भारतीय मानक

Indian Standard

IS/ISO 21029-1 : 2018

क्रायोजेनिक वेस्सेल — 1 000 लीटर से कम आयतन वाले वॅक्क्यूम इन्सुलेटेड परिवहनीय वेस्सेल

भाग 1 रचना, संरचना, निरीक्षण और परीक्षण

Cryogenic Vessels — Transportable Vacuum Insulated Vessels of Not More than 1 000 Litres Volume

Part 1 Design, Fabrication, Inspection and Tests

ICS 23.020.40

भारतीय मानक ब्यूरो
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NATIONAL FOREWORD

This Indian Standard (Part 1) which is identical to ISO 21029-1 : 2018 'Cryogenic vessels — Transportable vacuum insulated vessels of not more than 1 000 litres volume — Part 1: Design, fabrication, inspection and tests' issued by the International Organization for Standardization (ISO) was adopted by the Bureau of Indian Standards on recommendation of the Gas Cylinders Sectional Committee and approval of the Mechanical Engineering Division Council.

This standard is published in two parts. Other part of this series is:

Part 2 Operational requirements

The text of ISO standard has been approved as suitable for publication as an Indian Standard without deviations. Certain terminologies and conventions are, however, not identical to those used in Indian Standard. Attention is particularly drawn to the following:

a) Wherever the words 'International Standard' appear, referring to this standard, they should be read as 'Indian Standard'; and
b) Comma (,) has been used as a decimal marker, while in Indian Standards, the current practice is to use a point (.) as the decimal marker.

In this adopted standard, reference appears to certain International Standard for which Indian Standard also exist. The corresponding Indian Standard, which are to be substituted in their respective places, are listed below along with their degree of equivalence for the editions indicated:

International Standard	*Corresponding Indian Standard*	*Degree of Equivalence*
ISO 148-1 Metallic materials — Charpy pendulum impact test — Part 1: Test method	IS 1757 (Part 1) : 2020/ISO 148-1 : 2016 Metallic materials — Charpy pendulum impact test: Part 1 Test method (*fourth revision*)	Identical
ISO 3834-2 Quality requirements for fusion welding of metallic materials — Part 2: Comprehensive quality requirements	IS 15326 (Part 2) : 2022/ ISO 3834-2 : 2021 Quality requirements for fusion welding of metallic materials: Part 2 Comprehensive quality requirements (*second revision*)	Identical
ISO 4136 Destructive tests on welds in metallic materials — Transverse tensile test	IS 3600 (Part 3) : 2018/ISO 4136 : 2012 Method of testing fusion welded joints and weld metal in steel Part 3 Destructive tests on welds in metallic materials — Transverse tensile test (*fourth revision*)	Identical
ISO 5173 Destructive tests on welds in metallic materials — Bend tests	IS 3600 (Part 5) : 2018/ISO 5173 : 2009 Method of testing fusion welded joints and weld metal in steel: Part 5 Destructive tests on welds in metallic materials — Bend tests (*third revision*)	Identical
ISO 10474 : 2013 Steel and steel products — Inspection documents	IS/ISO 10474 : 2013 Steel and steel products — Inspection documents (*first revision*)	Identical

International Standard	*Corresponding Indian Standard*	*Degree of Equivalence*
ISO 15607 Specification and qualification of welding procedures for metallic materials — General rules	IS 16003 : 2022/ISO 15607 : 2019 Specification and qualification of welding procedures for metallic materials — General rules (*first revision*)	Identical
ISO 21011 Cryogenic vessels — Valves for cryogenic service	IS 18608 : 2024 Cryogenic vessels — Valves for cryogenic service	Not identical
ISO 21029-2 Cryogenic vessels — Transportable vacuum insulated vessels of not more than 1 000 litres volume — Part 2: Operational requirements	IS 18719 : 2024 Cryogenic vessels — Transportable vacuum insulated vessels of not more than 1 000 litres — Operational requirements	Not identical

The Committee has reviewed the provisions of the following International Standard referred in this adopted standard and has decided that it is acceptable for use in conjunction with this standard:

International Standard	*Title*
ISO 2244	Packaging — Complete, filled transport packages and unit loads — Horizontal impact tests
ISO 4126-1	Safety devices for protection against excessive pressure — Part 1: Safety valves
ISO 4126-2	Safety devices for protection against excessive pressure — Part 2: Bursting disc safety devices
ISO 5817	Welding — Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) — Quality levels for imperfections
ISO 9606-1	Qualification testing of welders — Fusion welding — Part 1: Steels
ISO 9606-2	Qualification test of welders — Fusion welding — Part 2: Aluminium and aluminium alloys
ISO 9712	Non-destructive testing — Qualification and certification of NDT personnel
ISO 10042	Welding — Arc-welded joints in aluminium and its alloys — Quality levels for imperfections
ISO 10675-1	Non-destructive testing of welds — Acceptance levels for radiographic testing — Part 1: Steel, nickel, titanium and their alloys
ISO 10675-2	Non-destructive testing of welds — Acceptance levels for radiographic testing — Part 2: Aluminium and its alloys
ISO 14732	Welding personnel — Qualification testing of welding operators and weld setters for mechanized and automatic welding of metallic materials
ISO 15613	Specification and qualification of welding procedures for metallic materials — Qualification based on pre-production welding test
ISO 15614-1	Specification and qualification of welding procedures for metallic materials — Welding procedure test — Part 1: Arc and gas welding of steels and arc welding of nickel and nickel alloys
ISO 15614-2	Specification and qualification of welding procedures for metallic materials — Welding procedure test — Part 2: Arc welding of aluminium and its alloys
ISO 17635	Non-destructive testing of welds — General rules for metallic materials
ISO 17636-1	Non-destructive testing of welds —Radiographic testing — Part 1: X- and gamma-ray techniques with film

International Standard	*Title*
ISO 17636-2	Non-destructive testing of welds — Radiographic testing — Part 2: X- and gamma-ray techniques with digital detectors
ISO 17637	Non-destructive testing of welds — Visual testing of fusion-welded joints
ISO 21013-1	Cryogenic vessels — Pressure-relief accessories for cryogenic service — Part 1: Reclosable pressure-relief valves
ISO 21013-2	Cryogenic vessels — Pressure-relief accessories for cryogenic service — Part 2: Non-reclosable pressure-relief devices
ISO 21013-3	Cryogenic vessels — Pressure-relief accessories for cryogenic service — Part 3: Sizing and capacity determination
ISO 21014	Cryogenic vessels — Cryogenic insulation performance
ISO 21028-1	Cryogenic vessels — Toughness requirements for materials at cryogenic temperature — Part 1: Temperatures below − 80 °C
ISO 21028-2	Cryogenic vessels —Toughness requirements for materials at cryogenic temperature — Part 2: Temperatures between − 80 °C and − 20 °C
ISO 23208	Cryogenic vessels — Cleanliness for cryogenic service

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 2022 ‘Rules for rounding off numerical values (*second revision*)’. The number of significant places retained in the rounded-off value should be the same as that of the specified value in this standard.

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CRYOGENIC VESSELS — TRANSPORTABLE VACUUM INSULATED VESSELS OF NOT MORE THAN 1 000 LITRES VOLUME

PART 1 DESIGN, FABRICATION, INSPECTION AND TESTS

1 Scope

This document specifies requirements for the design, fabrication, type test and initial inspection and test of transportable vacuum-insulated cryogenic pressure vessels of not more than 1 000 l volume. This document applies to transportable vacuum-insulated cryogenic vessels for fluids as specified in 3.1 and Table 1 and does not apply to such vessels designed for toxic fluids.

NOTE 1 This document does not cover specific requirements for refillable liquid hydrogen and LNG tanks that are primarily dedicated as fuel tanks in vehicles. For fuel tanks used in land and marine vehicles, see ISO 13985.

NOTE 2 Specific requirements for open top dewards are not covered by this document.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 148-1, *Metallic materials — Charpy pendulum impact test — Part 1: Test method*

ISO 2244, *Packaging — Complete, filled transport packages and unit loads — Horizontal impact tests*

ISO 3834-2, *Quality requirements for fusion welding of metallic materials — Part 2: Comprehensive quality requirements*

ISO 4126-1, *Safety devices for protection against excessive pressure — Part 1: Safety valves*

ISO 4126-2, *Safety devices for protection against excessive pressure — Part 2: Bursting disc safety devices*

ISO 4136, *Destructive tests on welds in metallic materials — Transverse tensile test*

ISO 5173, *Destructive tests on welds in metallic materials — Bend tests*

ISO 5817, *Welding — Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) — Quality levels for imperfections*

ISO 9606-1, *Qualification testing of welders — Fusion welding — Part 1: Steels*

ISO 9606-2, *Qualification test of welders — Fusion welding — Part 2: Aluminium and aluminium alloys*

ISO 9712, *Non-destructive testing — Qualification and certification of NDT personnel*

ISO 10474:2013, *Steel and steel products — Inspection documents*

ISO 10042, *Welding — Arc-welded joints in aluminium and its alloys — Quality levels for imperfections*

ISO 10675-1, *Non-destructive testing of welds — Acceptance levels for radiographic testing — Part 1: Steel, nickel, titanium and their alloys*

ISO 10675-2, *Non-destructive testing of welds — Acceptance levels for radiographic testing — Part 2: Aluminium and its alloys*

ISO 14732, *Welding personnel — Qualification testing of welding operators and weld setters for mechanized and automatic welding of metallic materials*

ISO 15607, *Specification and qualification of welding procedures for metallic materials — General rules*

ISO 15613, *Specification and qualification of welding procedures for metallic materials — Qualification based on pre-production welding test*

ISO 15614-1, *Specification and qualification of welding procedures for metallic materials — Welding procedure test — Part 1: Arc and gas welding of steels and arc welding of nickel and nickel alloys*

ISO 15614-2, *Specification and qualification of welding procedures for metallic materials — Welding procedure test — Part 2: Arc welding of aluminium and its alloys*

ISO 17635:2016, *Non-destructive testing of welds — General rules for metallic materials*

ISO 17636-1, *Non-destructive testing of welds — Radiographic testing — Part 1: X- and gamma-ray techniques with film*

ISO 17636-2, *Non-destructive testing of welds — Radiographic testing — Part 2: X- and gamma-ray techniques with digital detectors*

ISO 17637, *Non-destructive testing of welds — Visual testing of fusion-welded joints*

ISO 21011, *Cryogenic vessels — Valves for cryogenic service*

ISO 21013-1, *Cryogenic vessels — Pressure-relief accessories for cryogenic service — Part 1: Reclosable pressure-relief valves*

ISO 21013-2, *Cryogenic vessels — Pressure-relief accessories for cryogenic service — Part 2: Non-reclosable pressure-relief devices*

ISO 21013-3, *Cryogenic vessels — Pressure-relief accessories for cryogenic service — Part 3: Sizing and capacity determination*

ISO 21014, *Cryogenic vessels — Cryogenic insulation performance*

ISO 21028-1, *Cryogenic vessels — Toughness requirements for materials at cryogenic temperature — Part 1: Temperatures below -80 °C*

ISO 21028-2, *Cryogenic vessels —Toughness requirements for materials at cryogenic temperature — Part 2: Temperatures between −80 °C and −20 °C*

ISO 21029-2, *Cryogenic vessels — Transportable vacuum insulated vessels of not more than 1 000 litres volume — Part 2: Operational requirements*

ISO 23208, *Cryogenic vessels — Cleanliness for cryogenic service*

3 Terms and definitions

For the purposes of this document the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at https://www.iso.org/obp

3.1
cryogenic fluid
refrigerated liquefied gas
gas which is partially liquid because of its low temperature

Note 1 to entry: In the context of this document the (refrigerated but) non-toxic gases given in Table 1 and mixtures of them are referred to as cryogenic fluids.

Note 2 to entry: This includes totally evaporated liquids and supercritical fluids.

Table 1 — Refrigerated but non-toxic gases

UN No.[a]	Proper shipping name and description[a]
Asphyxiant gases	
1913	neon, refrigerated liquid
1951	argon, refrigerated liquid
1963	helium, refrigerated liquid
1970	krypton, refrigerated liquid
1977	nitrogen, refrigerated liquid
2187	carbon dioxide, refrigerated liquid
2591	xenon, refrigerated liquid
3136	trifluoromethane, refrigerated liquid
3158	gas, refrigerated liquid, N.O.S[b]
Oxidizing gases	
1003	air, refrigerated liquid
1073	oxygen, refrigerated liquid
2201	nitrous oxide, refrigerated liquid
3311	gas, refrigerated liquid, oxidizing, N.O.S[b]
Flammable gases	
1038	ethylene, refrigerated liquid
1961	ethane, refrigerated liquid
1966	hydrogen, refrigerated liquid
1972	methane, refrigerated liquid or natural gas, refrigerated liquid, with high methane content
3138	ethylene, acetylene and propylene mixture, refrigerated liquid, containing at least 71,5 % ethylene with not more than 22,5 % acetylene and not more than 6 % propylene
3312	gas, refrigerated liquid, flammable, N.O.S[b]

[a] U.N. No. and proper shipping name according to UN Recommendations.

[b] N.O.S. = not otherwise specified.

3.2
transportable cryogenic vessel
thermally insulated vessel comprising a complete assembly ready for service, consisting of an inner vessel, an outer jacket, all of the valves and equipment together with any additional framework, intended for the transport of one or more cryogenic fluids

3.3
thermal insulation
vacuum interspace between the inner vessel and the outer jacket

Note 1 to entry: The space may or may not be filled with material to reduce the heat transfer between the inner vessel and the outer jacket.

3.4
inner vessel
vessel intended to contain the cryogenic fluid

3.5
outer jacket
gas-tight enclosure that contains the inner vessel and enables the vacuum to be established

3.6
normal operation
intended operation of the vessel at maximum permissible pressure including the handling loads defined in 3.7

3.7
handling loads
loads exerted on the transportable cryogenic vessel in all normal conditions of transport including loading, unloading, moving by hand or by fork-lift truck

3.8
piping system
all pipes and piping components which can come in contact with cryogenic fluids including valves, fittings, pressure relief devices and their supports

3.9
equipment
devices that have a safety-related function with respect to pressure containment and/or control (e.g. protective or limiting devices, regulating and monitoring devices, valves, indicators)

3.10
manufacturer of the transportable cryogenic vessel
company that carries out the final assembly of the transportable cryogenic vessel

3.11
gross volume of the inner vessel
volume of the inner vessel, excluding nozzles, pipes etc. determined at minimum design temperature and atmospheric pressure

3.12
tare mass
mass of the empty transportable cryogenic vessel

3.13
net mass
maximum permissible mass of the cryogenic fluid which may be filled

Note 1 to entry: The maximum permissible mass is equal to the mass of the cryogenic fluid occupying 98 % of the net volume of the inner vessel under conditions of incipient opening of the relief device with the vessel in a level attitude and the mass of the gas at the same conditions in the remaining volume of the inner vessel.

Note 2 to entry: Cryogenic liquid helium can occupy 100 % of the volume of the inner vessel at any pressure.

3.14
gross mass
sum of tare mass plus net mass

3.15
pressure
pressure relative to atmospheric pressure, i.e. gauge pressure

3.16
automatic welding
welding in which all operations are performed without welding operator intervention during the process

Note 1 to entry: Manual adjustment of welding variables by the welding operator during welding is not possible.

[SOURCE: ISO 14732:2013, 3.1]

3.17
maximum allowable working pressure
MAWP
p_s
maximum effective gauge pressure permissible at the top of the vessel in its normal operating position including the highest effective pressure during filling and discharge

Note 1 to entry: Adapted from UN Model Regulations, Rev.19, Vol. II, 6.2.1.3.6.5.

3.18
net volume of the inner vessel
volume of the shell, below the inlet to the relief devices, excluding nozzles, pipes, etc. determined at minimum design temperature and atmospheric pressure

3.19
type approval
vessel type, which was successfully subjected to the design calculation and/or the experimental type test, as issued by the responsible authority or its delegate

Note 1 to entry: Vessel type is as defined by 10.2.2.

Note 2 to entry: If it can be proven that the calculation and the experimental tests also cover variants of the prototype these variants may be included in the type approval. If the type includes variants it might also be called "family".

3.20
relief plate/plug
plate or plug retained by atmospheric pressure but which allows relief of excess internal pressure

3.21
bursting disc device
non-reclosing pressure relief device ruptured by differential pressure

Note 1 to entry: It is the complete assembly of installed components including, where appropriate, the bursting disc holder.

4 Symbols

Symbol	Designation	Unit
A	cross sectional area of reinforcing element	mm^2
C, β	design factors	1
c	allowance for corrosion	mm
D	shell diameter	mm
D_a	external diameter e.g. of a cylindrical shell	mm
D_i	internal diameter e.g. of a cylindrical shell	mm
d_a	external diameter of tube or nozzle	mm
d_i	diameter of opening	mm
E	Young's modulus	N/mm^2
f	narrow side of rectangular or elliptical plate	mm

Symbol	Designation	Unit
I	moment of inertia of reinforcing element	mm^4
K	material property used for design	N/mm^2
K_T (e.g. K20 for material property at 20 °C)	material property at temperature T expressed in °C	N/mm^2
l_b, l'_b	buckling length	mm
n	number of lobes	1
p	design pressure as defined in 10.2.3.1.1	bar (MPa)
p_e	permissible external pressure limited by elastic buckling	bar (MPa)
p_k	strengthening pressure	bar (MPa)
p_p	permissible external pressure limited by plastic deformation	bar (MPa)
p_s	maximum permissible pressure	bar (MPa)
p_t	test pressure (see 10.2.3.1.2)	bar (MPa)
R	radius of curvature e.g. inside crown radius of dished end	mm
R_e (1 % proof stress for austenitic steel)	minimum guaranteed yield stress or 0,2 % proof stress	N/mm^2
R_m	minimum guaranteed tensile strength (actual or guaranteed)	N/mm^2
r	radius, e.g. inside knuckle radius of dished end and cones	mm
S	safety factor at design pressure, with respect to R_e	1
S_k	safety factor against elastic buckling at design pressure	1
S_p	safety factor against plastic deformation	1
s	minimum thickness	mm
s_e	actual wall thickness	mm
u	out of roundness (see 11.5.4.2)	1
v	factor indicative of the utilization of the permissible design stress in joints or factor allowing for weakenings	1
χ_i	(decay-length zone) distance over which governing stress is assumed to act	mm
Z	auxiliary value	1
ν	Poisson's ratio	1

5 General requirements

5.1 Applicable regulations may require conformity assessment.

5.2 The transportable cryogenic vessel shall safely withstand the mechanical and thermal loads and the chemical effects encountered during pressure testing and normal operation. These requirements are deemed to be satisfied if Clauses 6 to 11 are fulfilled. The vessel shall be marked in accordance with Clause 13, tested in accordance with Clause 12 and operated in accordance with ISO 21029-2.

5.3 Transportable cryogenic vessels shall be equipped with valves and pressure relief devices configured and installed in such a way that the vessel can be operated safely.

The inner vessel, the outer jacket and any section of pipework containing cryogenic fluid which can be trapped, shall be protected against over pressurization.

5.4 The transportable cryogenic vessel shall be cleaned for the intended service in accordance with ISO 23208 or an equivalent standard (e.g. EN 12300).

5.5 For transportable cryogenic vessel intended for service with flammable cryogenic fluids, all metallic components of the vessel shall be electrically continuous. The vessel shall be provided with a means of attachment to an earthing device(s) so that the resistance to earth is less than 10 Ω.

5.6 The manufacturer shall retain the documentation defined in Clause 14 for a period required by regulations (e.g. product liability). In addition, the manufacturer shall retain all supporting and background documentation issued by his subcontractors (if any) which establishes that the vessel conforms to this document.

6 Mechanical loads

6.1 General

The transportable cryogenic vessel shall resist the mechanical loads without suffering deformation which could affect safety and which could lead to leakage. This requirement can be validated by:

— calculation (10.2.1);

— experimental method (10.4);

— calculation and experimental method (10.1.3).

The mechanical loads to be considered are given in 6.2 and 6.3.

6.2 Load during the pressure test

The load exerted during the pressure test is given by:

$$p_t \geq 1{,}3\left(p_s + 1\right) \text{ in bar or } \left[p_t \geq 1{,}3 + \left(p_s + 0{,}1\right) \text{in MPa}\right]$$

where

p_t is the test pressure, in bar;

p_s is the maximum permissible pressure (= relief device set pressure), bar (+0,1 MPa);

+1 is the allowance for external vacuum.

6.3 Other mechanical loads

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

a) a pressure equal to the maximum permissible pressure in the inner vessel and pipework;

b) the pressure exerted by the liquid when the vessel is filled to capacity;

c) loads produced by the thermal movement of the inner vessel, outer jacket and interspace piping;

d) loads imposed in lifting and handling fixtures (at the vessel);

e) full vacuum in the outer jacket;

f) a pressure in the outer jacket equal to the set pressure of the relief device protecting the outer jacket;

g) load due to dynamic effects, when the vessel is filled to capacity, giving consideration to:

   1) the inner vessel support system including attachments to the inner vessel and outer jacket;

   2) the interspace and external piping;

   3) the outer jacket supports and, where applicable, the supporting frame.

6.3.2 Dynamic loads during normal operation, equal to twice the mass of the inner vessel when filled to the capacity shown on the data plate exerted by the inner vessel both horizontally and vertically, shall be considered.

6.3.3 If the vessel has a volume of more than 100 l or a gross mass of more than 150 kg or if the height of the centre of gravity of the fully loaded vessel is less than twice the smallest horizontal dimension at its base, the vertically upwards acting reference load may be reduced to equal the gross mass.

7 Chemical effects

Due to their temperatures and the materials of construction used, the possibility of chemical action on the inner surfaces in contact with the cryogenic fluids can be neglected.

Also, due to the fact that the inner vessel is inside an evacuated outer jacket, neither external corrosion of the inner vessel, nor corrosion on the inner surfaces of the outer jacket will occur. Therefore inspection openings are not required in the inner vessel or the outer jacket.

Corrosion allowance is also not required on surfaces in contact with the operating fluid or exposed to the vacuum interspace between the inner vessel and the outer jacket.

8 Thermal conditions

The following thermal conditions shall be taken into account:

a) for the inner vessel and its associated equipment the full range of temperature expected;

b) for the outer jacket and equipment thereof [other than equipment covered by a)]:

   1) a minimum working temperature of −20 °C;

   2) a maximum working temperature of 50 °C.

9 Material

9.1 General

For the materials used to manufacture the transportable cryogenic vessels, the following requirements shall be met.

9.2 Material properties

9.2.1 All materials that will, or might, be in contact with cryogenic fluids shall be in accordance with the relevant standards for compatibility for the specific cryogenic fluid(s) that they might be in contact with.

Particular consideration shall be given to material compatibility with cryogenic fluids that are either flammable or oxidants.

Material compatibility and cleanliness requirements for vessels intended for service in oxygen or other oxidising liquids are described in ISO 21010 and ISO 23208 (or in equivalent standard such as EN 12300).

For liquid hydrogen vessels, consideration shall be given to the possible presence of oxygen enriched air due to condensation on uninsulated cold parts. See also ISO 21010.

9.2.2 Materials used at low temperatures shall follow the toughness requirements of the relevant standard. For temperatures below −80 °C, see ISO 21028-1. For non-metallic materials low temperature suitability shall be demonstrated by providing sufficient test data.

9.2.3 The base materials, listed in Annex A, subject to meeting the extra requirements given in the main body of this document, are suitable for and may be used in the manufacture of the cryogenic vessels conforming to this document.

9.3 Inspection certificate

9.3.1 The material shall be declared by an inspection certificate 3.1 in accordance with ISO 10474.

9.3.2 The material manufactured to a recognized International Standard shall meet the testing requirements of ISO 21028-1 and ISO 21028-2 and shall be certified by inspection certificate 3.1 in accordance with ISO 10474.

9.3.3 The delivery of material which is not manufactured to a recognized standard shall be certified by inspection certificate 3.1 in accordance with ISO 10474 confirming that the material fulfils the requirements listed in 9.2. The material manufacturer shall follow a recognized standard for processing and establishing the guaranteed material properties.

9.4 Materials for outer jackets and equipment

The outer jacket and the equipment not subjected to cryogenic temperature shall be manufactured from material suitable for the intended service.

10 Design

10.1 Design options

10.1.1 General

The design shall be carried out in accordance with one of the options given in 10.1.2 or 10.1.3.

NOTE For design validation as part of type approvals see Annex G.

10.1.2 Design 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 be not less than the requirements given in 10.3. Additional calculations are required to ensure the design is satisfactory for the operating conditions including an allowance for dynamic loads.

Fatigue life calculation shall be conducted according to EN 13445-3, ASME VIII-2 or equivalent standards/codes, if the pressure loading is exceeding the limit of predominantly non-cyclic nature defined by the applied standard/code.

The fatigue life calculation shall be conducted for unlimited lifetime.

Alternatively, the fatigue life of the vessel may be specified. The user of the vessel shall estimate the operational fatigue load regime during the expected lifetime. Then the designer can take into account the operational load regime in the fatigue life calculation.

To avoid fatigue damage in case of cyclic loading, more severe fabrication, inspection and testing requirements are needed for critical areas of the pressure vessels, see also 12.3.4.

For cyclic loaded vessels, the absence of surface imperfections and the necessity of smooth transitions are essential. Only smooth transitions are allowed.

Similarly, shape imperfections such as peaking are absolutely critical and the maximum permissible peaking of the applied standard/code, or the value permitted in the fatigue analysis, shall not be exceeded.

10.1.3 Design by calculation and supplemented with experimental methods

This option requires validation of the pressure-retaining capacity by calculation except that the minimum wall thickness requirements of Tables 2 and 3 do not apply. Structural integrity shall be validated by experiment as described in 10.4.

The pressure-retaining capacity may be validated by experimental methods:

— if no design formulae are available for shape or material, or

— for vessels with a (p/V) lower than 1 000 bar/l (100 MPa/l).

Table 2 — Inner vessel minimum wall thickness

Inner vessel diameter, D (mm)	Minimum wall thickness s_0 for reference steel[a] (mm)
$D \le 400$	1
$400 < D \le 1\,800$	$0{,}5+\dfrac{D}{1\,200}$

[a] Reference steel material is material having a product $R_m \times A_5$ of 10 000. For other steels calculate the minimum thickness using the following formula:

$$s = \frac{21{,}4\ s_0}{\sqrt[3]{R_m \times A_5}}$$

where

R_m is the ultimate tensile strength, in newtons per square millimetre;

A_5 is the elongation at fracture, in per cent.

Table 3 — Outer jacket minimum wall thickness

Outer vessel diameter, *D* (mm)	**Minimum wall thickness s_0 for reference steel**[a] (mm)
$D \leq 1\,800$	$0{,}5+\frac{D}{1\,200}$

[a] Reference steel material is material having a product $R_m \times A_5$ of 10 000. For other steels calculate the minimum thickness using the following formula:

$$s = \frac{21{,}4\, s_0}{\sqrt[3]{R_m \times A_5}}$$

where

R_m is the ultimate tensile strength, in newtons per square millimetre;

A_5 is the elongation at fracture, in per cent.

10.2 Common design requirements

10.2.1 General

The requirements of 10.2.2 to 10.2.6 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 permissible pressure;

— specific mass (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);

— the fundamental shape;

— the decrease in the minimum mechanical properties of the material being used;

— 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 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 10.4.4.2 and 10.4.4.3) or the relevant calculations, shall be repeated to take account of these changes.

10.2.2 Design specification

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

— maximum permissible pressure;

— fluids to be used;

— liquid capacity;

— volume of the inner vessel;

— method of handling and securing;

— stacking arrangement;

— range of ambient temperatures.

A design document in the form of drawings with written text, if any, shall be prepared. It shall contain the information given above plus, where applicable, the following:

— definition of which components are designed 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;

— applicable material test certificates;

— 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 document;

— design test programme;

— non-destructive testing requirements;

— pressure test requirements;

— piping configuration including type, size and location of all valves and relief devices and other accessories if applicable;

— details of lifting points and lifting procedure.

10.2.3 Design loads

10.2.3.1 Inner vessel

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

a) Design pressure, p given in Formula (1);

$$p = p_s + p_l + 1 \text{ bar or } \left(p = p_s + p_l + 0{,}1\,\text{MPa}\right) \qquad (1)$$

where p_l is the pressure, in bars, exerted by the liquid contents when the vessel is filled to capacity and subject to dynamic loading;

b) loads imposed on the inner vessel due to the mass of the inner vessel and its contents when subject to dynamic loading;

c) 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:

1) cooldown (inner vessel warm – piping cold);

2) filling and withdrawal (inner vessel cold – piping cold);

3) transhipment and storage (inner vessel cold – piping warm);

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

10.2.3.1.2 The design shall be evaluated for the following condition.

Pressure test: the following value, defined with Formula (2) shall be used for validation purposes:

$$p_t \geq 1{,}3(p_s + 1) \text{ bar or } [p_t \geq 1{,}3(p_s + 0{,}1) \text{ MPa}] \quad (2)$$

where p_s is the maximum permissible pressure.

The 1 bar (or 0,1 MPa) is added to allow for the external vacuum. The primary membrane stress at test pressure shall not exceed the value prescribed in the relevant regulation and in no case shall it exceed the yield stress of the material.

For cryogenic vessels with a capacity above 450 l, the minimum test pressure shall be 3 bar (or 0,3 MPa). This requirement does not apply to heating or cooling systems and related service equipment.

10.2.3.2 Outer jacket

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

a) an external pressure of 1 bar (or 0,1 MPa);

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 10.2.3.1.1 c);

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 10.3.8).

10.2.3.3 Inner vessel supports

The inner vessel supports shall be suitable for the load defined in 10.2.3.1.1 c) plus loads due to differential thermal movements.

10.2.3.4 Outer jacket supports

The outer jacket supports shall be suitable for the load defined in 10.2.3.2 f).

10.2.3.5 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 10.3.8).

10.2.3.6 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 10.3.8).

10.2.3.7 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.

10.2.3.8 Piping and valves

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 permissible working pressure p_S plus 1 bar (or 0,1 MPa) for piping that is 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 10.2.3.1.1 c);

d) dynamic loads;

e) set pressure of thermal relief devices where applicable;

f) loads generated during pressure relief discharge.

10.2.4 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 cannot occur.

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

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

10.2.5 Pressure relief

10.2.5.1 General

Relief devices for inner vessels shall be in accordance with ISO 21013-1 and ISO 21013-2 as appropriate, with the exception that, for flammable gases, non-reclosable pressure-relief devices shall not be used.

Relief devices for inner vessels shall be sized in accordance with ISO 21013-3, taking into consideration the conditions stipulated in 10.2.5.2 and 10.2.5.3.

In sizing pressure relief devices the calculations shall take into account the back pressure developed by equipment that may be installed downstream of the outlet of the relief device, such as venting systems, and, in the case of flammable gas relief devices, flame arrestors.

Relief devices for outer jackets shall be in accordance with Annex B.

Systems shall be designed to meet the requirements given in 10.2.5.2 and 10.2.5.3.

10.2.5.2 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. Insulation performance evaluated as described in ISO 21014 shall be sufficient to satisfy the holding time requirement;

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 permissible pressure for condition a) and in excess of the test pressure for condition b) or c).

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

Shut-off valves or the 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 reseat instantly.

All pressure relief devices that can release flammable cryogenic fluid to the atmosphere shall be connected to a venting system that discharges the contents safely.

10.2.5.3 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 1,7 bar (or 0,17 MPa). The discharge area of the pressure relief device shall be not less than 0,171 mm^2/l capacity of the inner vessel but not less than 6 mm in diameter.

For calculating the resistance of the inner vessel and the outer vessel to the pressure, the maximum actual set values shall be considered.

10.2.5.4 Piping

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

10.2.6 Piping, valves and equipment

10.2.6.1 All piping, valves and equipment shall be suitable for use with the specific cryogenic fluid(s) for which the vessel may be used. Particular consideration shall be given to the suitability of components to be used with cryogenic fluids that are flammables or oxidants.

10.2.6.2 Because of the risk of fire and explosion with vessels used for flammable cryogenic fluids, the design of the piping shall provide for:

a) upward venting;

b) leak-tightness;

c) the vessel and piping to be purged with a non-flammable/non-oxidizing gas when required for the safe operation and maintenance of the vessel.

All lines that can release flammable cryogenic fluid to the atmosphere, such as filling lines and vent lines, shall be connected to a venting system that discharges the contents safely. Lines to atmosphere that are only used occasionally, such as purge lines used in relation to maintenance activities, need only be connected to the venting system when in use but shall have double isolation, in accordance with 10.2.6.3, at all other times.

10.2.6.3 Valves shall be conform to ISO 21011 and to ISO 4126-1.

For safety critical valves on vessels for flammable gas, depending of the material used (body, seals), consideration should be given to the use of valves certified as fire-safe in accordance with a standard such as API 607 or ISO 10497.

On vessels that are to be used for flammable cryogenic fluids, all lines that can be open to the atmosphere, such as filling lines and vent lines, shall be provided with two means of isolation, with the exception of relief devices which shall not have two means of isolation.

The main means of isolation shall be an isolation valve, located close to the vessel and easily accessible in an emergency. The secondary means of isolation shall be placed between the main isolation valve and atmosphere.

The secondary means of isolation may be an isolation valve, a non-return valve, a cap or a plug, as appropriate, with the exception of the secondary isolation for the liquid fill line which shall be either a non-return valve or a fail-closed automatic shut-off valve.

10.2.7 Degree of filling

The degree of filling of large transportable vacuum-insulated vessels intended for the carriage of flammable gases shall remain below the level at which, if the contents were raised to the temperature at which the vapour pressure equalled the opening pressure of the safety valve, the volume of the liquid would reach 98 % of the vessel's net volume at that temperature. The degree of filling for helium may be 100 % of net volume. Pre-trip inspection shall ensure that the above limits are not exceeded. The degree of filling shall be calculated or determined or put on the tank plate.

All vessels to be used for flammable cryogenic fluids shall be equipped with safety devices to protect against overfilling (level limiters).

10.3 Design by calculation

10.3.1 General

When design validation is by calculation in accordance with 10.1.2 or 10.1.3 the dimensions of the inner vessel and outer jacket shall be not less than that determined in accordance with this sub-clause.

10.3.2 Inner vessel

10.3.2.1 Wall thickness

The information given in 10.3.2.2 to 10.3.2.6, in conjunction with the calculation formulae of 10.3.7, shall be used to determine the pressure part thicknesses.

The actual wall thickness shall be not less than as shown in Table 3 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 C.

10.3.2.2 Design pressure, p

The internal design pressure p shall be as defined in 10.2.3.1.

The minimum design pressure shall be 2,31 bar (or 0,231 MPa).

The inner vessel shall be designed for a minimum external pressure equal to the set pressure of the outer jacket pressure relief device.

10.3.2.3 Material property, K_{20}

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

— for austenitic stainless steel, 1 % proof strength;

— for aluminium and aluminium alloys, 0,2 % proof strength.

K shall be the minimum value at 20 °C as 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;

— the welding procedures shall be suitably qualified.

For austenitic steel higher stress values due to work-hardening may be considered in the design only, if their presence in the component has been proved, the material (including welding seam) has sufficient residual elongation of rupture and still sufficient impact energy as minimum required.

If allowed by the applicable authorities where the vessel is to be operated.

10.3.2.4 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 see applicable method in Annex D;

  — knuckle region, $S_p = 1,6$.

10.3.2.5 Weld joint factors, v

For internal pressure (pressure on the concave surface), $v = 0,85$ or 1,0 (see Clause 12).

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

10.3.2.6 Corrosion allowances, c

$c = 0$

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

10.3.3 Outer jacket

10.3.3.1 General

The following, in conjunction with the calculation formulae of 10.3.7, shall be used to determine the pressure part thicknesses.

The actual wall thickness shall be not less than as shown in Table 3 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 C.

10.3.3.2 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 1 bar (or 0,1 MPa).

10.3.3.3 Material property, K_{20}

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 10.3.2.3;

— for carbon steel, K = yield strength.

NOTE Upper yield strength can be used.

10.3.3.4 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, $S_p = 1,6$, $S_k = 2,0 + 0,001\ 4\ R/s$;

  — knuckle region, $S_p = 1,2$.

10.3.3.5 Plastic deformation

Resistance to plastic deformation is determined by using Annex C with the appropriate safety factor S_p defined in 10.3.2.4 and 10.3.3.4.

10.3.3.6 Weld joint factor, v

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

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

10.3.3.7 Corrosion allowance, 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.

10.3.4 Supports, lifting points and frame

The supports and frame shall be designed for the loads defined in 10.2.3, 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.

10.3.5 Protective guards

External fittings shall be protected by a guard designed for the loads specified in 10.2.3.7. 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.

10.3.6 Piping

Piping shall be designed for the loads defined in 10.2.3.8 using established piping design methods and safety factors.

10.3.7 Calculation formulae

10.3.7.1 Cylindrical shells and spheres subject to internal pressure (pressure on the concave surface) (In case of using pressure unit in MPa, conversion shall be considered)

10.3.7.1.1 Field of application

Cylindrical shells and spheres where $D_a/D_i \leq 1{,}2$.

10.3.7.1.2 Openings

For reinforcement of openings see 10.3.7.7.

10.3.7.1.3 Calculation

The required minimum wall thickness, s, is

— for cylindrical shells, as per Formula (3):

$$s = \frac{D_a p}{20\left(\frac{K20}{S}\right)v + p} + c \tag{3}$$

— for spherical shells, as per Formula (4):

$$s = \frac{D_a p}{40\left(\frac{K20}{S}\right)v + p} + c \tag{4}$$

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

10.3.7.2.1 Field of application

Cylindrical shells where $D_a/D_i \leq 1{,}2$

10.3.7.2.2 Openings

Inner vessel openings shall be calculated in accordance with 10.3.7.7 using the external pressure as an internal pressure.

10.3.7.2.3 Calculation

Annex D gives two alternative calculation methods. Both methods give comparable results and shall be equally acceptable.

10.3.7.2.4 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.

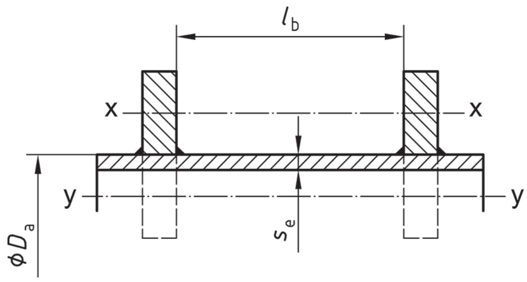


Figure 1 — Stiffening rings

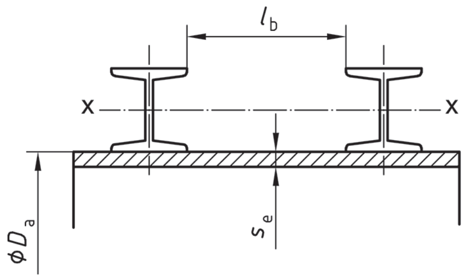


Figure 2 — Sectional material stiffeners

The stiffening rings welded to the shell shall satisfy the conditions in Formulae (5) and (6).

$$I \geq \frac{0{,}124\, p D_a^3}{10\, E} \sqrt{D_a (s-c)} \tag{5}$$

$$A \geq \frac{0{,}75\, p D_a}{10\, K} \sqrt{D_a (s-c)} \tag{6}$$

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 shall cover at least one third of the shell circumference and the number of weld discontinuities shall be at least 2*n*. The number of buckling lobes, *n*, is obtained as indicated in D.3.1.2.5.

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

Spherical shells subject to external pressure shall be evaluated in accordance with 10.3.7.4.4.

10.3.7.4 Dished ends subject to internal or external pressure

See Figures 3, 4 and 5.

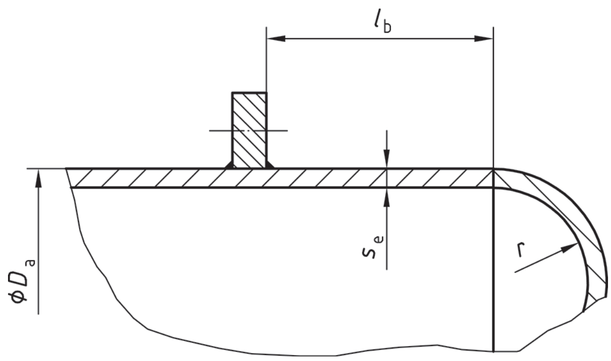


Figure 3 — Dished ends

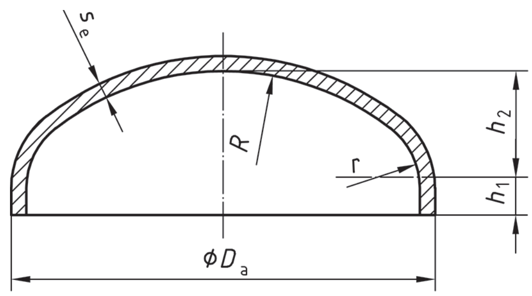


Figure 4 — Unpierced dished end

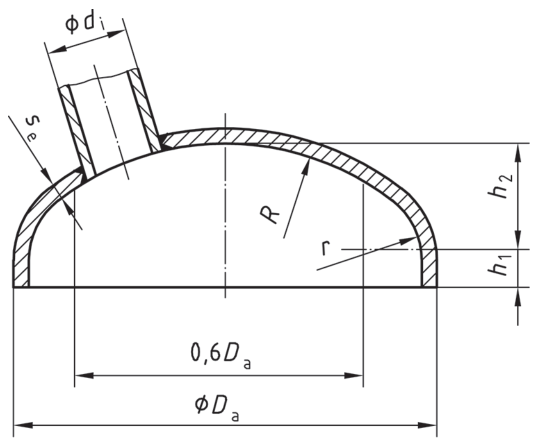


Figure 5 — Dished end with nozzle

10.3.7.4.1 Field of application

The following dish ends may be utilized:

a) hemispherical ends where $D_a/D_i \leq 1{,}2$;

b) 10 % torispherical ends where $R = 0{,}8\ D_a$ and $r = 0{,}1\ D_a$;

c) 2:1 torispherical ends where $R = 0{,}8\ D_a$ and $r = 0{,}154\ D_a$;

NOTE In the case of torispherical ends $0{,}002 \leq (s - c)/D_a \leq 0{,}1$.

d) 2:1 elliptical ends where $R = 0{,}9\ D_a$ and $r = 0{,}170\ D_a$;

NOTE In the case of elliptical ends $0{,}002 \leq (s - c)/D_a \leq 0{,}1$.

e) other torispherical head shapes may be used provided suitable calculations are carried out in accordance with 10.3.8.

10.3.7.4.2 Straight flange

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

— for 10 % torispherical ends, 3,5 s;

— for 2:1 torispherical ends, 3,0 s;

— for 2:1 elliptical ends, 3,0 s.

The straight flange may be shorter provided 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.

10.3.7.4.3 Internal pressure calculation (pressure on concave surface)

10.3.7.4.3.1 Crown and hemisphere thickness

The wall thickness of the crown region of dished ends and of hemispherical ends shall be determined using 10.3.7.1.3 for spherical shells with $D_a = 2(R + s)$.

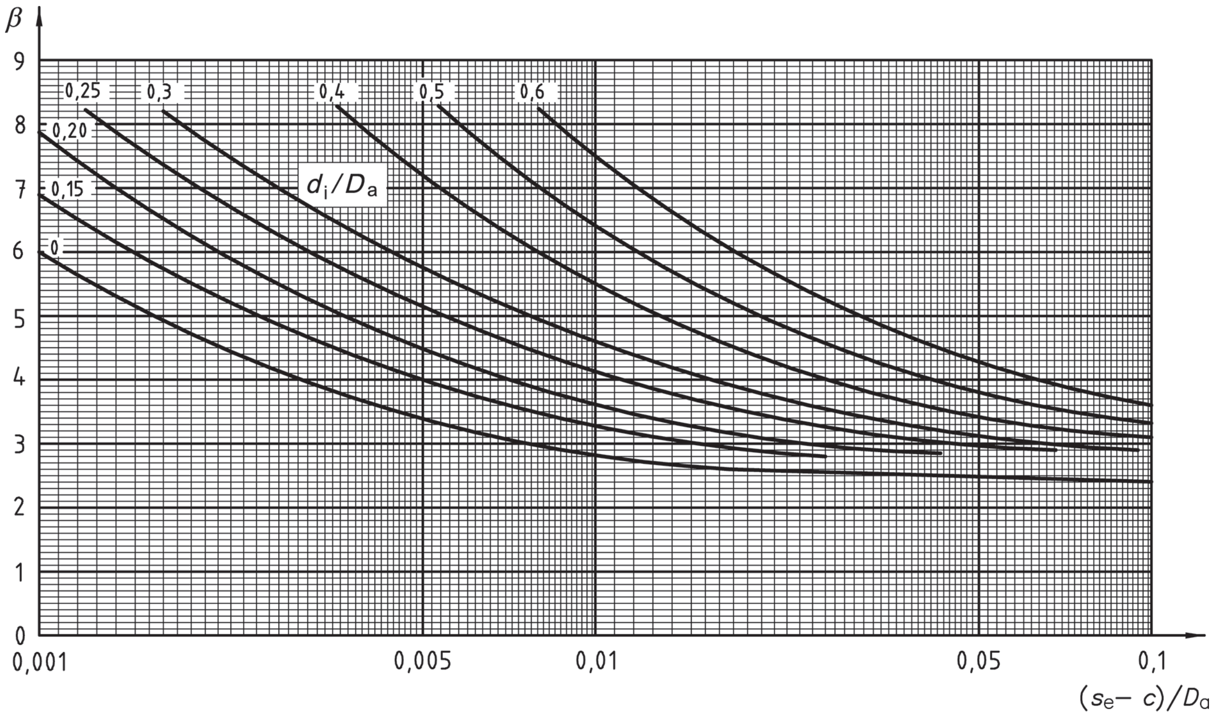
Openings within the crown area of 0,6 D_a of torispherical ends and in hemispherical ends shall be reinforced in accordance with 10.3.7.7. When pad type reinforcement is used, the edge of the pad shall not extend beyond the area of 0,8 D_a for 10 % torispherical ends or 0,7 D_a for 2:1 torispherical ends.

10.3.7.4.3.2 Torispherical end knuckle thickness and hemispherical end to shell junction thickness

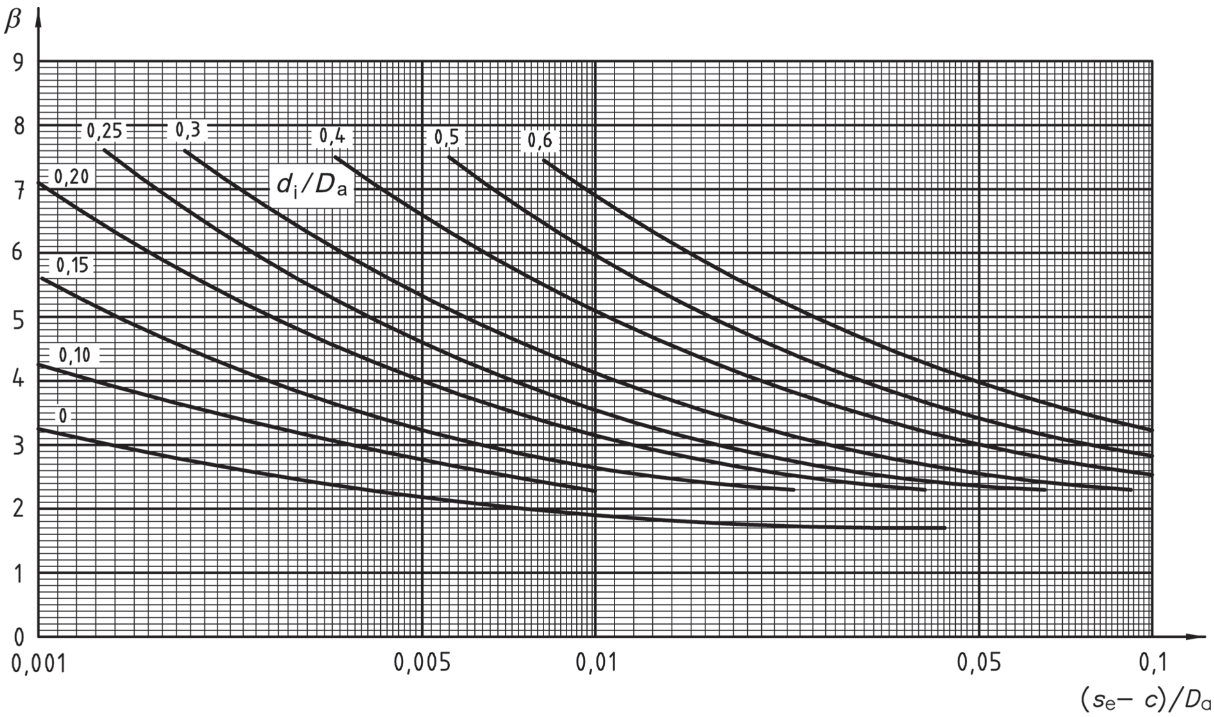
The required thickness of the knuckle region and hemispherical end junction shall be as per Formula (7).

$$s = \frac{D_a\ p\ \beta}{40\left(\frac{K_{20}}{S}\right)v} + c \qquad (7)$$

β is taken from Figure 6 a) for 10 % torispherical ends and from Figure 6 b) 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.



a) 10 % torispherical dished ends



b) 2:1 torispherical dished ends

Figure 6 — Design factors for torispherical dished ends

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

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

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

For hemispherical ends a β value of 1,1 shall be applied within the distance $x = 0{,}5\sqrt{R(s-c)}x$ from the tangent line joining the end to the cylinder, regardless of the ratio, $(s - c)/D_a$, where $x = 0{,}5\sqrt{R(s-c)}$.

10.3.7.4.3.3 Elliptical end crown and knuckle thickness

The required thickness of the crown and knuckle region shall be:

$$s = \frac{p \times D_i}{20 \times \left(\frac{K_{20}}{S}\right) \times v - 0{,}2p}$$

10.3.7.4.4 External pressure calculations (pressure on the convex surface)

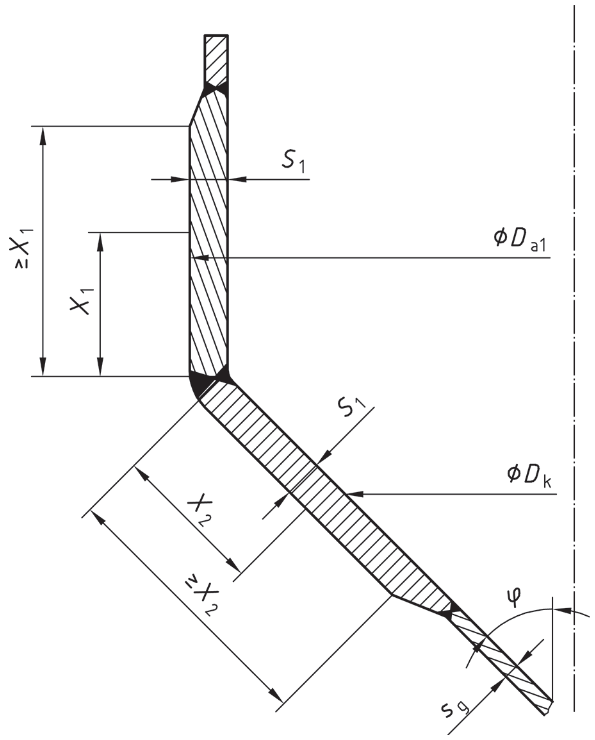
See Annex D.

10.3.7.5 Cones subject to internal or external pressure

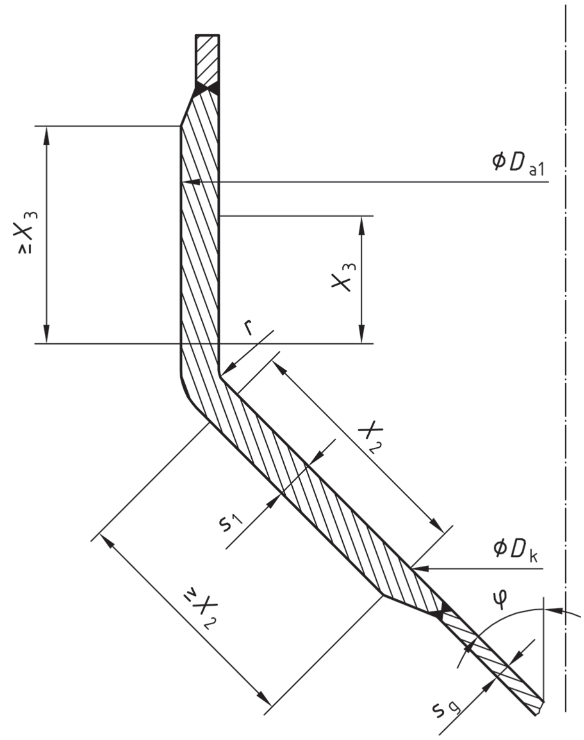
10.3.7.5.1 Symbols and units

For the purposes of 10.3.7.5, the following symbols apply in addition to those given in Clause 4.

A	area of reinforcing ring, in square millimetres
D_{a1}	outside diameter of connected cylinder (Figure 7 and Figure 9), in millimetres
D_{a2}	outside diameter at effective stiffening (Figure 9), in millimetres
D_k	design diameter (Figure 7), in millimetres
D_s	shell diameter at nozzle (Figure 8), in millimetres
I	moment of inertia about the axis parallel to the shell, in millimetres
l	cone length between effective stiffenings (Figure 9), in millimetres
s_g	required wall thickness outside the corner area, in millimetres
s_l	required wall thickness within the corner area, in millimetres
χ_i	characteristic lengths (i = 1,2,3) to define corner area (Figure 7, Figure 8 and 10.3.7.5.5), in millimetres
φ	cone angle, in degrees

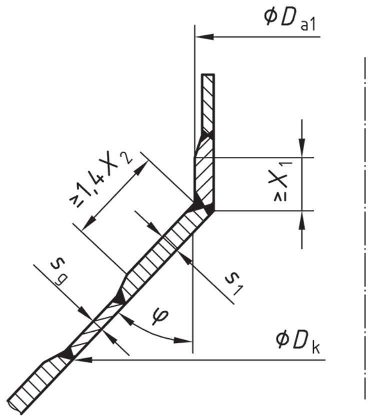


Corner joint



With knuckle

a) Convergent conical shells



b) Divergent conical shells

Figure 7 — Geometry of conical shells

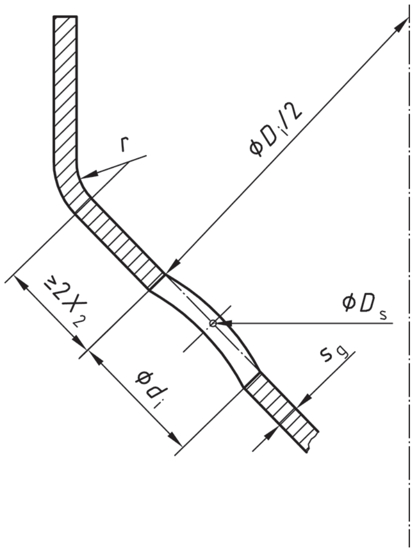


Figure 8 — Geometrical quantities in the case of loading by external pressure

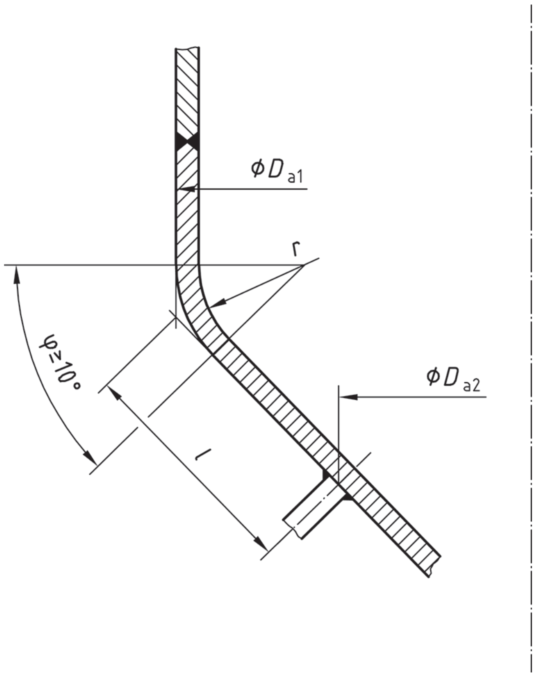


Figure 9 — Geometry of a cone opening

10.3.7.5.2 Field of application

Cones according to Figure 7 where $0{,}002 \le (s_g - c)/D_{a1} \le 0{,}01$ and $0{,}002 \le (s_l - c)/D_{a1} \le 0{,}01$.

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

10.3.7.5.3 Openings

Openings outside of the corner area (Figure 9) shall be designed as follows.

If $\varphi < 70°$, design according to 10.3.7.7 using an equivalent cylinder diameter according to Formula (8).

$$D_{\mathrm{i}} = \frac{D_{\mathrm{s}} + d_{\mathrm{i}} \ \sin \varphi}{\cos \varphi} \tag{8}$$

If $\varphi \geq 70°$, design according to 10.3.7.6.

10.3.7.5.4 Non-destructive testing

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

10.3.7.5.5 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 Figure 7 a) and b) by χ_1, χ_2, χ_3 calculated from Formulae (9), (10) and (11).

$$\chi_1 = \sqrt{D_{\mathrm{a}_1}(s_1 - c)} \tag{9}$$

$$\chi_2 = 0{,}7\sqrt{\frac{D_{\mathrm{a}_1}(s_1 - \mathrm{c})}{\cos\varphi}} \tag{10}$$

$$\chi_3 = 0{,}5\,\chi_1 \tag{11}$$

10.3.7.5.6 Internal pressure calculation ($\varphi \leq 70°$ pressure on concave surface)

a) Within corner area

The required wall thickness, s_1, within the corner area as calculated from Figure 10 a) to g) for the large end (convergent cones) and Figure 10 h) for the small end (divergent cones) of a cone using the following variables:

$\varphi, \dfrac{pS}{15\ Kv}$ and $\dfrac{r}{D_{a_1}}$ shall be not less than the required wall thickness, s_{g}, outside the corner area as calculated in Formula (12). For a corner joint use the curve for $r/D_{\mathrm{a}1} = 0$. For intermediate cone angles, φ, use linear interpolation. For intermediate values of $r/D_{\mathrm{a}1}$ the relevant interpolation equation stated in Figure 10 a) to h) shall be used.

The wall thickness, s_{l}, in the corner area shall not be less than the required thickness, s_{g}, outside the corner area as calculated in Formula (12).

A_{11} = +0,817 613 650 2

A_{21} = +1,038 186 188 2

A_{31} = +0,062 215 821 0

A_{41} = +0,009 692 963 5

A_{12} = +0,059 719 513 5

A_{22} = −0,241 259 378 0

A_{32} = −0,188 064 259 0

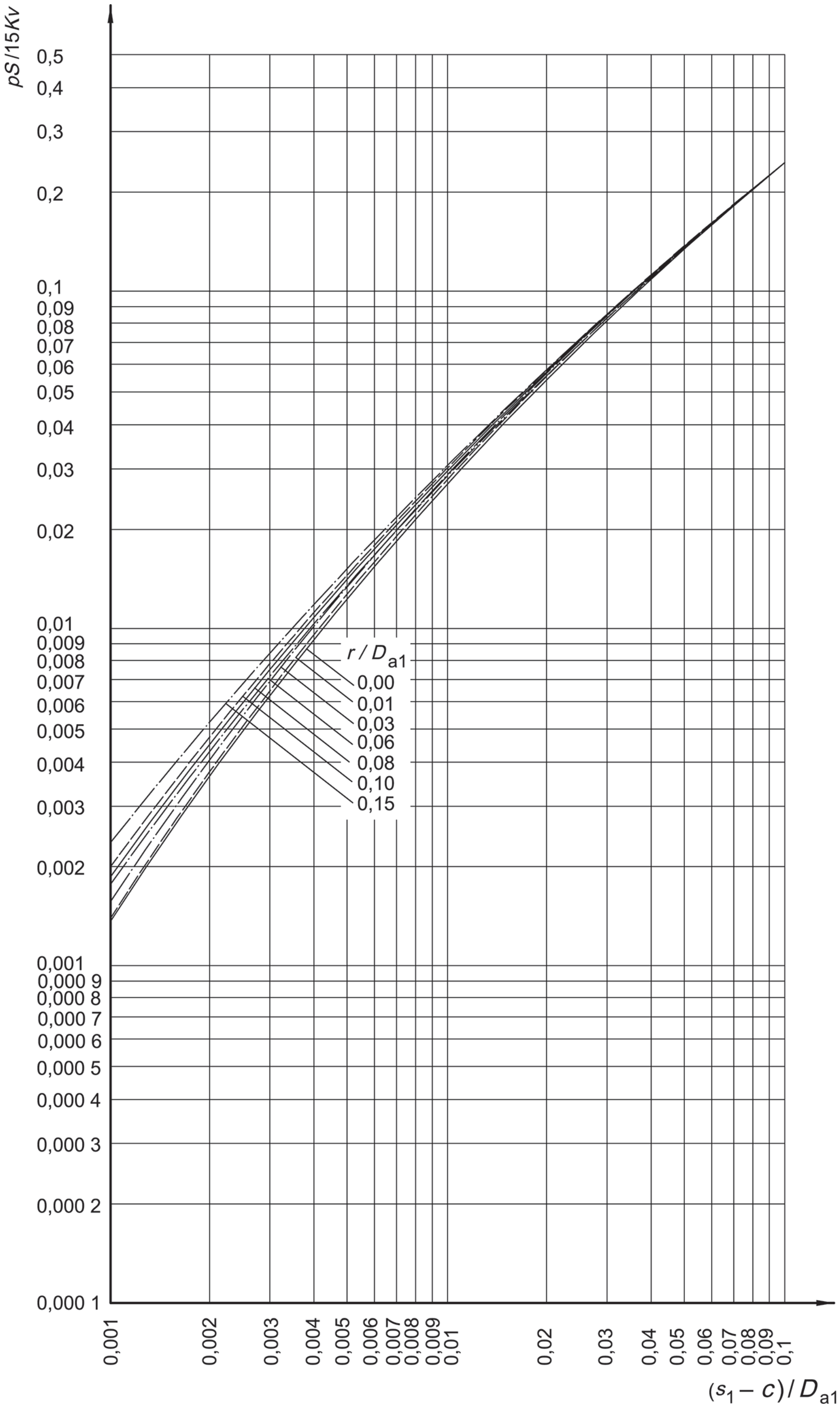
A_{42} = −0,032 453 658 7

$$X = \ln\left[\left(s_1 - c\right) / D_{a_1}\right]$$

$$Y = r / D_{a_1}$$

$$Z = \sum_{i=1}^{4}\sum_{i=1}^{2} A_{ij} - X^{i-1} - Y^{j-1}$$

$$\frac{pS}{15kv} = e^{Z}$$



a) Convergent cones with an opening angle φ = 10°

A_{11} = −0,143 080 313 5

A_{21} = +0,138 182 416 5

A_{31} = −0,176 590 600 5

A_{41} = −0,006 502 602 5

A_{12} = −0,446 269 297 7

A_{22} = −0,832 800 641 7

A_{32} = −0,148 603 365 7

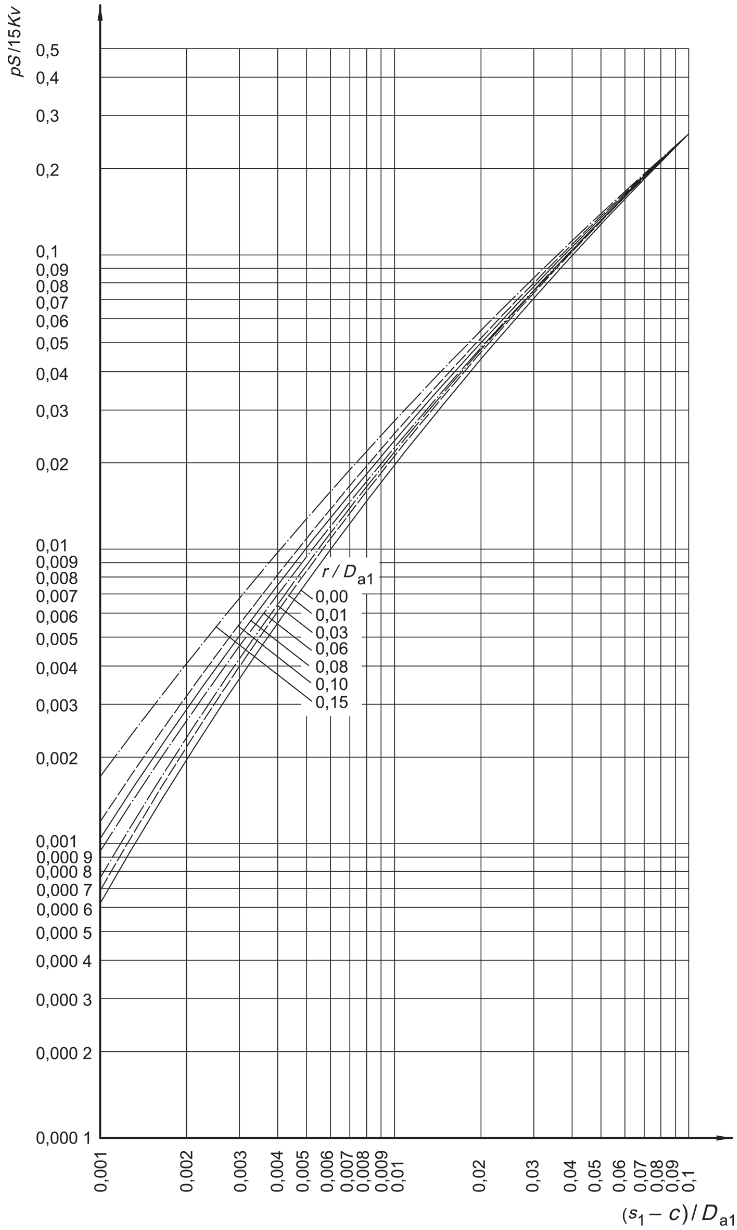
A_{42} = −0,028 151 995 0

$$X = \mathrm{In}\left[\left(s_1 - c\right) / D_{a_1}\right]$$

$$Y = r / D_{a_1}$$

$$Z = \sum_{i=1}^{4} \sum_{i=1}^{2} A_{\mathrm{ij}} - X^{i-1} - Y^{j-1}$$

$$\frac{pS}{15kv} = e^{Z}$$



b) Convergent cones with an opening angle φ = 20°

$A_{11} = +0{,}350\ 036\ 583\ 5$

$A_{21} = -0{,}244\ 082\ 237\ 4$

$A_{31} = -0{,}324\ 659\ 567\ 3$

$A_{41} = -0{,}019\ 053\ 507\ 2$

$A_{12} = -0{,}616\ 128\ 775\ 5$

$A_{22} = -0{,}625\ 810\ 920\ 5$

$A_{32} = -0{,}545\ 337\ 038\ 4$

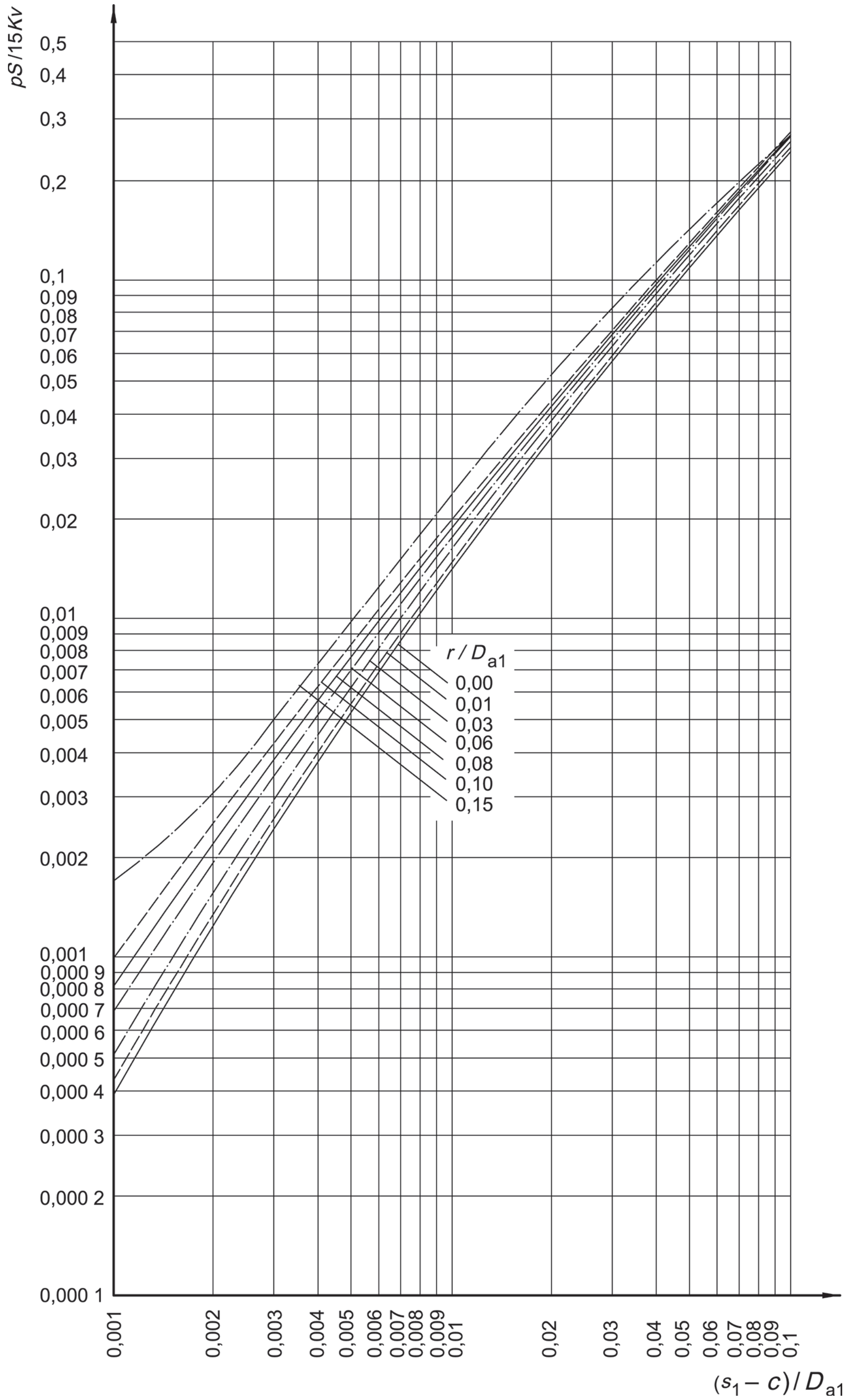
$A_{42} = -0{,}633\ 546\ 088\ 3$

$$X = \text{In}\left[\left(s_1 - c\right) / D_{\text{a}_1}\right]$$

$$Y = r / D_{\text{a}_1}$$

$$Z = \sum_{i=1}^{4} \sum_{i=1}^{2} A_{\text{ij}} - X^{i-1} - Y^{j-1}$$

$$\frac{pS}{15kv} = e^{Z}$$



c) Convergent cones with an opening angle φ = 30°

A_{11} = +0,857 590 246 6

A_{21} = +0,537 848 196 4

A_{31} = −0,198 665 329 8

A_{41} = −0,012 223 742 7

A_{12} = −0,819 824 767 4

A_{22} = −0,451 513 151 1

A_{32} = −0,325 843 767 5

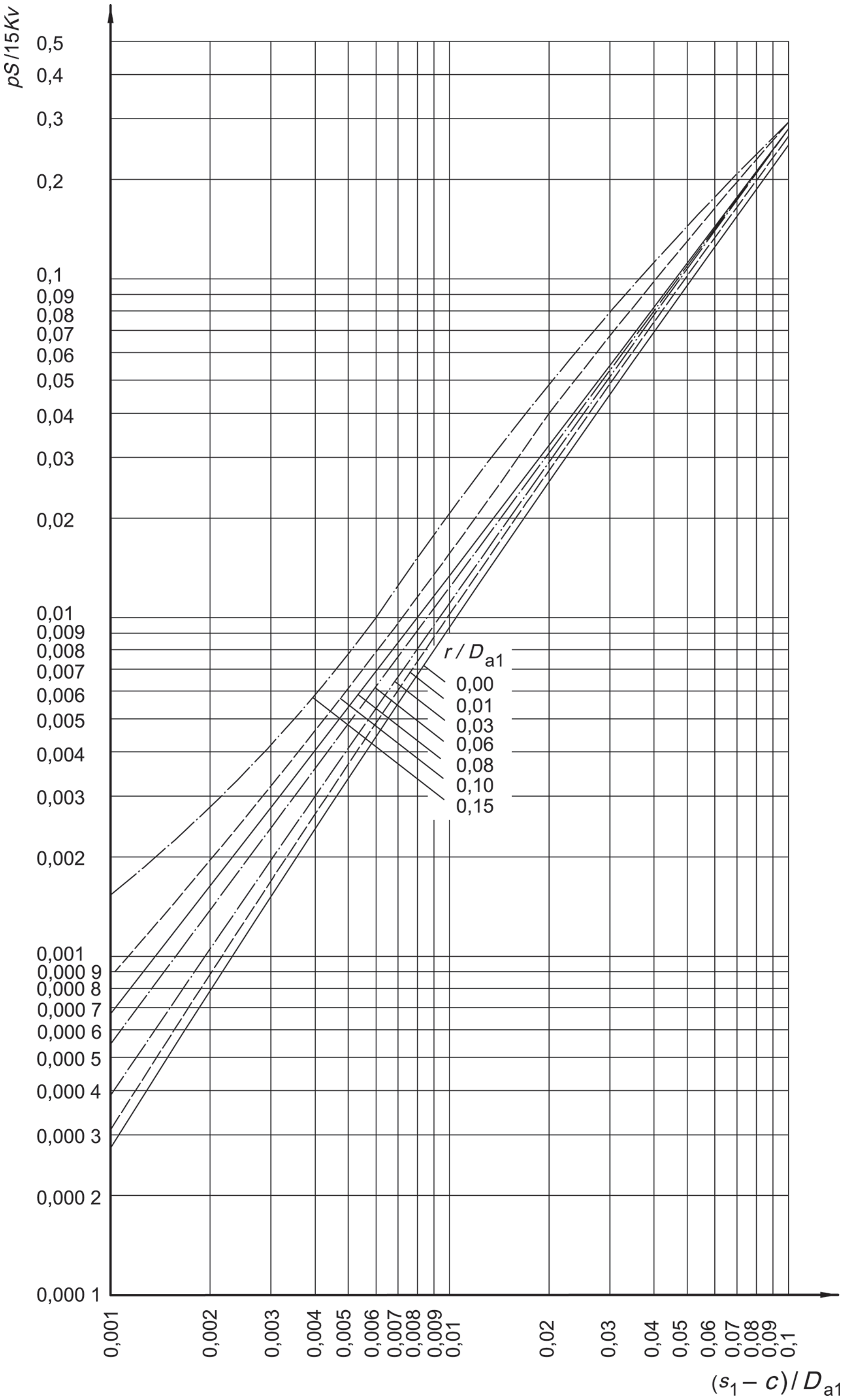
A_{42} = −0,117 702 214 9

$$X = \text{In}\left[\left(s_1 - c\right) / D_{a_1}\right]$$

$$Y = r / D_{a_1}$$

$$Z = \sum_{i=1}^{4} \sum_{i=1}^{2} A_{ij} - X^{i-1} - Y^{j-1}$$

$$\frac{pS}{15kv} = e^{Z}$$



d) Convergent cones with an opening angle φ = 40°

A_{11} = +0,278 991 786 0

A_{21} = +0,837 707 794 9

A_{31} = −0,165 668 843 2

A_{41} = −0,011 893 413 6

A_{12} = −0,020 628 753 0

A_{22} = −0,563 764 480 4

A_{32} = −0,571 145 072 1

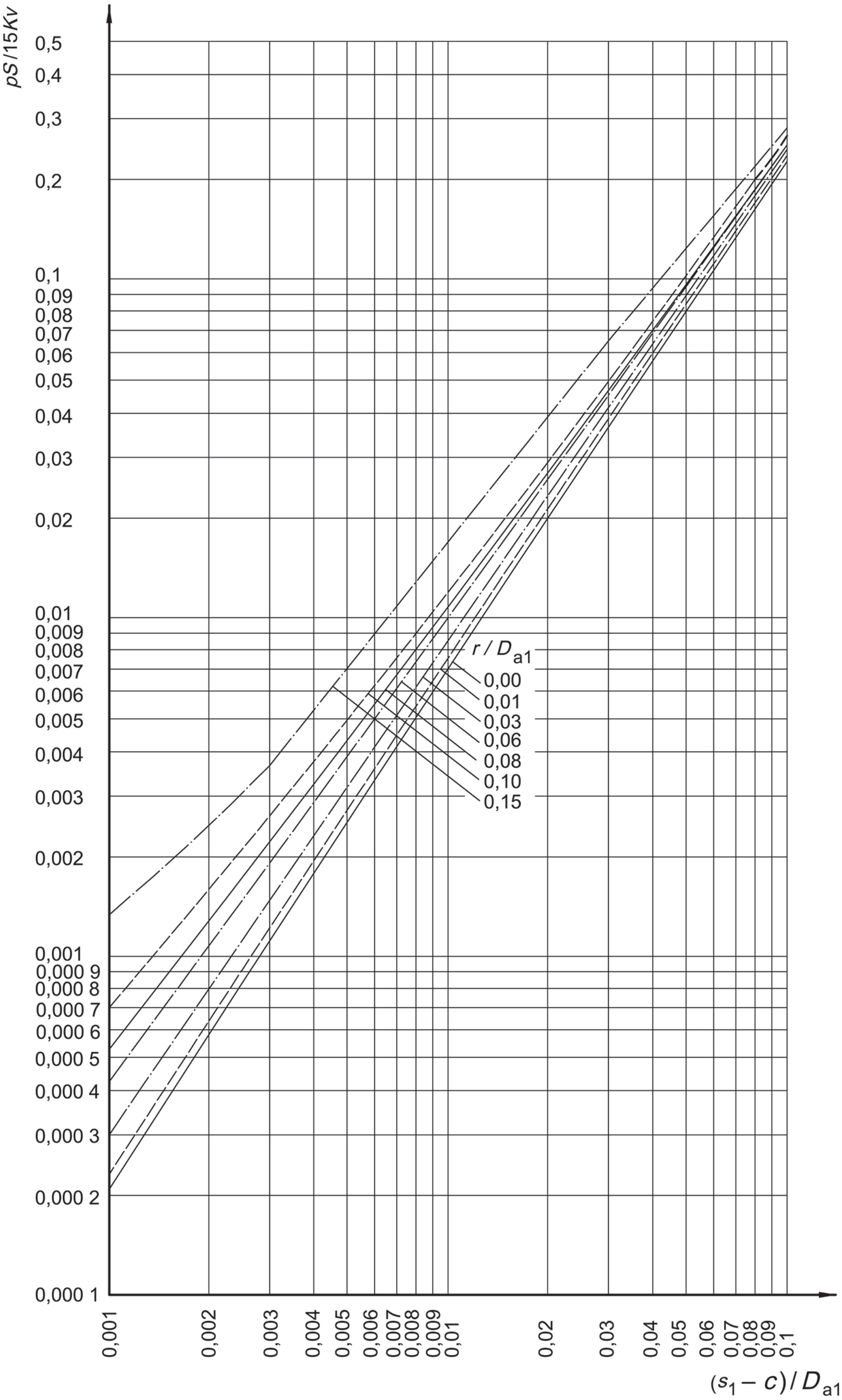
A_{42} = −0,060 021 610 9

$$X = \text{In}\left[\left(s_1 - c\right) / D_{\mathrm{a}_1}\right]$$

$$Y = r / D_{\mathrm{a}_1}$$

$$Z = \sum_{i=1}^{4} \sum_{i=1}^{2} A_{\mathrm{ij}} - X^{i-1} - Y^{j-1}$$

$$\frac{pS}{15kv} = e^Z$$



e) Convergent cones with an opening angle φ = 50°

A_{11} = +0,869 439 644 0

A_{21} = +0,365 916 386 0

A_{31} = −0,064 817 357 4

A_{41} = −0,005 734 561 7

A_{12} = +0,055 308 028 4

A_{22} = −0,051 126 044 0

A_{32} = +0,301 592 294 9

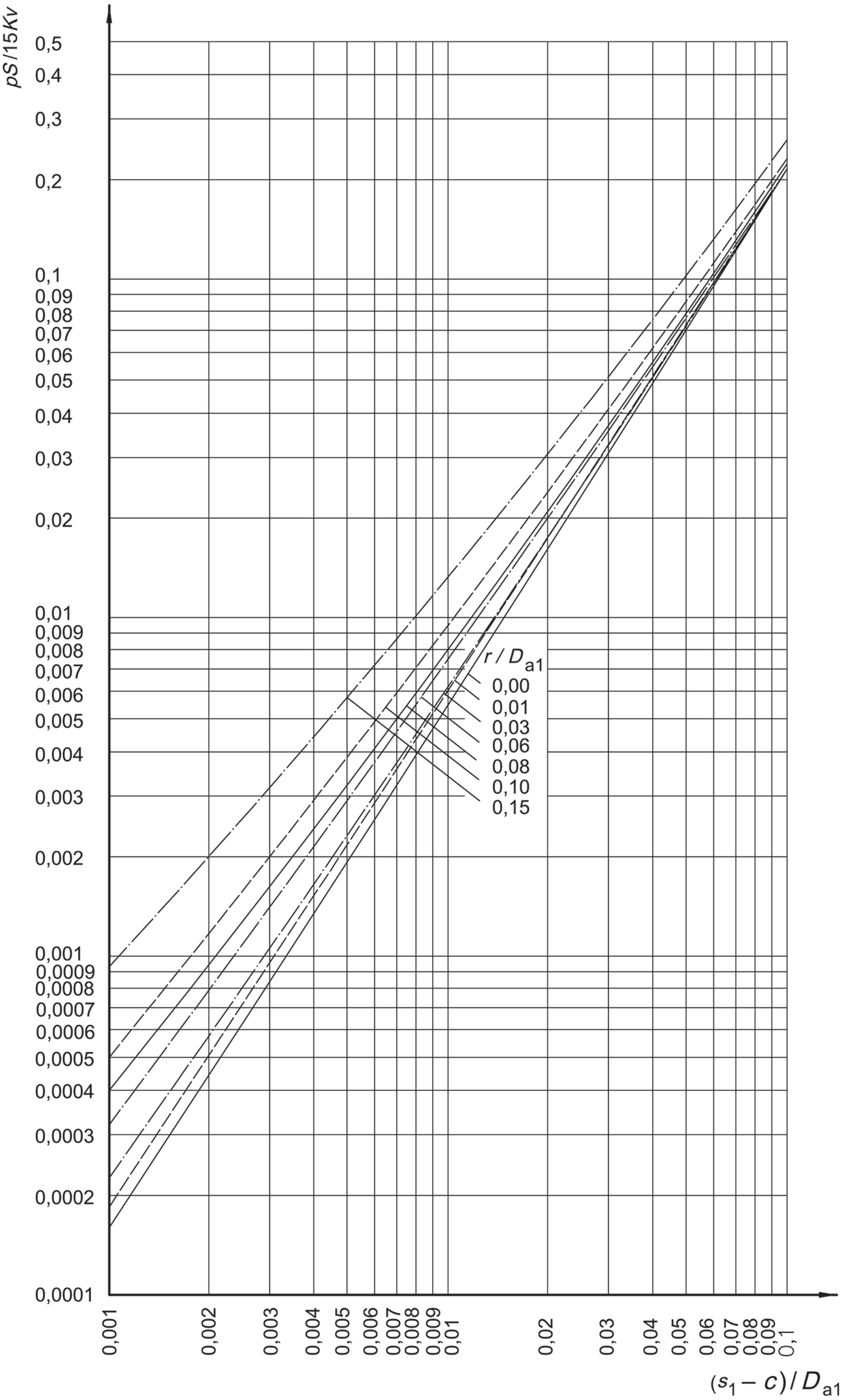
A_{42} = +0,009 020 188 8

$$X = \ln\left[\left(s_1 - c\right) / D_{a_1}\right]$$

$$Y = r / D_{a_1}$$

$$Z = \sum_{i=1}^{4}\sum_{i=1}^{2} A_{ij} - X^{i-1} - Y^{j-1}$$

$$\frac{pS}{15kv} = e^{Z}$$



f) Convergent cones with an opening angle φ = 60°

A_{11} = −0,313 440 643 0

A_{21} = +0,006 787 437 3

A_{31} = −0,369 797 742 9

A_{41} = −0,027 085 948 0

A_{12} = +17,879 816 063

A_{22} = +11,917 959 356

A_{32} = +2,908 387 399 7

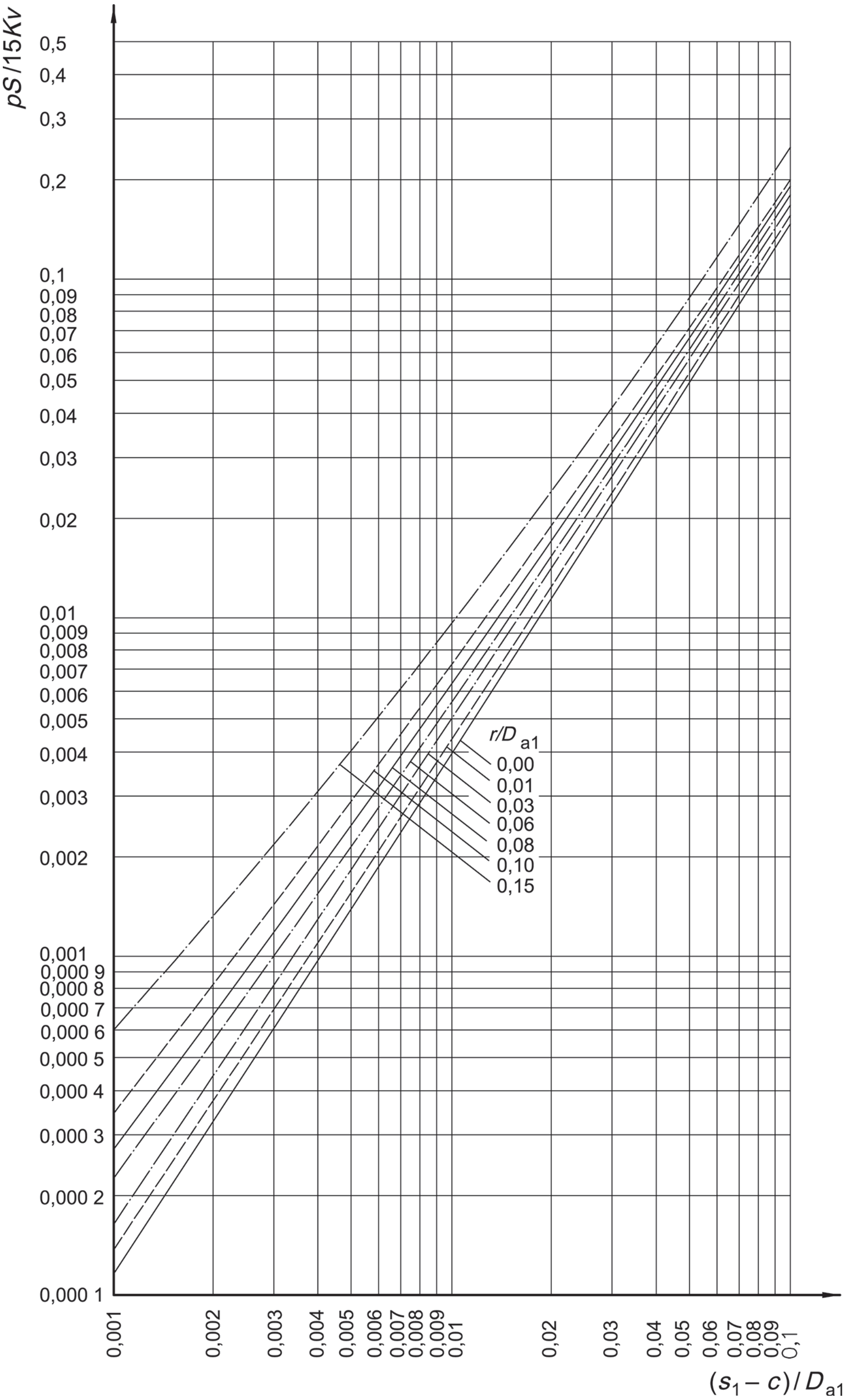
A_{42} = +0,192 469 266 8

$$X = \text{In}\left[\left(s_1 - c\right)/D_{a_1}\right]$$

$$Y = r / D_{a_1}$$

$$Z = \sum_{i=1}^{4}\sum_{i=1}^{2} A_{\text{ij}} - X^{i-1} - Y^{j-1}$$

$$\frac{pS}{15kv} = e^{Z}$$



g) Convergent cones with an opening angle φ = 70°

A_{11} = +1,275 961 366 0

A_{21} = +1,012 365 786 2

A_{31} = −0,021 535 468 1

A_{41} = +0,000 386 857 0

A_{12} = −0,019 369 678 0

A_{22} = +0,002 339 014 0

A_{32} = +0,000 004 617 3

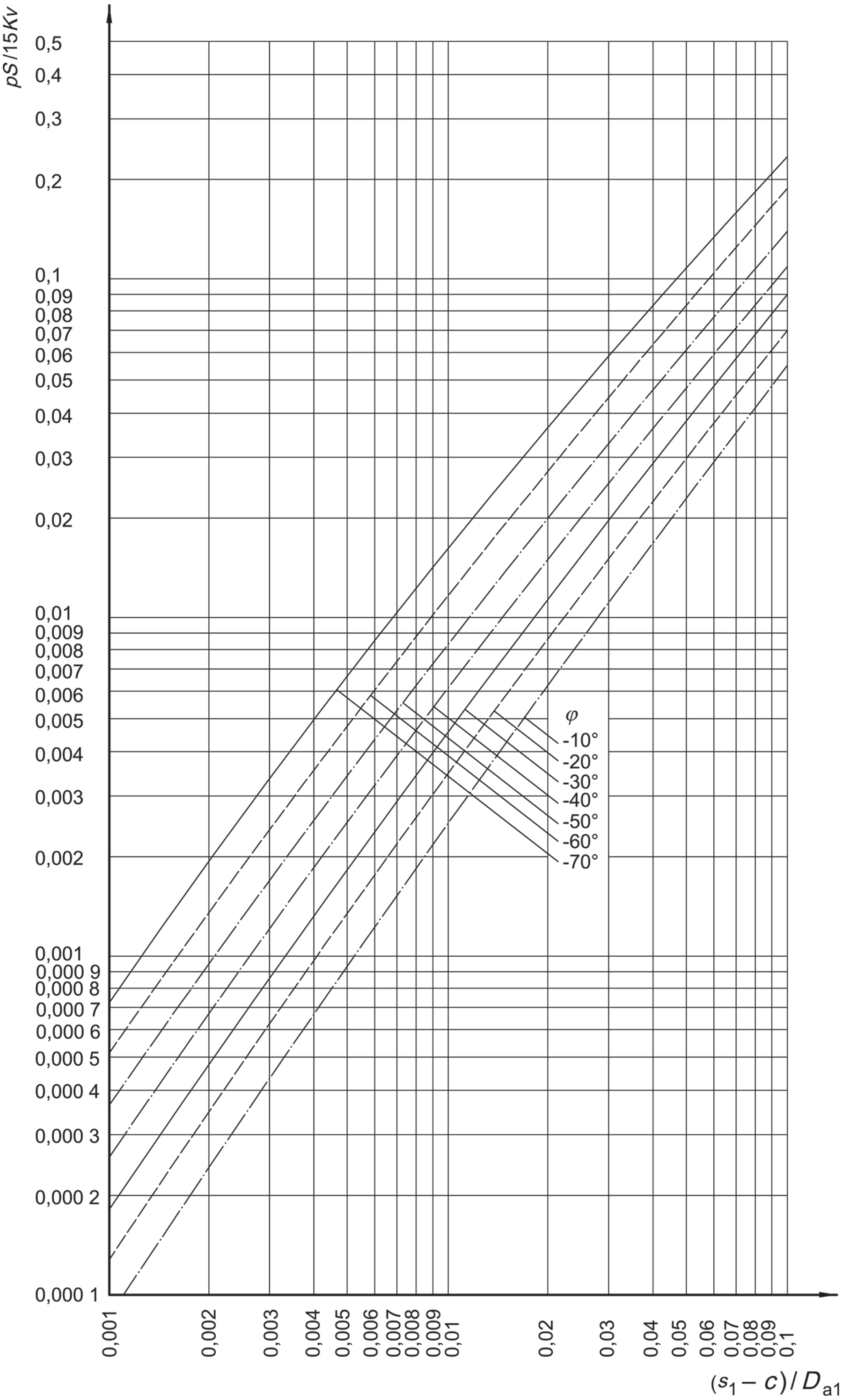
A_{42} = +0,000 000 302 5

$$X = \text{In}\left[\left(s_1 - c\right) / D_{\text{a}_1}\right]$$

$$Y = \left|\varphi\right| \ln$$

$$Z = \sum_{i=1}^{4} \sum_{i=1}^{2} A_{\text{ij}} - X^{i-1} - Y^{j-1}$$

$$\frac{pS}{15kv} = e^{Z}$$



h) Divergent cones with an opening angle φ from 10° to 70°

Figure 10 — Permissible value for convergent and divergent

b) Outside corner area

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

$$s_g = \frac{D_k \ p}{20\frac{K}{s}v - p} \times \frac{1}{\cos \varphi} + c \tag{12}$$

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.

10.3.7.5.7 Internal pressure calculation φ > 70° (pressure on the concave surface)

If $r \geq 0{,}01\ D_{a1}$, the required wall thickness is as per Formula (13).

$$s_l = s_g = 0{,}3\left(D_{a_1} - r\right) \times \frac{\varphi}{90}\sqrt{\frac{p}{10\frac{K}{S}v}} + c \tag{13}$$

10.3.7.5.8 External pressure calculation (pressure on the convex surface)

Stability against elastic buckling and plastic deformation shall be verified using 10.3.7.2 and an equivalent cylinder.

For the example shown in Figure 8 the equivalent cylinder diameter between the knuckle and the stiffener is as per Formula (14).

$$D_a = \frac{D_{a_1} + D_{a_2}}{2 \cos \varphi} \tag{14}$$

and the equivalent cylinder length is as per Formula (15).

$$l = \frac{D_{a_1} - D_{a_2}}{2 \sin \ \varphi} \tag{15}$$

Depending on the relevant boundary conditions the equivalent length between two effective stiffening sections shall be reliably estimated within the meaning of 10.3.7.2.

When $\varphi \geq 10°$ the corner area of a large end may be considered as effective stiffening.

For small ends the thickness in the corner area shall not be less than ×2,5 the required thickness of the conical shell with the same angle φ or a stiffener shall be fitted with the properties as per Formulae (16) and (17).

$$I \geq \frac{p(D_{a_1})^4}{960\left(\frac{K}{S_k}\right)} \tan\varphi \tag{16}$$

$$A \geq \frac{p(D_{a_1})^2}{80\left(\frac{K}{S_k}\right)} \tan\varphi \tag{17}$$

where

S_k is the safety factor to prevent elastic buckling, taken from 10.3.2.4 or 10.3.3.4;

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

The shell over a width of $0{,}5\sqrt{D_{a_1} \times s_1}$ may 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 10.3.7.5.6 above and the safety factors, S, from 10.3.2.4 or 10.3.3.4 increased by 20 %. For thicknesses in the corner area, v shall be the value applicable for internal pressure.

10.3.7.6 Flat ends

10.3.7.6.1 Field of application

Welded or solid flat ends where:

$$\frac{s-c}{D} \geq \sqrt[4]{\frac{0{,}0087p}{E}} \quad \text{and} \quad \frac{(s-c)}{D} \leq \frac{1}{3}$$

and Poisson's ratio is approximately 0,3.

10.3.7.6.2 Openings

Openings are calculated in accordance with 10.3.7.6.3 but with the C factor multiplied by C_A. C_A is given in Figure 11.

10.3.7.6.3 Calculation

The required minimum wall thickness of a circular flat end is given by Formula (18).

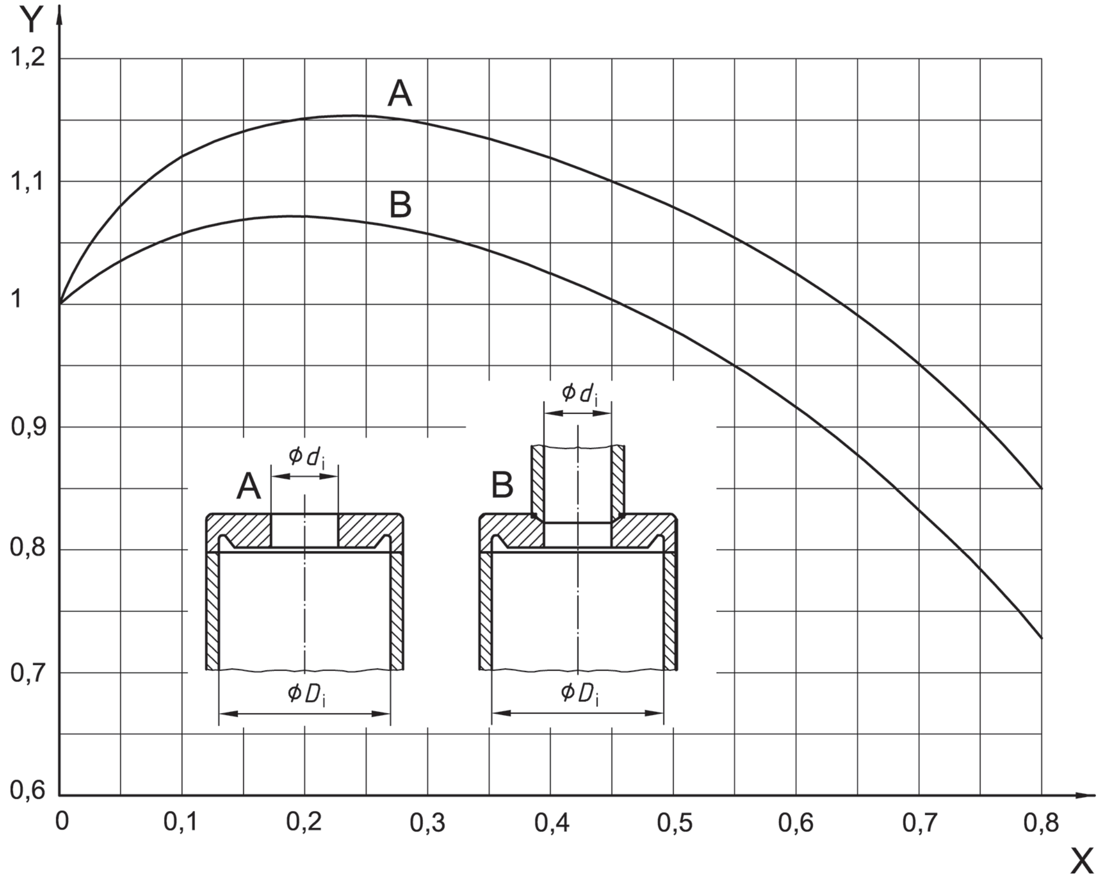
$$s = CD_1\sqrt{\frac{0{,}1pS}{K}} + c \tag{18}$$

where C and D_1 are taken from Figure 12.

The required minimum wall thickness of a rectangular or elliptical flat end is given by Formula (19).

$$s = CC_E f\sqrt{\frac{0{,}1pS}{K}} \tag{19}$$

where C_E is taken from Figure 13.



Key

X ratio d_i / D_i or d_i / f

Y opening factor C_A

Type A

d = inside diameter of opening

D_i = design diameter

f = short side of elliptical end

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

A_1 = 0,999 034 20

A_2 = 1,980 626 00

A_3 = 9,018 554 00

A_4 = 18,632 830 00

A_5 = 19,497 590 00

A_6 = 7,612 568 00

Type B

d = inside diameter of opening

D_i = design diameter

f = short side of elliptical end

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

A_1 = 1,001 003 44

A_2 = 0,944 284 68

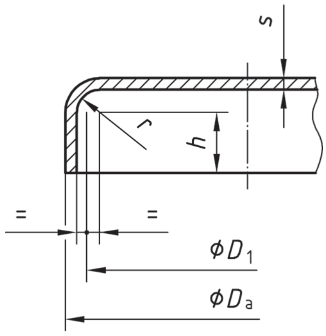
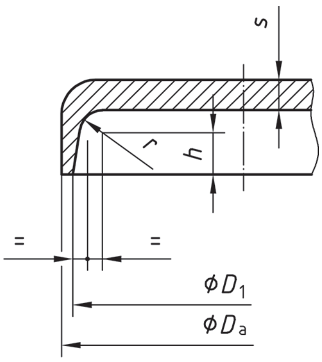
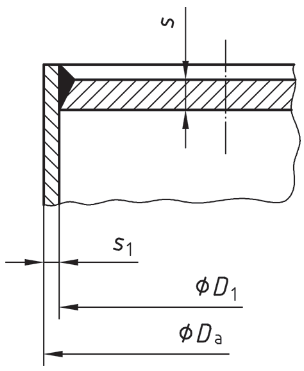
A_3 = 4,312 102 00

A_4 = 8,389 435 00

A_5 = 9,206 283 84

A_6 = 3,694 941 96

Figure 11 — Opening factor CA for flat ends and plates

<table>
<tr><th>Type of flat end design
(principle only)</th><th>Conditions</th><th>Design factor C</th></tr>
<tr><td rowspan="1">a) flanged flat end
</td><td>1. knuckle radius:
<table><tr><th>D_a</th><th>r min</th></tr><tr><td>≤ 500</td><td>30</td></tr><tr><td>> 500 ≤ 1 400</td><td>35</td></tr><tr><td>> 1 400 ≤ 1 600</td><td>40</td></tr><tr><td>> 1 600 ≤ 1 900</td><td>45</td></tr><tr><td>> 1 900</td><td>50</td></tr></table>
and $r \geq 1{,}3\ s$
2. cylindrical part: $h \geq 3{,}5\ s$</td><td>0,30</td></tr>
<tr><td rowspan="2">b) forged or pressed flat end
</td><td>1. knuckle radius:
$r \geq \frac{s}{3}$, however at least 8 mm</td><td>0,35</td></tr>
<tr><td>2. cylindrical part: $h \geq s$</td><td></td></tr>
<tr><td rowspan="2">c) flat plate welded into the shell from both sides
</td><td>plate thickness:
$s \leq 3\ s_1$</td><td>0,35</td></tr>
<tr><td>$s > 3\ s_1$</td><td>0,40</td></tr>
</table>

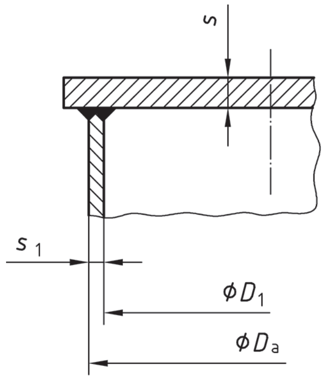
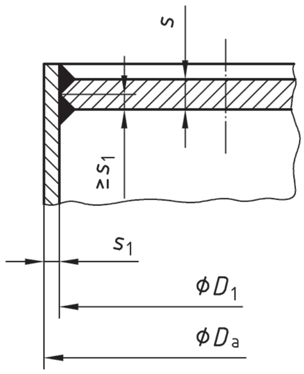
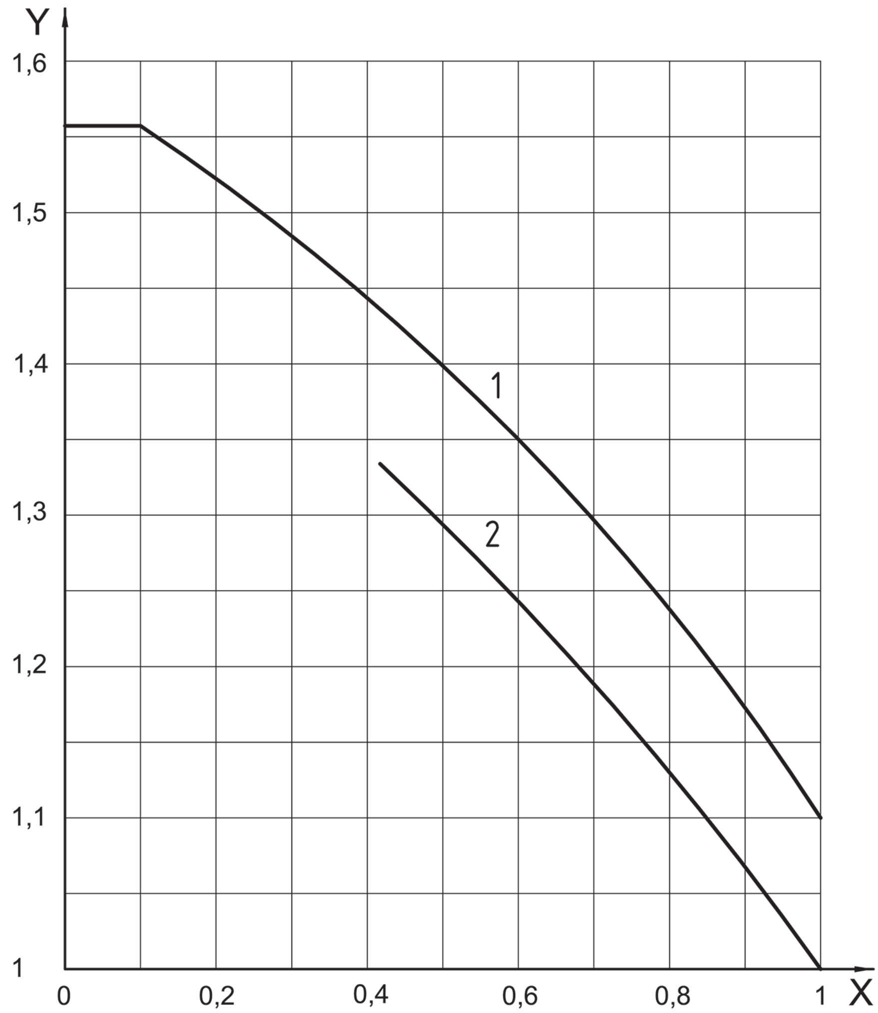
Type of flat end design (principle only)	**Conditions**	**Design factor C**
d) plate welded to the shell with welds at both sides of the latter	plate thickness:	0,40
	$s \leq 3\ s_1$ $s > 3\ s_1$ Only killed steels may be utilized. When plate material is employed, over an area of at least 3 s_1 in the weld zone there shall be no evidence of material discontinuities in the plate.	0,45
e) flat plate welded into the shell from one side only	plate thickness:	0,45
	$s \leq 3\ s_1$ $s > 3\ s_1$	0,50

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



Key

X ratio f/e

Y design factor C_E

1 rectangle

2 ellipse

Rectangular plates

f = short side of the rectangular plate

e = long side of the rectangular plate

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

A_1 = 1,589 146 00

A_2 = − 0,239 349 90

A_3 = − 0,335 179 80

A_4 = 0,085 211 76

Elliptical plates

f = short side of the rectangular plate

e = long side of the rectangular plate

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

A_1 = 1,489 146 00

A_2 = − 0,239 349 90

A_3 = − 0,335 179 80

A_4 = 0,085 211 76

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

10.3.7.7 Openings in cylinders, spheres and cones

10.3.7.7.1 Symbols and units

For the purposes of 10.3.7.7, the following symbols apply in addition to those given in Clause 4.

b	width of pad, ring or shell reinforcement, in millimetres
h	thickness of pad reinforcement, in millimetres
l	ligament (web) distance 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

10.3.7.7.2 Field of application

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

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

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

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

These design rules permit plastic deformation of up to 1 % at highly stressed local areas during pressure testing. Openings shall therefore be carefully designed to avoid abrupt changes in geometry.

NOTE Additional external forces and moments are not covered and would be considered separately where necessary.

10.3.7.7.3 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.

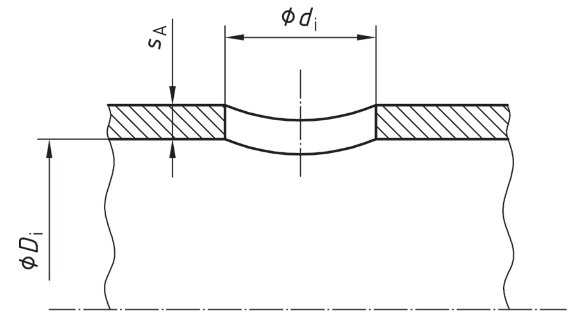


Figure 14 — Increased thickness of a cylindrical shell

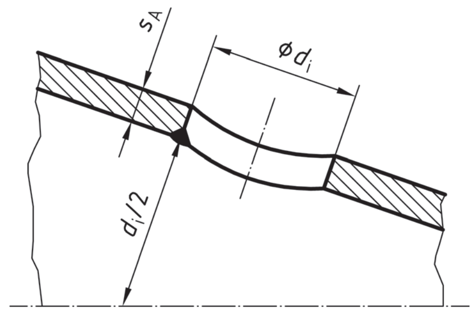


Figure 15 — Increased thickness of a conical shell

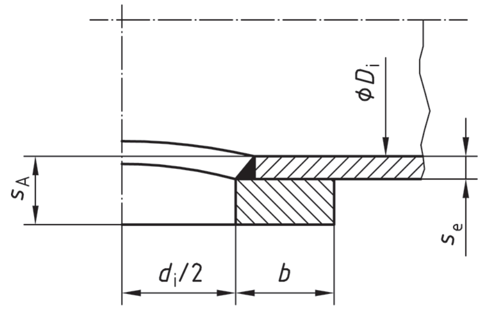


Figure 16 — Set-on reinforcement ring

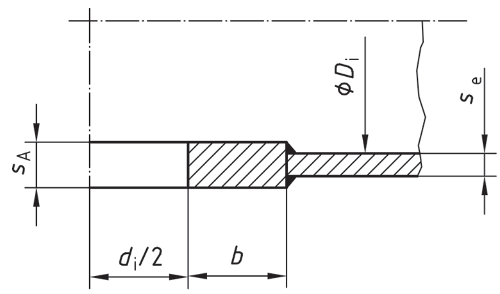


Figure 17 — Set-in reinforcement ring

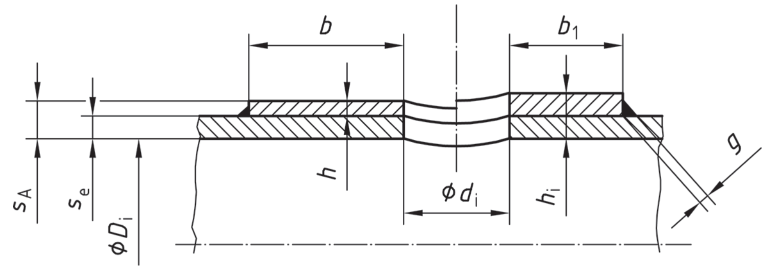


Figure 18 — Pad reinforcement

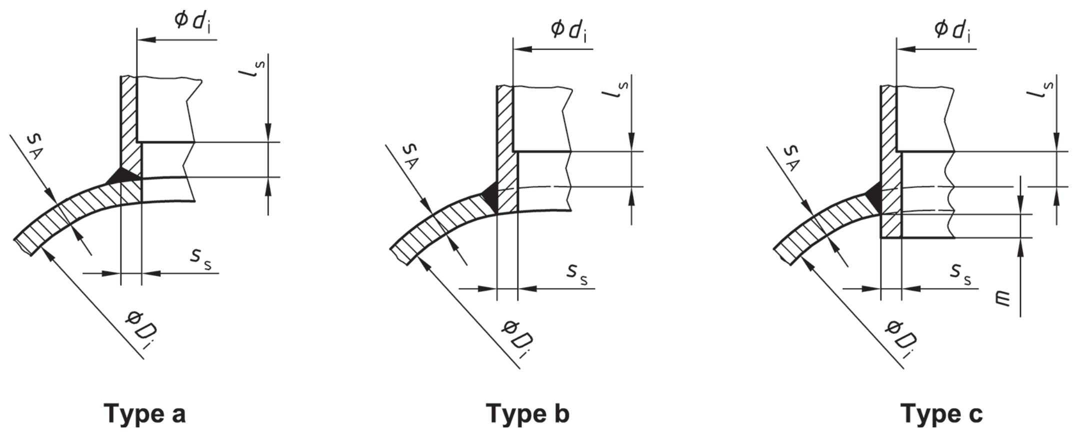


Figure 19 — Nozzle reinforcement

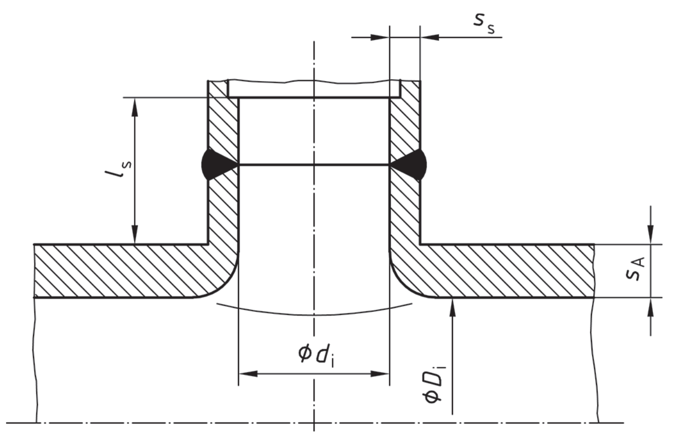
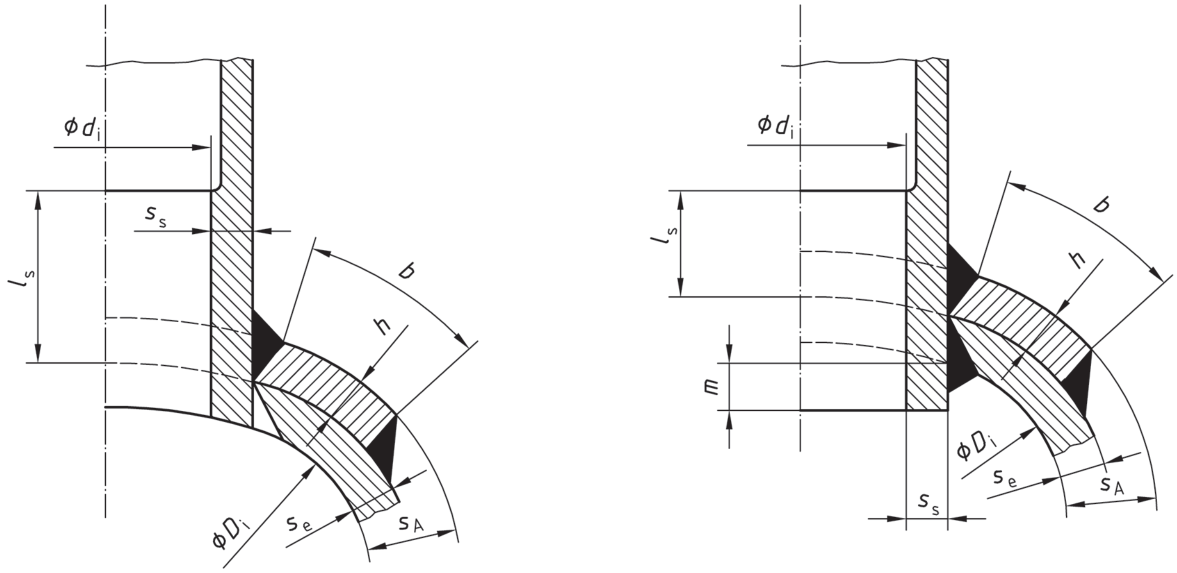


Figure 20 — Necked out opening



Type a Type b

Figure 21 — Pad

10.3.7.7.4 Design of openings

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

The throat thickness of a fillet weld 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 10.3.7.7.5 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.

10.3.7.7.5 Calculation

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.

Openings shall also be reinforced according to the following relationship in Formula (20).

$$\frac{p}{10}\left(\frac{A_p}{10_\sigma}+\frac{1}{2}\right)\leq\frac{K}{S} \tag{20}$$

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

The pressurized 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 22 to 25.

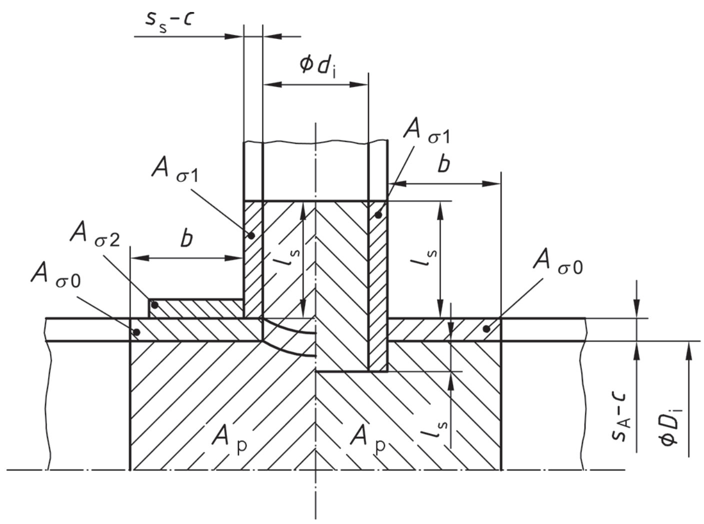


Figure 22 — Calculation scheme for cylindrical shells

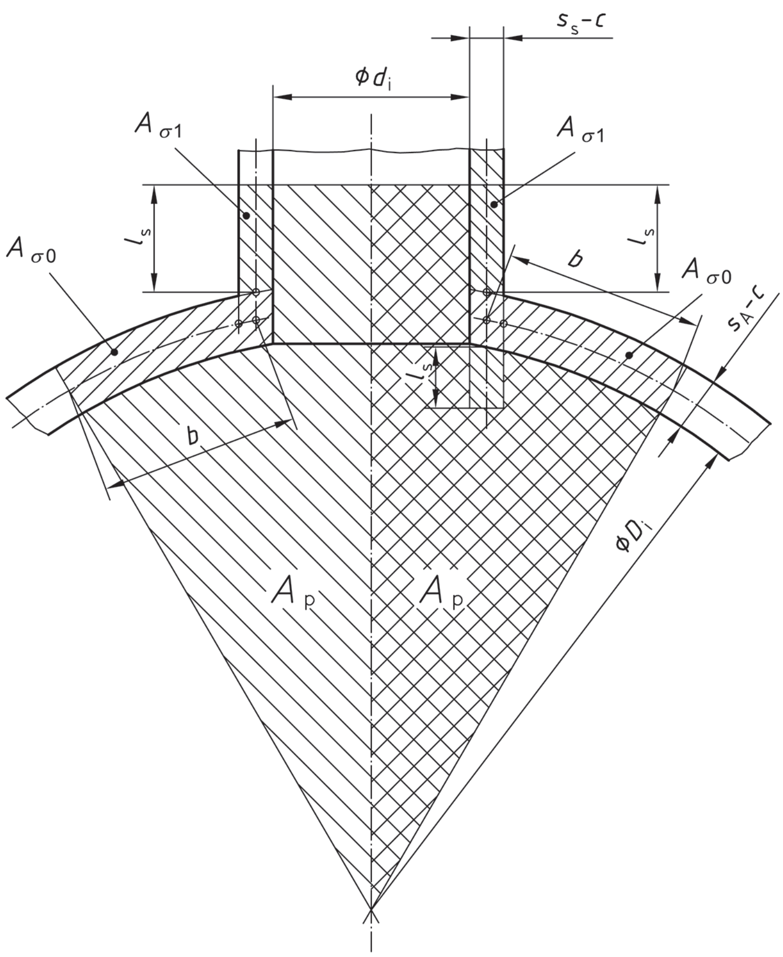


Figure 23 — Calculation scheme for spherical shells

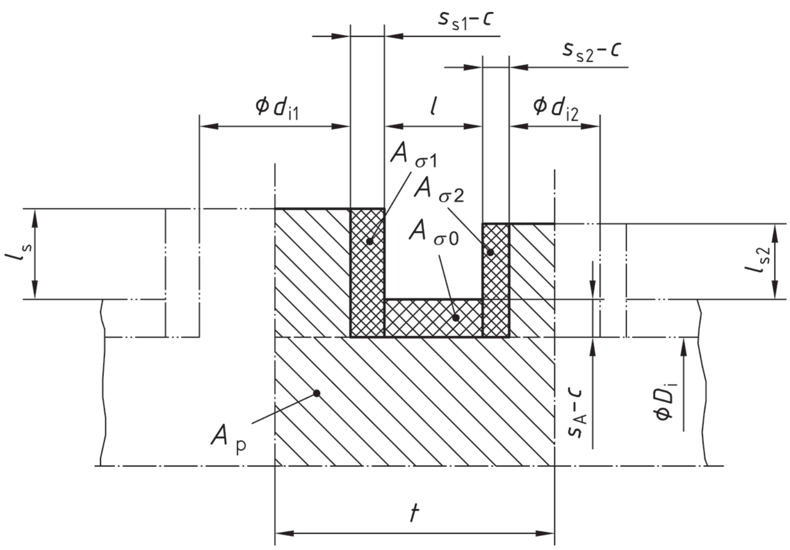


Figure 24 — Calculation scheme for adjacent nozzles in a sphere or in a longitudinal direction of a cylinder

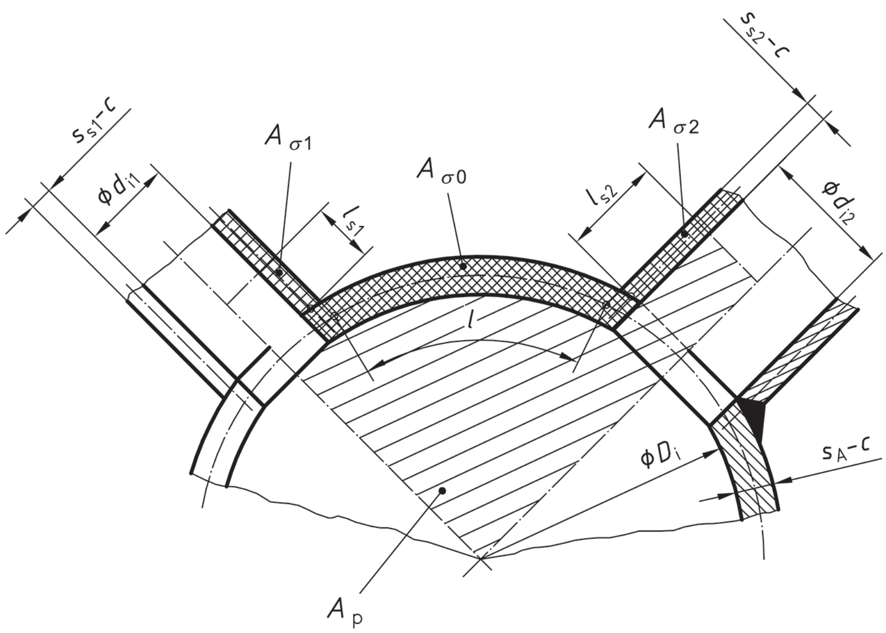


Figure 25 — Calculation scheme for adjacent nozzles in a sphere or in a circumferential direction of a cylinder

The maximum extent of the load-bearing cross-sectional area shall be not more than b as defined in Formula (22) for shells and l_s as defined in Formula (24) or (25) for nozzles.

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

$$l'_s = 0{,}5\, l_s$$

The restrictions of 10.3.7.7.7 and 10.3.7.7.8 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 Formula (21).

$$\left(\frac{K}{S}-\frac{p}{20}\right)A\sigma+\left(\frac{K_1}{S}-\frac{p}{20}\right)A\sigma_1+\left(\frac{K_2}{S}-\frac{p}{20}\right)A\sigma_2\leq\frac{p}{10}A_p \tag{21}$$

10.3.7.7.6 Ring or pad reinforcement or increased shell thickness

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:

$$b=\sqrt{(D_i+s_A-c)(s_A-c)} \tag{22}$$

with a minimum of 3 s_A (see Figures 16, 17 and 18).

The thickness of pad reinforcement in accordance with 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 Formula (23).

$$b_1h_1\geq bh \tag{23}$$

and the limits given above are observed.

10.3.7.7.7 Reinforcement by increased nozzle thickness

The wall thickness ratio shall satisfy $\dfrac{s_s-c}{s_A-c}$.

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 limits of reinforcement normal to the vessel wall are:

for cylinders and cones, $l_s=1{,}25\sqrt{(d_i+s-c)(s_s-c)}$ (24)

for spheres, $l_s=\sqrt{(d_i+s-c)(s_s-c)}$ (25)

The distance, l_s, may be reduced to l_{s1} provided that the thickness, s_s, is increased to s_{s1} according to Formula (26).

$$l_{s1}s_{s1}\geq l_ss_s \tag{26}$$

10.3.7.7.8 Reinforcement by a combination of increased shell and nozzle thicknesses

Shell and nozzle thicknesses may be increased in combination for the reinforcement of openings (Figure 21). For the calculation of reinforcement 10.3.7.7.7 and 10.3.7.7.8 shall be applied together.

The increase in shell thickness may be achieved by an actual increase in shell thickness or the addition of a pad.

10.3.7.7.9 Multiple openings

Multiple openings are regarded as single openings provided the distance, l, between two adjacent openings, (see Figures 24 and 25), complies with:

$$l \geq 2\sqrt{(D_i + s_A - c)(s_A - c)} \quad (27)$$

If l is less than as required by Formula (27) 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 (20) or (21), 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:

$$v_A = \left(t - d_i\right) / t \quad (28)$$

If the nozzles are not attached by full penetration welds, d_A shall be used in Formula (28).

10.3.8 Calculations for operating loads

Unless the design has been validated by experiment, calculations in addition to those in 10.3.7 are required to ensure that stresses due to operating loads are within acceptable limits. All load conditions expected during service shall be considered (see 10.2.3).

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, 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 C provides terminology and acceptable stress limits when an elastic stress analysis is performed.

10.4 Design validation by experimental method

10.4.1 General

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

10.4.2 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.

10.4.3 Tests for pressure integrity

10.4.3.1 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:

$$p_{\mathrm{t}} \geq 1{,}3\left(p_{\mathrm{s}}+1\right) \text{ bar [or } p_{\mathrm{t}} \geq 1{,}3\left(p_{\mathrm{s}}+0{,}1\right) \text{MPa]}$$

After this test all three vessels shall withstand a pressure test of $3\left(p_{\mathrm{s}}+1\right)$ bar [or $3(p_{\mathrm{s}}+0{,}1)$ MPa].

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

10.4.3.2 Piping and accessories

No specific pressure test is required if the nominal design pressure of piping and accessories is greater than the maximum allowable pressure, $\left(p_{\mathrm{s}}+1\right)$ bar [or $3(p_s+0{,}1)$ MPa].

10.4.4 Tests for structural integrity

10.4.4.1 General

After having undergone tests in accordance with 10.4.4.2 and 10.4.4.3, the transportable cryogenic vessel shall not show any visual permanent deformation that will render it unsuitable for use.

After having undergone tests in accordance with 10.4.4.4, 10.4.4.5 and 10.4.4.6, 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 utilized in subsequent tests.

10.4.4.2 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 min and then lowered to the ground. The test shall be repeated for each of the different lifting modes specified.

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

10.4.4.3 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 min. The applied load shall be at least equivalent to × 1,8 the total maximum gross mass of the number of similar vessels specified.

10.4.4.4 Vertical drop test

This test shall be carried out under the conditions defined in 10.4.5.

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

The impact surface shall be a concrete block of at least 1 m × 1 m by 0,1 m thick. The block shall be protected by a sheet of steel of at least 10 mm thick. The flatness of the protective sheet shall be such that the difference in level of any two points on its surface shall not exceed 2 mm. It shall be changed when it is significantly damaged. This test shall be carried out if any of the following conditions is met:

— capacity is less then 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.

10.4.4.5 Inverted drop test

This test shall be carried out under the conditions defined in 10.4.5.

The transportable cryogenic vessel shall be subjected to a vertical drop test so that it falls on to a rigid, flat, non-resilient, smooth and horizontal surface on an upper edge defined when the vessel is in a normal position (e.g. 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 is met:

— capacity is less then 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.

10.4.4.6 Horizontal impact test

This test first shall be carried out under the condition defined in 10.4.5.

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

d) Inclined plane test in accordance with ISO 2244. 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 ISO 2244.

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

e) Pendulum test as specified in ISO 2244. 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 angles.

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 on to two sides, as in b) above.

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

10.4.5 Test conditions

10.4.5.1 The transportable cryogenic vessel shall be filled with a test fluid that is inert with respect to materials used, and which may be water or the cryogenic fluid specified on the nameplate. The test may be carried out with the inner vessel pressurized at any value up to 90 % of the maximum permissible pressure and with the outer jacket under vacuum.

When, during testing, the transportable cryogenic vessel is filled with a fluid of a density less than that of the most dense fluid specified on the nameplate of the vessel, a correction shall be applied as indicated in 10.4.5.2 and 10.4.5.3.

10.4.5.2 Where a minimum drop height is specified, the height shall be increased to maintain the same potential energy using Formula (29).

$$H = H_0 \left(\frac{M_0}{M} \right) \tag{29}$$

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.

10.4.5.3 Where a minimum velocity is specified, the velocity on impact shall be increased to maintain the same kinetic energy, using Formula (30).

$$V = V_0 \sqrt{\frac{M_0}{M}} \tag{30}$$

where V_0 is the velocity on impact specified, in metres per second.

11 Fabrication

11.1 General

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

11.1.2 The manufacturer, shall maintain:

— 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.

11.2 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.

11.3 Cold forming

11.3.1 Austenitic stainless steel

Heat treatment after cold forming is not 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.

Heat treatment is required for cryogenic gases containing traces of sulfur, e.g. LNG.

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

11.3.2 Ferritic steel

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

11.3.3 Aluminium or aluminium alloys

Cold formed ends made from aluminium or an aluminium alloy do not normally require post forming heat treatment, unless there is a risk of stress corrosion in service. Treatment shall be carried out in accordance with the material standard.

11.4 Hot forming

11.4.1 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.

11.4.2 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 11.3.1 shall be complied with.

11.4.3 Aluminium or aluminium alloys

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

11.5 Manufacturing tolerances

11.5.1 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 18,4°. 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.

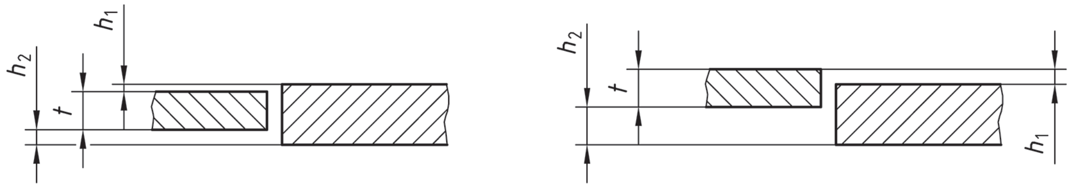
The distance between either surface of the thicker plate and the centreline of the thinner plate of tapered seams shall be:

— for longitudinal seams, not less than 35 % of the thickness of the thinner plate;

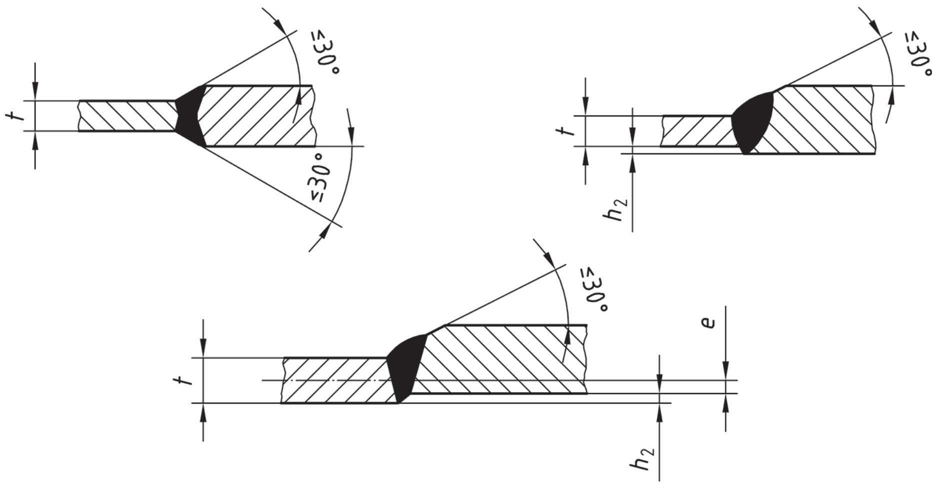
— for circumferential seams, not less than 25 % of the thickness of the thinner plate.

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

These requirements are illustrated in Figure 26.



a) Seams which do not require a taper



b) Seams which do require a taper

Key

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 $h_2 \leq 0{,}25t$

For longitudinal seams: $h_2 \leq 0{,}15t$ and $e = \frac{t}{2} - h \geq 0{,}35t$

For circumferential seams: $h \leq 0{,}25t$ and $e = \frac{t}{2} - h \geq 0{,}25t$

Figure 26 — Plate alignment

11.5.2 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.

11.5.3 Dished ends

The knuckle radius shall be not less than specified and any variation of the crown radius shall not be abrupt and shall adhere to the tolerance $^{+0{,}625}_{-1{,}25}$ %.

11.5.4 Cylinders

11.5.4.1 The actual circumference shall not deviate from the circumference calculated from the specified diameter by more than ±1,5 %.

11.5.4.2 The out of roundness, O, calculated from Formula (31).

$$O = \frac{200\,(D_{max} - D_{min})}{D_{max} + D_{min}} \tag{31}$$

shall not be greater than the values shown in Table 4.

Table 4 — Permitted out of roundness of cylinders

Wall thickness to diameter ratio	Permitted out of roundness for internal pressure	Permitted out of roundness for 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 be no greater than 1 % of their length or width.

For cylinders subjected 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 using a value of u determined according to Formula (32).

$$u = \frac{400}{D_a} q \tag{32}$$

where q is the depth of flattening, in millimetres.

11.5.4.3 Departure from a straight line shall be no greater than 0,5 % of the cylindrical length, except where otherwise required by the design.

11.6 Welding

11.6.1 General

This document requires that the welding method be appropriate and be carried out by qualified welders and/or operators, that the materials be compatible and that there be verification by a welding procedure test.

The manufacturer shall fulfil the standard quality requirements of ISO 3834-2.

11.6.2 Qualification

Welding procedures shall be approved in accordance with ISO 15614-1, ISO 15614-2 or ISO 15613.

Welders and welding operators shall be qualified in accordance with ISO 9606-1 or ISO 9606-2 or ISO 14732 as applicable.

11.6.3 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 pressurization. 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.

11.6.4 Welded joints

11.6.4.1 Some specific weld details appropriate to vessels conforming to this document are given in Annex F. These details show sound and currently accepted practice. It is not intended that these are mandatory nor should 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 in accordance with ISO 15614-1, ISO 15614-2 or ISO 15613 as applicable.

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

11.6.4.3 For vessels intended for flammable gas service the selection of joining materials and welding procedures shall take into consideration the prevention of secondary failure in the event of external fire.

11.6.4.4 For vessels intended for service in liquid oxygen or other oxidising cryogenic liquids, the internal weld details shall be such that debris, contaminants, hydrocarbons or degreasants cannot accumulate and thus cause a fire risk.

11.7 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 such joints. Similarly, operators shall be qualified in such procedures and only qualified personnel shall then carry out these procedures.

12 Initial inspection and testing

12.1 Quality plan

12.1.1 General

A quality plan forming part of the quality system referred to in 11.1.1 shall include, as a minimum, the inspection and testing stages listed 12.1.2.

12.1.2 Inspection stages during manufacture of an inner vessel

The following inspection stages shall be conducted during the 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.

12.1.3 Additional inspection stages during manufacture of a transportable cryogenic vessel

The following inspection stages shall be conducted during the manufacture of a transportable cryogenic vessel:

- verification of cleanliness and dryness of transportable cryogenic vessel (see ISO 23208);
- visual examination of welds;
- ensuring integrity of vacuum;
- leak testing of external piping;
- checking documentation and installation of pressure relief device(s);
- checking installation of vacuum space relief device;
- checking name plate and any other specified markings;
- examination of completed vessel including dimensional check.

12.2 Production control test plates

12.2.1 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.

12.2.2 Testing

The following tests are required:

— one face bend test in accordance with ISO 5173;

— one root bend test in accordance with ISO 5173;

— one tensile test transverse to the weld in accordance with ISO 4136.

Testing and acceptance shall be as required for welding procedure qualifications in accordance with ISO 15607.

An impact test in accordance with ISO 148-1 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 ISO 21028-1.

Some damage and deformation of the guard is acceptable provided that the integrity of the transportable cryogenic vessel and its safety systems is maintained.

12.3 Non-destructive testing

12.3.1 General

Non-destructive testing personnel shall be qualified for the duties in accordance with ISO 9712.

Non-destructive testing shall be carried out according ISO 17635 and ISO 5817 (for steel welds) or ISO 10042 (for aluminium welds), specifying general rules and standards to be applied to the different types of testing, for either the methodology or the acceptance level for metallic materials.

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

12.3.2 Extent of examination for surface imperfections

All welds shall be visually examined in accordance with ISO 17637 and ISO 5817 (or ISO 10042 for aluminium welds).

If any doubt arises, this examination shall be supplemented by surface-crack detection, (e.g. penetrant testing according ISO 3452-1 and ISO 23277).

Areas from which temporary attachments have been removed shall be ground smooth and subjected to surface crack detection.

12.3.3 Extent of examination for volumetric imperfections

Examination of the inner vessel for inner-vessel weld seams shall be carried out by radiographic examination in accordance with ISO 17636-1 and ISO 10675-1 (or ISO 10675-2 for aluminium welds).

A special case is made

— to use radiographic techniques with digital detectors and processing according ISO 17636-2, and

— to justify ultrasonic testing in accordance with ISO 17640 and ISO 11666, or other methods.

The extent of radiographic examination of main seams on the inner vessel shall be in accordance with Table 5 for manually produced seams and Table 6 for seams produced using automatic welding processes.

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

Table 5 — Extent of radiographic examination for manually welded seams

Weld joint factor	Radiographic examination		
	Longitudinal seams[a]	T junctions[a]	Circumferential seams[a]
1,0[b]	100 %[c]	100 %	25 %[c]
0,85	2 %	1 film per vessel	2 %

[a] When a butt weld occurs less than 50 mm from a nozzle cut out, additional radiographic film(s) shall be taken.

[b] 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.

[c] The level of radiographic examination 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.

Table 6 — Extent of radiographic examination for seams produced using automatic welding processes

Weld joint factor	Radiographic examination	
	T junctions and longitudinal seams[a]	Circumferential seams[a]
Any	The greater of one radiographic film per day or one radiographic film per 100 vessels[b]	The greater of one radiographic film per week or one radiographic film per 500 vessels[b]

[a] Where a butt weld occurs less than 50 mm from a nozzle cut out, additional radiographic film(s) shall be taken.

[b] 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;

there has been an interruption in production that may affect the quality of the weld. Here, additional radiographic film(s) shall be taken.

12.3.4 Acceptance criteria for surface and volumetric imperfections as classified in ISO 6520-1

12.3.4.1 Acceptance criteria for predominantly static loaded vessels

The results of the weld checks and inspections shall meet quality level C of ISO 5817 or ISO 10042 and the corresponding ISO standards for testing classes and acceptance levels, as defined in ISO 17635:2016, Annex A:

NDT method	Testing techniques and levels in accordance with	Acceptance levels in accordance with
Visual testing (VT)	ISO 17637	ISO 5817 Level C (for steel welds) ISO 10042 Level C (for aluminium welds)
Radiographic testing (RT)	ISO 17636-1 class B[a]	ISO 10675-1 Level 2 (for steel welds) ISO 10675-2 Level 2 (for aluminium welds)
Penetrant testing (PT)	ISO 3452-1	ISO 23277 Level 2X

[a] The minimum number of exposures for circumferential weld testing may correspond to the requirements of ISO 17636-1, class A.

Additional requirements for the following imperfections:

— stray arc (601) – removal plus 100 % penetrant testing to ensure no imperfection;

— spatter (602) – weld spatter shall be removed from all pressure parts and load carrying attachment welds.

— torn surface (603), grinding mark (604), chipping mark (605) shall be ground to provide a smooth transition;

— underflushing (606) shall not be permitted. Any local underflushing shall be related to design characteristics.

12.3.4.2 Acceptance criteria for fatigue loaded vessels

The results of the weld checks and inspections shall meet quality level B of ISO 5817 or ISO 10042 and the corresponding ISO standards for testing classes and acceptance levels as defined in ISO 17635:2016, Annex A:

NDT method	Testing techniques and levels in accordance with	Acceptance levels in accordance with
Visual testing (VT)	ISO 17637	ISO 5817 Level B (for steel welds) ISO 10042 Level B (for aluminium welds)
Radiographic testing (RT)	ISO 17636-1 class B[a]	ISO 10675-1 Level 1 (for steel welds) ISO 10675-2 Level 1 (for aluminium welds)
Penetrant testing (PT)	ISO 3452-1	ISO 23277 Level 2X

[a] The minimum number of exposures for circumferential weld testing may correspond to the requirements of ISO 17636-1, class A.

Additional requirements for the following imperfections:

— stray arc (601) – removal plus 100 % penetrant testing to ensure no imperfection;

— spatter (602) – weld spatter shall be removed from all pressure parts and load carrying attachment welds.

— torn surface (603), grinding mark (604), chipping mark (605) shall be ground to provide a smooth transition;

— underflushing (606) shall not be permitted. Any local underflushing shall be related to design characteristics.

12.3.4.3 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.

12.4 Rectification

12.4.1 General

Although unacceptable volumetric or surface defects may be repaired by removing the defects and rewelding, 100 % of all repaired welds shall be examined visually and radiographically to the original acceptance standards.

12.4.2 Manually welded seams

When repairs to welds are carried out as a result of radiographic examination that 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 characterized 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.

12.4.3 Seams produced using automatic welding processes

If any unacceptable defects are found by radiographic examination, all main weld seams shall be radiographically examined at 100 %, 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.

12.5 Pressure testing

12.5.1 Every inner vessel shall undergo a pressure test.

The test pressure shall not be less than $1,3(p_s + 1)$ bar or $1,3(p_s + 0,1)$ MPa

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.

As pneumatic testing is potentially a much more dangerous operation than hydraulic testing, it shall normally only be carried out on vessels of such design and construction that 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.

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

12.5.3 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 0,005 % (50 ppm).

12.5.4 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 or (p_S + 0,1 MPa);

— external piping, p_S.

13 Marking and labelling

The transportable cryogenic vessel shall bear the marking and labelling required by the applicable road/rail/sea regulations. Examples of tank plates (of the complete tank and of the inner vessel) for fixed tanks of road tankers (tank-vehicles), demountable tanks, tank-containers and tank swap bodies are given for information in Annex E.

14 Documentation

Technical documents delivered by the manufacturer to the owner consisting of:

— all certificates establishing the conformity with this document, e.g. material, pressure test, cleanliness, safety devices and other accessories if applicable;

— a short description of the vessel (including characteristic data, etc.);

— a list of fluids and their net mass for which the cryogenic vessel is designed;

— an operating manual (for the user) consisting of:

1) a short description of the vessel (including characteristic data, etc.);

2) a statement that the vessel is in conformity with this document;

3) the instructions for normal operation.

Annex A
(informative)

Base materials

Table A.1 — Pressure vessels

Specification no.	Material grade	Material number	Heat treatment condition
EN 10028-4	X8Ni9	1.566 2	HT 640 and HT 680
EN 10222-3	X8Ni9	1.566 2	—
EN 10217-7 – DIN 10216-5	X5CrNi 18–10	1.430 1	—
EN 10217-7 – DIN 10216-5	X2CrNiN 18–10	1.431 1	—
EN 10217-7 – DIN 10216-5	X6CrNiTi 18–10	1.454 1	—
EN 10217-7 – DIN 10216-5	X6CrNiNb 18–10	1.455 0	—
EN 10217-7 – DIN 10216-5	X5CrNiMo 17–12–2	1.440 1	—
EN 10217-7 – DIN 10216-5	X2CrNiMo 17–13–2	1.440 4	—
EN 10217-7 – DIN 10216-5	X6CrNiMoTi 17–12–2	1.457 1	—
EN 10217-7 – DIN 10216-5	X2CrNiMoN 17–13–3	1.442 9	—
EN 10217-7 – DIN 10216-5	X2CrNiMo 18–14–3	1.443 5	—
EN 10217-7 – DIN 10216-5	X2CrNiMo 17–13–3	1.443 6	—
EN 10217-7 – DIN 10216-5	X2CrNiMoN 17–13–5	1.443 9	—
ASME SA 353/SA 353M	9 % Nickel	K8134 0	N + N + T
ASME SA 553/SA 553M	Type 1 (9 %) Nickel	K8134 0	Q and T
ASME SA 522/SA 522M	Type 1 (9 %) Nickel	K8134 0	N + N + T or Q + T
EN 10028-7	X2CrNi18–9	1,430 7	—
EN 10028-7	X2CrNi19–11	1,430 6	—
EN 10028-7	X2CrNIN18–10	1,431 1	—
EN 10028-7	X5CrNiN19–9	1,431 5	—
EN 10028-7	X5CrNi18–10	1,430 1	—
EN 10028-7	X3CrNiMo17–12–2	1,440 1	—
EN 10028-7	X2CrNiMo17–12–2	1,440 4	—
EN 10028-7	X2CrNiMoN17–11–2	1,440 6	—
EN 10028-7	X2CrNiMoN17–13–3	1,442 9	—
EN 10222-5	X2CrNi18–9	1,430 7	—
EN 10222-5	X5CrNi18–10	1,430 1	—
EN 1022-5	X5CrNiMo17–12–2	1,440 1	—
EN 10222-5	X2CrNiMo17–12–2	1,440 4	—
EN 10088-3	X2CrNi19–11	1,430 6	—
EN 10088-3	X2CrNiN18–10	1,431 1	—
EN 10088-3	X5CrNi18–10	1,430 1	—
EN 10088-3	X5CrNiMo17–12–2	1,440 1	—
EN 10088-3	X2CrNiMo17–13–2	1,440 4	—
EN 10088-3	X2CrNiMoN17–12–2	1,440 6	—

Table A.1 *(continued)*

Specification no.	Material grade	Material number	Heat treatment condition
EN 10088-3	X2CrNiMo17–13–3	1,442 9	—
ASME SA 479/SA 479M	304L	S304 03	—
ASME SA 479/SA 479M	304	S304 00	—
ASME SA 479/SA 479M	316L	S316 03	—
ASME SA 479/SA 479M	316	S316 00	—
ASME SA 240	304, 304L, 316, 316L		—
JIS G 3127	SL9N520	1,566 2	—
JIS G 4303–4305	SUS304	1,430 1	—
JIS G4303-4305	SUS304L	1,430 7	—
JIS G4303-4305	SUS316	1,440 1	—
JIS G4303-4305	SUS316L	1,440 4	—
JIS G 4317–4320	SUS321	1,454 1	—
JIS G 4317–4320	SUS347	1,455 0	—
JIS G 4317–4320	SUS316	1,440 1	—
JIS G 4317–4320	SUS316L	1,440 4	—
JIS G 4317–4320	SUS317L	1,443 9	—
JIS G 4313–4315	SUS304	1,430 1	—
JIS G 4313–4315	SUS304L	1,430 7	—
JIS G 4313–4315	SUS304N1	1,440 6	—
JIS G4313-4315	SUS304LN	SUS304LN	—
JIS G4317-4320	SUS316L	1,440 6	—
JIS G4315-4315	SUS316LN	1,442 9	—
GB 3531	16MnDR	—	—
GB 3531	15MnNiDR	—	—
GB 3531	09MnNiDT	—	—
GB 150.2	08Ni3DR	—	—
GB 150.2	06Ni9DR	—	—
GB 24511	06Cr19Ni10	S30408	—
GB 24511	022Cr19Ni10	S30403	—
GB 24511	06Cr17Ni12Mo2	S31608	—
GB 24511	022Cr17Ni12Mo2	S31603	—

Table A.2 — Piping and pipe fittings

Specification no.	Material grade	Material number
ASTM A 182/A 182M	F304L	S30403
ASTM A 182/A 182M	FP304	S30400
ASTM A 182/A 182M	F316L	S31603
ASTM A 182/A 182M	F316	S31600
ASTM A 216/A 213M	TP304L	S30403
ASTM A 216/A 213M	TP304	S30400
ASTM A 216/A 213M	TP316L	S31603
ASTM A 231/A 213A	TP316	S31600
ASTM A 249/A 249M	TP316	S31600
ASTM A 249/A 249M	TP304L	S30403
ASTM A 249/A 249M	TP304	S30400
ASTM A 249/A 249M	TP316L	S31603
ASTM A 249/A249M	TP316	S31600
ASTM A 269	TP304L	S30403
ASTM A 269	TP304	S30400
ASTM A 269	TP316L	S31603
ASTM A 269	TP316	S31600
ASTM A 276	304L	S30403
ASTM A 276	304	S30400
ASTM A 276	316L	S31603
ASTM A 276	316	S31600
ASTM A 312/A 312M	TP304L	S30403
ASTM A 312/A 312M	TP304	S30400
ASTM A 312/A 312M	TP316L	S31603
ASTM A 312/A 312M	TP316	S31600
ASTM A 312/A 312M	TP321	S32100
ASTM A 403/A 403M	WP304L	S30403
ASTM A 403/A 403M	WP304	S30400
ASTM A 403/A 403M	WP316L	S31603
ASTM A 403/A 403M	WP316	S31600
ASTM A 632	TP304L	S30403
ASTM A 632	TP304	S30400
ASTM A 632	TP316L	S31603
ASTM A 632	TP316	S31600
ASTM A 733	TP304L	S30403
ASTM A 733	TP304	S30400
ASTM A 733	TP316L	S31603
NFA 49117	TUZ2CN18–10	—
NFA 49147	TUZ2CN18–10	—
NOTE Piping and pipe fittings to ASTM standards are seamless.		

Annex B
(normative)

Outer jacket relief devices

B.1 General

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

B.2 Requirements

B.2.1 General

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

Bursting disc devices shall be as specified in ISO 4126-2.

B.2.2 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 10.2.5.3. 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.

B.2.3 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.

B.2.4 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 ISO 4126-2.

B.2.5 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 ISO 4126-2.

B.2.6 Marking

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

Other pressure protection devices shall be marked with the number of this document.

Annex C
(normative)

Elastic stress analysis

C.1 General

When operating conditions are being considered, Annex C provides rules to be followed if elastic stress analysis is used to evaluate components of a transportable cryogenic vessel. Allowance for the effects of dynamic loads is made by using equivalent static loads as defined in 10.3.8.

C.4 and C.5 give alternative criteria for demonstrating the acceptability of design on the basis of elastic analysis. The criteria in C.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 C.2.1.

The stress intensities determined in this way shall be less than the permissible values given in C.3 and C.4 or C.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 document are not considered to be in cyclic service.

Figure C.1 and Table C.1 have been included as guidance, where C.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. C.4.5 explains the reason for separating them into two categories “general” and “secondary” in the case of thermal stresses.

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

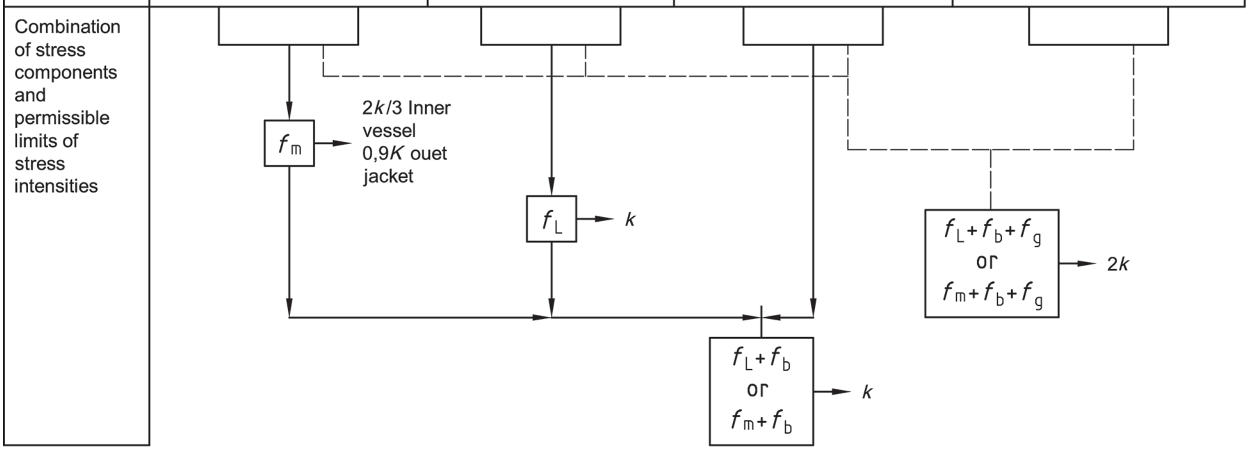
Vessel component	Location	Origin of stress	Type of stress	Classification
Cylindrical or spherical shell	Shell plate remote from discontinuities	Internal pressure	General membrane	f_m
			Gradient through plate thickness	f_g
		Axial thermal gradient	Membrane	f_g
			Bending	
	Junction with head or flange	Internal pressure	Membrane	f_L
			Bending	f_g

Table C.1 *(continued)*

Vessel component	Location	Origin of stress	Type of stress	Classification
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	f_m
		External load or moment	Bending across full section; stress component perpendicular to cross section	
	Near nozzle or other opening	External load or moment, or internal pressure	Local membrane	f_L
			Bending	f_g
	Any location	Temperature difference between shell and end	Membrane	f_g
			Bending	
Dished end or conical end	Crown	Internal pressure	Membrane	f_m
			Bending	f_b
	Knuckle or junction to shell	Internal pressure	Membrane	f_L
			Bending	f_g
Flat end	Centre region	Internal pressure	Membrane	f_m
			Bending	f_b
	Junction to shell	Internal pressure	Membrane	f_L
			Bending	f_g
Perforated end or shell	Typical ligament in a uniform pattern	Pressure	Membrane (average through cross section)	f_m
			Bending (average through width of ligament, but gradient through plate)	f_b
	Isolated or atypical ligament	Pressure	Membrane	f_m
			Bending	f_b
Nozzle	Cross section perpendicular to nozzle axis	Internal pressure or external load or moment	General membrane (average across full section); stress component perpendicular to section	f_m
		External load or moment	Bending across nozzle section	
	Nozzle wall	Internal pressure	General membrane	f_m
			Local membrane	f_L
			Bending	f_g
		Differential expansion	Membrane	f_g
			Bending	

NOTE Consideration should also be given to the possibility of buckling and excessive deformation in vessels with large diameter-to-thickness ratio.

Stress category	Primary			Secondary
	General	Local	Bending	
Description (for examples see Table D.1)	Average primary stress across solid section. Excludes discontinuities and concentrations. Produced only by mechanical loads.	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. Excludes 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



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 C.1 — Stress categories and limits of stress intensity

C.2 Terminology

C.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.

C.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:

a) end to shell junctions;

b) junctions between shells of different diameters or thicknesses;

c) nozzles.

C.2.3 Local structural discontinuity

A local structural discontinuity is a source of stress or strain intensification which 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. Typical cases are:

a) small fillet radii;

b) small attachments;

c) partial penetration welds.

C.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.

C.2.5 Shear stress

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

C.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.

C.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. A normal stress or a shear stress developed by the imposed loading, 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 C.2.8.

Examples of general primary stress are:

a) stress in a cylindrical or a spherical shell due to internal pressure or to distributed live loads;

b) bending stress in the central portion of a flat head due to pressure.

C.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 permissible general primary membrane stress does not extend in the meridional direction more than $0{,}5\sqrt{Rs}$ where R and s are respectively the radius and thickness of the component.

It is also considered to be local if, in the meridional direction, it is no closer than $2{,}5\sqrt{Rs}$ to another region where the limits of general primary membrane stress are exceeded.

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.

C.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.

C.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 localized falls into this category if it is of a type that cannot cause noticeable distortion, e.g.:

a) surface stresses in the wall of a vessel or pipe produced by thermal shock;

b) stress at a local structural discontinuity.

C.3 Limit for longitudinal compressive general membrane stress

The longitudinal compressive stress shall not 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 C.2 or C.3 in terms of p_e/p_{yss} and where

$$p_e = \frac{1{,}21 Es^2}{R^2} \text{ and } p_{yss} = \frac{1{,}86Ks}{R} \text{ for carbon steel and}$$

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

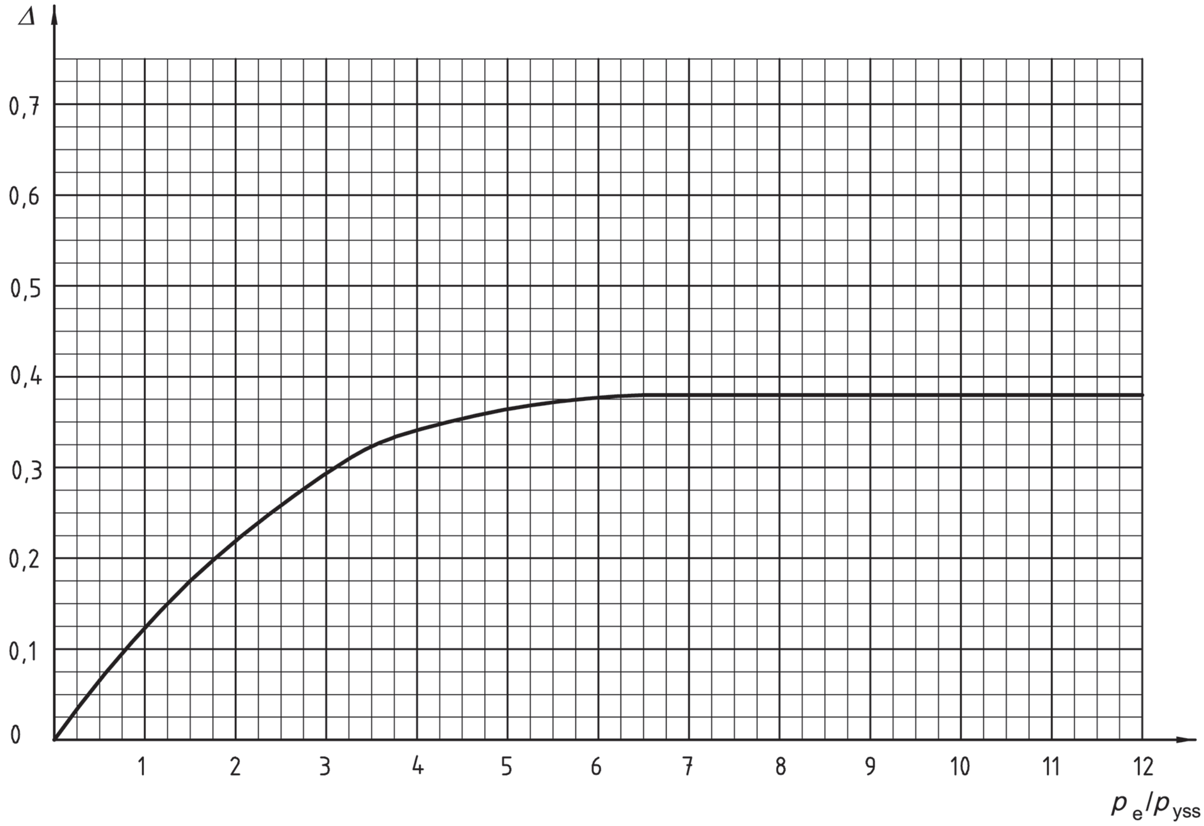


Figure C.2 — For vessels subject to external pressure

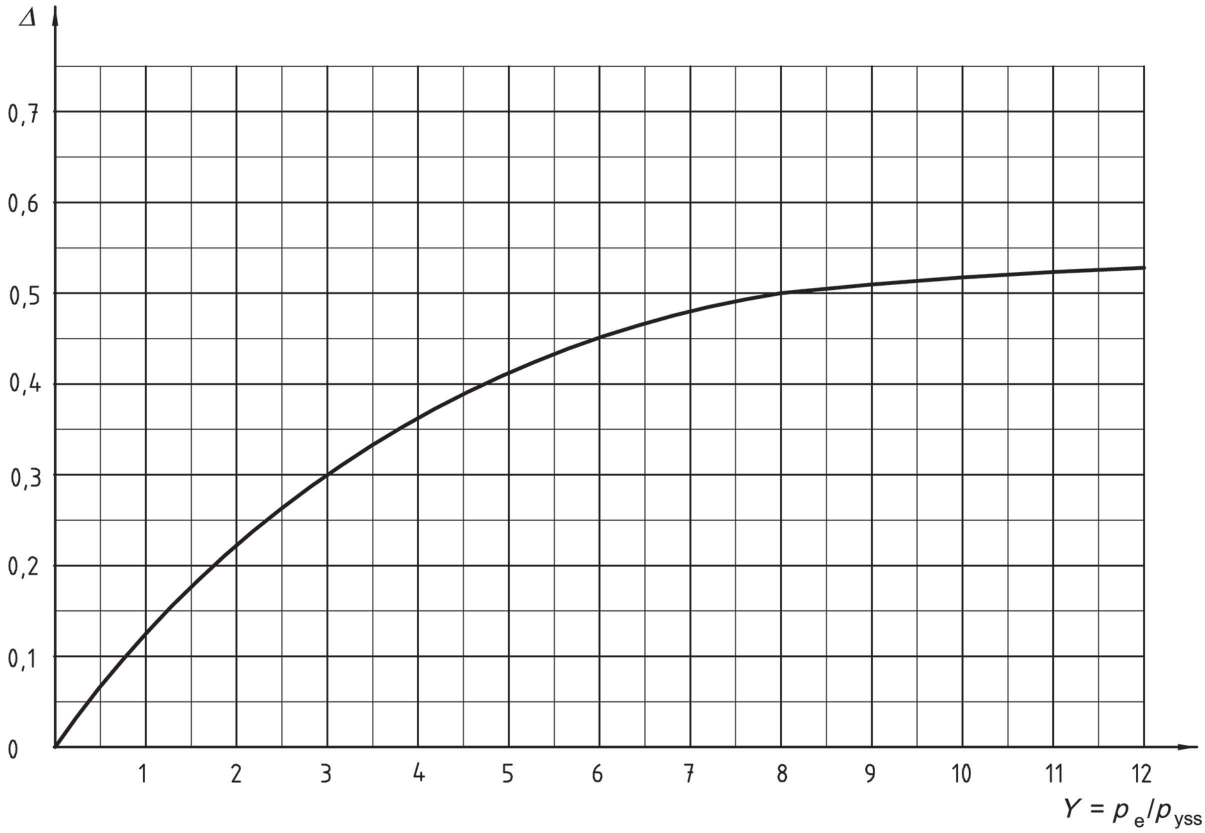


Figure C.3 — For vessels not subject to external pressure

C.4 Stress categories and stress limits for general application

C.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 C.4.2 to C.4.6. For each category, a stress intensity value is derived for a specific condition of design. To satisfy the analysis, this stress intensity shall fall within the limit detailed for each category.

C.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 C.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 permissible stress value $2K/3$ for the inner vessel and $0{,}9K$ for the outer jacket.

C.4.3 Local primary membrane stress category

The stresses falling within the local primary membrane stress category are those defined in C.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.

C.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 C.2.7 but the stress intensity value, f_{b}, $\left(f_{\mathrm{m}}+f_{\mathrm{b}}\right)$ or $\left(f_{\mathrm{L}}+f_{\mathrm{b}}\right)$, 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 the solid section. The stress intensity, f_{b}, $\left(f_{\mathrm{m}}+f_{\mathrm{b}}\right)$ or $\left(f_{\mathrm{L}}+f_{\mathrm{b}}\right)$, shall not exceed K.

C.4.5 Primary plus secondary stress category

The stresses falling within the primary plus secondary stress category are those defined in C.2.7 plus those of C.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), shall be included. The stress intensity value, $\left(f_{\mathrm{m}}+f_{\mathrm{b}}+f_{\mathrm{g}}\right)$ or $\left(f_{\mathrm{L}}+f_{\mathrm{b}}+f_{\mathrm{g}}\right)$, is the highest value of those stresses acting across the section under consideration and shall be limited to $2K$.

C.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 permissible stresses, the following two types of thermal stress are recognized, depending on the volume or area in which distortion takes place.

a) General thermal stress, 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 C.1 and Figure C.1.

   Examples of general thermal stress are:

1) stress produced by an axial thermal gradient in a cylindrical shell;

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

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

An example of a local thermal stress is a small cold spot in a vessel wall.

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

C.5.1 General

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

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

The criteria of C.2.8 are not applicable to this section.

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

C.5.2 Attachments and supports

The dimension in the circumferential direction of the loaded area shall 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 0,8K for the inner vessel and 0,9K for the outer jacket;

— the stress intensity due to the sum of primary membrane stresses 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.

C.5.3 Nozzles and openings

The nozzle or opening shall be reinforced in accordance with 10.3.7.7.

Under the design combined load the following stress limits apply:

— the primary membrane stress intensity should 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.

C.5.4 Additional stress limits

Where significant compressive membrane stresses are present, the possibility of buckling shall be investigated and the design modified if necessary (see C.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 0,9*K*.

Where shear stress is present alone, it should not exceed *K*/3. The maximum permissible bearing stresses shall not exceed *K*.

Annex D
(normative)

Components subject to external pressure (pressure on the convex surface) — Calculation

D.1 General

Annex D gives two calculation methods that are equally recognized and give comparable results.

Calculations are 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.

NOTE 1 The buckling length l_b is the maximum length of the shell between two reinforcing elements (see Figure 2).

NOTE 2 For vessels with dished ends, the buckling length starts at a distance of 1/3 the head depth from the tangent line.

D.2 Method 1

D.2.1 Cylindrical shells

D.2.1.1 Elastic buckling

Calculations are performed using Formula (D.1):

$$p_e = \frac{E}{S_k}\left\{\frac{20}{\left(n^2-1\right)\times\left[1+\left(n/Z\right)^2\right]^2}\times\frac{s-c}{D_a}+\frac{80}{12\times\left(1-\nu^2\right)}\times\left[n^2-1+\frac{2n^2-1-\nu}{1+\left(n/Z\right)^2}\right]\times\left(\frac{s-c}{D_a}\right)^3\right\} \tag{D.1}$$

where $Z = 0{,}5\sqrt{D_a/l_b}$ and n is an integer equal to or greater than 2 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 Formula (D.2):

$$n = 1{,}63\times\sqrt[4]{\frac{D_a^3}{l_b^2\left(s-c\right)}} \tag{D.2}$$

For tubes and pipes, calculations may be performed using Formula (D.3):

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

D.2.1.2 Plastic deformation

When $D_a/l_b \leq 5$

$$p_p = \frac{20K}{S_p} \times \frac{s-c}{D_a} \times \frac{1}{1 + \frac{1{,}5u\left(1-0{,}2D_a / l_b\right)D_a}{100(s-c)}} \tag{D.4}$$

When $D_a/l_b > 5$ the higher pressure obtained using Formulae (D.5) and (D.6) shall not be less than the external design pressure.

$$p_p = \frac{20K}{S_p} \frac{\left(s-c\right)}{D_a} \tag{D.5}$$

$$p_p = \frac{30K}{S_p} \times \left(\frac{s-c}{l_b}\right)^2 \tag{D.6}$$

D.2.1.3 Stiffening rings

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

a) for the inner vessel:

$$I \geq 0{,}124 \times \frac{P \times Da^3 \times \sqrt{D_a \times s}}{10 \times E} \tag{D.7}$$

b) for the outer jacket:

$$I \geq 0{,}042\ S_k \frac{p\ D_a{}^3 l'_b}{10E} \tag{D.8}$$

For demonstrated satisfactory experience, a factor of safety $S_k \geq 1{,}3$ is acceptable.

$$A \geq 0{,}5\, S_p \frac{p\, D_a\, l'_b}{10K} \tag{D.9}$$

The moment of inertia I is relative to the neutral axis of the reinforcing element cross-section parallel to the shell axis (see axis x–x in Figure 1).

The flat bar stiffness and the r, T, H or U profile stiffness shall satisfy the conditions given in Figure 1. Stiffening rings (full or partial) to provide structural integrity shall be securely attached to the outer jacket.

Where stiffening rings are joined to the shell by means of intermittent welds, the fillet welds at each side shall cover at least one third of the shell circumference and be uniformly distributed (see Figure 1) and the number of weld discontinuities shall be at least $2n$. The number of buckling lobes n is obtained as indicated in D.3.1.2.5.

D.2.2 Dished ends and spherical shells

D.2.2.1 Elastic buckling

There is adequate resistance to elastic buckling when:

$$p \leq 3{,}66 \frac{E}{S_k}\left(\frac{s-c}{R}\right)^2 \tag{D.10}$$

where $S_k = 2{,}0 + 0{,}001\,4\, R/(s - c)$.

D.3 Method 2

D.3.1 Cylindrical shells

D.3.1.1 Elastic buckling

If $\dfrac{l_b}{D_a} > 1{,}537 \dfrac{(1-\nu^2)^{0,25}}{\left(\dfrac{s}{D_a}\right)^{0,5}}$

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

If $\dfrac{l_b}{D_a} \leq 1{,}537 \dfrac{(1-\nu^2)^{0,25}}{\left(\dfrac{s}{D_a}\right)^{0,5}}$

$$p_e = \frac{24{,}2E\left(\dfrac{s}{D_a}\right)^{2,5}}{S_k\left(1-\nu^2\right)^{0,75}\left[\left(\dfrac{l_b}{D_a}\right) - 0{,}45\left(\dfrac{s}{D_a}\right)^{0,5}\right]}$$

D.3.1.2 Stiffening rings

D.3.1.2.1 Each stiffening ring shall have a minimum moment of inertia as determined by either of the following formulae:

$$I = \frac{S_k p {D_a}^3 l_b}{280E}$$

or

$$I' = \frac{S_k p {D_a}^3 l_b}{218E}$$

where

I is the required moment of inertia of the stiffening ring cross section about its neutral axis parallel to the axis of the shell:

I' is the required moment of inertia of the combined ring-shell cross section about its neutral axis parallel to the axis of the shell.

The required moment of inertia of the combined ring-shell section shall be maintained completely around the circumference of the cylinder unless the adequacy of the shell to carry the required critical collapse pressure is demonstrated through a finite element analysis method verified with scale model tests of each type of design.

D.3.1.2.2 If stiffening rings are used in designing the cylindrical portion (shell) of the inner vessel or vacuum jacket for external pressure, each ring shall be attached to the shell by fillet welds. Stiffening ring attachment welds on the outside of the vacuum jacket shall be continuous. All other ring attachment welds may be intermittent. Care should be taken in the design of ring attachments to minimize localized areas of buckling. Where intermittent welds are used, the total length of welds on each side of the ring shall be at least one third of the shell circumference or, if welded on one side, two thirds of the shell circumference. The intermittent attachment welds shall be uniformly distributed and if welded on both sides, shall be staggered as shown in Figure 1.

A portion of the shell may be included when calculating the moment of inertia of the ring. The effective width of shell plate, x, on each side of the attachment to the ring is given by the formula:

$$x = 0{,}78\left[\frac{D_\mathrm{a}\left(s-c\right)}{2}\right]^{0{,}5}$$

D.3.1.2.3 Where a stiffening ring consists of a closed section having two webs attached to the shell, the shell plate between the webs shall be included up to the limit of twice the value of A as defined in 10.3.7.2.4. The flange of the section, if not a standard structural shape, is subject to the same limitation, with x based on D_a and s of the shell. The closed section between the ring and shell shall be provided with a means of equalizing pressure on the space occupied by the ring.

D.3.1.2.4 Portions of the shell plate shall not be considered as contributing area to more than one stiffening ring or parts (webs) of one stiffening ring. If the stiffeners or webs of stiffeners should be so located that the maximum permissible effective shell sections overlap on either or both sides of a stiffener or web, the effective shell section for that stiffener or web shall be shortened by one-half of each overlap.

D.3.1.2.5 Length of the attachment weld segments shall not be less than 50 mm and shall have a maximum clear spacing between toes of adjacent weld segments of 8s for external rings and 12s for internal rings.

The number of intermittent attachment welds on each ring shall be at least 2n where n, is given by

$$n = 1{,}63\left[\frac{D_\mathrm{a}^{\ 3}}{l_\mathrm{b}^{\ 2}\left(s-c\right)}\right]^{0{,}25}$$

Size of the fillet weld leg size shall be not less than the smallest of the following:

a) 6 mm;

b) shell thickness, s;

c) web thickness of the stiffener ring, b.

D.3.2 Dished ends and spherical shells

The calculated pressure, p_c, shall not be less than the external design pressure.

For elastic buckling, $p_c = 1,25E\left(\frac{s}{R}\right)^2$

For plastic deformation, p_p, the pressure derived from the following formula shall be higher than p_e obtained for elastic buckling using the above formula.

$$p_p = \frac{20K_{20}\left(s-c\right)}{S_p\left(R+s\right)}$$

For ellipsoidal ends (R + s) may be taken as B_oD_a, where B_o is obtained from Table D.1

Table D.1 — Values of spherical radius factor, *B*o, for ellipsoidal end with pressure on convex side

$\frac{D_a}{2h_o}$	3,0	2,8	2,6	2,4	2,2	2,0	1,8	1,6	1,4	1,2	1,0
B_o	1,36	1,27	1,18	1,08	0,99	0,90	0,81	0,73	0,65	0,57	0,50
NOTE Interpolation is permitted for intermediate values.											

Annex E
(informative)

Marking and labelling information

The transportable cryogenic vessel can bear the following markings in clearly legible and durable characters:

a) On the inner vessel:

   1) name and address or other means of identification of the manufacturer of the inner vessel;

   2) serial number of the inner vessel;

   3) mark confirming successful final acceptance tests of the inner vessel.

b) On the outer jacket:

   The information marked on the inner vessel shall be repeated on the data plate mounted or permanently attached to the outer jacket:

   1) "ISO 21029" to show that the transportable cryogenic vessel is in conformity, and that the approval number if the design of the vessel is type approved;

   2) name and address or other means of identification of the manufacturer of the transportable cryogenic vessel;

   3) serial number of the transportable cryogenic vessel;

   4) maximum permissible working pressure (p_S in bar) of the transportable cryogenic vessel;

   5) test pressure of the transportable cryogenic vessel;

   6) volume of the inner vessel (in litres);

   7) tare mass (in kilograms) of the transportable cryogenic vessel;

   8) date of the final acceptance tests (month, year);

   9) final acceptance test mark;

   10) date of the next periodic inspection (year);

   11) the date of the last periodic inspection (month, year);

   12) last periodic inspection mark;

   13) reference to the operating instructions;

   14) (optional) instructions for transporting the transportable cryogenic vessel (lifting, lashing).

c) Prior to filling:

   1) a flow sheet with operating instructions;

   2) an unshortened identification of the fluid which is transported in accordance with the transport and substance regulations and its net mass in accordance with the documentation;

   3) danger labels in accordance with transport regulations;

4) risk and safety phrases associated with the gas content;

5) name and address of the fluid producer or supplier.

The marks as described under a) 1) to b) 13) should be permanently affixed, e.g. stamped, either on a reinforced part of the transportable cryogenic vessel, or on a ring, or on permanently affixed attachment(s).

The technique used for marking and attaching should not adversely affect the integrity of the transportable cryogenic vessel.

Marks described under c) 1) to c) 5) can either be stamped or indicated on a durable information disc or label attached to the transportable cryogenic vessel or indicated in an adherent and clearly visible manner such as painting or by an equivalent process.

Additional markings can be provided, provided that they do not obscure or create confusion with specified markings called for in this document.

Annex F
(informative)

Specific weld details

F.1 General

Specific weld details are given in F.2 which are currently in common usage in cryogenic vessels and are appropriate to this service. 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.

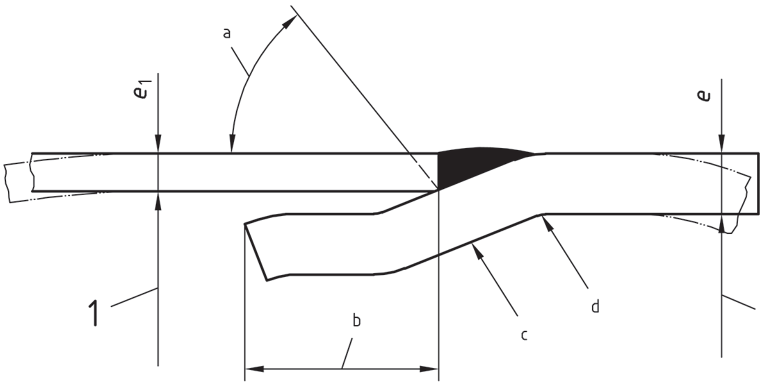
F.2 Weld details

F.2.1 General

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.

F.2.2 Joggle joint

(See Figure F.1.)



Key

1 I/DIA

a The bevel is optional.

b Selected length.

c The depth of offset = e_1.

d To avoid sharp break.

Figure F.1 — Joggle joint

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 is sufficiently clear of the knuckle radius to ensure that the edge of the circumferential seam is at least 12 mm clear of the knuckle; (see 10.3.7.4.2 for the 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;

   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) when the flanged section of a dished end is joggled, the joggle is sufficiently clear of the knuckle radius to ensure that the edge of the circumferential seam is at least 12 mm clear of the knuckle; (see 10.3.7.4.2 for the dimensions);

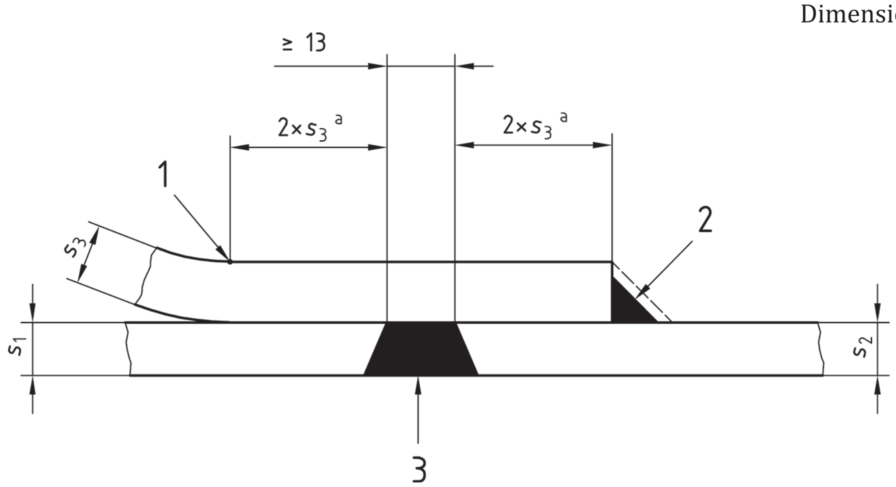
d) the offset section which forms the weld backing is a close fit within its mating section at the weld around the entire circumference;

e) the profile of the offset is a smooth radius without sharp corners;

f) on completion of welding the weld fills the groove smoothly to the full thickness of the plate edges being joined;

g) the junction of the longitudinal and circumferential seams is examined radiographically and found to be free from significant defects.

Dimensions in millimetres



Key

1 tangent point

2 continuous fillet weld

3 butt weld

s_1 cylinder thickness

s_2 cylinder thickness

s_3 end thickness

a Need not exceed 25 mm.

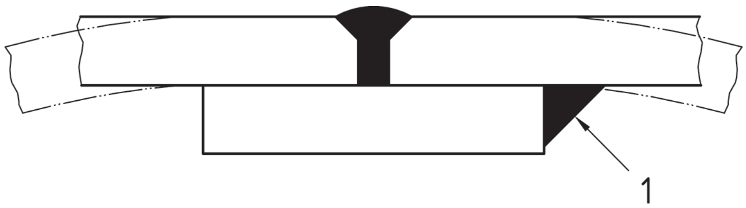
NOTE Cylinder thickness s_1 and s_2 may vary.

Figure F.2 — Intermediate end

F.2.3 Backing strip

See Figures F.2 and F.3.

The backing strip may only be used 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.



Key

1 intermittent or continuous fillet weld

Figure F.3 — Backing strip

F.2.4 End plate closure

See Figure F.4.

For two examples of the many ways of welding flat plates. See also Figure 12.

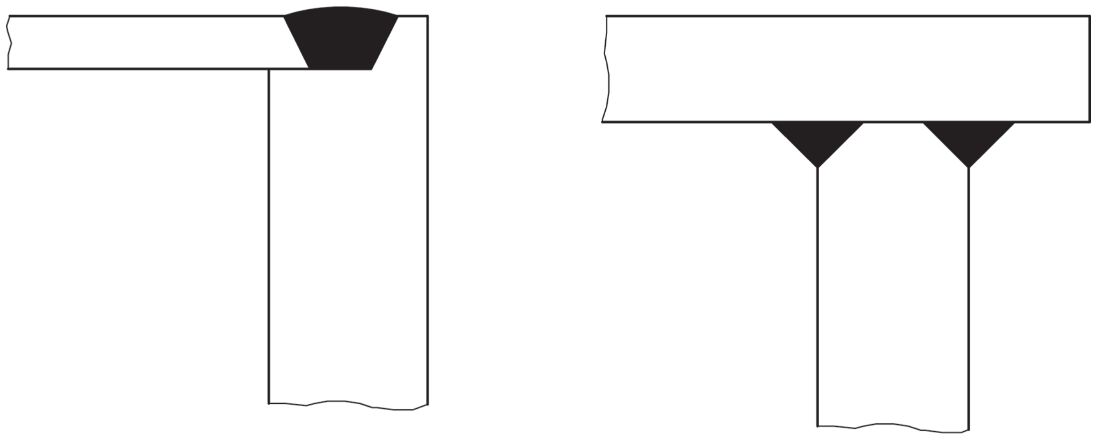


Figure F.4 — Examples of end plate closures

F.2.5 Non full penetration nozzle weld

See Figure F.5.

This type of weld may be used to attach the 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.

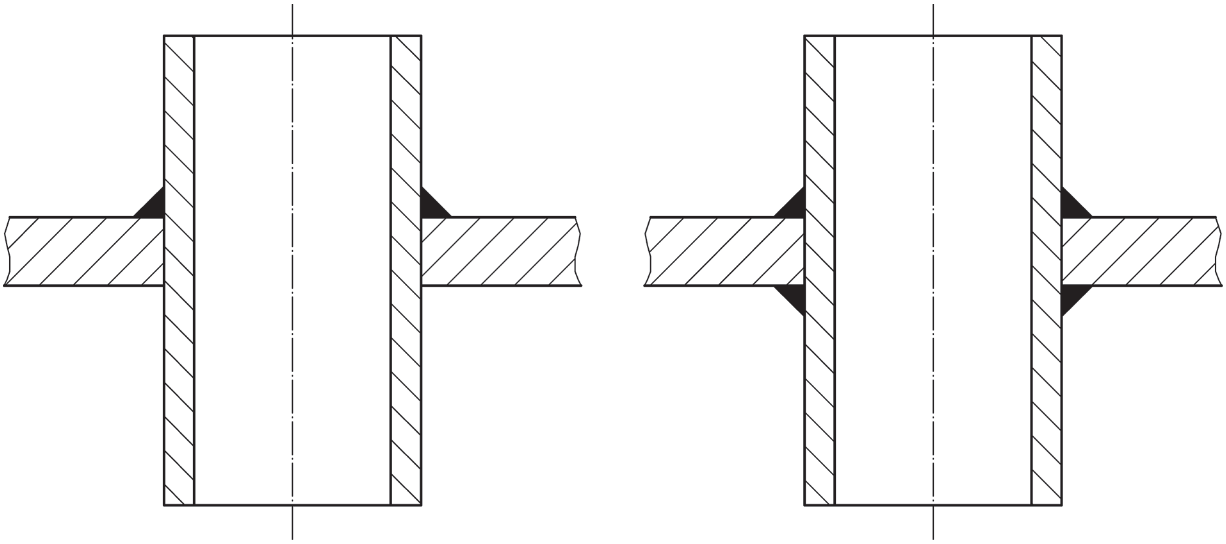


Figure F.5 — Non full penetration nozzles welds

F.2.6 Non continuous fillet weld on attachments

This type of weld 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 11.6.4.4.

Annex G
(informative)

Design validation as part of type approvals

The transportable cryogenic vessel should safely withstand the mechanical and thermal loads and the chemical effects encountered during pressure testing and normal operation. These requirements are deemed to be satisfied if Clauses 6 to 11 are fulfilled. These requirements should be validated under consideration of evidences/evidence combinations described in 6 and 10 due to a type test. Details shown in the Table G.1.

NOTE 1 One of the following method can be applied as an appropriated procedure for design verification.

Table G.1 — Design validation as part of types approvals

Methods	**I**		**II**
	Method acc. to Clause 10.3 **- Design by calculation**		**Method acc. to Clause 10.4** **-Design validation by experimental method**
Method	**DBF**	Annex C elastic stress analysis	
Mechanical loads	**See Clause 6**		
Chemical effect	**See Clause 7**		
Thermal condition	**See Clause 8**		
Material	**See Clause 9**		
Design	**See Clause 10**		
Design criteria			
Generals	**See Clause 10.1.2 and Clause 10.1.3 including determination of minimum wall thicknesses acc. to Table 2 and 3**		
	See Clause 10.2 "Common Design requirements"		
			See Clause 10.4.1 and 10.4.2
Additional	**See Note 2**		
Load condition			
Clause 6.2 Load during the pressure test	**O**	**O**	**X**
Clause 6.3.1 The following loads shall be considered to act in combination where relevant	**X**	**X**	**X**
Clause 6.3.2 Dynamic loads during normal operation	**O**	**X**	**X**
Clause 6.3.3 Further criteria	**See criteria if the Volume more than 100 l or gross mass more than 150 kg**		
Clause 7 Chemical effects	**See criteria**		

Table G.1 *(continued)*

Clause 8 Thermal conditions	**O**	**X**	**X**
Clause 10.1.2 Fatigue calculation	**O**	**X**	**O** $_a$
Clause 10.1.3 Minimum Wall thicknesses	**X**	**X**	**X**
Clause 10.4.3 Tests for pressure integrity	**-**	**-**	**X**
Clause 10.4.4 Tests for structural integrity	**-**	**X**	**X**
Note 2: X: Appropriated Test also for Combination **O: Additional Method required** **- : Not appropriated Method for this load condition**			**Index:** $_a$ **acc. to EN 13445-3: 2009,Annex T**

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