

Cryogenic vessels – Transportable vacuum insulated vessels of not more than 1 000 litres volume
 Part 2: Design, fabrication, inspection and testing
 English version of DIN EN 1251-2

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Kryo-Behälter – Ortsbewegliche, vakuum-isolierte Behälter mit einem Fassungsraum von nicht mehr als 1 000 Liter – Teil 2: Bemessung, Herstellung und Prüfung

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A comma is used as the decimal marker.

National foreword

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English version

Cryogenic vessels – Transportable vacuum insulated vessels of not more than 1 000 litres volume

Part 2: Design, fabrication, inspection and testing

Réceptacles cryogéniques – Réceptacles transportables, isolés sous vide, d'un volume n'excédant pas 1 000 litres – Partie 2: Conception, fabrication, inspection et essai

Kryo-Behälter – Ortsbewegliche, vakuum-isolierte Behälter mit einem Fassungsraum von nicht mehr als 1 000 Liter – Teil 2: Bemessung, Herstellung und Prüfung

This European Standard was approved by CEN on 1999-06-19.

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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.

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CEN

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

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Contents

Foreword	3
1 Scope	4
2 Normative references	4
3 Definitions and symbols	5
3.1 Definitions.....	5
3.2 Symbols	5
4 Design	7
4.1 Design validation options	7
4.2 Common design requirements	7
4.3 Design validation by calculation	12
4.4 Design validation by experimental method.....	27
5 Fabrication	59
5.1 General.....	59
5.2 Cutting.....	59
5.3 Cold forming.....	59
5.4 Hot forming.....	60
5.5 Manufacturing tolerances	60
5.6 Welding	63
5.7 Non-welded joints	63
6 Inspection and testing	64
6.1 Quality	64
6.2 Production control test plates	65
6.3 Non-destructive testing	65
6.4 Rectification.....	69
6.5 Pressure testing	69
Annex A (normative) Elastic stress analysis	70
A.1 General.....	70
A.2 Terminology.....	70
A.3 Limit for longitudinal compressive general membrane stress	72
A.4 Stress categories and stress limits for general application.....	73
A.5 Specific criteria, stress categories and stress limits for limited application	74
Annex B (informative) Recommended weld details	79
B.1 Scope	79
B.2 Weld detail	79
B.3 Oxygen service requirements.....	80
Annex C (normative) Additional requirements for flammable fluids	84
Annex D (normative) Outer jacket relief devices	85
D.1 Scope	85
D.2 Definitions.....	85
D.3 Requirements	85
Bibliography	86

Foreword

This European Standard has been prepared by Technical Committee CEN/TC 268 "Cryogenic vessels", the secretariat of which is held by AFNOR.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by July 2000, and conflicting national standards shall be withdrawn at the latest by July 2000.

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.

The standard has been submitted for reference into the RID and/or in the technical annexes of the ADR.

Therefore the standards listed in the normative references and covering basic requirements of the RID/ADR not addressed within the present standard are normative only when the standards themselves are referred to in the RID and/or in the technical annexes of the ADR.

The other parts of EN 1251 are :

- Part 1: Fundamental requirements ;
- Part 3: Operational requirements.

The Standard covers validation of design by calculation or by an experimental method.

1 Scope

This European Standard is applicable to the design, fabrication, inspection and testing of transportable vacuum insulated cryogenic vessels of not more than 1 000 litres volume and designed for a maximum allowable pressure greater than atmospheric.

This standard applies to transportable vacuum insulated cryogenic vessels for fluids as specified in EN 1251-1 and is not applicable to such vessels designed for toxic fluids.

For details of acceptable materials see clause 8 of EN 1251-1.

Additional requirements for flammable fluids are given in annex C.

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 288-3, *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 288-8, *Specification and approval of welding procedures for metallic materials – Part 8: Approval by a pre-production welding test*

EN 473, *Qualification and certification of NDT personnel - General principles*

EN 729-2, *Quality requirements for welding - Fusion welding of metallic materials – Part 2: Comprehensive quality requirements*

EN 729-3, *Quality requirements for welding - Fusion welding of metallic materials – Part 3: Standard quality requirements*

EN 895, *Destructive tests on welds in metallic materials - Transverse tensile test*

EN 910, *Destructive tests on welds in metallic materials - Bend tests*

EN 962, *Transportable gas cylinders - Valve protection devices caps and valve guards for industrial and medical gas cylinders – Design, construction and tests*

EN 970, *Non-destructive examination of fusion welds - Visual examination*

EN 1251-1, *Cryogenic vessels - Transportable vacuum insulated vessels of not more than 1 000 litres volume - Part 1: Fundamental requirements*

EN 1251-3, *Cryogenic vessels - Transportable vacuum insulated vessels of not more than 1 000 litres volume - Part 3: Operational requirements*

EN 1252-1, *Cryogenic Vessels – Materials - Part 1: Toughness requirements for temperatures below –80°C*

EN 1418, Welding personnel – Approval testing of welding operators for fusion welding and resistance weld setters for fully mechanized and automatic welding of metallic materials

EN 1435, *Non-destructive examination of welds - Radiographic examination of welded joints*

EN 1626, *Cryogenic Vessels - Valves for cryogenic service*

EN 1708-1, *Welding - Basic weld joint details in steel - Part 1 : Pressurized components*

EN 1797-1, *Cryogenic vessels - Gas/material compatibility - Part 1 : Oxygen compatibility*

EN 10045-1, *Metallic materials - Charpy impact test - Part 1: Test method*

EN 10204, *Metallic products - Types of inspection documents*

EN 12213, *Cryogenic vessels - Evaluation methods of thermal insulation performance*

EN 12300, *Cryogenic vessels - Cleanliness for cryogenic service*

EN 22244:1992, *Packaging - Complete, filled transport packages - Horizontal impact tests (horizontal or inclined plane tests - Pendulum test) (ISO 2244:1985)*

prEN ISO 4126-2, *Safety devices for protection against excessive pressure – Part 2: Bursting disc safety devices (ISO/DIS 4126-2:1996)*

EN ISO 6520-1, *Welding and allied processes - Classification of geometric imperfections in metallic materials - Part 1: Fusion welding (ISO 6520-1:1998)*

3 Definitions and symbols

3.1 Definitions

For the purposes of this standard, the following definitions apply in addition to those given in EN 1251-1:

3.1.1

automatic welding

welding in which the parameters are automatically controlled. Some of these parameters may be adjusted to a limited extent, either manually or automatically, during welding to maintain the specified welding conditions

3.1.2

maximum allowable pressure, P_s

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

3.1.3

volume of the inner vessel

the volume of the shell, excluding nozzles, pipes, etc. determined at minimum design temperature and atmospheric pressure

3.2 Symbols

For the purposes of this standard, the following symbols apply :

c	allowance for corrosion, in millimetres
d_i	internal diameter of tube or nozzle, in millimetres
f	narrow side of rectangular or elliptical plate, in millimetres
l_b	buckling length, in millimetres

n	Number
p	design pressure, in bar
p_e	allowable external pressure limited by elastic buckling, in bar
p_p	allowable external pressure limited by plastic deformation, in bar
r	radius e.g. inside knuckle radius of dished end and cones, in millimetres
s	required wall thickness including allowances, in millimetres
s_e	actual wall thickness, in millimetres
v	factor indicative of the utilisation of the permissible design stress in joints or factor allowing for weakening
x	(decay-length zone) distance over which governing stress is assumed to act, in millimetres
A	Area, in square millimetres
C, β	design factors
D	shell diameter, in millimetres
D_a	outside diameter e.g. of a cylindrical shell, in millimetres
D_i	internal diameter e.g. of a cylindrical shell, in millimetres
E	Young's modulus, in Newton per square millimetres
I	moment of inertia of stiffening ring, in millimetres ⁴
K	material property used for design, in Newton per square millimetres
R	radius of curvature e.g. inside crown radius of dished end, in millimetres
S	safety factor at design pressure
S_k	safety factor against elastic buckling at design pressure
S_p	safety factor against plastic deformation
Z	auxiliary value
ν	Poisson's ratio
u	out of roundness

4 Design

4.1 Design validation options

Each type of vessel shall be subject to validation of the design in accordance with one of the options given in 4.1.1, 4.1.2 or 4.1.3. The manufacturer shall consider the nature of the individual design, particularly the degree of novelty; a method of validation appropriate to that design; and the limitation of that method.

4.1.1 Validation by calculation

This option requires calculation of all pressure and load bearing components. The pressure part thicknesses of the inner vessel and outer jacket shall not be less than required by 4.3. Additional calculations are required to validate the design for the operating conditions including an allowance for dynamic loads.

4.1.2 Validation by experimental method

This option requires the pressure retaining capacity and structural integrity to be validated by experiment as detailed in 4.4.

4.1.3 Validation by calculation and experimental method

This option requires validation of the pressure retaining capacity by calculation except that the minimum wall thickness requirements of tables 1 and 2 do not apply. Structural integrity shall be validated by experiment as detailed in 4.4.

4.2 Common design requirements

4.2.1 General

The requirements of 4.2.2 to 4.2.7 are applicable to all vessels irrespective of the design validation option used. In the event of an increase in at least one of the following parameters :

- maximum allowable pressure ;
- density of the densest gas for which the vessel is designed ;
- maximum tare weight of the inner vessel ;
- nominal length and/or diameter of the inner shell,

or, in the event of any change relative

- to the type of material or grade (e.g. stainless steel to aluminium or change of stainless steels grades) ;
- to the fundamental shape ;
- to the decrease in the minimum mechanical properties of the material being used ;
- to the modification of the design of an assembly method concerning any part under stress, particularly as far as the support systems between the inner vessel and the outer jacket or the inner vessel itself or the protective frame, if any, are concerned.

The initial design validation programme shall be repeated to take account of these modifications.

In addition, if any changes affect the handling method or the stacking condition, the appropriate tests (complying respectively with 4.4.4.2 and 4.4.4.3) or the relevant calculations, shall be repeated to take account of these changes.

4.2.2 Design specification

To enable the design to be prepared the following information which defines a vessel type shall be available :

- maximum allowable pressure ;
- fluids intended to be used ;
- liquid capacity ;
- volume of the inner vessel ;
- method of handling and securing ;
- stacking arrangement.

A design document in the form of drawings and/or written text shall be prepared, it shall contain the information given above plus the following where applicable :

- definition of which components are validated by calculation and which are validated by experiment ;
- drawings with dimensions and thicknesses of load bearing components ;
- specification of all load bearing materials including grade, class, temper, testing etc. as relevant ;
- type of material test certificates in accordance with EN 10204 ;
- location and details of welds and other joints, welding and other joining procedures, filler, joining materials etc. as relevant ;
- calculations to verify compliance with this standard ;
- design validation test programme ;
- non destructive testing requirements ;
- pressure test requirements ;
- piping configuration including type, size and location of all valves and relief devices ;
- details of lifting points and lifting procedure.

4.2.3 Design loads

4.2.3.1 General

The transportable cryogenic vessel shall be able to withstand safely the mechanical and thermal loads and the chemical effects encountered during pressure test and normal operation.

4.2.3.2 Inner vessel

With the exception of a) the following loads shall be considered to act in combination where relevant :

- a) pressure test : The following value shall be used for validation purposes :

$$P_T \geq 1,3 (P_S + 1) \text{ bar} \quad \dots (1)$$

where :

P_S is the maximum allowable working pressure, in bar.

The 1 bar is added to allow for the external vacuum.

- b) pressure during operation, P_C , where :

$$P_C = P_S + P_L + 1 \text{ bar} \quad \dots (2)$$

P_L is the pressure, in bars, exerted by the liquid contents when the vessel is filled to capacity and subject to dynamic load ;

- c) reaction at the support points of the inner vessel due to the mass of the inner vessel and its contents when subject to dynamic load ;
d) load imposed by the piping due to the differential thermal movement of the inner vessel, the piping and the outer jacket.

The following cases shall be considered :

- cooldown (inner vessel warm - piping cold) ;
- filling and withdrawal (inner vessel cold - piping cold) ; and
- transshipment and storage (inner vessel cold - piping warm) ;

- e) load imposed on the inner vessel at its support points when cooling from ambient to operating temperature and during operation.

4.2.3.3 Outer jacket

The following loads shall be considered to act in combination where relevant :

- a) an external pressure of 1 bar ;
b) an internal pressure equal to the set pressure of the outer jacket pressure relief device ;
c) load imposed by the inner vessel and its contents at the support points in the outer jacket when subject to dynamic load ;
d) load imposed by piping as defined in 4.2.3.2 d) ;
e) load imposed at the inner vessel support points in the outer jacket when the inner vessel cools from ambient to operating temperature and during operation ;
f) reactions at the outer jacket support points due to the mass of the transportable cryogenic vessel and its contents when filled to capacity and subject to dynamic load (see 4.3.8).

4.2.3.4 Inner vessel supports

The inner vessel supports shall be suitable for the load defined in 4.2.3.2 c) plus loads due to differential thermal movements.

4.2.3.5 Outer jacket supports

The outer jacket supports shall be suitable for the load defined in 4.2.3.3 f).

4.2.3.6 Lifting points

Lifting points shall be suitable for lifting the transportable cryogenic vessel when filled to capacity and subject to vertical dynamic load, when lifted in accordance with the specified procedure (see 4.3.8).

4.2.3.7 Frame

Where a frame is part of the transportable cryogenic vessel it shall be suitable for the static and dynamic loads imposed during storage, lifting and transport. This shall include loads due to stacking vessels where applicable (see 4.3.8).

4.2.3.8 Protective guards

Guards fitted for the protection of fittings and external pipework shall be designed to withstand a load equal to the mass of the transportable cryogenic vessel filled to capacity applied in the horizontal or vertical direction.

The load shall be equal to twice the total mass if any of the following conditions is met :

- capacity less than 100 l ;
- total mass less than 150 kg ;
- the height of the centre of gravity of the transportable cryogenic vessel, when filled to capacity, including any framework elements, is more than twice the smaller horizontal dimension of its base.

4.2.3.9 Piping

Piping including valves, fittings and supports shall be designed for the following loads, with the exception of a) the loads shall be considered to act in combination where relevant :

- a) pressure test : Not less than the allowable working pressure P_S plus one bar for piping inside the vacuum jacket ;
- b) pressure during operation : Not less than the set pressure of the system pressure relief device ;
- c) thermal loads defined in 4.2.3.2 d) ;
- d) dynamic loads ;
- e) set pressure of thermal relief devices where applicable ;
- f) loads generated during pressure relief discharge.

4.2.4 Corrosion allowance

Corrosion allowance is not required on surfaces in contact with the operating fluid. Corrosion allowance is not required on other surfaces if they are adequately protected against corrosion.

4.2.5 Inspection openings

Inspection openings are not required in the inner vessel or the outer jacket.

NOTE 1 Due to the combination of materials of construction and operating fluids, internal corrosion will not occur.

NOTE 2 The inner vessel is inside the evacuated outer jacket and hence external corrosion of the inner vessel will not occur.

NOTE 3 The elimination of inspection openings also assists in maintaining the integrity of the vacuum in the interspace.

4.2.6 Pressure relief

4.2.6.1 General

Relief devices for inner vessels shall be in accordance with the appropriate European standards.

Relief devices for outer jackets shall be in accordance with annex D.

Systems shall be designed to meet the following requirements.

4.2.6.2 Inner vessel

The inner vessel shall be provided with at least two pressure relief devices to protect the vessel against excess pressure due to the following :

- a) normal heat leak ;

NOTE Insulation performance evaluated as described in EN 12213 shall be sufficient to satisfy the holding time requirement of EN 1251-3.

- b) heat leak with loss of vacuum ;
- c) failure in the open position of a pressure build up system.

Excess pressure means a pressure in excess of 110 % of the maximum allowable pressure for condition a) and in excess of the test pressure for condition b) or c).

An exception is made for vessels less than 450 litres capacity where at least one pressure relief device shall be provided.

Shut off valves or equivalent may be installed upstream of pressure relief devices, provided that additional devices and interlocks are fitted to ensure that the vessel has sufficient relief capacity at all times.

The pressure relief system shall be sized so that the pressure drop during discharge does not cause the valve to reseal instantly.

4.2.6.3 Outer jacket

A pressure relief device shall be fitted to the outer jacket. The device shall be set to open at a pressure of not more than 0,5 bar. The discharge area of the pressure relief device shall be not less than 0,34 mm²/l capacity of the inner vessel but not less than 10 mm diameter.

4.2.6.4 Piping

Any section of pipework containing cryogenic fluid which can be trapped shall be protected by a relief valve or other suitable relief device.

4.2.7 Valves

Valves shall be in accordance with EN 1626.

4.3 Design validation by calculation

4.3.1 General

When design validation is by calculation in accordance with 4.1.1 or 4.1.3 the dimensions of the inner vessel and outer jacket shall not be less than that determined in accordance with this sub-clause.

4.3.2 Inner vessel

4.3.2.1 Wall thickness

The following shall be used to determine the pressure part thicknesses in conjunction with the calculation formulae of 4.3.7.

The actual wall thickness shall be not less than shown in table 1 unless either

- a) the design has been validated by experiment ; or
- b) a stress analysis has been carried out, and assessed in accordance with annex A.

Table 1 — Inner vessel minimum wall thickness

Inner vessel Diameter D (mm)	Minimum wall thickness s_0 for reference steel ¹⁾ (mm)
$D \leq 400$	1
$400 < D \leq 1\,800$	$1 + \frac{D - 400}{700}$
1) Reference steel material is material having a product $R_m \times A_5$ of 10 000. For other materials calculate the minimum thickness using the following formula : $s = \frac{21,4s_0}{\sqrt[3]{R_m \times A_5}}$ where R_m is the ultimate tensile strength, in Newtons per square millimetre ; A_5 is the elongation at fracture, in per cent.	

4.3.2.2 Design pressure p

The internal design pressure p shall be equal to P_T as defined in 4.2.3.2.

The inner vessel need not be designed for external pressure.

4.3.2.3 Material property K at 20°C

The material property K to be used in the calculations shall be as follows :

- for austenitic stainless steel and aluminium, 1 % proof strength ;
- for aluminium alloys, 0,2 % proof strength.

K shall be the minimum value at 20 °C taken from the material standard. In the case of austenitic stainless steels the specified minimum value may be exceeded by up to 15% provided this higher value is attested in the inspection certificate.

Higher values of K may be used provided that the following conditions are met :

- the material manufacturer shall guarantee compliance with this higher value, in writing, when accepting the order ;
- the increased properties shall be verified by testing each rolled plate or coil of the material to be delivered ;
- the increased properties shall be attested in the inspection certificate.

For austenitic stainless steel a strength value obtained in work hardened material may be used in the design provided this value and adequate ductility is maintained in the finished component.

4.3.2.4 Safety factors S , S_p and S_k

The safety factors to be used are as follows :

- internal pressure (pressure on the concave surface) :

$$S = 1,33$$

- external pressure (pressure on the convex surface) :

- cylindrical shells $S_p = 1,4$

$$S_k = 2,6$$

- spherical region $S_p = 2,1$

$$S_k = 2,6 + 0,0018R / s$$

- knuckle region $S_p = 1,6$.

4.3.2.5 Weld joint factors ν

For internal pressure (pressure on the concave surface) $\nu = 0,85$ or $1,0$ - see clause 6.

For external pressure (pressure on the convex surface) $\nu = 1,0$.

4.3.2.6 Allowances c

$$c = 0$$

NOTE No allowance is required for austenitic stainless steel, aluminium and aluminium alloys.

4.3.3 Outer jacket

4.3.3.1 General

The following shall be used to determine the pressure part thicknesses in conjunction with the calculation formulae of 4.3.7.

The actual wall thickness shall be not less than shown in table 2 unless either

- a) the design has been validated by experiment ; or,
- b) a stress analysis has been carried out and assessed in accordance with annex A.

Table 2 — Outer jacket minimum wall thickness

Outer Jacket Diameter D (mm)	Minimum wall thickness s_0 for reference steel ¹⁾ (mm)
$D \leq 1\,800$	$0,5 + \frac{D}{1200}$
1) Reference steel material is material having a product $R_m \times A_5$ of 10 000. For other materials calculate the minimum thickness using the following formula : $s = \frac{21,4s_0}{\sqrt[3]{R_m \times A_5}}$ where R_m is the ultimate tensile strength, in Newton per square millimetre ; A_5 is the elongation at fracture, in per cent.	

4.3.3.2 Design pressure p

The internal design pressure p shall be equal to the set pressure of the outer jacket pressure relief device.

The external design pressure shall be one bar.

4.3.3.3 Material property K at 20 °C

The material property K to be used in the calculations shall be as follows :

- for austenitic stainless steel, aluminium and aluminium alloys, material property values shall be as defined in 4.3.2.3.
- for carbon steel K = yield strength.

NOTE Upper yield strength may be used.

4.3.3.4 Safety factors S , S_p and S_k

The safety factors to be used are as follows :

- internal pressure (pressure on the concave surface) :

$$S = 1,1$$

- external pressure (pressure on the convex surface) :

- cylindrical shells $S_p = 1,1$

$$S_k = 2,0$$

— spherical region $S_p = 1,6$

$$S_k = 2,0 + 0,0014 R / s$$

— knuckle region $S_p = 1,2$

4.3.3.5 Weld joint factors ν

For internal pressure (pressure on the concave surface) $\nu = 0,7$.

For external pressure (pressure on the convex surface) $\nu = 1,0$.

4.3.3.6 Allowances c

For austenitic stainless steel $c = 0$.

For aluminium and aluminium alloys $c = 0$.

For carbon steel $c = 1,0$ mm.

c may be reduced to zero if the external surface is adequately protected against corrosion.

4.3.4 Supports, lifting points and frame

The supports and frame shall be designed for the loads defined in 4.2, using established structural design methods and safety factors.

When designing the inner vessel support system the temperature and corresponding mechanical properties to be used may be those of the component in question when the inner vessel is filled to capacity with cryogenic fluid.

4.3.5 Protective guards

External fittings shall be protected by a guard designed for the loads specified in 4.2.3.8. The requirements are satisfied if the fittings to be protected are either

- within a guard which is permanently attached to the transportable cryogenic vessel ; or
- located within the outline of the transportable cryogenic vessel, e.g. within an end which is domed inwards.

Some damage and deformation of the guard is acceptable provided that the integrity of the transportable cryogenic vessel and its safety systems is maintained with no leakage of fluid except for small quantities escaping from the safety devices protecting the inner vessel.

4.3.6 Piping

Piping shall be designed for the loads defined in 4.2.3.9 using established piping design methods and safety factors.

4.3.7 Calculation formulae

4.3.7.1 Cylindrical shells and spheres subject to internal pressure (pressure on the concave surface)

4.3.7.1.1 Scope

Cylindrical shells and spheres where :

$$D_a / D_i \leq 1,2$$

4.3.7.1.2 Openings

For weakening factor ν due to openings see 4.3.7.7.

4.3.7.1.3 Calculation

The required minimum wall thickness s is

— for cylindrical shells

$$s = \frac{D_a p}{\frac{20K\nu}{S} + p} + c \quad \dots (3)$$

— for spherical shells

$$s = \frac{D_a p}{\frac{40K\nu}{S} + p} + c \quad \dots (4)$$

4.3.7.2 Cylindrical shells subject to external pressure (pressure on the convex surface)

4.3.7.2.1 Scope

Cylindrical shells where

$$D_a / D_i \leq 1,2$$

4.3.7.2.2 Openings

Openings shall be calculated in accordance with 4.3.7.7 using the external pressure as an internal pressure.

4.3.7.2.3 Calculation

Calculations shall be performed for elastic buckling and for plastic deformation. The lowest calculated pressure p_e or p_p shall not be less than the external design pressure.

The buckling length l_b is the length of the unsupported cylindrical shell (see figures 1 and 2). Other forms of stiffening section may be used.

For vessels with dished ends, the buckling length starts at the junction of the cylinder and the knuckle region of the dished end (see figure 3).

4.3.7.2.4 Plastic buckling

Calculations are performed using the following formula :

$$p_e = \frac{E}{S_k} \left(\frac{20}{\left(n^2 - 1\right) \left[1 + \left(\frac{n}{Z}\right)^2\right]^2} \frac{s - c}{D_a} + \frac{80}{12(1 - \nu^2)} \left[n^2 - 1 + \frac{2n^2 - 1 - \nu}{1 + \left(\frac{n}{Z}\right)^2} \right] \left[\frac{s - c}{D_a} \right]^3 \right) \quad \dots (5)$$

where $Z = 0,5\pi D_a / l_b$ and n is an integer equal to or greater than two and greater than Z , so determined that the value for p_e is a minimum. n denotes the number of lobes produced by the buckling process which may occur at

the circumference in the event of failure. The number of lobes can be estimated using the following approximation equation :

$$n = 1,63 \sqrt[4]{\frac{D_a^3}{l_b^2(s-c)}} \quad \dots (6)$$

For tubes and pipes, calculations may be performed using the following simplified formula:

$$p_e = \frac{E}{S_k} \times \frac{20}{1-\nu^2} \times \left(\frac{s-c}{D_a} \right)^3 \quad \dots (7)$$

4.3.7.2.5 Plastic deformation

When $D_a / l_b \leq 5$

$$p_p = \frac{20K}{S_p} \times \frac{s-c}{D_a} \times \frac{1}{1 + \frac{u(1-0,2 D_a / l_b) D_a}{100 (s-c)}} \quad \dots (8)$$

When $D_a / l_b > 5$

the higher pressure obtained using equations (9) and (10) shall not be less than the external design pressure.

$$p_p = \frac{20K}{S_p} \frac{(s-c)}{D_a} \quad \dots (9)$$

$$p_p = \frac{30K}{S_p} \times \left(\frac{s-c}{l_b} \right)^2 \quad \dots (10)$$

4.3.7.2.6 Stiffening rings

In addition to the ends, effective reinforcing elements may be regarded as including the types of element illustrated in figures 1 and 2. The stiffening rings welded to the shell shall satisfy the following conditions :

$$I \geq \frac{0,124 p D_a^3}{10E} \sqrt{D_a (s-c)} \quad \dots (11)$$

$$A \geq \frac{0,75 p D_a}{10K} \sqrt{D_a (s-c)} \quad \dots (12)$$

The moment of inertia I is relative to the neutral axis of the reinforcing elements cross-section parallel to the shell axis (see axis $x - x$ in figures 1 and 2). Narrow and high reinforcing elements of the kind shown in figure 1 may undergo severe buckling. Where the height of the element is greater than eight times its width, a more accurate calculation shall be made.

Where stiffening rings are joined to the shell by means of intermittent welds, the fillet welds at each side must cover at least one third of the shell circumference and the number of weld discontinuities must be at least $2n$. The number of buckling lobes n is obtained as indicated in 4.3.7.2.4).

4.3.7.3 Spheres subject to external pressure (pressure on the convex surface)

Spherical shells subject to external pressure shall be evaluated in accordance with 4.3.7.4.4.

4.3.7.4 Dished ends subject to internal or external pressure

4.3.7.4.1 Scope

Hemispherical ends where $D_a / D_i \leq 1,2$

10% torispherical ends where $R = D_a$ and $r = 0,1D_a$

and

2:1 torispherical ends where $R = 0,8D_a$ and $r = 0,154D_a$

In the case of torispherical ends $0,001 \leq (s - c) / D_a \leq 0,1$

Other torispherical head shapes may be used provided suitable calculations are carried out in accordance with 4.3.8.

4.3.7.4.2 Straight flange

The straight flange length h_1 (figures 4 and 5) shall be not less than :

— for 10 % torispherical ends, $3,5 s$;

— for 2:1 torispherical ends, $3,0 s$.

The straight flange may be shorter providing that in the case of inner vessels the circumferential joint between the dished end and the cylinder is non destructively tested as required for a weld joint factor of 1,0.

4.3.7.4.3 Internal pressure calculation (pressure on concave surface)

a) crown and hemisphere thickness :

The wall thickness of the crown region of dished ends and of hemispherical ends shall be determined using 4.3.7.1.3 for spherical shells with $D_a = 2(R + s)$.

Openings within the crown area of $0,6D_a$ of torispherical ends and in hemispherical ends shall be reinforced in accordance with 4.3.7.7. When pad type reinforcement is used the edge of the pad shall not extend beyond the area of $0,8D_a$ for 10 % torispherical ends or $0,7D_a$ for 2:1 torispherical ends.

b) torispherical end knuckle thickness and hemispherical end to shell junction thickness :

The required thickness of the knuckle region and hemispherical end junction shall be :

$$s = \frac{D_a p \beta}{40K_v} + c \quad \dots (13)$$

β is taken from figure 6a for 10 % torispherical ends and from figure 6b for 2:1 torispherical ends as a function of $(s - c) / D_a$. Iteration is necessary.

D_a is the diameter of the end as shown in figures 4 and 5.

When there are openings outside the area $0,6D_a$ the required thickness is found from figures 6a and 6b using the appropriate curve for the relevant value of d_i / D_a .

The lower curves of figure 6a and 6b apply when there are no openings outside the area $0,6D_a$.

If the ligament on the connecting line between adjacent openings is not entirely within the $0,6D_a$ region the ligament shall not be less than half the sum of the opening diameters.

For hemispherical ends a β value of 1,1 shall be applied within the distance x from the tangent line joining the end to the cylinder, regardless of the ratio, $(s-c)/D_a$,

where $x = 0,5\sqrt{R(s-c)}$

4.3.7.4.4 External pressure calculations (pressure on the convex surface)

a) elastic buckling :

There is adequate resistance to elastic buckling when :

$$p \geq 3,66 \frac{E}{S_k} \left(\frac{s-c}{R} \right)^2 \quad \dots (14)$$

b) plastic deformation :

Resistance to plastic deformation is determined by using 4.3.7.1 with the appropriate safety factor S_p defined in 4.3.2.4 and 4.3.3.4.

4.3.7.5 Cones subject to internal or external pressure

4.3.7.5.1 Symbols and units

For the purposes of 4.3.7.5, the following symbols apply in addition to those given in 3.2 :

A	area of reinforcing ring, in square millimetres
D_{a1}	outside diameter of connected cylinder (figure 7), in millimetres
D_{a2}	outside diameter at effective stiffening (figure 9), in millimetres
D_k	design diameter (figure 7), in millimetre
D_s	shell diameter at nozzle (figure 8), in millimetres
I	moment of inertia about the axis parallel to the shell, in millimetres ⁴
l	cone length between effective stiffenings (figure 9), in millimetres
s_g	required wall thickness outside corner area, in millimetres
s_l	required wall thickness within corner area, in millimetres
x_i	characteristic lengths ($i = 1,2,3$) to define corner area (figure 11 and 4.3.7.5.5), in millimetres
φ	cone angle, in degrees

4.3.7.5.2 Scope

Cones according to figure 7 where

$$0,001 \leq \frac{s_g - c}{D_{a_i}} \leq 0,1$$

and

$$0,001 \leq \frac{s_l - c}{D_{a_i}} \leq 0,1$$

For external pressure $\varphi \leq 70^\circ$. Small ends with a knuckle can be safely assessed and verified as a small end with a corner joint.

4.3.7.5.3 Openings

Openings outside of the corner area (figure 8) shall be designed as follows

If $\varphi < 70^\circ$ design according to 4.3.7.7 using an equivalent cylinder diameter of

$$D_i = \frac{D_s + d_i \sin \varphi}{\cos \varphi} \quad \dots (15)$$

If $\varphi \geq 70^\circ$ design according to 4.3.7.6.

4.3.7.5.4 Non destructive testing

All corner joints shall be subject to the examination required for a weld joint factor of 1,0.

4.3.7.5.5 Corner area

The corner area is that part of the cone where the dominant stresses are bending stresses in the longitudinal direction.

The corner area is defined in figures 7a and 7b by x_1 , x_2 , x_3 calculated from the following equations :

$$x_1 = \sqrt{D_{a_1} (s_1 - c)} \quad \dots (16)$$

$$x_2 = 0,7 \sqrt{\frac{D_{a_1} (s_1 - c)}{\cos \varphi}} \quad \dots (17)$$

$$x_3 = 0,5x_1 \quad \dots (18)$$

4.3.7.5.6 Internal pressure calculation $\varphi \leq 70^\circ$ (pressure on concave surface)

a) within corner area :

The required wall thickness (s_1) within the corner area as calculated from figures 10.1 to 10.7 for the large end and figure 10.8 for the small end of a cone using the following variables

$$\varphi, \frac{pS}{15K_v} \text{ and } \frac{r}{D_{a_1}}$$

shall be not less than the required wall thickness, s_g , outside the corner area as calculated in formula (19).

For a corner joint use the curve for $r/D_{a1} = 0$.

For intermediate cone angles (φ) use linear interpolation.

For intermediate values of r/D_{a1} the relevant interpolation equation stated in figures 10.1 to 10.8 shall be used.

The wall thickness s_1 in the corner area shall not be less than the required thickness s_g outside of the corner area as calculated in formulae (19).

b) outside corner area :

The required wall thickness, s_g , outside the corner area is calculated from

$$s_g = \frac{D_k p}{20 \frac{K}{s} v - p} \times \frac{1}{\cos \varphi} + c \quad \dots (19)$$

where :

— for the large end, $D_k = D_{a1} - 2[s_1 + r(1 - \cos \varphi) + x_2 \sin \varphi]$

— for the small end, D_k is the maximum diameter of the cone, where the wall thickness is s_g .

4.3.7.5.7 Internal pressure calculation $\varphi > 70^\circ$ (pressure on the concave surface)

If $r \geq 0,01D_{a1}$ the required wall thickness is

$$s_1 = s_g = 0,3(D_{a1} - r) \times \frac{\varphi}{90} \sqrt{\frac{p}{10 \frac{K}{s} v}} + c \quad \dots (20)$$

4.3.7.5.8 External pressure calculation (pressure on the convex surface)

Stability against elastic buckling and plastic deformation shall be verified using 4.3.7.2 and an equivalent cylinder.

For the example shown in figure 9 the equivalent cylinder diameter between the knuckle and the stiffener is

$$D_a = \frac{D_{a1} + D_{a2}}{2 \cos \varphi} \quad \dots (21)$$

and the equivalent cylinder length is

$$l = \frac{D_{a1} - D_{a2}}{2 \sin \varphi} \quad \dots (22)$$

Depending on the relevant boundary conditions the equivalent length between two effective stiffening sections shall be reliably estimated within the meaning of 4.3.7.2.

When $\varphi \geq 10^\circ$ the corner area of a large end can be considered as effective stiffening.

For small ends the thickness in the corner area shall not be less than 2,5 times the required thickness of the conical shell with the same angle φ or a stiffener shall be fitted with the following properties:

$$I \geq S_k \frac{p D_{a1}^4}{960E} \tan \varphi \quad \dots (23)$$

$$A \geq S_k \frac{p D_{a1}^2}{80K} \tan \varphi \quad \dots (24)$$

where :

S_k is the safety factor to prevent elastic buckling from 4.3.2.4 or 4.3.3.4.

D_{a1} is the diameter in accordance with figure 7b.

The shell over a width of $0,5\sqrt{D_{a1}s_l}$ can be used to calculate the moment of inertia and the area.

In addition the corner joint should not be regarded as a classical boundary condition i.e. the overall length should be formed from the individual meridional length of the cone and cylinder.

In addition the cone shall be verified using 4.3.7.5.6 above and the safety factors S from 4.3.2.4 or 4.3.3.4 increased by 20 %. For thicknesses in the corner area v shall be the value applicable for internal pressure.

4.3.7.6 Flat ends

4.3.7.6.1 Symbols and units

For the purposes of 4.3.7.6, the following symbols apply in addition to those given in 3.2 :

d_1, d_2 etc. opening diameters in millimetres ;

D_1, D_2 etc. flat end diameters in millimetres.

4.3.7.6.2 Scope

Welded or solid flat ends where :

$$\frac{(s - c)}{D} \geq 4 \sqrt{\frac{0,0087 p}{E}}$$

and

$$\frac{(s - c)}{D} \leq \frac{1}{3}$$

and Poisson's ratio is approximately 0,3.

4.3.7.6.3 Openings

Openings are calculated in accordance with 4.3.7.6.4 but with the C factor multiplied by C_A , C_A is given in figure 11.

4.3.7.6.4 Calculation

The required minimum wall thickness of a circular flat end is

$$s = CD_1 \sqrt{\frac{0,1pS}{K}} + c \quad \dots (25)$$

C and D_1 are taken from figure 12.

The required minimum wall thickness of a rectangular or elliptical flat end is

$$s = CC_E f \sqrt{\frac{0,1pS}{K}} + c \quad \dots (26)$$

C_E is taken from figure 13

4.3.7.7 Openings in cylinders, spheres and cones

4.3.7.7.1 Symbols and units

For the purposes of 4.3.7.7, the following symbols apply in addition to those given in 3.2 :

b	width of pad, ring or shell reinforcement, in millimetres
h	thickness of pad-reinforcement, in millimetres
l	ligament (web) between two nozzles, in millimetres
l_s	length of nozzle reinforcement, in millimetres
m	protruding length, in millimetres
s_A	required wall thickness at opening edge, in millimetres
s_S	wall thickness of nozzle, in millimetres
t	in this context : centre-to-centre distance between two nozzles, in millimetres
v_A	compensation factor for the weakening effect of openings

4.3.7.7.2 Scope

Round openings and the reinforcement of round openings of unlimited diameter in cylindrical and spherical shells within the following limits :

$$0,002 \leq \frac{(s-c)}{D_a} \leq 0,1$$

$$\frac{(s-c)}{D_a} < 0,002 \text{ is acceptable if } \frac{d_i}{D_a} \leq \frac{1}{3}$$

NOTE 1 These rules only apply to cones if the wall thickness is determined by the circumferential stress.

NOTE 2 Additional external forces and moments are not covered by this section and need to be considered separately where necessary.

NOTE 3 These design rules permit plastic deformations of up to 1 % at highly stressed local areas during pressure test. Openings must therefore be carefully designed to avoid abrupt changes in geometry.

4.3.7.7.3 Reinforcement methods

Openings may be reinforced by one or more of the following methods :

- increase of shell thickness, see figures 14 and 15 ;
- set in or set on ring reinforcement, see figures 16 and 17 ;
- pad reinforcement, see figure 18 ;
- increase of nozzle thickness, see figures 19 and 20 ;
- pad and nozzle reinforcement, see figure 21.

Where ring or pad reinforcement is used on the inner vessel the space between the two fillet welds shall be vented into the vacuum space.

4.3.7.7.4 Design of openings

The fillet weld on a reinforcing pad shall have a minimum throat thickness of half of the pad thickness.

The critical dimensions of each nozzle to shell weld shall be not less than the required thickness of the thinner part.

Where the strength of the reinforcing material is lower than the strength of the shell material an allowance in accordance with e) shall be made in the design calculations. If the strength of the reinforcing material is higher than the strength of the shell material no allowance for the increased strength is permitted.

4.3.7.7.5 Calculation

a) The weakening factor v_A for nozzles perpendicular to the shell can be read with sufficient accuracy from figures 22. The wall thickness s_A in these figures is the required wall thickness. s_A has to be determined by iteration.

Where the material property K of the reinforcement is lower than that of the shell the cross section of pad reinforcement and the thickness of nozzle reinforcement shall be reduced by the ratio of K values before determining the factor v_A .

When $v_A < v$ the value obtained from figures 22 for individual nozzles or from formula 35 for multiple nozzles shall be used in place of v to determine the wall thickness s_A at the edge of the opening v_A does not affect the required wall thickness away from the opening.

b) Openings can also be reinforced according to the following relationship ;

$$\frac{p}{10} \left(\frac{A_p}{A_\sigma} + \frac{1}{2} \right) \leq \frac{K}{s} \quad \dots (27)$$

which is based on equilibrium between the pressurised area A_p and the load bearing cross sectional area A_σ . The wall thickness obtained from this relationship must not be less than the thickness of the unpierced shell.

The pressurised area A_p and the load bearing cross sectional area A_σ which equals $A_{\sigma 0} + A_{\sigma 1} + A_{\sigma 2}$ are obtained from figures 23 to 26.

The maximum extent of the load bearing cross sectional area shall be not more than b as defined in formula (29) for shells and l_s as defined in formula (31) or (32) for nozzles.

The protrusion of a nozzle may be included as load bearing cross sectional area up to a maximum length of

$$l'_s = 0,5l_s$$

The restrictions of 4.3.7.7.7 and 4.3.7.7.8 below shall be observed.

If the material property K_1 , K_2 etc. of the reinforcing material is lower than that of the shell the dimensions shall comply with

$$\left(\frac{K}{S} - \frac{p}{20}\right) A \sigma_0 + \left(\frac{K_1}{S} - \frac{p}{20}\right) A \sigma_1 + \left(\frac{K_2}{S} - \frac{p}{20}\right) A \sigma_2 \geq \frac{p}{10} \cdot A_p \quad \dots (28)$$

The calculation method selected, i.e. a) or b) shall be indicated in the design documents.

4.3.7.7.6 Reinforcement by increased shell thickness

The weakening factor v_A of openings to figures 14 and 15 shall be taken from the lower curve of figures 22.

4.3.7.7.7 Ring or pad reinforcement

If the actual wall thickness of the cylinder or sphere is less than the required thickness s_A at the opening, the opening is adequately reinforced if the wall thickness s_A is available round the opening over a width of

$$b = \sqrt{(D_1 + s_A - c)(s_A - c)} \quad \dots (29)$$

with a minimum of $3 s_A$ see figures 16, 17 and 18.

The thickness of pad reinforcement to figure 18 shall not be more than the actual wall thickness to which the pad is attached.

Internal pad reinforcement is not allowed.

For calculation purposes s_A shall be limited to not more than twice the actual wall thickness.

The width of the pad reinforcement may be reduced to b_1 provided the pad thickness is increased to h_1 according to

$$b_1 h_1 \geq b h \quad \dots (30)$$

and the limits given above are observed.

4.3.7.7.8 Reinforcement by increased nozzle thickness

For reinforcement in accordance with figures 19 and 20 the weakening factor v_A shall be taken from figures 22 for the wall thickness ratio

$$\frac{s_s - c}{s_A - c}$$

The wall thickness of protruding nozzles according to figure 19 type (c) may be reduced by 20 % if the nozzle protrusion $m \geq s_s$.

The wall thickness ratio shall satisfy $\frac{s_s - c}{s_A - c} \leq 2,0$.

The wall thickness s_A at the opening shall extend over a width b in accordance with formula (29) with a minimum of $3 s_A$.

The thickness s_s shall extend over a length l_s from the shell as follows

— for cylinders and cones, $l_s = 1,25\sqrt{(d_i + s_s - c)(s_s - c)}$... (31)

— for spheres, $l_s = \sqrt{(d_i + s_s - c)(s_s - c)}$... (32)

The distance l_s may be reduced to l_{s1} provided that the thickness s_s is increased to s_{s1} according to the following:

$$l_{s1}s_{s1} \geq l_s s_s \quad \dots (33)$$

4.3.7.7.9 Reinforcement by a combination of increased shell and nozzle thicknesses

Pad and nozzle thicknesses may be increased in combination for the reinforcement of openings (figure 21). For the calculation of reinforcement 4.3.7.7.7 and 4.3.7.7.8 shall be applied together.

4.3.7.7.10 Multiple openings

Multiple openings are regarded as single openings provided the distance l between two adjacent openings, figures 25 and 26, complies with :

$$l \geq 2\sqrt{(D_i + s_A - c)(s_A - c)} \quad \dots (34)$$

If l is less than required by formula (34) a check shall be made to determine whether the cross section between openings is able to withstand the load acting on it. Adequate reinforcement is available if the requirement of formula (27) or (28), as appropriate is met.

Nozzles joined to the shell in line by full penetration welds with the wall thickness calculated for internal pressure only may be designed with a weakening factor

$$v_A = (t - d_i)/t \quad \dots (35)$$

If the nozzles are not attached by full penetration welds, d_A shall be used in formula (35).

4.3.8 Calculations for operating loads

Unless the design feature has been validated by experiment calculations in addition to those in 4.3.7, additional calculations are required to ensure that stresses due to operating loads are within acceptable limits. All load conditions expected during service shall be considered (see 4.2.3).

For these calculations, a comprehensive calculation method shall be used in accordance with European standards (in preparation) or in accordance with the documents given in Bibliography.

Acceptable calculation methods include :

- finite element ;
- finite difference ;
- boundary element ;
- established calculation method.

In these calculations static loads shall be substituted for static plus dynamic loads. The static loads used shall be as follows :

- in the horizontal plane, twice the total mass in any direction ;
- in the vertical plane, the total mass upwards and twice the total mass downwards.

Each of these loads is considered to act in isolation and include the mass of the component under consideration.

The upward load shall be increased to twice the total mass if any of the following conditions is met :

- capacity less than 100 l ;
- total mass less than 150 kg ;
- the height of the centre of gravity of the transportable cryogenic vessel including any framework elements, and when filled to capacity is more than twice the smaller horizontal dimension of its base.

Stress levels resulting from the loads induced by the mass of the cryogenic liquid shall be limited to acceptable stress levels which may be based on material properties at the operating temperature of the component being validated.

The analysis shall take into account gross structural discontinuities, but need not consider local stress concentrations.

Annex A provides terminology and acceptable stress limits when an elastic stress analysis is performed.

4.4 Design validation by experimental method

4.4.1 General

When design validation is by experiment, prototype units shall be manufactured and tested in accordance with the following.

4.4.2 Procedure for experimental test programme

A test programme shall be prepared taking into account the transportable cryogenic vessels operating requirements.

The test programme shall be designed to establish the cryogenic vessel's pressure integrity and structural integrity.

Each prototype transportable cryogenic vessel shall undergo the same quality control tests as required during manufacture of production vessels.

The actual thickness of critical load bearing components shall be measured and recorded, together with their mechanical properties.

4.4.3 Tests for pressure integrity

4.4.3.1 Inner vessel

The ability of the inner vessel to withstand internal pressure shall be validated with the following test.

Three inner vessels consisting of parts subjected directly to test pressure shall undergo a fatigue test of 10 000 cycles between atmospheric pressure and a pressure P_T , where :

$$P_T \geq 1.3(P_s + 1) \text{ bar}$$

After this test all three vessels shall withstand a pressure test of $3(P_s + 1)$ bar.

The test pressure and the cycle test pressure shall be increased where the shell or head thickness is thicker than specified or if the actual material used has better mechanical properties than specified.

4.4.3.2 Piping and accessories

No specific pressure test is required if the nominal pressure of piping and accessories is greater than the maximum allowable pressure, $(P_s + 1)$ bar.

4.4.4 Tests for structural integrity

4.4.4.1 General

After having undergone tests in accordance with 4.4.4.2 and 4.4.4.3, the transportable cryogenic vessel shall not show any permanent deformation that will render it unsuitable for use.

After having undergone tests in accordance with 4.4.4.4, 4.4.4.5 and 4.4.4.6, some damage and deformation of the vessel including loss of vacuum is acceptable, but the integrity of the transportable cryogenic vessel and its safety systems shall be maintained with no leakage of fluid, except for small quantities escaping from the safety devices protecting the inner vessel.

A single container may be used to demonstrate structural integrity but where damage or deformation within acceptable limits occurs on any test an undamaged container may be utilised in subsequent tests.

4.4.4.2 Lifting test

The transportable cryogenic vessel shall be loaded to twice its gross mass.

The transportable cryogenic vessel shall be lifted and suspended for 5 minutes and then lowered to the ground. The test shall be repeated for each of the different lifting modes specified.

There a transportable cryogenic vessel can be lifted with slings or ropes, these shall be inclined at 45° to the vertical axis.

4.4.4.3 Stacking test

Where stacking is specified, the transportable cryogenic vessel, filled to capacity and equipped with its framework, shall withstand the specified load.

The transportable cryogenic vessel shall be set with its base on a rigid horizontal floor and the required load applied vertically at the top of the framework for at least 5 minutes. The applied load shall be at least equivalent to 1,8 times the total maximum gross mass of the number of similar vessels specified.

4.4.4.4 Vertical drop test

This test shall be carried out under the conditions defined in 4.4.5.

The transportable cryogenic vessel shall be dropped from a height of not less than 1,2 m onto a rigid, flat, non-resilient, smooth and horizontal surface in accordance with EN 962, so that the vessel strikes the floor on its base.

4.4.4.5 Inverted drop test

This test shall be carried out under the conditions defined in 4.4.5.

The transportable cryogenic vessel shall be subject to a vertical drop test so that it falls on a rigid, flat, non-resilient, smooth and horizontal surface on an upper edge defined when the vessel is in a normal position (for example, the shorter upper edge, provided this can be defined).

To do so, the transportable cryogenic vessel is suspended at least 1,2 m above the ground at a point diametrically opposite to the impact area, so that the centre of gravity is vertically above the upper edge.

This test shall be carried out if any of the following conditions are met:

- capacity is less than 100 l ;
- total mass is less than 150 kg ;
- the height of the centre of gravity of the transportable cryogenic vessel, when filled to capacity, including any framework elements, exceeds twice the smaller horizontal dimension of its base.

4.4.4.6 Horizontal impact test

This test first shall be carried out under the condition defined in 4.4.5.

The transportable cryogenic vessel in its normal shipping position, shall be subject to a horizontal impact test according to one of the following methods :

- a) inclined plane test in accordance with EN 22244. In this test the transportable cryogenic vessel is placed on its base on a trolley rolling on a plane inclined by 10 ° to the horizontal ;

The horizontal velocity on impact shall be not less than 2,6 m/s. The impact shall occur on a rigid, flat, non-resilient, smooth and vertical surface, in accordance with 4.1 of EN 22244:1992.

The transportable cryogenic vessel shall strike successively in two directions at right angles.

- b) pendulum test as specified in EN 22244. In this test the transportable cryogenic vessel is suspended in its normal position. The horizontal velocity on impact shall be not less than 2,6 m/s. The impact vessel shall strike a rigid, non-resilient smooth, flat and vertical surface. The transportable cryogenic vessel shall strike it successively in two directions at right angle ;

- c) drop test. In this test the transportable cryogenic vessel shall be suspended in a right angle position compared to its normal operating position and dropped vertically from a height of 0,35 m, successively onto two sides, as in b) above.

NOTE This method of testing may only be used when the position of the centre of gravity in the test position does not affect the result.

4.4.5 Test conditions

4.4.5.1 The transportable cryogenic vessel shall be filled with a test fluid, which may be water or may be a cryogenic fluid specified on the nameplate. The test may be carried out with the inner vessel pressurised at any value up to 90 % of the maximum allowable pressure and with the outer jacket under vacuum.

When, during testing the transportable cryogenic vessel is filled with a fluid with a density lighter than that of the most dense fluid specified on the nameplate of the vessel, a correction shall be applied as indicated in 4.4.5.2 and 4.4.5.3.

4.4.5.2 Where a minimum drop height is specified the height shall be increased to maintain the same potential energy using the formula:

$$H = H_0 \left(\frac{M_0}{M} \right) \quad \dots (36)$$

where :

- H_0 is the drop height specified, in metres ;
- M_0 is the rated gross mass on the nameplate, in kilogrammes ;
- M is the actual gross mass during test, in kilogrammes.

4.4.5.3 Where a minimum velocity is specified, the velocity on impact shall be increased to maintain the same kinetic energy, using the formula :

$$V = V_0 \sqrt{\frac{M_0}{M}} \quad \dots (37)$$

where :

- V_0 is the velocity on impact specified, in metres per second ;
- M_0 is the rated gross mass on the nameplate, in kilogrammes ;
- M is the actual gross mass during test, in kilogrammes.

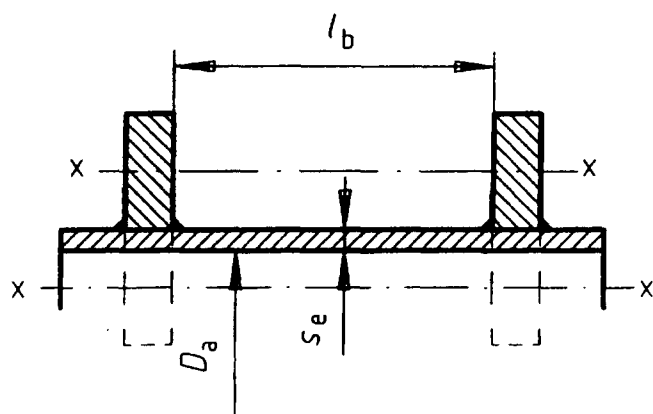


Figure 1 — Stiffening rings

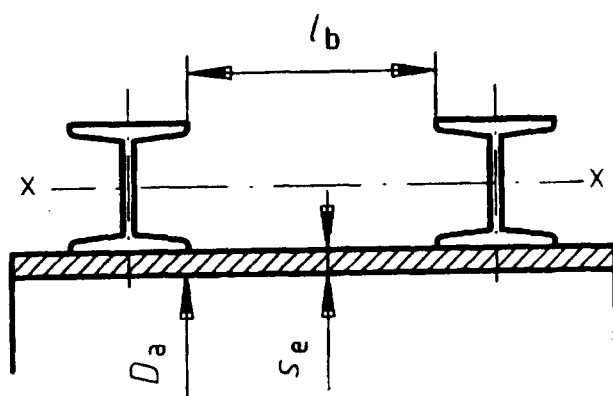


Figure 2 — Sectional material stiffeners

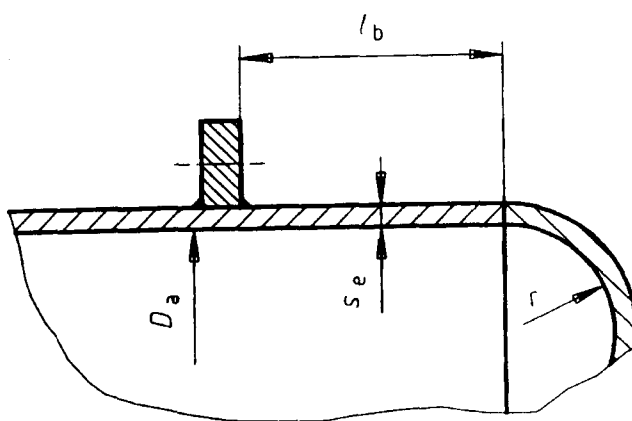


Figure 3 — Dished ends

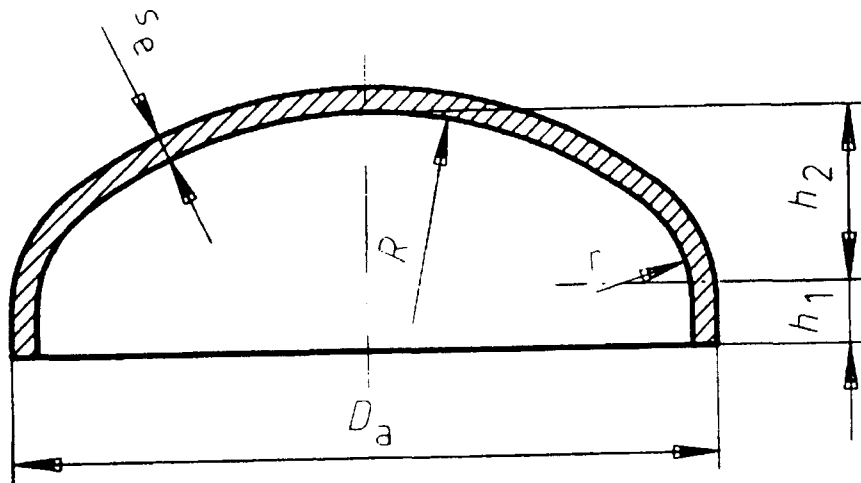


Figure 4 — Unpierced dished end

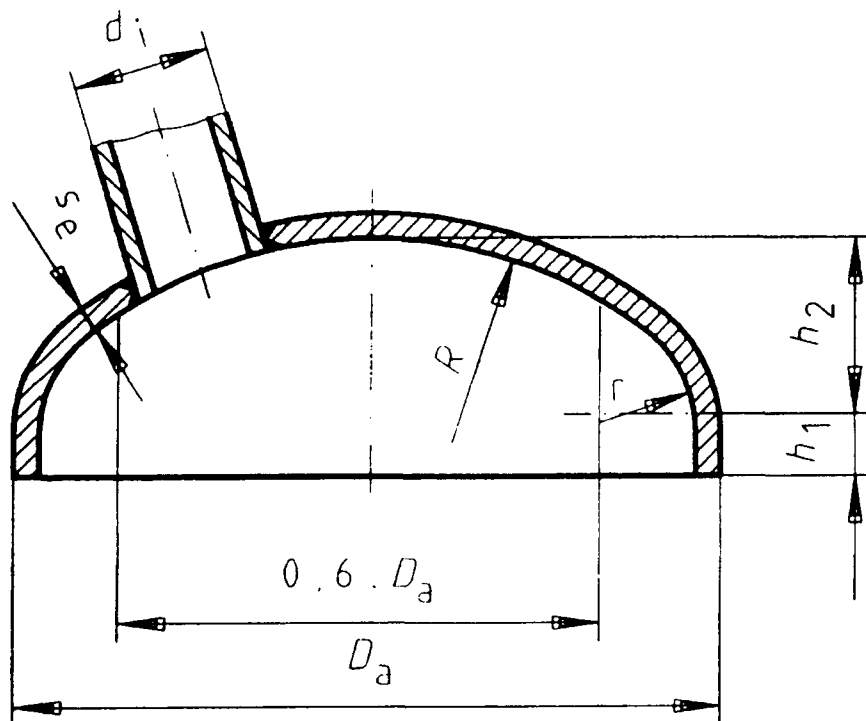


Figure 5 — Dished end with nozzle

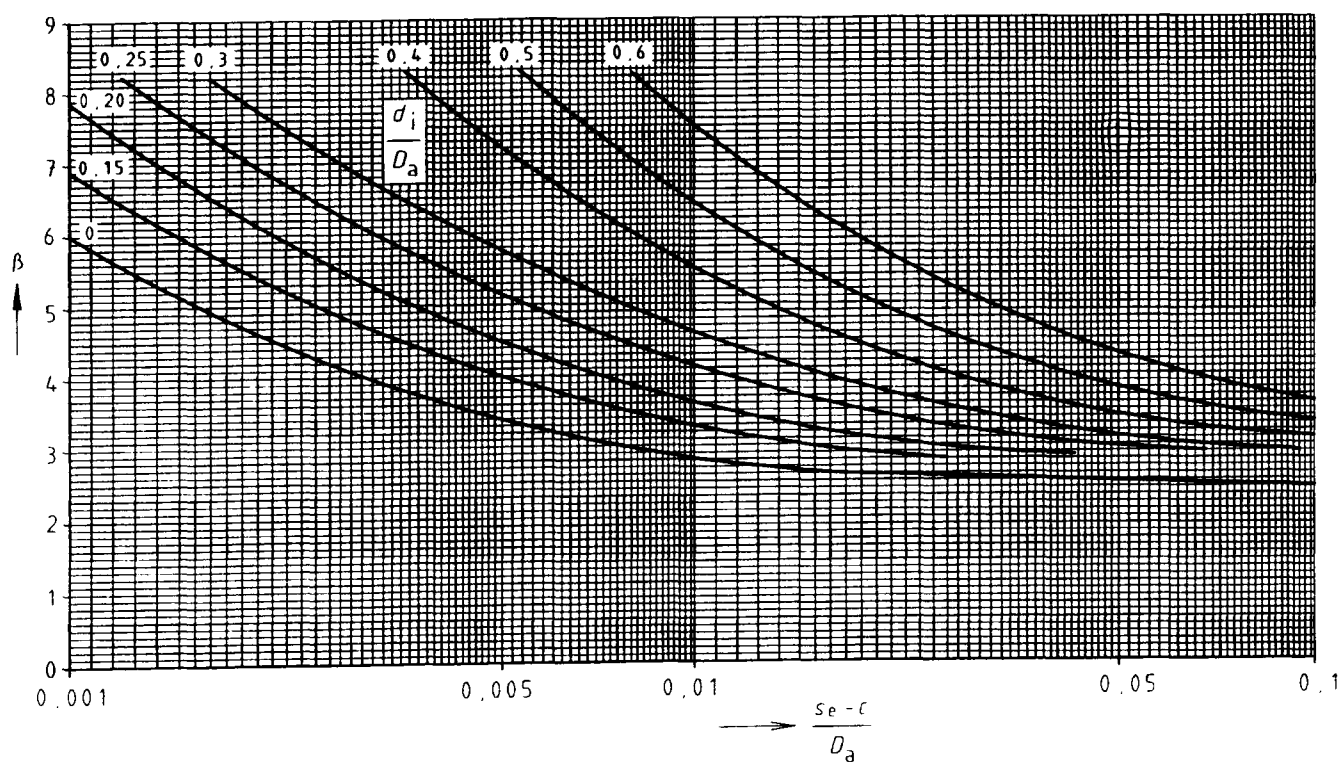


Figure 6a — Design factors for 10 % torispherical dished ends

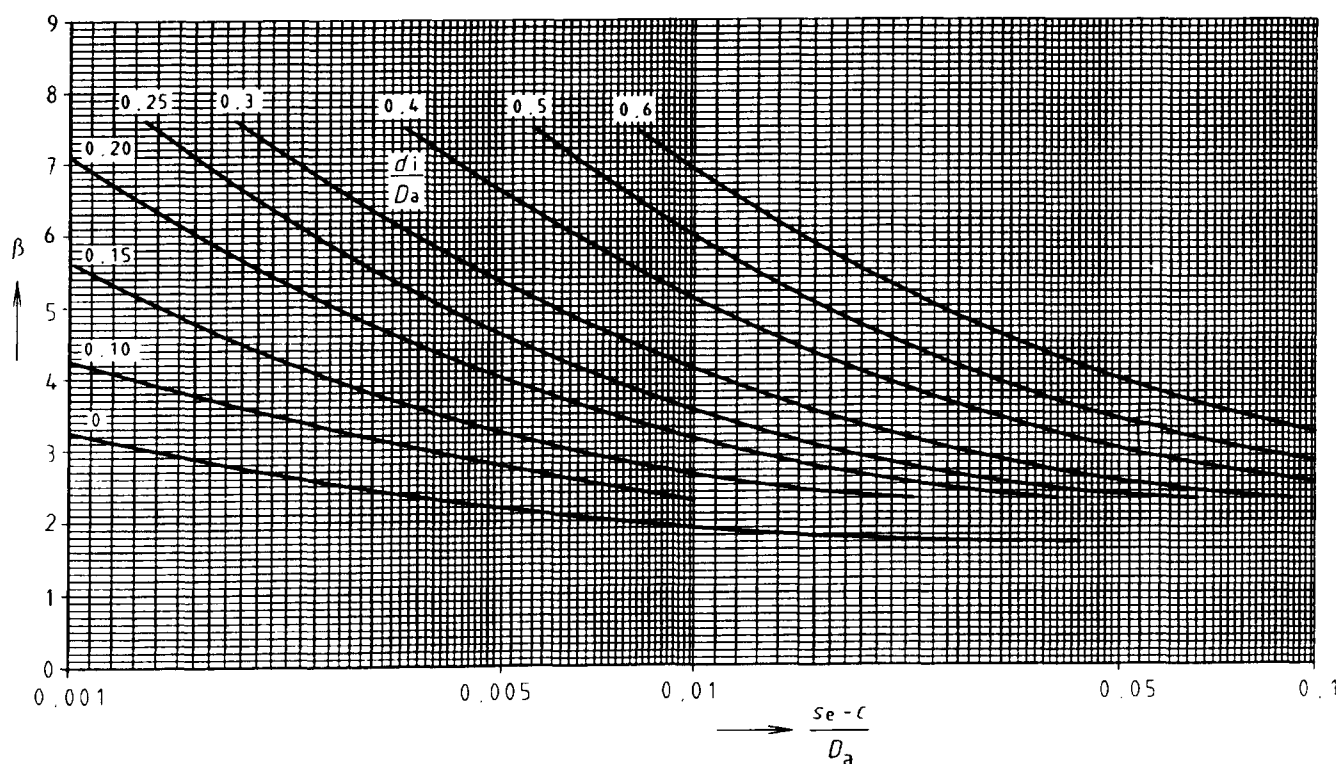
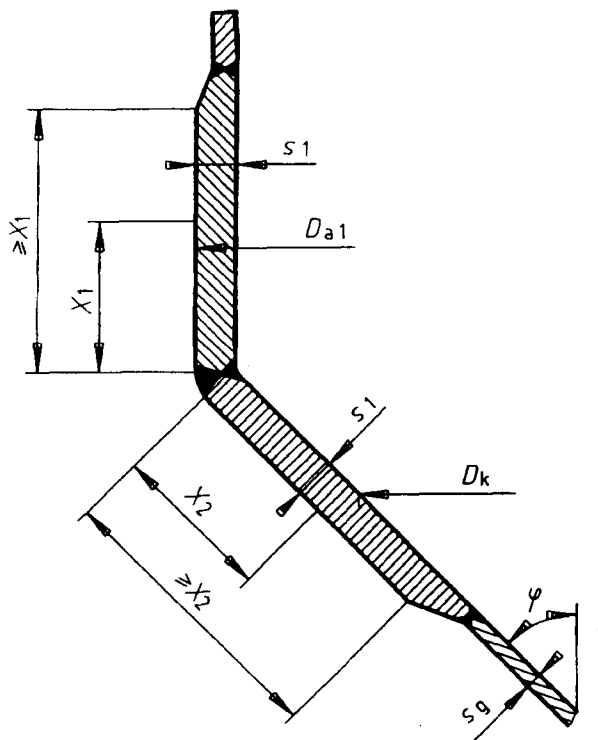
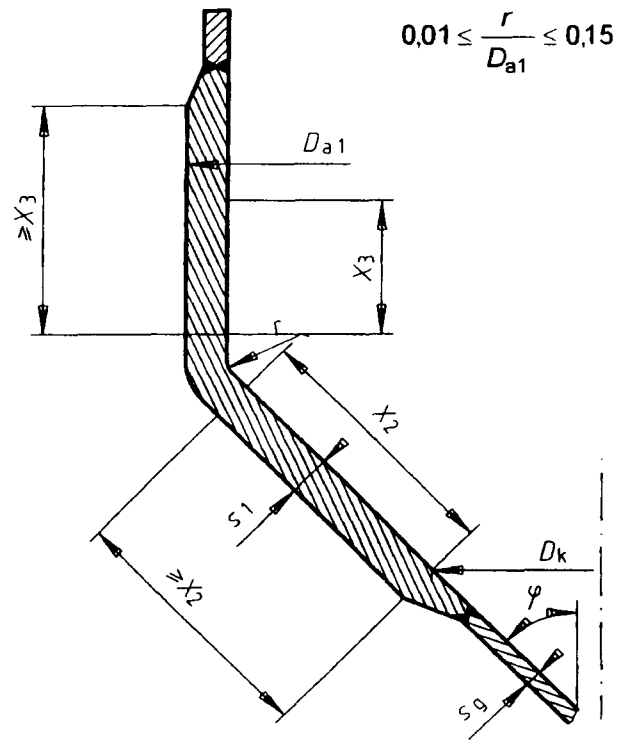


Figure 6b — Design factors for 2:1 torispherical dished ends

Figure 6 — Design factors for torispherical dished ends



Corner joint



With knuckle

Figure 7a — Geometry of convergent conical shells

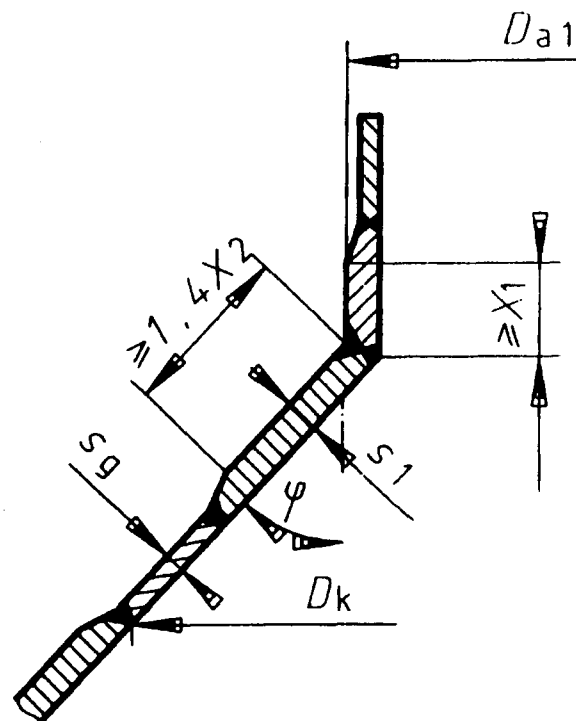


Figure 7b — Geometry of divergent conical shells

Figure 7 — Geometry of conical shells

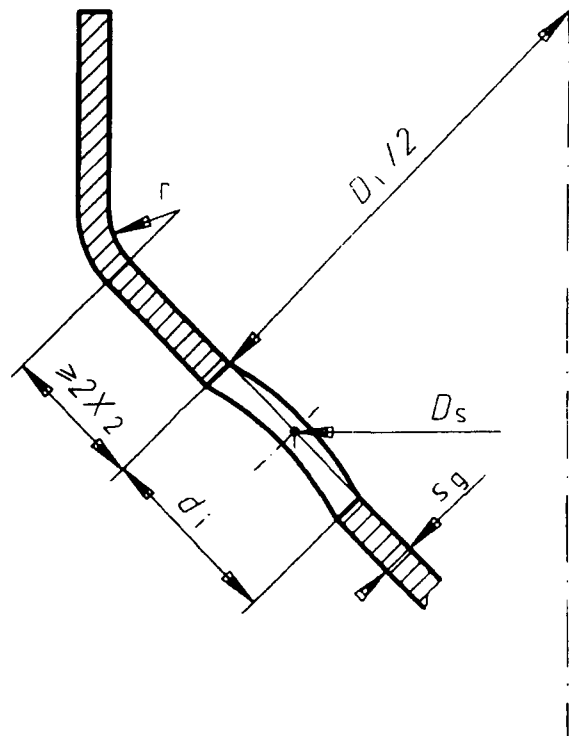


Figure 8 — Geometry of a cone opening

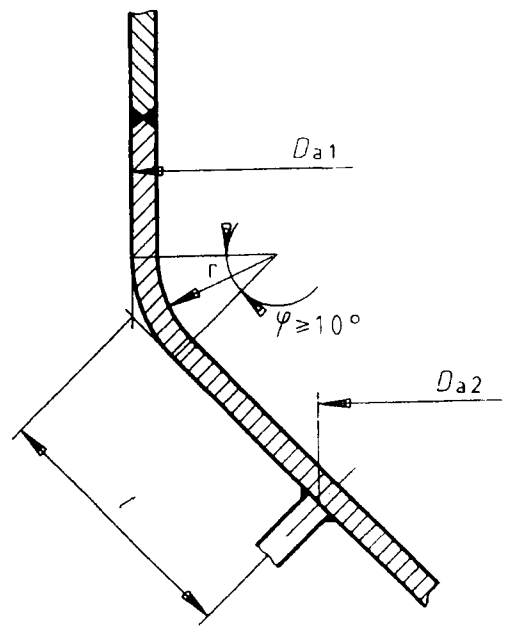


Figure 9 — Geometrical quantities in the case of loading by external pressure

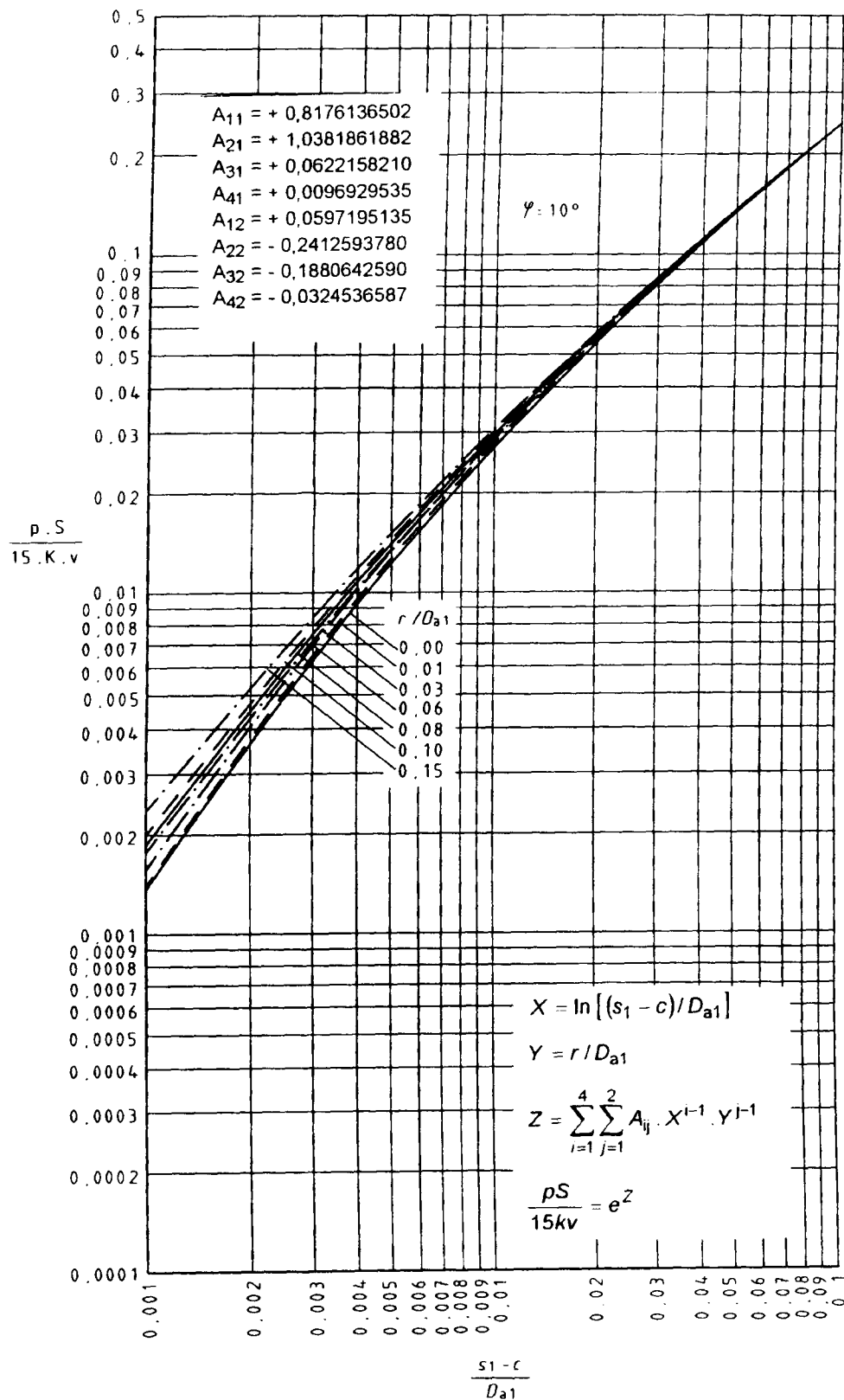


Figure 10.1 — Permissible value $\frac{p.S}{15.K.v}$ for convergent cone with an opening angle $\varphi = 10^\circ$

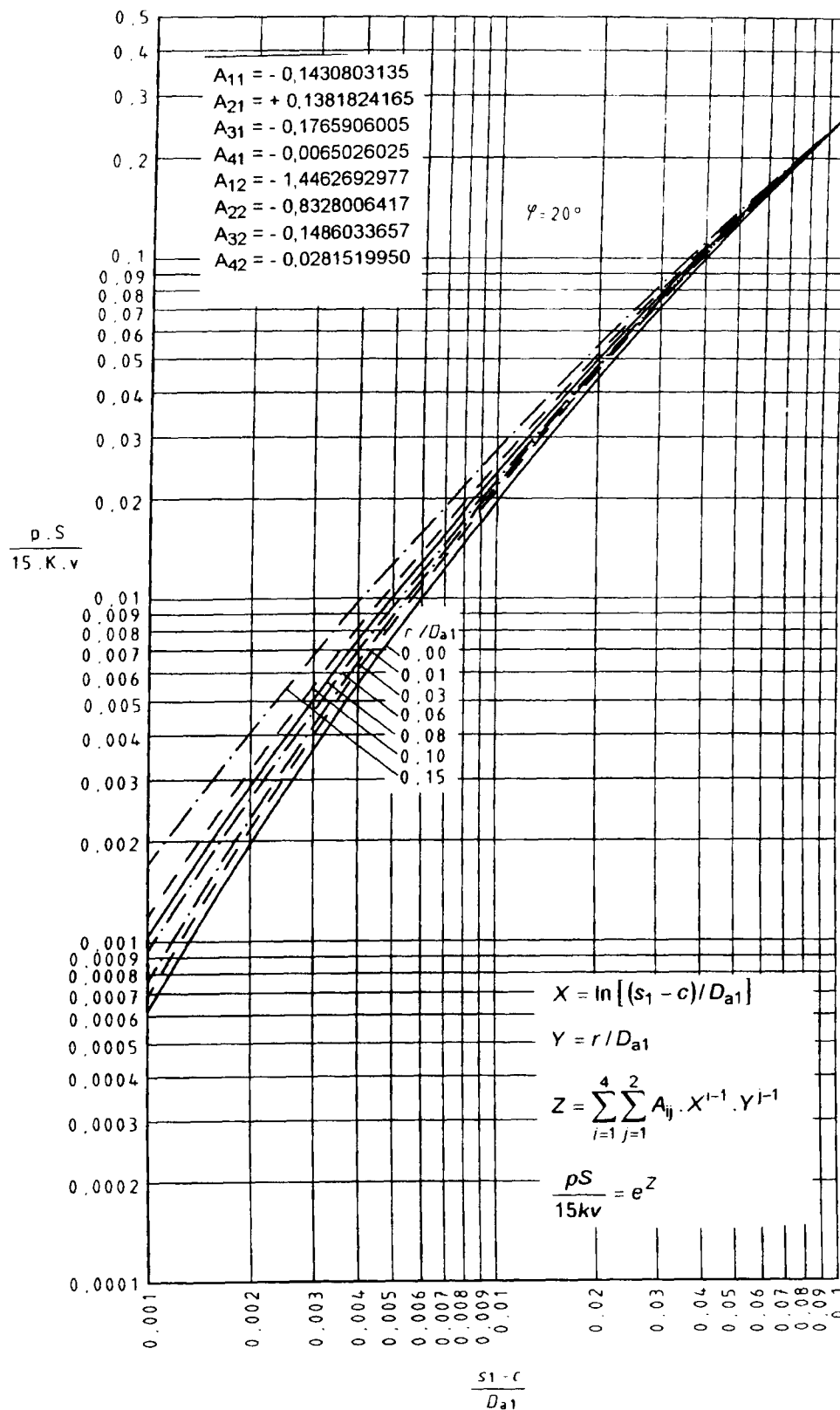


Figure 10.2 — Permissible value $\frac{p.S}{15K.v}$ for convergent cone with an opening angle $\varphi = 20^\circ$

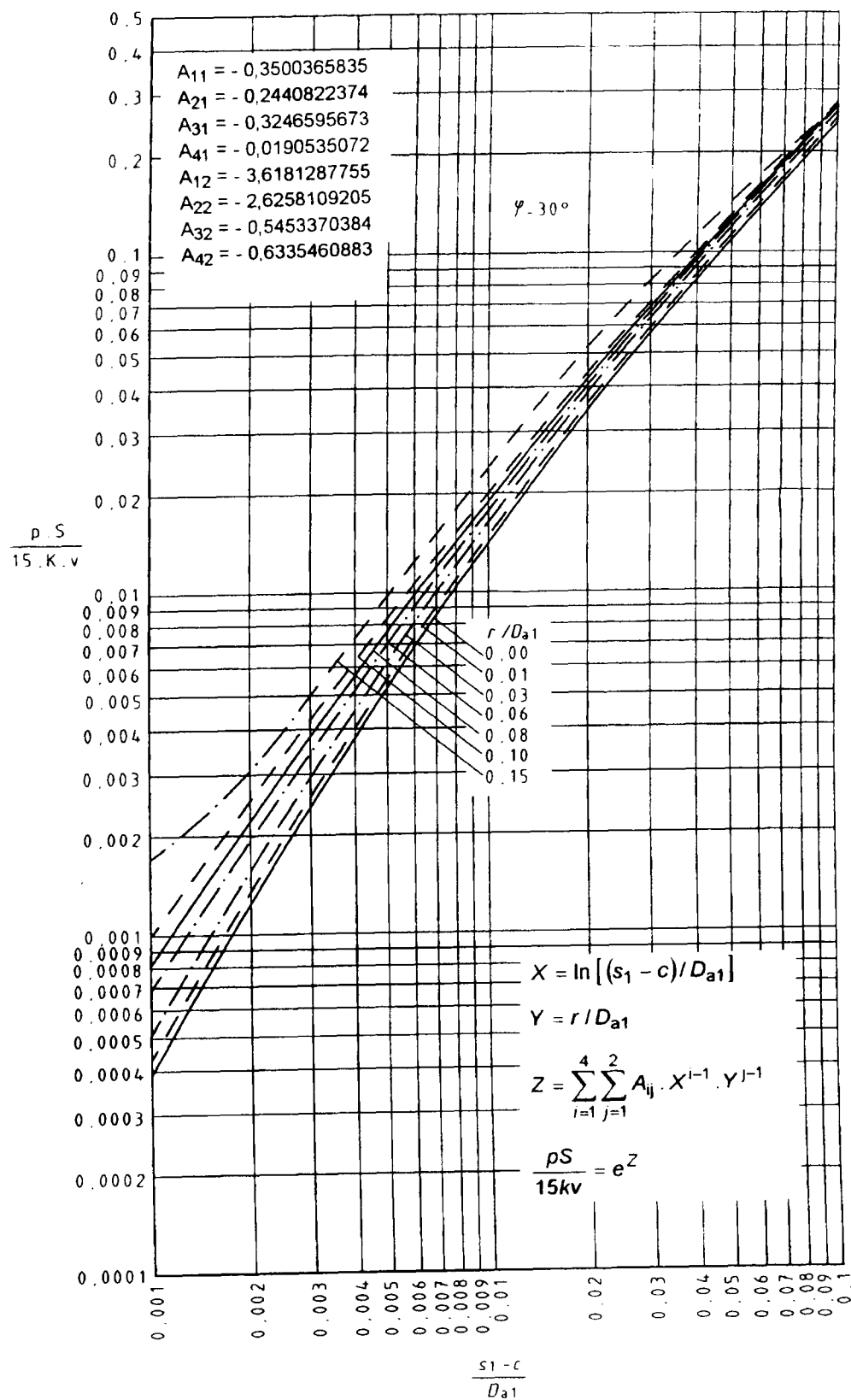


Figure 10.3 — Permissible value $\frac{p.S}{15K.v}$ for convergent cone with an opening angle $\varphi = 30^\circ$

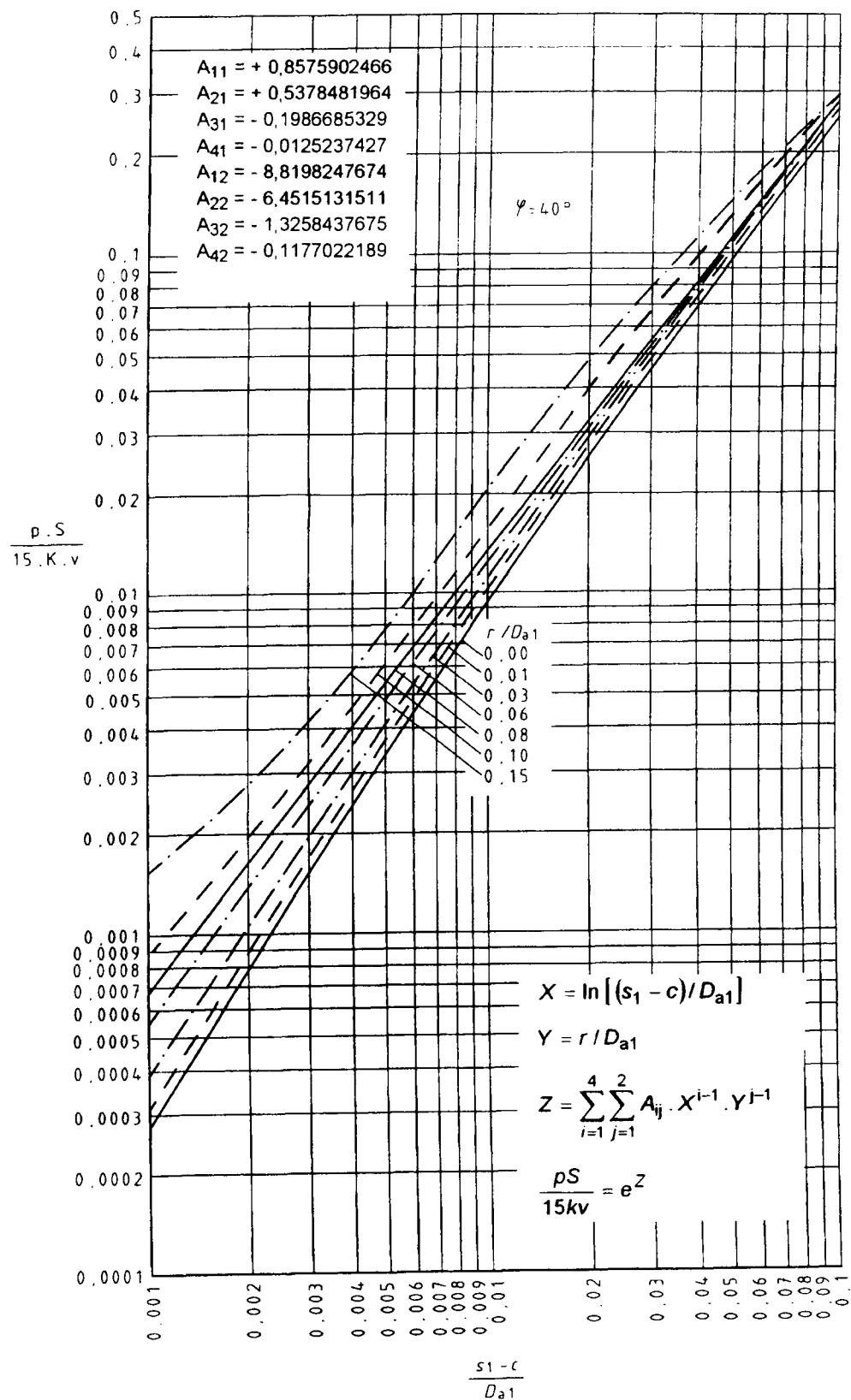


Figure 10.4 — Permissible value $\frac{p.S}{15K.v}$ for convergent cone with an opening angle $\varphi = 40^\circ$

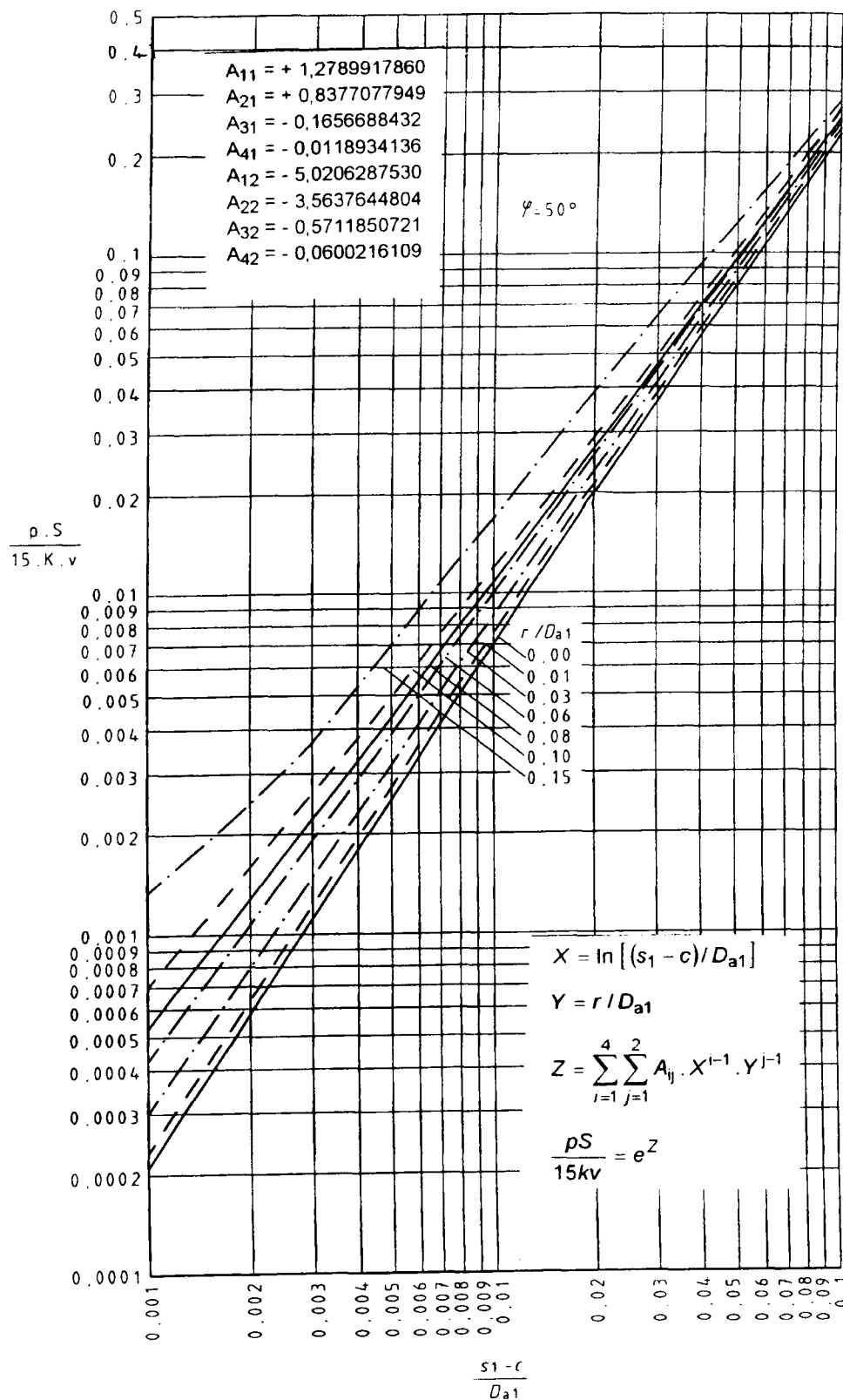


Figure 10.5 — Permissible value $\frac{p.S}{15K.v}$ for convergent cone with an opening angle $\varphi = 50^\circ$

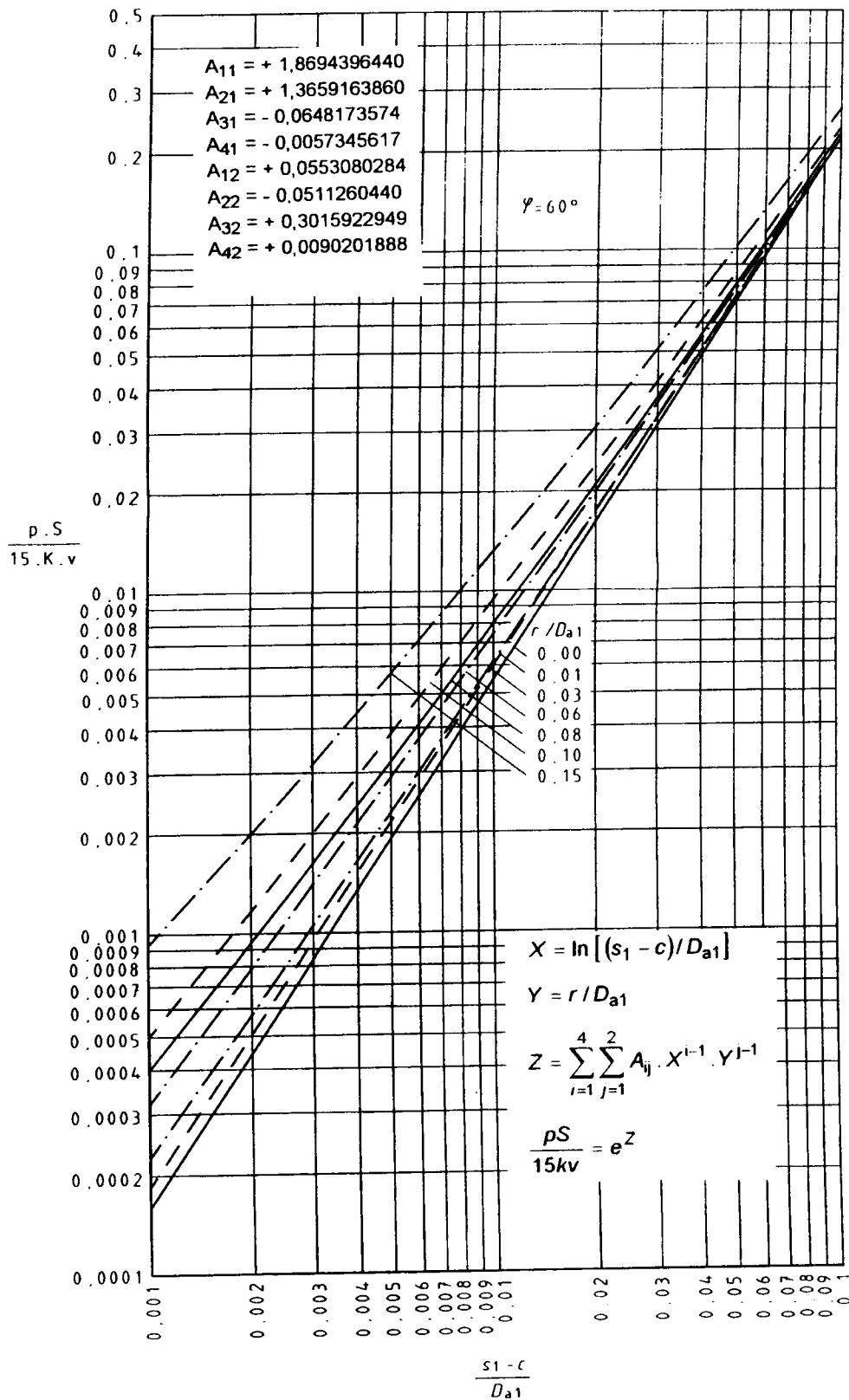


Figure 10.6 — Permissible value $\frac{p.S}{15K.v}$ for convergent cone with an opening angle $\varphi = 60^\circ$

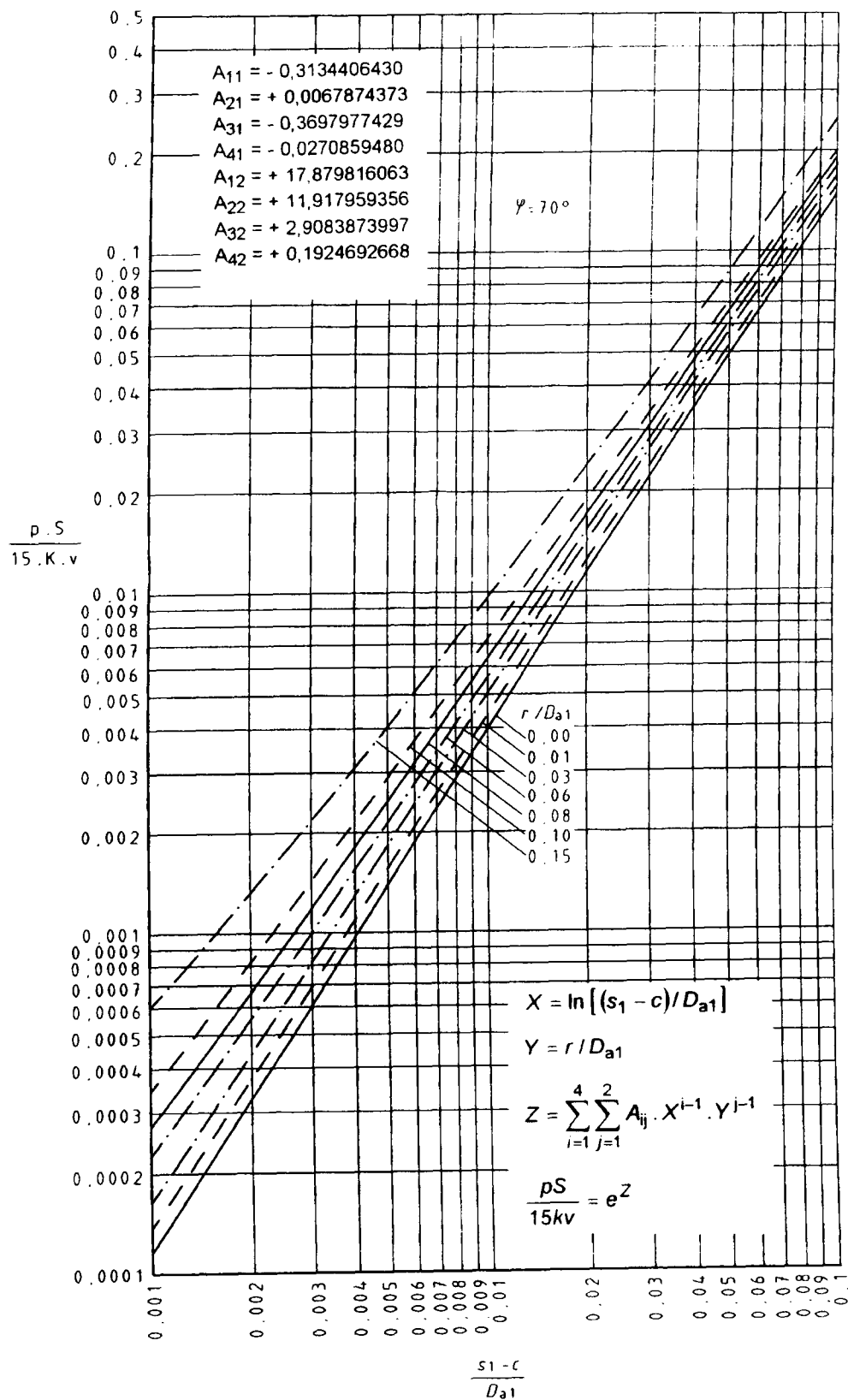


Figure 10.7 — Permissible value $\frac{p.S}{15K.v}$ for convergent cone with an opening angle $\varphi = 70^\circ$

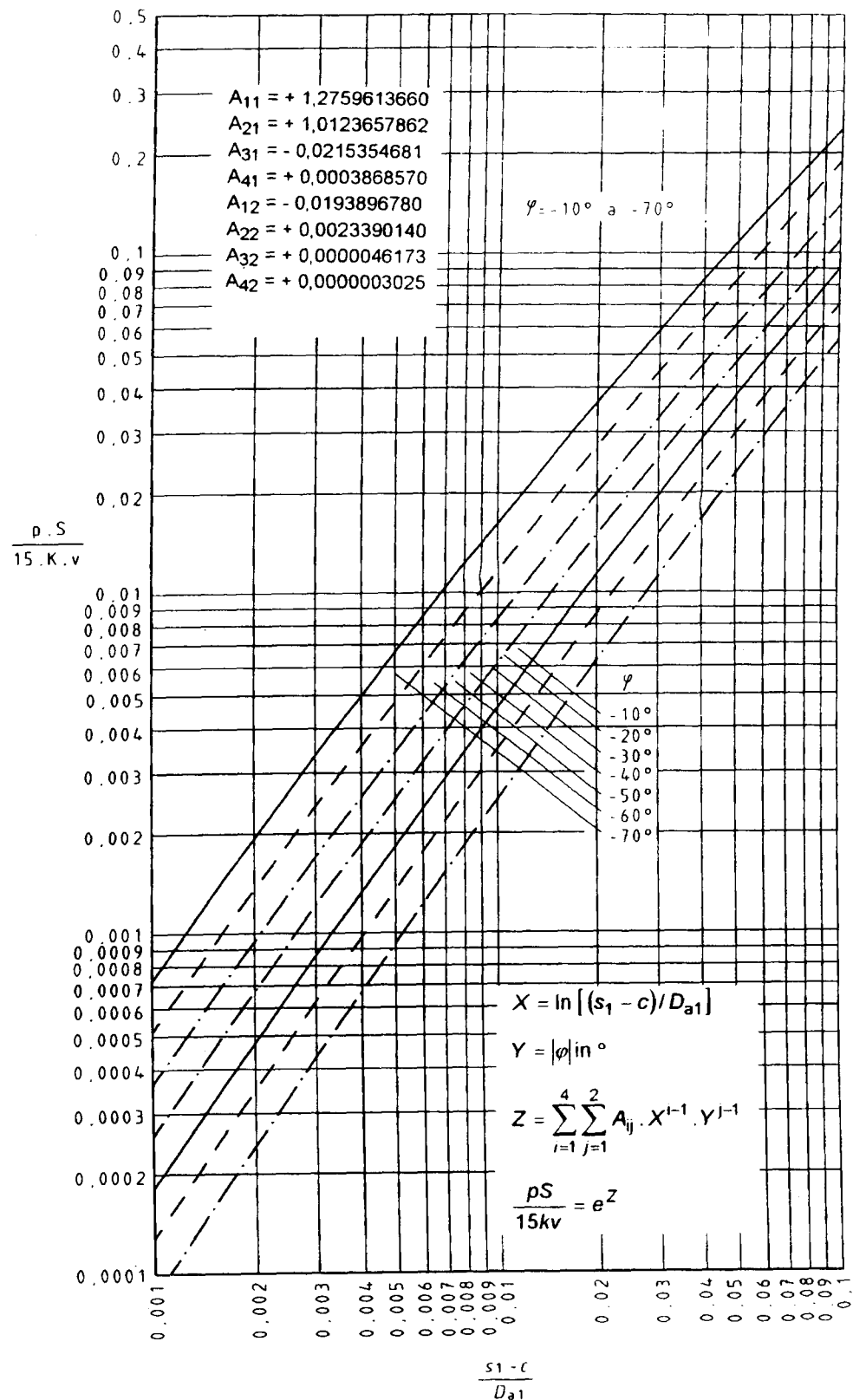
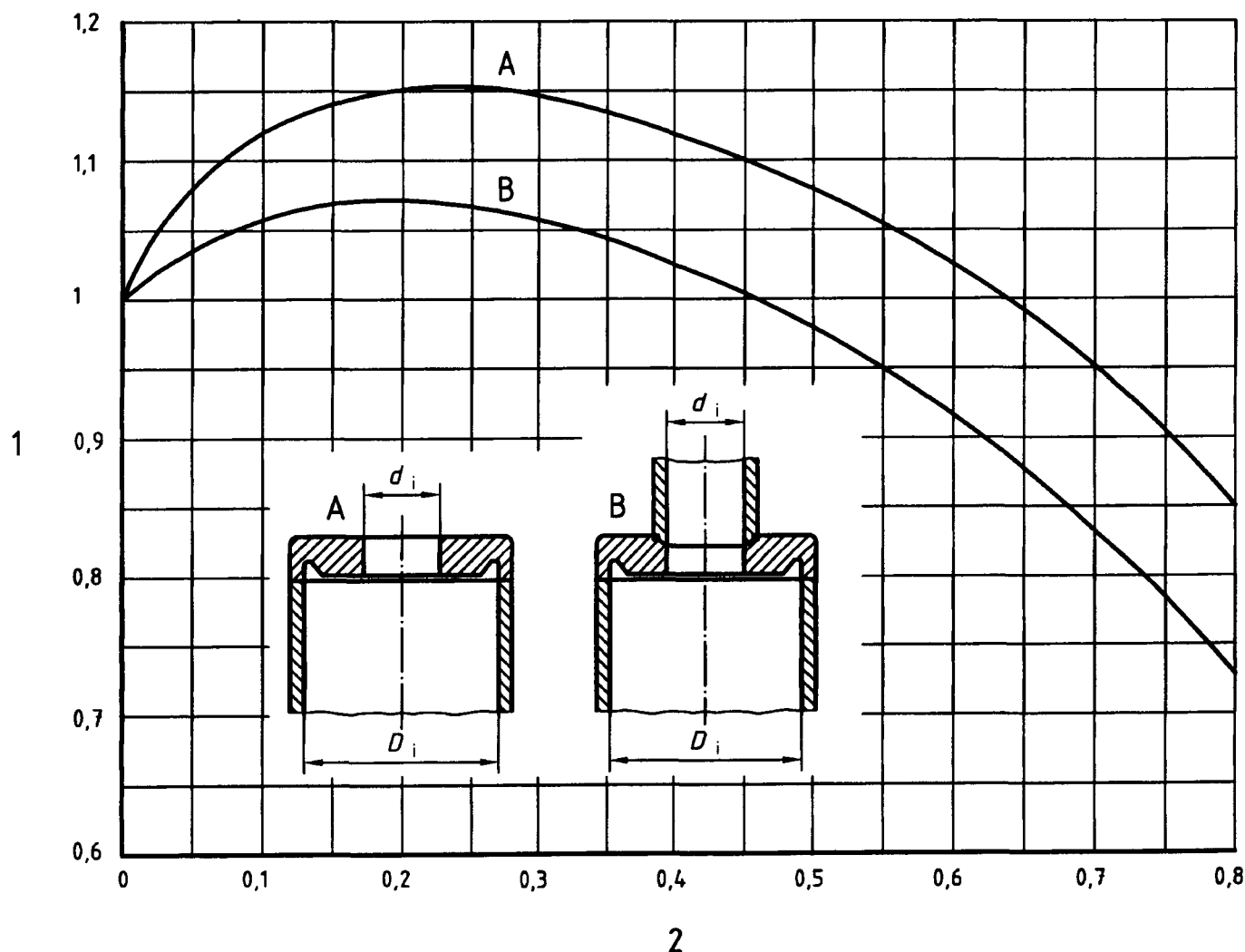


Figure 10.8 — Permissible value $\frac{p.S}{15K.v}$ for convergent cone with an opening angle $\varphi = 80^\circ$

Figure 10 — Permissible value $\frac{p.S}{15K.v}$ for convergent cones



Key : 1 = Opening factor C_A ; 2 = ratio d/D_i resp. d/f

Figure 11 — Opening factor C_A for flat ends and plates

Type A

d = inside diameter of opening
 D_i = design diameter
 f = short side of elliptical end

$$C_A = \begin{cases} \sum_{i=1}^6 A_i \left(\frac{d}{D_i} \right)^{i-1} & | 0 < \left(\frac{d}{D_i} \right) \leq 0,8 \\ \sum_{i=1}^6 A_i \left(\frac{d}{f} \right)^{i-1} & | 0 < \left(\frac{d}{f} \right) \leq 0,8 \end{cases}$$

$A_1 = 0,99903420$
 $A_2 = 1,98062600$
 $A_3 = 9,01855400$
 $A_4 = 18,63283000$
 $A_5 = 19,49759000$
 $A_6 = 7,61256800$

Type B

d = inside diameter of opening
 D_i = design diameter
 f = short side of elliptical end

$$C_A = \begin{cases} \sum_{i=1}^6 A_i \left(\frac{d}{D_i} \right)^{i-1} & | 0 < \left(\frac{d}{D_i} \right) \leq 0,8 \\ \sum_{i=1}^6 A_i \left(\frac{d}{f} \right)^{i-1} & | 0 < \left(\frac{d}{f} \right) \leq 0,8 \end{cases}$$

$A_1 = 1,00100344$
 $A_2 = 0,94428468$
 $A_3 = 4,31210200$
 $A_4 = 8,38843500$
 $A_5 = 9,20628384$
 $A_6 = 3,69494196$

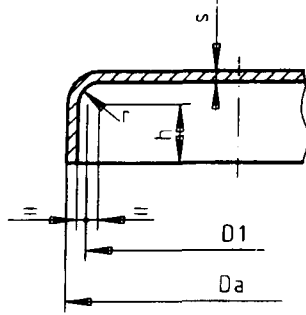
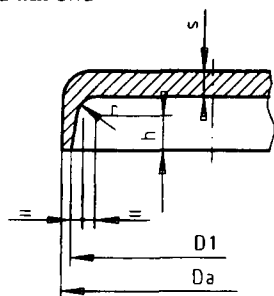
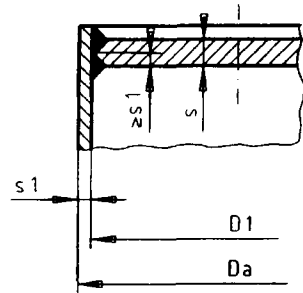
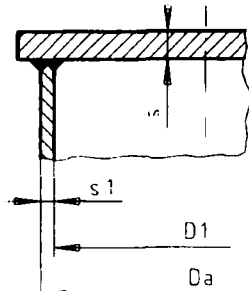
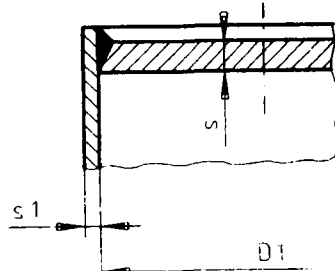
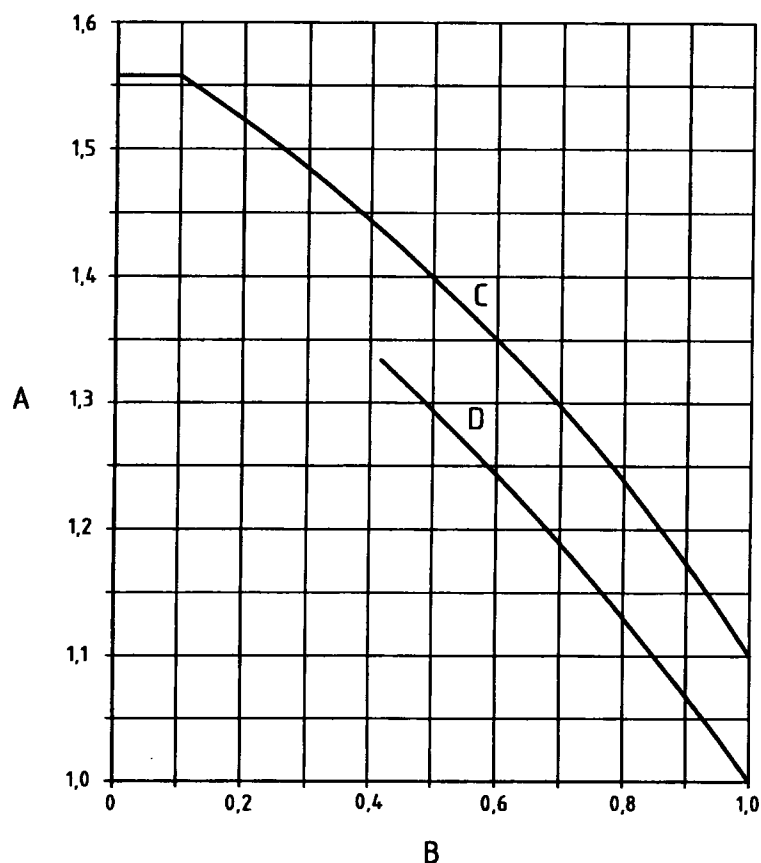
Type of flat end design (principle only)	conditions	design factor <i>C</i>												
a) flanged flat end 	1. knuckle radius: <table border="1"><thead><tr><th><i>D_a</i></th><th><i>r</i> min</th></tr></thead><tbody><tr><td>up to 500</td><td>30</td></tr><tr><td>over 500 up to 1 400</td><td>35</td></tr><tr><td>over 1 400 up to 1 600</td><td>40</td></tr><tr><td>over 1 600 up to 1 900</td><td>45</td></tr><tr><td>over 1 900</td><td>50</td></tr></tbody></table> and $r \geq 1,3s$ 2. cylindrical part: $h \geq 3,5s$	<i>D_a</i>	<i>r</i> min	up to 500	30	over 500 up to 1 400	35	over 1 400 up to 1 600	40	over 1 600 up to 1 900	45	over 1 900	50	0,30
<i>D_a</i>	<i>r</i> min													
up to 500	30													
over 500 up to 1 400	35													
over 1 400 up to 1 600	40													
over 1 600 up to 1 900	45													
over 1 900	50													
b) forged or pressed flat end 	1. knuckle radius: $r \geq \frac{s}{3}$, however at least 8 mm 2. cylindrical part: $h \geq s$	0,35												
c) flat plate welded into the shell from both sides 	plate thickness : $s \leq 3s_1$ $s > 3s_1$	0,35 0,40												
d) plate welded to the shell with welds at both sides of the latter 	plate thickness : $s \leq 3s_1$ $s > 3s_1$ Only killed steels may be utilised. When plate material is employed, over an area of at least $3s_1$ in the weld zone there must be no evidence of material discontinuities in the plate.	0,40 0,45												
e) flat plate welded into the shell from one side only 	plate thickness : $s \leq 3s_1$ $s > 3s_1$	0,45 0,50												

Figure 12 — Design factors for unstayed circular flat ends and plates



Key : A = Design factor C_E ; B = ratio f/e ; C = rectangle ; D = Ellipse

Figure 13 — Design factor C_E for rectangular or elliptical flat plates

Rectangular plates

f = short side of the rectangular plate

e = long side of the rectangular plate

$$C_E = \begin{cases} \sum_{i=1}^4 A_i \left(\frac{f}{e} \right)^{i-1} & | 0,1 < \left(\frac{f}{e} \right) \leq 1,0 \\ 1,562 & | 0 < \left(\frac{f}{e} \right) \leq 0,1 \end{cases}$$

$$\begin{aligned} A_1 &= 1,58914600 \\ A_2 &= - 0,23934990 \\ A_3 &= - 0,33517980 \\ A_4 &= 0,08521176 \end{aligned}$$

Elliptical plates

f = short side of the rectangular plate

e = long side of the rectangular plate

$$C_E = \sum_{i=1}^4 A_i \left(\frac{f}{e} \right)^{i-1} \quad | 0,43 < \left(\frac{f}{e} \right) \leq 1,0$$

$$\begin{aligned} A_1 &= 1,58914600 \\ A_2 &= - 0,23934990 \\ A_3 &= - 0,33517980 \\ A_4 &= 0,08521176 \end{aligned}$$

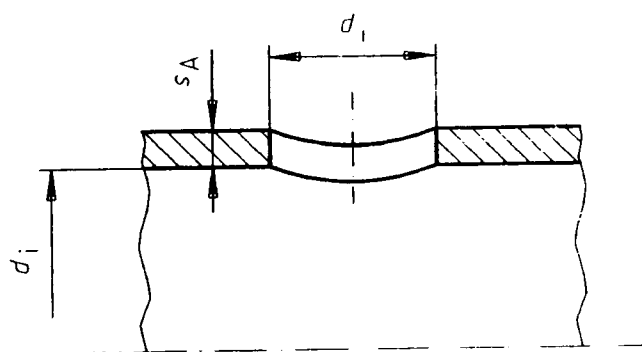


Figure 14 — Increased thickness of a cylindrical shell

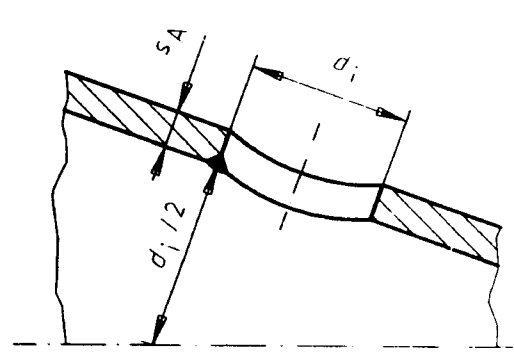


Figure 15 — Increased thickness of a conical shell

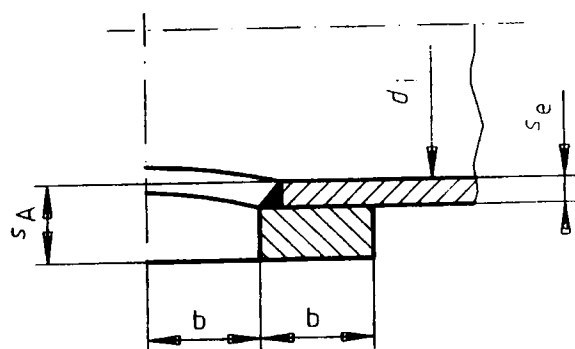


Figure 16 — Set-on reinforcement ring

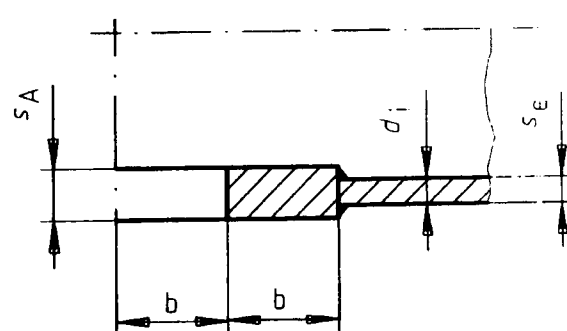
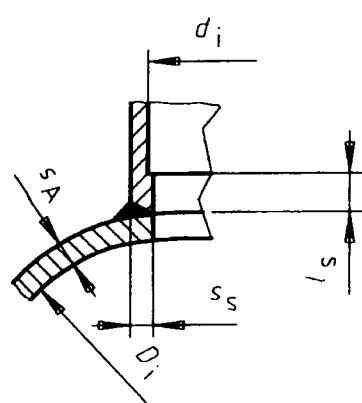
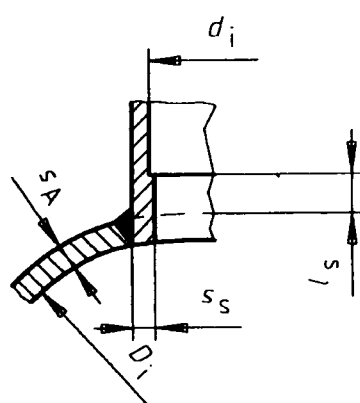


Figure 17 — Set-in reinforcement ring

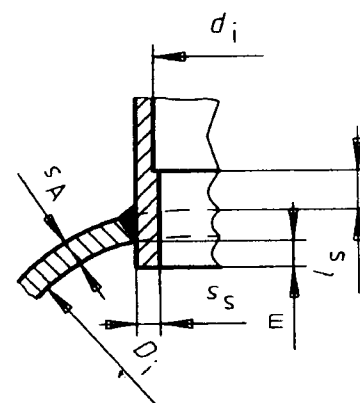
Figure 18 — Pad reinforcement



type a)



type b)



type c)

Figure 19 — Nozzle reinforcement

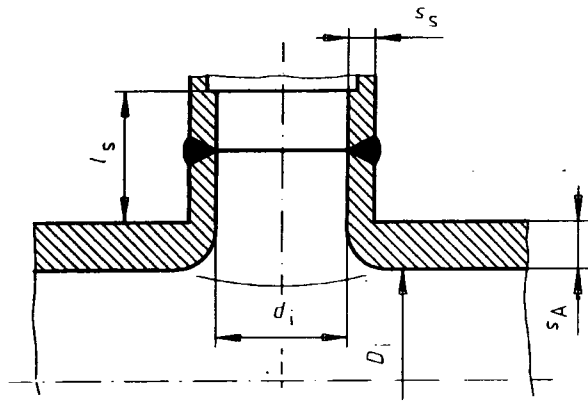


Figure 20 — Necked out opening

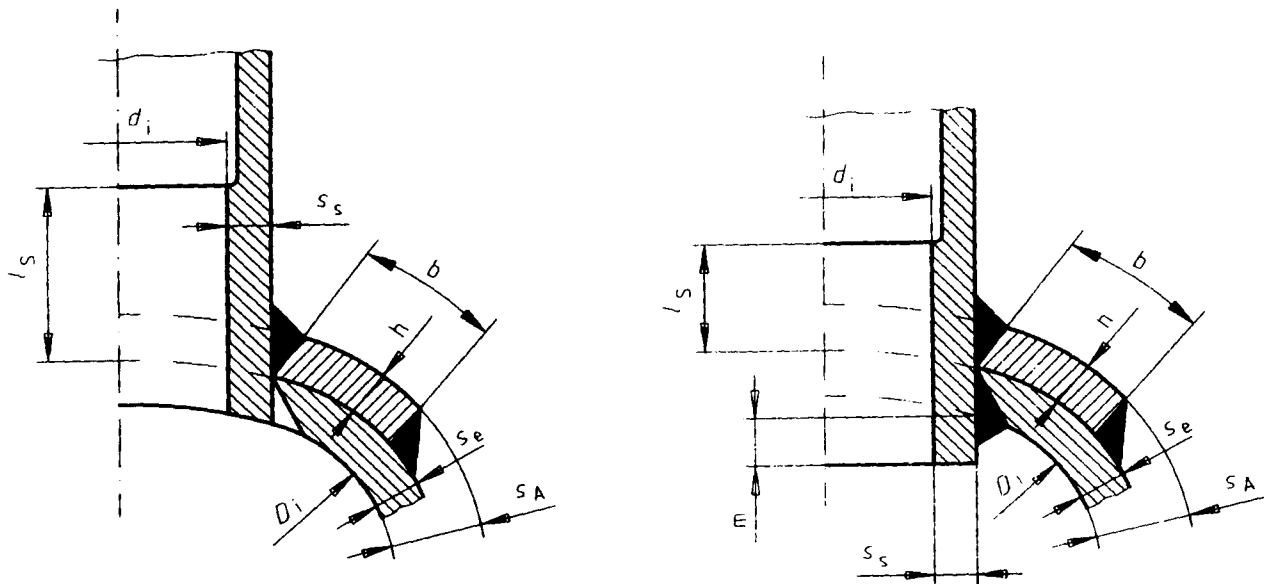
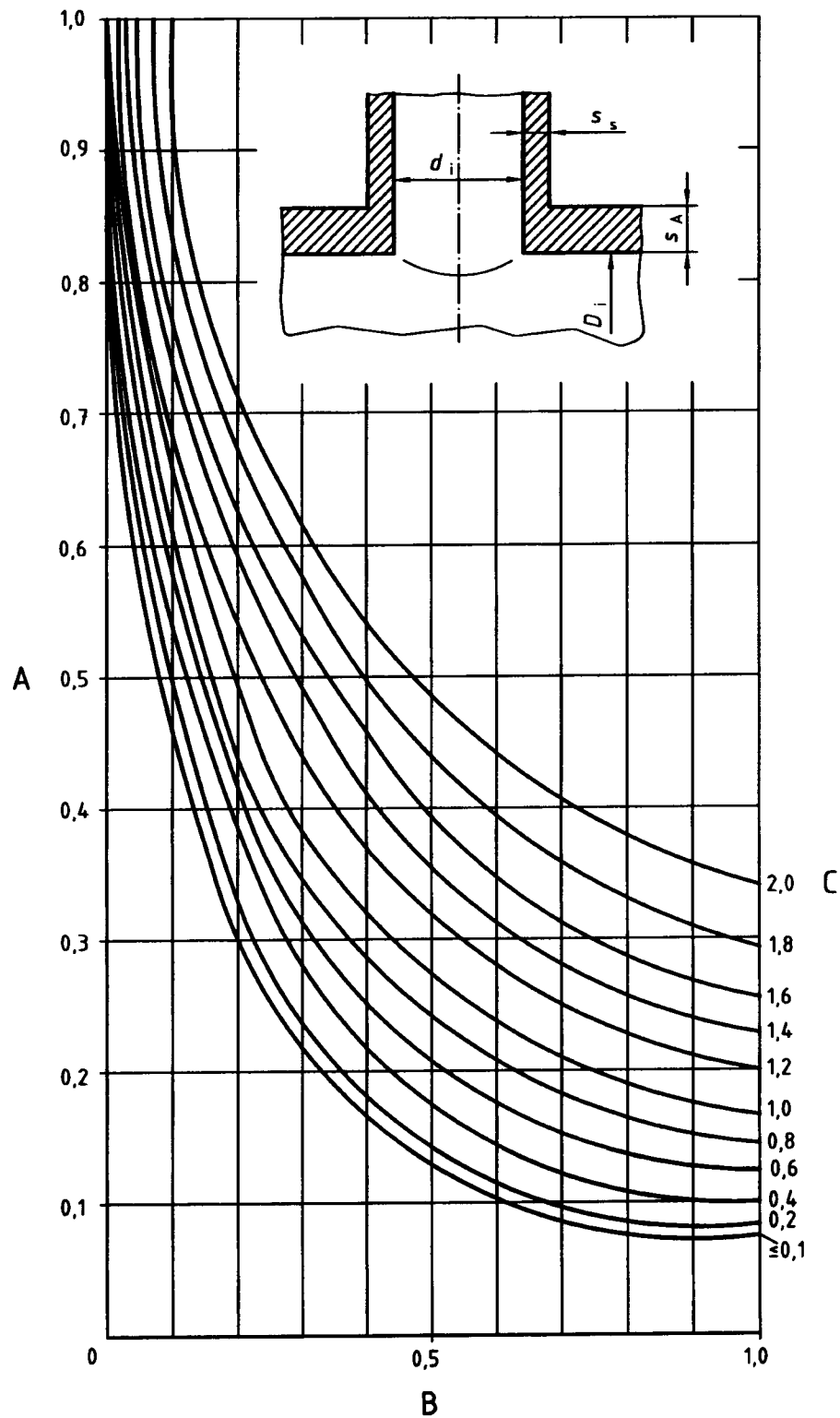
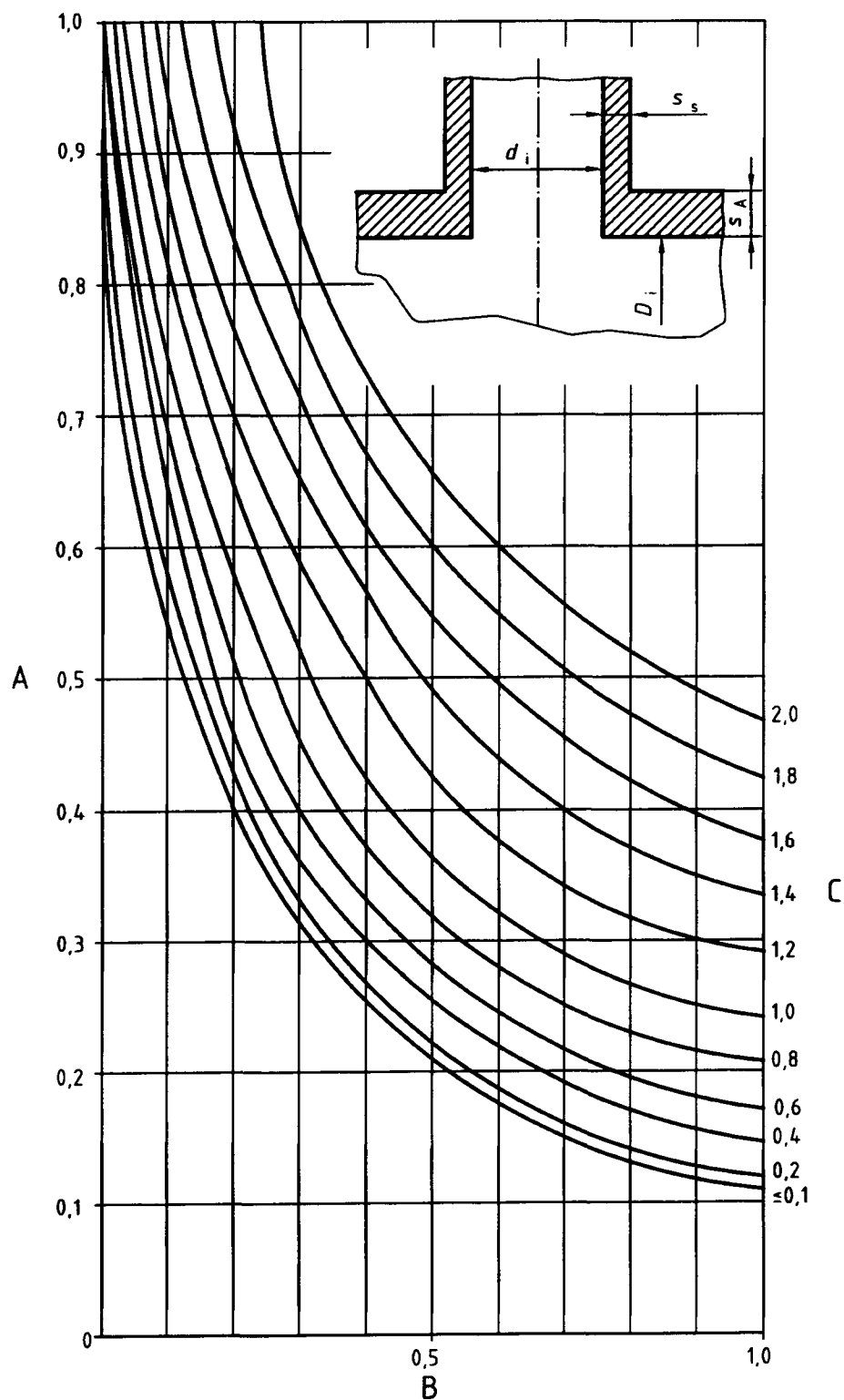


Figure 21 — Pad



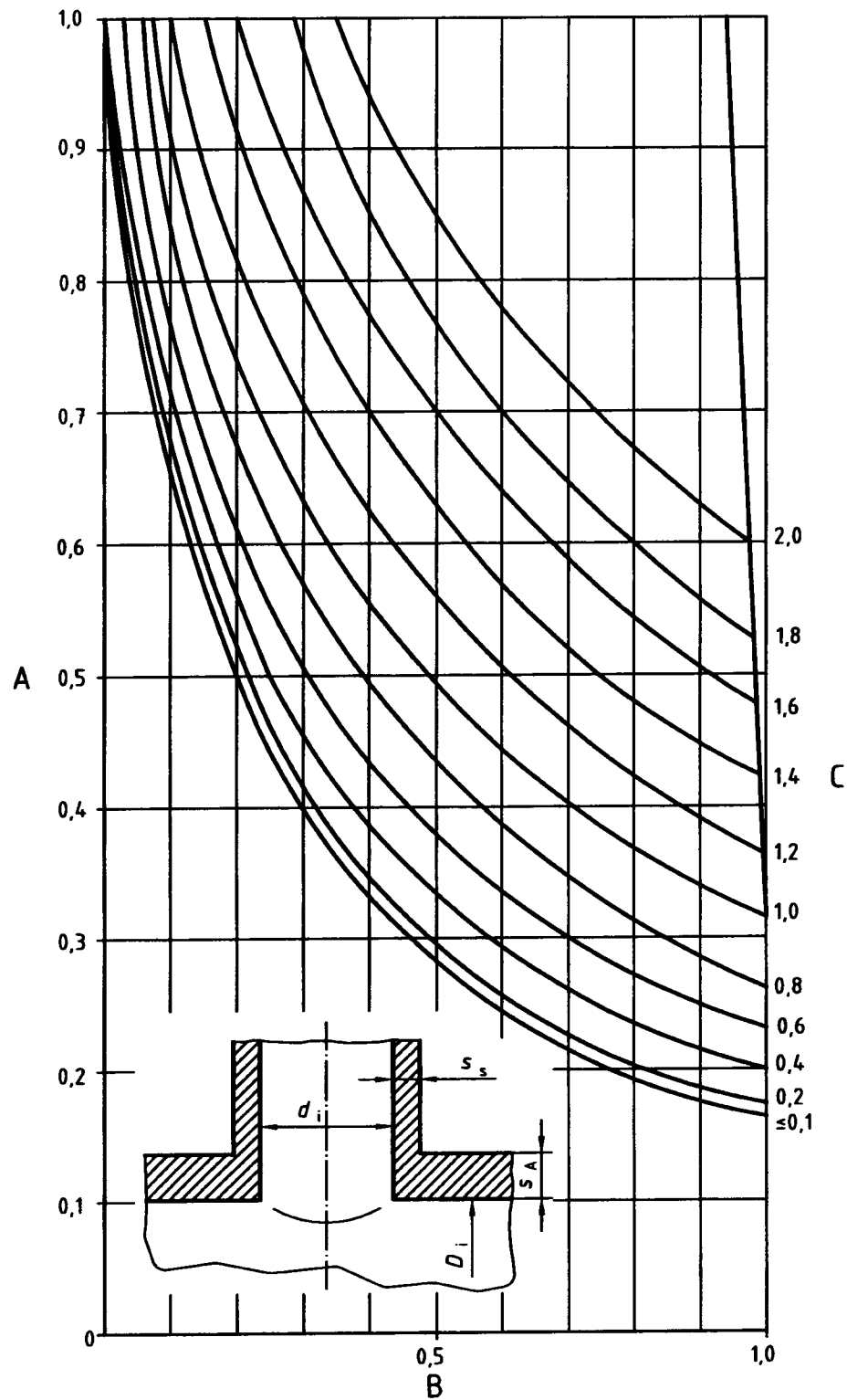
Key : A = Weakening factor V_A ; B = Diameter ratio d_i/D_i ; C = Wall thickness ratio $(s_s - c)/(s_A - c)$

Figure 22a — Weakening factor V_A for openings and branches perpendicular to the shell in cylinders and cones ($s_A / D \geq 0,002$)



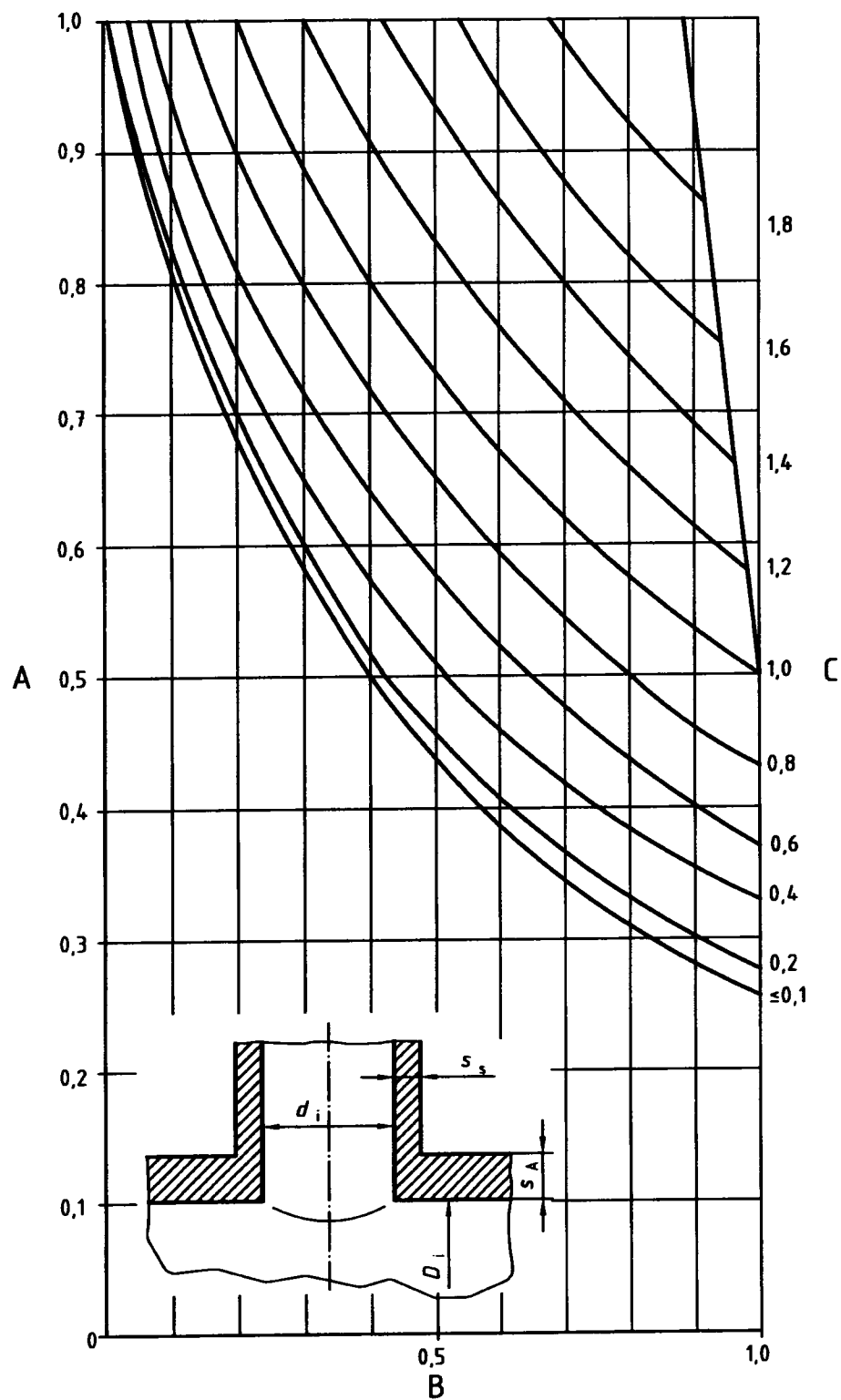
Key : A = Weakening factor V_A ; B = Diameter ratio d_i/D_i ; C = Wall thickness ratio $(s_s-c)/(s_A-c)$

Figure 22b — Weakening factor V_A for openings and branches perpendicular to the shell in cylinders and cones ($s_A / D \geq 0,005$)



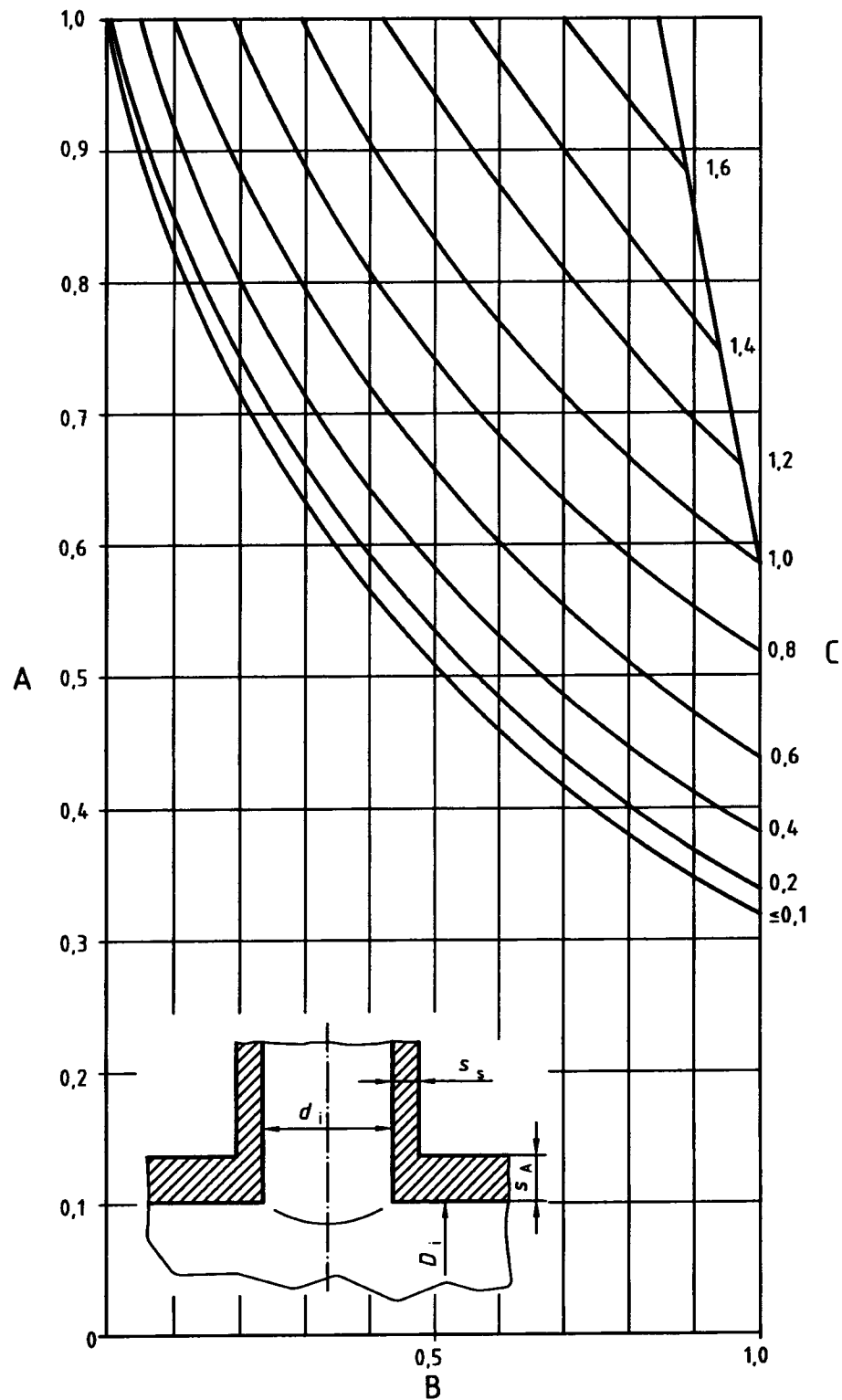
Key : A = Weakening factor V_A ; B = Diameter ratio d/D_i ; C = Wall thickness ratio $(s_s-c)/(s_A-c)$

Figure 22c — Weakening factor V_A for openings and branches perpendicular to the shell in cylinders and cones ($s_A / D \geq 0,01$)



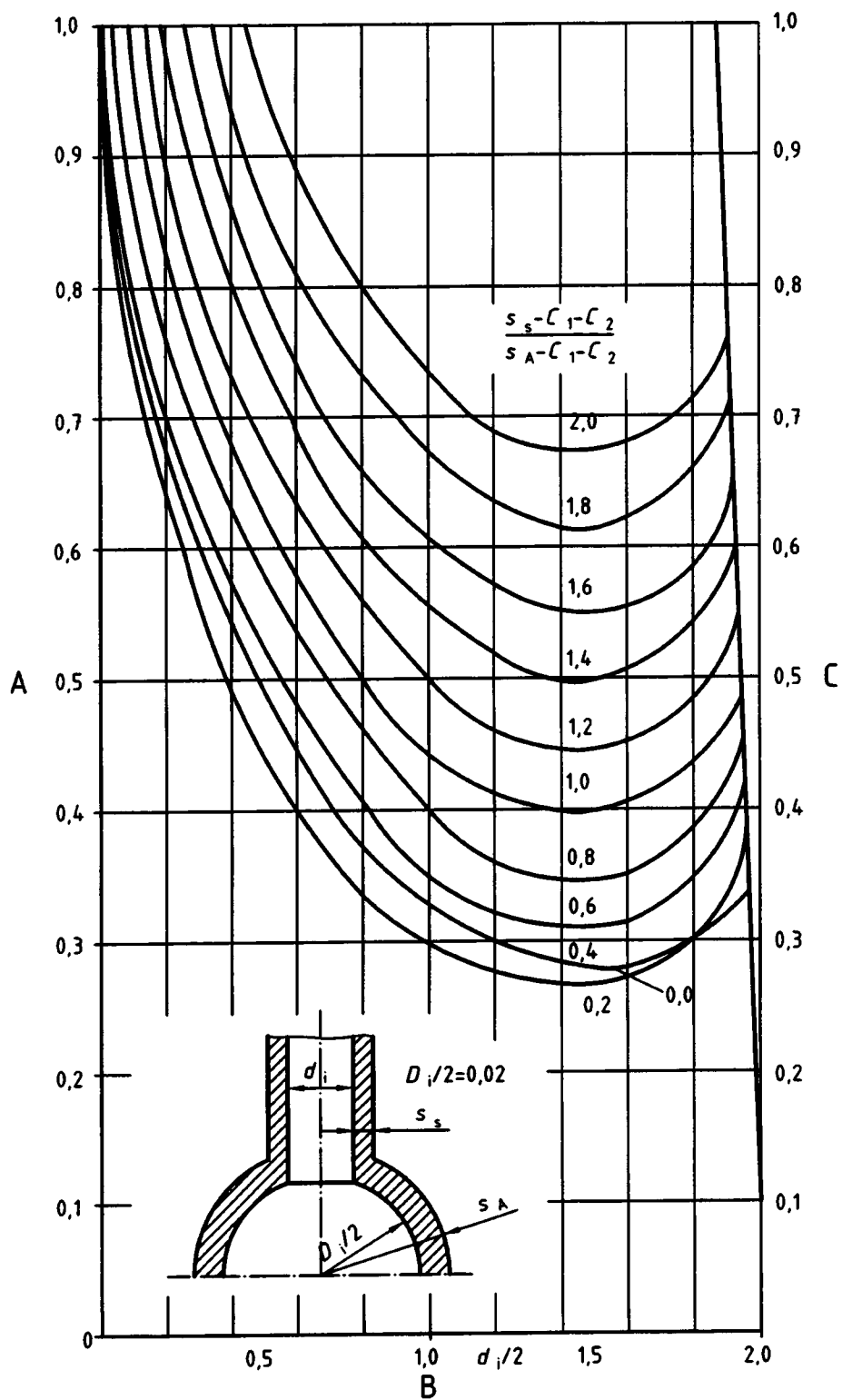
Key : A = Weakening factor V_A ; B = Diameter ratio d_i/D_i ; C = Wall thickness ratio $(S_S - C)/(S_A - C)$

Figure 22d — Weakening factor V_A for openings and branches perpendicular to the shell in cylinders and cones ($S_A / D \geq 0,05$)



Key : A = Weakening factor V_A ; B = Diameter ratio d/D_i ; C = Wall thickness ratio $(s_s - c)/(s_A - c)$

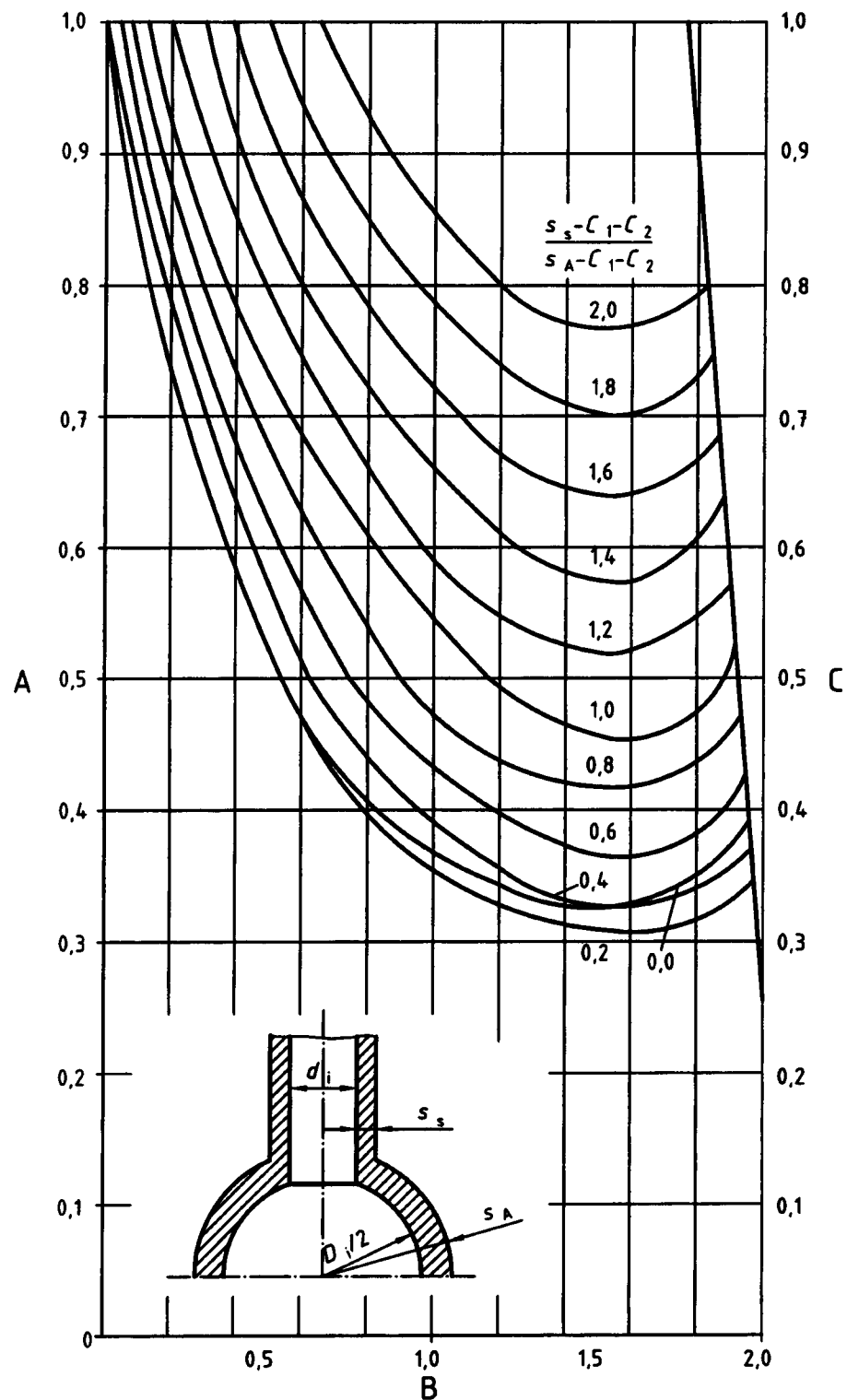
Figure 22e — Weakening factor V_A for openings and branches perpendicular to the shell in cylinders and cones ($s_A / D \geq 0.1$)



Key : A = Weakening factor V_A ; B = Related opening diameter $d_i/(D/2)$; C = Wall thickness ratio $(s_s - c)/(s_A - c)$

Figure 22f — Weakening factor V_A for openings and branches perpendicular to the shell in cones

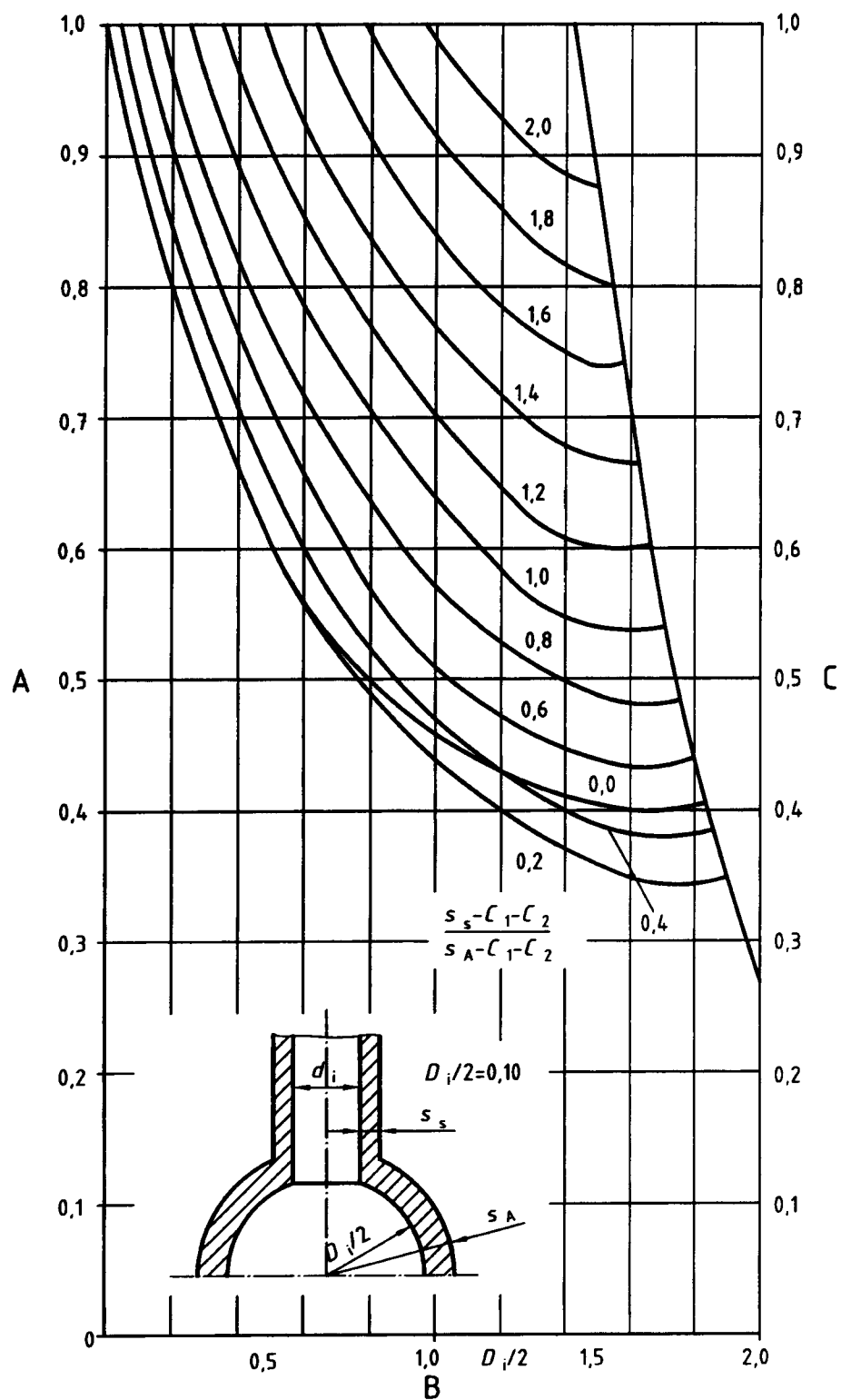
$$\left(s_A / \frac{D_1}{2} = 0,02 \right)$$



Key : A = Weakening factor V_A ; B = Related opening diameter $d_i/(D_i/2)$; C = Wall thickness ratio $(s_s - c)/(s_A - c)$

Figure 22g — Weakening factor V_A for openings and branches perpendicular to the shell in cones

$$\left(s_A / \frac{D_i}{2} = 0,04 \right)$$



Key : A = Weakening factor V_A ; B = Related opening diameter $d_i / (D_i/2)$; C = Wall thickness ratio $(s_s - C) / (s_A - C)$

Figure 22h — Weakening factor V_A for openings and branches perpendicular to the shell in

$$\text{cones} \left(S_A / \frac{D_1}{2} = 0,10 \right)$$

Figure 22 — Weakening factor V_A

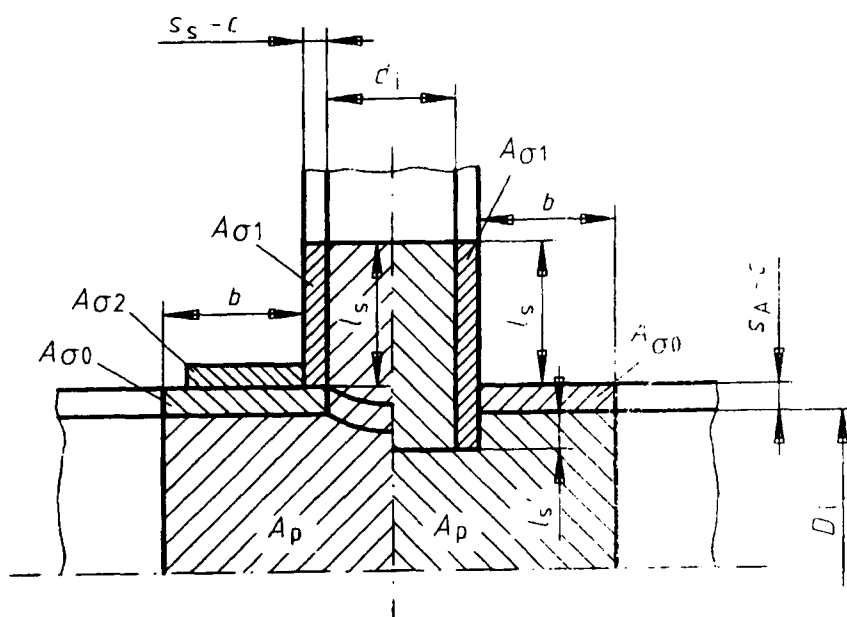


Figure 23 — Calculation scheme for cylindrical shells

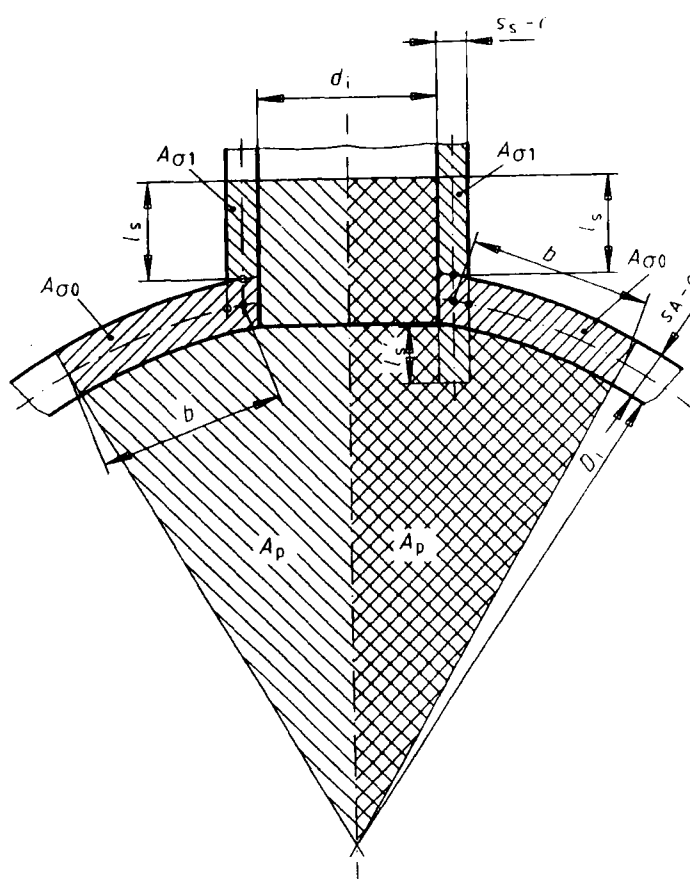


Figure 24 — Calculation scheme for spherical shells

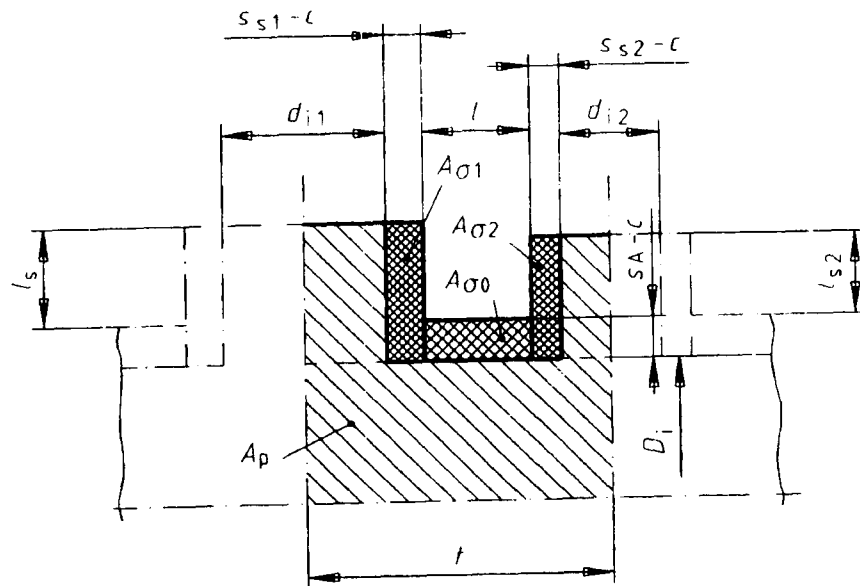


Figure 25 — Calculation scheme for adjacent nozzles in a sphere or in a longitudinal direction of a cylinder

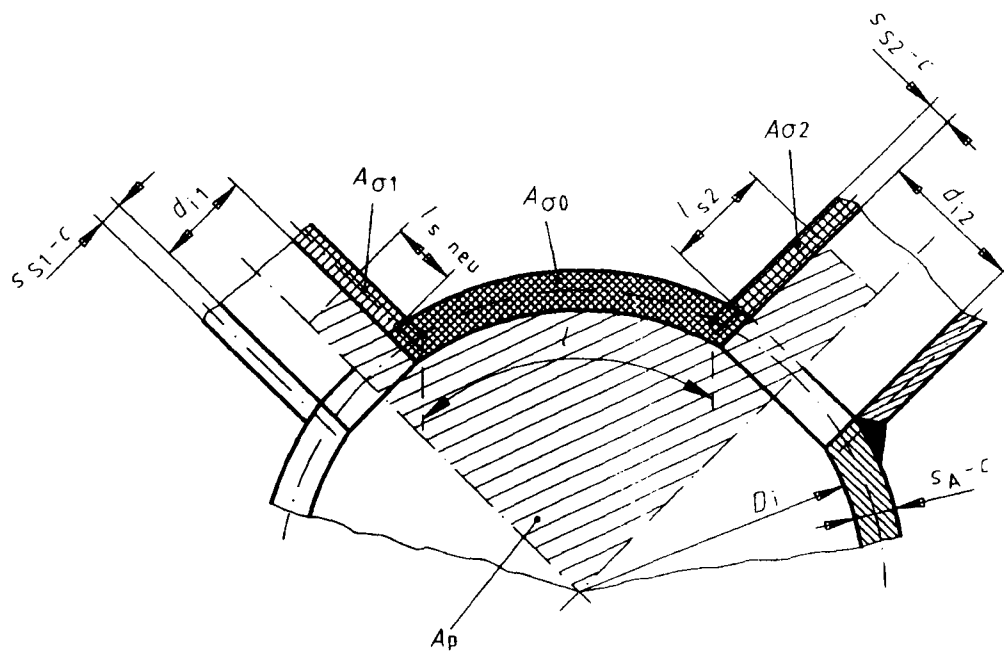


Figure 26 — Calculation scheme for adjacent nozzles in a sphere or in a circumferential direction of a cylinder

5 Fabrication

5.1 General

5.1.1 The manufacturer shall have a quality system in operation (e.g. EN ISO 9000).

5.1.2 The manufacturer, or his sub-contractor, shall have equipment available to ensure manufacture and testing in accordance with the design.

5.1.3 The quality system shall ensure that the manufacturer maintains :

- a system of material traceability for pressure bearing parts used in the construction of the inner vessel ;
- design dimensions within specified tolerances ;
- necessary cleanliness of the inner vessel, associated piping and other equipment which could come in contact with the cryogenic fluid.

5.2 Cutting

Material shall be cut to size and shape by thermal cutting, machining or by cold shearing. Thermally cut material shall be dressed back by machining or grinding. Cold sheared material need not be dressed.

5.3 Cold forming

5.3.1 Austenitic stainless steel

No heat treatment after cold forming is required in any of the following cases :

- a) the test certificate for the base material shows an elongation at fracture A_5 of more than 30 % and the cold forming deformation is not more than 15 % or it is demonstrable that the residual elongation is not less than 15 % ;
- b) the cold forming deformation is more than 15 % and it is demonstrated that the residual elongation is not less than 15 % ;
- c) for formed heads, the test certificate for the base material shows an elongation at fracture A_5 :
 - not less than 40 % in the case of wall thicknesses not more than 15 mm at operating temperatures down to -196° C ;
 - not less than 45 % in the case of wall thicknesses more than 15 mm at operating temperatures down to - 196° C ;
 - not less than 50 % at operating temperatures below -196° C.

Where heat treatment is required this shall be carried out in accordance with the material standard.

5.3.2 Ferritic steel

Material for the outer jacket, including cold formed ends with or without joggled joints, does not require post forming heat treatment.

5.3.3 Aluminium or aluminium alloy

When there is no risk of stress corrosion in service cold formed ends made from aluminium or aluminium alloy do not require post forming heat treatment.

5.4 Hot forming

5.4.1 General

Forming shall be carried out in accordance with a written procedure. The forming procedure shall specify the heating rate, the holding temperature, the temperature range and time for which the forming takes place and shall give details of any heat treatment to be given to the formed part. Each requirement shall have its means of verification defined.

5.4.2 Austenitic stainless steel

Material shall be heated uniformly in an appropriate atmosphere without flame impingement, to a temperature not exceeding the recommended hot forming temperature of the material. When forming is carried out after the temperature of the material has fallen below 900 °C the requirements of 5.3.1 shall be complied with.

5.4.3 Aluminium or aluminium alloy

Where elongation at fracture of the formed material is shown to be greater than 10%, then post forming heat treatment is not required.

5.5 Manufacturing tolerances

5.5.1 Plate alignment

Except where a tapered transition is provided, misalignment of the surfaces of adjacent plates at welded seams shall be :

- for longitudinal welds, not more than 15 % of the thickness of the thinner plate ;
- for circumferential welds, not more than 25 % of the thickness of the thinner plate.

Where a taper is provided between the surfaces, this shall have a slope of not more than 30°. The taper may include the width of the weld, the lower surface being built up with added weld metal if necessary. Where material is removed from a plate to provide a taper, the thickness of either plate shall not be reduced below that required for the design.

The distance between either surface of the thicker plate and the centre line of the thinner plate of tapered seams shall be :

- for longitudinal seams, not less than 35 % of the thickness of the thinner plate ;
- for circumferential seams, not less than 25 % of the thickness of the thinner plate.

In no case shall the surface of any plate lie between the centre lines of the two plates.

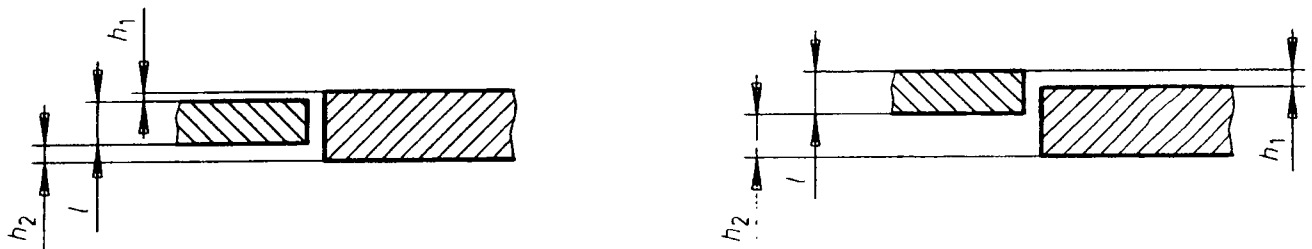
These requirements are illustrated in figure 27.

Nomenclature

h, h_1, h_2 = surface misalignments

t = thickness of the thinner plate

e = distance from the surface of the thicker plate to the centreline of the thinner plate



For longitudinal seams :

$$h_1 \leq 0,15t$$

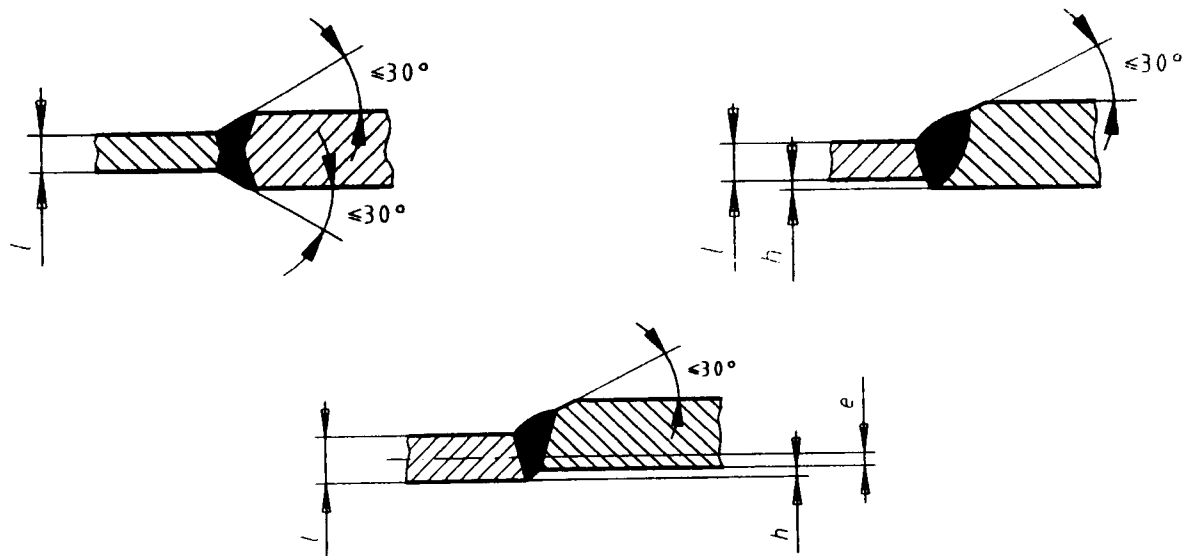
and $h_2 \leq 0,15t$

For circumferential seams :

$$h_1 \leq 0,25t$$

and $h_2 \leq 0,25t$

Figure 27a — Seam which do not require a taper



For longitudinal seams :

$$h_1 \leq 0,15t$$

$$\text{and } e = \frac{t}{2} - h \geq 0,35t$$

For circumferential seams :

$$h_1 \leq 0,25t$$

$$\text{and } e = \frac{t}{2} - h \geq 0,25t$$

Figure 27b — Seam which do require a taper

Figure 27 — Plate alignment

5.5.2 Thickness

The thickness of the vessel shall not be less than the design thickness. This shall be taken as the thickness of the vessel after manufacture and any variations in thickness shall be gradual.

5.5.3 Dished ends

The depth of the dishing, excluding the straight flange, shall not be less than the theoretical depth. The knuckle radius shall not be less than specified and the crown radius shall not be greater than specified. Any variation of the profile shall not be abrupt but shall merge gradually into the specified shape

5.5.4 Cylinders

5.5.4.1 The actual circumference shall not deviate from the circumference calculated from the specified diameter by more than $\pm 1,5 \%$.

5.5.4.2 The out of roundness calculated from the expression

$$\text{Out of roundness} = \frac{200(D_{\max} - D_{\min})}{D_{\max} + D_{\min}} \% \quad \dots (38)$$

shall not be greater than the values shown in table 3.

Table 3 — Permitted out of roundness

Wall thickness to diameter ratio	Permitted out of roundness for	
	internal pressure	external pressure
$s/D \leq 0,01$	2,0 %	1,5 %
$s/D > 0,01$	1,5 %	1,5 %

When determining out of roundness, the elastic deformation due to the mass of the vessel shall be deducted. Individual bulges and dents shall be within the permitted tolerances. Such bulges and dents shall be smooth and their depth, measured as a deviation from the normal curvature or from the line of the cylindrical shell, shall not be greater than 1 % of their length or width.

For cylinders subject to external pressure and where the circumference has a flattened portion, it shall be demonstrated that the shell has sufficient strength to avoid plastic deformation where the depth of flattening is greater than 0,4 % of the outside diameter of the cylinder. The depth of flattening shall be measured as a deviation from the normal curvature or from the line of the cylindrical shell. Adequate strength may be determined by calculation in accordance with formula (8), using a value of ν determined as follows :

$$u = \frac{400}{D_a} q \% \quad \dots (39)$$

where :

- q is the depth of flattening, in millimetres ;
- D_a is the external diameter of the cylinder, in millimetres.

5.5.4.3 Departure from a straight line shall be not greater than 0,5 % of the cylindrical length, except otherwise required by the design.

5.6 Welding

5.6.1 Qualification

Manufacturers of welded vessels shall have a welding quality system in operation, taking into account the quality requirements for welding in accordance with EN 729-2 or EN 729-3 as appropriate.

Welding procedures shall be approved in accordance with EN 288-3, EN 288-4 or EN 288-8.

Welders shall be approved in accordance with EN 287-1 or EN 287-2 and for automatic welding operators in accordance with EN 1418.

5.6.2 Temporary attachments

Temporary attachments welded to pressure bearing parts shall be kept to a practical minimum.

Temporary attachments welded directly to pressure bearing parts shall be compatible with the immediately adjacent material.

It is permissible to weld dissimilar metal attachments to intermediate components, such as pads, which are connected permanently to the pressure containing part. Compatible welding materials shall be used for dissimilar metal joints.

Temporary attachments shall be removed from the inner vessel prior to the first pressurisation. The removal technique shall be such as to avoid impairing the integrity of the inner vessel and shall be by chipping or grinding. Any rectification necessary by welding of damaged regions shall be undertaken in accordance with an approved welding procedure.

The area of the inner vessel from where the temporary attachments have been removed shall be dressed smooth and examined by appropriate non-destructive testing.

Any attachments on the outer jackets may be removed by thermal cutting as well as by the methods described above.

5.6.3 Welded joints

5.6.3.1 Some weld details are given in Annex B. These details show sound and currently accepted practice. It is not intended that these are mandatory nor shall they restrict the development of welding technology in any way.

The manufacturer, in selecting an appropriate weld detail, shall consider :

- the method of manufacture ;
- the service conditions ;
- the ability to carry out necessary non-destructive testing.

Other weld details may be used provided their suitability is proven by procedure approval according to EN 288-3, EN 288-4 or EN 288-8 as applicable.

5.6.3.2 Where any part of a vessel is made in two or more courses, the longitudinal weld seams of adjacent courses shall be staggered by $4e$ with 10mm minimum measured to the edge of the longitudinal joint.

5.7 Non-welded joints

Where non-welded joints are made between metallic materials and/or non-metallic materials, procedures shall be established in a manner similar to that used in establishing welding procedures, and these procedures shall be followed for all joints. Similarly, operators shall be qualified in such procedures and only qualified personnel shall then carry out these procedures.

6 Inspection and testing

6.1 Quality

6.1.1 General

A quality plan forming part of the quality system referred to in 5.1.1 shall include as a minimum, the inspection and testing stages listed below.

6.1.2 Inspection stages during manufacture of an inner vessel

- verification of material test certificates and correlation with materials ;
- approval of weld procedure qualification records ;
- approval of welders qualification records ;
- examination of material cut edges ;
- examination of set up of seams for welding including dimensional check ;
- examination of weld preparations, tack welds ;
- visual examination of welds ;
- verification of non-destructive testing ;
- testing production control test plates ;
- verification of cleaning of inside surface of vessel ;
- examination of completed vessel including dimensional check ;
- pressure test and where necessary record permanent set.

6.1.3 Additional inspection stages during manufacture of a transportable cryogenic vessel

- verification of cleanliness and dryness of transportable cryogenic vessel ;
- visual examination of welds ;
- ensure integrity of vacuum ;
- leak test of external piping ;
- check documentation and installation of pressure relief device(s) ;
- check installation of vacuum space relief device ;
- check name plate and any other specified markings ;
- examination of completed vessel including dimensional check.

6.2 Production control test plates

6.2.1 Number of tests required

Production control test plates shall be produced and tested for the inner vessel as follows :

- a) one test plate per vessel for each welding procedure on longitudinal joints ;
- b) after 10 sequential test plates to the same procedure have successfully passed the tests, testing may be reduced to one test plate per 100 vessels.

Production control test plates are not required for the outer jacket.

6.2.2 Testing

The following tests are required :

- one face bend test in accordance with EN 910 ;
- one root bend test in accordance with EN 910 ;
- one tensile test transverse to the weld in accordance with EN 895.

Testing and acceptance shall be as required for welding procedure qualifications according to the appropriate parts of EN 288.

An impact test in accordance with EN 10045-1 shall be carried out for austenitic stainless steel when the thickness is greater than 5 mm and the toughness requirements shall follow the relevant standards ; for temperatures below - 80 °C, see EN 1252-1.

6.3 Non-destructive testing

6.3.1 General

Non-destructive testing personnel shall be qualified for the duties according to EN 473.

The radiographic examination shall be carried out in accordance with EN 1435. Each radiographic film shall consist of a minimum length of 200 mm or the length of the weld where this is less than 200 mm.

Non-destructive testing for volumetric imperfections is not required on the outer jacket of transportable cryogenic vessels.

6.3.2 Extent of examination for surface imperfections

Visual examination (if necessary aided by x5 lens) shall be carried out in accordance with EN 970 on all weld deposits. If any doubt arises, this examination shall be supplemented by surface crack detection.

Arc strike contact points and areas from which temporary attachments have been removed shall be ground smooth and subjected to surface crack detection.

6.3.3 Extent of examination for volumetric imperfections

Examination of the inner vessel for volumetric imperfections shall be by radiographic examination unless a special case is made to justify ultrasonic or other methods. The extent of radiographic examination of main seams on the inner vessel shall be in accordance with table 4 for manually produced seams and table 5 for seams produced using automatic welding processes.

When two hemispherical ends are welded together without a straight flange, the weld is to be tested as a longitudinal weld.

Table 4 — Extent of radiographic examination for manually welded seams

Weld joint factor	Radiographic examination		
	Longitudinal seams ¹⁾	T junctions ¹⁾	Circumferential seams ¹⁾
1,0 ³⁾	100 % ²⁾	100 %	25 % ²⁾
0,85	2 %	1 film per vessel	2 %
1) When a butt weld occurs less than 50mm from a nozzle cut out, additional radiographic film(s) shall be taken. 2) The level of radiographic examination marked (2) may be reduced to 10 % of each vessel if 25 vessels have been successfully built using the same welding procedure, provided — the welding procedure is unaltered ; — the welding experience has been retained in the workshop ; — the testing methods are the same ; — the results of non-destructive testing have not revealed any unacceptable systematic imperfections. 3) The extent of radiographic examination required for vessels whose design has been validated by testing, shall be the same as that required for vessels with a weld joint factor 1,0.			

Table 5 — Extent of radiographic examination for seams produced using automatic welding processes

Weld joint factor	Radiographic examination	
	T junctions and longitudinal seams ¹⁾	Circumferential seams ¹⁾
Any	The greater of one radiographic film per day or one radiographic film per 100 vessels ²⁾	The greater of one radiographic film per week or one radiographic film per 500 vessels ²⁾
1) Where a butt weld occurs less than 50 mm from a nozzle cut out, additional radiographic film(s) shall be taken. 2) A radiographic film shall be taken after — any new setting of any welding machine or change of welding operator. A new setting is taken to mean a significant change in basic parameters of the welding procedure or the use of a new welding procedure ; — where there has been an interruption in production that may affect the quality of the weld, additional radiographic film(s) shall be taken.		

6.3.4 Acceptance levels

6.3.4.1 Acceptance levels for surface imperfections

Table 6 shows the acceptance criteria for surface imperfections.

Table 6 — Acceptance levels for surface imperfections

Imperfection	EN ISO 6520-1 reference	Limit for acceptable imperfection
Lack of penetration	402	Not permitted
Undercut	5011	Where the thickness is less than 3 mm no visible undercut is permitted. Where the thickness is not less than 3 mm, slight and intermittent undercut is acceptable, provided that it is not sharp and is not more than 0,5 mm.
Shrinkage groove	5013	As undercut
Root concavity	515	As undercut
Excessive penetration	504	Where the thickness is less than 5 mm, excessive penetration shall be not more than 2 mm. Where the thickness is not less than 5 mm, excessive penetration shall not be more than 3 mm.
Excess weld material	502	Where the thickness is less than 5 mm, excess weld metal shall not be greater than 2 mm and the weld shall be smooth. Where the thickness is 5 mm or greater, the maximum excess weld metal shall not exceed 3 mm and the weld shall be smooth.
Irregular surface	514 509 511 513 517	Reinforcement to be of continuous and regular shape with complete filling of groove.
Overlap	506	Not permitted
Linear misalignment	507	See 5.5.1
Arc strike Spatter Tungsten spatter Torn surface Grinding mark Chipping mark	610 602 6021 603 604 605	Grind smooth, acceptable subject to thickness measurement and surface crack detection test.
Surface cracks		Not permitted

6.3.4.2 Acceptance levels for internal volumetric imperfections

Table 7 shows the acceptance criteria for internal volumetric imperfections detected by radiographic examination.

Table 7 — Acceptance levels for internal volumetric imperfections

Imperfection	EN ISO 6520-1 reference	Limit for acceptable imperfection
Cracks and lack of sidewall fusion	4011	Not permitted
Incomplete root fusion	4013	Not permitted
Flat root concavity		Acceptable if full weld depth is at least equal to the wall thickness and the depth of the concavity is less than 10% of the wall thickness
Inclusions (including oxide in aluminium welds). Strings of pores, worm holes parallel to the surface and strings of tungsten.	303 304 2014 2015	Up to 7 mm length acceptable where $e < 10$ Up to 2/3rds of thickness of weld where $e > 10$
Interrun fusion defects and root defects in multipass weld	4012	As inclusions
Multiple in-line inclusions		Collectively the total length shall not be greater than the thickness in any length of 6 times the thickness. The gap between inclusions shall be greater than twice the length of the larger inclusion.
Area of general porosity visible on a film		Acceptable if less than 2 % of projected area of weld
Individual pores	2011	Acceptable if diameter is less than 25 % of the thickness with a maximum of 4 mm
Worm holes perpendicular to the surface	2021	Where the thickness is less than 10 mm, worm holes are not permitted. Where the thickness is not less than 10 mm, isolated cases are acceptable provided the depth is estimated to be not more than 30 % of the thickness.
Tungsten inclusions	3041	Where the thickness is less than 12 mm, tungsten inclusions are acceptable provided the length is not more than 3 mm. Where the thickness is not less than 12 mm, tungsten inclusions are acceptable provided the length is not more than 25 % of the thickness.

6.3.4.3 Extent of examination of non-welded joints

Where non-welded joints are used between metallic materials and/or non-metallic materials, the quality plan referred to in 6.1 shall include reference to an adequate technical specification.

This technical specification shall include the description of the requirements for inspection and testing, together with the criteria necessary to allow for the repair of any defects.

6.4 Rectification

6.4.1 General

Unacceptable volumetric or surface defects may be repaired by removing the defects and rewelding. All repair welds shall be examined 100 % visually and radiographically to the original acceptance standards.

6.4.2 Manually welded seams

When repairs to welds are carried out as a result of radiographic examination which is less than 100 %, an additional radiographic film (200 mm) shall be taken either side of the repair to ensure the defect was isolated and not systematic. Where the defects are systematic and characterised by frequent occurrence of the same defect, the extent of examination shall be increased to 100 % until the cause of the defects has been found and eliminated.

6.4.3 Seams produced using automatic welding processes

If any unacceptable defects are found by radiographic examination, all main weld seams shall be 100 % radiographically examined on all vessels produced with the same welding machine and welding procedure from the start of the production period or from the last accepted non-destructive test.

6.5 Pressure testing

6.5.1 Every inner vessel shall undergo a pressure test.

The test pressure shall not be less than $1,3(P_s + 1)$ bar.

Where the test is carried out hydraulically the pressure shall be held for long enough to allow all the surfaces and joints to be examined visually. The vessel shall not show any sign of general plastic deformation.

Instead of a hydraulic test, a pneumatic test using a gas may be performed using the same value of test pressure but the visual examination of the joints shall take place at a pressure not more than 80 % of the test pressure.

Pneumatic testing is potentially a much more dangerous operation than hydraulic testing and should normally only be carried out on vessels of such design and construction where it is not practical for them to be filled with liquid, or on vessels for use in processes where the removal of such liquids is either impractical, lengthy or gives rise to other safety considerations.

6.5.2 Vessels which have been repaired subsequent to the pressure test shall be re-subjected to the specified pressure test after completion of the repairs.

6.5.3 In the case of austenitic stainless steel vessels, where water is used, the chloride content of the water shall be controlled to not more than 50 ppm.

6.5.4 Joints in the piping system shall be subjected to a leak test at a pressure not less than the following :

- interspace piping $P_s + 1$ bar ;
- external piping P_s bar.

Annex A **(normative)** **Elastic stress analysis**

A.1 General

This annex provides rules to be followed if an elastic stress analysis is used to evaluate components of a transportable cryogenic vessel for operating conditions. The effects of dynamic loads are to be allowed for by using equivalent static loads as defined in 4.3.8.

A.4 and A.5 give alternative criteria for demonstrating the acceptability of design on the basis of elastic analysis. The criteria in A.5 apply only to local stresses in the vicinity of attachments, supports, nozzles, etc.

The calculated stresses in the area under consideration are grouped into the following stress categories :

- general primary membrane stress ;
- local primary membrane stress ;
- primary bending stress ;
- secondary stress.

Stress intensities f_m , f_L , f_b , and f_g can be determined from the principle stresses f_1 , f_2 and f_3 in each category using the maximum shear stress theory of failure, see A.2.1.

The stress intensities so determined shall be less than the allowable values given in A.3 and A.4 or A.5.

Peak stresses need not be considered as they are only relevant when evaluating designs for cyclic service. Transportable cryogenic vessels within the scope of this standard are not considered to be in cyclic service.

Figure A.1 and table A.1 have been included to guide the designer, where clause A.4 is used for evaluation, in establishing stress categories for some typical cases and stress intensity limits for combinations of stress categories. There will be instances when references to definitions of stresses will be necessary to classify a specific stress condition to a stress category. A.4.5 explains the reason for separating them into two categories "general" and "secondary" in the case of thermal stresses.

A.2 Terminology

A.2.1 Stress intensity

The stress intensity is twice the maximum shear stress, i.e. the difference between the algebraically largest principal stress and the algebraically smallest principal stress at a given point. Tension stresses are considered positive and compression stresses are considered negative.

A.2.2 Gross structural discontinuity

A gross structural discontinuity is a source of stress or strain intensification that affects a relatively large portion of a structure and has a significant effect on the overall stress or strain pattern or on the structure as a whole.

Examples of gross structural discontinuities are :

EXAMPLE 1: end to shell junctions.

EXAMPLE 2: junctions between shells of different diameters or thicknesses.

EXAMPLE 3: nozzles

A.2.3 Local structural discontinuity

A local structural discontinuity is a source of stress or strain intensification that affects a relatively small volume of material and does not have a significant effect on the overall stress or strain pattern or on the structure as a whole.

EXAMPLE 1: small fillet radii.

EXAMPLE 2: small attachments.

EXAMPLE 3: partial penetration welds.

A.2.4 Normal stress

The normal stress is the component of stress normal to the plane of reference; this is also referred to as direct stress.

Usually the distribution of normal stress is not uniform through the thickness of a part, so this stress is considered to be made up in turn of two components one of which is uniformly distributed and equal to the average value of stress across the thickness of the section under consideration, and the other of which varies with the location across the thickness.

A.2.5 Shear stress

The shear stress is the component of stress acting in the plane of reference.

A.2.6 Membrane stress

The membrane stress is the component of stress that is uniformly distributed and equal to the average value of stress across the thickness of the section under consideration.

A.2.7 Primary stress

A primary stress is a stress produced by mechanical loadings only and so distributed in the structure that no redistribution of load occurs as a result of yielding. It is a normal stress, or a shear stress developed by the imposed loading, that is necessary to satisfy the simple laws of equilibrium of external and internal forces and moments. The basic characteristic of this stress is that it is not self-limiting. Primary stresses that considerably exceed the yield strength will result in failure, or at least in gross distortion. A thermal stress is not classified as a primary stress. Primary stress is divided into "general" and "local" categories. The local primary stress is defined in A.2.8.

Examples of general primary stress are :

EXAMPLE 1: The stress in a cylindrical or a spherical shell due to internal pressure or to distributed live loads;

EXAMPLE 2: The bending stress in the central portion of a flat head due to pressure.

A.2.8 Primary local membrane stress

Cases arise in which a membrane stress produced by pressure or other mechanical loading and associated with a primary and/or a discontinuity effect produces excessive distortion in the transfer of load to other portions of the structure.

Conservatism requires that such a stress be classified as a primary local membrane stress even though it has some characteristics of a secondary stress. A stressed region may be considered as local if the distance over which the stress intensity exceeds 110% of the allowable general primary membrane stress does not extend in the meridional direction more than $0,5\sqrt{Rs}$ and if it is not closer in the meridional direction than $2,5\sqrt{Rs}$ to another region where the limits of general primary membrane stress are exceeded.

Where R and s are respectively the radius and thickness of the component.

An example of a primary local stress is the membrane stress in a shell produced by external load and moment at a permanent support or at a nozzle connection.

A.2.9 Secondary stress

A secondary stress is a normal stress or a shear stress developed by the constraint of adjacent parts or by self-constraint of a structure. The basic characteristic of a secondary stress is that it is self-limiting. Local yielding and minor distortions can satisfy the conditions that cause the stress to occur and failure from one application of the stress is not be expected.

An example of secondary stress is the bending stress at a gross structural discontinuity.

A.2.10 Peak stress

The basic characteristic of a peak stress is that it does not cause any noticeable distortion and is objectionable only as a possible source of a fatigue crack. A stress that is not highly localised falls into this category if it is of a type that cannot cause noticeable distortion.

EXAMPLE 1: The surface stresses in the wall of a vessel or pipe produced by thermal shock.

EXAMPLE 2: The stress at a local structural discontinuity.

A.3 Limit for longitudinal compressive general membrane stress

The longitudinal compressive stress is not to exceed $0,93\Delta K$ for carbon steel and $0,73\Delta K$ for austenitic stainless steel and aluminium alloys. Where Δ is obtained from figure A.2 or A.3 in terms of P_e / P_{yss} and where

$$P_e = \frac{1,21Es^2}{R^2}$$

and

$$P_{yss} = \frac{1,86Ks}{R} \quad \text{for carbon steel}$$

and

$$P_{yss} = \frac{1,46Ks}{R} \quad \text{for austenitic stainless steel and aluminium alloys}$$

A.4 Stress categories and stress limits for general application

A.4.1 General

A calculated stress depending upon the type of loading and/or the distribution of such stress will fall within one of the five basic stress categories defined in A.4.2 to A.4.6. For each category, a stress intensity value is derived for a specific condition of design. To satisfy the analysis this stress intensity should fall within the limit detailed for each category.

A.4.2 General primary membrane stress category

The stresses falling within the general primary membrane stress category are those defined as general primary stresses in A.2.7 and are produced by pressure and other mechanical loads, but excluding all secondary and peak stresses. The value of the membrane stress intensity is obtained by averaging these stresses across the thickness of the section under consideration. The limiting value of this stress intensity f_m is the allowable stress value $2K/3$ for the inner vessel and $0,9K$ for the outer jacket.

A.4.3 Local primary membrane stress category

The stresses falling within the local primary membrane stress category are those defined in A.2.8 and are produced by pressure and other mechanical loads, but excluding all thermal and peak stresses. The stress intensity f_L is the average value of these stresses across the thickness of the section under consideration and is limited to K .

A.4.4 General or local primary membrane plus primary bending stress category

The stresses falling within the general or local primary membrane plus primary bending stress category are those defined in A.2.7 but the stress intensity value f_b , $(f_m + f_b)$ or $(f_L + f_b)$ is the highest value of those stresses acting across the section under consideration excluding secondary and peak stresses. f_b is the primary bending stress intensity, which means the component of primary stress proportional to the distance from centroid of solid section. The stress intensity f_b , $(f_m + f_b)$ or $(f_L + f_b)$ is not to exceed K .

A.4.5 Primary plus secondary stress category

The stresses falling within the primary plus secondary stress category are those defined in A.2.7 plus those of A.2.9 produced by pressure, other mechanical loads and general thermal effects. The effects of gross structural discontinuities, but not of local structural discontinuities (stress concentrations), should be included. The stress intensity value $(f_m + f_b + f_g)$ or $(f_L + f_b + f_g)$ is the highest value of these stresses acting across the section under consideration and is to be limited to $2K$.

A.4.6 Thermal stress

Thermal stress is a self-balancing stress produced by a non-uniform distribution of temperature or by differing thermal coefficients of expansion. Thermal stress is developed in a solid body whenever a volume of material is prevented from assuming the size and shape that it normally should under a change in temperature.

For the purpose of establishing allowable stresses, the following two types of thermal stress are recognised, depending on the volume or area in which distortion takes place :

- a) General thermal stress is associated with distortion of the structure in which it occurs. If a stress of this type neglecting stress concentrations, exceeds $2K$ the elastic analysis may be invalid and successive thermal cycles may produce incremental distortion. This type is therefore classified as secondary stress in table A.1 and figure A.1.

Examples of general thermal stress are:

EXAMPLE 1 : The stress produced by an axial thermal gradient in a cylindrical shell.

EXAMPLE 2 : The stress produced by the temperature difference between a nozzle and the shell to which it is attached.

- b) Local thermal stress is associated with almost complete suppression of the differential expansion and thus produces no significant distortion. Such stresses are only considered from the fatigue standpoint.

EXAMPLE : A small cold spot in a vessel wall.

A.5 Specific criteria, stress categories and stress limits for limited application

A.5.1 General

The criteria and stress limits for particular stress categories are specified in A.5.2. to A.5.4. for elastically calculated stresses adjacent to attachments and supports and to nozzles and openings which are subject to the combined effects of pressure and externally applied loads.

The minimum separation between adjacent loaded attachments, pads, nozzles or openings or other stress concentrating features shall not be less than $2,5\sqrt{Rs}$.

R and s are respectively the radius and thickness of the component. The criteria of A.2.8 are not applicable to this section.

If design acceptability is demonstrated by A.5 then the use of A.4 is not required.

A.5.2 Attachments and supports

The dimension in the circumferential direction of the loaded area must not exceed one third of the shell circumference. The stresses adjacent to the loaded area due to pressure acting in the shell may be taken as the shell pressure stresses without any concentrating effects due to the attachment.

Under the design combined load the following stress limits apply :

- the primary membrane stress intensity shall not exceed $0,8 K$ for the inner vessel and $0,9K$ for the outer jacket ;
- the stress intensity due to the sum of primary membrane and primary bending stresses shall not exceed $4K/3$;
- the stress intensity due to the sum of primary membrane stresses, primary bending stresses and thermal stresses shall not exceed $2K$.

A.5.3 Nozzles and openings

The nozzle or opening shall be reinforced in accordance with 4.3.7.7.

Under the design combined load the following stress limits apply :

- the primary membrane stress intensity shall not exceed $0,8K$;
- the stress intensity due to the sum of primary membrane stresses and primary bending stresses shall not exceed $1,5K$;
- the stress intensity due to the sum of primary membrane stresses, primary bending stresses and thermal stresses shall not exceed $2K$.

A.5.4 Additional stress limits

Where significant compressive membrane stresses are present the possibility of buckling should be investigated and the design modified if necessary (see A.3). In cases where the external load is highly concentrated, an acceptable procedure is to limit the sum of membrane and bending stresses (total compressive stress) in any direction at the point to $0.9K$.

Where shear stress is present alone, it should not exceed $\frac{K}{3}$. The maximum permissible bearing stresses shall not exceed K .

Table A.1 — Classification of stresses for some typical cases

Vessel component	Location	Origin of stress	Type of stress	Classification	
Cylindrical or Spherical shell	Shell plate remote from discontinuities	Internal pressure	General membrane Gradient through plate thickness	f_m f_g	
		Axial thermal gradient	Membrane Bending	f_g f_g	
	Junction with head or flange	Internal pressure	Membrane Bending	f_L f_g	
		Any shell or end	Any section across entire vessel	External load or moment, or internal pressure	General membrane average across full section. Stress component perpendicular to cross section
		External load or moment	Bending across full section. Stress component perpendicular to cross section	f_m	
		Near nozzle or other opening	External load or moment, or internal pressure	Local membrane Bending	f_L f_g
		Any location	Temperature difference between shell and end	Membrane Bending	f_g f_g
		Dished end or Conical end	Crown	Internal pressure	Membrane Bending
Knuckle or junction to shell	Internal pressure		Membrane Bending	f_L f_g	
Flat end	Centre region	Internal pressure	Membrane Bending	f_m f_b	
	Junction to shell	Internal pressure	Membrane Bending	f_L f_g	
Perforated end or shell	Typical ligament in a uniform pattern	Pressure	Membrane (average through cross section) Bending (average through width of ligament, but gradient through plate)	f_m f_b	
	Isolated or atypical ligament	Pressure	Membrane Bending	f_m f_b	
Nozzle	Cross section perpendicular to nozzle axis	Internal pressure or external load of moment	General membrane (average across full section). Stress component perpendicular to section	f_m	
		External load or moment	Bending across nozzle section	f_m	
	Nozzle wall	Internal pressure	General membrane Local membrane Bending	f_m f_L f_g	
		Differential expansion	Membrane Bending	f_g f_g	
* Consideration should also be given to the possibility of buckling and excessive deformation in vessels with large diameter-to-thickness ratio					

Stress category	Primary	Local	Bending	Secondary
Description (for examples see table A.1)	General	Average stress across any solid section. Considers discontinuities but not concentrations. Produced only by mechanical loads	Component of primary stress proportional to distance from centroid of solid section. Excluded discontinuities and concentrations. Produced only by mechanical loads	Self-equilibrating stress necessary to satisfy continuity of structure. Occurs at structural discontinuities. Can be caused by mechanical load or differential thermal expansion. Excludes local stress concentrations.
Symbol (see note 2)	f_m	f_L	f_b	f_g
Combination of stress components and allowable limits of stress intensities	The diagram illustrates the combination of four stress components: f_m (General), f_L (Local), f_b (Bending), and f_g (Secondary). f_m is processed through two paths: one multiplied by $2K/3$ for the inner vessel and $0.9K$ for the outer jacket, and another multiplied by K. f_L is multiplied by K. f_b and f_g are each multiplied by K. The final result is the sum of these components, either $f_L + f_b + f_g$ or $f_m + f_b + f_g$.			

NOTE 1 The stresses in category f_g are those parts of the total stress which are produced by thermal gradients, structural discontinuities, etc..., and do not include primary stresses which may also exist at the same point. It should be noted, however, that a detailed stress analysis frequently gives the combination of primary and secondary stresses directly and, when appropriate, this calculated value represents the total of f_m (or f_L) + f_b + f_g and not f_g alone.

NOTE 2 The symbols f_m , f_L , f_b and f_g do not represent single quantities but rather sets of six quantities representing the six stress components.

Figure A.1 — Stress categories and limits of stress intensity

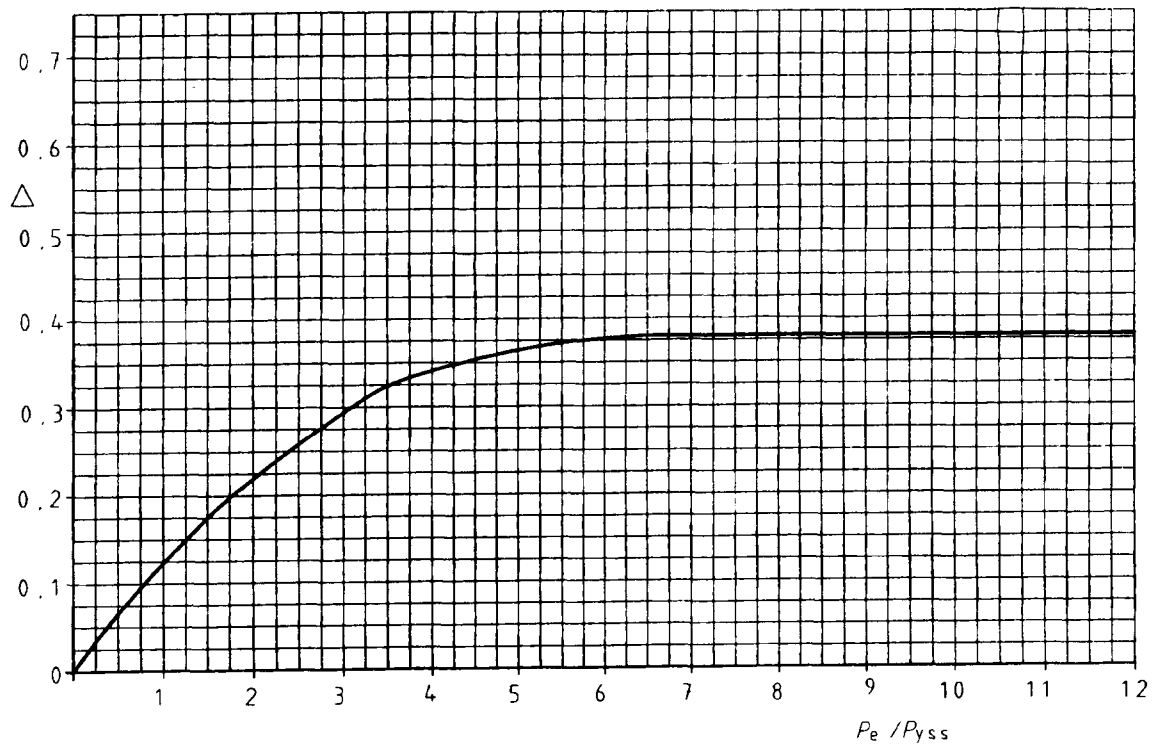


Figure A.2 — For vessels subject to external pressure

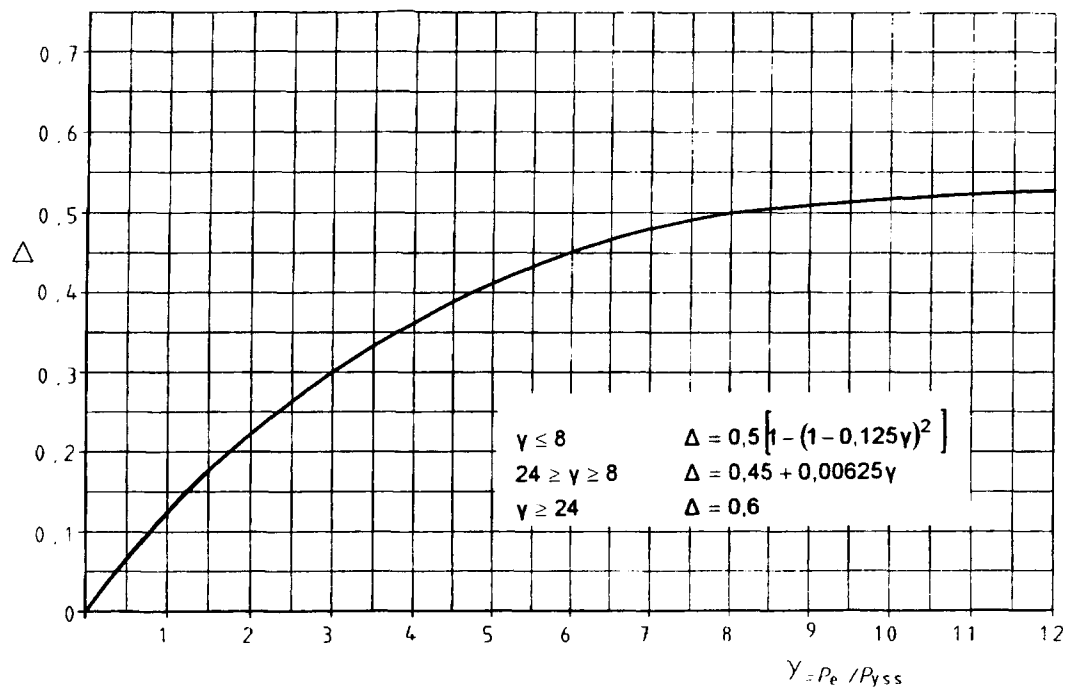


Figure A.3 — For vessels not subject to external pressure

Annex B **(informative)** **Recommended weld details**

B.1 Scope

Although the scope of EN 1708-1 does not specifically consider the application of weld details to cryogenic vessels, the manufacturer may consult it for guidance. The following specific weld details are currently in common usage in cryogenic vessels and are appropriate to this service.

B.2 Weld detail

In general the welds are to be adequate to carry the expected loads and need not be designed on the basis of joint wall thickness.

B.2.1 Joggle joint, see figure B.1.

This joint may be used for cylinder to cylinder and end to cylinder (excluding cone to cylinder) connections provided that :

- a) when the flanged section of a dished end is joggled, the joggle shall be sufficiently clear of the knuckle radius to ensure that the edge of the circumferential seam is at least 12mm clear of the knuckle; refer to 4.3.7.4.2 for dimensions ;
- b) when a cylinder with a longitudinal seam is joggled :
 - 1) the welds are ground flush internally and externally for a distance of approximately 50 mm prior to joggling with no reduction of plate thickness below the required minimum ; and
 - 2) on completion of joggling the area of the weld is subjected to dye penetrant examination and is proven to be free of cracks ;
- c) the offset section which forms the weld backing is a close fit within its mating section at the weld round the entire circumference ;
- d) the profile of the offset is a smooth radius without sharp corners ;
- e) on completion of welding the weld shall fill the groove smoothly to the full thickness of the plate edges being joined ;
- f) the junction of the longitudinal and circumferential seams are examined radiographically and found to be free from significant defects.

B.2.2 Backing strip, see figure B.3

May be used only for circumferential seams in cylinders, ends, nozzles and interspace pipes, when the second side is inaccessible for welding and provided that non-destructive testing can be satisfactorily carried out where applicable.

B.2.3 End plate closure, see figure B.4 for two examples of the many ways of welding flat plates. See also figure 12, main text.

B.2.4 Non full penetration nozzle weld, see figure B.5

May be used to attach set in nozzles to ends and cylinders provided that the strength of the attachment welds can be demonstrated to be sufficient to contain the design nozzle loadings.

B.2.5 Non continuous fillet weld on attachments

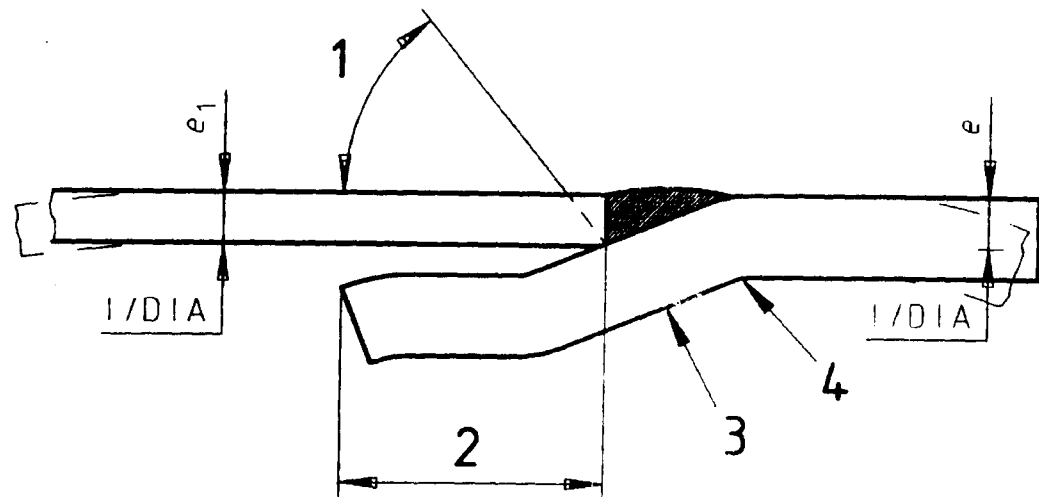
May be used for all attachments to main pressure components provided that the following criteria are met :

- strength is adequate for design loadings ;
- crevices between attached component and main pressure envelope can be demonstrated not to conflict with B.3.

B.3 Oxygen service requirements

The need for gas/material compatibility and cleanliness of equipment in liquid oxygen and other oxidising liquid service are described in EN 1797-1 and EN 12300.

The internal weld details shall be such that debris, contaminants, hydrocarbons or degreasants can not accumulate so as to cause a fire risk in future operation.

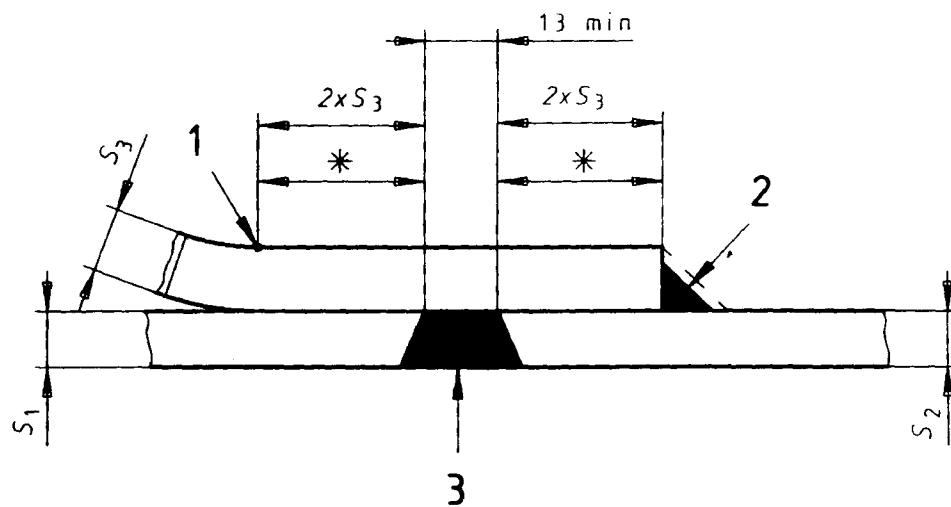


KEY :

- 1 Bevel optional
- 2 As desired
- 3 Depth of offset = e_1
- 4 Avoid sharp break

Figure B.1 — Joggle joint

Dimension in mm

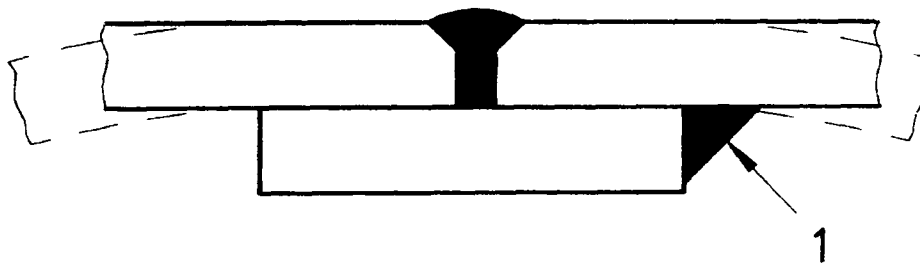


Key :

- 1 Tangent point
- 2 Continuous fillet
- 3 Butt weld
- s1 cylinder thickness
- s2 cylinder thickness
- s3 end thickness
- * need not exceed 25 mm

NOTE Cylinder thickness s1 and s2 may vary

Figure B.2 — Intermediate end



Key :

1 Intermittent or continuous fillet

Figure B.3 — Backing strip

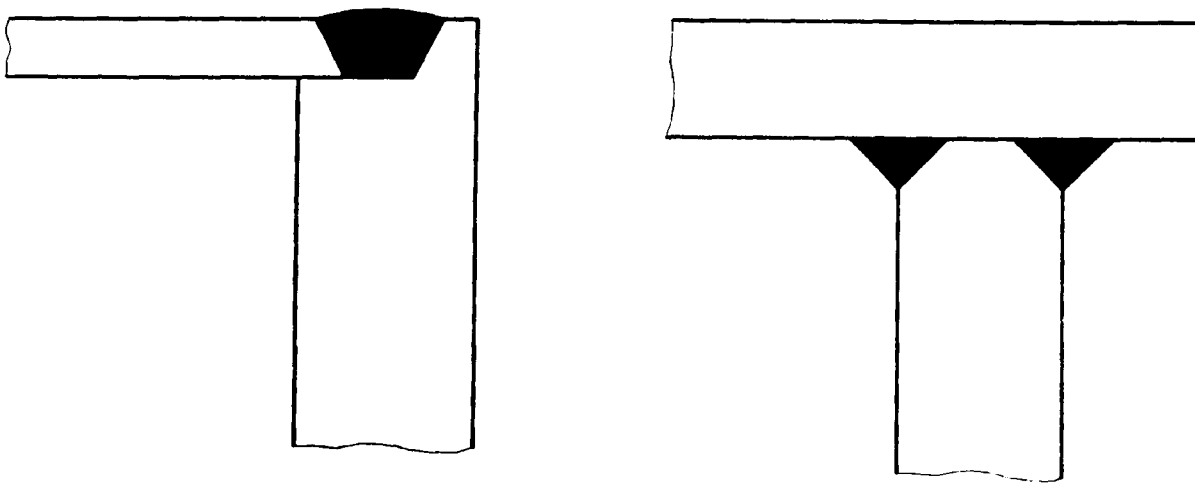


Figure B.4 — Examples of end plate closures

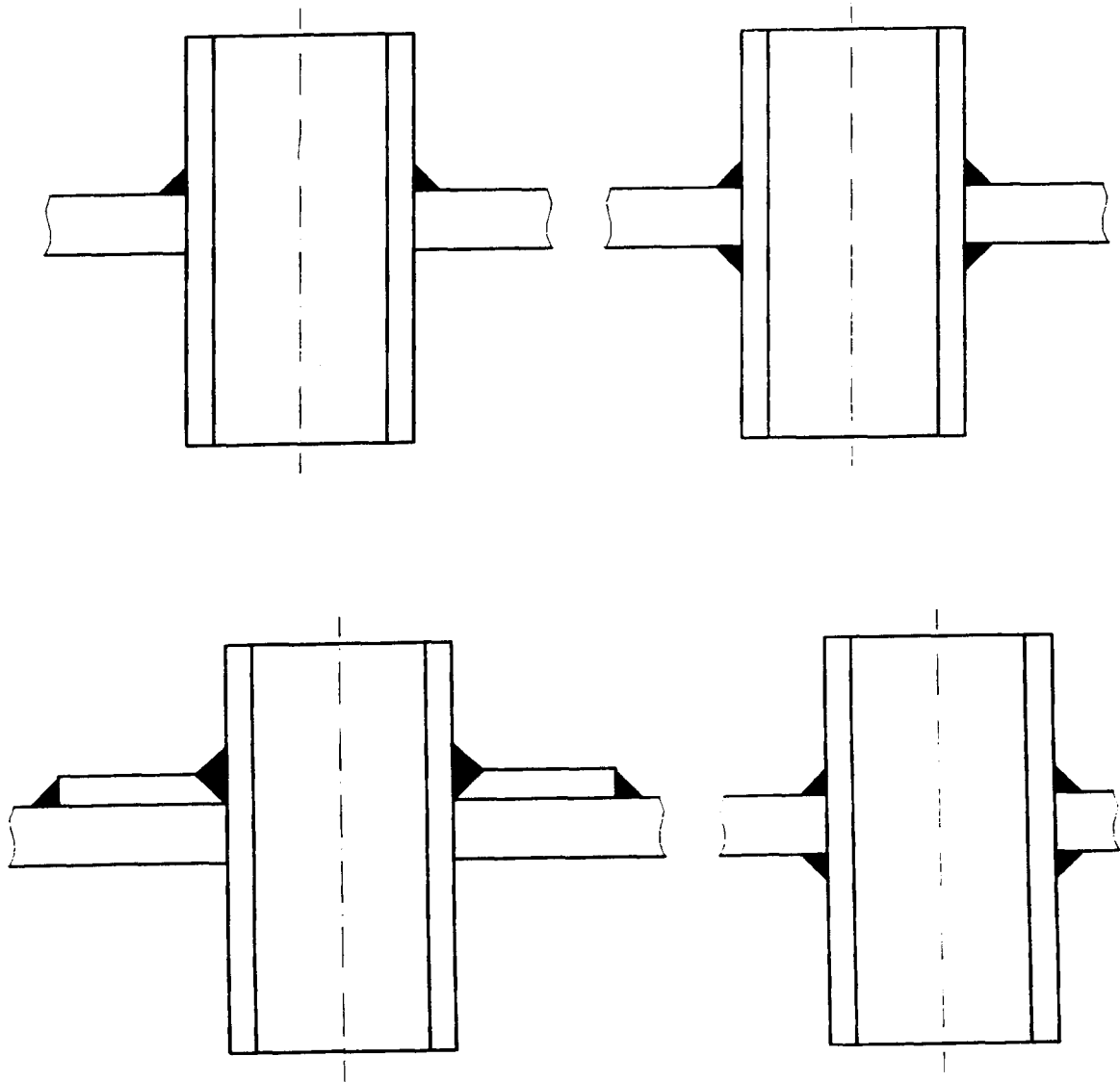


Figure B.5 — Non full penetration nozzle welds

Annex C **(normative)** **Additional requirements for flammable fluids**

C.1 In addition to the requirement of clauses 1 to 6 transportable vacuum insulated vessels designed for use with the gases listed in the item group 3°F of table 1 of EN 1251-1 shall comply with the following additional items.

C.2 Means shall be provided to ensure that the vessel is not filled to more than 95% of its total volume, with liquid boiling at the opening pressure of the relief device.

C.3 Means shall be provided to allow all vent pipes including pressure relief devices and purge valves to be connected, during operation, to a venting system that discharges the contents safely.

C.4 In sizing pressure relief devices, the designer shall take account of the back pressures developed by flame arrestors and venting systems.

C.5 All materials used shall be compatible with the specific cryogenic flammable fluid under consideration.

C.6 All valves and equipment shall be suitable for use with the specific cryogenic flammable fluid under consideration.

C.7 The selection and use of materials and jointing procedures shall be carefully considered in the design to avoid secondary failure in the event of external fire.

C.8 All metallic components of the vessel shall be electrically continuous. The vessel shall be provided with the means of attachment to earthing devices so that the resistance to earth is less than 10 ohms.

C.9 In the particular case of liquid hydrogen the possibility of air condensing (with possible oxygen enrichment) on uninsulated cold parts shall be considered. See also EN 1797-1.

C.10 The liquid fill line secondary isolation valve shall be either a non-return valve or fail-closed automatic shut-off valve.

C.11 Each line opening to atmosphere, other than safety valves and purge lines, shall be provided with two closing devices. The first shall be close to the vessel and capable of being readily accessible in emergency. The second shall be a non return valve or cap place on the atmosphere side of the main isolation valve.

C.12 Vessels shall be equipped with safety devices against overfilling (level limiter).

Because of the risk of fire and explosion consideration shall be given in the design of the vessel to the provision of :

- a) upward venting ;
- b) leak-tight piping and equipment (for valves see EN 1626) ;
- c) arrangements allowing the vessel (initially) and the loading/filling pipework system to be purged with a non-flammable/non-oxidising gas.

Annex D **(normative)** **Outer jacket relief devices**

D.1 Scope

This annex covers the requirements for design, manufacture and testing of pressure protection devices required on outer jackets of vacuum insulated cryogenic vessels in order to reduce any accidental accumulation of pressure.

D.2 Definitions

For the purpose of this annex, the following definitions apply :

D.2.1

relief plate/plug

a plate or plug retained by atmospheric pressure only which allows relief of excess internal pressure

D.2.2

bursting disc device

a non-reclosing pressure relief device ruptured by differential pressure. It is the complete assembly of installed components including where appropriate the bursting disc holder

D.3 Requirements

D.3.1 General

The device shall be either a relief plate/plug or a bursting disc.

Bursting disc devices shall be in accordance with prEN ISO 4126-2.

D.3.2 Design

The pressure protection device shall be capable of withstanding full vacuum and all demands of normal vessel operation including its own mass acceleration during transportation.

The set pressure and the open relieving area are specified in 4.2.6.3. Consideration shall be given to prevention of blocking of the device by insulation materials during operation.

The plate or plug of a relief plate/plug type device shall be designed and installed such that it cannot harm personnel when ejected.

D.3.3 Materials

The pressure protection devices shall be resistant to normal atmospheric corrosion. The materials of construction shall be suitable for the range of ambient temperatures expected in service.

D.3.4 Testing

Relief plate/plug type relieving devices shall not require testing other than a prototype test to verify the set pressure.

Burst disc assemblies shall be tested in accordance with prEN ISO 4126-2.

D.3.5 Inspection

Relief plate/plug type devices shall be subjected to an inspection programme that ensures compliance with the drawings or specification.

Bursting discs shall be inspected in accordance with prEN ISO 4126-2.

D.3.6 Marking

Bursting discs shall be marked in accordance with prEN ISO 4126-2.

Other pressure protection devices shall be marked with this EN number.

Bibliography

BS 5500:1997 "Specification for unfired fusion welded pressure vessels"

CODAP 1995 "French code for the construction of pressure vessels"

AD - Merkblätter