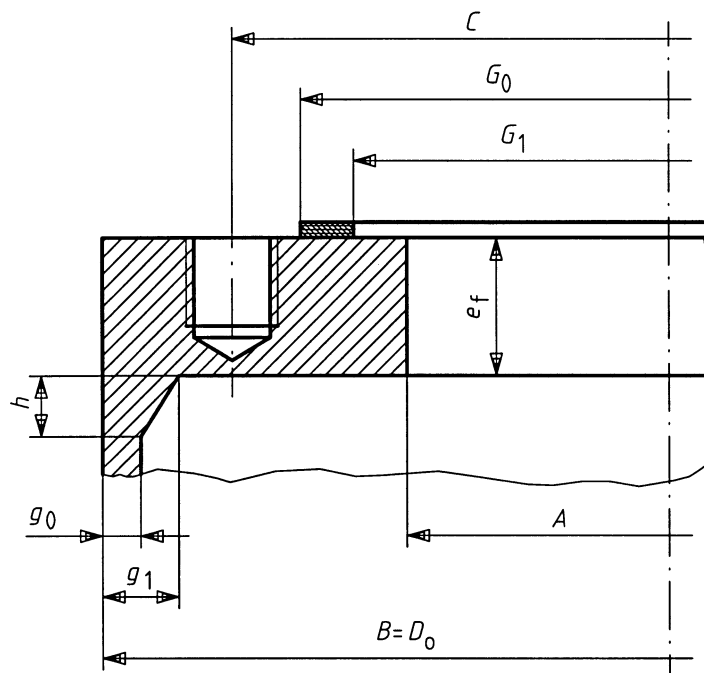


Figure 6.4.5.3-1 — Reverse narrow-faced gasket flange

#### 6.4.5.3.2 Bolt loads and areas

Bolts shall be calculated in accordance with 6.4.5.1.2.

#### 6.4.5.3.3 Flange loads and moments

Loads, lever arms and moments shall be calculated in accordance with 6.4.5.1.3, with the modifications stated in Table 6.4.5.3.3-1.

Table 6.4.5.3.3-1 — Loads and lever arms for operating conditions

Loads		Lever arms	
$H_D = \frac{\pi}{4} \times D_i^2 P$	(6.4.5.3.3-1)	$h_D = \frac{B - C - g_1}{2}$	(6.4.5.3.3-2)
$H_T = \frac{\pi}{4} (D_i^2 - G^2) \times P$	(6.4.5.3.3-3)	$h_T = \frac{2C - G - D_i}{2}$	(6.4.5.3.3-4)
NOTE 1 For loose-type flanges: $g_1 = 0$ in equation (6.4.5.3.3-2).			
NOTE 2 The sign of $h_T$ [equation (6.4.5.3.3-4)], which can be negative, shall be taken into account.			

6.4.5.3.4 Flange stresses

Stresses shall be calculated in accordance with 6.4.5.1.4, using as the moment  $M$ :

- for operating conditions:

$$M = \frac{M_{op}}{A} \tag{6.4.5.3.4-1}$$

- for the bolting-up condition:

$$M = \frac{M_b}{A} \tag{6.4.5.3.4-2}$$

6.4.5.4 Reverse full-faced gasket flanges

Hereafter, calculations apply to reverse flanges with full-faced gaskets, shown in Figure 6.4.5.4-1. Configurations of flanges represented in Figure 6.4.5-1 are accepted.

If the inside shell diameter  $D_i$  is less than 300 mm, the configuration shown in Figure 6.4.5-1e can be used without back fillet weld (see Figure 6.4.5.3-2). In such a case the flange thickness  $e_f$ , shown in Figure 6.4.5.3-2, shall be used in the calculations.

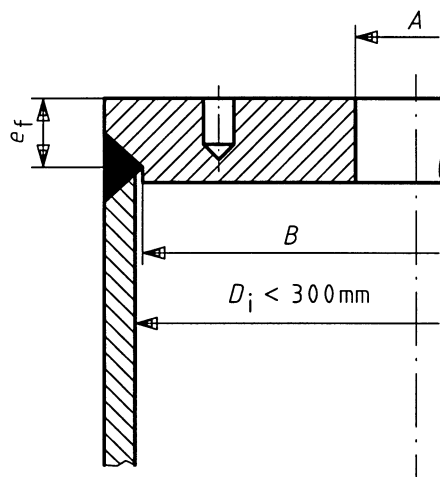


Figure 6.4.5.3-2 — Alternative configuration of reverse flange when internal diameter is less than 300 mm

**6.4.5.4.1 Symbols**

For the purpose of the calculations, the following symbols are additional to, or modify, those given in 3.2 and 6.4.5.1.1.

$A$  inside diameter of flange  
 $B$  outside diameter of flange  
 $D_i$  inside diameter of shell:  
 $D_i = B - 2g_0$  for integral-type (6.4.5.4.1-1)

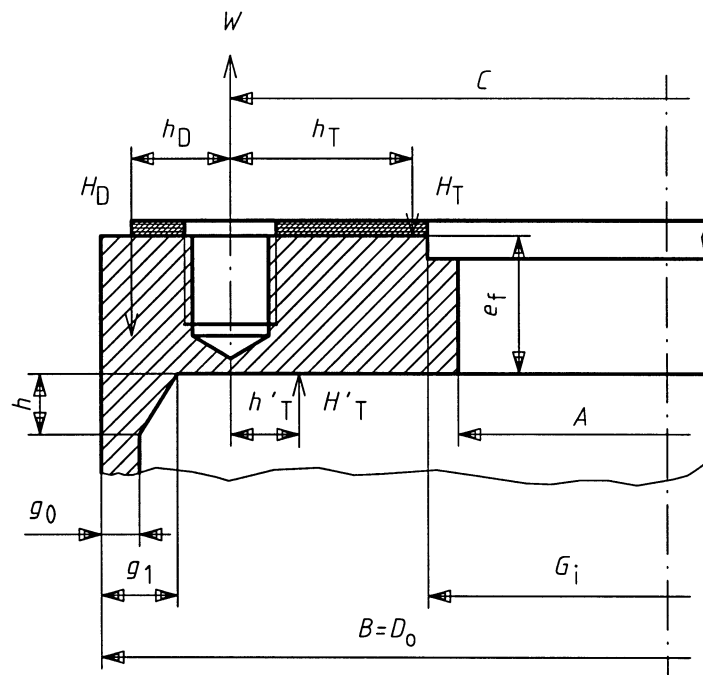
$D_i = B$  for loose-type (6.4.5.4.1-2)

$d_h$  diameter of bolt holes

$h'_T$  radial distance from bolt circles to circle on which  $H'_T$  acts

$H_T$  hydrostatic end force due to pressure on flange face

$$K = \frac{B}{A} \quad (6.4.5.4.1-3)$$



**Figure 6.4.5.4-1 — Reverse full-faced gasket flange**

**6.4.5.4.2 Bolt loads and areas**

Bolts shall be calculated in accordance with 6.4.5.1.2.

**6.4.5.4.3 Flange loads and moments**

Loads, lever arms and moments shall be calculated in accordance with 6.4.5.1.3, with the modifications stated in Table 6.4.5.4.3-1.

Table 6.4.5.4.3-1 — Loads and lever arms for operating conditions

Loads		Lever arms	
$H_D = \frac{\pi}{4} \times D_i^2 P$	(6.4.5.4.3-1)	$h_D = \frac{B - C - g_1}{2}$ (unchanged)	(6.4.5.4.3-2)
$H_T = \frac{\pi}{8} \times [(C - d_h)^2 - G_i^2] P$	(6.4.5.4.3-3)	$h_T = \frac{2C + d_h - 2G_i}{6}$	(6.4.5.4.3-4)
$H_G = \pi 2b C m P$	(6.4.5.4.3-5)	$h_G = 0$	(6.4.5.4.3-6)
$H'_T = \frac{\pi}{4} \times [(D_i^2 - G_i^2)] P$	(6.4.5.4.3-7)	$h'_T = \frac{2C - D_i - G_i}{4}$	(6.4.5.4.3-8)
$M_{op} = H_T h_T - H_D h_D + H'_T h'_T$			(6.4.5.4.2-9)
NOTE1 For loose-type flanges: $g_1 = 0$ in equation (6.4.5.4.3-2).			
NOTE2 The sign of $h_T$ [equation (6.4.5.4.3-4)], which you can be negative, shall be taken into account.			

**6.4.5.4.4 Flange stresses**

Stresses shall be calculated in accordance with 6.4.5.1.4, using as the moment  $M$ :

$$M = \frac{M_{op}}{A} \quad (6.4.5.4.4-1)$$

**6.4.6 Compensation calculation for cylindrical shells, spherical shells and dished ends****6.4.6.1 General**

The design method specified in 6.4.6.4 to 6.4.6.7 shall apply to cylindrical shells, spherical shells and dished ends having circular or elliptical openings, where the assumptions and conditions specified in 6.4.6.2 to 6.4.6.3.5 are satisfied.

Branches shall not be larger than 0,5 of the diameter of the shell to which they are fitted. The maximum distance from the centre of the dished ends to the outer edge of any attachment of reinforcement or of any opening shall not be greater than  $0,4D_o$  (see Figure 6.4.6-1).

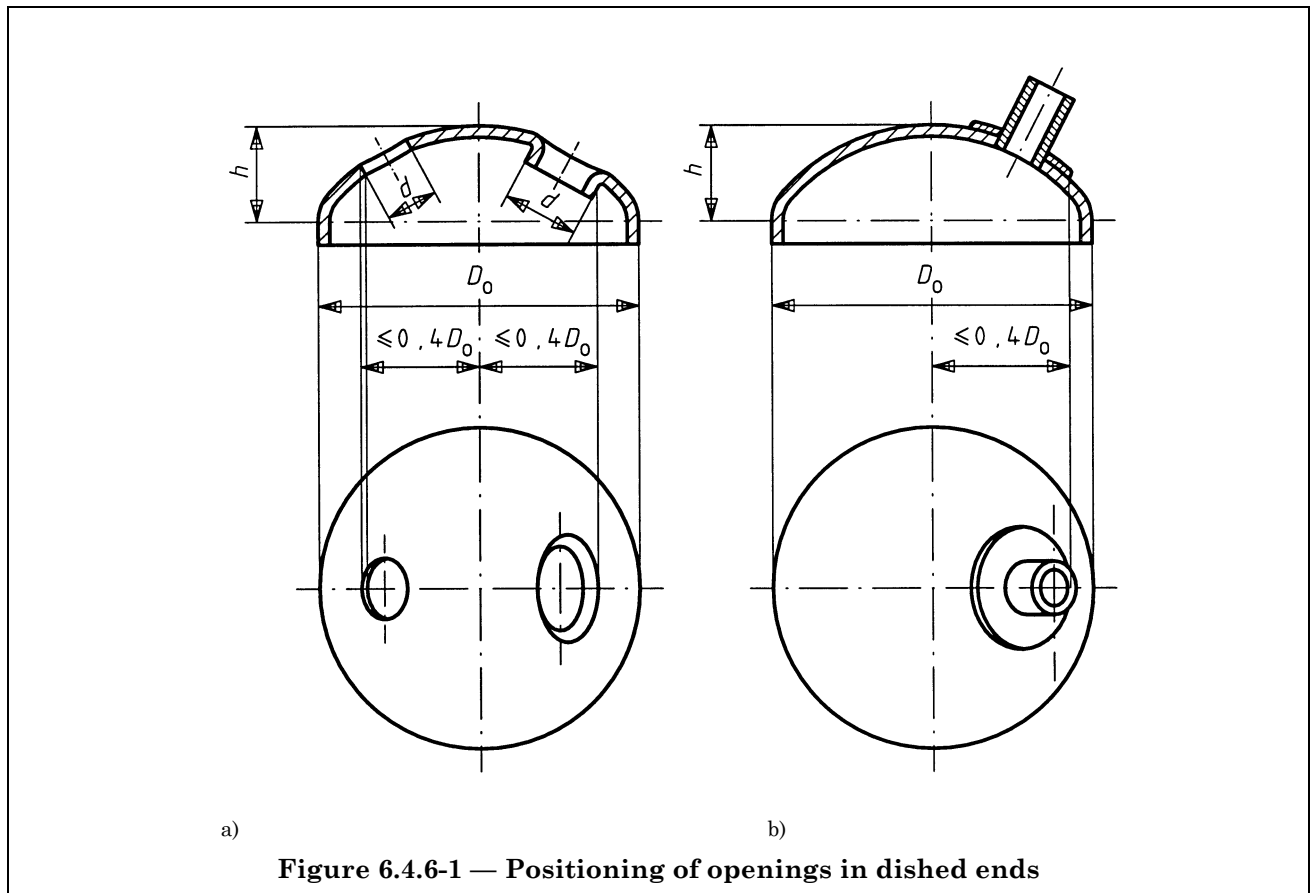


Figure 6.4.6-1 — Positioning of openings in dished ends

#### 6.4.6.2 Distance between openings

The distance between openings or branches, measured from the outside of the branches, pads or compensating plates, shall be not less than  $2 \times l_m$ , where:

$$l_m = \sqrt{(2r_{im} + e_{am})e_{am}} \quad (6.4.6.2-1)$$

and  $e_{am}$  is the thickness of the main body in corroded conditions, i.e.  $e_{as}$  or  $e_{ah}$  respectively, and  $r_{im}$  is the inside radius of curvature of the main body, i.e.:

$$r_{im} = \frac{D_o}{2} - e_{as} \quad (6.4.6.2-2)$$

in the case of shells, and

$$r_{im} = r_{ih} \quad (6.4.6.2-3)$$

in the case of hemispherical or torispherical ends, and

$$r_{im} = \frac{d_{is}^2}{4h} \quad (6.4.6.2-4)$$

in the case of elliptical ends.

However, distances smaller than  $2 \times l_m$  but not smaller than 5 times the nominal wall thickness may be allowed if the reinforcement calculation provided in the following clauses is made using, for each opening, reduced values of the lengths contributing to the reinforcement in such a way that the sum of these lengths does not exceed the actual distance between the openings.

**6.4.6.3 Reinforcement**

Shells and dished ends 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 the thickness required for the main body without openings (see Figure 6.4.6.3-1a and Figure 6.4.6.3-1b);
- b) by set-on welded compensating plates (see Figure 6.4.6.3-1c and Figure 6.4.6.3-1d);
- c) by set-in welded pads (see Figure 6.4.6.3-1e and Figure 6.4.6.3-1f);
- d) by set-on or set-in welded branches (see Figure 6.4.6.3-1g and Figure 6.4.6.3-1h);
- e) by combinations of the above-mentioned measures (see Figure 6.4.6.3-1i and Figure 6.4.6.3-1j);
- f) by formed and extruded branches (see Figure 6.4.6.3-1k and Figure 6.4.6.3-1l).

**6.4.6.3.1** The reinforcement area 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 method laid down in the following paragraphs. The applied method is derived from equation (6.4.2-1) for cylindrical shells and from equation (6.4.3.1-1) for spherical shells and spherical sections of dished ends respectively and leads to relationships between a pressure-loaded area  $A_p$  and a stress-loaded cross-sectional area  $A_f$  (see Figure 6.4.6.3-1). Under certain circumstances the calculation may need to be repeated using a corrected assumption of the reinforcement area.

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

**6.4.6.3.3** In the case of elliptical openings without branches, the ratio between the major and the minor axis shall not exceed 1,5. For elliptical openings in cylindrical shells, the dimension extending in the direction of the generatrix shall be taken as the diameter for design purposes. For elliptical openings in dished ends, the major dimension shall be so taken.

**6.4.6.3.4** Expanded branches shall not be considered as reinforcement and shall be calculated in accordance with 6.4.6.4. Set-on or set-in welded branches may be considered as reinforcement in accordance with weld joint design of 6.2.

**6.4.6.3.5** Reinforcement of openings by compensating plates is permitted only under the following condition:

$$\frac{d_{ib}}{d_{is}} \leq 0,3 \quad (6.4.6.3.5-1)$$

**6.4.6.4 Reinforcement by increased wall thickness**

The reinforcement can be attained by an increased wall thickness of the main body, compared with that of the main body without openings. This wall thickness shall exist at least up to a distance  $l_m$  [see equation (6.4.6.2-1)] measured from the edge of the opening, as shown in Figure 6.4.6.3-1a and Figure 6.4.6.3-1b.

Furthermore the following condition shall be satisfied:

$$P \left[ \frac{A_p}{A_f} + 0,5 \right] \leq f \quad (6.4.6.4-1)$$

where

$A_p$  is the pressure loading area;

$A_f$  is the cross-sectional area effective as compensation (see Figure 6.4.6.3-1).



**6.4.6.5 Reinforcement by compensating plates**

Compensating plates shall have close contact with the main body, and shall be of a material in accordance with 5.1.

The width of compensating plates  $l_p$  considered as contributing to the reinforcement shall not exceed  $l_m$ :

$$l_p \leq l_m \quad (6.4.6.5-1)$$

according to Figure 6.4.6.3-1c and Figure 6.4.6.3-1d.

The value of  $e_{ap}$  used for the determination of  $A_{fp}$  in equation (6.4.6.5-3) shall not exceed  $e_{am}$ , and the nominal thickness of the compensating plates shall not exceed 1,5 times the nominal thickness of the main body:

$$e_p \leq 1,5 e_m \quad (6.4.6.5-2)$$

Furthermore, the following condition shall be satisfied:

$$P \left[ \frac{A_p}{A_{fm} + 0,7 A_{fp}} + 0,5 \right] \leq f \quad (6.4.6.5-3)$$

where  $A_{fm}$  and  $A_{fp}$  are the cross-sectional areas of the main body and of the compensating plate effective as compensation.

**6.4.6.6 Reinforcement by pads**

Only pads of the set-in welded type in accordance with Figure 6.4.6.3-1e and Figure 6.4.6.3-1f shall be used. The width of the pads  $l_p$  considered as contributing to the reinforcement shall not exceed  $l_m$ :

$$l_p \leq l_m \quad (6.4.6.6-1)$$

The value of  $e_{ap}$  used in the determination of  $A_{fp}$  in equation (6.4.6.6-2) shall not exceed twice  $e_{am}$ .

Furthermore, the following condition shall be satisfied:

$$P \left[ \frac{A_p}{A_{fm} + A_{fp}} + 0,5 \right] \leq f \quad (6.4.6.6-2)$$

**6.4.6.7 Reinforcement by branches**

The wall thickness of branches (nozzles) shall exceed the thickness calculated to withstand internal pressure for a length  $l_b$  [see equation (6.4.6.7.1-3)] measured from the exterior wall of the main body. This requirement is independent of any reinforcement provided either by increasing the wall thickness of the main body or by fitting compensating plates (see Figure 6.4.6.3-1g, Figure 6.4.6.3-1h, Figure 6.4.6.3-1i and Figure 6.4.6.3-1j).

If the branches are threaded, the thickness of the thread shall not be considered for the compensation calculations.

Branches shall be of cylindrical type only; however this does not apply to inspection openings of the elliptical type.

**6.4.6.7.1 Branch connections normal to the shell**

For branch connections normal to the shell without compensating plate(s), the following condition shall be satisfied:

$$P \left[ \frac{A_p}{A_{fm} + A_{fb}} + 0,5 \right] \leq f \quad (6.4.6.7.1-1)$$

and with compensating plate(s):

$$P \left[ \frac{A_p}{A_{fm} + A_{fb} + 0,7 A_{fp}} + 0,5 \right] \leq f \quad (6.4.6.7.1-2)$$

The areas  $A_p$ ,  $A_{fm}$ ,  $A_{fb}$  and  $A_{fp}$  shall be determined in accordance with Figure 6.4.6.3-1g to Figure 6.4.6.3-1l, where the lengths contributing to the reinforcement shall be not more than  $l_m$  for the shell [see equation (6.4.6.2-1)], and

$$l_b = 0,8 \sqrt{(d_{ob} - e_{ab}) e_{ab}} \quad (6.4.6.7.1-3)$$

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 Figure 6.4.6.3-1h, Figure 6.4.6.3-1i and Figure 6.4.6.3-1j) shall be:

$$l_{bi} = 0,5 l_b \quad (6.4.6.7.1-4)$$

The dimensions of the compensating plate to be used in the calculation shall be:

$$e_{ap} \leq e_{am} \quad (6.4.6.7.1-5)$$

and

$$l_p \leq l_m \quad (6.4.6.7.1-6)$$

Equations (6.4.6.7.1-1) and (6.4.6.7.1-2) apply only when the allowable stress  $f$  for the material of the main body (and the compensating plate) is equal to or lower than the allowable stress  $f_b$  for the branch.

When the allowable stress  $f_b$  is lower than  $f_m$ , the following conditions apply:

$$P [A_p + 0,5 (A_{fm} + A_{fb})] \leq f A_{fm} + f_b A_{fb} \quad (6.4.6.7.1-7)$$

and

$$P [A_p + 0,5 (A_{fm} + A_{fb} + 0,7 A_{fp})] \leq f (A_{fm} + 0,7 A_{fp}) + f_b A_{fb} \quad (6.4.6.7.1-8)$$

For expanded branches and for welded branches not considered as reinforcement (see 6.2), equation (6.4.6.4-1) applies.

**6.4.6.7.2 Oblique branch connection in shells**

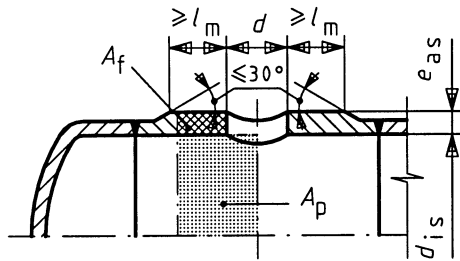
The following requirements apply to branches on shells lying in a plane perpendicular to the longitudinal axis of the shell and having an angle  $\psi$  formed with the normal, which shall not exceed  $50^\circ$ .

The higher stress may occur in the lateral section (Figure 6.4.6.3-2a, partial view I) or in the longitudinal section (Figure 6.4.6.3-2a, partial view II). Equation (6.4.6.7.1-1) or (6.4.6.7.1-2) shall apply to both cases with the areas  $A_p$  and  $A_f$  (see Figure 6.4.6.3-2aI and Figure 6.4.6.3-2aII) 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 equation 6.4.6.2-1, and for the branch in accordance with equation 6.4.6.7.1-3.

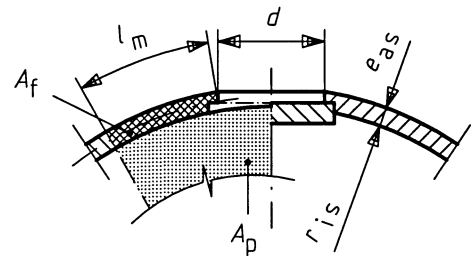
Branches on shells lying in the plane containing the longitudinal axis of the shell and having an angle  $\psi$  formed with the normal not exceeding  $50^\circ$  shall be reinforced in the longitudinal plane as provided in Figure 6.4.6.3-2b, using equations of 6.4.6.7.1.

**6.4.6.7.3 Oblique branch connection in dished ends**

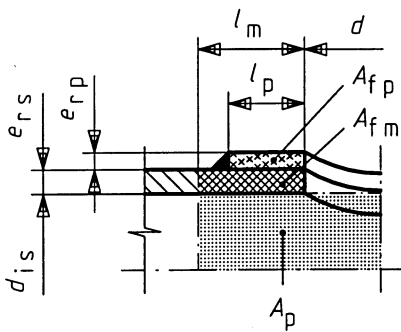
The following requirements apply to branches in spherical shells lying in a plane that contains the axis of the branch and the centre of the spherical shell. Using the symbols shown in Figure 6.4.6.3-2c, spherical shells with an oblique branch shall be calculated in accordance with 6.4.6.7.1.



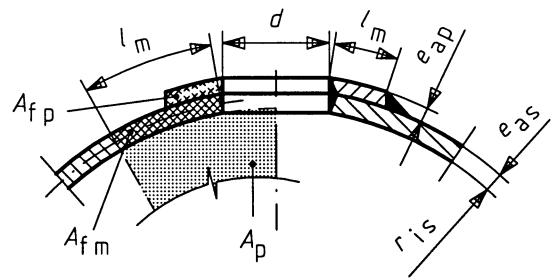
a) Cylindrical shells — Reinforcement by increased wall thickness



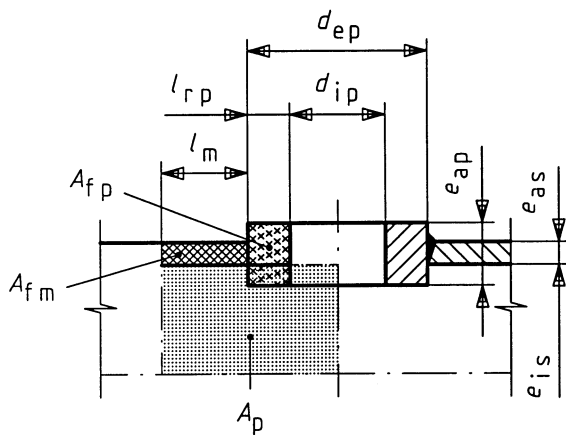
b) Spherical shells and dished ends — Reinforcement by increased wall thickness



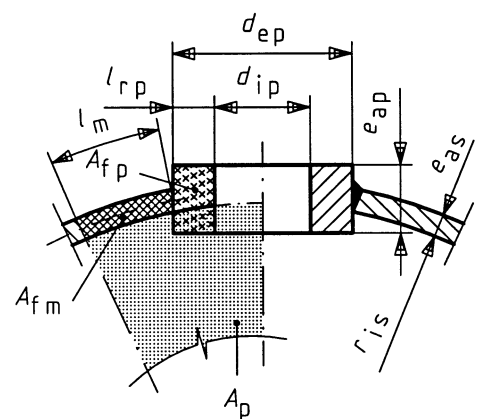
c) Cylindrical shells — Reinforcement by compensating plates



d) Spherical shells and dished ends — Reinforcement by compensating plates

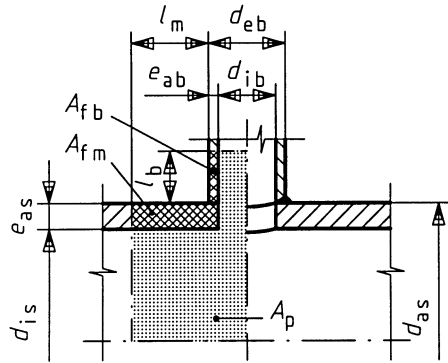


e) Cylindrical shells — Reinforcement by pads

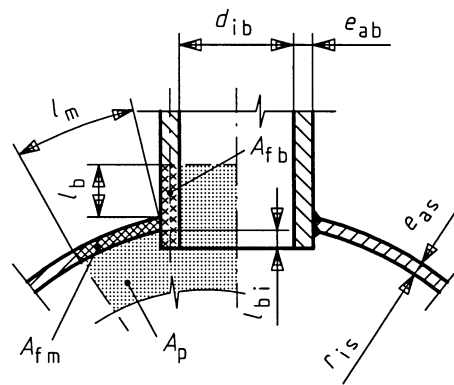


f) Spherical shells and dished ends — Reinforcement by pads

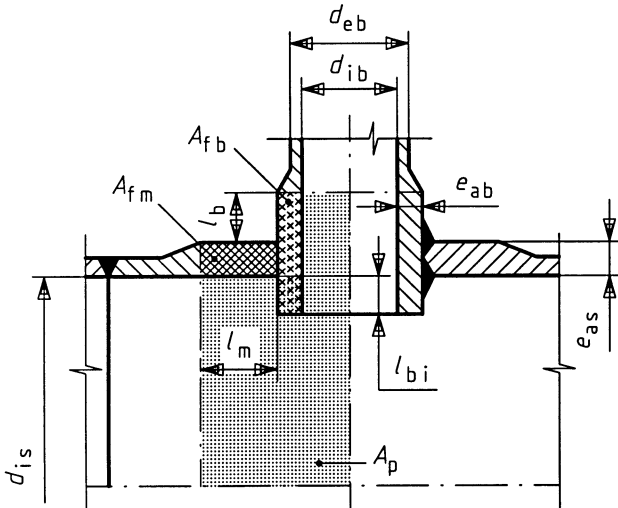
**Figure 6.4.6.3-1 — Reinforcement of openings and branches**



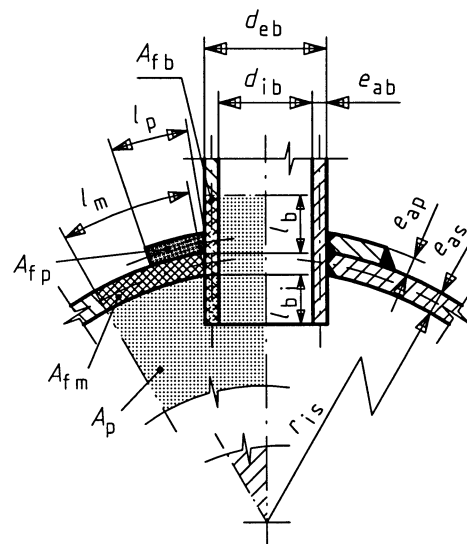
g) Cylindrical shells — Reinforcement by branches



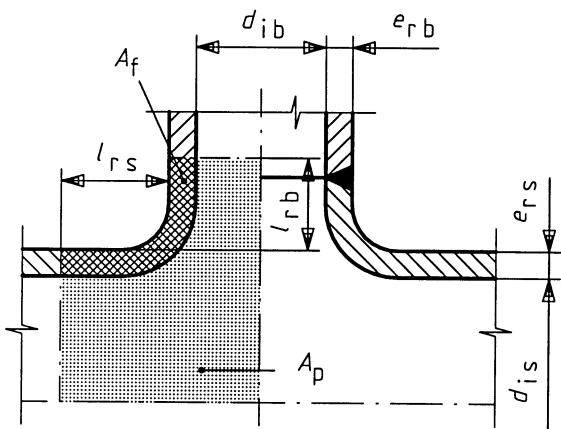
h) Spherical shells and dished ends — Reinforcement by branches



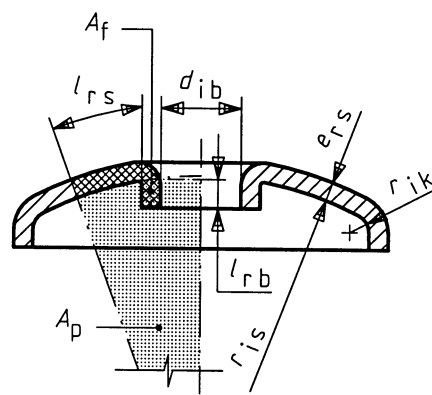
i) Cylindrical shells — Combined reinforcement



j) Spherical shells and dished ends — Combined reinforcement

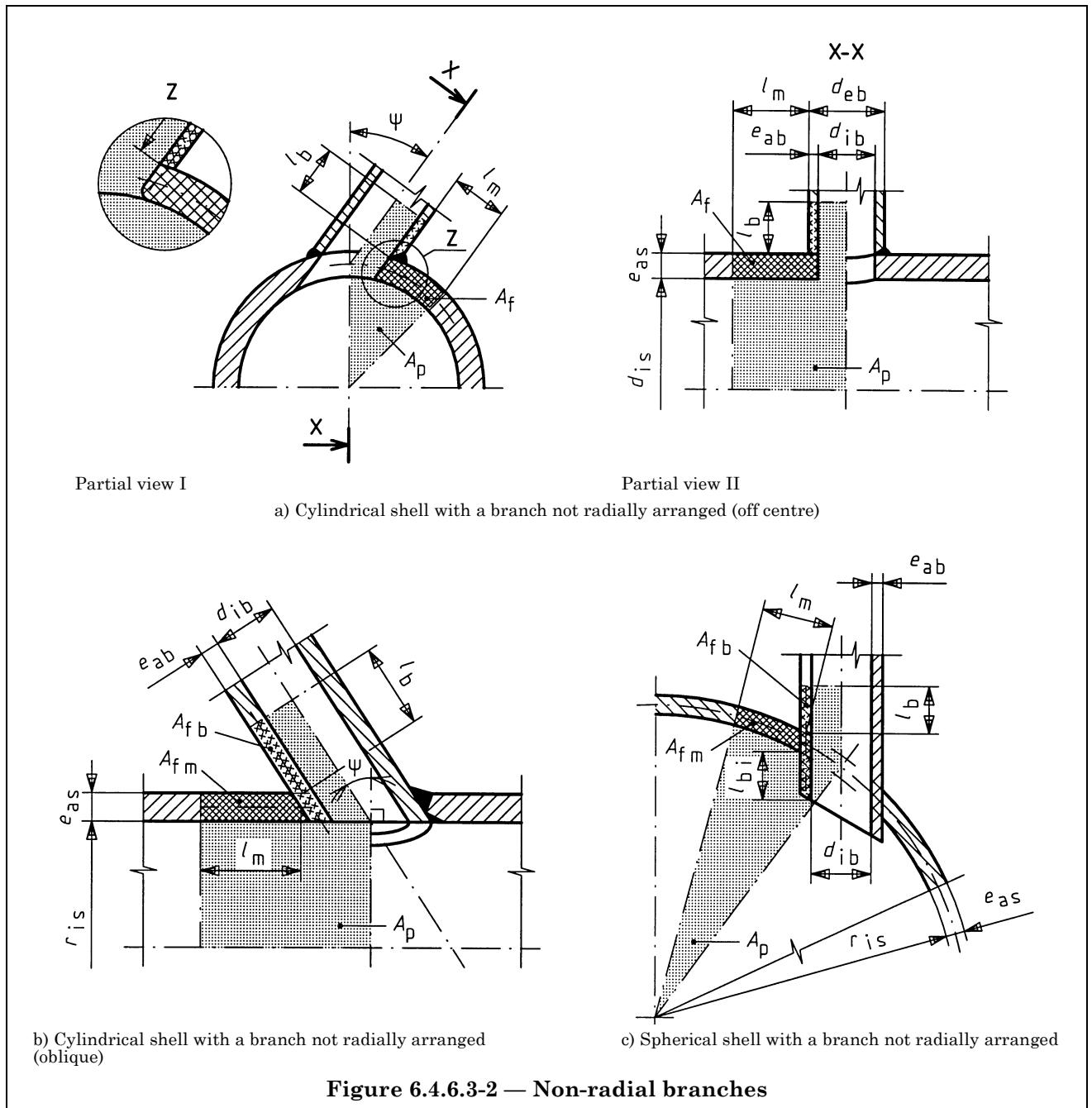


k) Cylindrical shells — Extruded branch in a cylindrical shell



l) Spherical shells and dished ends — Intruded branch in a dished end

**Figure 6.4.6.3-1 — Reinforcement of openings and branches (continued)**



**6.4.7 Compensation calculations for flat ends and covers that have an opening of  $D_i/2$  or less**

Flat ends and covers that have an opening with  $d \leq D_i/2$  shall be provided with reinforcement as follows (see Figure 6.4.7-1).

The available reinforced area  $A_R$  is given by:

$$A_R = (e_a - e_c)L \tag{6.4.7-1}$$

where

$e_c$  is the calculated thickness of 6.4.4;

$e_a$  is the actual plate thickness of flat end or cover.

$$L = \max\left[\left(e_a + 75\right); \left(\frac{d}{2}\right)\right] \quad (6.4.7-2)$$

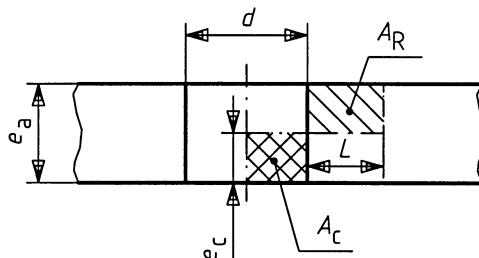
The required reinforcement area  $A_c$  is given by:

$$A_c = e_c \times \frac{d}{2} \quad (6.4.7-3)$$

The area  $A_R$  shall be:

$$A_R \geq 0,5 A_c \quad (6.4.7-4)$$

If the area  $A_R$  is less than  $0,5A_c$ , then the thickness of the plate shall be increased.



$d$  is the diameter of opening;  
 $e_a$  is the actual thickness of the shell plate;  
 $e_c$  is given by equations (6.4.4.1-1) or (6.4.4.2-a1) respectively.

**Figure 6.4.7-1 — Openings in flat ends and covers**

## 6.5 Experimental method

This method can only be used if the product of  $PS$  and  $V$  is not more than 3 000 bar·l, or if the maximum working temperature does not exceed 100 °C. Where fatigue loadings exist, they shall be given special consideration (see 6.1).

Additional symbols:

- $c_s$  is the shell corrosion allowance
- $e_{ms}$  is the measured thickness of the shell before pressure test
- $e_s$  is the nominal wall thickness of the shell
- $R_{eT,act}$  is the actual yield strength as measured on the plate used for the vessel
- $R_{m,act}$  is the actual tensile strength as measured on the plate used for the vessel
- $t_s$  is the absolute value of the negative tolerance taken from the shell material standard
- $u_i$  is the circumferential length at cross-section  $i$ , after pressure test
- $u_{i0}$  is the circumferential length at cross-section  $i$ , before pressure test

**6.5.1** Wall thicknesses shall be so determined as to enable the vessels to resist at ambient temperature a pressure equal to at least 5 times the maximum working pressure, with a permanent circumferential deformation of no more than 1 %.

**6.5.2** In order to verify the chosen design, the following tests shall be performed at room temperature on at least one worst-case prototype per vessel type:

- a pressure test at 5 times the maximum working pressure;
- a burst test;
- a tensile test on the plate/coil used for the shell of the prototype.

If the product of  $PS$  and  $V$  is more than 50 bar·l, the assessment of the worst case(s) shall be agreed upon by the manufacturer and approval inspection body, and the tests shall be witnessed by the approval inspection body.

**6.5.3** Before the pressure test, the actual wall thickness of the shell shall be determined, and the circumferential lengths of the vessel shall be measured at not less than three different cross-sections with an accuracy of 0,2 %. The measurement shall be at a distance of not less than 20 mm from any discontinuity (knuckle connection, branch, etc.).

**6.5.4** The pressure test and the burst test shall be performed using water at a temperature of between 7 °C and 25 °C.

**6.5.5** During the pressure test, the pressure shall be increased at an average rate of not more than 1,0 bar/s until a pressure of 5 times the designated maximum working pressure has been reached. This pressure shall be held for at least 5 min; the vessel shall show no signs of leakage. The pressure shall then be reduced to zero and the circumferential lengths at the same cross-sections as used in **6.5.3** determined.

The following condition shall be fulfilled:

$$100 \times \frac{u_i - u_{i0}}{u_{i0}} \times \frac{R_{eT,act}}{R_{eT}} \times \frac{e_{ms}}{e_s - t_s - c_s} \leq 1 \quad (6.5.5-1)$$

**6.5.6** During the burst test the pressure shall be re-applied and increased gradually until rupture occurs. The burst pressure shall be higher than:

$$5PS \times \frac{R_{m,act}}{R_m} \times \frac{e_{ms}}{e_s - t_s - c_s} \quad (6.5.6-1)$$

No parts shall become detached, nor splinters projected, and rupture shall not initiate in any weld.

**6.5.7** Limiting values of the parameters  $t$ ,  $R_{eT}$  and  $R_m$  used in the calculation of the condition given in 6.5.5 and in evaluating the limit value for the burst pressure given in **6.5.6**, may be different from those stated in the material standard if:

- these limit values or the limit values for the products  $(e-t)R_{eT}$  and  $(e-t)R_m$  are stated on the drawing; and
- each plate/coil/pipe is checked accordingly.

In such a case, the thickness of each pipe, plate or a plate from a coil end shall be determined, and  $R_{eT,act}$  and  $R_{m,act}$  shall be determined by one tensile test on this plate or pipe if it does not exceed 7,0 m, or by two tensile tests on plates, pipes and coils (end and tail end) if the length exceeds 7,0 m.

## 6.6 Access and inspection openings

### 6.6.1 General

All vessels shall be provided with openings adequate in size and number to allow access for internal inspection and cleaning.

The number, size and location of inspection openings shall be in accordance with the requirements given in **6.6.2** and **6.6.3**.

The limits for the height of necks or rings given in **6.6.2** may be exceeded if the internal dimensions are increased accordingly. Rings and necks of conical shape shall have an inclination of at least 15°; for inclinations less than 15°, the limits for cylindrical shapes apply. Access and inspection openings of the type in which the internal pressure forces the cover plate against a flat gasket shall have a total clearance

between the neck or ring and the spigot or recess of such covers not exceeding 3 mm, i.e. 1,5 mm all round, and the spigot depth shall be sufficient to trap the gasket.

### **6.6.2 Types and dimensions of access and inspection openings**

#### **6.6.2.1 Sightholes**

Sightholes are openings with an inside diameter of at least 30 mm (small sightholes) or 50 mm (large sightholes). The flange height shall not exceed the diameter of the opening.

#### **6.6.2.2 Handholes**

Handholes are openings through which a hand and a lamp can be inserted. Handhole dimensions shall be not less than 80 mm × 100 mm or 100 mm inside diameter. The height of the neck or ring shall not exceed 65 mm, or 100 mm in the case of conical shapes.

#### **6.6.2.3 Headholes**

Headholes are openings through which the head, an arm and a lamp can be introduced simultaneously. Headhole dimensions shall be not less than 220 mm × 320 mm or 320 mm inside diameter. The height of the neck or ring shall not exceed 100 mm, or 120 mm in the case of a conical shape.

#### **6.6.2.4 Manholes**

Manholes are openings through which a person not carrying any auxiliary equipment can enter and leave the vessel. Manhole dimensions shall be not less than 320 mm × 420 mm or 420 mm inside diameter. The height of the neck or ring shall not exceed 150 mm.

### **6.6.3 Types, location and minimum number of access and inspection openings**

The types, location and minimum number of inspection openings required for vessels of spherical shape are given in Table 6.6.3-2, and for all other shapes in Table 6.6.3-1.

Drainage ports, standpipes for safety devices, and other branch connections that can be easily dismantled, can be used as sightholes provided that they permit direct examination of the various parts of the inner wall, particularly the seams. They shall meet the requirements of 6.6.2.1.

However, if the end has a bolted cover, which on removal allows all internal welded areas to be checked, no further inspection openings are required.

### **6.6.4 Alternative requirements for sightholes openings on small vessels**

For vessels with internal diameter lower than or equal to 450 mm, the requirements of 6.6.2, 6.6.3 and Table 6.6.3-1 may be modified as follows:

- a) The inside diameter of the sightholes shall be large enough to permit proper internal cleaning and shall not be less than:
  - 19 mm for vessels with an internal diameter up to and including 350 mm;
  - 24 mm for vessels with an internal diameter greater than 350 mm and up to and including 450 mm.
- b) If through these smaller sightholes the internal surface is not completely visible, then it is essential that the visual inspection be supplemented by an additional inspection method which shall be detailed by the manufacturer in his instructions (see Clause 11).
- c) The inspection procedure proposal by the manufacturer shall be verified on a prototype vessel and approved by the inspection body.



**Table 6.6.3-1 — Types and minimum number of access and inspection openings in vessels other than spherical vessels**

Internal diameter, $D_i$ mm	Length of cylindrical section, $L$ mm	Minimum number and type of openings
$D_i \leq 300$	—	One small sighthole in each end. If $L$ exceeds 1 000 mm, an additional large sighthole shall be provided <sup>a</sup>
$300 < D_i \leq 450$	$L \leq 1\,500$	Two large sightholes, one near or in each end, or one handhole <sup>a</sup> in the central third of the cylindrical section
	$L > 1\,500$	One handhole near each end of the cylindrical section <sup>a</sup> or in the ends. If the distance between the handholes exceeds 1 500 mm, an additional handhole <sup>a</sup> shall be provided
$450 < D_i \leq 840$	$L \leq 1\,500$	Two large sightholes, one near or in each end, or one handhole <sup>a</sup> in the central third of the cylindrical section
	$1\,500 < L \leq 3\,000$	One headhole in the central third of the cylindrical section, or handholes as in the case $300 < D_i \leq 450, L > 1\,500$
	$L > 3\,000$	The number of inspection openings shall be increased such that the maximum distance between headholes does not exceed 3 000 mm, and that between handholes 2 000 mm. Handholes shall be located near each end of the ends of the cylindrical section, or in each end, and one in the central third of the cylindrical section
$840 < D_i \leq 1\,200$	$L \leq 2\,000$	One headhole in the central third of the cylindrical section, or two handholes, one near each end of the cylindrical section or in the ends, or one manhole
	$L > 2\,000$	One manhole, or inspection opening as in the case $D_i \leq 840, L > 3\,000$
$D_i > 1\,200$	—	One manhole
<sup>a</sup> Sightholes and handholes have to be located such as to provide a view of the longitudinal seam and the bottom surfaces at the drainage opening. NOTE Where alternatives are provided for in this table, the choice is at the discretion of the manufacturer.		

**Table 6.6.3-2 — Types and minimum number of access and inspection openings in spherical vessels**

Internal diameter, $D_i$ mm	Minimum number and type of openings
$D_i \leq 450$	Two large sightholes, or one handhole
$450 < D_i \leq 840$	One handhole, or one headhole
$840 < D_i \leq 1\ 200$	One headhole, or one manhole
$D_i > 1\ 200$	One manhole

NOTE Where alternatives are provided for in this table, the choice is at the discretion of the manufacturer.

## 6.7 Drainage openings

**6.7.1** Drainage openings shall be provided and the threads shall be in accordance with the requirements of EN 10226-1 or ISO 228-1 and shall be not less than:

- for  $V$  up to 300 l:  $R\ 3/8$  or  $R_p\ 3/8$  or  $G\ 3/8$ ;
- for  $V$  above 300 l:  $R\ 1/2$  or  $R_p\ 1/2$  or  $G\ 1/2$ .

**6.7.2** The vessel design shall ensure provision for adequate venting of air during hydraulic testing.

## 6.8 Supports

**6.8.1** The design of supports shall take into account the stresses induced into the main body by the weight of the vessel and of possible superimposed equipment, and by other loadings (e.g. alternating loadings from a compressor).

To preclude such additional loadings inducing harmful stresses into the main body, the welding of supports edge-on to the main body is not permitted (see Figure 6.8-1a1). Reinforcing plates shall be used for the attachment of the supports to the main body (see Figure 6.8-1a2, Figure 6.8-1b and Figure 6.8-1c) and shall meet the following requirements:

- the minimum width of reinforcing plate shall be 50 mm;
- the thickness of reinforcing plate shall be in the range between the thickness of the shell and 2 times the thickness of the shell;
- the reinforcing plate shall be radiused to a minimum of 3 times the thickness;
- the reinforcing plate shall have a tell-tale hole.

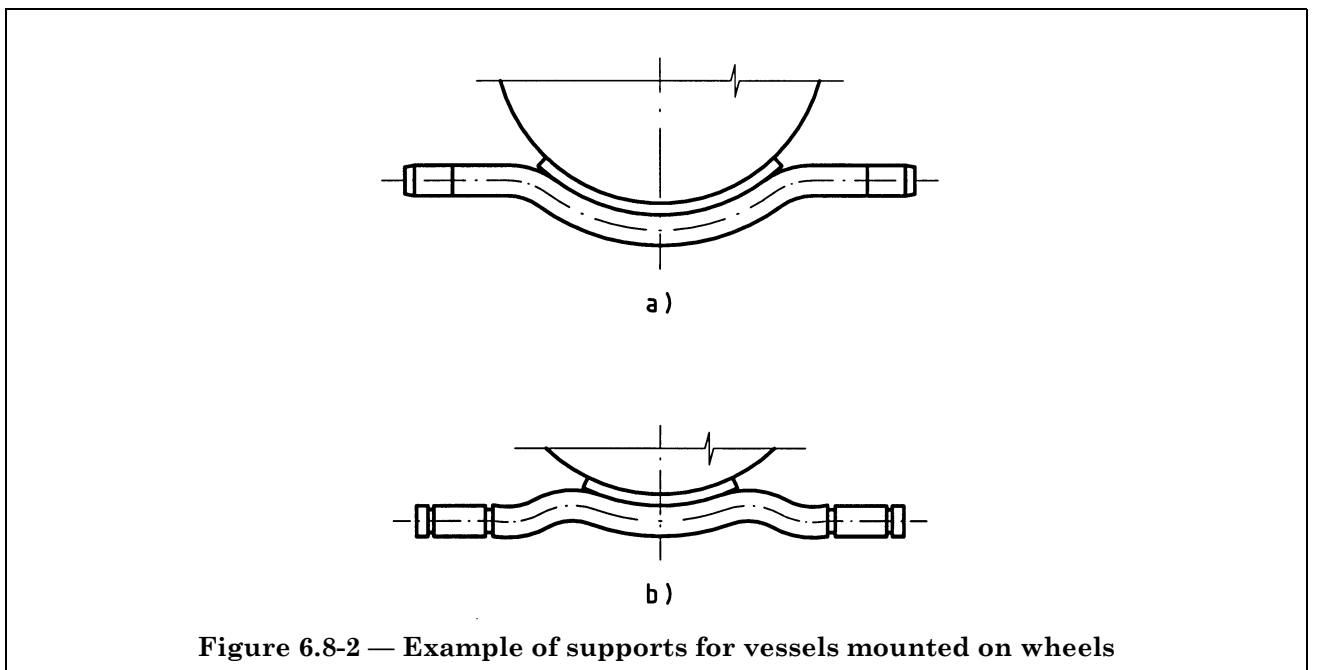
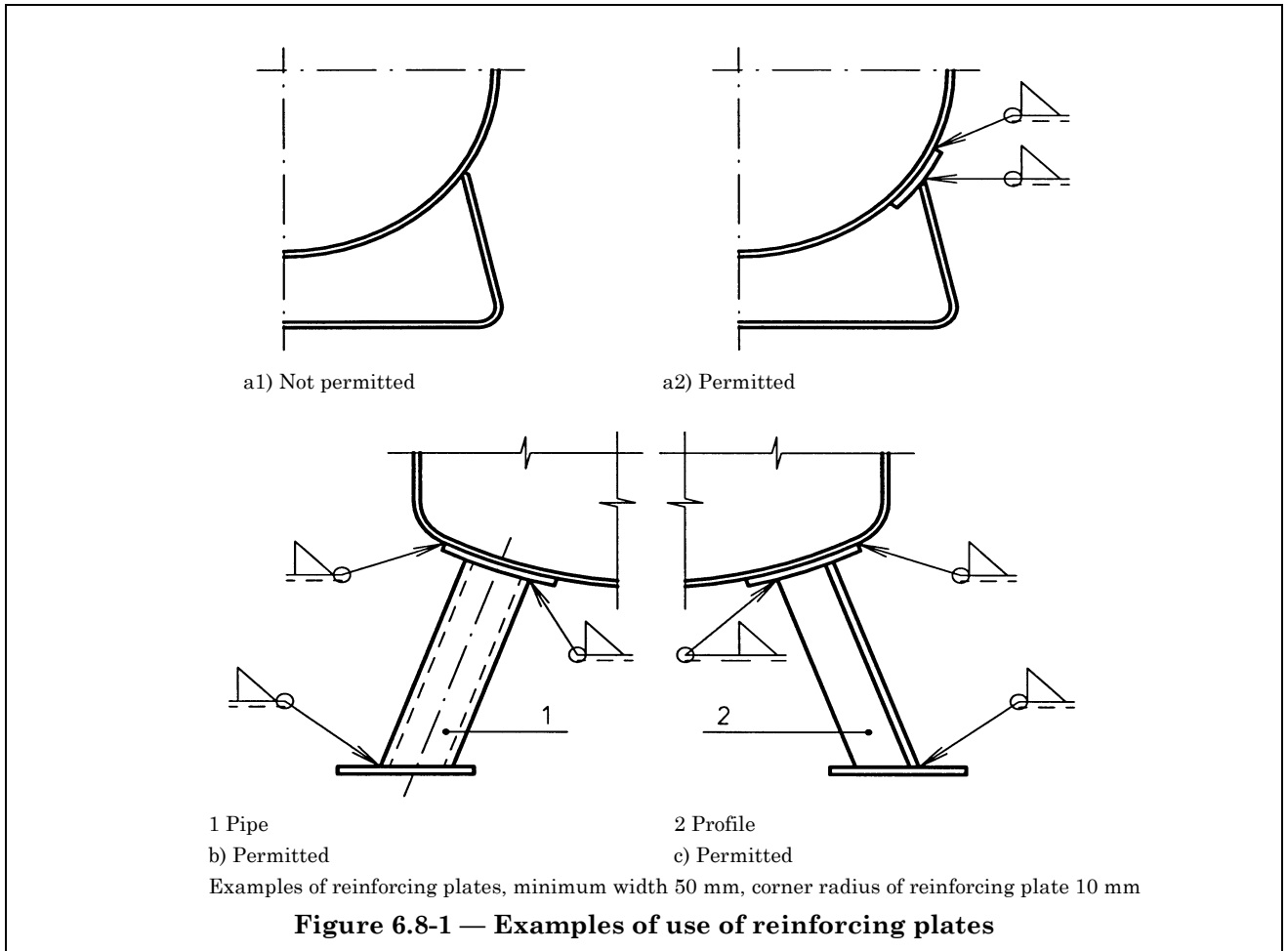
The construction shown in Figure 6.8-2a and Figure 6.8-2b shall not be used without reinforcing plates.

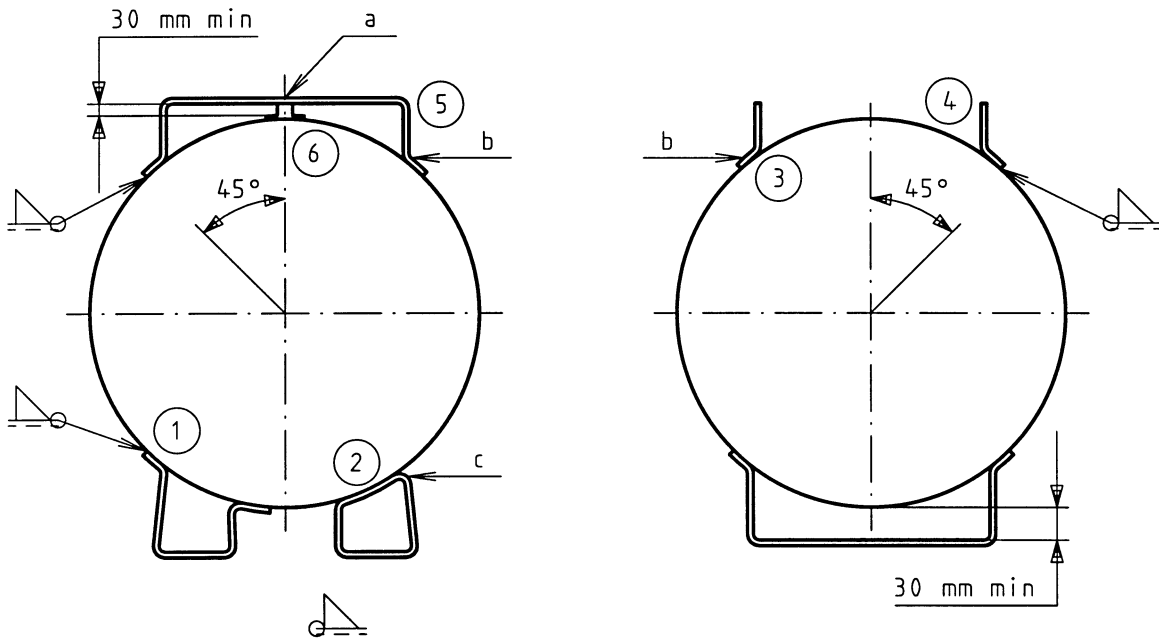
**6.8.2** Reinforcing plates are not deemed necessary for vessels which are not supporting a compressor or rotating machinery.

Reinforcing plates are also not deemed necessary for vessels which are supporting a compressor or rotating machinery when the outside diameter of the main body is not greater than 310 mm, and provided that the compressor is not rigidly fixed to the vessel.

Figure 6.8-3a to Figure 6.8-3d show different arrangements for these particular cases; designs of support other than those provided by the figures may be used, but the minimum criteria of the figures shall be met.

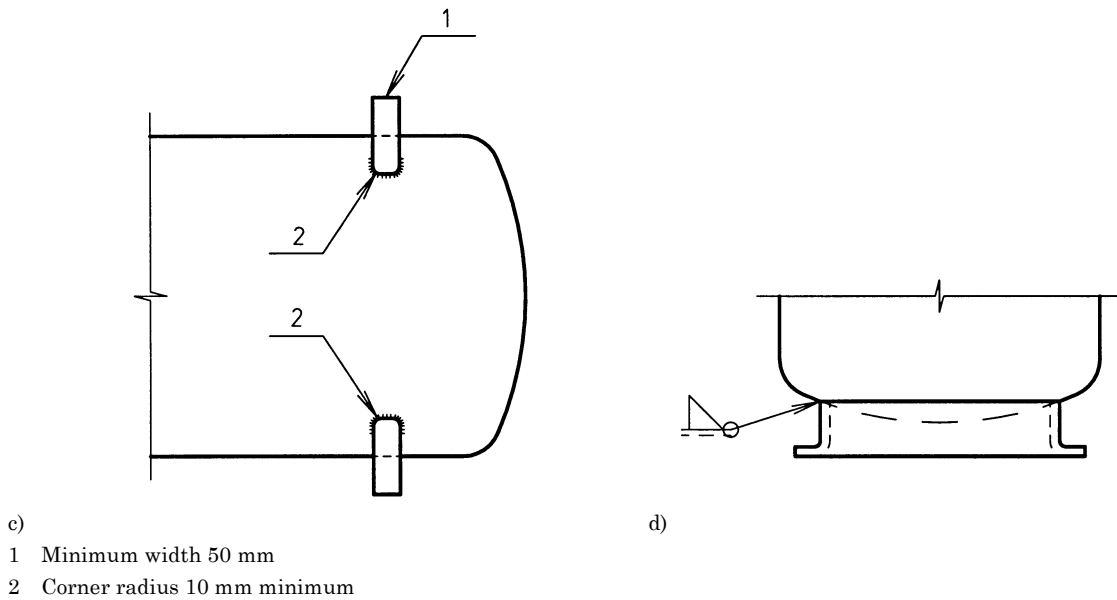
**6.8.3** The manufacturer shall detail in his instructions the additional loadings which were taken into account in the design, as well as the method of fixing the vessel to its base.





- a) Supporting plate
- b) Minimum length  $6e$
- c) Radius

NOTE Welds 1, 3, 4 and 5 are not welded on the inside of the support.



**Figure 6.8-3 — Example of supports for vessels without the use of reinforcing plates (see 6.8.2)**

## 7 Fabrication

### 7.1 Manufacturing and testing equipment

The manufacturer or his subcontractor shall have available appropriate equipment and personnel to ensure correct manufacture and testing.

### 7.2 Forming of ends and shell

#### 7.2.1 General

Flat and dished ends shall be formed from a single plate. Dishing and flanging shall be carried out by a mechanical forming procedure, e.g. by pressing or spinning. Hand forming is not permitted.

#### 7.2.2 Steel cold-formed ends or joggle ends

Ends with thickness less than or equal to 6 mm may be used without post-forming heat treatment; however, ends with an inwardly pierced form, (see Figure 6.4.6-1a), shall be heat-treated.

Ends with thickness over 6 mm but less than or equal to 8 mm, shall undergo post-forming heat treatment where the minimum temperature for the required impact test is lower than  $-10\text{ }^{\circ}\text{C}$ .

Ends with thickness over 8 mm shall not be used without post-forming heat treatment.

The heat treatment after cold forming is normalizing. For the steels specified in 5.1.1, the heat treatment temperature shall be in the range  $890\text{ }^{\circ}\text{C}$  to  $950\text{ }^{\circ}\text{C}$ . If the range is not given in the steel standard, the temperature to be used for normalizing should be given by the steel producer.

Care shall be taken when galvanizing vessels made with cold-formed non-heat-treated ends.

#### 7.2.3 Steel hot-formed dished ends

Hot-formed dished ends shall be normalized. However, the normalizing may be omitted providing:

- the hot forming is carried out in one operation at the normalizing temperature; or if hot forming is carried out in more than one operation, the product is cooled below the transformation temperature before the last operation and this operation is then carried out at the normalizing temperature; and
- the specified properties (such as  $R_{eH}$ ,  $R_m$ ,  $A\%$  and  $KCV$ ) are complied with and can also be obtained after further normalizing treatment.

#### 7.2.4 Aluminium cold-formed ends

Cold-formed ends made from aluminium alloys shall not be used without post-forming heat treatment.

The material properties after heat treatment shall be within the range stated in the base material standards.

#### 7.2.5 Steel shell

A steel shell pierced with extruded branches shall be heat-treated. The heat treatment after cold forming shall be normalizing.

### 7.3 Typical connections of main body

#### 7.3.1 Longitudinal welds

Only butt welded joints shall be used. The maximum misalignment shall be limited to the values in Table 7.3-1. If backing strips are used on longitudinal seams, they shall be removed.

#### 7.3.2 Circumferential welds

Only butt welded joints and joggled end welds shall be used for connection of shell and formed ends. Backing strips may be used, but this practice shall be avoided when internal welding is possible. Typical examples of joggled ends are shown in Figure 7.3.2-1. Typical examples of butt welded joints are shown in Figure 7.3.2-2 and Figure 7.3.2-3.

The maximum misalignment of butt welds shall be limited to the values in Table 7.3-1. If this misalignment is exceeded, the surface of thicker plate shall be tapered at a slope of 1:4, including the width of the weld metal (see Figure 7.3.2-5). The centre-lines of plates shall be aligned within the limits given in Table 7.3-1.

The typical welded connections between flat ends and shell shall be as shown in Figure 6.2.5-1.

The typical welded connections between flanges and shell shall be as shown in Figure 6.2.6-1.

**7.4 Welding**

No welding shall be carried out on the pressurized parts of a vessel once the hydraulic test has been successfully completed.

If a manual root run on the reverse side is made prior to a second run made by an automatic process then the root weld shall be taken back to the sound metal to remove any inclusions, i.e. slag etc.

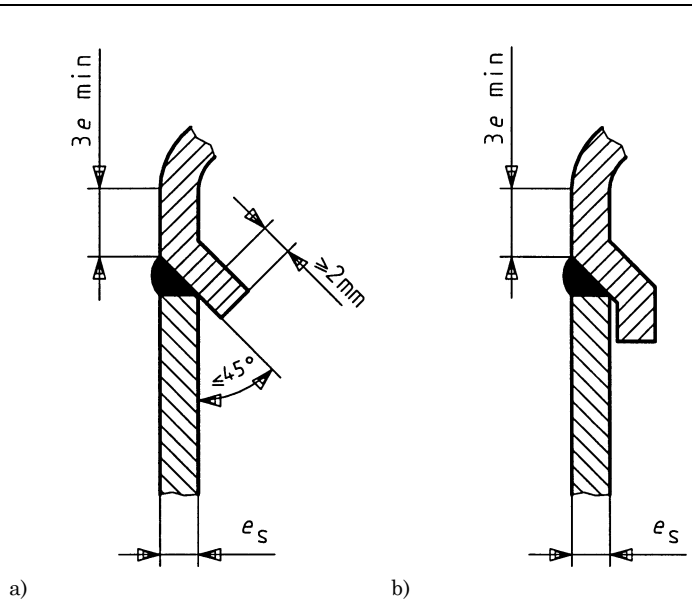
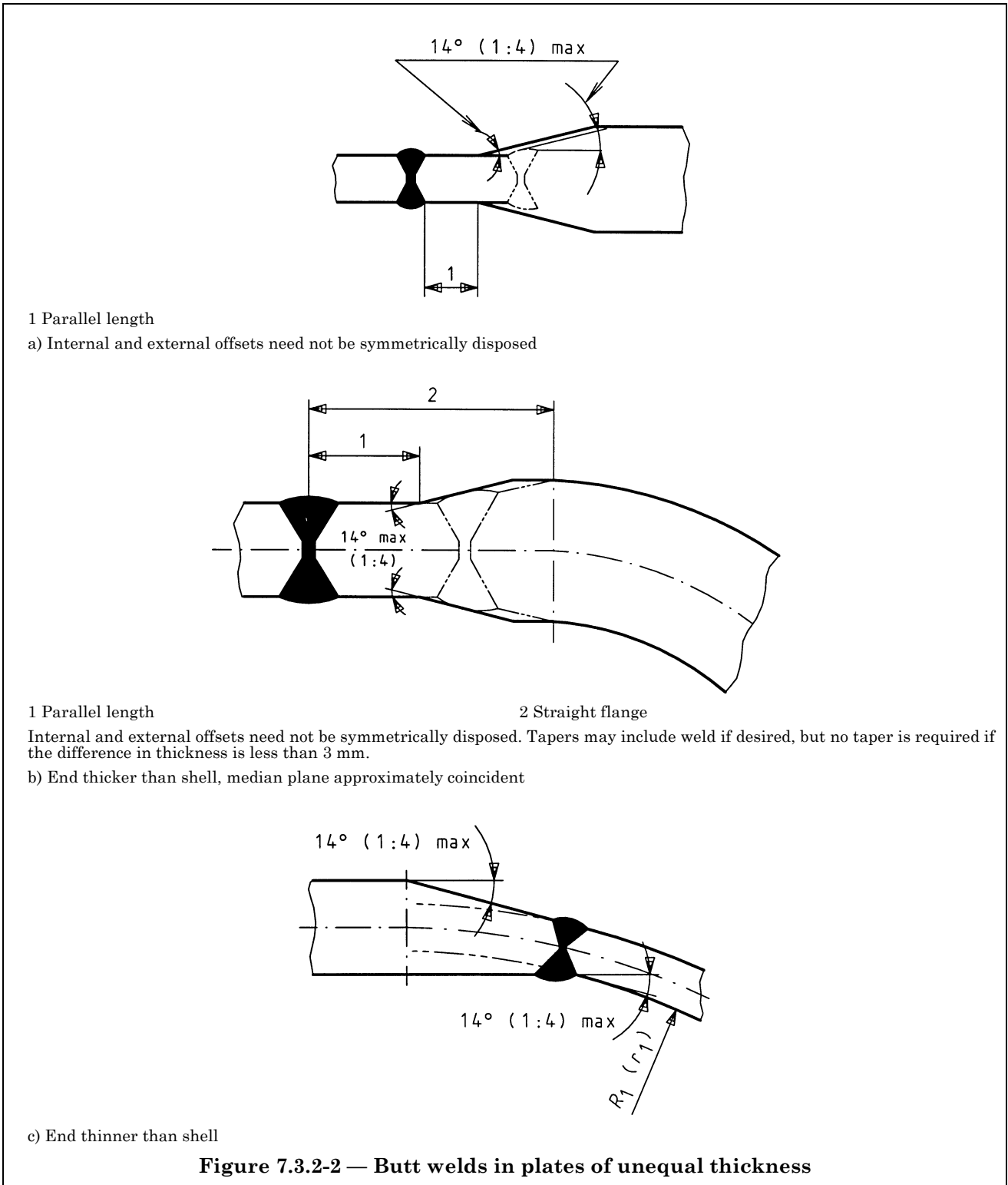
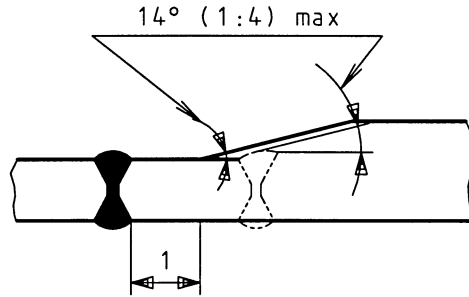
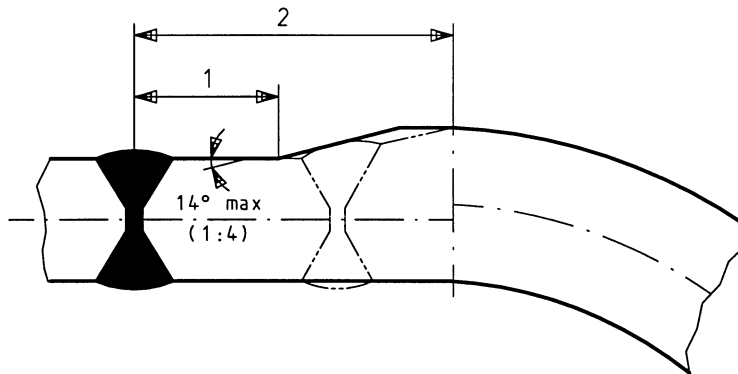


Figure 7.3.2-1 — Typical examples of joggle ends





- 1 Parallel length
- a) Taper may be inside vessel or outside



- 1 Parallel length
- 2 Straight flange
- Offset may be internal or external.
- Tapers may include weld if desired.
- b) End thicker than shell, median plane offset

**Figure 7.3.2-3 — Butt welds with offset of median lines**



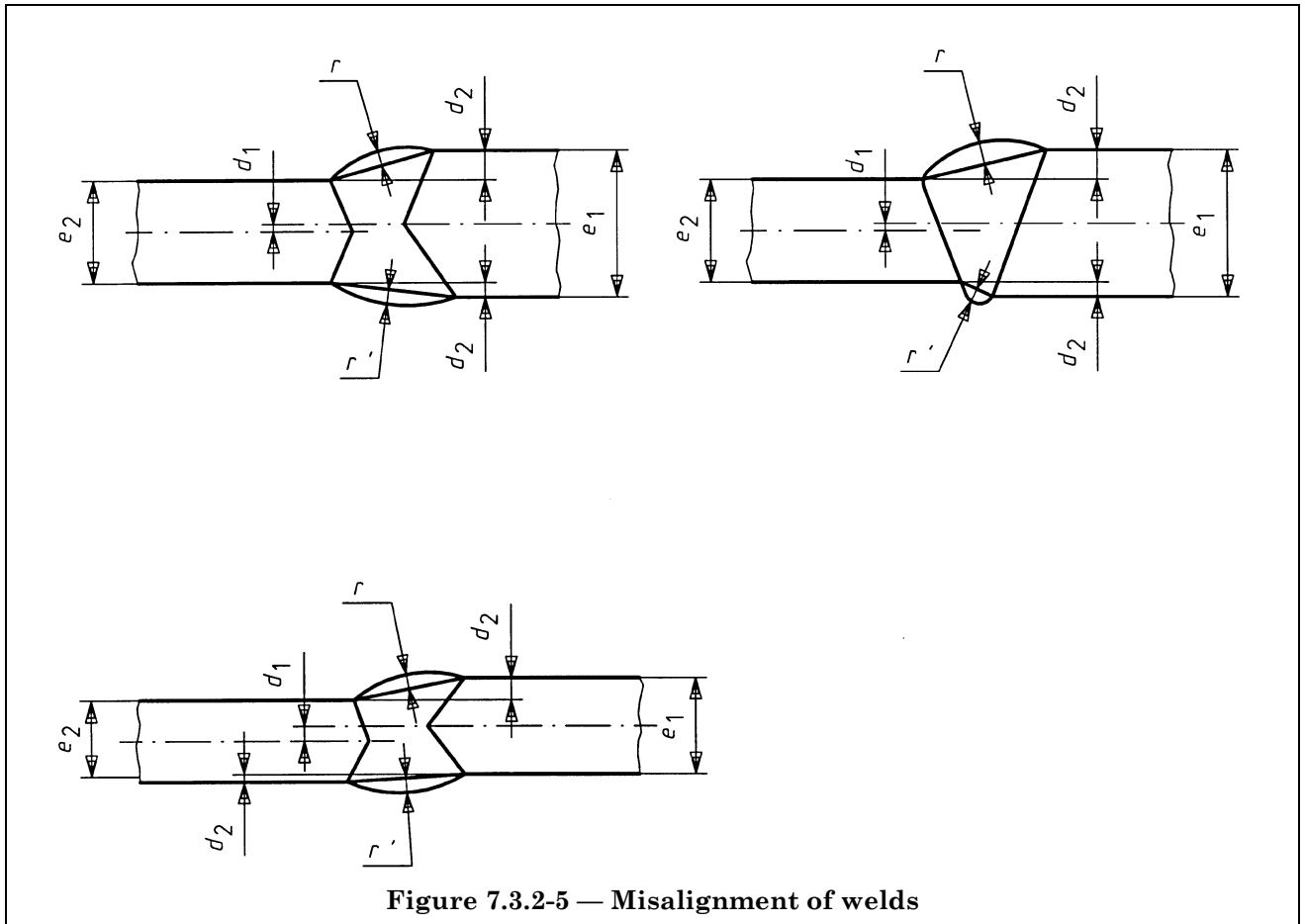


Figure 7.3.2-5 — Misalignment of welds

Table 7.3-1 — Maximum misalignment

Longitudinal joints	Circumferential joints
$d_1 \leq e/10$	$d_1 \leq \max \left[ \frac{e}{4}; 1 \text{ mm} \right]$
$d_2 \leq e/4$	$d_2 \leq e/4$
NOTE $e$ is the smaller of $e_1$ or $e_2$ ; see Figure 7.3.2-5.	

## 8 Qualification of welders and welding operators

Testing and approval of welders and welding operators shall be in accordance with EN 287-1, EN 287-2 and EN 1418, as applicable. The testing and approval shall be carried out by an approved inspection body.

## 9 Qualification of welding procedures

### 9.1 General

Welding procedures shall be qualified in accordance with EN 288-3 and EN 288-4. The testing and qualification shall be carried out by an approved inspection body.

## 9.2 Additional requirements for steel vessels

In addition to the requirements of 9.1, supplementary tests shall be undertaken for the welding procedure qualification of longitudinal and circumferential welds of the main body:

- two transverse face bend tests with a mandrel diameter of  $2e$  through an angle of  $180^\circ$  (EN 910);
- two transverse reverse bend tests with a mandrel diameter of  $2e$  through an angle of  $180^\circ$  (EN 910).

NOTE The bend tests included in EN 288-3 need not be carried out.

When the nominal thickness is greater than 5 mm:

- three Charpy V-notch tests on the weld material (EN 875);
- three Charpy V-notch tests on the HAZ (EN 875).

The average failure energy  $KCV$  for three test-pieces at the minimum working temperature shall not be less than  $35 \text{ J/cm}^2$ . Not more than one of the three values may be less than  $35 \text{ J/cm}^2$ , with a minimum of  $25 \text{ J/cm}^2$ .

When the minimum working temperature is greater than  $-10^\circ\text{C}$ , the  $KCV$  energy shall be checked at  $-10^\circ\text{C}$ .

## 9.3 Existing welding procedures

If the qualification of an existing welding procedure, in accordance with a standard of the EN 288 series, does not comply with the requirements indicated in 9.2, these requirements shall be verified on coupon-plates performed before the beginning of the production. The testing shall be carried out by an approved inspection body.

# 10 Testing

## 10.1 Calibration

All measurement, inspection and test equipment used for final acceptance of vessels shall be calibrated.

## 10.2 Vessels designed by calculation method

### 10.2.1 General

All welded joints shall be visually examined for surface and profile defects, and shall comply with the requirements of EN 25817 for steel vessels and EN 30042 for aluminium vessels. The level of acceptable defects shall be B.

If flanges are manufactured by bending and subsequent welding, these welds are considered to be main seams.

NOTE 1 Visual examination may be aided by magnetic particle or dye penetrant examination.

Longitudinal and circumferential welds shall be subjected to non-destructive tests or/and destructive tests inspection (see Table 10.2.1-1 to Table 10.2.1-4).

The manufacturer's inspector shall conduct the tests detailed in Table 10.2.1-1 to Table 10.2.1-4, which show the minimum amount of testing in relation to the calculation coefficient  $K_c$  and the shell coefficient  $K_s$  (see 6.4.2).

The normal amount of testing to be carried out by the manufacturer or/and by the approved inspection body, when the shell coefficient  $K_s$  is taken as equal to 1 (see 6.4.2), is given in:

- Table 10.2.1-1 for welds made by an automatic welding process. The calculation coefficient  $K_c$  shall be taken as equal to 1.
- Table 10.2.1-2 for welds made by a non-automatic welding process. The calculation coefficient  $K_c$  shall be taken as equal to 1,15.

NOTE When a manual root is completed by an automatic welding process, the calculation coefficient  $K_c$  may be taken as equal to 1.

A lower amount of testing may be carried out when the shell coefficient  $K_s$  is taken as equal to 1,25 (see 6.4.2), which is given in:

- Table 10.2.1-3 when an automatic welding process is used ( $K_c = 1$ );
- Table 10.2.1-4 when a non-automatic welding process is used ( $K_c = 1,15$ ).

### 10.2.2 *Alternative testing requirements*

If, in the calculation, a design pressure,  $P$ , of at least 1,25 times the maximum working pressure,  $PS$ , is used, the amount of testing in Table 10.2.1-3 and Table 10.2.1-4 suffices.

The alternatives offered in Table 10.2.1-3 and Table 10.2.1-4 are selected at the choice of the manufacturer.

### 10.2.3 *Non-destructive testing*

#### 10.2.3.1 *Personnel certification*

Non-destructive testing personnel shall be certified in accordance with EN 473.

#### 10.2.3.2 *Imperfections*

The imperfections found by radiographic methods shall be compared with the level of acceptable imperfections given by EN 25817 or EN 30042. The level of acceptable imperfections shall be B.

#### 10.2.3.3 *Radiographic*

The radiographic technique shall comply with class B of EN 1435 and achieve a minimum density of 2, and a maximum density of 4.

#### 10.2.3.4 *Ultrasonic tests*

The use of ultrasonic tests is not specified in this standard.

### 10.2.4 *Destructive testing of welds*

In cases where coupon plates are requested in Table 10.2.1-1 to Table 10.2.1-4, the following tests shall be carried out.

#### 10.2.4.1 *Destructive tests carried out for vessels of classes 2 and 3*

The following tests shall be carried out:

- one transverse face bend test (EN 910);
- one transverse reverse bend test (EN 910).

For steel vessels intended for a service temperature colder than  $-10\text{ }^{\circ}\text{C}$  and with nominal wall thickness greater than 5 mm, the following tests shall be carried out:

- three Charpy V-notch tests on the weld material (EN 875);
- three Charpy V-notch tests on the HAZ (EN 875);
- one macro test (ISO 3057).

These tests shall be performed as indicated in Clause 9.

**Table 10.2.1-1 — Amount of testing required for welds made by an automatic welding process where  $K_C = 1,0$  and  $K_S = 1,0$  (see 6.4.2)**

Testing by the manufacturer: for all classes			Testing by the approved inspection body <sup>a</sup> : for the verification procedure (see Table 4.1)
Test on	NDT (see 10.2.3)	DT (see 10.2.4.1)	Verification DT
Each vessel	100 % visual inspection	—	
Each welding machine and each weld procedure	<p style="text-align: center;"><b>After any new setting<sup>b</sup></b> (with the agreement of the approved inspection body for classes 1 and 2)</p> <p style="text-align: center;">or</p> <p>One film with a minimum length of 200 mm of the longitudinal weld</p> <p style="text-align: center;">or</p> <p>One coupon plate as an extension from the first longitudinal weld</p>		<p>Longitudinal welds: one test per batch (with minimum one per 6 months)</p> <p>Tests: see 10.2.4.2</p> <p>In the case of circumferential welds made with a different procedure: one test coupon per batch; same tests as for longitudinal welds</p>
	<p style="text-align: center;"><b>During manufacture<sup>c</sup></b></p> <p>One film with a minimum length of 200 mm of the longitudinal weld, including at least one T-junction for each batch of 100 vessels<sup>d</sup>, but not less than one film per day of production.</p> <p>In the case of circumferential welds made with different welding procedures, and also when only circumferential welds are used: the same tests as for longitudinal welds, but at the rate of one film per 500 vessels, or at least one per 5 days of production</p>		<p style="text-align: center;">or</p> <p>Films covering a length of circumference for one vessel per batch. The T-junction, including the weld start and stop of each circumferential weld, shall be covered (with minimum one per year)</p>
NOTE 1 It is advisable to make checks on welds that are produced after a halt in production.			
NOTE 2 When two hemispherical ends are welded together without a straight flange, the weld is to be tested as a longitudinal weld.			
NOTE 3 Films on circumferential welds only concern butt and joggled end joints.			
<p><sup>a</sup> Testing by the approved inspection body is required only in the case of verification. This requirement is not part of the EC Directive and therefore is not part of the harmonized standard.</p> <p><sup>b</sup> A new setting is taken to mean a change in the basic parameters of the welding procedure.</p> <p><sup>c</sup> The maximum period of time between such tests shall not exceed 3 months.</p> <p><sup>d</sup> If the film, after new setting, includes a T-junction, this film shall satisfy the manufacturing requirements for the first 100 vessels.</p>			

**Table 10.2.1-2 — Amount of testing required for welds made by a non-automatic welding process where  $K_C = 1,15$  and  $K_S = 1$  (see 6.4.2)**

Testing by the manufacturer: for all classes			Testing by the approved inspection body <sup>a</sup> : for the verification procedure (see Table 4-1)
Test on	NDT (see 10.2.3)	DT (see 10.2.4.1)	Verification DT
Each vessel	100 % visual inspection	—	Longitudinal welds: one test per batch (with minimum one per 6 months)
Each welding machine and each weld procedure	<p style="text-align: center;"><b>During manufacture</b></p> <p style="text-align: center;">and</p> <div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <p>Films of longitudinal weld taken every 40 vessels. Two films, each covering 200 mm of the longitudinal weld, including two T-junctions, on one vessel<sup>b</sup></p> </div> <div style="width: 45%;"> <p>One coupon plate every 3 months in extension from the first longitudinal weld.</p> </div> </div> <p style="text-align: center;">and</p> <div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <p>When only circumferential welds are used, the same tests as for longitudinal welds, but at the rate of one film per 200 vessels, or at least one per month of production<sup>b</sup></p> </div> <div style="width: 45%;"> <p>One coupon plate every year</p> </div> </div>		<p>Test: see 10.2.4.2</p> <p>In the case of circumferential welds made with a different procedure: one test coupon per batch; same tests as for longitudinal welds</p> <p style="text-align: center;">or</p> <p>Films covering a length of circumference for one vessel per batch. The T-junction, including the weld start and stop of each circumferential weld, shall be covered (with minimum one per year)</p>
NOTE 1 It is advisable to make checks on welds that are produced after a halt in production.			
NOTE 2 When two hemispherical ends are welded together without a straight flange, the weld is to be tested as a longitudinal weld.			
NOTE 3 Films on circumferential welds only concern butt and joggled end joints.			
<sup>a</sup> Testing by the approved inspection body is required only in the case of verification. This requirement is not part of the EC Directive and therefore is not part of the harmonized standard.			
<sup>b</sup> The maximum period of time between such tests shall not exceed 3 months.			

**Table 10.2.1-3 — Alternative amount of testing required for welds made by an automatic welding process where  $K_C = 1,0$  and  $K_S = 1,25$  (see 6.4.2)**

Testing by the manufacturer: for all classes			Testing by the approved inspection body <sup>a</sup> : for the verification procedure (see Table 4.1)
Test on	NDT (see 10.2.3)	DT (see 10.2.4.1)	Verification DT
Each vessel	100 % visual inspection	—	Longitudinal welds: one test per batch (with minimum one per 6 months)
Each welding machine and each weld procedure	<b>After any new setting<sup>b</sup></b> (with the agreement of the approved inspection body for classes 1 and 2)		Tests: see 10.2.4.2  In the case of circumferential welds made with a different procedure: one test coupon per batch; same tests as for longitudinal welds
	One film with a minimum length of 200 mm of the longitudinal weld	or One coupon plate as an extension from the first longitudinal weld	
	<b>During manufacture<sup>c</sup></b>		or
	One film with a minimum length of 200 mm of the longitudinal weld, including at least one T-junction for each batch of 500 vessels <sup>d</sup> , but not less than one film per 5 days of production.  When only circumferential welds are used, the same tests as for longitudinal welds, but at the rate of one film per 2 500 vessels, or at least one per month of production	—	One film with a minimum length of 200 mm of each circumferential weld, including a T-junction, on one vessel per batch (with minimum one per year)
NOTE 1 It is advisable to make checks on welds that are produced after a halt in production.			
NOTE 2 When two hemispherical ends are welded together without a straight flange, the weld is to be tested as a longitudinal weld.			
NOTE 3 Films on circumferential welds only concern butt and joggled end joints.			
<sup>a</sup> Testing by the approved inspection body is required only in the case of verification. This requirement is not part of the EC Directive and therefore is not part of the harmonized standard.			
<sup>b</sup> A new setting is taken to mean a change in the basic parameters of the welding procedure.			
<sup>c</sup> The maximum period of time between such tests shall not exceed 3 months.			
<sup>d</sup> If the film, after new setting, includes a T-junction, this film shall satisfy the manufacturing requirements for the first 100 vessels.			

**Table 10.2.1-4 — Amount of testing required for welds made by a non-automatic welding process where  $K_C = 1,15$  and  $K_S = 1,25$  (see 6.4.2)**

Testing by the manufacturer: for all classes			Testing by the approved inspection body <sup>a</sup> : for the verification procedure (see Table 4.1)
Test on	NDT (see 10.2.3)	DT (see 10.2.4.1)	Verification DT
Each vessel	100 % visual inspection	—	Longitudinal welds: one test per batch (with minimum one per 6 months)
Each welder and each weld procedure	<b>During manufacture</b>		Tests: see 10.2.4.2  In the case of circumferential welds made with a different procedure: one test coupon per batch; same tests as for longitudinal welds
	and	and	
	Films of longitudinal weld taken every 200 vessels. Two films, each covering 200 mm of the longitudinal weld, including two T-junctions, on one vessel <sup>b</sup>	One coupon plate every year in extension of a longitudinal weld	or Films covering 100 % of circular welds on one vessel per batch (with minimum one per year)
	and	and	
	When only circumferential welds are used, the same tests as for longitudinal welds, but at the rate of one film per 1 000 vessels, or at least one per 6 months of production	One coupon plate every year	
NOTE 1 It is advisable to make checks on welds that are produced after a halt in production.			
NOTE 2 When two hemispherical ends are welded together without a straight flange, the weld is to be tested as a longitudinal weld.			
NOTE 3 Films on circumferential welds only concern butt and joggled end joints.			
<sup>a</sup> Testing by the approved inspection body is required only in the case of verification. This requirement is not part of the EC Directive and therefore is not part of the harmonized standard.			
<sup>b</sup> The maximum period of time between such tests shall not exceed 3 months.			

#### 10.2.4.2 Destructive tests carried out for vessels of class 1

The tests indicated in 10.2.4.1 shall be witnessed and verified by the approved inspection body in the case of verification.

If, after a new setting, the approved inspection body has witnessed and verified coupon plates, the results shall be used for the verification.

#### 10.2.5 Acceptance criteria

##### 10.2.5.1 Coupon plates

If any test performed on a coupon plate shows an unsatisfactory result, the reason for the failure shall be investigated. Two supplementary coupon plates shall be prepared and tested. If one of the re-test results is unsatisfactory, the batch of vessels from which the coupon plates were prepared shall be rejected.

**10.2.5.2 Radiographic tests**

If the tests identify unacceptable defects, the reason for the failures shall be investigated. Then an additional examination shall be performed along a length twice that of the part tested.

If this second test reveals an unacceptable defect, a test shall be performed on the whole of the weld under examination, as well as on all welds of the batch in production.

If the re-test fails, the whole batch of vessels submitted for acceptance shall be rejected.

If the re-test reveals no unacceptable defects, the weld is accepted provided that the defective parts are repaired and the test carried out after this repair shows no unacceptable defects.

**10.3 Vessels designed by experimental method****10.3.1 General**

All welded joints shall be visually examined for profile defects and shall comply with the requirements of EN 25817 for steel vessels and EN 30042 for aluminium vessels. The level of acceptable defects shall be B.

If flanges are manufactured by bending and subsequent welding, these welds are considered to be main seams.

NOTE Visual examination may be aided by magnetic particle or dye penetrant examination.

**10.3.2 Tests carried out by the manufacturer**

The manufacturer shall select one vessel, either:

- at the beginning of the day; or
- at the end of the day; and
- at any new setting;
- in the case of non-automatic welding, at least one per welder/operator per day.

On these vessels, the manufacturer shall perform:

- a pressure test as described in 6.5.3, 6.5.4 and 6.5.5;
- a burst test as described in 6.5.6.

In deviation of 6.5.5 and 6.5.6, the condition:

$$100 \times \frac{u_1 - u_{i0}}{u_{i0}} \leq 1 \quad (10.3.2-1)$$

shall be fulfilled, and the burst test pressure shall be higher than 5PS.

**10.3.3 Tests carried out by the approved inspection body**

In the case of verification, the approval inspection body shall select at random five vessels from each batch and shall carry out a hydraulic test.

**10.3.4 Acceptance criteria****10.3.4.1 Tests carried out by the manufacturer**

If a burst test fails, the reason for the failure shall be investigated. Two supplementary vessels shall be selected. The manufacturer shall perform on each vessel:

- a pressure test as described in 6.5.3, 6.5.4 and 6.5.5;
- a burst test as described in 6.5.6.

If one burst test fails, the whole production of the day concerned by the same welder and/or the same welding process shall be rejected.



**10.3.4.2 Tests carried out by the approved inspection body**

If a burst test fails, the reason for the failure shall be investigated. Two supplementary vessels shall be selected from the defective batch and two vessels at the beginning of the next batch produced by the same welder and/or the same welding process. The approved inspection body shall perform on each vessel:

- a pressure test as described in 6.5.3, 6.5.4 and 6.5.5;
- a burst test as described in 6.5.6.

If one burst test fails, the whole batch of vessels concerned and the vessels of the next batch by the same welder or/and the same welding process shall be rejected.

**10.4 Testing records****10.4.1 General**

All destructive tests and non-destructive tests performed by the manufacturer shall be recorded.

For each test, the following information shall be indicated:

- date and place of testing,
- name of the inspector or subcontractor,
- results of testing,
- serial number or batch number of vessels on which the test was performed.

**10.4.2 Non-destructive test and destructive test reports for prototype examination**

The non-destructive test and destructive test reports issued for delivery of a type-examination certificate shall be kept by the manufacturer for a period of 10 years.

**10.4.3 Vessels of classes 1 and 2**

The vessels selected for burst tests, the coupon plates used for mechanical tests and X-ray films in production shall be kept by the manufacturer until after the next visit of an approved inspection body concerning verification and/or surveillance.

**10.4.4 Vessels of class 3**

X-ray films, macros and laboratory reports of destructive tests (coupon plates and burst tests) performed during the production of vessels of class 3 shall be kept by the manufacturer for a period of 10 years at least.

**10.5 Pressure test**

**10.5.1** Every vessel shall undergo a pressure test.

**10.5.2** For a hydraulic test,  $P_h$  shall be the value given by the following equation:

$$P_h = 1,5 P \quad (10.5.2-1)$$

The test pressure shall be held at  $P_h$  long enough to allow all the surfaces and joints to be examined visually. The vessel shall not show any sign of plastic deformation or leakage.

Subject to agreement, a pneumatic test on each vessel may be performed using the value  $P_h$  above.

**WARNING.** It should be borne in mind that pneumatic testing is potentially a much more dangerous operation than hydraulic testing in that, irrespective of vessel size, any failure during test is likely to be of a highly explosive nature. It should, therefore, only be undertaken after consultation with the inspecting authority and after ensuring that the safety measures comply with relevant legislation.

**10.5.3** Every vessel which fails the pressure test shall be rejected. Repair of such vessels is permissible, but in these cases the pressure test shall be repeated.

## 11 Instructions to accompany the vessel

- a) particulars given on the vessel nameplate, including the serial identification;
- b) the use for which the vessel has been designed, including the additional loadings, if any, taken into account in the design, and the method of fixing the vessel;
- c) indication of the corrosion allowance of the main parts (shell, ends, flange, internal end, if any) and of the actual wall thickness of the main parts;
- d) where necessary, the maintenance and installation requirements for vessel safety;
- e) a declaration that the vessel is in accordance with the requirements of this standard (see Annex B);
- f) for information to the customer, a statement on the test certificate that no welding operations are to be carried out on pressurized parts of the vessel.

NOTE This documentation is to be in the language, or languages, of the country of destination.

## 12 Marking

the vessel or data plate shall bear the following information:

- the maximum working pressure  $PS$ , in bars;
- the test pressure  $P_h$ , in bars;
- the maximum working temperature  $T_{max}$ , in degrees Celsius;
- the minimum working temperature  $T_{min}$ , in degrees Celsius;
- the capacity of the vessel  $V$ , in litres;
- the adopted corrosion allowance  $c$ , in millimetres, or “F” if the vessel is internally coated;
- the actual thickness;
- the name or mark of the manufacturer;
- the type and serial or batch identification of the vessel and year of manufacture;
- the identification of the approved inspection body when required by this standard;
- the number of this standard (i.e. EN 286-1);
- the CE marking for pressure vessels greater than 50 bar·l, manufactured in accordance with the Directive.

Where a data plate is used, it shall be so designed that it cannot be re-used and shall include a vacant space to enable other information to be provided (e.g. test or proof mark).

The inscriptions shall be affixed in a visible, easily legible and indelible form to the vessel or to a data plate attached to the vessel in such a way that it cannot be removed or become illegible during the lifetime of the vessel in the working environment.

## Annex A (normative) Verification

### A.1 General requirements

Verification shall be performed by an approved inspection body on batches of vessels submitted by their manufacturer or by his authorized representative. Batches shall be accompanied by the type-examination certificate (see Annex D) or by the certificate of approval of the design and manufacturing schedule (certificate of adequacy) (see Annex C).

When a batch is examined, the inspection body shall ensure that the vessels have been manufactured and checked in accordance with the design and manufacturing schedule and shall perform a hydrostatic test or, subject to the agreement of the Member State, a pneumatic test on each vessel in the batch at a pressure  $P_h$ , equal to 1,5 times the vessel's design pressure. Moreover, the inspection body shall carry out tests on test-pieces taken from a representative production test-piece or from a vessel, as the manufacturer chooses, in order to examine weld quality. The tests shall be carried out on longitudinal welds. However, where differing welding techniques are used for longitudinal and circumferential welds, the tests shall be repeated on representative test-pieces of circumferential welds.

### A.2 Construction verification

The inspection body shall perform the following checks and examinations.

#### A.2.1 *Check of the manufacturing record*

See Annex E.

#### A.2.2 *External and internal inspection, dimensional check*

The inspection body shall check the identification of the vessel, e.g. the data plate, and shall inspect the vessels visually, externally and internally for defects, especially the seams.

The inspection shall be performed before any permanent covering coatings are applied.

The inspection body shall check dimensions of shells, ends, nozzles, bolts and other parts that are of importance to the safety of the vessel, for conformity with the drawings. Distances important for safety (e.g. distance of nozzles) shall be checked if considered necessary.

NOTE Normally it is adequate if 10 % of vessels are checked and inspected, these to be selected by the approved inspection body.

#### A.2.3 *Destructive testing*

Destructive testing as required by the final column of Table 10.2.1-1, Table 10.2.1-2, Table 10.2.1-3 and Table 10.2.1-4 shall be witnessed by the approved inspection body and the results certified.

#### A.2.4 *Non-destructive testing*

Non-destructive testing of butt weld seams as required by 10.2.3 shall be checked by the approved inspection body. This includes spot checks of films; if the films are not available, spot NDT shall be performed according to Table 10.2.1-1, Table 10.2.1-2, Table 10.2.1-3 and Table 10.2.1-4.

## Annex B (normative) Declaration of conformity — Surveillance

### B.1 General

#### B.1.1 *Declaration of conformity*

Pressure vessels in accordance with this standard whose product of  $PS$  and  $V$  exceeds 50 bar·l but which do not exceed 3 000 bar·l are, at the choice of the manufacturer, subject to verification, (see Annex A) or subject to the declaration of conformity (see 3.1.5).

#### B.1.2 *Surveillance* (see 3.1.7)

By the declaration of conformity, the manufacturer becomes subject to surveillance in the case where the product of  $PS$  and  $V$  exceeds 200 bar·l. The purpose of surveillance is to ensure that the manufacturer duly fulfils the obligations required by this standard.

In the case of vessels manufactured in accordance with an approved specimen, for which a type-examination certificate exists, surveillance shall be the responsibility of the approved inspection body which issued this type-examination certificate.

In the case of vessels not manufactured in accordance with an approved specimen, surveillance shall be the responsibility of the approved inspection body which issued the certificate of approval of the design and manufacturing schedule (certificate of adequacy), (see C.2).

## **B.2 Procedures required before commencement of manufacture of vessels of classes 2 and 3 (see Clause 4) subject to a declaration of conformity**

### **B.2.1 Manufacturer's responsibilities**

The manufacturer shall appoint a management representative who, irrespective of other responsibilities, shall have defined authority and responsibility for ensuring that the requirements of this standard are implemented and maintained.

Before commencing manufacture, the manufacturer shall submit to the approved inspection body which issued the type-examination certificate or the certificate of approval of design and manufacturing schedule, certificate of adequacy (see Annex C), a document describing the manufacturing processes and all of the predetermined, systematic measures taken to ensure conformity of the pressure vessels with this standard.

These documents shall include the design and manufacturing schedule and the following documents:

- a) a description of the means of manufacture and inspection appropriate to the construction of the vessels;
- b) an inspection document describing the appropriate examinations and tests to be carried out during manufacture, together with the procedures thereof and the frequency with which they are to be performed;
- c) an undertaking to carry out the examinations and tests in accordance with the inspection document referred to above and to have a hydrostatic test carried out on each vessel, in accordance with this standard;
- d) the addresses of the places of manufacture and storage, and the date on which manufacture is to commence.

In addition, when the product of *PS* and *V* exceeds 200 bar·l, the manufacturer shall authorize access to the said places of manufacture or storage by the body responsible for the surveillance, for inspection purposes, and allow that body to select sample vessels and provide it with all necessary information, in particular:

- the design and manufacturing schedule;
- the inspection report;
- the type-examination certificate or certificate of adequacy, where appropriate;
- the manufacturing record, including particularly a report on examinations carried out.

### **B.2.2 Approved inspection body's responsibility**

The inspection body responsible for the surveillance shall examine the documents referred to in B.2.1a and B.2.1c in order to check their conformity with the requirements of this standard and with:

- a) the conditions stated in the design and manufacturing approval certificate; or
- b) the design and manufacturing record and the conditions stated in the type-examination certificate.

Manufacturing shall not commence before the approved inspection body has issued written approval.

**B.3 Procedures required during manufacture of vessels of classes 2 and 3 (see Clause 4) subject to a declaration of conformity****B.3.1 Manufacturer's responsibilities**

The manufacturer shall ensure that the inspection and testing is carried out in accordance with the documented procedures to complete the evidence of full conformance of the vessel to this standard. The inspection and test status of vessels shall be identified by using markings, authorized stamps, tags, labels, inspection records, physical location or other suitable means which indicate conformance or non-conformance of vessels with regard to inspection and tests performed. Records shall identify the inspection authority responsible for the release of conforming vessels.

The manufacturer shall maintain control of vessels that do not conform to the requirements of this standard.

All non-conforming vessels shall be clearly identified and segregated when practical, to prevent unauthorized use, delivery or mixing with conforming vessels.

Repaired or re-worked vessels shall be re-inspected in accordance with documented procedures.

**B.3.2 Approved inspection body's responsibilities**

For vessels whose product of  $PS$  and  $V$  exceeds 200 bar·l, the inspection body responsible for surveillance shall, during fabrication:

- a) ensure that the manufacturer manufactures and checks the vessel in accordance with the documents described in **B.2.1**;
- b) take random samples, two at each visit (see also **B.3.4b**), at the place of manufacture or storage of vessels, for inspection purposes as given in **B.3.3** and **B.3.4**.

**B.3.3 Frequency of inspection body operation**

Initial operations a) and b) of **B.3.2** shall be carried out within 2 months of the commencement of manufacture, and afterwards random checks will be made at the normal rate of one visit per year if the rate of production of vessels of the same type is up to 3 000 per year, and two visits if production is more than 6 000 per year. For production quantities between these, the frequency of visits will be adjusted.

**B.3.4 Surveillance checks and tests**

To ensure that the manufacturer produces and checks vessels subject to the declaration of conformity in accordance with this standard the inspection body responsible for the surveillance shall perform the following checks, inspections, examinations and tests.

- a) Check of the design and manufacturing record, the inspection report and the report on the examinations and tests carried out, in particular with respect to completeness, consistency, validity of certificates, qualification of personnel etc..
- b) The inspection body shall select at random at least two vessels in such a manner that at least one vessel per type is selected per year. On these vessels it shall perform an external and internal inspection, a dimensional check, a non-destructive test of all butt welds (radiographic examination) and a hydrostatic test (see **A.1**).

If the experimental method (see **6.5**) is used for the determination of wall thicknesses, pressure tests and burst tests as described in **10.3.2** shall be performed on two randomly selected vessels by the inspection body, instead of the non-destructive tests.

- c) The inspection body shall make available to the manufacturer a surveillance report of the investigations performed.

## Annex C (normative)

### Design and manufacturing schedules

#### C.1 Content

The design and manufacturing schedules shall contain the name of the manufacturer and the place of manufacture, and the following:

- a) a detailed manufacturing drawing of the vessel type;
  - b) the instructions;
  - c) a document describing:
    - 1) the materials selected;
    - 2) the welding processes used;
    - 3) the checks to be carried out;
    - 4) any pertinent details relating to the vessel design, including the design pressure;
    - 5) the certificates relating to the suitable qualification of the welding operation and of the welders or operators;
- NOTE If the certificates for the welding operation, operators or welders are not available, this should not prevent the approved body from evaluating the other documents. However, they should be submitted before approval is given or manufacturing commences;
- 6) the inspection documents for the materials used for the manufacture of parts and assemblies contributing to the strength of the pressure vessel, or a specimen of these inspection documents;
  - 7) a specimen of the proposed report on examination and tests;
  - 8) a specimen form of the manufacturing record (see Annex E).

#### C.2 Approval of design and manufacturing schedule (certificate of adequacy)

If vessels are not manufactured on the basis of a type-examination certificate, the manufacturer or his authorized representative shall submit to an approved inspection body an application for design approval and enclose three copies of this design and manufacturing schedule (see C.1)

Various vessels or vessel types can be included in one design and manufacturing schedule, but all vessel details (including branches, nozzles and attachments) of the production envisaged shall be included.

The approved inspection body shall examine these documents in order to check the conformity of the design, of the required tests, and of the qualifications, with the requirements of this standard. If they are in agreement with the requirements of this standard, the approved inspection body shall draw up a design approval certificate (certificate of adequacy) which shall be forwarded to the applicant.

## Annex D (normative)

### Type examination

Type examination is the procedure by which an approved inspection body ascertains and certifies that a prototype vessel satisfies the provisions of this Part of this standard. The manufacturer or his authorized representative shall submit to an approved inspection body an application for type examination.

The application shall include three copies of the design and manufacturing schedule (see Annex C) and a prototype vessel which is representative of the production envisaged.

If the application is lodged for various vessels, a prototype vessel is required for each vessel type.

Various vessels or vessel types can be included in one design and manufacturing schedule, but all vessel details (including branches, nozzles and attachments) of the production envisaged shall be included.

The approved inspection body shall examine the documents in order to check the conformity of design, of the required tests and of qualifications with the requirements of this standard.

The approved inspection body shall also verify that the vessel has been manufactured in conformity with the design and manufacturing schedule and is representative of the type, and shall perform appropriate examinations and tests (including 100 % NDT of main seams and a hydraulic test) to check that the vessel complies with the requirements of this standard.

If the design and manufacturing schedule and the prototype(s) comply with the provisions of this Part of EN 286, the approved inspection body shall draw up a type-examination certificate (per vessel type) which shall be forwarded to the applicant. The certificate shall state the conclusions of the examination, indicate any conditions to which its issue may be subject and be accompanied by the descriptions and drawings necessary for identification of the approved prototype.

## **Annex E (normative)**

### **Content of the manufacturing record**

The manufacturing record for vessels shall contain (at least) the following:

#### *a) General information*

- the name and mark of the manufacturer;
- the place of manufacture;
- the certificates relating to the suitable qualifications of the welding operation and of the welders or operators;
- the reports of the examinations and tests performed.

#### *b) Specific information*

- the manufacturer's ciphers identifying the vessels (e.g. no... through....);
- the type approval number or the number of the certificate of approval of the design and manufacturing schedule (certificate of adequacy);
- the diameter of the vessels;
- the capacity of the vessels;
- the maximum working pressure;
- the maximum working temperature;
- the minimum working temperature, if below  $-10\text{ }^{\circ}\text{C}$ ;
- the test pressure;
- the drawing number(s);
- the date of manufacture;
- batch size;
- the inspection document for the materials used in the manufacture of (main) pressurized assemblies;
  - for small component parts, other than the shell and ends, with diameters up to 250 mm, a declaration by the manufacturer that only material with the required certificates has been used may be supplied by the manufacturer instead of the inspection document;
  - the date of the hydrostatic test with the signature of the manufacturer's inspector and, in the case of verification, the inspector of the approved inspection body.

#### *c) Records*

For subsequent traceability, records shall be maintained of the vessel number/customer.

## **Annex F (normative)**

### **Test of the protection against corrosion**

#### **F.1 Test samples**

For the purposes of the following tests, a vessel typical of those to be produced is divided up into four parts (samples) which comprise 50 % of an end and 25 % of the cylindrical shell.

These tests are to be carried out once per 10 000 vessels or per 6 months, whichever comes first, or when changing the coating procedure (type of material, method of application, processing etc.).

A reliable and enduring protection against corrosion according to **6.3.3** is present if the requirements of **F.2** and **F.3** are met with the four samples.

## F.2 Grid test of paints

For a description of the apparatus, procedure to be used and evaluation of the grid test, see EN ISO 2409:1994, Clauses 2, 3, 4, 5 (except for 5.1.1 and 5.1.2) and 6.

The surface of the sample shall conform to the classification 0 or 1 of EN ISO 2409:1994, 6.1.

## F.3 Salt spray test

The test solution, apparatus, method of pressure and procedure to be used shall be in accordance with ISO 7253:1996, Clauses 5, 6, 9 and 11.

The samples shall be stored in the open air for a minimum of 72 h until the paint is fully hardened, and shall then be subjected to the salt spray test for a period of 96 h.

After completion of the salt spray test, the samples shall be gently washed or dipped in clean running water not warmer than 38 °C to remove salt deposits from their surface, and then immediately dried. Drying shall be accomplished with a stream of clean compressed air.

A careful and immediate examination shall be made for the extent of corrosion of the dried test samples. The following acceptance criteria apply:

- a) signs of blistering, and loss of adhesion of coatings are not allowed;
- b) corrosion spots not exceeding 1 mm diameter at a frequency not exceeding 1 % are allowed.

Edges or areas damaged in sample preparation, purposely unpainted areas such as threads, and areas purposely damaged by the grid test (see F.2) shall be disregarded in the corrosion evaluation.

For the purposes of assessing the frequency of corrosion spots, divide the area of the sample into significant surface areas not less than 5 000 mm<sup>2</sup> each. Divide the area of the significant surface of the sample hypothetically into squares which have 5 mm long sides. This is easily done by placing a graticule made of fully flexible transparent plastics material on the sample so as to cover the most corroded area.

Count the number  $N$  of 5 mm squares in the significant area of the sample and the number  $m$  of such squares containing one or more corrosion spots.

When evaluating the sample, squares more than half-occupied by the sample shall be counted as full squares; those less than half-occupied shall be ignored.

If a spot appears to lie in more than one square, it shall be counted only once in the evaluation.

Determine the frequency of the corrosion spots as a percentage, from the expression:

$$\text{frequency} = 100 \times \frac{m}{N}$$

An illustration of a 1 % frequency is shown in Figure F.1.

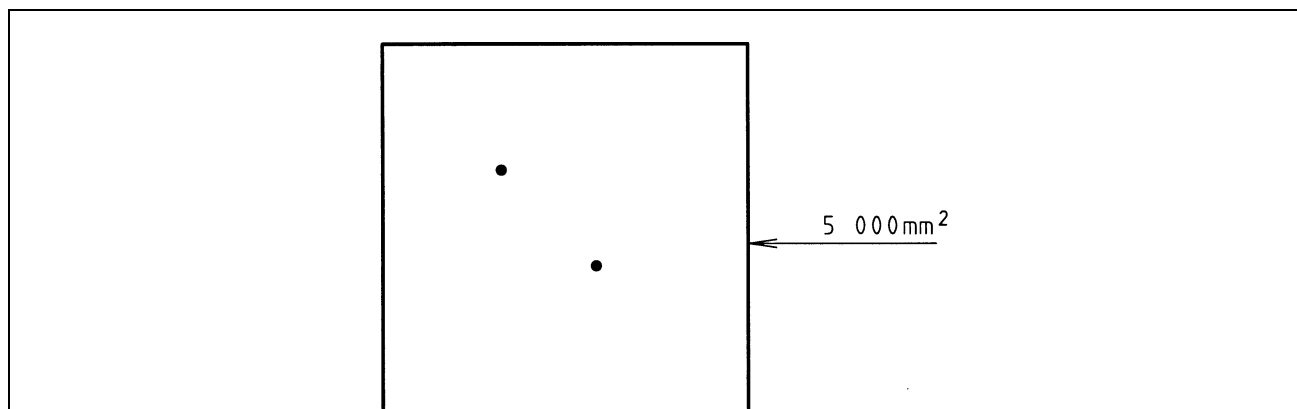


Figure F.1 — Illustration of a 1 % frequency of corrosion spots



## Annex G (informative)

### Essential safety requirements

This annex repeats the essential safety requirements contained in the Directive 87/404/EEC. The essential safety requirements for the vessels are set out below.

#### G.1 Materials

Materials must be selected according to the intended use of the vessels and in accordance with G.1.1 to G.1.4.

##### G.1.1 Pressurized parts

The materials referred to in Article 1 used for manufacturing the pressurized parts must be:

- capable of being welded;
- ductile and tough, so that a rupture at minimum working temperature does not give rise to either fragmentation or brittle-type fracture;
- not adversely affected by ageing.

For steel vessels, the materials must in addition meet the requirements set out in G.1.1.1 and, for aluminium or aluminium alloy vessels, those set out in G.1.1.2.

They must be accompanied by an inspection slip drawn up by the producer of the materials as described in annex II.

##### G.1.1.1 Steel vessels

Non-alloy quality steels meet the following requirements.

- a) They must be non-effervescent and be supplied after normalization treatment, or in an equivalent state.
- b) The content per product of carbon must be less than 0,25 %; that of sulfur and phosphorus must each be less than 0,05 %.
- c) They must have the following mechanical properties per product.
  - The maximum tensile strength  $R_{m,max}$  must be less than 580 N/mm<sup>2</sup>.
  - The elongation after rupture must be:
    - if test-pieces are taken parallel to the direction of rolling:  
thickness  $\geq 3$  mm:  $A \geq 22$  %  
thickness  $< 3$  mm:  $A_{80\text{ mm}} \geq 17$  %
    - if test-pieces are taken perpendicular to the direction of rolling:  
thickness  $\geq 3$  mm:  $A \geq 20$  %  
thickness  $< 3$  mm:  $A_{80\text{ mm}} \geq 15$  %.
  - the average failure energy  $KCV$  for three longitudinal test-pieces at minimum working temperature must not be less than 35 J/cm<sup>2</sup>. Not more than one of the three figures may be less than 35 J/cm<sup>2</sup>, with a minimum of 25 J/cm<sup>2</sup>.

In the case of steels used in the manufacture of vessels whose minimum working temperature is lower than  $-10$  °C and whose wall thickness exceeds 5 mm, this property must be checked.

##### G.1.1.2 Aluminium vessels

Non-alloy aluminium must have an aluminium content of at least 99,5 %, and those alloys described in Article 1(2) must display adequate resistance to intercrystalline corrosion at maximum working temperature.

Moreover, these materials must satisfy the following requirements:

- a) they must be supplied in an annealed state; and
- b) must have the following mechanical characteristics per product:
  - the maximum tensile strength  $R_{m,max}$  must be no more than  $350 \text{ N/mm}^2$ ;
  - the elongation after rupture must be:
    - $A \geq 16 \%$  if the test-piece is taken parallel to the direction of rolling;
    - $A \geq 14 \%$  if the test-piece is taken perpendicular to the direction of rolling.

### G.1.2 Welding materials

The welding materials used to manufacture the welds on or of the vessel must be appropriate to and compatible with the materials to be welded.

### G.1.3 Accessories contributing towards the strength of the vessel

These accessories (e.g. bolts and nuts) must be made of a material specified in 1.1 or of other kinds of steel, aluminium or an appropriate aluminium alloy compatible with materials used for the manufacture of pressurized parts.

The latter materials must, at minimum working temperature, have an appropriate elongation after rupture, and toughness.

### G.1.4 Non-pressurized parts

All unpressurized parts of welded vessels must be of materials which are compatible with that of the components to which they are welded.

## G.2 Vessel design

The manufacturer must, when designing the vessel, define the use to which it will be put, and select:

- the minimum working temperature  $T_{min}$ ;
- the maximum working temperature  $T_{max}$ ;
- the maximum working pressure  $PS$ .

However, should a minimum working temperature exceeding  $-10 \text{ }^\circ\text{C}$  be selected, the qualities required of the materials must be satisfied at  $-10 \text{ }^\circ\text{C}$ .

The manufacturer must also take account of the following provisions:

- it must be possible to inspect the inside of vessels;
- it must be possible to drain the vessels;
- the mechanical qualities shall be maintained throughout the period of use of the vessel for the intended purpose;
- the vessels shall, bearing in mind their prescribed use, be adequately protected against corrosion;

and the fact that under the conditions of use envisaged:

- the vessels will not be subjected to stresses likely to impair their safety in use;
- internal pressure will not permanently exceed the maximum working pressure  $PS$ ; however, it may momentarily do so by up to  $10 \%$ .

Circular and longitudinal seams must be made using full-penetration welds or welds of equivalent effectiveness. Convex ends other than hemispherical ones shall have a cylindrical edge.

### G.2.1 Wall thickness

If the product  $PS \times V$  is not more than  $3\,000 \text{ bar}\cdot\text{l}$ , the manufacturer must select one of the methods described in G.2.1.1 and G.2.1.2 for determining vessel wall thickness; if the product  $PS \times V$  is more than  $3\,000 \text{ bar}\cdot\text{l}$ , or if the maximum working temperature exceeds  $100 \text{ }^\circ\text{C}$ , such thickness must be determined by the method described in G.2.1.1.

The actual wall thickness of the cylindrical section and ends shall, however, be not less than  $2 \text{ mm}$  in the case of steel vessels and not less than  $3 \text{ mm}$  in the case of aluminium or aluminium alloy vessels.

### G.2.1.1 Calculation method

The minimum thickness of pressurized parts must be calculated having regard to the intensity of the stresses and to the following provisions.

- The calculation pressure to be taken into account must not be less than the maximum working pressure selected.
- The permissible general membrane stress must not exceed the lower of the values  $0,6 R_{ET}$  or  $0,3 R_m$ . The manufacturer must use the  $R_{ET}$  and  $R_m$  minimum values guaranteed by the material manufacturer in order to determine the permissible stress.

However, where the cylindrical portion of the vessel has one or more longitudinal welds made using a non-automatic welding process, the thickness calculated as above must be multiplied by the coefficient 1,15.

### G.2.1.2 Experimental method

Wall thickness must be so determined as to enable the vessels to resist at ambient temperature a pressure equal to at least 5 times the maximum working pressure, with a permanent circumferential deformation factor of no more than 1 %.

## G.3 Manufacturing processes

Vessels shall be constructed and subjected to production checks in accordance with the design and manufacturing record referred to in annex II, section 3.

### G.3.1 Preparation of the component parts

Preparation of the component parts (e.g. forming and chamfering) must not give rise to surface defects or cracks or changes in the mechanical characteristics likely to be detrimental to the safety of the vessels.

### G.3.2 Welds on pressurized parts

The characteristics of welds and adjacent zones must be similar to those of the welded materials, and shall be free of any surface or internal defects detrimental to the safety of the vessels.

Welds must be performed by qualified welders or operators possessing the appropriate level of competence, in accordance with approved welding processes. Such approval and qualification tests must be carried out by approved inspection bodies.

The manufacturer must also, during manufacture, ensure consistent weld quality by conducting appropriate tests using adequate procedures. These tests must be the subject of a report.

### G.4 Placing in service of the vessels

Vessels must be accompanied by the instructions drawn up by the manufacturer, as referred to in annex II, section 2.

## **A2** Annex H (normative) Requirements for peaking

### **H.1 Local irregularities in vessel profile**

Irregularities in profile (e.g. dents, buckling, flats on nozzle positions) shall be smooth and the depth shall be checked by a 20° gauge and shall not exceed the following values:

- a) 2 % of the gauge length; or
- b) 2,5 % of the gauge length provided that the length of the irregularities does not exceed one quarter of the length (with a maximum of 1 m) of the shell part between two circumferential joints.

Greater irregularities require proof by calculation or strain gauge measurement that the stresses are permissible.

### **H.2 Peaking on longitudinal butt welds**

When irregularity in the profile occurs at the welded joint and is associated with “flats” adjacent to the weld, the irregularity in profile or (peaking) shall not exceed the values given in Tables H.1 and H.2.

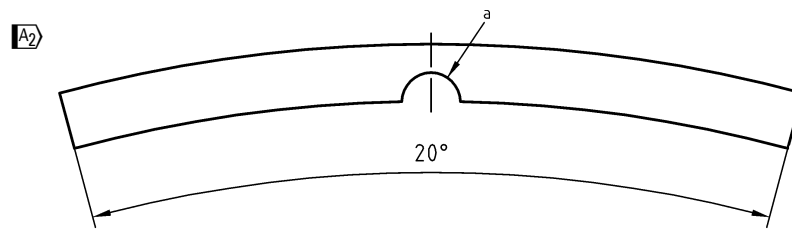
Measurement for peaking shall be made by means of a 20° profile gauge (or template), see Figure H.1, or other types of gauge such as bridge gauges or needle gauges.

For outwards peaking two readings shall be taken,  $P_1$  and  $P_2$  on each side of the joint, at any particular location, the maximum peaking is determined using Equation (H.1)

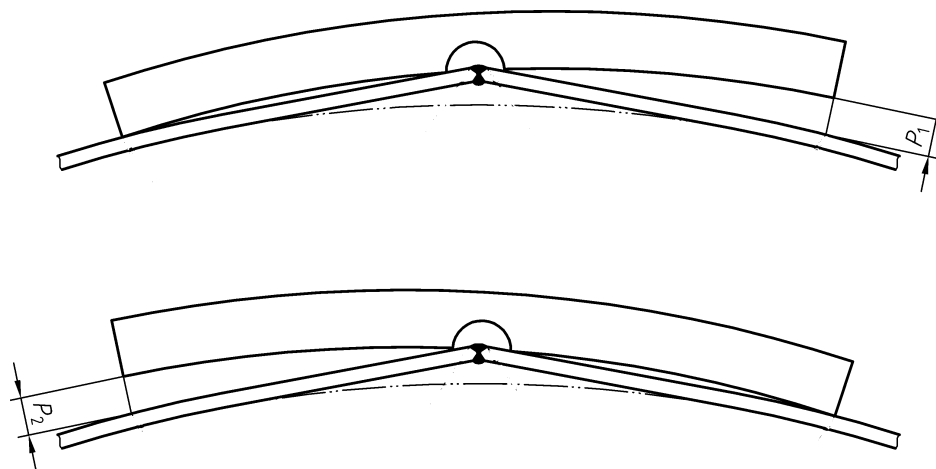
$$P = 0,25 \cdot (P_1 + P_2) \quad (\text{H.1})$$

The inwards peaking  $P$  shall be measured.

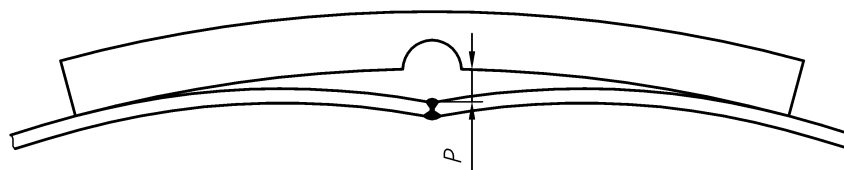
The inside radius of the gauge shall be equal to the nominal outside radius of the vessel. **A2**



a) Sufficient cut-out to adequately keep clear off the weld reinforcement



b) For outwards peaking two readings  $P_1$  and  $P_2$  shall be taken



c) For inwards peaking  $P$  shall be measured

**Figure H.1 — Gauge details, measurement of peaking**

Measurements shall be taken at approximately 250 mm intervals on longitudinal seams to determine the location with the maximum peaking value. The maximum peaking value for dynamic and cyclic loads shall be in accordance with Table H.1 and for static loads in accordance with Table H.2.  $\sqrt{A_2}$



**Table H.1 — Maximum permitted peaking  $P$  in longitudinal welds for dynamic and cyclic loads**

Dimensions in millimetres

Vessel wall thickness $e$	Maximum permitted peaking $P$
$e \leq 3$	1,5
$3 \leq e < 6$	2,5
$6 \leq e < 9$	3,0
$9 \leq e$	the lesser of $e/3$ , or 10 mm

NOTE 1 For cyclic loaded pressure vessels see also EN 13445-3:2002 and EN 13445-5:2002, Annex G in respect of peaking requirements.

Peaking values in excess of the above are only permitted when supported by special analysis but in any case must not exceed the values in Table H.2.

**Table H.2 — Maximum permitted peaking  $P$  in longitudinal welds for pressure vessels subject of non cyclic loads**

Dimensions in millimetres

Vessel ratio wall thickness $e$ to diameter $D$	Maximum permitted peaking $P$
$e/D \leq 0,025$	5
$e/D > 0,025$	10

NOTE 2 See also EN 13445-5:2002 for testing group 4 vessels for additional limits on peaking.



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