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BSI Standards Publication

GRP tanks and vessels for use above ground

Part 3: Design and workmanship

bsi.

National foreword

This British Standard is the UK implementation of EN 13121-3:2016. It supersedes BS 4994:1987 and BS EN 13121-3:2008+A1:2010 which are withdrawn.

The UK participation in its preparation was entrusted to Technical Committee PRI/5, UK steering committee for CEN/TC 210 GRP tanks.

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

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

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European foreword

This document (EN 13121-3:2016) has been prepared by Technical Committee CEN/TC 210 “GRP tanks and vessels”, the secretariat of which is held by SFS.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by October 2016, and conflicting national standards shall be withdrawn at the latest by October 2016.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document supersedes EN 13121-3:2008+A1:2010.

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

For relationship with EU Directive, see informative Annex ZA, which is an integral part of this document.

The following changes were made in this new edition of EN 13121-3:

— the standard was totally revised so as to make it comply with EN 1990; and

— sections covering "Flat panels" and "Loading from local loads" removed from the standard.

EN 13121, *GRP tanks and vessels for use above ground*, is currently composed of the following parts:

— *Part 1: Raw materials — Specification conditions and acceptance conditions*;

— *Part 2: Composite materials — Chemical resistance*;

— *Part 3: Design and workmanship*;

— *Part 4: Delivery, installation and maintenance*;

— *Part 5: Example of calculation* (CEN/TR 13121-5; in preparation).

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It has been assumed in the drafting of this European Standard that the execution of its provisions is entrusted to appropriately qualified and experienced people.

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

Introduction

The five parts of EN 13121 together define the responsibilities of the tank or vessel manufacturer and the materials to be used in their manufacture.

EN 13121-1 specifies the requirements and acceptance conditions for the raw materials - resins, curing agents, thermoplastics linings, reinforcing materials and additives. These requirements are necessary in order to establish the chemical resistance properties determined in EN 13121-2 and the mechanical, thermal and design properties determined in this part of EN 13121. Together with the workmanship principles determined in this Part 3, requirements and acceptance conditions for raw materials ensure that the tank or vessel will be able to meet its design requirements. EN 13121-4 of this standard specifies recommendations for delivery, handling, installation and maintenance of GRP tanks and vessels

The design and manufacture of GRP tanks and vessels involve a number of different materials such as resins, thermoplastics and reinforcing fibres and a number of different manufacturing methods. It is implicit that vessels and tanks covered by this standard are made only by manufacturers who are competent and suitably equipped to comply with all the requirements of this standard, using materials manufactured by competent and experienced material manufacturers.

Metallic vessels, and those manufactured from other isotropic, homogeneous materials, are conveniently designed by calculating permissible loads based on measured tensile and ductility properties. GRP, on the other hand, is a laminar material, manufactured through the successive application of individual layers of reinforcement. As a result there are many possible combinations of reinforcement type that will meet the structural requirement of any one-design case. This allows the designer to select the laminate construction best suited to the available manufacturing facilities and hence be most cost effective.

In considering a layered GRP structure it is assumed that it is the glass reinforcement that provides the stiffness and strength required to resist mechanical loadings. Also, since the quantity of glass reinforcement is most readily assessed by weight, the weight of glass per unit area (m) is used instead of thickness in determining mechanical properties, thus the concepts of load and modulus are replaced by unit strength (u) and unit modulus (X), these being defined in Table 1.

It is possible that future advances in resin technology would allow tanks and vessels to be considered for operating temperatures above 120 °C. Should such a situation arise and a manufacturer wish to take advantage of such developments then all other requirements of this standard will be maintained and such tanks and vessels will only be designed in accordance with the advanced design method given in 7.9.3.

NOTE To convert a unit load, or a unit modulus to a load and a modulus respectively, U and X may be simply divided by t, where t is the thickness per weight of glass per unit area of the lamina, or laminate under consideration.

1 Scope

This European Standard gives requirements for the design, fabrication, inspection, testing and verification of GRP tanks and vessels with or without thermoplastics lining for storage or processing of fluids, factory made or site built, non-pressurized or pressurized up to 10 bar, for use above ground. Further requirements are presented in normative Annex G.

The terms vessels and tanks as used in this part of EN 13121 include branches up to the point of connection to pipe work or other equipment by bolting and supports, brackets or other attachments bonded directly to the shell.

This part of EN 13121 covers vessels and tanks subject to temperatures between – 40 °C and 120 °C.

Excluded from this part of EN 13121 are:

— tanks and vessels for the transport of fluids;

— underground storage tanks;

— spherical vessels;

— vessels and tanks of irregular shape;

— tanks and vessels with double containment where the double wall is considered structural;

— tanks and vessels which are subject to the risk of explosion, or failure of which may cause an emission of radioactivity;

— specification for fibre reinforced cisterns of one piece and sectional construction for the storage, above ground, of cold water (see EN 13280).

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 59, *Glass reinforced plastics — Determination of indentation hardness by means of a Barcol hardness tester*

EN 1092-1, *Flanges and their joints — Circular flanges for pipes, valves, fittings and accessories, PN designated — Part 1: Steel flanges*

EN 1990, *Eurocode — Basis of structural design*

EN 1991–1-1, *Eurocode 1: Actions on structures — Part 1-1: General actions — Densities, self-weight, imposed loads for buildings*

EN 1991-1-3, *Eurocode 1 — Actions on structures — Part 1-3: General actions - Snow loads*

EN 1991-1-4, *Eurocode 1: Actions on structures — Part 1-4: General actions - Wind actions*

EN 1991-1-5, *Eurocode 1: Actions on structures — Part 1-5: General actions - Thermal actions*

EN 1991-4, *Eurocode 1 — Actions on structures — Part 4: Silos and tanks*

EN 1993 (all parts), *Eurocode 3: Design of steel structures*

EN 1993-1-1, *Eurocode 3: Design of steel structures — Part 1-1: General rules and rules for buildings*

EN 1993-1-6:2007, *Eurocode 3 — Design of steel structures — Part 1-6: Strength and Stability of Shell Structures*

EN 1998 (all parts), *Eurocode 8 — Design of structures for earthquake resistance*

EN 1998-1, *Eurocode 8: Design of structures for earthquake resistance — Part 1: General rules, seismic actions and rules for buildings*

EN 1998-4:2006, *Eurocode 8 — Design of structures for earthquake resistance — Part 4: Silos, tanks and pipelines*

EN 10025-2, *Hot rolled products of structural steels — Part 2: Technical delivery conditions for non-alloy structural steels*

EN 13067, *Plastics welding personnel — Qualification testing of welders — Thermoplastics welded assemblies*

EN 13121-1:2003, *GRP tanks and vessels for use above ground — Part 1: Raw materials — Specification conditions and acceptance conditions*

EN 13121-2:2003, *GRP tanks and vessels for use above ground — Part 2: Composite materials — Chemical resistance*

EN 13121-4, *GRP tanks and vessels for use above ground — Part 4: Delivery, installation and maintenance*

EN 13445-3:2014, *Unfired pressure vessels — Part 3: Design*

EN 13555, *Flanges and their joints — Gasket parameters and test procedures relevant to the design rules for gasketed circular flange connections*

EN 13923, *Filament-wound FRP pressure vessels — Materials, design, manufacturing and testing*

EN ISO 75-2, *Plastics — Determination of temperature of deflection under load — Part 2: Plastics and ebonite (ISO 75-2)*

EN ISO 291, *Plastics — Standard atmospheres for conditioning and testing (ISO 291)*

EN ISO 527-4, *Plastics — Determination of tensile properties — Part 4: Test conditions for isotropic and orthotopic fibre-reinforced plastic composites (ISO 527-4)*

EN ISO 899-1, *Plastics — Determination of creep behaviour — Part 1: Tensile creep (ISO 899-1)*

EN ISO 899-2, *Plastics — Determination of creep behaviour — Part 2: Flexural creep by three-point loading (ISO 899-2)*

EN ISO 1172, *Textile-glass-reinforced plastics — Prepregs, moulding compounds and laminates — Determination of the textile-glass and mineral-filler content — Calcination methods (ISO 1172)*

EN ISO 2592, *Determination of flash and fire points — Cleveland open cup method (ISO 2592)*

EN ISO 3915, *Plastics — Measurement of resistivity of conductive plastics (ISO 3915)*

EN ISO 7500-1, *Metallic materials — Calibration and verification of static uniaxial testing machines — Part 1: Tension/compression testing machines — Calibration and verification of the force-measuring system (ISO 7500-1)*

EN ISO 9513, *Metallic materials — Calibration of extensometer systems used in uniaxial testing (ISO 9513)*

EN ISO 11357-2, *Plastics — Differential scanning calorimetry (DSC) — Part 2: Determination of glass transition temperature and glass transition step height (ISO 11357-2)*

EN ISO 14125, *Fibre-reinforced plastic composites — Determination of flexural properties (ISO 14125)*

EN ISO 14692-3:2002, *Petroleum and natural gas industries — Glass-reinforced plastics (GRP) piping — Part 3: System design (ISO 14692-3:2002)*

ISO 48, *Rubber, vulcanized or thermoplastic — Determination of hardness (hardness between 10 IRHD and 100 IRHD)*

ASTM D4541-09, *Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers*

ASME B16.5/16.47, *Pipe Flanges and Flanged Fittings: NPS 1/2 Through NPS 24 Metric/Inch Standard*

3 Terms and definitions

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

3.1
manufacturer
organization that designs, manufactures and tests the vessel or tank in accordance with this standard

3.2
purchaser
organization or individual that buys the finished vessel or tank and specifies the process requirements

3.3
authorized inspecting authority
body or organization that maybe required to check that the design, materials and construction comply with this standard

Note 1 to entry: For this standard, when PS ≤ 0,5 bar.

3.4
vessel
closed container subject to applied pressure or vacuum, with or without hydrostatic head, including branches up to the first flanged connection

3.5
notified body
certificated organization listed by the European commission of pressure equipment

Note 1 to entry: For this standard, when PS > 0,5 bar.

3.6
internal inspection authority
inspector from the manufacturer which is independent from the workshop

3.7
tank
container for the storage of fluids subject only to the fluid hydrostatic head and freely vented to atmosphere, including branches up to the first flanged connection

3.8
laminate
resin reinforced with glass fibre

3.9
gel coat
thin layer of resin on the surface of a laminate that may or not be reinforced with a glass or a synthetic fibre tissue

3.10
cure
chemical reaction resulting in the polymerized laminate

3.11
post cure
application of heat to take the polymerization to a final stage

3.12
maximum allowable pressure
PS
maximum pressure for which the equipment is designed, as specified by the manufacturer

3.13
differential pressure
difference of pressure on both sides of a component

3.14
design pressure
p_D
design pressure used in the calculations for a component

3.15
maximum/minimum allowable temperature
TS
maximum/minimum temperatures for which the equipment is designed, as specified by the manufacturer

3.16
test temperature
temperature at which the pressure test of the equipment is carried out

3.17
test pressure
PT
pressure to which the tank or vessel is tested

4 Symbols and abbreviations

For the purposes of this document, the symbols and abbreviations common to all clauses and annexes are given in Table 1. All dimensions are given in millimetres.

Further symbols are defined in the relevant clauses as required.

Table 1 — Standard symbols and abbreviations

Symbol	Unit	Definition
A	mm	Distance
a	mm	Dimension
b	mm	Dimension
d	mm	Diameter
D	mm	Internal diameter of tank, vessel
Δ	-	Difference or additional
E	N/mm²	Modulus of elasticity = $\frac{X}{t}$
ε	%	Strain
F	-	Buckling design factor
ϕ	°	Half the angle at the apex of the cone
Θ	°	Support saddle angle
g	m/s²	Gravity
γ_m	-	Partial factor for material property
$\gamma_{F,i}$	-	Partial factor for action
hi	mm	Height of dished end
H	mm	Height of cone
I	mm⁴	Second moment of area
k	-	Correction factor
K	-	Overall design factor
l	mm	Length
L	mm	Overall length
m	kg/m²	Mass per unit area
M	Nmm	Bending moment
u	N/mm	Unit load = load/width
ν	–	Poisson's ratio
P	N	Direct load
p	N/mm²	Pressure
Q	N	Shear load
r	mm	Knuckle radius
R	mm	Radius
ρ	kg/m³	Density of liquid
σ	N/mm²	Stress = $\frac{U}{t}$ and $\frac{n}{t}$
t	mm	Thickness
τ	N/mm²	Shear stress

Symbol	Unit	Definition
T	°C	Temperature
TS	°C	Design temperature
U_{lam}	N/mm	Unit load for the laminate
U	N/mm per kg/m² glass	Ultimate tensile unit strength of the laminate (UTUS)
V	m³	Volume
x	–	Coordinate in axial direction
X	N/mm	Unit modulus = Load/width x strain
X_{i}	N/mm per kg/m² glass	Unit tensile-modulus of the lamina per kg/m² glass
n	N/mm	Applied unit load

Table 2 — Abbreviations

Abbreviations		
CSM	-	Chopped strand mat
ECTFE	-	Ethylene-chlorotrifluoroethylene copolymer
FEP	-	Fluorinated ethylene-propylene copolymer
FU	-	Furane
FW	-	Filament winding
HDT	°C	Heat deflection temperature
IRHD	°	International rubber hardness
ln	-	Natural logarithm
PF	-	Phenolic
PFA	-	Perfluoro-alkoxy copolymer
PP-B	-	Polypropylene, block polymer
PP-H	-	Polypropylene, homopolymer
PP-R	-	Polypropylene, random polymer
PVC-U	-	Polyvinyl chloride, unplasticized
PVDF	-	Polyvinylidene fluoride
UP	-	Unsaturated polyester
VE	-	Vinyl ester
WR	-	Woven roving
CRL	-	Chemical Resistant Layer, see EN 13121–2
VL	-	Veil Layer, see EN 13121–2
TPL	-	Thermoplastics Liner, see EN 13121–2
Lam	-	Laminate
OD	-	Outside Diameter
ID	-	Inside Diameter

5 Information and requirements to be supplied and documented

5.1 General

The manufacturer shall produce a design and fabrication report as detailed in 17.3. This shall be certified by the manufacturer and be available for approval by the purchaser and/or inspection authority as appropriate.

The design/fabrication report shall be issued to the purchaser and a copy kept by the manufacturer for a minimum of five years.

It shall be the manufacturer responsibility to conduct production tests as specified in Clause 7 and to record the results to permit verification that such tanks/vessels are in compliance with this standard.

The tests as specified in Clause 7 and report along with the definitive documented items and requirements specified in this standard shall be satisfied before a claim of compliance with this standard can be made and verified.

5.2 Information to be obtained by the manufacturer

The following information shall be supplied by the purchaser and shall be fully documented. Both the definitive requirements specified throughout the standard and the documented items shall be satisfied before claim of compliance with this standard can be made and verified.

a) Process conditions:

   1) materials to be handled (names, concentration, relative densities and toxicity) including likely impurities or contaminations;

   2) design pressure (or vacuum) including test requirements and design temperature;

   3) operating pressure (or vacuum) and temperature;

   4) mode of operation, e.g. process cycling conditions;

   5) any abrasion or erosion problems that may be encountered;

b) site conditions:

   1) nature of ambient atmosphere including any extremes of temperature;

   2) superimposed loads, e.g. wind, snow and associated pipework;

   3) loads imposed by personnel during erection and operation;

   4) seismic loading;

   5) general layout of site;

c) special conditions:

   1) boiling;

   2) vibration due to adjacent plant;

   3) agitation details;

4) danger of mechanical impact and damage;

5) loads imposed during transport;

6) finish, e.g. if fire-resisting;

d) details of any special or additional test or inspection required and where these shall be carried out;

e) exemption to apply a pigmented coating to the vessel before final inspection;

f) facilities for testing;

g) applicable regulations e.g. laws, statutory orders and decrees;

h) name of Inspecting Authority, if applicable;

i) requirements for packaging, despatch and installation.

5.3 Information to be prepared by the manufacturer

The manufacturer shall, before commencing manufacture, prepare calculations, drawings and a construction specification in documented form, which shall be made available as required.

This specification document shall include but shall not be limited to the following:

Dished ends: Lay-up details, crown radius, inside knuckle radius, torispherical shape plus minimum thickness.

Shell barrel: Lay-up details, thickness, diameter.

Flanges (including blind flanges): Type, standard and pressure rating as indicated in Tables 24 to 29 or for non-standard flanges: minimum thickness, drilling, inside and outside diameters, hub dimensions and facing details.

Gaskets: Type, rating, material, thickness, inside and outside diameters and gasket seating data.

Branches, nozzles, drains: The lay-up details, dimensions such as the wall thickness and outside diameter. Also the method of assembly, loads to be specified if applicable; location of openings relative to each other.

Body joints: Lay-up details, wall thickness and length.

Reinforcement: Details for nozzles, supports, lifting lugs, etc.

Covers, manholes: Lay-up details, dimensions including minimum thickness, drilling size of bolt holes and pitch circle diameter.

Conical sections: Lay-up details, minimum thickness and straight length of cone, including angle of cone, radius of knuckle to shell (if applicable); diameter at large and small ends of cone.

Supports (horizontal vessel): Number of saddles dimensions including baseplate. Foundation details: distance from tangent line of dished ends to centre of supports, distance between supports and heights of vessel centre line to support foot baseplate.

Supports (vertical vessel): Skirt dimensions including diameter, height, thickness, lay-up details including method of attachment to shell/dished end; if supports are used, number off, thickness of webs, height, etc., base ring diameters, inside and outside, thickness, number and pitch of holding down bolts.

Lifting lugs: Number of, thickness, hole size, lifting angle, lug dimensions, location of lugs, overlay details.

Flat plates: Lay-up details, length, breadth and thickness of stiffeners, if fitted, including pitch, number of.

Internals: Brackets, tray supports, etc.

Tolerances: Any special tolerances that are required above those given in Figures 64 to 67.

Flat Bases: Requirements for the use of flat bases to be in accordance with EN 13121-4.

Attachment for ladders /access platforms and other fittings: Details of method of attachment and overlay construction.

5.4 Final documentation

The final documentation shall be in accordance with the requirements of Subclause 17.3.

6 Material

6.1 General

The materials of construction to be used for tanks and vessels to this European Standard shall conform to the requirements of EN 13121-1.

The recommendations of the raw material suppliers for the usage of their materials shall be followed. Pigments shall not be used except when required for inclusion in the external resin flow coat, or to meet the requirements of 6.3 and 6.4.

Limited use of thixotropic agents may be made provided their inclusion does not interfere with visual examination (see Table 32), or the chemical and mechanical properties of the cured resin system as required by EN 13121-2.

6.2 Chemical protective barrier

6.2.1 General

The chemical protective barrier shall be selected in accordance with the requirements of EN 13121-2:2003. The chemical barrier construction shall be ignored in any strength, or stability calculation.

6.2.2 Thermoplastics linings

These linings are designated as TPL in EN 13121-2:2003, 4.4. The minimum thickness of the linings shall be in accordance with EN 13121-2:2003, Table 1.

6.2.3 Resin based linings

Where a resin based lining is used as the chemical barrier, the selection of the type of barrier to be used for any application and its corresponding thickness shall be in accordance with the relevant sections of EN 13121-2:2003.

Where the barrier is designed as a single protective system, reference (SPL) in clauses of EN 13121-2:2003, the surface veil (VL) may be either C glass, synthetic veil, carbon fibre or ECR glass.

The subsequent chopped strand mat(s), or sprayed fibre layers shall be applied to the VL before cure and shall have fibre content between 25 % and 35 % by mass.

Where the barrier is a resin layer system reference (RL) EN 13121-2:2003, 3.1, the thickness of the barrier shall be between 0,3 mm and 0,7 mm.

6.3 Flammability

When required by local or national fire regulations or specified the external surface layer(s) shall be modified to have the appropriate surface spread of flame characteristic.

6.4 Electrical resistivity

Where the build-up of static electricity may cause problems the surface resistivity of those parts of the tank, or vessel in contact with the fluid shall not exceed 10^6 Ω, or the volume resistivity 10^6 Ωm, when tested in accordance with the test method given in Clause D.12.

7 Mechanical properties

7.1 General

The mechanical properties of the laminate shall not be less than the values given in Table 3 when measured in accordance with the test methods given in Clauses D.5 and D.6 for laminate having glass content by mass within the range:

— Chopped strand mat (CSM) laminates: 25 % to 35 %;

— Woven roving (WR) laminates: 45 % to 55 %;

— Filament wound (FW) laminates: 60 % to 75 %.

The manufacturer shall be allowed to use mechanical properties of higher value than those quoted in Table 3 provided the values are based on tests done in a statistically significant manner and verified at the manufacturing stage, see 7.9.3.

The tests shall be carried out by an independent and certified test laboratory.

7.2 Heat deflection temperature

The heat deflection temperature of the cured resin system used for the reinforced laminate shall be at least 20 °C higher than the design temperature of the tank or vessel.

7.3 Laminate construction

The final external surface of the tank or vessel which shall be a minimum of 450 g/m² CSM or continuous filament windings construction, shall be finished with a surface veil.

Table 3 — Minimum properties of laminate layers

Type of reinforcement	**Direction**	**Applicable criteria**	**UTUS**	**Unit Tensile Modulus**
			U_i N/mm per kg/m² glass	X_i N/mm per kg/m² glass
CSM	All		200	14 000
CSM (furane/ phenolic)	All		140	14 000
WR	Warp	$\xi \geq \frac{1}{6}$	500 x ξ	4 000+24 000 x ξ
		$\xi < \frac{1}{6}$	60	4 000
	Weft	$\xi \leq \frac{5}{6}$	500 × (1-ξ)	4 000+24 000 × (1-ξ)
		$\xi > \frac{5}{6}$	60	4 000
WR (furane/ phenolic)	Warp	$\xi \geq \frac{1}{6}$	320 x ξ	4 000+24 000 x ξ
		$\xi < \frac{1}{6}$	40	4 000
	Weft	$\xi \leq \frac{5}{6}$	500 × (1-ξ)	4 000+24 000 × (1-ξ)
		$\xi > \frac{5}{6}$	40	4 000
FW	Fibre direction	85° < θ < 90°	500	28 000
FW (furane/ phenolic)	Fibre direction	85° < θ < 90°	280	28 000
Shear strength $f_{v,k} = \tau_k \geq 60$ N/mm² in plane (τ_{xy}) and transverse (τ_{xz}, τ_{yz}) Interlaminar lap shear strength $f_{lap,k} = \tau_{lap,k} \geq 20$ N/mm² Shear modulus $G_{xy} = 3\,300$ N/mm²				
Thermal expansion coefficients of laminates $\alpha_1 = 30 * 10^{-6}$ 1/K — CSM-laminates and FW-laminates in axial direction with 90° WR unidirectional layers and CSM layers $\alpha_2 = 25 * 10^{-6}$ 1/K — Mixed laminates and FW-laminates (0°/90°) reinforced in axial direction with unidirectional layers $\alpha_3 = 15 * 10^{-6}$ 1/K — FW-laminates in circumference direction				

where

ξ is the ratio of the mass of glass in either the warp or weft direction, to the total mass of glass of the lamina layer;

θ is the angle between the direction of winding and axis of the cylinder;

U_i is the ultimate tensile unit strength (UTUS), i.e. the strength of a reinforced lamina *i*, expressed as a force per unit width per unit weight;

X_i is the unit tensile modulus, i.e. the ratio of the load per unit width to the corresponding direct strain, in a loaded tensile test specimen per unit mass, of reinforcement type *i*.

7.4 Laminate thickness

The thickness of an individual lamina layer t_i shall be determined using Formula (1), represented graphically in Annex B:

$$t_i = \left(\frac{1}{\rho_g} + \frac{(100 - m_g)}{m_g \cdot \rho_r} \right) \cdot 10^3 \quad (1)$$

where

t_i is the thickness of lamina layer type i (mm), of mass 1 kg/m²;

m_g is the % glass content by mass in layer i kg/m²;

ρ_r is the density of the cured resin (kg/m³);

ρ_g is the density of the glass (kg/m³).

7.5 Laminate properties

The mechanical properties used in the design calculations shall be verified in accordance with the requirements of 7.8. Laminate properties may be determined form basic lamina properties using the methods given in Annex B. For the advanced design proofed values shall be available in accordance with 7.9.3.

7.6 Inter-laminar shear strength

7.6.1 Laminate

The inter-laminar shear strength between laminate layers, when tested in accordance with the test method given in Clause D.7 shall not be less than the values given in Table 4. Where combinations of laminates are used, the lowest value shall be used.

Table 4 — Minimum inter-laminar shear strengths

Type of reinforcement	Inter-laminar shear strength N/mm²
CSM	7,0
CSM (furane and phenolic)	5,0
WR cloth	6,0
WR cloth (furane and phenolic)	4,0
FW (fibre direction)	6,0
FW (furane and phenolic)	4,0

7.6.2 Thermoplastics linings

The shear strength of the bond of the reinforcement to the thermoplastics lining shall not be less than the values given in Table 5 when tested in accordance with the test method given in D.8.

Table 5 — Minimum bond shear strengths for thermoplastics linings

Lining material	Bond shear strength N/mm^2
PVC–U and PVC-C	7,0
PP – H: PP-B: PP-R	3,5
PVDF	5,0
ECTFE, FEP, PFA	5,0

7.7 Peel strength of laminates

The peel strength of laminates shall have a minimum value of $n_{Rk\perp}$ = 10 N/mm of width, when tested in accordance with the test method given in Clause D.9.

7.8 Pull-off strength of laminates and thermoplastic liner

The pull-off strength (commonly referred to as adhesion) of a thermoplastics lining or a laminate from the main laminate (for example the overlay laminate in a cylinder to bottom joint from the main laminates) shall not be less than the values given in Table 6 when tested in accordance with the test method given in Clause D.20. All liner materials except PVC shall have a fabric backing.

Table 6— Minimum pull-off strength of laminates or thermoplastics linings

Material combination	Pull-off strength N/mm^2
GRP to GRP	3,5
GRP to PVC-U and PVC-C	3,5
GRP to PP – H: PP-B or PP-R	2,5
GRP to PVDF	3,5
GRP to ECTFE, FEP or PFA	3,5

7.9 Selection of physical properties of materials and allowable design factors

7.9.1 General

A unit strength approach together with stability criteria have been adopted in this standard for the design of laminated GRP structures subject to static load conditions (i.e. pressure, vacuum and mechanical loads).

The manufacturer can use the minimum specified properties as given in Table 3, which shall be verified by testing in accordance with 7.9.2, designated as the basic design method, or by carrying out an extended mechanical test program establish higher mechanical properties for the particular laminate configuration to be used (see 7.9.3), designated as the advanced design method.

7.9.2 Basic design

The minimum specified properties shall be verified by carrying out tests on five individual samples, for:

a) glass content (loss on ignition) according to the test method given in Clause D.2;

b) unit tensile modulus (based on load carried at 0,25 % strain) according to the test method given in Clause D.6;

c) ultimate tensile unit strength, according to the test method given in Clause D.5;

d) inter-laminar shear test (based on max. shear load over a specified shear length), according to the test method given in Clause D.7;

e) Barcol hardness test, according to the test method given in Clause D.11;

f) short term creep test, according to the test method given in Clause D.10;

g) flexural strength of laminate, according to the test method given in Clause D.19.

When a thermoplastics lining material is utilized the following additional tests shall be carried out:

h) lap shear strength (to establish the bond strength in shear between liner and laminate over a specified shear length), according to the test method given in Clause D.8;

i) peel strength (to establish the bond strength in peel between liner and laminate), according to the test method given in Clause D.9;

j) UTUS of lining material, according to the test method given in Clause D.3;

k) UTUS of lining welds according to the test method given in Clause D.3.

For the ultimate properties of filament windings refer to EN 13923.

The respective values to be used shall be calculated from the mechanical test results, either by:

l) the arithmetic average of the 5 test results or

m) the arithmetic average of the 3 remaining test results when the maximum and minimum values are discarded.

The lowest value determined from (a) or (b) above shall be greater than or equal to the specified properties given in Table 3, in order to use the values of Table 3.

7.9.3 Advanced design

Higher values for material properties, based on the tests detailed in Annex D can be used, provided that a minimum of 3 × 10 pieces of specimens with different thicknesses from the same type of laminate construction are used for all mechanical tests. These tests shall be carried out by an accredited testing laboratory.

The design values to be used shall be calculated as follows:

The standard deviation, *s*, is a statistical measure of the spread of results. For a test programme consisting of *N* tests (where $N \geq 10$) each having a result of value, *J*, the standard deviation, *s*, from the mean of the test results may be obtained from:

$$s = \sqrt{\frac{\sum(\ln J - \overline{J})^2}{N-1}} \quad (2)$$

where

s is the standard deviation;

N is the number of tests;

J is the actual test result;

$\bar{J}$ is the log. mean value of the test results.

The characteristic value to be input into the design formula is:

$$\bar{J} - k \cdot s$$

where

N	5	6	7	8	9	10	11	12	13	14	15	30
k(75 %)	2,46	2,34	2,25	2,19	2,14	2,10	2,07	2,05	2,03	2,01	1,99	1,65

When authenticated historical test data are already available, the characteristic value shall be verified by testing a further five samples and taking the average of these test results, or the average of three test results where the max. and min. is discarded. The lowest figure thus calculated shall be greater than the advanced design characteristic value $\bar{J} - k \cdot s$.

Where sample data falls below the historical values, this will necessitate a reassessment of the vessel design.

7.9.4 Design factors

Design factors shall be applied to the obtained mechanical property values as follows:

7.9.5 Overall design factors *K* and *F*

7.9.5.1 Overall design factor

The overall design factor *K* for long term loads shall be determined from Formula (3):

$$K = \gamma_M \cdot \gamma_{F,i} \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4 \cdot A_5 \qquad (3)$$

The maximum and minimum values of the partial influence factors are given in Table 8.

For γ_M refer to 7.9.5.7 and $\gamma_{F,i}$ is given in 9.3.

The buckling design factor *F* for long term loads shall be determined from Formula (4):

$$F = \gamma_M \cdot \gamma_{F,i} \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4 \cdot \sqrt{A_5} \qquad (4)$$

The partial design factor A_5 varies according to the nature of the loading, different values being obtained for tensile or flexural loadings and for short-term or long-term loading conditions, see 7.9.5.6. A_5 shall be proved against the global safety factor according to 8.3.

7.9.5.2 Derivation of partial influence factor A_1

A_1 is the partial influence factor relating to the test verification of material properties and shall be determined as follows and as summarized in Table 8.

$A_1 = 2,0$ when the maximum allowable load is determined from the properties given in Table 3 and verified byvalid historical test no older than 18 months.

$A_1 = 1,5$ when the maximum allowable load is determined from the properties given in Table 3 and verified by acceptable historic test data - no older than 12 months.

$A_1 = 1,3$ when the maximum allowable load is determined from the properties given in Table 3 and verified by testing sample laminates in accordance with 7.9.2.

$A_1 = 1,2$ when the maximum allowable load is determined from the properties given in Table 3 and verified by testing actual samples from the vessel or tank in accordance with 7.9.2.

$A_1 = 1,0$ when the maximum allowable load is determined by testing actual samples from the vessel or tank in accordance with 7.9.3.

7.9.5.3 Derivation of partial influence factor A_2

A_2 is the partial design factor relating to the chemical environment and is derived from EN 13121-2:2003.

7.9.5.4 Derivation of partial influence factor A_3

A_3 is the partial design factor relating to the influence of the design temperature and resin HDT and is obtained from Formula (5):

$$A_3 = 1,0 + 0,4 \frac{TS - 20}{HDT - 30} \quad (5)$$

and for an insulated tank from Formula (6):

$$A_3 = 1,0 + 0,4 \frac{TS}{HDT - 30} \quad (6)$$

A_3 shall always be > 1,0 and ≤ 1,4. If the formula results in A_3 > 1,4 a resin with higher HDT shall be used. Where the formula results in a value smaller than 1,0 then A_3 = 1,0 shall be used.

The value of A_3 is increased by 0,05 if the laminate is not post-cured.

7.9.5.5 Derivation of partial influence factor A_4

A_4 is the partial influence factor relating to the expected number of operation cycles, where cycles relate to pressure or temperature or temperature and pressure. For the design strain levels allowed in this standard, the factor shall be 1,0.

7.9.5.6 Derivation of partial influence factor A_5

A_5 is the partial design factor relating to long term performance of the laminate and shall be determined either by reference to Table 7 or by testing in accordance with Clause D.15.

In the absence of test data A_5 shall be taken from Table 7.

Table 7 — Value of partial influence factor A_5

	A_5	A_5 Tension and Compression		A_5 Flexural	
	Short-term loading	Life time of tank or vessel		Life time of tank or vessel	
Reinforcement-resin system Polyester- and Vinyl ester	up to 30 min	up to 10 years	up to 50 years	up to 10 years	up to 50 years
WR	1,0	1,25	1,30	1,50	1,90
CSM	1,0	2,00	2,40	2,00	2,40
FW circumferential	1,0	1,20	1,30	1,30	1,40
FW axial	1,0	1,50	1,60	1,60	1,70

Where combination laminates of CSM/WR/FW shall be used, the value of A_5 shall be taken for the major constituent.

For intermediate life times between 10 and 50 years, values of A_5 may be determined by linear interpolation.

When the value of A_5 is to be determined by testing of the laminate, the test to be carried out shall be in accordance with Clause D.15.

An early assessment of the partial design factor A_5 can be determined using the short-term creep test (see Clause D.10), but the final value used in the design shall be that determined from the long term creep test (see Clause D.15).

The partial design factor A_5 shall not be less than 1,20, except for short-term loads (see Table 7).

For the calculation of the buckling factor F (see 7.9.5.1), only the A_5 value for flexural shall be used.

For the calculation of the overall design Factor K (see 7.9.5.1) the A_5 value depends upon the applied load under consideration. Where the loading is a combination of both tension and flexural, the A_5 value for tension shall be used.

7.9.5.7 Partial factor for material properties

The partial material factor is γ_M = 1,40 for all laminates.

Table 8 — Summary of design methods and partial influence factors

	Permissible design approach		
	Advanced design	Basic design	
		Either	Or
Derivation of mechanical material properties (test)	User-defined material properties in accordance to 7.9.3 the material properties shall be verified on each manufactured tank according to 17.5.3	User-defined material properties in accordance to 7.9.2 the material properties shall be verified on each manufactured tank according to 17.5.3	User-defined material properties in accordance to 7.9.2 the material properties shall be verified on each manufactured tank according to 17.5.3
Historical material test datas	Historic data only acceptable with support from a limited production test programme by an authorized inspecting authority.	Historic data acceptable if similar laminate design has been produced within 12 months of the last test.	Historic data acceptable if similar laminate design has been produced within 18 months of the last test.
Partial influence factor relating to the level of the test verification of material properties.	A_1 = 1,0 For mechanical properties A_1 = 1,0 when using historic test data and verifying tests in accordance to 7.9.3	A_1 = 1,2 (vessel cut- outs) A_1 = 1,3 (sample laminates) A_1 = 1,5 (If no additional testing is carried out and historic test data are used to support the design properties)	A_1 = 2,0
Partial design factor relating to the chemical resistance of the laminate	A_2 (from EN 13121–2:2003)	A_2 (from EN 13121–2:2003)	A_2 (from EN 13121–2:2003)
Partial influence factor relating to the design temperature of the vessel and resin HDT	A_3 (7.9.5.4)	A_3 (7.9.5.4)	A_3 (7.9.5.4)
Partial influence factor relating to cyclical loading	A_4 (7.9.5.5) = 1	A_4 (7.9.5.5) = 1	A_4 (7.9.5.5) = 1
Partial influence factor relating to long term behaviour	A_5 (7.9.5.6)	A_5 (7.9.5.6)	A_5 = 2,4
Minimum design factor K with γ_F = 1,5	K (minimum) = 4 K (minimum) = 5 if A_5 is not determined by test program D.15.of Annex D	K (minimum) = 6	K (minimum) = 8
Minimum buckling design factor F with γ_F = 1,5	$F \geq 2,7$	$F \geq 3,0$	$F \geq 4,0$

8 Determination of design strain and loadings

8.1 General

This standard allows three approaches for determining the basic properties of the laminate as detailed in Clause 7 depending on the material test programmes undertaken.

Having established these properties, the basic design strain limitations and design loadings shall be determined as follows.

8.2 Limit design strains

8.2.1 General

The following are the limit design strains for a laminate construction taking into consideration both the design and test requirements.

8.2.2 Limit resin strain ε_{ar}

The limit strain ε_{ar} for each type of resin used shall be determined from:

$$\varepsilon_{ar} \leq 0{,}1 \cdot \varepsilon_R \tag{7}$$

where

ε_R is the elongation at break of the unreinforced resin

8.2.3 Limit strain for laminate or lamina ε_{lim}

The lamina design strain $\varepsilon_d = \varepsilon_{lim}$ shall be the least of

a) design strain for a number of laminates.

Table 9 — Design strain $\varepsilon_d = \varepsilon_{lim}$ for different laminates

Laminate of type of polyester resin	CSM	Mixed lam. WR	Wound laminate		
			0° / 90° laminate axial circumference		±65°
Polyester resin	0,30 %	0,25 %	0,20 %	0,27 %	0,27 %
Bisphenol-Vinyl resin	0,35 %	0,30 %	0,23 %	0,30 %	0,30 %
Novolak-Vinyl resin	0,30 %	0,25 %	0,20 %	0,27 %	0,27 %
Furane resin	0,20 %	0,15 %	0,15 %	0,20 %	0,15 %

The limit strains in Table 9 apply only if $0{,}1 \cdot \varepsilon_R$ of the resin are larger than the values in the table, otherwise use $0{,}1 \cdot \varepsilon_R$.

The condition for these strains is: the first layer to the liquid or medium shall be a CSM with ≥ 300 g/m^2.

For tanks or vessels with a corrosion resistant layer the limit strain shall be the design strain of the used resin in the CRL or the structure, whichever is lower.

b) For PVDF, PP, ECTFE and PFA thermoplastics liners, the limit strain shall be the design strain of the lamina. For PVC-U thermoplastic liners ε_{lim} = 0,20 % and for PVC-C ε_{lim} = 0,20 % are the limit strains.

For rarely occurring short-term emergency conditions, less than 10 times during the life of the tank or vessel, with each duration less than 30 min, a higher maximum design strain of 0,4 % may be used for equipment using resin systems having elongation to failure greater than 2,0 %. This is not acceptable for tanks and vessels with PVC liner.

When this design approach is used for a tank or vessel and the emergency condition occurs in service, each occasion that the condition arises shall be recorded and consideration shall then be given to assessing those areas of the tank or vessel subjected to the higher design strain and the requirement when to inspect the tank or vessel.

8.2.4 Limit test strain ε_{test}

Tanks and vessels shall be tested in accordance with the requirements of Annex C and shall be designed such that the maximum strain in the item when tested shall not exceed the following limits:

$$\varepsilon_{test} \le 1{,}3 \cdot \varepsilon_{\lim} \qquad (8)$$

8.3 Limit design laminate loadings

The limit design unit loading of the laminate shall be determined from the limit unit loading for lamina which is given in Formulae (9) and (10):

$$U_{i,d,R} = U_{lam,k} / \left(\gamma_M \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4\right) \quad \text{for } (\gamma_F \cdot A_5)\text{-factored loads (ultimate limit state)} \qquad (9)$$

$$U_{i,\varepsilon} = U_{i,k} = \varepsilon_{\lim} \cdot X_i \quad \text{for unfactored loads (characteristic combination, serviceability limit state)} \qquad (10)$$

A_5 for long-term variable load shall be verified against the global factor as follows:

$$A_{5,K} = K_{\min.} / \left(\gamma_M \cdot \gamma_F \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4\right) \text{ and} \qquad (11)$$

$$A_{5,F} = \left[F_{\min.} / \left(\gamma_M \cdot \gamma_F \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4\right)\right]^2 \quad \text{where } \gamma_M \cdot \gamma_F = 1{,}4 \cdot 1{,}5 = 2{,}1$$

$K_{\min.}$ and $F_{\min.}$ are given in Table 8.

The above lamina values shall be used to calculate the corresponding values for the lamina and laminate design unit load as given in 8.3 and 8.4, to be used in the overall design analysis as detailed in Clause 10.

Where U_{lam} and X_{lam} are given in 8.4.2 or from experimental data for advanced design test result shall be available.

8.4 Determination of the mechanical values from laminates

8.4.1 General

The laminate values are the essential basis for calculation of tanks and vessels. For this reason the used values in the calculation should be verifiable and documented.

For vessels which have an internal pressure *PS > 0,5 bar* the following sentence shall be taken into account.

Laminates shall be considered, in the sense of the Directive 2014/68/EU for pressure equipment, as materials. For Pressure Equipment Category III and IV a particular material appraisal is required. The appraisal should be drawn up by the notified body responsible (see Annex ZA).

8.4.2 Calculation of laminate values without experimental test data

For each region of the tank or vessel, a proposed laminate construction shall be determined by taking into account the design unit load for each constituent laminate layer as calculated in accordance with 8.2, 8.3 and Annex B. These design loadings shall be related to the unit loads to be carried by the region of the structure concerned. The laminate construction shall whenever possible be symmetrical.

$$U_{lam,k} = (U_1 \cdot m_1 \cdot n_1 + U_2 \cdot m_2 \cdot n_2 \ldots\ldots U_i \cdot m_i \cdot n_i) \qquad (12)$$

For the proposed laminate construction X_{lam} is given by Formula (13):

$$X_{\mathbf{lam,k}} = X_1 \cdot m_1 \cdot n_1 + X_2 \cdot m_2 \cdot n_2 \ldots\ldots X_{\mathbf{i}} \cdot m_{\mathbf{i}} \cdot n_{\mathbf{i}} \qquad (13)$$

where

$U_{\mathbf{lam,k}}$ is the characteristic ultimate tensile unit load;

$U_{\mathbf{i}}$ is the ultimate tensile unit load carrying capacity of lamina layer *i*, N/mm, per kg/m² glass from 8.3;

m_i is the mass of reinforcement per unit area in one layer of type *i*, kg/m² glass;

n_i is the number of layers of type i in the construction under consideration (for filament winding, a layer shall consist of two helixes wound at ± θ°);

n is the maximum applied unit load to be carried by the laminate at the region under consideration, N/mm;

$X_{lam,k}$ is the unit tensile modulus of laminate, N/mm;

X_i is the unit tensile modulus of layer type i, N/mm per kg/m² glass.

To assess the design of a filament wound tank or vessels see EN 13923 for detailed method of analysis.

8.4.3 Laminate with experimental data

The laminate construction shall whenever possible be symmetrical.

For each laminate proved values for $U_{\mathrm{lam,k}}$ and $X_{\mathrm{lam,k}}$ shall be available.

8.5 Laminate thickness

Where values of laminate thickness are required in calculations, these shall be taken as the sum of the individual lamina layer thicknesses making up the laminate or from the experimental data.

The thickness of each lamina layer, for design purposes, shall be determined from the glass content for that layer using Formula (1).

The minimum laminate thickness excluding any chemical barrier shall be 3 mm for tanks subject only to hydrostatic head of liquid contents, and 5 mm for vessels subject to internal pressure or vacuum.

The structural laminate shall whenever possible be symmetrical about the midpoint of structural wall.

Abrupt changes in laminate thickness shall be avoided. The blending taper between regions of differing thickness shall not be steeper than 1 in 6.

9 Design

9.1 Introduction

According to EN 1990 the relevant design situations shall be selected taking into account the circumstances under which the vessel or tank is required to fulfil its function. The selected design situations shall be sufficiently severe and varied so as to encompass all conditions that can reasonably be foreseen to occur during the execution and use of the vessel or tank. The most severe combination of conditions may include:

a) internal pressure, or external pressure;

b) static head of contents(working and test conditions);

c) weight of vessel or tank and contents;

d) design temperature;

e) superimposed and wind loads;

f) flexural moments due to eccentric loads;

g) localized loads acting at the supports, lugs and other attachments;

h) shock loads;

i) thermal actions, loads due to heating or cooling and thermal gradients;

j) loads applied during transport on rail, road or ship and on erection;

k) loads imposed by personnel during erection and operation;

l) fatigue;

m) any requirements for fire resistance of attached vessel, or tank supports, e.g. skirt, legs;

n) seismic.

Two assessments shall be carried out, namely:

a) for $\gamma_F \cdot A_5$-factored loads (Ultimate limit state) the unit load at the laminate shall be ≤ $U_{i,d}$;

b) for unfactored loads (Characteristic combination, serviceability limit state) the unit load at the laminate shall be ≤ $U_{i,\varepsilon} = U_{i,k,\varepsilon}$.

Examples of short-term loads are wind, snow, seismic, personnel and installation loads.

Simplification of the design analysis can be achieved if the largest value of A_5 factor is used for all calculations in the design analysis.

9.2 Determination of external loads

9.2.1 Snow loads

Snow loadings shall be taken from EN 1991-1-3.

9.2.2 Wind loads

The wind loads shall be taken from EN 1991-1-4.

Consideration shall be given to open top tanks with large diameters, since wind effects could produce severe movement of contents, resulting in spillage or excessive loading on the tank. If this cannot be quantified, it is recommended that a roof be provided unless previous experience with similar conditions has proved satisfactory. The rim of open top tanks requires to be stiffened either with a flange or stiffener to prevent ovalization.

Wind load on roof and catch basin according to EN 1991-4.

The following force coefficient shall be used:

— c_f – cylindrical vessel = 0,8, for all situations including nozzles

— c_f – ladder = 1,6, for 20 % of section view

— c_f – platform = 1,2, for 40 % of section view

— c_f – other additional = 1,2

For cylindrical vessels in a row or grouped arrangement, with a distance between tanks ≤ D the dynamic maximum wind pressure shall be increased by a factor of 1,15.

For external pressure arising from wind loading p_{wind} shall be:

— p_{wind} = 0,6 · dynamic maximum wind pressure for closed vessels;

— p_{wind} = 1,6 · dynamic maximum wind pressure for open vessels.

Due to their temporary character, reduced wind loads may be used for erection situations according to EN 1991-1-4 and EN 1991-1-6.

9.2.3 Seismic loads

9.2.3.1 General

The computation of seismic loads given here is a simplified method. It allows a design when the eigenvalues of the construction are unknown. This requires, however, that the tanks or vessels are placed at ground level and that the spectral acceleration magnification factor β_0 = 2,5 with 5 % viscous damping. It is recommended that seismic actions need not be considered to act during test conditions. Reference can be made to EN 1998-4.

The expression for the peak height of the sloshing wave is [EN 1998-4:2006, Formula (A.15)]:

$$d_{\max} = \frac{0{,}84 \cdot R \cdot S_e \cdot (T_{c1})}{g} = \frac{0{,}84 \cdot R \cdot S_d \cdot (T_{c1}) \cdot q}{g}$$

where

$S_e(T_{c1})$ is the elastic response spectral acceleration at the 1st convective mode of the fluid for a damping value appropriate for the sloshing response.

9.2.3.2 Material properties

The required material parameters for verification are determined according to Clause 7 or relevant material tests. The material properties in Table 10 can be used for the calculation of the oscillation period T, and evidence for strain.

Table 10 — Material properties

Modulus of elasticity	$E_e = 1{,}5 \cdot \sqrt{E_{\phi,b} \cdot E_x}$
Viscous damping	5 %
Behaviour coefficient	q = 1,5

9.2.3.3 Design values of ground acceleration

The design values for the ground acceleration $a_g = a_{gR} \cdot \gamma_I$ are given in EN 1998-1.

9.2.3.4 Design acceleration

The oscillation period T of the vessels or tanks determines the abscissa value the response spectrum, which is decisive for the calculation of the design acceleration. Under the assumption $T_A = T_B = 0$:

$T \le T_C$ (plateau area): $S_d(T) = a_g \cdot S \cdot \frac{2{,}5}{q}$ (14)

$T_C < T \le T_D$: $S_d(T) = a_g \cdot S \cdot \frac{2{,}5}{q} \cdot \frac{T_C}{T} \ge \beta \cdot a_g$ (15)

$T_D < T$: $S_d(T) = a_g \cdot S \cdot \frac{2{,}5}{q} \cdot \frac{T_C \cdot T_D}{T^2} \ge \beta \cdot a_g$ (16)

where

- a_g is the design ground acceleration $\left(a_g = \gamma_I \cdot a_{gR}\right)$;
- T is the vibration period of vessel or tank in [s];
- T_C is the upper limit of the period of the constant spectral acceleration branch;
- T_D is the value defining the beginning of the constant displacement response range of the spectrum;
- γ_I is the importance factor, 1,2 ≤ γ_I ≤ 2,0 (see EN 1998–1 and EN 1998–4);
- S is the soil factor (see EN 1998 (all parts));
- $S_d(T)$ is the design spectrum;
- β is the lower bound factor for the horizontal design spectrum (see EN 1998 (all parts); the recommended value for β is 0,2.);
- q is the behaviour factor (recommended value for q is 1,5).

The vibration period for an anchored liquid filled vertical vessel with nothing built-on, can be calculated as follows (cantilever with uniform mass distribution and nearly constant bending stiffness):

$$T = \sqrt{\frac{\rho_{liquid} \cdot h_{liquid}}{E_e \cdot t_{1/2}}} \cdot D \cdot \left[0{,}628 \cdot \left(\frac{h_{liquid}}{D} \right)^2 + \frac{2 \cdot h_{liquid}}{D} + 1{,}49 \right] \tag{17}$$

9.2.3.5 Unit loads

For all unit loads the formulae in Clauses 9 to 16 are valid and γ_F = 1,0.

The total mass of the liquid is assumed to be moving in unison with the shell and the sloshing movement of liquid at the surface is neglected.

The total horizontal load is:

$$H_{AE} \cong S_d(T) \cdot W_G \qquad W_G \approx dead\ load(vessel) + V \cdot \rho_{liquid} \tag{18}$$

Moment:

For the moment the gravity point of the liquid should be recognized. For flat bottom tanks is $h_s = h_{liquid}/2$ and for tanks with a skirt $h_s = h_{liquid}/2 + h_{skirt}$.

$$M_{AE} = H_{AE} \cdot h_s \tag{19}$$

9.2.4 Insulation loads

Insulation loads shall be those relating from the self-weight of the insulation, including cladding.

When rigid foams are used for the insulation high external pressure can be exerted on the inner shell. Due to expansion this effect shall be considered in the design of the vessel.

9.2.5 Loads resulting from connections

For the loads resulting from pipes, valves and other items connected to the tank or vessel a design method can be found in Bijlaard [7]. Pipework shall be designed to minimize loadings applied to the tank or vessel. The additional moments caused by these loads shall be minimized.

9.2.6 Agitation

The manufacturer shall determine the loads from the agitator and those imposed on any associated baffles. These loads shall be considered as imposed loads on the tank or vessel. Wherever possible, agitators should be independently supported from the tank or vessel.

9.2.7 Pressure due to inadequate venting

Where the venting system to a tank may be susceptible to blockage or impediment, an analysis shall be used to determine the suction pressure arising during tank discharge at the peak rate. This analysis shall consider the possible adiabatic nature of the process. It shall not be possible to close the venting system.

The purchaser of a vessel with an external pressure PS_{ep} and/or an overpressure PS_{op} is responsible for suitable safety devices to ensure that the limit values for pressures are not exceeded.

9.2.8 Personnel loading

Whenever personnel are required to walk onto the tops of tanks or vessels the tank or vessel top shall be designed to accommodate this additional loading. In the absence of any personnel loading value being specified, the following loads shall be used:

— p_{access} = 1,5 kN/m² over the total area and/or

— P_{access} = 1,5 kN over an area of 300 mm in diameter.

Snow and access loads shall not be considered to act together.

9.2.9 Internal stresses in vessels and tanks due temperatures

The load cases “sunlight” and “temperature gradient” on the wall thickness need not be taken into account.

Different temperatures in a vessel or tank for example between the cylinder and the bottom can cause additional loads in the connection cylinder / bottom or cylinder / bottom / skirt support. These loads shall be considered.

To determine the additional loads due to the temperature differences ΔT listed below shall be used:

Design temperature	located indoors	located outdoors
$TS \leq 40$ °C;	$\Delta T = 0$ K	$\Delta T = 0$ K
40 °C < $TS \leq 60$ °C;	$\Delta T = 10$ K	$\Delta T = 20$ K
60 °C < $TS \leq 80$ °C;	$\Delta T = 15$ K	$\Delta T = 30$ K
$TS > 80$ °C;	$\Delta T = 20$ K	$\Delta T = 40$ K

The factor for the resulting unit loads is: $\gamma_F \cdot A_5 = 1{,}0$.

9.3 Verification by the partial factor method

9.3.1 General

9.3.1.1 General remarks

As verification method for the tanks or vessels the partial factor method according to EN 1990 shall be used.

When using the partial factor method, it shall be verified that, in all relevant design situations, no relevant limit state is exceeded when design values for actions or effects of actions and resistances are used in the design models.

For the selected design situation and the relevant limit states the individual actions for the critical load cases should be combined as detailed in EN 1990. However actions that cannot exist simultaneously due to physical or functional reasons should not be considered to act together in combinations of actions.

9.3.1.2 Principle of limit states design

A distinction shall be made between ultimate limit states and serviceability limit states:

a) Ultimate limit states:

   The limit states that concern:

   1) the safety of people, and/or

   2) the safety of structure

   shall be classified as ultimate limit states.

Limit states shall be related to the design situations:

— persistent design situations, which refer to the conditions of normal use;

— transient design situations, which refer to temporary conditions applicable to the structure e.g. during execution or repair;

— accidental design situations, which refer to exceptional conditions applicable to the structure or to its exposure e.g. to fire, explosion, impact or the consequences of localized failure;

— seismic design situations, which refer to conditions applicable to the structure when subjected to seismic events.

b) Serviceability limit states:

   The limit states that concern:

   1) the functioning of the structure or structural members under normal use;

   2) the comfort of people;

   3) the appearance of the construction works;

   shall be classified as serviceability limit states.

The combinations of actions to be taken into account in the relevant design situations should be appropriate for the serviceability requirements and performance criteria being verified.

9.3.1.3 Combination of actions

According to EN 1990 all actions shall be classified as follows:

— permanent actions (G), e.g. self-weight of the vessel or tank, fixed equipment, and indirect actions caused by shrinkage and uneven settlements;

— variable actions (Q), e.g. personnel loads, wind actions or snow loads;

— accidental actions (A), e.g. explosions, or impact from vehicles;

— seismic actions (A_E).

For each critical load case, the design values of the effects of actions (E_d) shall be determined by combining the values of actions that are considered to occur simultaneously. Each combination of actions should include a leading variable action or an accidental action.

a) Ultimate limit state:

Fundamental combination for persistent or transient design situations:

$$E_d = \sum \gamma_{G,j} \cdot G_{k,j} \cdot A_5^{long\,term} \oplus \gamma_{Q,1} \cdot Q_{k,1} \cdot A_5^{load\,time} \oplus \sum \gamma_{Q,i} \cdot \psi_{o,i} \cdot Q_{k,i} \cdot A_5^{load\,time} \tag{20}$$

Combinations of actions for accidental design situations:

$$E_{dA} = \sum \gamma_{GA,j} \cdot G_{k,j} \cdot A_5^{long\,term} \oplus A_d \cdot A_5^{short\,term} \oplus \psi_{1,1} \cdot Q_{k,1} \cdot A_5^{load\,time} \oplus \sum \psi_{2,i} \cdot Q_{k,i} \cdot A_5^{load\,time} \tag{21}$$

Combinations of actions for seismic design situations:

$$E_{dAE} = \sum G_{k,j} \cdot A_5^{long\,term} \oplus A_{Ed} \cdot A_5^{short\,term} \oplus \sum \psi_{2,i} \cdot Q_{k,i} \cdot A_5^{load\,time} \tag{22}$$

Verifications of static equilibrium and resistance:

When considering a limit state of static equilibrium of the structure, it shall be verified that:

$$E_{d,dst} \leq E_{d,stb} \tag{23}$$

When considering a limit state of rupture or excessive deformation of a section, member or connection, it shall be verified that:

$$E_d \leq R_d \tag{24}$$

b) Serviceability limit state:

Characteristic combination (used to verify limit strain):

$$E_{d,rare} = \sum G_{k,j} \oplus \sum Q_{k,1} \oplus \sum \psi_{o,1} \cdot Q_{k,i} \tag{25}$$

Frequent combination:

$$E_{d,frequ} = \sum G_{k,j} \oplus \psi_{1,1} \cdot Q_{k,1} \oplus \sum \psi_{2,i} \cdot Q_{k,i} \tag{26}$$

Quasi-permanent combination:

$$E_{d,rare} = \sum G_{k,j} \oplus \sum \psi_{2,i} \cdot Q_{k,i} \tag{27}$$

Verifications:

It shall be verified that:

$$E_d \leq C_d \tag{28}$$

where

$\oplus$	implies “to be combined with”;
Σ	implies “the combined effect of”;
$G_{k,j}$	is the characteristic value of permanent action *j*;
$Q_{k,1}$	is the characteristic value of the leading variable action;

$Q_{k,i}$	is the characteristic value of the accompanying variable action *i*;
A_d	is the design value of an accidental action;
A_{Ed}	is the design value of seismic action ($A_{Ed} = \gamma_I \times A_{Ek}$; refer to EN 1998 (all parts));
$\gamma_{G,j}$	is the partial factor for permanent action *j*;
$\gamma_{Q,1}$	is the partial factor for the leading variable action;
$\gamma_{Q,i}$	is the partial factor for the accompanying variable action *i*;
$\psi_{o,i}$	is factor for combination value of a variable action $Q_{k,i}$;
$\psi_{1,i}$	is factor for frequent value of a variable action $Q_{k,i}$;
$\psi_{2,i}$	is factor for quasi-permanent value of a variable action $Q_{k,i}$;
$A_5^{load\,time}$	is the influence of load exposure time;
E_d	is the design value of effect of actions;
$E_{d,dst}$	is the design value of effect of destabilizing actions;
$E_{d,stb}$	is the design value of effect of stabilizing actions;
R_d	is the design value of the corresponding resistance;
C_d	is the limiting design value of the relevant serviceability criterion.

Index:	*d*	design value
	k	characteristic value
	j	item of permanent load, $j \geq 1$
	i	item of variable load, $i \geq 1$

Table 11 — Ψ-factors based on EN 1990

Action	ψ_0	ψ_1	ψ_2
Pressures:			
- Long term pressures	1,0	1,0	1,0
- Short-term pressures	0	0	0
Imposed loads in buildings, category (see EN 1991–1–1)			
- Category A: domestic, residential areas	0,7	0,5	0,3
- Category B: office areas	0,7	0,5	0,3
- Category C: congregation areas	0,7	0,7	0,6
- Category D: shopping areas	0,7	0,7	0,6
- Category E: storage areas	1,0	0,9	0,8
Traffic loads:			
- Category F: vehicle weight ≤ 30kN	0,7	0,7	0,6
- Category G: 30kN ≤ vehicle weight ≤ 160kN	0,7	0,5	0,3
- Category H: roofs	0	0	0
Snow loads on buildings (see EN 1991–1–3)[a]:			
Finland, Iceland, Norway, Sweden	0,7	0,5	0,2
Remainder of CEN Member States,			
- for sites located at altitude H > 1 000 m a.s.l.	0,7	0,5	0,2
- for sites located at altitude H ≤ 1 000 m a.s.l.	0,5	0,2	0
Wind loads on buildings (see EN 1991–1–4)	0,6	0,2	0
Temperature (non-fire) in buildings (see EN 1991–1–5)	0,6	0,5	0
Settlement	1,0	1,0	1,0
The grey marked ψ-factors are given informatively. Normally, for the analysis of a standard tank, they do not have to be used.			
[a] For countries not mentioned below, see relevant local conditions.			

Table 12 — Design values of actions

Design criterion	Action	Symbol	Situation	
			P/T	A/AE
Failure of the structure by breakage or excessive deformation	Independent permanent actions:			
	unfavourable	$\gamma_{G,sup}$	1,35	1,00
	favourable	$\gamma_{G,inf}$	1,00	1,00
	For liquid filling			
	unfavourable	$\gamma_{G,sup}$	1,35	1,00
	favourable	$\gamma_{G,inf}$	0	0
	Independent variable actions:			
	unfavourable	$\gamma_{Q,sup}$	1,50	1,00
	favourable	$\gamma_{Q,inf}$	0	0
	Accidental actions:	γ_A		1,00
	Seismic actions:	γ_{AE}		1,00
Static loss of equilibrium	Permanent actions:			
	Dead load of the structure and of non-bearing parts, permanent actions which originate from foundation soil, ground water and free upcoming water			
	unfavourable	$\gamma_{G,sup}$	1,10	1,00
	favourable	$\gamma_{G,inf}$	0,90	0,95
	For small fluctuations of the permanent actions, as for example for the verification of buoyancy safety			
	unfavourable	$\gamma_{G,sup}$	1,05	1,00
	favourable	$\gamma_{G,inf}$	0,95	0,95
	For liquid filling			
	unfavourable	$\gamma_{G,sup}$	1,10	1,00
	favourable	$\gamma_{G,inf}$	0	0
	Variable actions:			
	unfavourable	$\gamma_{Q,sup}$	1,50	1,00
	favourable	$\gamma_{Q,inf}$	0	0
	Accidental actions:	γ_A		1,00
	Seismic actions:	γ_{AE}		1,00
P: Permanent design situation T: Transient design situation A: Accidental design situation AE: Seismic design situation				
The grey marked design criterion is given informatively. Normally, for the analysis of a standard tank, it is not relevant.				

The most severe combination of *n* actions may be determined as follows:

— Write all *n* loads line by line (with γ_F and $A_5^{load\,time}$ if necessary) in an *n·1*-matrix *E*.

— Write all *m* possible combinations column by column (in terms of combination values) in an *n·m*-matrix Ψ. Each column of this matrix represents a possible combination of loads.

— Multiply the transpose of *E* with Ψ and find the maximum entry in the resulting matrix. The column number of the maximum is the column number of the most severe combination in Ψ.

For example:

$$E=\begin{pmatrix}\gamma_{F,g,1}\cdot G_{c,1}\cdot A_5^{long\,term}\\ \gamma_{F,q,1}\cdot Q_{c,1}\cdot A_5^{load\,time}\\ \gamma_{F,q,2}\cdot Q_{c,2}\cdot A_5^{load\,time}\\ \gamma_{F,q,3}\cdot Q_{c,3}\cdot A_5^{load\,time}\\ \gamma_{F,q,4}\cdot Q_{c,4}\cdot A_5^{load\,time}\end{pmatrix}\;,\;\psi=\begin{pmatrix}1&1&1&1\\1&\psi_{o,1}&\psi_{o,1}&\psi_{o,1}\\\psi_{o,2}&1&\psi_{o,2}&\psi_{o,2}\\\psi_{o,3}&\psi_{o,3}&1&\psi_{o,3}\\\psi_{o,4}&\psi_{o,4}&\psi_{o,4}&1\end{pmatrix}\Rightarrow E_d=\max\left(E^T\cdot\psi\right)$$

NOTE For a detailed example see CEN/TR 13121–5.

The value of partial loading factor γ_F shall comply with the factor given in EN 1991-4.

For example:

$\gamma_{F,j}=\gamma_{G,j}=\gamma_{Q,j}$	partial safety factor for the load j
$\gamma_{F,w}=\gamma_{G,j}=1{,}35$	for permanent clear loads (e.g. dead load, filling)
$\gamma_{F,p}=\gamma_{Q,j}=1{,}50$	changing loads (e.g. pressure, wind, snow e.g.)
$\gamma_{F,r}=\gamma_{Q,j}=1{,}00$	restraint loads (temperature e.g.)
$\gamma_{F,s}=\gamma_{Q,j}=1{,}00$	serviceability limit states
$\gamma_{F,e}=\gamma_{Q,j}=1{,}00$	extraordinary burden (earth quake e.g.)
$\gamma_{F,red}=\gamma_{Q,j}=0{,}90$	for dead load, if the operational demands reduced
$\gamma_{F,w}=\gamma_{Q,j}=1{,}35$	for mounting loads

The most frequent combination at each region of the tank or vessel is given in Clause 10. These combinations are examples only and they do not make use of ψ-factors. For further information about the partial safety factor concept, see EN 1990.

9.3.2 Dimensioning by using (A_5·γ)-factored loads

For the "(A_5·*γ*)-factored load dimensioning" (ultimate limit state), the following formula shall be satisfied

$$A_5\cdot E_i\cdot\gamma_{F,i}\leq\frac{R_k}{\gamma_M\cdot A_1\cdot A_2\cdot A_3\cdot A_4}\qquad(29)$$

where

E_i is the load effect

R_k is the resistance of the material (laminate)

By all indications, the effecting loads shall be multiplied by $\gamma_{F,i}$ and the corresponding influence factor A_5. These ($A_5 \cdot \gamma_F$)-factored loads determine the particular tensions $\sigma_{d,R}$ or $n_{d,R}$.

The following applies:

$$\frac{\Sigma \sigma_{i,d,R}}{\dfrac{f_{i,k}}{\gamma_M \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4}} \leq 1 \quad or \quad \frac{\Sigma n_{i,d,R}}{\dfrac{U_{lam,i,k}}{\gamma_M \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4}} \leq 1$$

For strain limit only the unfactored loads of the characteristic combination in the serviceability limit state shall be calculated for the proof of strain.

$$\frac{\Sigma \sigma_{i,\varepsilon}}{E_{i,m}} \leq \varepsilon_{\lim} \quad or \quad \frac{\Sigma n_{i,\varepsilon}}{X_{lam,i,m}} \leq \varepsilon_{\lim} \qquad (30)$$

where

$\sigma_{i,d,R}$ is strength from $A_5 \cdot \gamma_{F,i}$-factored loads

$n_{i,d,R}$ is unit load from $A_5 \cdot \gamma_{F,i}$-factored loads

$\sigma_{i,\varepsilon}$ is the strength from unfactored loads

$n_{i\varepsilon}$ is the unit load from unfactored loads

$f_{i,k}$ is the characteristic strength for the corresponding laminate

$U_{lam,I,k}$ is the characteristic ultimate unit load for the corresponding laminate

$E_{i,m}$ is the characteristic mean value of the corresponding E-modulus. To simplify, the characteristic value can be calculated and multiplied by 1,1

$X_{lam,i}$ is the characteristic unit tensile or flexural modulus for the corresponding laminate

9.4 Drawings and design calculations

Where the design incorporates reinforcement with directional properties, the orientation of the fibres shall be specified on drawings and in calculations in order to ensure that the structural properties required by the design are obtained, the full drawing requirements are given in 17.3.

9.5 Design details

9.5.1 Design temperature *TS*

The design temperature *TS* shall be as defined in Clause 3.

9.5.2 Pressure

The design pressure, p_d, i.e. the pressure at the point under consideration to be used in calculations to establish the required strength of the component parts of a vessel or tank and shall take in to account the following pressure loads:

PS		maximum allowable pressure $(+/-)$ short or long term
$p_{hp} = \rho \cdot g \cdot h_{liquid}$		long term (hydrostatic pressure)
p_{wind}	see 9.2.2	short-term
p_{snow}	see 9.2.2	short-term or long term (normally 2 months)

p_{access} see 9.2.2 short-term

p_d shall be the worst values of the combination of the individual pressure loads.

Minimum pressure emptying −3 mbar and filling +5 mbar above static head as short-term loads. Long term pressure only if present.

10 Design analysis

10.1 Symbols and units

Symbol	Unit	Definition
α	1/°C	thermal expansion coefficient
λ	-	shell parameter
D	mm	internal diameter of tank/vessel
D_{pc}	mm	pitch circle diameter of anchorage bolts
D_m	mm	mean diameter of cone section
D_s	mm	neutral axis of stiffener ring
d_{co} or d_c	mm	diameter of the nozzle cut-out
E	N/mm²	modulus of elasticity
E_b	N/mm²	flexural modulus
E_s	N/mm²	modulus of elasticity of stiffener
E_x	N/mm²	tensile modulus of laminate in axial direction
$E_{x,b}$	N/mm²	flexural modulus of laminate in axial direction
E_ϕ	N/mm²	tensile modulus of laminate in circumferential direction
$E_{\phi,b}$	N/mm²	flexural modulus of laminate in circumferential direction
ε		strain
ε_{lim}		limit strain of laminate or lamina (= design strain ε_d)
ε_ϕ		strain in circumferential direction
ε_x		strain in axial direction
G_{xy}	N/mm²	shear modulus of laminates
h_{Liquid}	mm	height of liquid
I_s	mm⁴	moment of inertia of stiffener
l_{over}	mm	length overlapping laminate
L_c	mm	length of local thickening
L_j	mm	length of overlay/side of a joint
L_s	mm	distance between two stiffeners or supports
m	Nm/m	unit moment
M	Nmm	bending moment
M_d	Nmm	calculation of bending moment

Symbol	Unit	Definition
M_H	Nmm	maximum flexural moment at saddle horn of horizontal vessel support
M_S	Nmm	flexural moment in stiffening ring
n	N/mm	unit load
n_c	N/mm	unit load, cut out
n_{cr}	N/mm	critical axial unit load causing axial instability failure
n_{over}	N/mm	unit load, overlapping laminate
$n_{x,w}$	N/mm	unit load, axial direction, due to weight
n_x	N/mm	unit load, axial direction
n_ϕ	N/mm	unit load, circumferential direction
N_b	-	number of anchorage bolts
N_S	N	normal load in the stiffener ring
p_d	N/mm²	design pressure
p_{cr}	N/mm²	pressure causing instability failure
p_{hp}	N/mm²	hydrostatic pressure
PS	N/mm²	maximum pressure (= maximum allowable pressure according to EU Directive 2014/68/EU)
PS_{op}	N/mm²	maximum internal pressure (overpressure)
PS_{ep}	N/mm²	maximum external pressure
t	mm	thickness of shell
t_k	mm	thickness of cylinder knuckle area
t_s	mm	thickness of stiffener
t_z	mm	thickness of the lower part of a cylinder in case of skirt
t_{ez}	mm	thickness of the lower part of a cylinder in case of flat bottom
t_{over}	mm	thickness overlapping laminate
W_D	N	calculation weight
W	N	weight
X	N/mm	unit modulus
Z	mm³	section modulus

Subscripts	
ΔT	due to temperature difference
ϕ	circumferential direction
b, B	bending
Bk	bottom knuckle area

Subscripts	
e	for any possible actions
ε	due strain
d	design (D in pressure rules)
cr	critical
cyl	cylinder
ep	external pressure
F	flexural
H	saddle horn
hp	hydrostatic pressure
k	knuckle area
k	characteristic values
lam	laminate
L	load
M	due to flexural moment
N	due to normal load
op	internal pressure
p	due to pressure
over	for over laminate
R	ring
R	rupture, design for bearing capability
S	stiffener
Sk	skirt
Sku	upper part of skirt
snow	due to snow
T	due to tensile load
W or w	due to weight
wind	due to wind
x	axial direction

10.2 Vertical vessels or tanks, cylinders under loads (t < 0,01·D)

10.2.1 Circumferential loadings

The maximum circumferential unit loads n_ϕ shall be determined from Formula (31):

$$n_{\varphi,d,R} = \frac{p_{d,R} \cdot D}{2} \quad or \quad n_{\varphi,d,\varepsilon} = \frac{p_{\mathbf{d},\varepsilon} \cdot D}{2} \tag{31}$$

where

$$p_{d,R} = PS_{op} \cdot A_{5,i} \cdot \gamma_{F,p} + p_{hp} \cdot A_{5,i} \cdot \gamma_{F,w} \tag{32}$$

Respectively $p_{d,\varepsilon} = PS_{op} + p_{hp}$ (33)

For the selected laminate use 9.3.2 to proof the circumferential load bearing capacity.

For radial stability $p_{d,cr} = PS_{ep} \cdot \sqrt{A_{5,i}} \cdot \gamma_{F,p} + p_{wind} \cdot \gamma_{F,p}$ (34)

10.2.2 Combined axial loading

The maximum axial unit loading n_x at the point under consideration shall be determined from the combined axial unit loadings due to:

a) Pressure:

axial unit load $n_{x,p,d,R} = \dfrac{p_{d,R} \cdot D}{4}$ *or* $n_{x,p,d,\varepsilon} = \dfrac{p_{\mathbf{d},\varepsilon} \cdot D}{4}$ (35)

where

$$p_{d,R} = PS_{op} \cdot A_{5,i} \cdot \gamma_{F,p} + \sum \left(p_{e,i} \cdot A_{5,i} \cdot \gamma_{F,i} \right)$$

respectively $p_{d,\varepsilon} = PS_{op} + \sum p_{e,i}$

For axial stability case the axial compression caused by external pressure need not be taken into account:

$$p_{d,cr} = 0$$

where

$p_{e,i}$ is any other pressure load

b) Flexural moment due to wind or snow loads (determined by an applicable local code):

axial unit load $n_{\mathbf{x,M,d,R}} = \dfrac{4 \cdot M_{\mathbf{d,R}}}{\pi \cdot D^2}$ *or* $n_{\mathbf{x,M,d},\varepsilon} = \dfrac{4 \cdot M_{\mathbf{d},\varepsilon}}{\pi \cdot D^2}$ *or* $n_{\mathbf{x,M,d,cr}} = \dfrac{4 \cdot M_{\mathbf{d,cr}}}{\pi \cdot D^2}$ (36)

where

$$M_{d,R} = M_{wind} \cdot \gamma_{F,p} + \sum \left(M_{e,i} \cdot A_{5,i} \cdot \gamma_{F,i} \right)$$

respectively $M_{d,\varepsilon} = M_{wind} + \sum M_{e,i}$

For axial stability case:

$$M_{d,cr} = M_{wind} \cdot \gamma_{F,p} + \sum \left(M_{e,i} \cdot \sqrt{A_{5,i}} \cdot \gamma_{F,i} \right)$$

where

$M_{e,i}$ is any other flexural moment.

c) Weight of vessel, fittings, contents, attachments applied and personnel loads:

axial unit load $$n_{\mathbf{x,W,d,R}} = \frac{W_{\mathbf{d,R}}}{\pi \cdot D} \quad or \quad n_{\mathbf{x,W,d,}\varepsilon} = \frac{W_{\mathbf{d,}\varepsilon}}{\pi \cdot D} \quad or \quad n_{\mathbf{x,W,d,cr}} = \frac{W_{\mathbf{d,cr}}}{\pi \cdot D} \qquad (37)$$

where

$$W_{d,R} = W \cdot A_{5,i} \cdot \gamma_{F,W} + \sum \left(W_{e,i} \cdot A_{5,i} \cdot \gamma_{F,i} \right)$$

respectively $W_{d,\varepsilon} = W + \sum W_{e,i}$

For axial stability case:

$$W_{d,cr} = W \cdot \sqrt{A_{5,i}} \cdot \gamma_{F,w} + \sum \left(W_{e,i} \cdot \sqrt{A_{5,i}} \cdot \gamma_{F,i} \right)$$

where

$W_{e,i}$ is any other weight loading.

The combined axial unit loading, n_x, is the sum of the values obtained from formulae above, having due regard for the direction of loads.

For shell in:

tension: $$n_{x,d,R} = n_{x,p,d,R} + n_{x,M,d,R} + n_{x,W,d,R} \qquad (38)$$

strain: $$n_{x,d,\varepsilon} = n_{x,p,d,\varepsilon} + n_{x,M,d,\varepsilon} + n_{x,W,d,\varepsilon} \qquad (39)$$

For the selected laminate use 9.3.2 to proof the axial load bearing capacity.

For the shell instability (i.e. compressive loading):

$$n_{x,d,cr} = n_{x,M,d,cr} + n_{x,W,d,cr} \qquad (40)$$

The maximum value of $n_{x,d,cr}$ shall meet the stability criteria as given in 10.3.2.

10.3 Cylindrical shells subject to compressive loadings — critical buckling criteria

10.3.1 General

The cylindrical shell shall be checked to ensure that it is of sufficient thickness to resist collapse from either the individual axial or circumferential compressive loading as well as their combined effect where applicable.

10.3.2 Critical axial buckling load

When there is a compressive axial load a check calculation shall be made to ensure that the region of the shell subject to the highest compressive load is adequate to resist collapse by buckling. The compressive buckling unit load for the shell is:

$$n_{\mathbf{cr}} = k \cdot \sqrt{E_{\varphi\mathbf{b}} \cdot E_{\mathbf{x}}} \cdot \frac{t^2}{D} \qquad (41)$$

where

$E_{\phi b}$ is the flexural modulus in the circumferential direction

E_x is the axial modulus

t is the actual shell thickness

$$k = \frac{0,84}{\sqrt{1 + \frac{D}{200 \cdot t}}}$$

For shells without cut-outs and if the axial compression n_x results from bending the factor k shall be increased by a factor of 1,2:

The following criterion shall be met:

$$\frac{n_{\mathbf{x,d,cr}}}{n_{\mathbf{cr}} / (\gamma_M \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4)} \leq 1 \quad (42)$$

Regarding shell sections or skirt supports,10.6.4.3.7, with cut outs, the formula for k for such sections is:

when

$$\frac{d_{\mathbf{co}}}{\left(\frac{D \cdot t}{2}\right)^{0.5}} \leq 3,5 \quad k = \frac{0,78}{\sqrt{1 + \frac{D}{200 \cdot t}}} \quad (43)$$

and when

$$\frac{d_{\mathbf{co}}}{\left(\frac{D \cdot t}{2}\right)^{0.5}} > 3,5 \quad k = \frac{0,54}{\sqrt{1 + \frac{D}{200 \cdot t}}} \quad (44)$$

where

d_{co} = diameter of the cut-out and t is the general thickness of the shell in the cut-out region. If the gap between openings is less than the largest d_{co}, use the sum of $d_{co,1}$ and $d_{co,2}$.

10.3.3 Critical circumferential buckling pressure

For short cylinders $L_S \leq 6 \cdot D$.

Cylinders with stepwise variable wall thicknesses shall be replaced according to EN 1993-1-6:2007, D.2 by an equivalent cylinder comprising three sections. t_o and l_o are values for the top section.

$$p_{\mathbf{cr}} = 2,40 \cdot C_\Theta \cdot \sqrt[4]{E_{\varphi\mathbf{b}}^3 \cdot E_{\mathbf{x}}} \cdot \frac{D}{L_{\mathbf{S}}} \cdot \left(\frac{t}{D}\right)^{2,5} \quad (45)$$

where

L_S is the effective length of the cylinder, or the distance between two stiffeners, see Figure 1. For normal tanks or vessels C_Θ = 1,0. For open tops then C_Θ = 0,6.

For long cylinders i.e. L_S or $L > 6 \cdot D$

$$p_{\mathbf{cr}} = 2,1 \cdot E_{\varphi\mathbf{b}} \cdot \left(\frac{t}{D}\right)^3 \quad (46)$$

the following criterion shall be met:

$$\frac{p_{\mathbf{d,cr}}}{p_{cr}\,/\,(\gamma_M \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4)} \leq 1 \tag{47}$$

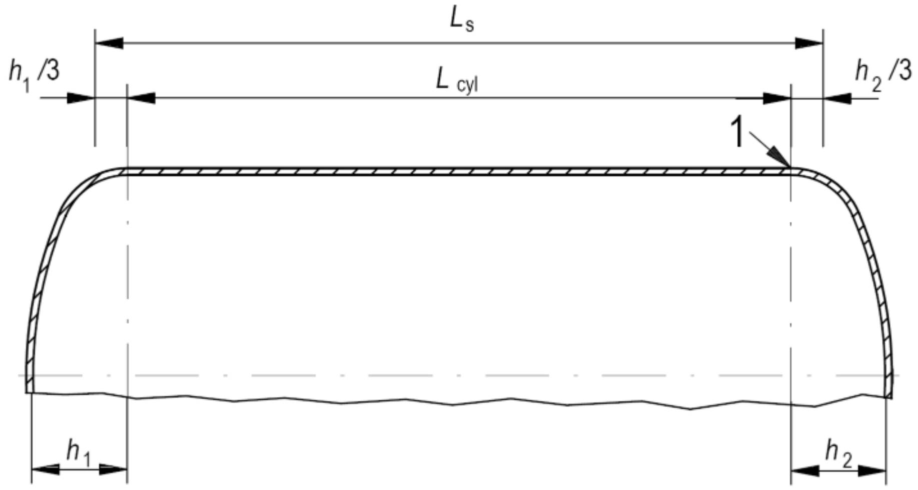
10.3.4 Combined axial and radial compressive loadings

For combined axial and radial loadings, the following criterion shall be met

$$\left(\frac{n_{x,d,cr}}{n_{cr}\,/\,(\gamma_M \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4)}\right)^{1,25} + \left(\frac{p_{d,cr}}{p_{cr}\,/\,(\gamma_M \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4)}\right)^{1,25} \leq 1 \tag{48}$$

where

$n_{x,d,cr}$ is given in 10.2.2, n_{cr} in 10.3.2 and p_{cr} in 10.3.3.

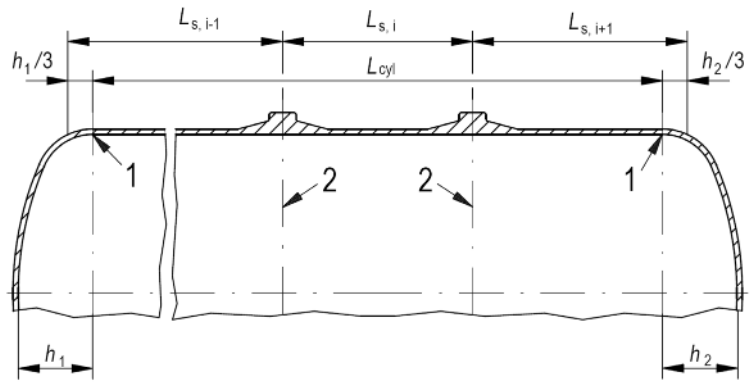


Key

1 tangent point

NOTE L_s can be the cylinder length if the knuckle is proven to act as a stiffener (see Figure 44).

Figure 1 — Effective length of unstiffened cylinders



Key

1 tangent point

2 C_L of stiffener

NOTE L_s can be the cylinder length if the knuckle is proven to act as a stiffener as shown in Figure 44.

Figure 2 — Effective length between stiffeners on cylinder

10.3.5 Critical buckling pressure for cylindrical shell stiffened with external or internal rings

When the thickness obtained from 10.3.3 or 10.3.4 results in an unacceptably high value, the shell may be subdivided and recalculated using a shorter effective length.

All stiffening rings shall encircle the cylinder and any joints in the ring shall be so designed to develop the full stiffness of the ring. All rings shall be bonded to the shell.

The critical general instability pressure p_{cr} is given by Formula (49):

$$p_{cr} = \left[\left(E_{\varphi b}^{3} \cdot E_{x} \right)^{0,25} \cdot \frac{2 \cdot t_{c}}{D} \cdot \frac{\lambda^{4}}{\left(m^{2} - 1 + \frac{\lambda^{2}}{2} \right) \cdot \left(m^{2} + \lambda^{2} \right)^{2}} + \frac{8 \cdot \left(m^{2} - 1 \right) \cdot E_{s} \cdot I_{s}}{L_{s} \cdot D_{s}^{3}} \right] \quad (49)$$

To find the minimum value of p_{cr} use m = 2,3, ... etc.

Where $L > 20 \cdot D$ or the contribution from the shell is ignored, the shell parameter λ given in Formula (51), is zero in Formula (49) and the ring stiffness is given by Formula (50):

$$E_{s} \cdot I_{s} \geq \frac{\gamma_{M} \cdot A_{1} \cdot A_{2} \cdot A_{3} \cdot A_{4} \cdot p_{d,cr} \cdot L_{s} \cdot D_{s}^{3} \cdot F}{24} \quad (50)$$

where

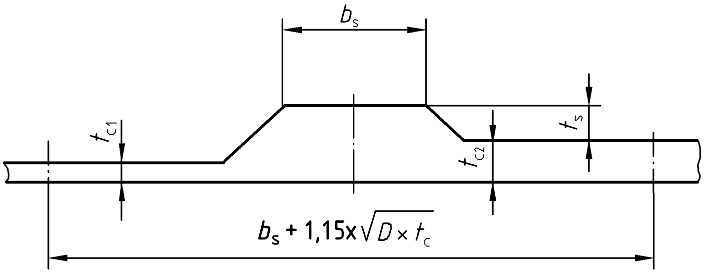
- m is the circumferential buckling wave number, 2,3 .. ;
- E_s is the flexural modulus of the stiffener, in the hoop direction;
- λ is the shell parameter;
- I_S is the second moment of area of the stiffener, see Figures 3 and 4;
- L_S is the mean length of the fields adjacent to the stiffener;
- t_c is the minimum shell thickness of t_{c1} or t_{c2} in the area of the stiffener, see Figure 3;
- L_{cyl} is the total cylindrical length of the vessel.

$$\lambda = \frac{\pi \cdot D}{2 \cdot \left(L_{cyl} + \frac{h_{1} + h_{2}}{3} \right)} \quad (51)$$

The following criterion shall be met:

$$\frac{p_{d,cr}}{p_{cr} / \left(\gamma_{M} \cdot A_{1} \cdot A_{2} \cdot A_{3} \cdot A_{4} \right)} \leq 1 \quad (52)$$

a) For a solid GRP stiffener the basic dimensions to be used are given as follows and shown in Figure 3. Where the effective width of the shell used in this calculation equals $b_s + 1{,}15 \cdot \sqrt{D \cdot t_c}$:



Key

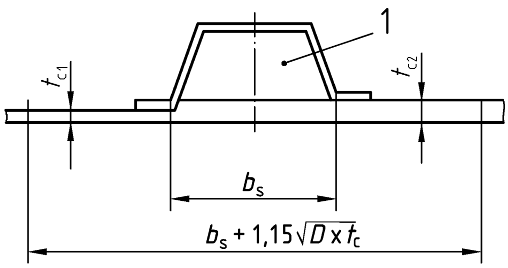
$5 \cdot t_c \leq b_S \leq 20 \cdot t_S$; and

$1{,}5 \cdot t_c \leq t_S \leq 4 \cdot b_S$; and

$b_s \leq 300$ mm

Figure 3 — Solid GRP stiffener configuration

b) For other GRP-stiffener configurations the basic dimensions to be used, are as shown in Figure 4:



Key

1 infill (foam) or open

NOTE t_c = average thickness

Figure 4 — Other GRP stiffener configurations

c) For steel rings:

It is permissible to use encapsulated steel rings as stiffeners provided that:

1) the modulus of elasticity of steel is used for E_s, in the stiffener design;

2) the design shall ensure that the steel is adequately protected against corrosion;

3) the design temperature does not exceed 60 °C.

10.4 Conical shells

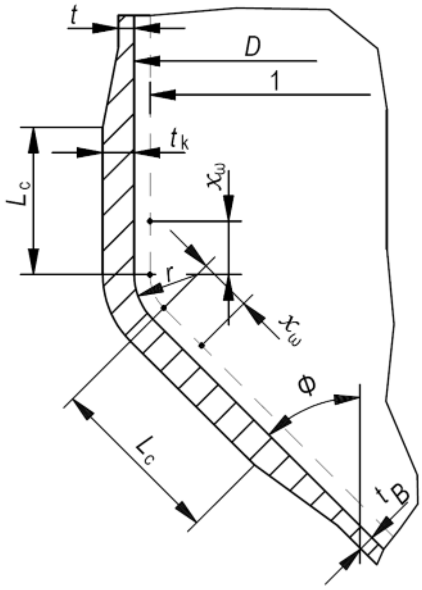
10.4.1 General requirements

The geometry of conical shells shall be one of the forms shown in Figure 5 and Figure 6.

Conical sections with knuckle, shown in Figure 5 shall be used for all materials with or without thermoplastics liner, except as noted below. The knuckle radius r, should preferably be not less than $0{,}1 \cdot D$, but shall not be less than $0{,}06 \cdot D$, where D is the adjacent shell diameter. The maximum included angle of the cone at its apex shall be 150° for all cones subject to pressure or vacuum.

Conical sections without knuckle (non-preferred construction), shown in Figure 6 may only be used for all materials without thermoplastics liner and for fabric backed thermoplastic lined tanks. This construction shall be restricted to tanks for static storage duty only with maximum dimensions of up to 1,5 m diameter, a cylindrical height of 2 m and a maximum included angle of the cone at its apex of 120°.

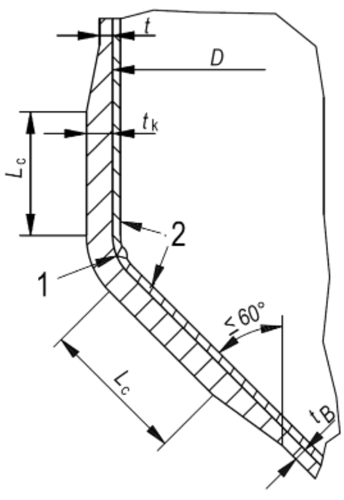
Conical covers of storage tanks not subject to internal or external pressure manufactured without a knuckle radius shall be designed in accordance with 10.4.5. A knuckle radius is not required for conical covers when the applied internal pressure is less than 65 mbar or the external pressure is less than 6 mbar.



Key

1 liner χω > 80mm i.e. position of welds

Figure 5 — Conical section with knuckle, with or without thermoplastics liner



Key

1 conductive layer behind weld

2 no voids here behind welded area

Figure 6 — Conical section without knuckle (non-preferred construction)

10.4.2 Shallow conical ends

Shallow conical ends having an included angle at the apex of more than 150° shall be designed as a flat end using 10.9.

10.4.3 Conical ends subject to internal pressure

10.4.3.1 Pressures

The pressures for these parts are defined below:

For internal pressure:

$$p_{d,R} = PS_{op} \cdot A_{5,i} \cdot \gamma_{F,p} + p_{hp} \cdot A_{5,i} \cdot \gamma_{F,w} \qquad (53)$$

$$p_{d,\varepsilon} = PS_{op} + p_{hp} \qquad (54)$$

For radial stability:

$$p_{d,cr} = PS_{ep} \cdot \sqrt{A_{5,i}} \cdot \gamma_{F,p} + p_{wind} \cdot \gamma_{F,p} \qquad (55)$$

10.4.3.2 Circumferential unit loading in cone

For conical ends having an included angle at the apex equal to or less than 150° the circumferential unit load shall be determined from Formula (56):

Circumferential unit load:

$$n_{\varphi,p,d,R} = \frac{p_{d,R} \cdot D}{2 \cdot \cos\varphi} \quad or \quad n_{x,p,d,\varepsilon} = \frac{p_{\mathbf{d},\varepsilon} \cdot D}{2 \cdot \cos\varphi} \qquad (56)$$

where

ϕ is half the angle at the apex of the cone and D is defined in Figure 5.

For the selected laminate use 9.3.2 to proof the circumferential load bearing capacity.

10.4.3.3 Axial unit load in cone to knuckle junction

a) For ends of the form of conical sections with knuckle, with or without thermoplastics liner, shown in Figure 5, the axial unit load shall be determined from Formula (57):

$$n_{x,p,d,R} = \frac{p_{d,R} \cdot D \cdot K_{c1}}{2} \quad or \quad n_{x,p,d,\varepsilon} = \frac{p_{\mathbf{d},\varepsilon} \cdot D \cdot K_{c1}}{2} \qquad (57)$$

where

K_{c1} is obtained from Table 13.

For the selected laminate use 9.3.2 to proof the axial load bearing capacity.

Table 13— Concentration factor K_{c1} for conical shells with knuckle

$\frac{r}{D}$	K_{c1} for Φ					
	10°	20°	30°	45°	60°	75°
0,06	1,57	2,18	2,55	3,22	4,10	6,28
0,08	1,52	2,02	2,34	2,74	3,51	5,53
0,1	1,46	1,86	2,13	2,26	2,93	4,79
0,15	1,33	1,46	1,46	1,53	1,93	3,59
0,2	1,06	1,20	1,20	1,26	1,53	2,79
0,3	1,00	1,06	1,13	1,20	1,33	1,86

b) For ends of the form of conical sections without knuckle (non-preferred construction) shown in Figure 6, the axial unit load shall be determined from Formula (58):

$$n_{x,p,d,R} = \frac{p_{d,R} \cdot D \cdot K_{c2}}{2} \quad or \quad n_{x,p,d,\varepsilon} = \frac{p_{\mathbf{d},\varepsilon} \cdot D \cdot K_{c2}}{2} \tag{58}$$

where

K_{c2} is obtained from Table 14

For the selected laminate use 9.3.2 to proof the axial load bearing capacity.

Table 14— Concentration factor K_{c2} for conical shells without knuckle

$\frac{t_{\mathbf{k}}}{D}$			K_{c2} for Φ	
	15°	30°	45°	60°
0,002	2,94	5,62	8,90	13,6
0,005	2,05	3,70	5,80	8,70
0,01	1,60	2,75	4,12	6,30
0,02	1,24	2,00	3,00	4,40
0,04	1,00	1,55	2,20	3,20
0,05	1,00	1,45	2,00	2,75

Any calculated increase in construction of the knuckle region shall extend onto the shell and cone a distance L_c determined from Formula (59):

$$L_{\mathbf{c}} = \sqrt{\frac{D \cdot t_{\mathbf{k}}}{\cos \varphi}} \tag{59}$$

In the case of conical ends to cylindrical shells having directionally oriented laminates e.g. filament wound shells, see also EN 13923.

10.4.4 Conical ends subject to external pressure

10.4.4.1 Strength requirement

The circumferential unit load shall be computed according 10.4.3.2. The laminate selected using 9.3.2 shall have a load bearing capacity equal to or greater than that given in 10.4.3.2 and 10.4.3.3.

10.4.4.2 Elastic stability

10.4.4.2.1 General

The conical shell shall be checked to ensure that it is of sufficient thickness to resist collapse from the individual axial or the circumferential compressive loading as well as their combined effect where applicable.

10.4.4.2.2 Critical radial buckling pressure p_{cr}

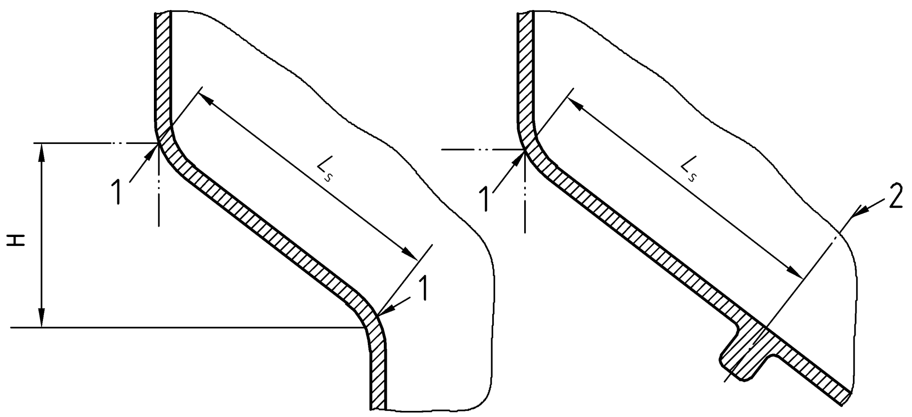
For short conical shells $L \leq 6 \cdot D_m$

$$p_{\mathbf{cr}} = 2{,}40 \cdot \sqrt[4]{E_{\varphi\mathbf{b}}^{3} \cdot E_x} \cdot \frac{D_m}{\cos\varphi \cdot L_\mathrm{S}} \cdot \left(\frac{\cos\varphi \cdot t}{D_\mathbf{m}} \right)^{2{,}5} \qquad (60)$$

where

$L_s = \dfrac{H}{\cos\varphi}$ is the effective length of the conical cylinder, or the distance between stiffeners, see Figure 7;

D_m is the mean diameter of the cone section being designed = $(D_1 + D_2) / 2$.



Key

1 tangent point

2 centre line of stiffener

Figure 7 — Effective lenght between stiffeners for cones subject to external pressure

For long conical shells $L > 6 \cdot D_m$

$$p_{cr} = 2{,}1 \cdot E_{\varphi b} \left(\frac{\cos\varphi \cdot t}{D_m} \right)^{3} \qquad (61)$$

the following criterion shall be met:

$$\frac{p_{d,cr}}{p_{cr}/\left(\gamma_M \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4\right)} \leq 1 \tag{62}$$

If stiffeners are used on the conical shell, 10.3.5 shall be used for the design of the stiffeners with D_m as D.

10.4.4.2.3 Axial compressive loading

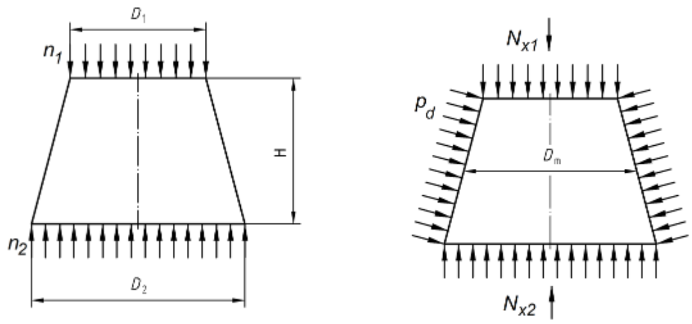
When there is a compressive axial load a check calculation shall be made to ensure that the region of the shell subject to the highest compressive load is adequate to resist collapse by buckling:

$$n_{cr} = k \cdot \sqrt{E_{\varphi b} \cdot E_x} \cdot \frac{t^2 \cdot \cos\varphi}{D_m} \tag{63}$$

$$k = \frac{0{,}84}{\sqrt{1 + \frac{D_m}{200 \cdot t \cdot \cos\varphi}}} \tag{64}$$

the following criterion shall be met:

$$\frac{n_{\mathbf{1,d,cr}} \ \ and \ \ n_{\mathbf{2,d,cr}}}{n_{\mathbf{cr}} / (\gamma_M \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4)} \leq 1 \tag{65}$$



a) Axial compression **b) External pressure**

Figure 8 — Conical shells subject to axial load and external pressure

n_1 and n_2 are the normal unit axial loads at the change of geometry, under axial load N_{x1} and N_{x2}:

$$n_{1,x,d,cr} = \frac{N_{x1}}{\pi \cdot D_1} \quad n_{2,x,d,cr} = \frac{N_{x2}}{\pi \cdot D_2} \tag{66}$$

where

$N_{x1} = \sum\left(N_{x1,i} \cdot \sqrt{A_{5,i}} \cdot \gamma_{F,i}\right)$ and

$N_{x2} = \sum\left(N_{x2,i} \cdot \sqrt{A_{5,i}} \cdot \gamma_{F,i}\right)$

10.4.4.2.4 Combined axial and radial compressive loadings

For combined axial and radial loadings, the following criterion shall be met:

$$\left(\frac{n_{i,x,d,cr}}{n_{cr}/(\gamma_M \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4)}\right)^{1,25} + \left(\frac{p_{d,cr}}{p_{cr}/(\gamma_M \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4)}\right)^{1,25} \leq 1 \quad (67)$$

p_{cr} is given in 10.4.4.2.2;

n_{cr} is given in 10.4.4.2.3.

10.4.5 Shell conical covers

10.4.5.1 Covers subject to internal pressure

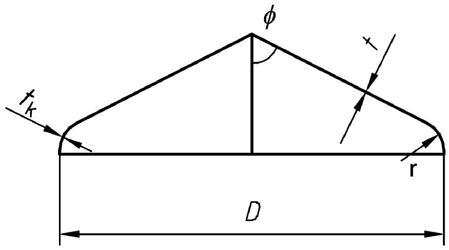


Figure 9 — Conical covers

For conical covers when 60° ≤ ϕ ≤ 75° and where $0 \leq \frac{r}{D} \leq 0{,}1$, the unit load in the axial direction in the knuckle is given by the following formula. For covers outside these parameters the covers shall be designed as a flat plate.

$$n_{\mathbf{x,p,d,R}} = \frac{\alpha_{\mathbf{b}} \cdot p_{\mathbf{D,R}}}{\sin\varphi \cdot \cos\varphi} \cdot \left(\frac{D}{t_{\mathbf{k}}}\right)^{1+\beta_{\mathbf{b}}} \times t_{\mathbf{k}} \quad or \quad n_{\mathbf{x,p,d},\varepsilon} = \frac{\alpha_{\mathbf{b}} \cdot p_{\mathbf{D},\varepsilon}}{\sin\varphi \cdot \cos\varphi} \cdot \left(\frac{D}{t_{\mathbf{k}}}\right)^{1+\beta_{\mathbf{b}}} \cdot t_{\mathbf{k}} \quad (68)$$

where

$$\alpha_{\mathbf{b}} = -64 \cdot \left(\frac{r}{D}\right)^2 + 7{,}6 \cdot \left(\frac{r}{D}\right) + 0{,}13 \quad (69)$$

$$\beta_{\mathbf{b}} = 51{,}6 \cdot \left(\frac{r}{D}\right)^2 - 8{,}18 \cdot \left(\frac{r}{D}\right) + 0{,}52 \quad (70)$$

For the selected laminate use 9.3.2 to proof the load bearing capacity.

10.4.5.2 Conical covers subject to external pressure

The stability of the cover is given by the following formula

$$p_{\mathbf{cr}} = 13{,}58 \cdot \left(\frac{t}{D}\right)^{2{,}5} \cdot E_b \cdot \sin\varphi \cdot \left(\cos\varphi^{1{,}5}\right) \quad (71)$$

where

E_{b} is the unit flexural modulus (minimum) of the conical cover construction.

The following criterion shall be met:

$$\frac{p_{\mathbf{d,cr}}}{p_{cr}\,/\,(\gamma_M \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4)} \leq 1 \qquad (72)$$

$p_{\mathrm{d,cr}}$ is given in 10.4.3.

10.5 Dished end

10.5.1 General requirements

Dished ends shall be one of the following shapes:

Hemispherical end see Figure 10. Dished ends with knuckles according Figure 11 which has following limitations: for the crown radius 0,8·D ≤ R ≤ D and the knuckle radius shall be a minimum of 0,1·D and a maximum of 0,25 D.

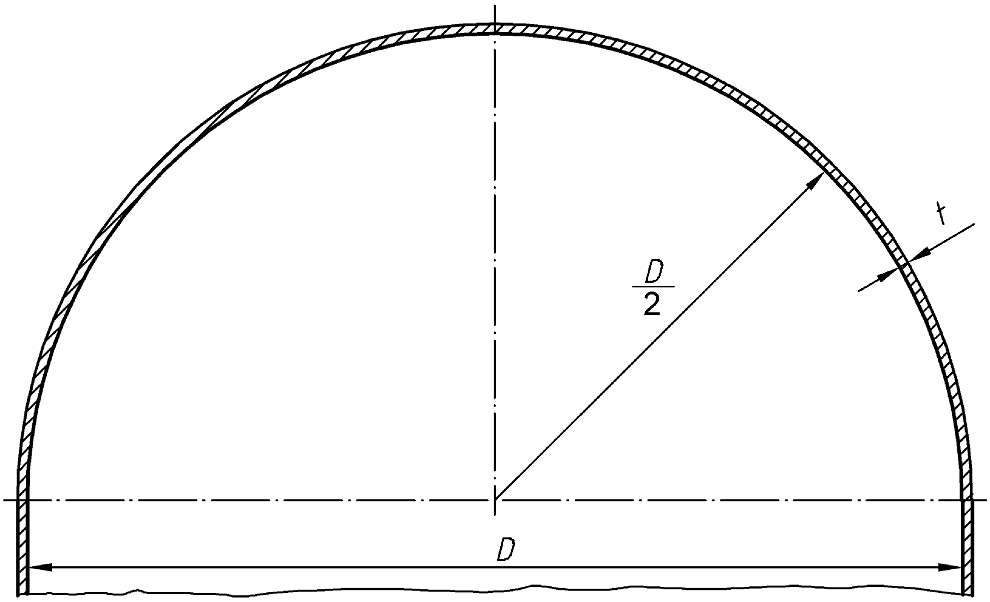
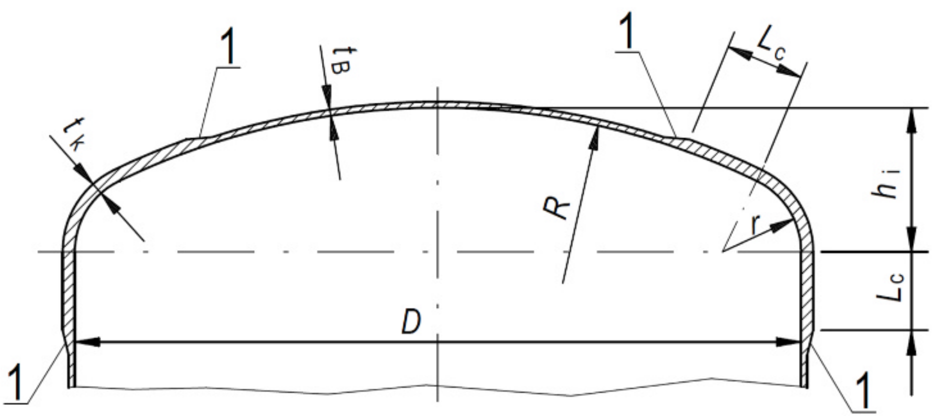


Figure 10 — Hemispherical dished ends



Key

1 taper < 1:6

Figure 11 — dished ends with knuckles

10.5.2 Dished ends subject to internal pressure

The pressures for these parts are defined below:

$$p_{d,R} = PS_{op} \cdot A_{5,i} \cdot \gamma_{F,p} + p_{hp} \cdot A_{5,i} \cdot \gamma_{F,w} \tag{73}$$

$$p_{d,\varepsilon} = PS_{op} + p_{hp} \tag{74}$$

The unit loading in the crown region of dished ends with knuckles and hemispherical ends shall be determined from the following formula

$$n_{p,d,R} = 0{,}6 \cdot p_{d,R} \cdot R \quad or \quad n_{p,d,\varepsilon} = 0{,}6 \cdot p_{d,\varepsilon} \cdot R \tag{75}$$

where

R is the radius of the crown region.

The unit loading in the knuckle region of dished ends with knuckles shall be given by the following formula

$$n_{k,p,d,R} = \frac{p_{d,R} \cdot D \cdot K_d}{2} \quad or \quad n_{k,p,d,\varepsilon} = \frac{p_{\mathbf{d},\varepsilon} \cdot D \cdot K_d}{2} \tag{76}$$

The value of K_d shall be determined from Table 15 for trial thicknesses.

In the case of dished ends with knuckles that may require a greater laminate in the knuckle region than on the crown, the extra laminate (taper 1:6) shall extend a distance L_c determined from the following formula onto both the crown and shell.

$$L_{\mathbf{c}} = \sqrt{D \cdot t_k} - 4 \cdot \left(t_k - t_b\right) \tag{77}$$

where

t_k is the thickness of the knuckle, determined from the value of $n_{k,p}$.

For the selected laminate use 9.3.2 to proof the load bearing capacity.

Table 15— Concentration factors K_d for dished end knuckles

$\frac{h_i}{D}$	$\frac{t}{D}$	K_d	
		$R = D$	$R < D$
		$0,1 \leq \frac{r}{D} \leq 0,15$	$0,15 \leq \frac{r}{D} \leq 0,25$
0,2	0,005	2,95	not allowed
	0,01	2,85	
	0,02	2,65	
	0,04	2,35	
	0,05	2,25	
0,25	0,005	2,35	1,90
	0,01	2,25	1,80
	0,02	2,10	1,75
	0,04	1,85	1,70
	0,05	1,75	1,70
0,32	0,005	1,95	1,45
	0,01	1,85	1,45
	0,02	1,60	1,40
	0,04	1,40	1,35
	0,05	1,30	1,30
shapes of standardized dished bottoms		if $\frac{r}{D}$ = 0,10 and R = D torispherical	if $\frac{r}{D}$ = 0,154 and R = 0,8D elliptical

10.5.3 Stability for dished ends subject to external pressure

The critical buckling pressure shall be given by the following formula:

$$p_{\mathbf{cr}} = 0{,}242 \cdot E_{\mathbf{b}} \left(\frac{t}{R}\right)^2 \quad (78)$$

the following criterion shall be met:

$$\frac{p_{\mathbf{d,cr}}}{p_{cr} / (\gamma_M \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4)} \leq 1 \quad (79)$$

with:

$$p_{d,cr} = PS_{ep} \cdot \sqrt{A_{5,i}} + \sum \left(p_i \cdot \sqrt{A_{5,i}} \cdot \gamma_{F,p} \right) \quad (80)$$

where

p_i = any other pressure.

10.6 Design of flat bottoms and skirts for vertical tanks and vessels

10.6.1 Definitions

The following loads apply for all design formulae:

Internal pressures:

$$p_{d,R} = PS_{op} \cdot A_{5,i} \cdot \gamma_{F,p} + p_{hp} \cdot A_{5,i} \cdot \gamma_{F,w} \quad (81)$$

$$p_{d,\varepsilon} = PS_{op} + p_{hp} \quad (82)$$

Loads from moments:

$$M_{d,R} = \sum \left(M_{e,i} \cdot A_{5,i} \cdot \gamma_{F,i} \right) \quad (83)$$

$$M_{d,\varepsilon} = \sum M_{e,i}$$

For axial stability $M_{d,cr} = \sum \left(M_{e,i} \cdot \sqrt{A_{5,i}} \cdot \gamma_{5,i} \right)$ (84)

where

M_e = any other flexural moment

Weight of vessel, fittings, contents, attachments applied and personnel loads:

$$W_{d,R} = W \cdot A_{5,i} \cdot \gamma_{F,w} + \sum \left(W_{e,i} \cdot A_{5,i} \cdot \gamma_{F,i} \right) \quad (85)$$

$$W_{d,\varepsilon} = W + \sum W_{e,i} \quad (86)$$

for axial stability $W_{d,cr} = W \cdot \sqrt{A_{5,i}} \cdot \gamma_{F,w} + \sum \left(W_{e,i} \cdot \sqrt{A_{5,i}} \cdot \gamma_{F,i} \right)$ (87)

where

W_e = any other weight loading, for example liquid load for the skirt.

10.6.2 Fully supported, flat bottom tanks

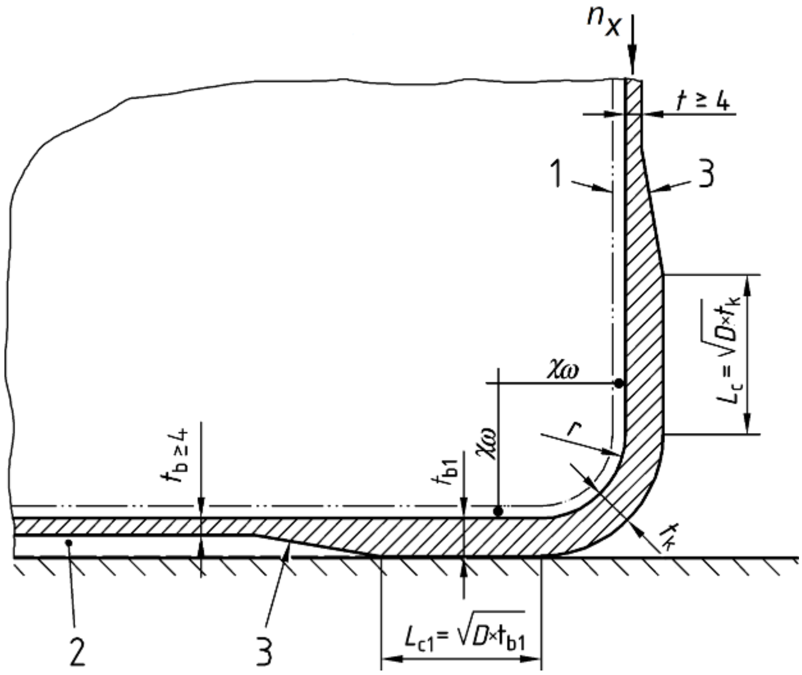
10.6.2.1 General

Continuous support shall be provided over the whole area of the flat bottom except where sumps or bottom run offs shall be accommodated. The unsupported region of the base shall be designed as a flat plate. The gaps in the supports to allow for bottom branches shall be sized so that there is room for gussets (see Figure 30 and Figure 31) and so that high local loads are not imposed on the additional reinforcement which is used for compensation of the branch opening.

Anchorages shall be provided if under the worst conditions there is a tendency for the shell to lift off its foundation. A design procedure to cover case of uplift in tanks is given in Clause 14 and typical holding down arrangements are shown in EN 13121-4.

The structural requirements for the lower section of the cylinder, including the design of the knuckle thickness t_k shall be determined as follows.

Dimensions in millimetres



Key

1 thermoplastics liner as required
$\chi\omega$ > 80 mm the minimum weld position

2 infill required if taper greater than 1:10 if $t_{b1}/t_b > 2$

3 less than 1: 10 taper

Figure 12 — Lined and unlined tanks and vessels with a knuckle radius (preferred construction)

$$L_\mathbf{c} = \sqrt{D \cdot t_\mathbf{k}} \tag{88}$$

For the selected laminate use 9.3.2 to proof the load bearing capacity.

Extent of local thickening for sharp corner junction:

$$L_\mathbf{c} = \sqrt{D \cdot t_\mathbf{k}} \text{ for the Barrel} \tag{89}$$

and

$$L_\mathbf{c1} = \sqrt{D \cdot t_\mathbf{b1}} \text{ for the Base} \tag{90}$$

10.6.2.2 Flat bottoms with a knuckle radius of: 30 mm ≤ *r* ≤ 150 mm (Figure 12)

The maximum axial unit load n_{xk1} in the knuckle is given by the following formulae.

a) unit load $n_{x,k1}$ from internal pressure (hydrostatic plus overpressure):

$$n_{x,k1,d,R} = 3 \cdot k_p \cdot p_{d,R} \cdot D \quad or \quad n_{x,k1,d,\varepsilon} = 3 \cdot k_p \cdot p_{d,\varepsilon} \cdot D \tag{91}$$

where

$$k_\mathbf{p} = 0,22 + \left(0,6 + 0,01415 \cdot \frac{D}{t_\mathbf{k}}\right) \cdot \left(\frac{2 \cdot r}{D} - 4,44 \cdot \left(\frac{t_\mathbf{k}}{D}\right)^{1,15} - 0,04\right) \tag{92}$$

and k_p shall always be ≥ 0,22.

b) unit load $n_{x,k2}$ from loads at the cylindrical wall in the axial direction, $\Sigma n_{x,i}$ from dead loads, wind, weight, etc.

$$n_{x,k2,d,R} = 6 \cdot k_n \cdot \Sigma n_{x,i,d,R} \quad or \quad n_{x,k2,d,\varepsilon} = 6 \cdot k_n \cdot \Sigma n_{x,i,d,\varepsilon} \tag{93}$$

where

$n_{x,i,d}$ see 10.2.2

$$k_\mathbf{n} = \left| 1,38 + 0,41 \cdot \frac{r}{D} \cdot \left(\frac{D}{t_\mathbf{k}}\right)^{1,15} - 0,077 \cdot \left(\frac{r}{t_\mathbf{k}}\right)^2 \right| \tag{94}$$

The maxima of these loads occur in different positions and the interaction of these loads is given by Formulae (95) and (96):

$$n_{x,d,R} = n_{x,k1,d,R} + 0,3 \cdot n_{x,k2,d,R} \quad or \quad n_{x,d,\varepsilon} = n_{x,k1,d,\varepsilon} + 0,3 \cdot n_{x,k2,d,\varepsilon} \tag{95}$$

or

$$n_{x,d,R} = n_{x,k2,d,R} + 0,3 \cdot n_{x,k1,d,R} \quad or \quad n_{x,d,\varepsilon} = n_{x,k2,d,\varepsilon} + 0,3 \cdot n_{x,k1,d,\varepsilon} \tag{96}$$

The maximum value of $n_{x,d,R,(\varepsilon)}$ shall be used in the design.

For the selected laminate use 9.3.2 to proof the load bearing capacity.

Also the circumferential unit load shall be checked to ensure that it is less than the load bearing capacity in the circumferential direction.

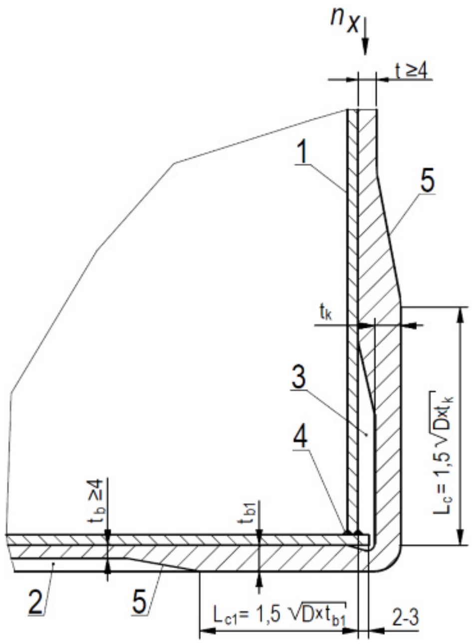
10.6.2.3 Flat bottoms with a knuckle radius of *r* ≤ 30 mm (Figure 12)

The maximum axial unit load in the knuckle region from internal pressure (hydrostatic plus overpressure) is given by the following formulae if $0,8 \cdot t_k \le t_{b1} \le t_k$:

$$n_{x,p,d,R} = 0,72 \times p_{d,R} \times D \quad or \quad n_{x,p,d,\varepsilon} = 0,72 \times p_{d,\varepsilon} \times D \tag{97}$$

10.6.2.4 Flat bottoms with a knuckle radius of *r* = 0 mm (Figure 13)

Dimensions in millimetres



Key

1 fabric backed thermoplastics liner

2 infill required if taper greater than 1:10 if $t_{b1}/t_b > 2$

3 resin/CSM infill (Including conductive layer)

4 weld 3 runs minimum

5 less than 1:10 taper

Figure 13 — Fabric backed thermoplastics lined tanks and vessels without a formed knuckle (Non-Preferred Construction)

For fabric backed thermoplastic lined vessels with a sharp corner when used, see Figure 13, the following formulae for the influence of the internal pressure shall apply.

$$n_{x,p,d,R} = 0,9 \cdot p_{d,R} \cdot D \qquad or \qquad n_{x,p,d,\varepsilon} = 0,90 \cdot p_{d,\varepsilon} \cdot D \qquad (98)$$

The maximum unit load is given by:

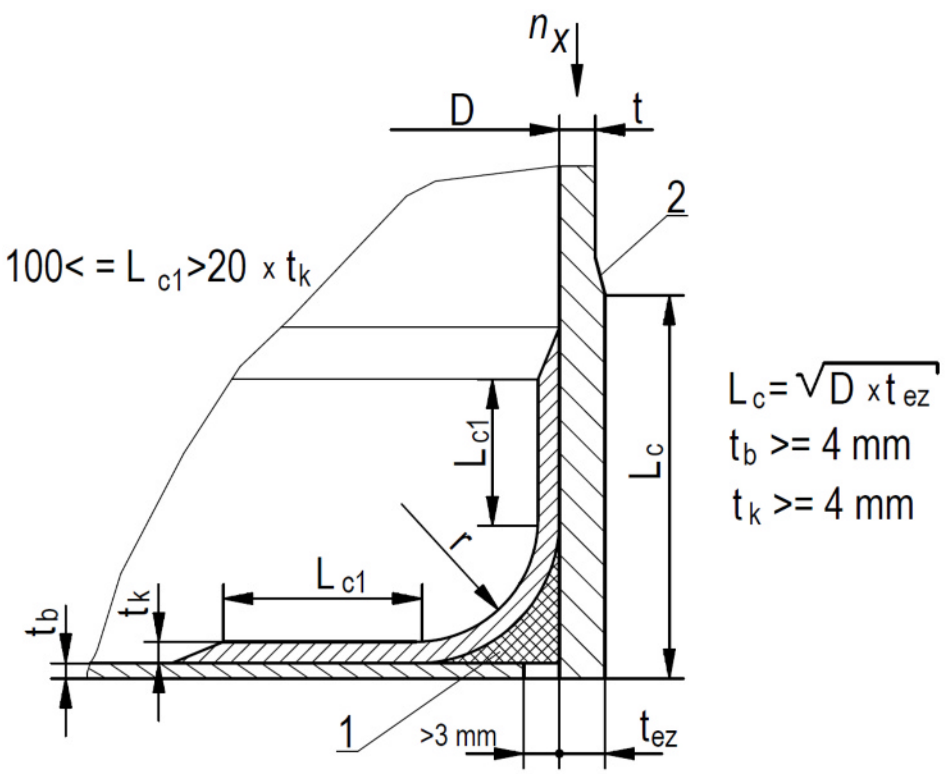
$$n_{x,d,R} = \pm n_{x,p,d,R} \pm n_{x,M,d,R} - n_{x,W,d,R} \qquad or \qquad n_{x,d,\varepsilon} = \pm n_{x,p,d,\varepsilon} \pm n_{x,M,d,\varepsilon} - n_{x,W,d,\varepsilon} \qquad (99)$$

For the selected laminate use 9.3.2 to proof the load bearing capacity.

Any increase in thickness over the lower section of the shell or base, shall extend a distance L_c from the end of the knuckle, see Figure 13.

10.6.2.5 Membrane bottom

Dimensions in millimetres



Key

1 infill, stiffness E ≤ 10 N/mm[2]

2 barrel taper

Figure 14 — Flat bottom in membrane design

The design for the knuckle radius at the membrane bottom is done in two parts. In $n_{Kr,1}$ the main part is the bending stresses and in $n_{Kr,2}$ the main part is the membrane stresses:

$$n_{Kr,1,d,R} = 0{,}106 \cdot p_{d,R} \cdot D \cdot \frac{t_k}{t_{eZ}} \cdot \sqrt{\frac{D}{r}} \cdot \frac{E_{x,b}}{E_{\varphi}} \cdot \left(\frac{E_{b,bottom}}{E_{x,b}}\right)^{2/3} \quad (100)$$

$$n_{Kr,2,d,R} = 3 \cdot p_{d,R} \cdot r$$

or

$$n_{Kr,1,\varepsilon} = 0{,}106 \cdot p_{d,\varepsilon} \cdot D \cdot \frac{t_k}{t_{eZ}} \cdot \sqrt{\frac{D}{r}} \cdot \frac{E_{x,b}}{E_{\varphi}} \cdot \left(\frac{E_{b,bottom}}{E_{x,b}}\right)^{2/3} \quad (101)$$

$$n_{Kr,2,\varepsilon} = 3 \cdot p_{d,\varepsilon} \cdot r$$

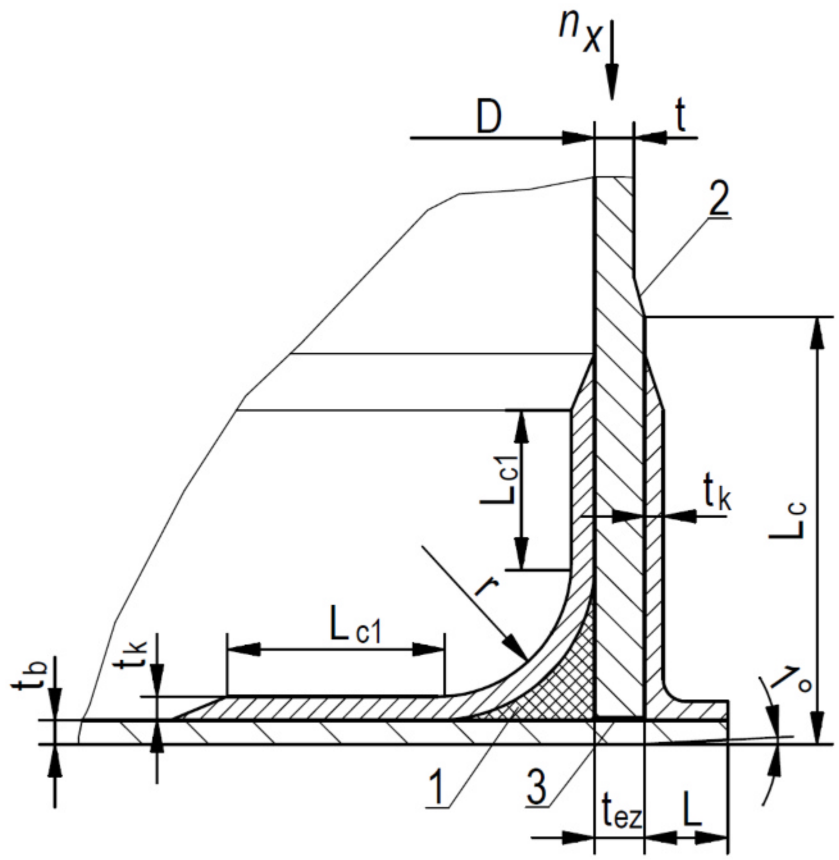
Limits: 50 mm ≤ r ≤ 250 mm

0,0125 ≤ r/D ≤ 0,075

4 mm ≤ t_k ≤ 12 mm but less than 0,6·t_{eZ}

For the selected laminate use 9.3.2 to proof the load bearing capacity.

10.6.2.6 Flat bottom design with membrane disc beneath cylinder



Key

1 resin paste infill or foam

2 75 mm ≤ taper ≥ 1:6

3 resin paste or chopped strand mat

Figure 15 — Flat bottom with membrane disc beneath cylinder

where

$t_{ez} = 2 \cdot t$ or design with Formula (97). The maximum value is chosen.

$L_c = 1{,}5 \cdot \sqrt{D \cdot t_{ez}}$

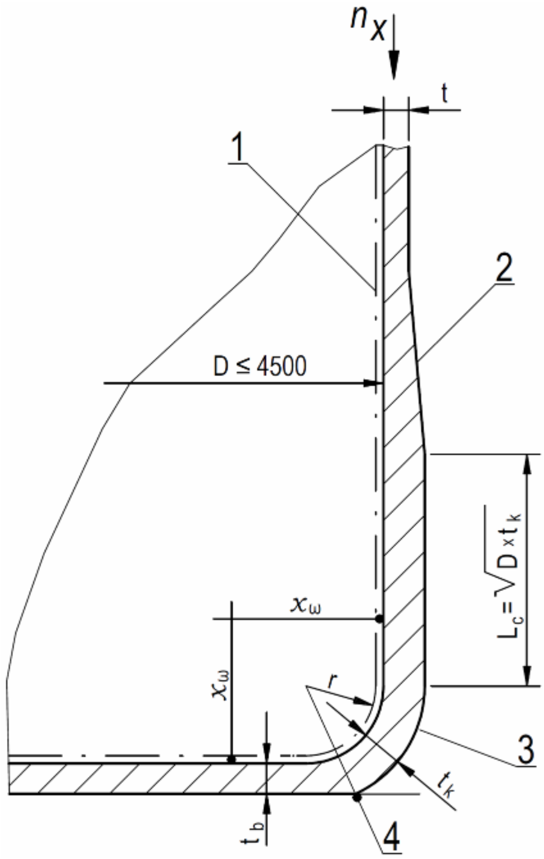
$t_k = D^{0{,}2}$

$100 \leq L_{c1} \geq 20 \cdot t_k$ and $r = 0{,}01 \cdot D_r$

$t_b \geq 4$ mm

$3 \cdot t_{ez} \leq L \leq 75\, mm$

10.6.2.7 Truncated bottom (D ≤ 4500 mm)



Key

1 thermoplastics liner as required

2 taper 1: 6

3 $t_k \geq t + t_b$ (minimum)

4 Care shall be taken to ensure t_k extends round to be fully supported by the base foundation.

5 40 mm ≤ r ≤ 100 mm

Figure 16 — Flat bottom in truncated design

Minimum Base Thickness t_b

if D ≤ 2 000 mm then t_b ≥ 5 mm;

if 2 000 mm < D ≤ 3 500 mm then t_b ≥ 7,2 mm;

if 3 500 mm < D ≤ 4 500 mm then t_b ≥ 10 mm.

The maximum axial unit load in the knuckle region from internal pressure (hydrostatic plus overpressure) is given by the following formulae if $0{,}6 \cdot t_k \leq t_b \leq t_k$:

$$n_{x,p,d,R} = 0{,}72 \cdot p_{d,R} \cdot D \quad or \quad n_{x,p,d,\varepsilon} = 0{,}72 \cdot p_{d,\varepsilon} \cdot D \qquad (102)$$

Should any of the above parameters be exceeded a FE Analysis (Annex F) or an experimental design verification (see 17.6) shall be carried out to prove the design type is suitable.

10.6.2.8 Influence of temperature

If the bottom cannot expand in consequence of ΔT, the following additional unit loads occur for all constructions excluding the membrane bottom.

The unit load $n_{x,\Delta T,d,R}$, due to the effects of the differential temperature ΔT in accordance with 9.2.9 and the thermal expansion coefficient α_i according to Table 3, is given by:

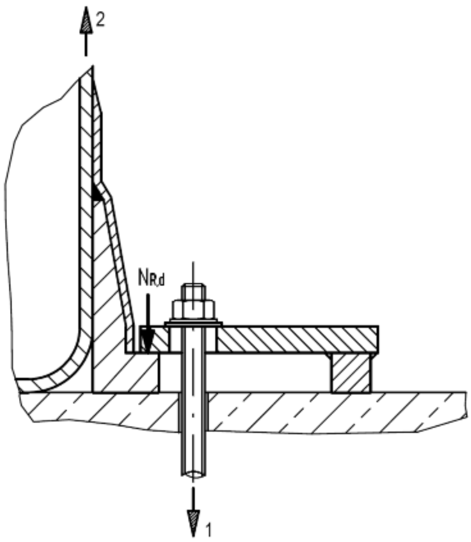
$$n_{x,\Delta T,d,R} = n_{x,\Delta T,d,\varepsilon} = 1{,}5 \cdot E_x \cdot \alpha_{i,\varphi} \cdot \Delta T \cdot t_k \quad (103)$$

10.6.3 Vessels with flat bases subjected to pressure

When vessels having a flat base are required to be designed to withstand an internal pressure load, the base shall be fully supported on a rigid plinth or structure and the axial pressure loading in the shell, shall be reacted by either, an angle ring or individual brackets attached to the shell and bolted to the support structure as indicated in Figure 17.

If external pressure > 3 mbar the pressure shall be compensated by an equivalent height of liquid or the bottom shall be designed for this pressure.

NOTE For design of an anchorage system see Clause 14.



Key

1 reaction load

2 pressure load

Figure 17 — Typical anchorage arrangement for flat bottom tank or vessel

10.6.4 Dished bottom and conical bottom configurations

10.6.4.1 Leg supports

Individual leg supports may be attached directly to the tank or vessel, see the limitations specified in 12.2.2.1.

10.6.4.2 Ring supports

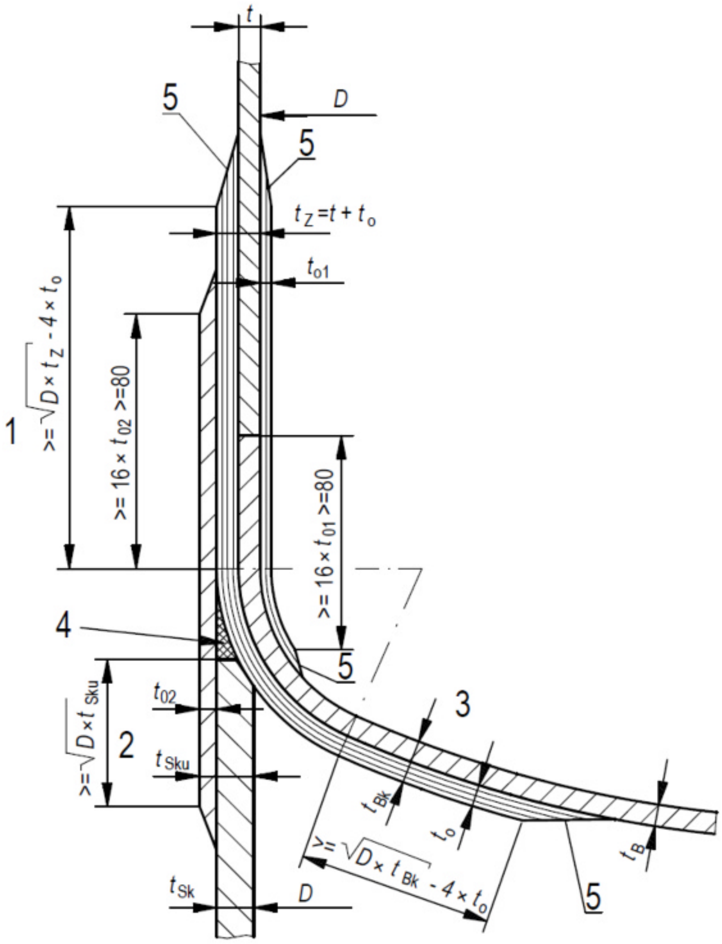
Steel ring supports which are integral with the tank or vessel should only be used when the design temperature is below 60 °C unless special detail design analysis is undertaken to determine that the thermal strain and applied strain due to the loading configuration does not exceed the limiting design strain determined in Clause 8.

10.6.4.3 Design of skirt supported vessels

10.6.4.3.1 General

There are three critical areas in the design of vessel supported by a skirt, the lower part of the cylinder (region 1), the upper part of the skirt (region 2) and the knuckle region of the bottom end of the vessel (region 3), these regions are shown in Figures 18 to 22 for different forms of construction.

Dimensions in millimetres

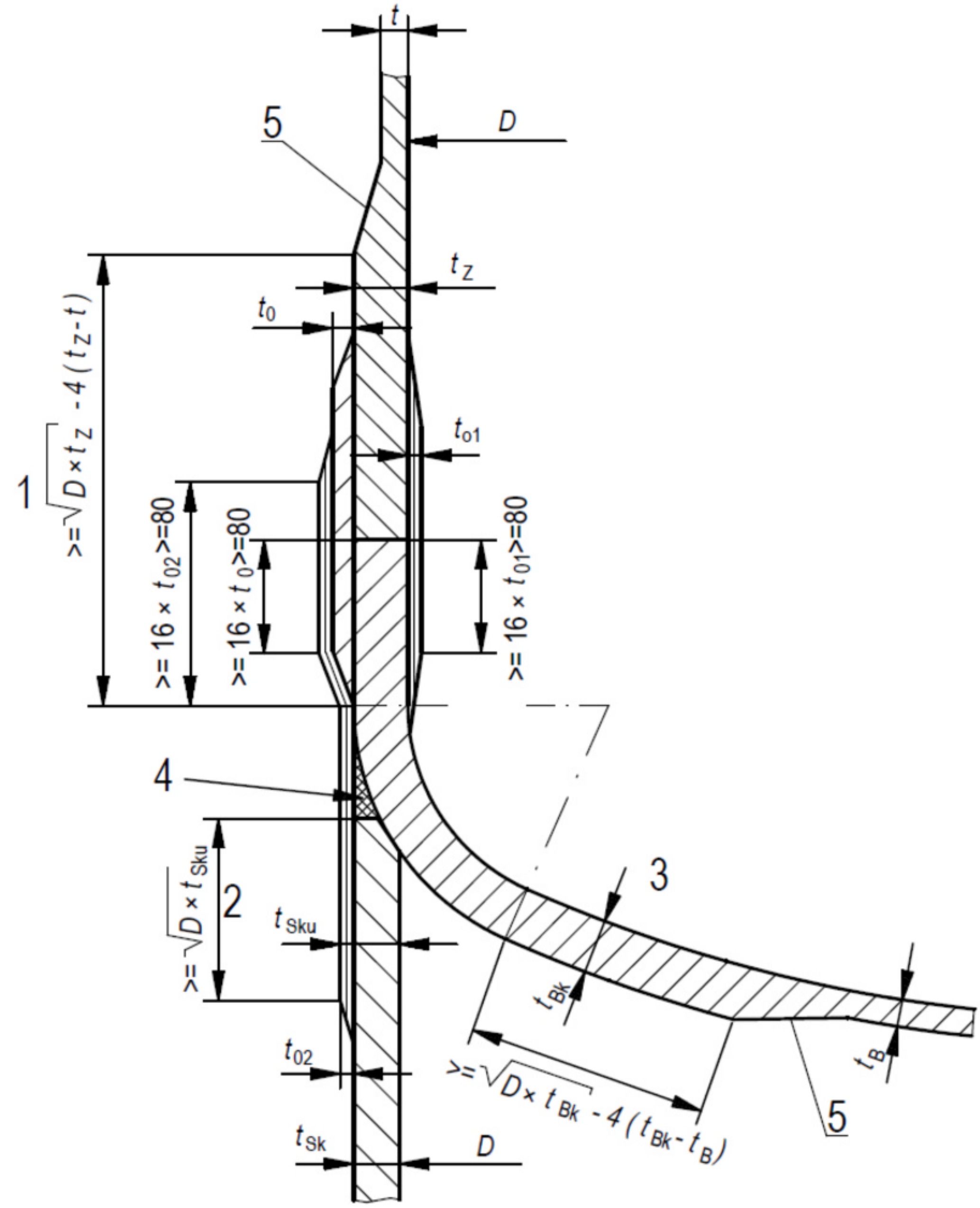


Key

1	region 1	2	region 2
3	region 3	4	resin paste infill
5	taper < 1:6		

Figure 18 — Critical design regions 1, 2, 3 for skirt supported vessels without liner

Dimensions in millimetres

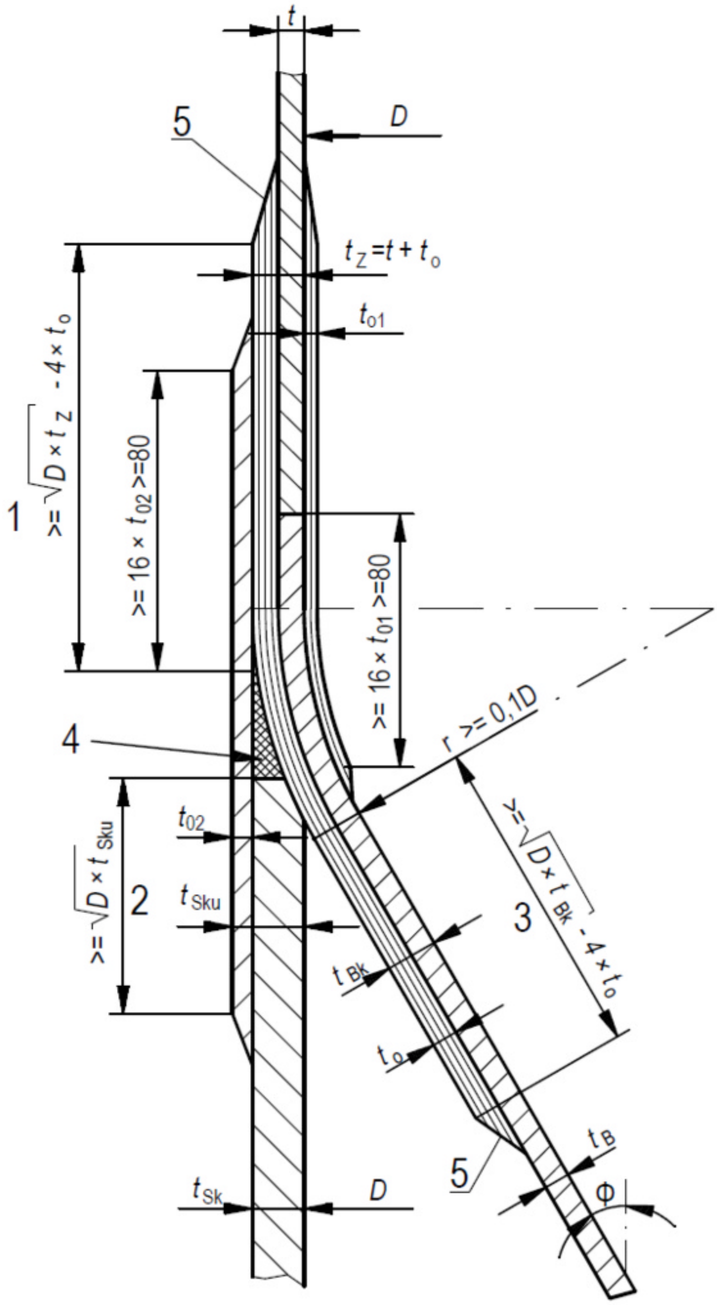


Key

1	region 1	2	region 2
3	region 3	4	resin paste infill
5	taper < 1:6		

Figure 19 — Critical design regions 1, 2, 3 for skirt supported vessels without liner

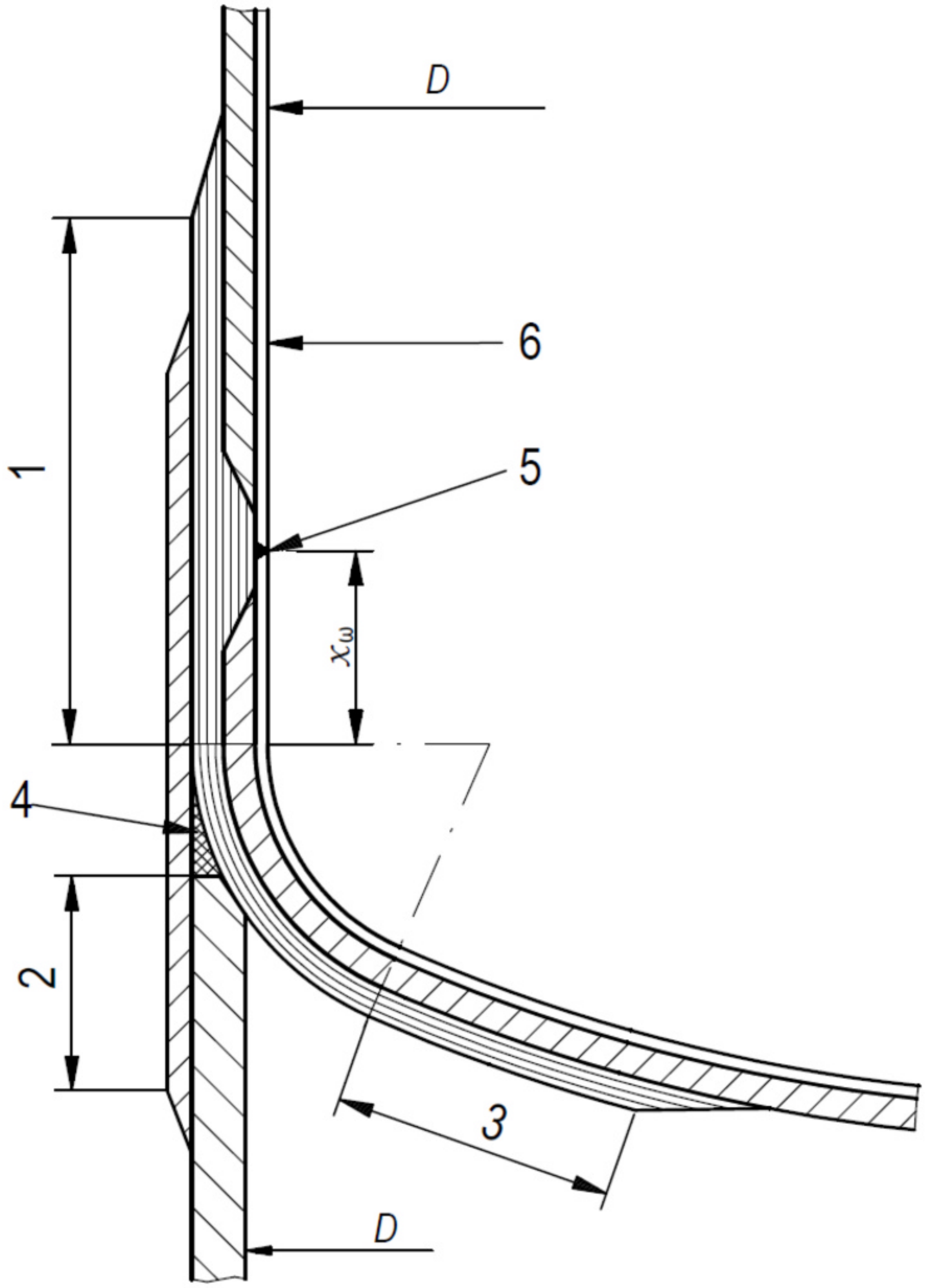
Dimensions in millimetres



Key

1	region 1	2	region 2
3	region 3	4	resin paste infill
5	taper < 1:6		

Figure 20 — Conical bottom with ϕ ≤ 45°; critical design regions 1, 2, 3 for skirt supported vessels



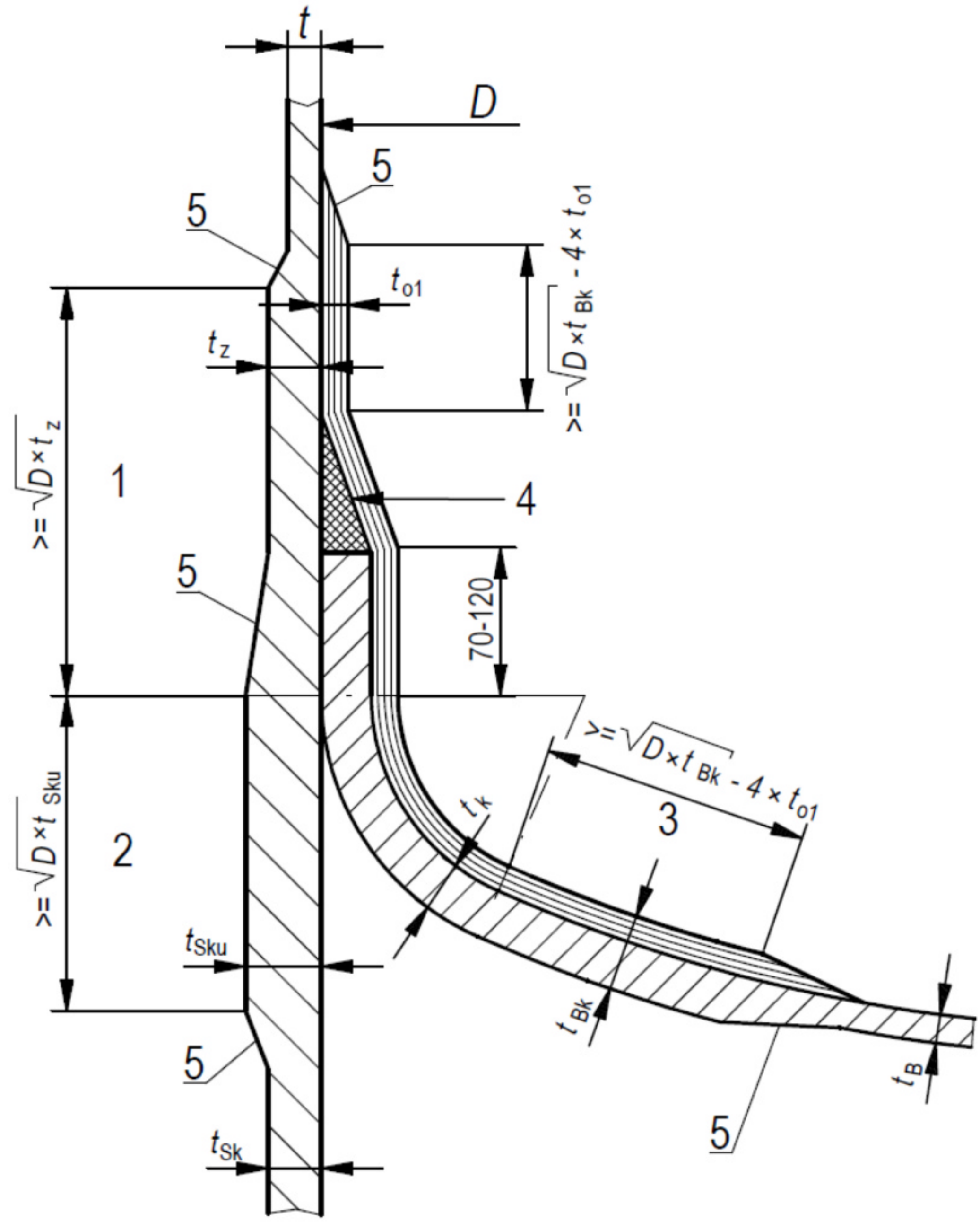
Key

1	region 1	2	region 2
3	region 3	4	resin paste infill
5	position of weld χω > 80 mm	6	liner

NOTE Overlay dimensions and details as per Figure 19.

Figure 21 — Critical design regions for skirt supported vessels with liner

Dimensions in millimetres



Key

1	region 1	2	region 2
3	region 3	4	resin paste infill
5	taper < 1:6		

Figure 22 — Critical design regions for skirt supported vessels without liner

10.6.4.3.2 Unit load for lower part of cylinder region 1

The unit load in the axial direction in the cylinder from discontinuities, $n_{x,z,p}$, is given by the following formula.

$$n_{x,z,p,d,R} = C_z \cdot p_{d,R} \cdot D \quad or \quad n_{x,z,p,d,\varepsilon} = C_z \cdot p_{d,\varepsilon} \cdot D \qquad (104)$$

where

C_z = 0,9 for bottoms with $R = D$ or C_z = 0,6 for bottoms with $R \leq 0{,}8 \cdot D$.

For conical ends use formula in 10.4.3.

p_d includes both internal pressure PS_{op} and hydrostatic pressure p_{hp}.

The unit load $n_{x,z,\Delta T}$, due to the effects of the differential temperature ΔT in accordance with 9.2.9 and the thermal expansion coefficient, α_i, according to Table 3, is given by:

$$n_{\mathbf{x,z,\Delta T,d,R}} = n_{\mathbf{x,z,\Delta T,d},\varepsilon} = 0{,}6 \cdot E_{\mathbf{x}} \cdot \alpha_{i,\varphi} \cdot \Delta T \cdot t_z \quad (105)$$

$$n_{x,z,d,R} = \pm n_{x,z,p,d,R} \pm n_{x,M,d,R} - n_{x,W,d,R} \pm n_{x,z,\Delta T,d,R} \quad or$$
$$n_{x,z,d,\varepsilon} = \pm n_{x,z,p,d,\varepsilon} \pm n_{x,M,d,\varepsilon} - n_{x,W,d,\varepsilon} \pm n_{x,z,\Delta T,d,\varepsilon} \quad (106)$$

For the selected laminate use 9.3.2 to proof the load bearing capacity.

10.6.4.3.3 Unit load for upper part of skirt, region 2

The unit load in the axial direction in the skirt from internal pressure, $n_{x,Sku,p}$ is given by:

$$n_{x,Sku,p,d,R} = C_{Sku} \cdot p_{hp} \cdot A_{5,i} \cdot \gamma_{F,w} \cdot D \quad or \quad n_{x,Sku,p,d,\varepsilon} = C_{Sku} \cdot p_{hp} \cdot D \quad (107)$$

where

C_{Sku} = 1,2 for bottoms with $R = D$ or C_{Sku} = 0,6 for bottoms with $R \leq 0{,}8 \cdot D$.

For conical ends use formula in 10.4.3.

The unit load, $n_{x,Sku,\Delta T}$, due to the effects of the differential temperature, ΔT, in accordance with 9.2.9 and the thermal expansion coefficient, α_i, according to Table 3, is given by:

$$n_{\mathbf{x,Sku,\Delta T,d,R}} = n_{\mathbf{x,Sku,\Delta T,d},\varepsilon} = 0{,}6 \cdot E_{\mathbf{x}} \cdot \alpha_{i,\varphi} \cdot \Delta T \cdot t_{Sku} \quad (108)$$

$$n_{x,Sku,d,R} = \pm n_{x,Sku,p,d,R} \pm n_{x,M,d,R} - n_{x,W,d,R} \pm n_{x,Sku,\Delta T,d,R} \quad or$$
$$n_{x,Sku,d,\varepsilon} = \pm n_{x,Sku,p,d,\varepsilon} \pm n_{x,M,d,\varepsilon} - n_{x,W,d,\varepsilon} \pm n_{x,Sku,\Delta T,d,\varepsilon} \quad (109)$$

For the selected laminate use 9.3.2 to proof the load bearing capacity.

$$L_{\mathbf{c,Sku}} \geq \sqrt{D \cdot t_{\mathbf{Sku}}} \quad (110)$$

10.6.4.3.4 The unit load in the knuckle region, region 3

The maximum unit load in the knuckle n_k, region shall be given by 10.4.3.3 for conical ends and 10.5.2 for dome ends.

The unit load $n_{x,Bk,\Delta T}$, due to the effects of differential temperature ΔT in accordance with 9.2.9 and the thermal expansion coefficient α_i according to Table 3, is given by:

$$n_{\mathbf{x,Bk,\Delta T,d,R}} = n_{\mathbf{x,Bk,\Delta T,d},\varepsilon} = 0{,}9 \cdot E_{\mathbf{x}} \cdot \alpha_{i,\varphi} \cdot \Delta T \cdot t_{Bk} \quad (111)$$

$$n_{x,Bk,d,R} = \pm n_{x,p,d,R} \pm n_{x,Bk,\Delta T,d,R} \quad or \quad n_{x,Bk,d,\varepsilon} = \pm n_{x,p,d,\varepsilon} \pm n_{x,Bk,\Delta T,d,\varepsilon} \quad (112)$$

For the selected laminate use 9.3.2 to proof the load bearing capacity.

Length of the area:

$$L_{\mathbf{c}} \geq \sqrt{D \cdot t_{\mathbf{Bk}}} - 4 \cdot t_o \text{ or } L_{\mathbf{c}} \geq \sqrt{D \cdot t_{\mathbf{Bk}}} - 4(t_{Bk} - t_B) \text{ or } L_{\mathbf{c}} \geq \sqrt{D \cdot t_{\mathbf{Bk}}} - 4 \cdot t_{o1} \quad (113)$$

The maximum unit load for any internal overlay connecting the bottom dome to the cylinder, see Figure 22, is given by the following formula.

$$n_{over,d,R} = p_{d,R} \cdot D/2 \quad \text{or} \quad n_{over,d,\varepsilon} = p_{d,\varepsilon} \cdot D/2 \quad (114)$$

where

p_{d} includes both internal pressure PS_{op} and hydrostatic pressure p_{hp} where applicable.

For the selected laminate use 9.3.2 to proof the load bearing capacity.

The minimum reinforcement for the internal overlay connecting the bottom shall be 3 × 450 g/m² CSM plus corrosion barrier, for a $D < 2$ m and 4 × 450 g/m² CSM, plus a corrosion barrier for $D > 2$ m for constructions shown in Figures 18 to 22.

10.6.4.3.5 Unit load at the skirt

The axial loads from flexural moment due to wind or seismic load (determined to an applicable local code):

Axial unit load $$n_{\mathbf{x,Sk,M,d,R}} = \frac{4 \cdot M_{\mathbf{d,R}}}{\pi \cdot D^2} \quad \text{or} \quad n_{\mathbf{x,Sk,M,d,}\varepsilon} = \frac{4 \cdot M_{\mathbf{d,}\varepsilon}}{\pi \cdot D^2} \quad \text{or} \quad n_{\mathbf{x,Sk,M,d,cr}} = \frac{4 \cdot M_{\mathbf{D,cr}}}{\pi \cdot D^2} \quad (115)$$

where

$$M_{d,R} = M_{wind} \cdot \gamma_{F,p} + \sum \left(M_{e,i} \cdot A_{5,i} \cdot \gamma_{F,i} \right)$$

respectively $M_{d,\varepsilon} = M_{wind} + \sum M_{e,i}$

for axial stability case $M_{d,cr} = M_{wind} \cdot \gamma_{F,p} + \sum \left(M_{e,i} \cdot \sqrt{A_{5,i}} \cdot \gamma_{F,i} \right)$

where

M_{e} = any other flexural moment.

Weight of vessel, filling-liquid fittings, snow, contents, attachments applied and personnel loads:

Axial unit load $$n_{\mathbf{x,Sk,W,d,R}} = \frac{W_{\mathbf{d,R}}}{\pi \cdot D} \quad \text{or} \quad n_{\mathbf{x,Sk,M,d,}\varepsilon} = \frac{W_{\mathbf{d,}\varepsilon}}{\pi \cdot D} \quad \text{or} \quad n_{\mathbf{x,Sk,M,d,cr}} = \frac{W_{\mathbf{d,cr}}}{\pi \cdot D} \quad (116)$$

where

$$W_{d,R} = W \cdot A_{5,i} \cdot \gamma_{F,w} + \sum \left(W_{e,i} \cdot A_{5,i} \cdot \gamma_{F,i} \right)$$

respectively $W_{d,\varepsilon} = W + \sum W_{e,i}$

For axial stability case $W_{d,cr} = W \cdot \sqrt{A_{5,i}} \cdot \gamma_{F,w} + \sum \left(W_{e,i} \cdot \sqrt{A_{5,i}} \cdot \gamma_{F,i} \right)$

where

W_{e} = any other weight loading, filling-liquid, snow and other additions.

The combined axial unit loading n_x is the sum of the values obtained from formulae above, having due regard for the direction of loading.

For the skirt:

tension: $n_{x,Sk,d,R} = n_{x,Sk,M,d,R} + n_{x,Sk,W,d,R}$ (117)

strain: $n_{x,Sk,d,\varepsilon} = n_{x,Sk,M,d,\varepsilon} + n_{x,Sk,W,d,\varepsilon}$ (118)

For the selected laminate use 9.3.2 to proof the load bearing capacity.

For the shell instability (i.e. compressive loading):

$$n_{x,Sk,d,cr} = n_{x,Sk,M,d,cr} + n_{x,Sk,W,d,cr} \tag{119}$$

the following criterion shall be met:

$$\frac{n_{\mathbf{x,Sk,d,cr}}}{n_{\mathbf{cr}} / (\gamma_M \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4)} \leq 1 \tag{120}$$

where

$$n_{\mathbf{cr}} = k \cdot \sqrt{E_{\varphi\mathbf{b}} \cdot E_{\mathbf{x}}} \cdot \frac{t^2}{D} \tag{121}$$

with

$E_{\phi b}$ = flexural modulus in circumferential direction of the skirt and

E_x = axial modulus of the skirt

$$k = \frac{0{,}84}{\sqrt{1 + \frac{D}{200 \cdot t}}}$$

10.6.4.3.6 Overlay laminate connection skirt - vessel

The maximum unit load for any outside overlay laminate from the cylinder to the skirt is given by:

$$\begin{aligned} n_{\mathbf{over,d,R}} &= \pm n_{x,Sk,M,d,R} - n_{x,Sk,W,d,R} + 0{,}2 \cdot p_{\mathbf{d,hp}} \cdot D \quad or \\ n_{\mathbf{over,d,}\varepsilon} &= \pm\, n_{x,Sk,M,d,\varepsilon} - n_{x,Sk,W,d,\varepsilon} + 0{,}2 \cdot p_{\mathbf{d,hp}} \cdot D \end{aligned} \tag{122}$$

For the selected laminate use 9.3.2 to proof the load bearing capacity.

The lap shear load in the overlay is given by:

$$\tau_{\mathbf{over,d}} = \frac{n_{\mathbf{over,d,R}}}{\ell_{\mathbf{over}}} \quad \text{and} \quad \tau_{\mathbf{over,d}} \leq \frac{\tau_k}{(\gamma_M \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4)} \tag{123}$$

and

$$\ell_{\mathbf{over}} \leq 16 \cdot t_{\mathbf{over}} \tag{124}$$

The minimum reinforcement for the external overlay shall be 3 × 450 g/m[2] CSM.

10.6.4.3.7 Cut-outs in a skirt

When cut outs are required in a skirt, the skirt shall be adequately reinforced and comply with the requirements for compensation of the openings as given in 10.8. For the stability of the skirt the formulae given in 10.3.2 shall be used.

The maximum unit load in the region of the cut-out, without any additional reinforcements, is given by:

$$n_{\mathbf{x,Sk,d,R}} = \left(\frac{n_{x,Sk,W,d,R} \cdot \pi \cdot D}{A_{\mathbf{c}}} \right) + \left(\frac{n_{x,Sk,M,d,R} \cdot \pi \cdot D^2 / 4 + (n_{x,Sk,W,d,R} \cdot \pi \cdot D) \cdot e_c}{Z_{\mathbf{c}}} \right) \quad or$$

$$n_{\mathbf{x,Sk,d},\varepsilon} = \left(\frac{n_{x,Sk,W,d,\varepsilon} \cdot \pi \cdot D}{A_{\mathbf{c}}} \right) + \left(\frac{n_{x,Sk,M,d,\varepsilon} \cdot \pi \cdot D^2 / 4 + (n_{x,Sk,W,d,\varepsilon} \cdot \pi \cdot D) \cdot e_c}{Z_{\mathbf{c}}} \right) \tag{125}$$

where

$$A_{\mathbf{c}} = D \cdot \left[\pi - \alpha_{\mathbf{c}} \right] \tag{126}$$

$$Z_{\mathbf{c}} = \frac{D^3 \cdot \left[\pi - \alpha_{\mathbf{c}} - 0{,}5 \cdot \sin 2\alpha_{\mathbf{c}} \right] - A_{\mathbf{c}} \cdot e_{\mathbf{c}}^2}{8 \cdot \left(e_{\mathbf{c}} + 0{,}5 \cdot D \cdot \cos \alpha_c \right)} \tag{127}$$

$$\alpha_{\mathrm{c}} = \arcsin \left(\frac{d_{\mathrm{co}}}{D} \right) \tag{128}$$

$$e_{\mathbf{c}} = \frac{D \cdot \sin \alpha_{\mathbf{c}}}{2 \cdot (\pi - \alpha_{\mathbf{c}})} \tag{129}$$

For the selected laminate use 9.3.2 to proof the load bearing capacity.

For the stability:

k for such sections is given by the following formulae when:

$$\frac{d_{\mathbf{co}}}{\left(\frac{D \cdot t_{Sk}}{2} \right)^{0.5}} \leq 3{,}5 \quad k = \frac{0{,}78}{\sqrt{1 + \frac{D}{200 \cdot t_{Sk}}}} \tag{130}$$

and when

$$\frac{d_{\mathbf{co}}}{\left(\frac{D \cdot t_{Sk}}{2} \right)^{0.5}} > 3{,}5 \quad k = \frac{0{,}54}{\sqrt{1 + \frac{D}{200 \cdot t_{Sk}}}} \tag{131}$$

where

d_{co} = diameter of cut-out and t_{Sk} the general thickness of the shell in the cut out region.

$$n_{\mathbf{x,Sk,d,cr}} = \left(\frac{n_{x,Sk,W,d,cr} \cdot \pi \cdot D}{A_{\mathbf{c}}} \right) + \left(\frac{n_{x,Sk,M,d,cr} \cdot \pi \cdot D^2 / 4 + (n_{x,Sk,W,d,cr} \cdot \pi \cdot D) \cdot e_c}{Z_{\mathbf{c}}} \right) \tag{132}$$

the following criterion shall be met:

$$\frac{n_{\mathbf{x,Sk,d,cr}}}{n_{\mathbf{cr}} / (\gamma_M \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4)} \leq 1 \tag{133}$$

n_{cr} is given in 10.6.4.3.5.

10.7 Circumferential seams for cylindrical joints

10.7.1 General

When sections of a vessel are to be joined together by, either, an overlap of laminate onto a component part, or, the joining of two sections together by use of a butt joint, the procedures in this clause shall be used.

Typical joint details are shown in Figure 23 for tanks or vessels manufactured without a thermoplastics lining and Figure 24 for tanks or vessels manufactured with a thermoplastics liner.

The overlap/overlay laminate l_{over} shall be terminated with a taper no steeper than 1: 6.

The maximum unit load for a cylindrical joint is given by Formula (134).

$$\begin{aligned} n_{\mathbf{over,d,R}} &= \pm\, n_{x,M,d,R} - n_{x,W,d,R} + n_{x,p,d,R} \quad or \\ n_{\mathbf{over,d,}\varepsilon} &= \pm\, n_{x,M,d,\varepsilon} - n_{x,W,d,\varepsilon} + n_{x,p,d,\varepsilon} \end{aligned} \tag{134}$$

the $n_{x,i}$ are shown in 10.2.2.

For the selected laminate use 9.3.2 to proof the load bearing capacity.

The shear load in the overlay is given by the following formula:

$$\tau_{\mathbf{over,d}} = \frac{n_{\mathbf{over,d,R}}}{l_{\mathbf{over}} - 2 \cdot t_{over}} \quad \text{and} \quad \tau_{\mathbf{over,d}} \leq \frac{\tau_{lap;k}}{(\gamma_M \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4)} \tag{135}$$

and for the proof:

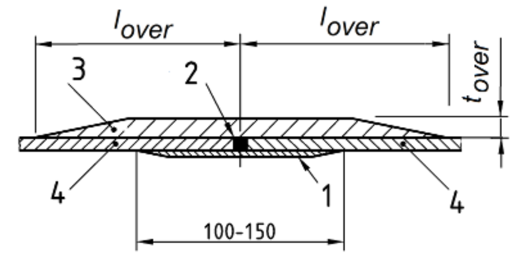
$$l_{\mathbf{over}} \leq 16 \cdot t_{\mathbf{over}} \tag{136}$$

The minimum reinforcement for the external overlay shall be 3 × 450 g/m^2 CSM.

The overlap/overlay laminate shall have a minimum length of 100 mm for skin or main laminates < 6 mm and 150 mm for main laminates > 6 mm and shall have a minimum length of $16 \cdot t_{over}$ above these values to each side of the joint.

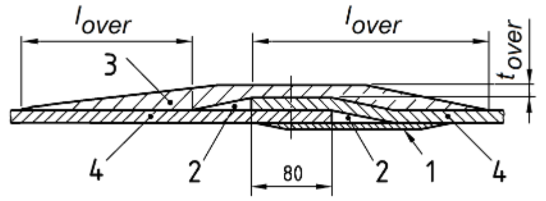
Joints shall be positioned clear of regions of high local loading e.g. knuckles, branch positions, transitional changes in section, etc.

Dimensions in millimetres



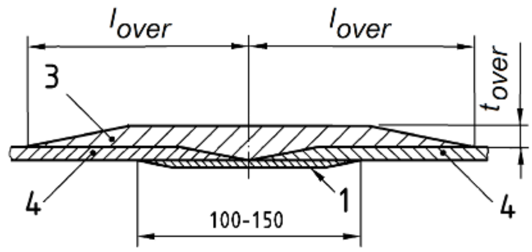
Key

1 internal sealing strip
2 resin/paste infill (min)
3 overlay
4 main laminate



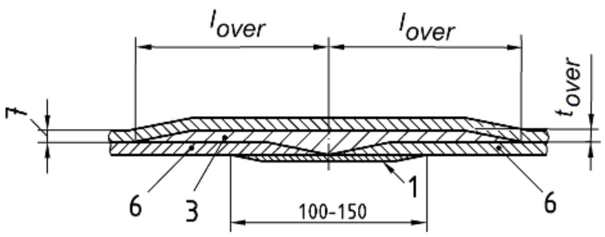
Key

1 internal sealing strip
2 resin/paste infill (min)
3 overlay
4 main laminate



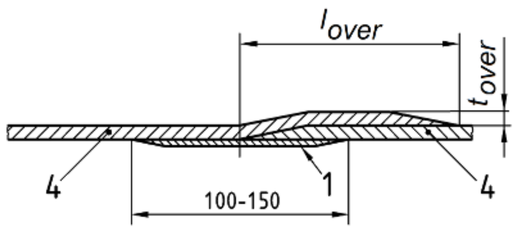
Key

1 internal sealing strip
3 overlay
4 main laminate



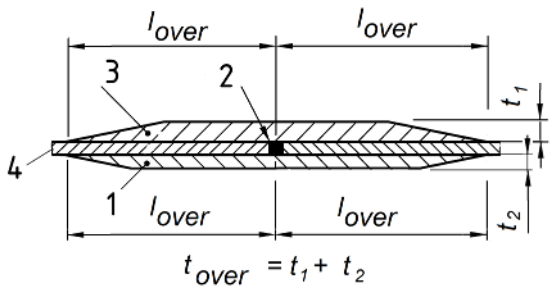
Key

1 internal sealing strip
3 overlay
6 thin skin
7 remainder of shell laminate



Key

1 internal sealing strip
4 main laminate

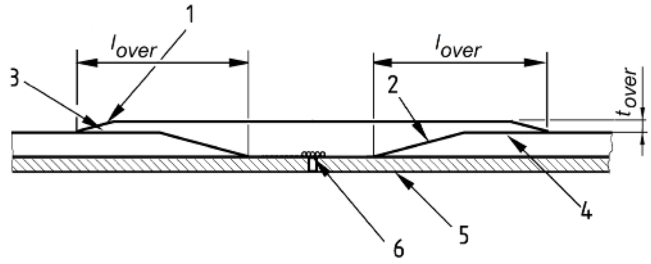


Key

1 internal overlay
2 resin/paste infill (min)
3 external overlay
4 main laminate

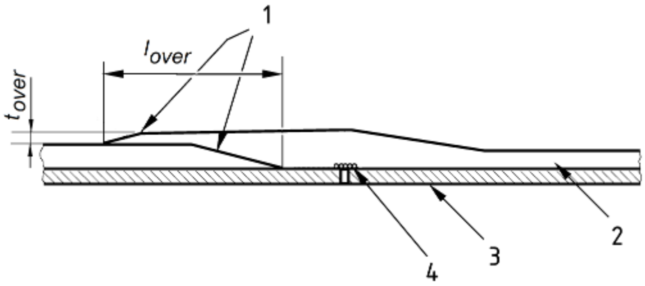
$t_2 \geq 0{,}3 \times t_1$

Figure 23 — Typical main seam joints for tanks and vessels without thermoplastics linings



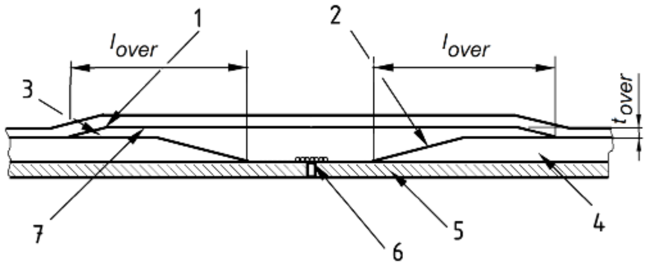
Key

1 all tapers not steeper than 1:6
2 all tapers not steeper than 1:6
3 overlay
4 main laminate
5 thermoplastics lining
6 conductive layer behind weld



Key

1 all tapers not steeper than 1:6
2 overlay
3 thermoplastics lining
4 conductive layer behind weld



Key

1 all tapers not steeper than 1:6
2 all tapers not steeper than 1:6
3 overlay
4 thin skin 1,2 kg/m² to 2,4 kg/m² CSM min
5 thermoplastics lining
6 conductive layer behind weld
7 remainder of shell laminate

Figure 24 — Typical main seam joints for tanks and vessels with thermoplastics linings

10.7.2 Construction without thermoplastics liner

Where accessible an internal sealing strip shall be applied as shown in Figure 23, this sealing strip shall comprise the greater of any non-structural chemical barrier, or 2 layers of 450 g/m^3 CSM, the minimum total width of any sealing strip shall be 100 mm and the maximum 150 mm.

10.7.3 Construction with thermoplastics liner

All thermoplastics welds shall have full penetration and, when accessible, shall have a sealing weld applied to the inside of the liner. A conductive resin/laminate layer shall be applied to all welds before application of the main laminate, see Figure 24 and branch designs given in 10.8.

10.8 Openings, branches and compensating laminate

10.8.1 General

Openings and branches in tanks/vessels subject to external pressure shall be designed in accordance with the requirements for such equipment subjected to internal pressure, using the greater of internal or external pressure at the branch position.

The maximum dimension of openings in cylindrical shells covered by this standard shall be $d_c \leq 0{,}3 \cdot D$. Openings exceeding $0{,}3 \cdot D$ and all openings of non-circular shape shall be given special consideration, but shall conform with the basic requirements of this standard.

Openings in dished heads shall be located entirely within a circle of radius $\leq 0{,}4 \cdot D$. The maximum dimension of openings in dished heads covered by this standard shall be $d_c \leq 0{,}5 \cdot D$.

Wherever possible a branch shall not be positioned in the knuckle region of a dished head, if this is not possible for whatever reason the maximum diameter of branch shall be $\sqrt{D \cdot t_k}$.

10.8.2 Symbols

D	diameter of the shell
d_c	diameter of hole pierced in the shell/end
d_b	nominal diameter of the branch
d_r	outer diameter of compensation = (d_c + $2 \cdot l_a$)
t_c	thickness of the shell at the branch position
t_1	thickness of the compensation layers, see Figures 25 to 33
t_2	thickness of the pull out reinforcement layers, see Figures 25 to 33
t_3	thickness of the internal overlay laminate, see Figures 25 to 33
t_k	thickness of the knuckle of the dome.
U_d	limit unit loading of shell laminate for $\gamma_F \cdot A_5$-loads, see 9.3.2
$U_{d,c}$	limit unit loading of compensation laminate material for $\gamma_F \cdot A_5$-loads, see 9.3.2
X_d	unit moduls from the shell laminate
$X_{d,c}$	unit moduls from compensate laminate
ε_d	limit strain ε_{lim} from the shell laminate
$\varepsilon_{d,c}$	limit strain ε_{lim} from the compensate laminate
t_a	thickness of total reinforcement required at branch position (= t_c + t_1 + t_2)
l_a	length of the compensation layers at a branch.

10.8.3 Compensation requirements for openings

Compensating laminate shall perform two functions namely:

a) to replace the load bearing capability lost in piercing the tank or vessel and

b) to attach the branch to the tank or vessel in shear.

The design of the branches shall be in accordance with one of the types shown in Figures 25 to 33.

The calculation for the cut-outs is given by the following formula. According to the design, a disc-shaped reinforcement is required for the compensating layer around the cut-out.

The maximum unit load at the cut-out is given by formula

$$n_{\max\varphi,d,R} = n_{\varphi,d,R} \cdot v_A \quad or \quad n_{\max\varphi,d,\varepsilon} = n_{\varphi,d,\varepsilon} \cdot v_A \tag{137}$$

$$n_{\max x,d,R} = n_{x,d,R} \cdot v_A \quad or \quad n_{\max x,d,\varepsilon} = n_{x,d,\varepsilon} \cdot v_A \tag{138}$$

where

v_A is the load concentration factor given by Formula (139):

$$v_{\mathbf{A}} = 1{,}5 \cdot \left(1 + \frac{d_{\mathbf{c}}}{2 \cdot \sqrt{D \cdot t_{\mathbf{a}}}} \right) \tag{139}$$

and $n_{i,d,R}$ or $n_{i,d,\varepsilon}$ is given in 10.2.1 or 10.2.2.

$$n_{\max,d,R} \le U_{R,d} + U_{R,d,c} \quad or \quad n_{\max,d,\varepsilon} \le \varepsilon_{d,c} \cdot X_{d,\mathbf{c}} + \varepsilon_d \cdot X_d \tag{140}$$

The laminate selected from 9.3.2 shall have a load bearing capacity, given in Formula (140), equal to or greater than that computed in Formulae (137) and 138. The minimum compensation shall be three layers of 450 g/m² CSM.

The length of the compensation laminate (taper 1:6) shall be the greater of 100 mm, or l_a given by Formula (141):

$$l_{\mathrm{a}} = \sqrt{D \cdot t_{\mathrm{a}}} - 3 \cdot (t_1 + t_2) \tag{141}$$

where

$$t_1 + t_2 = t_{over}$$

If the cut-out ≤ 150 mm the length of the compensation laminate can be 100 mm.

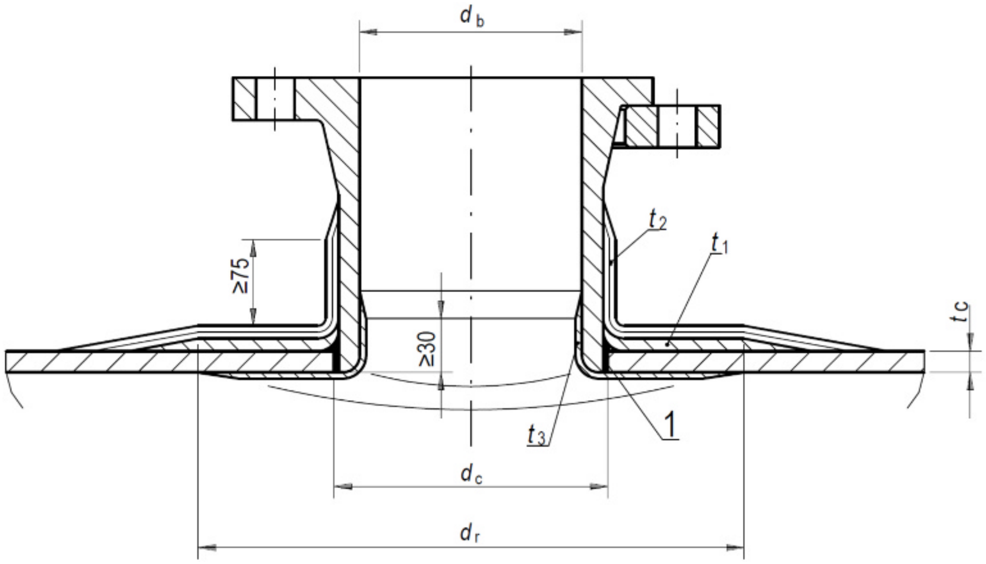
The minimum inside overlapping laminate excluding corrosion barrier at the branch for pressureless vessels and tanks for branches below liquid level, see Figures 25 to 33, shall be

$$t_3 \ge \frac{p_d \cdot d_c}{2 \cdot U_{R,d,c}} \tag{142}$$

The minimum of the inner reinforcement is

for d_c ≤ 50 mm	t_3 ≥ 1 × 300 g/m² CSM
for 50 mm < d_c ≤ 150 mm	t_3 = 2 × 450 g/m² CSM
for 150 mm < d_c < 400 mm	t_3 ≥ 3 × 450 g/m² CSM
for d_c ≥ 400 mm	t_3 ≥ 4 × 450 g/m² CSM

Dimensions in millimetres

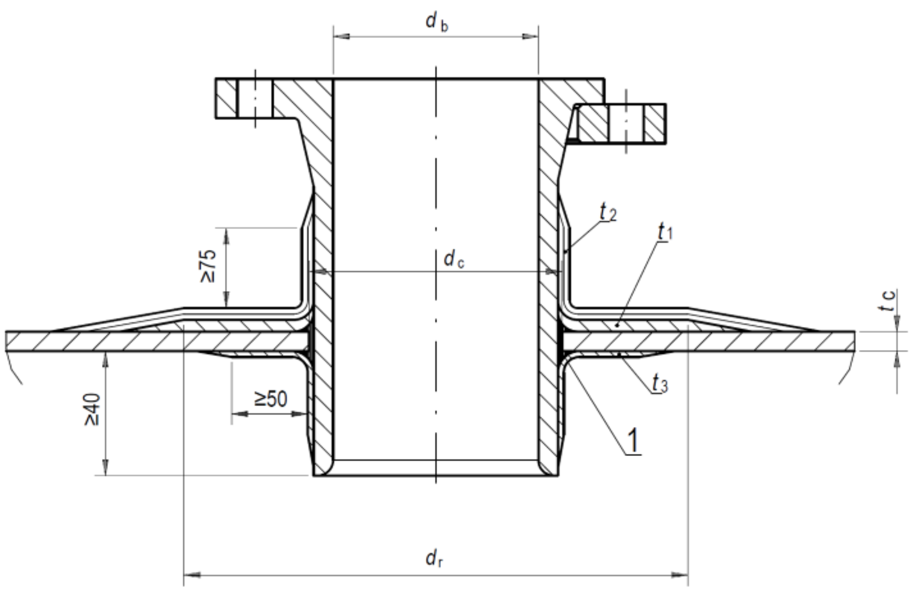


Key

1 glass fibre/resin infill

Figure 25 — Branches — Flush set in branch without thermoplastics lining

Dimensions in millimetres

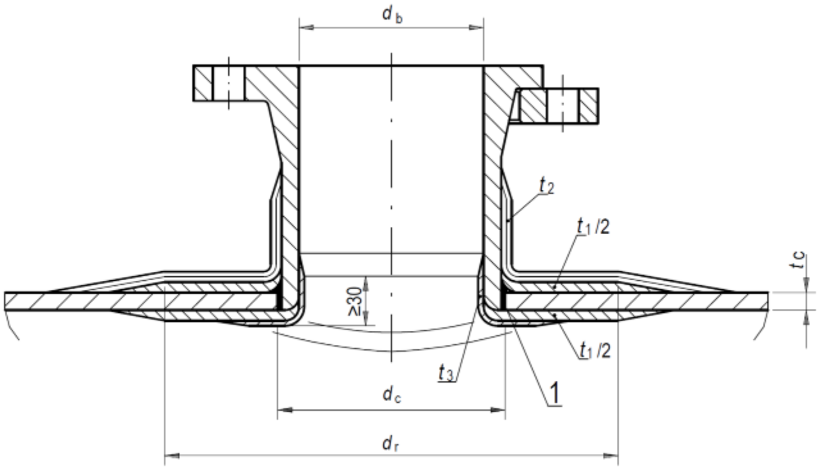


Key

1 glass fibre/resin infill

Figure 26 — Branches—Set through branch without thermoplastics lining

Dimensions in millimetres

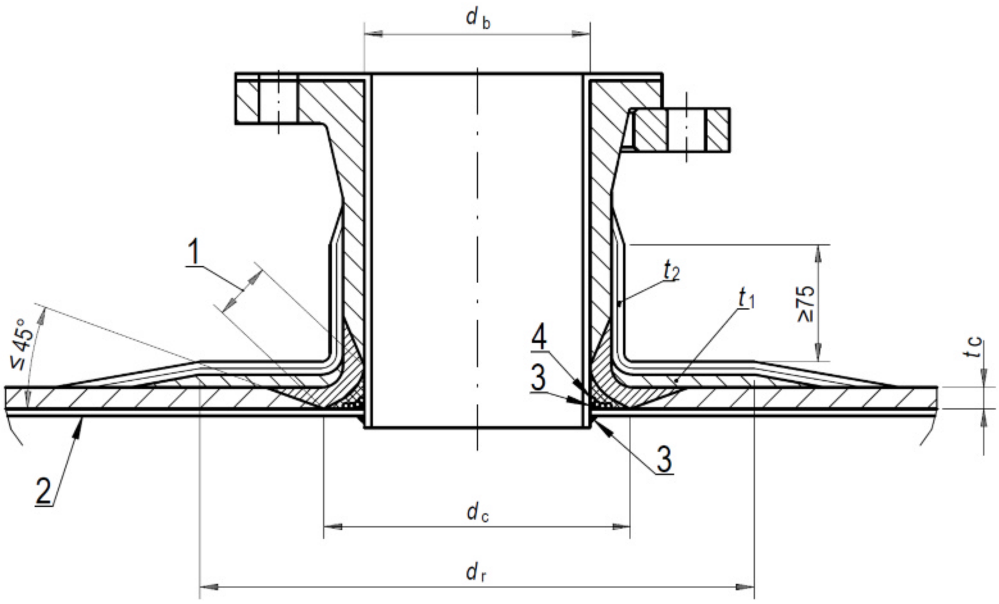


Key

1 main shell laminate

Figure 27 — Branches — With internal and external overlay without thermoplastics lining

Dimensions in millimetres



Key

1 laminate cut-back to allow lining to be welded then refilled with glass fibre/resin. (Gap minimum necessary for access and conductive layer)

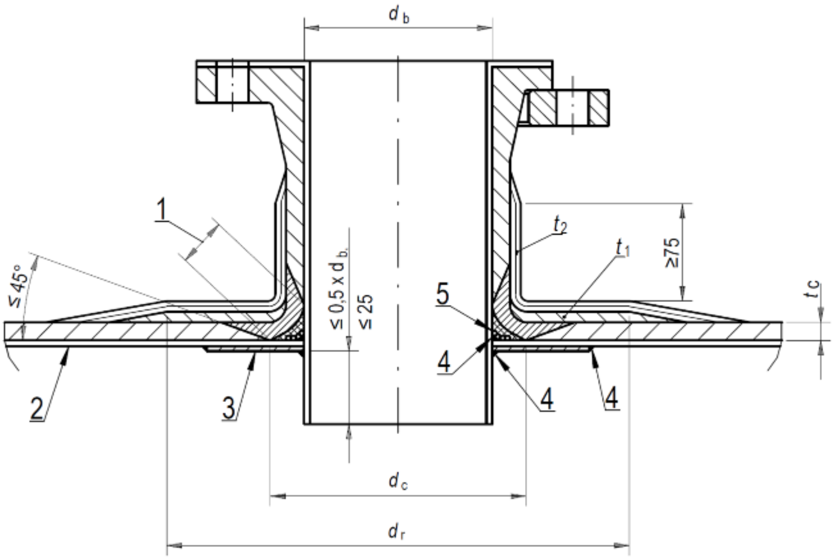
2 thermoplastic lining

3 welds internally and externally

4 conductive layer

Figure 28 — Branches — Flush branch with thermoplastics lining

Dimensions in millimetres



Key

1 laminate cut-back to allow lining to be welded then refilled with glass fibre/resin. (Gap minimum necessary for access and conductive layer)

2 thermoplastics lining

3 optional pad of lining material. PVC-U up to 60 °C; PP up to 80 °C

4 welds

5 conductive layer

Figure 29 — Branches — Set through branch with thermoplastics lining

Dimensions in millimetres

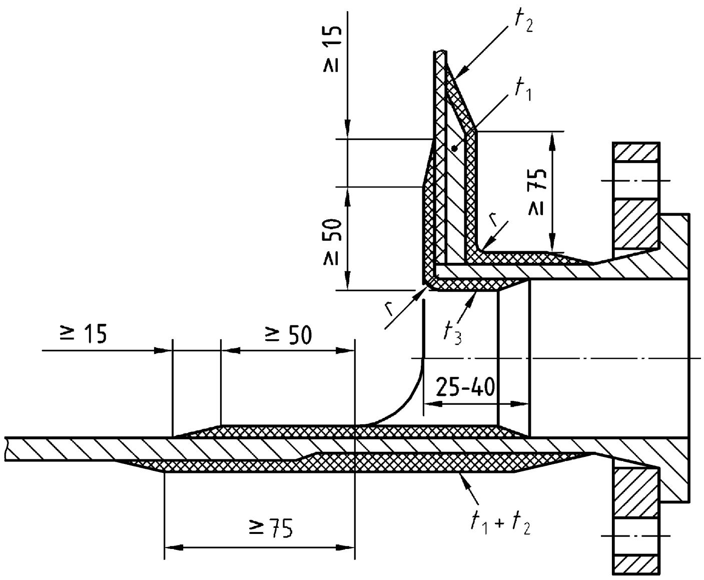


Figure 30 — Branches — Flush base branch without liner

Dimensions in millimetres

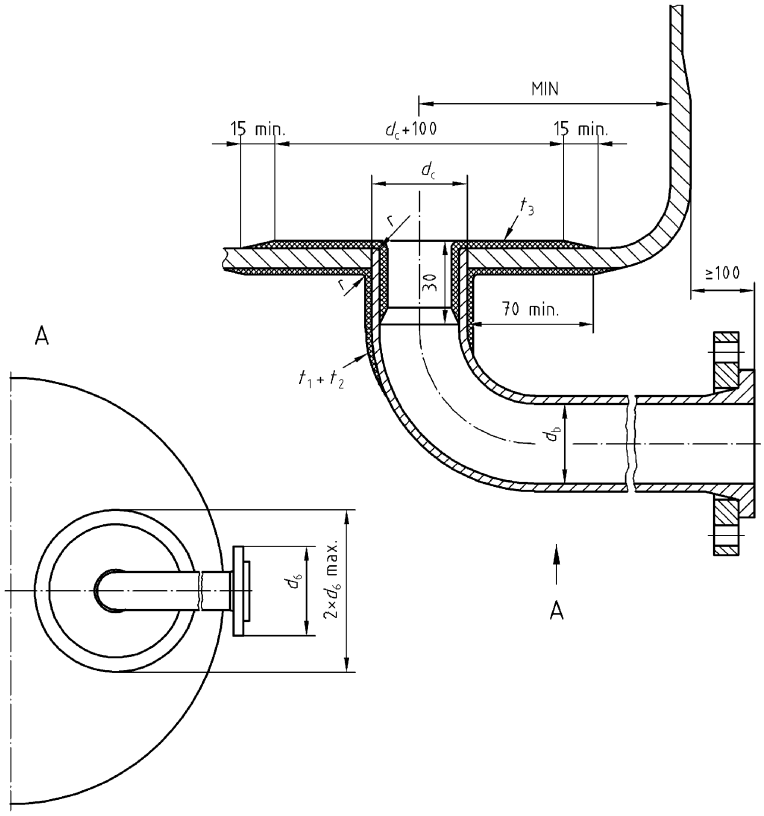
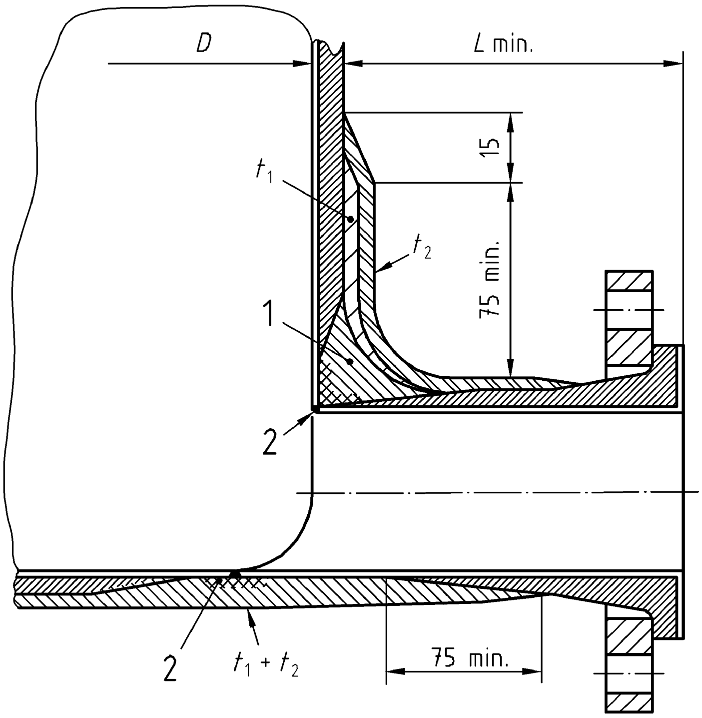


Figure 31 — Branches — Bottom outlet branch without thermoplastics liner

Dimensions in millimetres

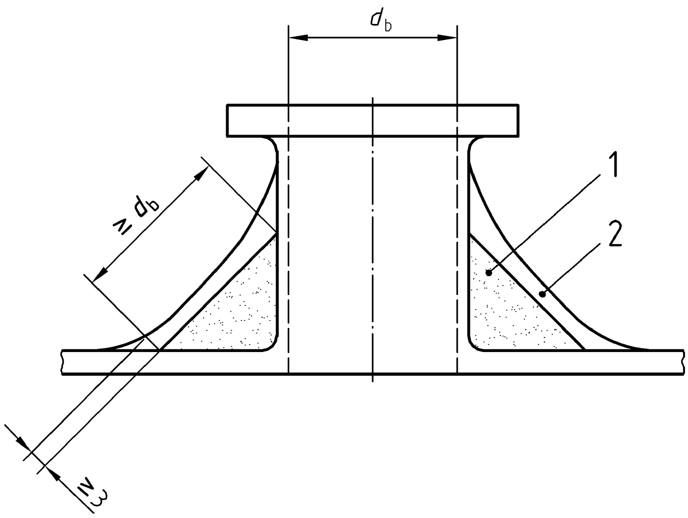


Key

1 resin paste infill (min)

2 welds plus conductive layer behind weld

Figure 32 — Branches — Flush base branch with thermoplastics liner



Key

1 infill

2 overlay

NOTE All corner radii to be 6 mm nominal.

Figure 33 — Branches — Gusseted branch

10.8.4 Pull out load from nozzles

A check calculation shall be made to ensure that the overlay design loading in shear is equal to or greater than the pull-out unit load, $n_{b,d,R}$, determined by Formula (143):

$$n_{\mathbf{b,d,R}} = \frac{p_{\mathbf{d,R}} \cdot d_{\mathbf{c}}}{4} \tag{143}$$

where

$$p_{d,R} = PS_{overpr.} \cdot A_{5,i} \cdot \gamma_{F,p} + \sum \left(p_{e,i} \cdot A_{5,i} \cdot \gamma_{F,i} \right)$$

The limit lap shear stresses are given by Formula (144):

$$\tau_d \leq \frac{n_{\mathbf{b,d,R}}}{16 \cdot t_{\mathbf{over}}} \leq \frac{\tau_{\mathbf{lap,k}}}{(\gamma_M \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4)} \tag{144}$$

where

$\tau_{lap,k}$ is the lap shear strength of the laminate given by D.7 or Table 4

The minimum overlay laminate shall be 3 × 450 g/m² CSM.

The length of the overlay laminate extending up on the branch shall not be less than 75 mm for all branch sizes, see Figures 25 to 33.

Also the load bearing capability of the proportion of compensating laminate applied up the branch, to attach the branch in tension, shall be greater than the branch axial load $n_{\mathbf{b,d,R}}$.

10.8.5 Prevention of failure in peel

If all the overlay laminate is applied outside the main shell, the total pull-out load exerted by the branch shall be resisted by the bond between the overlay laminate and the main shell laminate. The soundness of particular design details shall be either demonstrated by prototype testing or verified from experience.

Where the unit pull-out load $n_{\mathbf{b,d,R}}$, exceeds the peel strength of the laminate bond as determined by tests, the branch shall be redesigned. In the case of tanks or vessels without thermoplastics linings, improved resistance to pull-out may be obtained from the internal sealing laminate specified in 10.8.3.

10.8.6 Pad connections

10.8.6.1 General

Studded pads shall comply with the minimum requirements of 10.8.6.2 and 10.8.6.3 and the minimum dimensions shown in Figure 34. If high moments from the piping are expected, or if it is intended to mount a valve directly on the tank or vessel, the design of the pad shall be designed in accordance with the relevant steel vessel standard, but shall not be used at temperatures above 60 °C. At higher temperatures, the solution according to Figure 35 is preferable.

10.8.6.2 Studs

The studs shall be manufactured in a material, which will not be significantly corroded if it comes in contact with the contents of the tank or vessel.

The studs shall only be fitted into a metal reinforcing ring by one of the following methods (see Figure 34):

a) screwing;

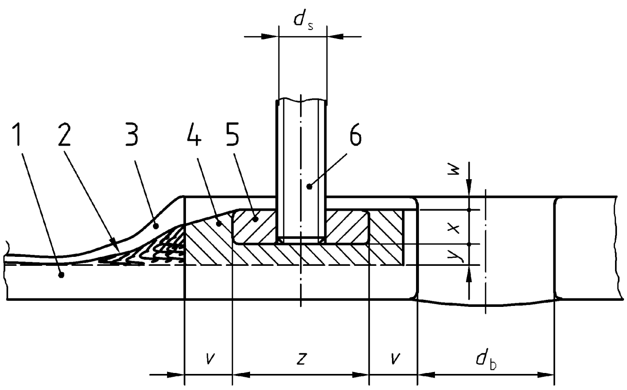
b) screwing and welding.

Screwing shall be used to permit stud replacement where the likelihood of damage to studs in service is high, or where machining of the joint face is required.

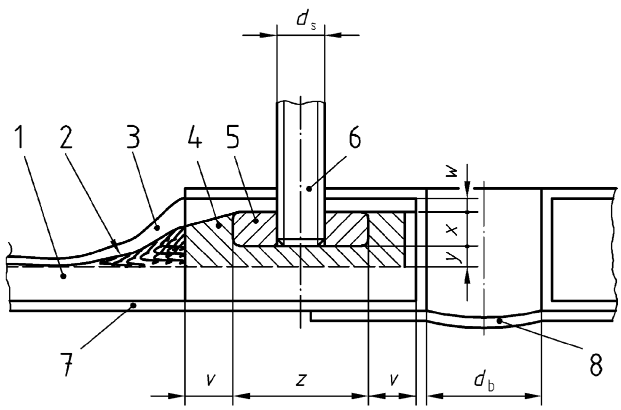
10.8.6.3 Metal rings

The material of the metal ring shall be not less than the proportions shown in Figure 34 and the studs shall not protrude beyond the inner face. Studs which are retained by screwing only shall either be fitted into blind tapings in the ring, or alternatively a metal plate welded over the inner face of the ring can be used to prevent the studs from being screwed too far.

The metal ring shall be cleaned to remove any scale or surface deposits and degreased before bonding into the pad.



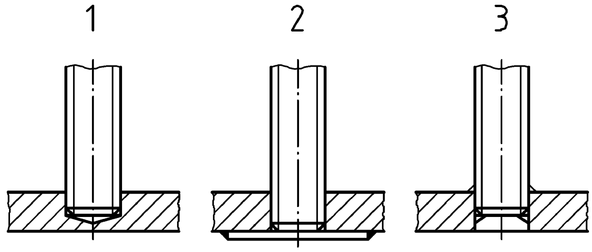
a)



b)

Key

1 shell laminate
2 taper glass infill
3 overlay
4 solid glass/resin infill
5 ring
6 stud
7 thermoplastics liner
8 optional pad of thermoplastics



c)

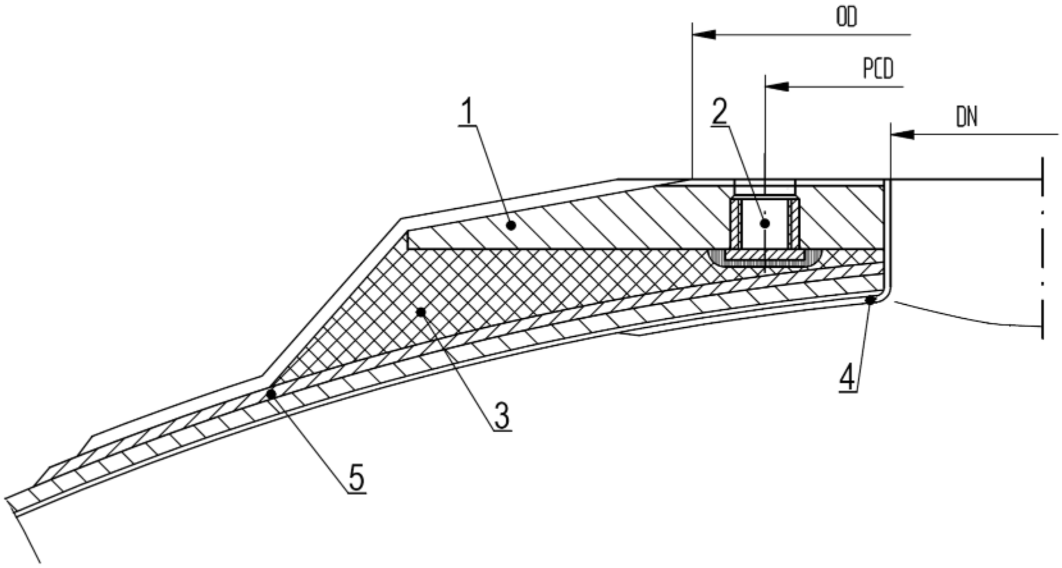
Key

1 screwed into blind hole
2 screwed with welded back plate
3 screwed and welded

Dimension	**Minimum values**
v	d_s
w	0,75 d_s
x	D_s + 3mm
y	Thickness of compensation see 10.8.3
z	3 d_s

Figure 34 — Pads for vessels

10.8.6.4 Studs with steel insert nuts



Key

1 FRP
2 steel insert nut
3 putty
4 3xMat 450 g/m² + veil
5 opening compensating laminate

Figure 35 — Stud with threaded insert nuts

10.8.7 Screwed connections

Screwed connections, including nipples and tapped branches, shall not be used.

10.8.8 Access and inspecting openings

All tanks or vessels shall be provided with inspection and/or access openings, so located as to permit visual examination of the interior of the tank or vessel.

10.8.9 Gusset on branches

All branches with an internal diameter of 80 mm or less shall be provided with supporting solid conical gusset, which shall be fitted after completion of the main laminate and compensation (see Figures 25 to 33) if the standout is greater 200 mm and additional forces on the branch can be expected.

The slant length of the conical gusset shall not be less than the internal diameter of the branch, and the thickness of the overlay of the conical core (either solid resin and glass infill or polyurethane foam) shall not be less than 3 mm (see Figures 25 to 33).

10.9 Flat Panels or Blind flanges

10.9.1 General

Flat panels manufactured in accordance with this standard shall be fabricated using materials having isotropic properties e.g. CSM or orthotropic properties e.g. CSM/WR, as the only reinforcing material. The formulae in this clause are based on consideration of both the maximum allowable unit skin loading (tensile or compressive) an overriding limiting allowable maximum deflection of 1,5 times the panel thickness *t*.

10.9.2 Symbols

β	strength constant appropriate to combination of plate edge condition and type of loading
d_p	diameter over which pressure acts on circular panel
E_b	flexural modulus of laminate under consideration, in N/mm²
$m_{p,d,R(\varepsilon)}$	design moment for bearing capability or stain in Nm/m
$m_{W,d,R(\varepsilon)}$	design moment due to local load W, in Nm/m
r_0	radius of local load
r_p	radius of panel, or in the case of isosceles triangular panels, the length of one of the equal sides
t	thickness of panel
t_{min}	deflection limited minimum allowable thickness
W	applied local load, in N

10.9.3 Circular panels

10.9.3.1 General

The formulae are valid for gaskets inside bolt circle diameter. For full-face gaskets these formulae are conservative.

10.9.3.2 Circular panels under uniformly distributed load

The unit moment, m_p, due to uniformly distributed load shall be determined from Formula (145):

$$m_{p,d,R} = \beta_1 \cdot d_p^2 \cdot p_{d,R} \text{ or } m_{p,d,\varepsilon} = \beta_1 \cdot d_p^2 \cdot p_{d,\varepsilon} \tag{145}$$

where

$$p_{d,R} = PS \cdot A_{5,i} \cdot \gamma_{F,p} + \sum p_{e,i} \cdot A_{5,i} \cdot \gamma_{F,i}$$

$$p_{d,\varepsilon} = PS + \sum p_{e,i}$$

β_1 is a constant having the following values:

β_1 = 0,03125 for type 1 edge conditions = fixed;

β_1 = 0,0516 for type 2 edge conditions = simply supported:

$p_{e,i}$ is any other pressure load, for example wind or snow etc.

For the select laminate use Formula (146) for bearing capability or strain limit.

$$\frac{\Sigma m_{p,d,R} \cdot \frac{6}{t^2}}{\frac{f_{i,k}}{\gamma_M \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4}} \leq 1 \quad or \quad \frac{\Sigma m_{p,d,R} \cdot \frac{6}{t}}{\frac{U_{lam,i,k}}{\gamma_M \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4}} \leq 1 \tag{146}$$

$$\frac{6 \cdot \Sigma m_{p,d,\varepsilon}}{E_{i,m} \cdot t^2} \leq \varepsilon_{\lim} \quad or \quad \frac{6 \cdot \Sigma m_{p,d,\varepsilon}}{X_{lam,i,m} \cdot t} \leq \varepsilon_{\lim}$$

10.9.3.3 Circular panels under central local load

The moment $m_{W,d}$ due to concentrated load $W = p \cdot \pi \cdot r_o^2$ for a simply supported flat plate shall be determined from Formula (147):

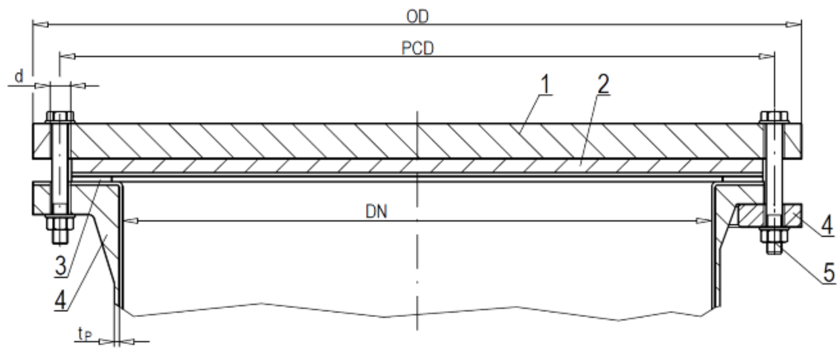
$$m_{W,d,R} = \frac{W_{d,R}}{4 \cdot \pi} \left[\frac{(1-\nu) \cdot \ln D}{2 \cdot r_o} + 1 \right] \quad (147)$$

respectively

$$m_{W,d,\varepsilon} = \frac{W_{d,\varepsilon}}{4 \cdot \pi} \left[\frac{(1-\nu) \cdot \ln D}{2 \cdot r_o} + 1 \right]$$

For the select laminate use Formula (146) for bearing capability or strain limit.

10.9.3.4 Blind flange arrangements with steel backing plate



Key

1 steel backing plate

2 laminate cover (with or without lining)

3 gasket inside bolt circle

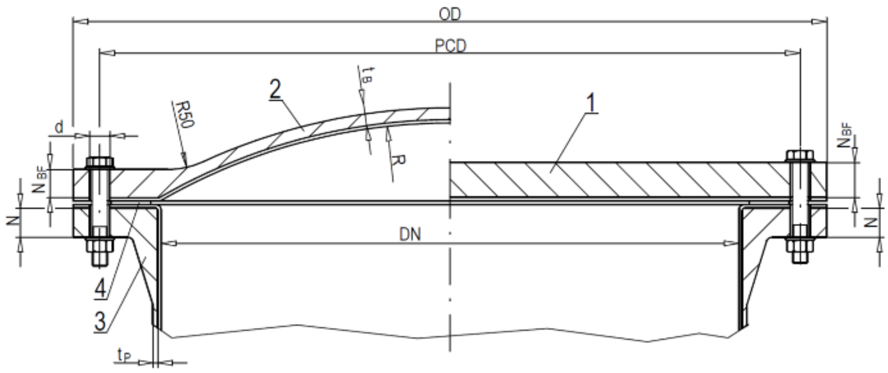
4 steel backing flange

5 bolts or stud bolts

Figure 36 — Blind flange with steel backing plate

10.9.3.5 Blind flange arrangements with GRP cover plate

Dimensions in millimetres



Key

1 flat cover plate of GRP
2 spherical dished cover of GRP
3 GRP flange
4 gasket

$N_{BF} \geq N$

Figure 37 — Typical design GRP blind flange

a) Flat blind flanges:

The unit moment, m_p, due to uniformly distributed load over the flat blind flange shall be determined from Formula (148):

$$m_{p,d,R} = 0{,}053 \cdot p_{d,R} \cdot DN \cdot PCD \quad or \quad m_{p,d,\varepsilon} = 0{,}053 \cdot p_{d,\varepsilon} \cdot DN \cdot PCD \tag{148}$$

where

$$p_{d,R} = PS \cdot A_{5,i} \cdot \gamma_{F,p} + \sum \left(p_{ei} \cdot A_{5,i} \cdot \gamma_{F,i} \right) \text{ for GRP}$$

$$p_{d,R} = PS \cdot \gamma_{F,p} + \sum \left(p_{ei} \cdot \gamma_{F,i} \right) \text{ for steel}$$

respectively $p_{d,\varepsilon} = PS + \sum p_{e,i}$ for GRP

DN is the nominal diameter of blind flange

PCD is the bolt circle of the blind flange

$p_{e,i}$ = any other pressure load, for example wind or snow, etc.

For the select laminate use Formula (149) for bearing capability or Formula (150) for strain limit.

$$\frac{\Sigma m_{p,d,R} \cdot \frac{6}{t^2}}{\frac{f_{i,k}}{\gamma_M \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4}} \leq 1 \quad or \quad \frac{\Sigma m_{p,d,R} \cdot \frac{6}{t}}{\frac{U_{lam,i,k}}{\gamma_M \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4}} \leq 1 \tag{149}$$

$$\frac{6 \cdot \Sigma m_{p,d,\varepsilon}}{E_{i,m} \cdot t^2} \leq \varepsilon_{\lim} \quad or \quad \frac{6 \cdot \Sigma m_{p,d,\varepsilon}}{X_{lam,i,m} \cdot t} \leq \varepsilon_{\lim} \tag{150}$$

For steel the requirements of EN 1993-1-1 shall be met.

The deflection is given by:

$$f = 0{,}049 \cdot \frac{p_{d,R} \cdot DN \cdot PCD^3 \cdot A_3}{E_b \cdot N_{BF}^3 \cdot \gamma_{F,p}} \leq 1{,}5 \cdot N_{BF} \quad (151)$$

The angle at PCD is:

$$\hat{\phi} = 0{,}14 \cdot \frac{p_{d,R} \cdot DN \cdot PCD^2 \cdot A_3}{E_b \cdot N_{BF}^3 \cdot \gamma_{F,p}} \leq 0{,}025 \quad (152)$$

b) Spherical domed covers:

Validity condition: R ≤ DN.

To meet tightness requirements, for the dimensioning of the cover-flange refer to Clause 11.

For the spherical section in the flange/sphere the following applies:

The unit load, $n_{p,d}$, due to interfered stresses in the flange/sphere shall be determined as follows:

$$n_{p,d,R} = 1{,}5 \cdot p_{d,R} \cdot R \cdot \beta_e \quad or \quad n_{p,d,\varepsilon} = 1{,}5 \cdot p_{d,\varepsilon} \cdot R \cdot \beta_e \quad (153)$$

with: $\beta_e = 2{,}18 - 0{,}593 \cdot \log \bar{x} + 0{,}381 \cdot (\log \bar{x})^2 - 0{,}12 \cdot (\log \bar{x})^3 + 0{,}4 \cdot (\log \bar{x})^4$

for $\bar{x} = \frac{t_B}{R} \cdot \sqrt{DN \cdot t_B} \leq 3$

and $\beta_e = 2{,}0$ for $\bar{x} > 3$

For selected laminate use Formula (154) for bearing capability or Formula (155) for strain limit:

$$\frac{\Sigma n_{p,d,R} / t_B}{\dfrac{f_{i,k}}{\gamma_M \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4}} \leq 1 \quad or \quad \frac{\Sigma n_{p,d,R}}{\dfrac{U_{lam,i,k}}{\gamma_M \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4}} \leq 1 \quad (154)$$

$$\frac{\Sigma n_{p,d,\varepsilon}}{E_{i,m} \cdot t_B} \leq \varepsilon_{\lim} \quad or \quad \frac{\Sigma n_{p,d,\varepsilon}}{X_{lam,i,m}} \leq \varepsilon_{\lim} \quad (155)$$

For stability analysis of the sphere refer to 10.5.3.

10.10 Horizontal tanks and vessels

10.10.1 Types of supports

Horizontal vessels may be supported in two ways:

a) by two or more rigid saddles placed at intervals along the length of the vessel having a minimum support angle of 120°;

b) by two or more flexible saddles which embrace the lower region of the vessel for 180°, or by two or more slings secured to a supporting structure, again supporting the vessel for 180°.

These two arrangements are shown diagrammatically in Figure 38 and Figure 39.

For tanks and vessels supported on two or more saddles, either of two design methods can be used, namely, a rigid support analysis – see 10.10.4.2 / 10.10.4.3.2 or a flexible support analysis – see 10.10.4.3.3. These two design methods only differ in their detail at the saddle position, where the actual method and type of supports effects the loading distribution in the shell in the region of saddle.

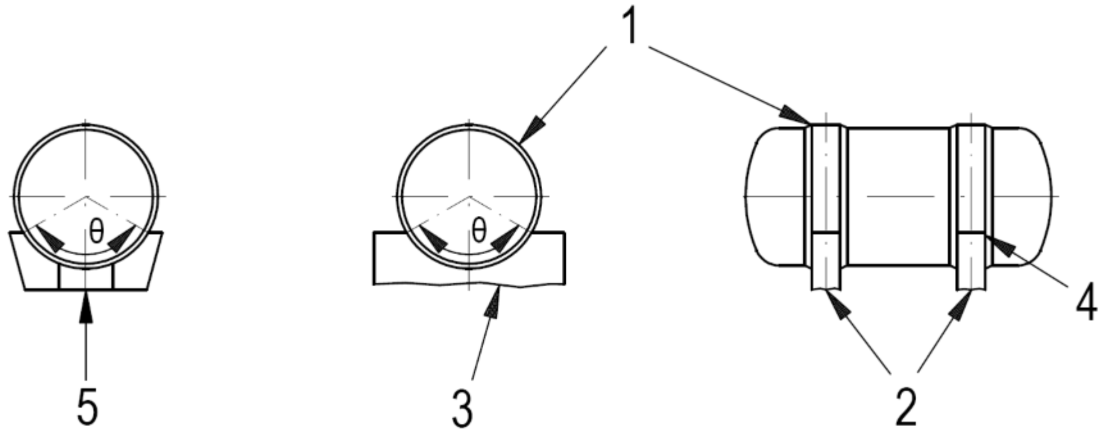
The static loading formulae for the flexural moments, shear forces and the saddle reactions are the same.

Many of the formulae contain factors that have been derived by experimental and rigorous analytical methods and the relevant references to this work are added for continuity.

For the purposes of this European Standard, the definitions of the two types of saddle configuration are:

c) a rigid saddle is one where over the area of support the vessel shell is constrained to the saddle. Such saddles are usually manufactured from either a solid steel fabrication, or pre-cast in concrete.

d) a soft saddle is one where at the area of support, the saddle supporting strap is flexible allowing the saddle and vessel to deform together.



Key

1 ring stiffeners when necessary

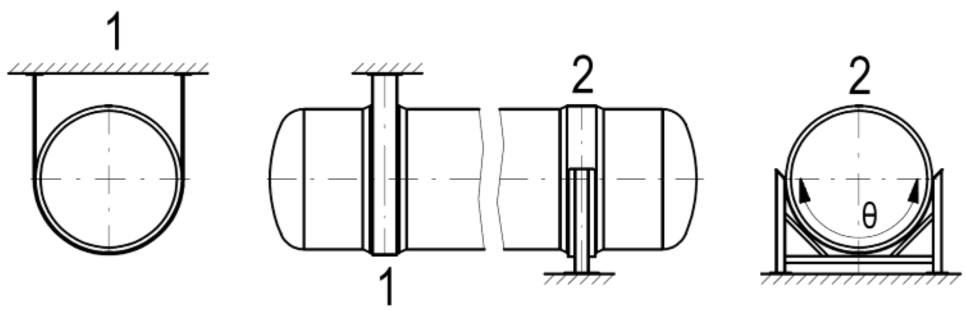
2 saddle θ ≥ 120°

3 concrete rigid saddle

4 saddle edge radiused

5 steel rigid saddle

Figure 38 — Typical rigid saddle support arrangements for horizontal tanks and vessels



Key

1 sling support θ ≥ 180°

2 flexible steel saddle θ ≥ 180°

Figure 39 — Typical flexible saddle arrangement for horizontal tanks and vessels

Supports shall be designed to provide free horizontal movement of the vessel, or where they are rigidly attached to the vessel the saddle support shall be mounted to allow free expansion of the vessel.

When more than two supports shall be used, the values of the support reactions can be calculated from a continuous beam analysis or strain energy methods, but these analytical methods shall make due allowance for any variations that may exist in the level of the supports in practice. The conditions of the supports considered for the analysis shall be fully reproduced on the actual installation.

When rigid saddles are not an integral part of the vessel and not physically attached to it, a flexible interface shall be fitted, minimum 4 mm thick, between the saddle and the vessel comprising either rubber or a low modulus cushioning material.

10.10.2 Symbols

A	is the distance from saddle centre to end of parallel section of barrel;
H_i	is the height of the dished end;
b_1	is the width of saddle;
$E_{x,b}$, $E_{\phi,b}$	are the flexural modulus of laminate (N/mm^2) in the axial and circumferential directions;
E_x, E_ϕ	are the tensile modulus of laminate (N/mm^2) in the axial and circumferential directions;
ϕ	is the coordinate in the circumferential direction;
I	is the second moment of area of the vessel at the position of analysis and equals $\pi \cdot D^3 \cdot t / 8$;
K_1- K_{11}	are factors defined in the text;
L_s	is the distance between supports or stiffeners;
L_{cyl}	is the cylindrical length of vessel;
L	= L_{cyl} in the formulae;
n_x, n_ϕ	are the unit loads in the axial and circumferential direction;
$n_{x,h}$	is the horizontal unit load;
$n_{x,v}$	is the vertical unit load;
$n_{\phi m}$	is the membrane unit load in circumferential direction
$n_{\phi b}$	is the load from bending in circumferential direction;
PS_{op}	is the maximum internal pressure;
PS_{ep}	is the external pressure;
θ	is the total angle of saddle support;
ε_ϕ	is the strain in circumferential direction;
ε_x	is the strain in axial direction;
Q	is the shear force at section being analyzed;
$2 \cdot W_1 = W_t$	is the total weight of horizontal vessel and contents on the saddles;
X	is the co-ordination in the axial direction;
W	Is the load distribution.

NOTE Suffixes 1, 2, 3 ... are used to define particular values in the analysis as given in the text.

10.10.3 Unit loads of the cylindrical shell

10.10.3.1 Unit loads in circumferential direction due to pressure

The design unit loadings shall be determined as follows:

Loading due to vessel weight – see the following formula:

$$n_{\varphi b,d,R} = 0{,}15 \cdot \rho \cdot g \cdot L_s^2 \cdot A_5 \cdot \gamma_{F,w} \quad or \quad n_{\varphi b,d,\varepsilon} = 0{,}15 \cdot \rho \cdot g \cdot L_s^2 \qquad (156)$$

where

L_s is the distance between two saddle supports.

The load due to vessel contents and pressure given by the following formula:

$$n_{\varphi m,d,R} = \left(2 \cdot PS_{op} \cdot \gamma_{F,p} + \rho \cdot g \cdot D\left(1 - \cos\varphi\right) \cdot \gamma_{F,w}\right) \cdot \frac{D \cdot A_5}{4} \quad or$$
$$n_{\varphi m,d,\varepsilon} = \left(2 \cdot PS_{op} + \rho \cdot g \cdot D\left(1 - \cos\varphi\right)\right) \cdot \frac{D}{4} \qquad (157)$$

The maximum tensile loads occur when the vessel is semi-filled, at $\phi = 90°$, which occurs at the bottom of the vessel and is given by the following formula:

$$n_{\varphi,d,R} = n_{\varphi b,d,R} + n_{\varphi m,d,R} \quad or \quad n_{\varphi,d,\varepsilon} = n_{\varphi b,d,\varepsilon} + n_{\varphi m,d,\varepsilon} \qquad (158)$$

For the selected laminate use 9.3.2 to proof the load bearing capacity.

10.10.3.2 Unit loads in axial direction and lateral forces for a symmetrical support on two saddles

10.10.3.2.1 General

Taking the vessel on two supports as shown in Figure 40.

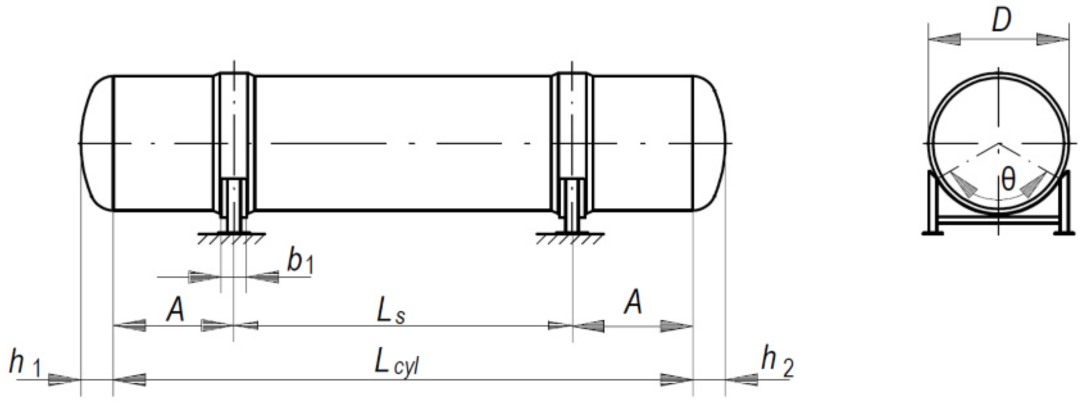
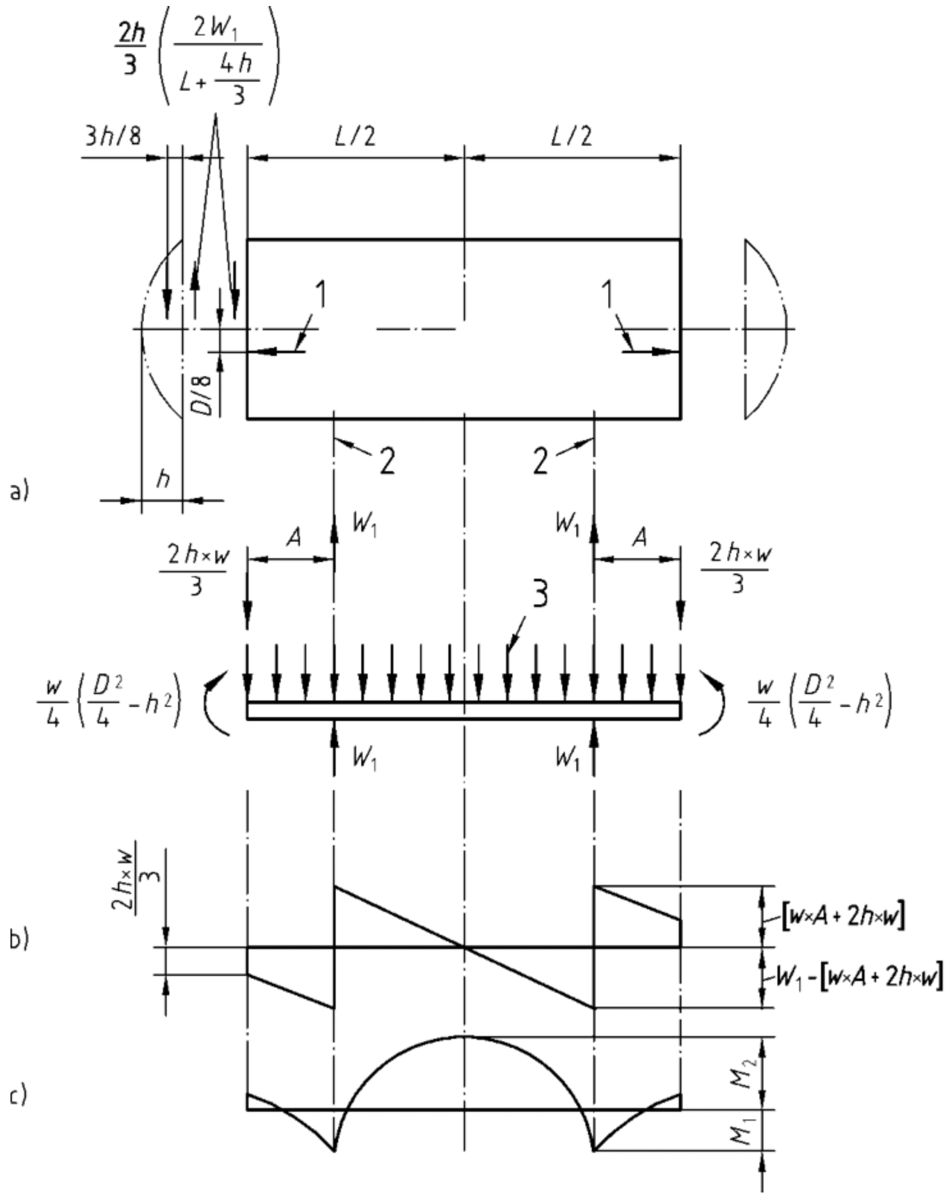


Figure 40 — Vessel on two supports

The corresponding flexural moment and shear force diagrams are given in Figure 41.



Key

a loads and reactions

b shear force diagram

c bending moment diagram

1 hydrostatic loads on ends $=\dfrac{w\cdot D}{2}$

2 support centre line

3 load intensity $w=\left(\dfrac{2\cdot W_1}{L+\dfrac{4\cdot h}{3}}\right)$

Figure 41 — Cylindrical vessel acting as a beam on two supports

The dimension $\frac{3 \cdot h}{8}$ is an approximation for the distance from the tangent plane to the centre of gravity of the dished end and its contents for all ranges of dished end covered by this European Standard.

10.10.3.2.2 Determination of longitudinal flexural moment

The determination of the longitudinal flexural moment shall be derived from considering the vessel behaving as a beam supported at the saddle positions under self-weight, vessel contents, hydraulic pressure, any super-imposed loadings and the effects of the hydrostatic pressure on the vessel ends, which produces additional flexural moments on the vessel.

From Figure 41 the flexural moment at the support is given by:

$$M_1 = \frac{w}{4} \cdot \left(\frac{D^2}{4} - h^2 - 2 \cdot A^2 - \frac{8 \cdot h \cdot A}{3} \right) \tag{159}$$

The flexural moment at mid span is given by:

$$M_2 = \frac{w}{8} \cdot \left[L^2 + \frac{D^2}{2} - 2 \cdot h^2 - 4 \cdot L \cdot A - \frac{16 \cdot h \cdot A}{3} \right] \tag{160}$$

where

$$w = \frac{2 \cdot W_1}{L + \frac{4 \cdot h}{3}} \tag{161}$$

10.10.3.2.3 Axial unit load at mid-span

In addition to the loading from overall flexural moment, the vessel is also subjected to axial loads arising from pressure on the ends of the vessel producing an axial unit load, n_{xp}, given by:

$$n_{x,p,d,R} = \frac{p_{d,R} \cdot D}{4} \quad or \quad n_{x,p,d,\varepsilon} = \frac{p_{\mathbf{d},\varepsilon} \cdot D}{4} \tag{162}$$

where

$$p_{d,R} = PS_{op} \cdot A_{5,i} \cdot \gamma_{F,p} + \sum \left(p_{e,i} \cdot A_{5,i} \cdot \gamma_{F,i} \right)$$

respectively $p_{d,\varepsilon} = PS_{op} + \sum p_{e,i}$

where p_e = any other pressure load, here hydrostatic pressure from liquid.

For axial stability case $p_{d,cr} = 0$ due to vacuum or external pressure.

Flexural moment due to weight, seismic, or snow loads (wind load can be neglected) determined to an applicable local code:

$$n_{\mathbf{x,M,d,R}} = \frac{4 \cdot M_{\mathbf{d,R}}}{\pi \cdot D^2} \quad or \quad n_{\mathbf{x,M,d},\varepsilon} = \frac{4 \cdot M_{\mathbf{d},\varepsilon}}{\pi \cdot D^2} \quad or \quad n_{\mathbf{x,M,d,cr}} = \frac{4 \cdot M_{\mathbf{d,cr}}}{\pi \cdot D^2} \tag{163}$$

where

$$M_{d,R} = M_2 \cdot A_{5,i} \cdot \gamma_{F,w} + \sum \left(M_{e,i} \cdot A_{5,i} \cdot \gamma_{F,i} \right)$$

respectively $M_{d,\varepsilon} = M_2 + \sum M_{e,i}$

For axial stability case $M_{d,cr} = M_2 \cdot \sqrt{A_{5,i}} \cdot \gamma_{F,w} + \sum \left(M_{e,i} \cdot \sqrt{A_{5,i}} \cdot \gamma_{F,i} \right)$

where

M_e = any other flexural moment.

The vessel does not act as a beam in practice and the loadings are subject to intensification effects and the beam loadings are modified using factors K_7 and K_8 which are given by the following formulae.

The factor K_7 is for tensile loading is

$$K_7 = \left(1{,}385 - 0{,}476 \cdot \frac{L_s}{D} + 0{,}24 \cdot \left(\frac{L_s}{D} \right)^2 - 0{,}024 \cdot \left(\frac{Ls}{D} \right)^3 \right) \geq 1 \tag{164}$$

and for compressive loadings

$$K_8 = \left(2{,}71 + \frac{D}{600 \cdot t} - 1{,}376 \cdot \frac{L_s}{D} + 0{,}308 \cdot \left(\frac{L_s}{D} \right)^2 - 0{,}024 \cdot \left(\frac{L_s}{D} \right)^3 \right) \geq 1 \tag{165}$$

Hence the maximum axial load, n_x

highest point $n_{x1,d,R} = n_{x,p,d,R} - n_{x,M,d,R} \cdot K_8$ (166)

lowest point $n_{x2,d,R} = n_{x,p,d,R} + n_{x,M,d,R} \cdot K_7$ (167)

strain: $n_{x,d,\varepsilon} = n_{x,d,\varepsilon} + n_{x,M,d,\varepsilon} \cdot K_7$ (168)

For the selected laminate use 9.3.2 to proof the load bearing capacity.

For the shell instability (i.e. compressive loading):

$$n_{x,d,cr} = n_{x,M,d,cr} \cdot K_8 - n_{x,p,d,cr} \tag{169}$$

The maximum value of $n_{x,d,cr}$ shall be also be checked against the stability criteria as given in 10.3.

10.10.3.2.4 Axial unit load at saddle positions

The axial unit load at the saddle positions due to M_1 is calculated on the basis that only part of the cross-section of the shell at the saddle position is effective.

The axial loadings are given by:

$$n_{\mathbf{x,M,d,R}} = \frac{4 \cdot M_{\mathbf{d,R}}}{\pi \cdot D^2} \quad or \quad n_{\mathbf{x,M,d,}\varepsilon} = \frac{4 \cdot M_{\mathbf{d,}\varepsilon}}{\pi \cdot D^2} \quad or \quad n_{\mathbf{x,M,d,cr}} = \frac{4 \cdot M_{\mathbf{d,cr}}}{\pi \cdot D^2} \tag{170}$$

where

$$M_{d,R} = M_1 \cdot A_{5,1} \cdot \gamma_{F,w} + \sum \left(M_{e,i} \cdot A_{5,i} \cdot \gamma_{F,i} \right)$$

respectively $M_{d,\varepsilon} = M_1 + \sum M_{e,i}$

For axial stability case $M_{d,cr} = M_1 \cdot \sqrt{A_{5,i}} \cdot \gamma_{F,w} + \sum \left(M_{e,i} \cdot \sqrt{A_{5,i}} \cdot \gamma_{F,i} \right)$

highest point $n_{x1,d,R} = n_{x,p,d,R} - n_{x,M,d,R} / K_1$ (171)

lowest point $n_{x2,d,R} = n_{x,p,d,R} + n_{x,M,d,R} / K_2$ (172)

strain: $n_{x,d,\varepsilon} = n_{x,d,\varepsilon} + n_{x,M,d,\varepsilon} / K_2$ (173)

For the selected laminate use 9.3.2 to proof the load bearing capacity.

For the shell instability (i.e. compressive loading):

$$n_{x,d,cr} = n_{x,M,d,cr} / K_2 - n_{x,p,d,cr} \quad (174)$$

Design factors K_1 and K_2 are given in Table 16.

Table 16 — Design factors K_1 and K_2

Condition	Saddle angle θ	K_1	K_2
Shell stiffened by end or rings, i.e. A < $\frac{D}{4}$ or rings provided	Up to 180	$1/K_7$	$1/K_8$
Shell unstiffened by end or rings, i.e. A > $\frac{D}{4}$ and no rings provided [6]	120	0,107	0,192
	135	0,132	0,234
	150	0,161	0,279
	165	0,193	0,328
	180	0,229	0,380

10.10.3.3 Shear forces

The distribution of shear force in the shell is given in Figure 41 for a vessel on two supports, or from the corresponding continuous beam analysis, when the vessel is supported on more than two saddles.

For the two saddle configuration the maximum shear forces Q_d at the saddle position are:

The shear load at the cantilever side of the support position is given by the following formula:

$$Q_{d,R} = w \cdot \left(A + \frac{2 \cdot h}{3} \right) \cdot A_5 \cdot \gamma_{F,w} \quad or \quad Q_{d,cr} = w \cdot \left(A + \frac{2 \cdot h}{3} \right) \cdot \sqrt{A_5} \cdot \gamma_{F,w} \quad (175)$$

and at the support side between saddles the shear load is given by the following formula:

$$Q_{d,R} = w \cdot \left(\frac{L}{2} - A \right) \cdot A_5 \cdot \gamma_{F,w} \quad or \quad Q_{d,cr} = w \cdot \left(\frac{L}{2} - A \right) \cdot \sqrt{A_5} \cdot \gamma_{F,w} \quad (176)$$

where

w is taken from 10.10.2.

The saddle region may be either stiffened (i.e. stiffening rings added, to shell or by proximity of the support region to the end) or left unstiffened (i.e. left as a plain cylinder).

Stiffened shells have $A \leq \frac{D}{4}$; or are stiffened by rings in the plane of saddle; all other shells are considered as unstiffened.

In both cases the full cross section of the shell shall be available to carry the resulting shear force.

The shear stress, τ, for the maximum of $Q_{d,R}$ is given by Formula (177) where K_3 is determined from Table 17.

$$\tau_{d,R} = \frac{2 \cdot Q_{d,R} \cdot K_3}{D \cdot t} \qquad (177)$$

Table 17 — Design factor K_3 [6]

Condition	Saddle angle θ °	$A > \frac{D}{4}$ K3	$A < \frac{D}{4}$ K3
shell unstiffened by rings and shells stiffened by rings adjacent to saddle	120	1,171	0,880
	135	0,958	0,654
	150	0,799	0,485
	165	0,675	0,357
	180	0,577	0,260
shell stiffened by rings in plane of saddle	Up to 180	0,319	0,319

For $f_{v,k} = \tau_k = 60\ N/mm^2$ the following applies;

$$\frac{\tau_{d,R}}{\dfrac{\tau_k}{\gamma_M \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4}} \leq 1 \qquad (178)$$

If the measured value of ultimate shear strength of the laminate is available, this value can be used in place of the 60 N/mm^2 in formula above.

10.10.3.4 Shear-buckling

At the support area, shear-buckling is possible and the critical shear buckling strength is given by Formula (179) and the applied shear strength is given by Formula (180) using the maximum value of the shear force Q at the support position under consideration.

$$\tau_{\mathbf{cr}} = k_q \cdot \left(E_{\mathbf{x}}^3 \cdot E_{\varphi,\mathbf{b}}^5\right)^{0,125} \cdot \left(\frac{t}{D}\right)^{1,25} \cdot \left(\frac{D}{L_{\mathbf{s}}}\right)^{0,5} \qquad (179)$$

where

k_q = 1,31 for τ = constant in circumferential and axial direction (torsion)

k_q = 14 for $\tau = \tau_{max} \cdot \sin\varphi$; $\varphi = 0$ at the highest point (bending)

$$\tau_{d,cr} = \frac{2 \cdot Q_{d,cr} \cdot K_3}{D \cdot t} \qquad (180)$$

the following criterion shall be met:

$$\left(\frac{\tau_{d,cr}}{\tau_{cr}/(\gamma_m \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4)}\right) \leq 1 \qquad (181)$$

10.10.3.5Stability of shell

The stability of the shell shall be checked in accordance with the relevant requirements of 10.3, the maximum compressive unit load in the shell being given when the pressure loading is zero or negative, using 10.10.3.2.3 or 10.10.3.2.4.

If an external pressure is also acting, then:

$$p_{d,cr} = PS_{ep} \cdot \sqrt{A_{5,i}} \cdot \gamma_{F,p} + p_{wind} \cdot \gamma_{F,p}$$

the following criterion shall be met:

$$\left(\frac{n_{x,d,cr}}{n_{cr}/(\gamma_m \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4)}\right)^{1,25} + \left(\frac{p_{d,cr}}{p_{cr}/(\gamma_m \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4)}\right)^{1,25} \leq 1 \qquad (182)$$

The critical radial buckling load, p_{cr}, shall be determined from 10.3.3 and the critical axial load, n_{cr}, from 10.3.2. When the thickness of the shell results in unacceptably high values, the vessel shell can be stiffened by rings adjacent to the saddle where Table 16 shows the change in magnitude possible, by reference to the respective values of K_1 and K_2.

10.10.3.6Unit loads in axial direction and lateral forces for a vessel on three or more saddles

For vessels on three or more saddles, use a beam analysis to determine the load distribution on the vessel.

The maximum tensile unit load and the compressive unit load are given by Formulae (183) and (184):

$$n_{\mathbf{x,d,R}} = 0,25 \cdot p \left\{ PS_{op} \cdot D \cdot \gamma_{F,p} + \rho \cdot g \cdot \left(\frac{D^2}{2} + 0,125 \cdot \left(4 \cdot L_\mathbf{s}^2 + D^2\right) \cdot K_7 \right) \cdot \gamma_{F,w} \right\} \cdot A_5$$
$$\text{or} \quad n_{\mathbf{x,d},\varepsilon} = 0,25 \cdot \left\{ PS_{op} \cdot D + \rho \cdot g \cdot \left(\frac{D^2}{2} + 0,125 \cdot \left(4 \cdot L_\mathbf{s}^2 + D^2\right) \cdot K_7 \right) \right\} \qquad (183)$$

$$n_{\mathbf{x,d,cr}} = 0,25 \cdot \left\{ PS_{op} \cdot D \cdot \gamma_{F,p} + \rho \cdot g \cdot \left(\frac{D^2}{2} - 0,125 \cdot \left(4 \cdot L_\mathbf{s}^2 + D^2\right) \cdot K_8 \right) \cdot \gamma_{F,w} \right\} \cdot \sqrt{A_5} \qquad (184)$$

For the selected laminate use formula in 9.3.2 to proof the axial load bearing capacity.

The maximum compressive loads from formula above shall be checked for stability of the shell, see the critical axial load, n_{cr}, given in 10.3.2.

The maximum shear force and corresponding shear stresses is given by Formula (185):

$$Q_{d,R} = 0,156 \cdot \rho \cdot g \cdot \pi \cdot D^2 \cdot L_\mathbf{s} \cdot A_5 \cdot \gamma_{F,w}$$
$$\text{or} \quad Q_{d,cr} = 0,156 \cdot \rho \cdot g \cdot \pi \cdot D^2 \cdot L_\mathbf{s} \cdot \sqrt{A_5} \cdot \gamma_{F,w} \qquad (185)$$

$$\tau_{d,R} = \frac{2 \cdot Q_{d,R} \cdot K_3}{D \cdot t} \quad \text{or} \quad \tau_{d,cr} = \frac{2 \cdot Q_{d,cr} \cdot K_3}{D \cdot t} \qquad (186)$$

For the load bearing see 10.10.3.3 and for the shear-buckling see 10.10.3.4.

For the stability of shell see 10.10.3.5.

10.10.4 Unit loads on saddle position

10.10.4.1 General

When designing the saddle position consideration shall be given to the most unfavourable loading case at the saddle position.

The following formulae are used to determine the loadings on the saddle positions.

The load at the saddle for vessels supported on two saddles is given by the following formula:

$$W_1 = \frac{W_\mathbf{t}}{2} \tag{187}$$

and when supported on more than two saddles, the load is given by a continuous beam analysis, however for the ring design, a more conservative value of saddle load is taken, which is given by

$$W_1 = \frac{W_\mathbf{t}}{n-1} \tag{188}$$

where

n is the number of saddles.

10.10.4.2 Circumferential unit load - unstiffened shell

10.10.4.2.1 General

The most important values of circumferential loadings are those that arise at the centre of the saddle position in the region of the saddle horn (i.e. the highest point of the saddle support) this being the most critical, and the other at the lowest cross-section (i.e. the nadir).

10.10.4.2.2 Maximum unit load at nadir of saddle for unstiffened shell

$$W_{1,d,R} = W_1 \cdot A_5 \cdot \gamma_{F,w} \quad or \quad W_{1,d,\varepsilon} = W_1 \tag{189}$$

Maximum unit load at nadir:

$$n_{\varphi 5,d,R} = \frac{K_5 \cdot W_{1,d,R}}{(b_1 + 10 \cdot t)} \quad or \quad n_{\varphi 5,d,\varepsilon} = \frac{K_5 \cdot W_{1,d,\varepsilon}}{(b_1 + 10 \cdot t)} \tag{190}$$

where

K_5 is given in Table 18.

Table 18 — Design factor K_5 [6]

θ	120°	135°	150°	165°	180°
K_5	0,76	0,711	0,673	0,645	0,624

a) For the selected laminate using 9.3.2 to proof the load bearing capacity.

b) Where the saddle and vessel are rigidly fixed together over their total contact surface, the value K_5 used shall be 1/10 of the value given in Table 18.

c) Where loose saddles are used, the full value of K_5 shall be used, or where relevant experimental data are available this can be used.

10.10.4.2.3 Loading at horn of saddle for unstiffened shell or shell stiffened by head

a) The maximum flexural moment at the stiffener occurs at the saddle horn and is given by:

$$M_{H,d,R} = \frac{K_6 \cdot W_{1,d,R} \cdot D}{2} \quad or \quad M_{\mathrm{M},d,\varepsilon} = \frac{K_6 \cdot W_{1,d,\varepsilon} \cdot D}{2} \tag{191}$$

where

K_6 is given in Table 19.

Table 19 — Design factor K_6 [6]

$\frac{2A}{D}$	Θ				
	120°	135°	150°	165°	180°
< 0,5	0,0132	0,0103	0,0079	0,0059	0,0041
≥ 1,0	0,0528	0,0413	0,0316	0,0238	0,0165

The variation $0{,}5 < \frac{2 \cdot A}{D} < 1{,}0$ is assumed linear and other values for K_6 can be obtained by linear interpolation.

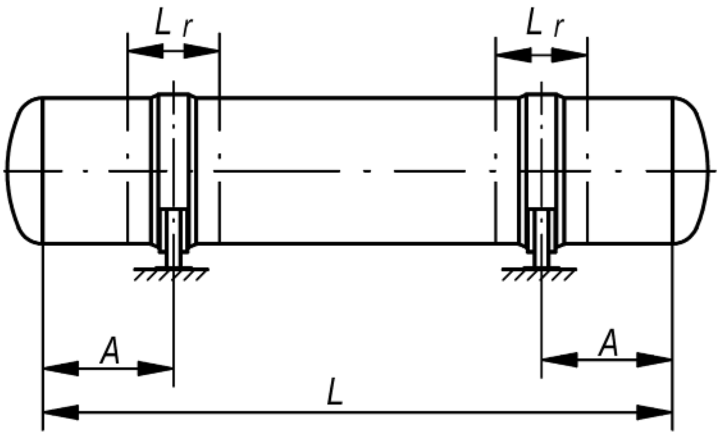


Figure 42 — Diagrammatic representation of width of vessel L_r resisting M_H

When $L \geq 4 \cdot D$, $A \leq 1{,}2 \cdot D$, if no ring stiffeners are provided.

The flexural component of the circumferential unit load is given by the following formula and uses the effective width of shell of $L_r \geq 2 \cdot D$:

$$n_{\varphi 1b,d,R} = \frac{3 \cdot K_6 \cdot W_{1,d,R}}{2 \cdot t} \quad or \quad n_{\varphi 1b,d,\varepsilon} = \frac{3 \cdot K_6 \cdot W_{1,d,\varepsilon}}{2 \cdot t} \tag{192}$$

And when $L < 4 \cdot D$, the flexural component of the circumferential unit load is given by Formula (193) and $\frac{L}{2}$ is the effective width of shell $L_r = \frac{L}{2}$:

$$n_{\varphi 2b,d,R} = \frac{6 \cdot K_6 \cdot W_{1,d,R} \cdot D}{L \cdot t} \quad or \quad n_{\varphi 2b,d,\varepsilon} = \frac{6 \cdot K_6 \cdot W_{1,d,\varepsilon} \cdot D}{L \cdot t} \tag{193}$$

b) Compressive unit load in normal load at saddle horn:

The direct component of the circumferential unit load at the horn is given by:

$$n_{\varphi,d,R} = \frac{W_{1,d,R}}{4 \cdot (b_1 + 10 \cdot t)} \quad or \quad n_{\varphi,d,\varepsilon} = \frac{W_{1,d,\varepsilon}}{4 \cdot (b_1 + 10 \cdot t)} \tag{194}$$

c) The maximum circumferential unit load at horn ($n_{\Phi 6}$), which is compressive, is given by:

1) when L ≥ 4·D

$$n_{\varphi 6,d,R} = -n_{\varphi,d,R} - n_{\varphi 1b,d,R} \quad or \quad n_{\varphi 6,d,\varepsilon} = -n_{\varphi,d,\varepsilon} - n_{\varphi 1b,d,\varepsilon} \tag{195}$$

2) and when L < 4·D

$$n_{\varphi 6,d,R} = -n_{\varphi,d,R} - n_{\varphi 2b,d,R} \quad or \quad n_{\varphi 6,d,\varepsilon} = -n_{\varphi,d,\varepsilon} - n_{\varphi 2b,d,\varepsilon} \tag{196}$$

10.10.4.3 Shell stiffened with rings in plane of the saddles

10.10.4.3.1 Cross section values of the rings

A typical stiffening ring is shown in Figure 43.

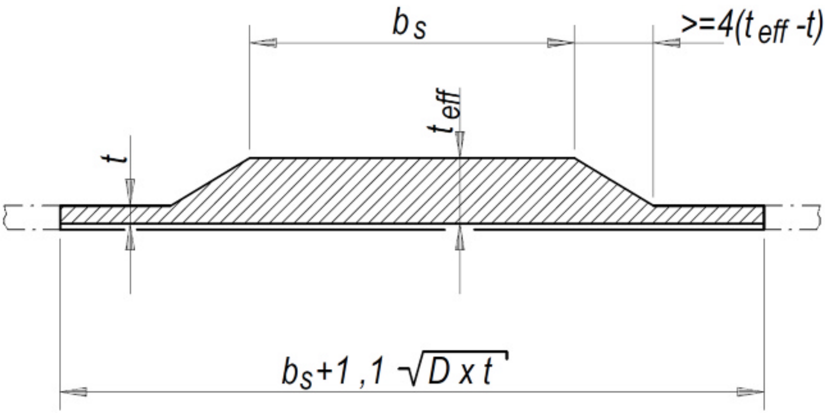


Figure 43 — Typical stiffening ring

The cross section values of typical rings are determined as follows.

$$y = \frac{\sum (A_i \cdot E_\mathbf{i} \cdot y_i)}{\sum (A_i \cdot E_\mathbf{i})} \tag{197}$$

$$A_\mathrm{S} = \frac{\sum (A_i \cdot E_\mathbf{i})}{E_\mathbf{s}}; \tag{198}$$

$$I_\mathrm{S} = \frac{\sum (I_\mathbf{i} \cdot E_\mathbf{i})}{E_\mathbf{s}}; \tag{199}$$

$$W_S = \frac{I_S}{y} \qquad (200)$$

$$t_{\mathbf{eff,N}} = \frac{A_S}{b_S} \qquad (201)$$

$$t_{\mathbf{eff,B}} = \sqrt{\frac{6 \cdot W_S}{b_S}} \qquad (202)$$

where

E_s is the modulus of the stiffener ring material;

b_s is the width of the stiffener ring and shall have a minimum width of 200 mm;

I_S is the second moment of inertia of the stiffener ring plus effective width of the shell $b_s + 1{,}1 \cdot \sqrt{D \cdot t}$ for standard saddle systems;

A_S is the cross section area of the stiffener ring plus effective width of the shell $b_s + 1{,}1 \cdot \sqrt{D \cdot t}$ for standard saddle systems;

y is the distance from the neutral axis to the outside line of the stiffener;

W_S is the section modulus of the stiffener ring plus effective width of the shell $b_s + 1{,}1 \cdot \sqrt{D \cdot t}$ for standard saddle systems;

$t_{eff,N}$ is the equivalent thickness for normal forces of a ring with a width b_s and the same cross section values as them of a ring plus effective width of the shell $b_s + 1{,}1 \cdot \sqrt{D \cdot t}$;

$t_{eff,B}$ is the equivalent thickness for bending of a ring with a width b_s and the same cross section values as them of a ring plus effective width of the shell $b_s + 1{,}1 \cdot \sqrt{D \cdot t}$.

10.10.4.3.2 Circumferential unit loads in the ring - Vessels supported on rigid saddles

10.10.4.3.2.1 Loading at nadir of saddle for shell stiffened with rings

$$W_{1,d,R} = W_1 \cdot A_5 \cdot \gamma_{F,w} \qquad or \qquad W_{1,d,\varepsilon} = W_1 \qquad (203)$$

Maximum unit load at nadir:

$$n_{\varphi 5,d,R} = \frac{K_5 \cdot W_{1,d,R}}{b_S} \quad or \quad n_{\varphi 5,d,\varepsilon} = \frac{K_5 \cdot W_{1,d,\varepsilon}}{b_S} \qquad (204)$$

where

K_5 is given in Table 18.

a) For the selected laminate use 9.3.2 to proof the load bearing capacity for the thickness $t_{eff,N}$.

b) Where the saddle and vessel are rigidly fixed together over their total contact surface, the value K_5 used shall be 1/10 of the value given in Table 18.

c) Where loose saddles are used, the full value of K_5 shall be used, or where relevant experimental data are available this can be used.

10.10.4.3.2.2 Loading at horn of saddle for shell stiffened with rings

a) The maximum flexural moment at the stiffener occurs at the saddle horn and is given by:

$$M_{s,d,R} = \frac{K_{6,R} \cdot W_{1,d,R} \cdot D}{2} \quad or \quad M_{s,d,\varepsilon} = \frac{K_{6,R} \cdot W_{1,d,\varepsilon} \cdot D}{2} \tag{205}$$

where

$K_{6,R}$ is given in Table 20.

Table 20 — Design factor $K_{6,R}$ (EN 13445–3)

$\frac{2 \cdot A}{D}$	Θ				
	120°	135°	150°	165°	180°
< 0,5	0,0158	0,0124	0,0095	0,0072	0,0050
≥ 1,0	0,0317	0,0248	0,0190	0,0143	0,0099

The variation $0{,}5 < \frac{2 \cdot A}{D} < 1{,}0$ is assumed linear and other values for $K_{6,R}$ can be obtained by linear interpolation.

b) Compressive unit load in normal load at saddle horn:

The direct component of the circumferential unit load at the horn is given by:

$$N_{s,d,R} = K_9 \cdot W_{1,d,R} \quad or \quad N_{s,d,\varepsilon} = K_9 \cdot W_{1,d,\varepsilon}$$

where

K_9 is given in Table 21.

Table 21 — Design factor K_9 (EN 13445–3)

Θ	120°	135°	150°	165°	180°
K_9	0,34	0,33	0,30	0,28	0,25

c) The maximum unit load in the stiffener ring is given by

$$n_{\mathbf{s,d,R}} = \pm \frac{M_{\mathbf{s,d,R}}}{W_{\mathbf{s}}} \cdot t_{\mathbf{eff,B}} - \frac{N_{\mathbf{s,d,R}}}{b_{\mathbf{s}}} \quad or \quad n_{\mathbf{s,d},\varepsilon} = \pm \frac{M_{\mathbf{s,d},\varepsilon}}{W_{\mathbf{s}}} \cdot t_{\mathbf{eff,B}} - \frac{N_{\mathbf{s,d},\varepsilon}}{b_{\mathbf{s}}} \tag{206}$$

For W_s, b_s and t_{eff} refer to 10.10.4.3.1.

Use 9.3.2 for the selected laminate to proof the load bearing capacity of the thickness $t_{eff,B}$.

10.10.4.3.3 Circumferential unit loads in the ring - Vessels supported on flexible supports or slings

10.10.4.3.3.1 General

The design of a vessel on two soft saddles in this section means that the vessel is supported using a flexible steel saddle-band which envelopes the vessel for 180° and is fixed to a stiff steel construction, and is based upon the work reported in [3] of the Bibliography.

10.10.4.3.3.2 Design of the stiffener rings at the saddle positions

a) Standard case, rings are arranged in the cylindrical shell:

The unit loads in the stiffener ring are given as follows:

Moment M_s in the stiffener ring is given by:

$$M_{\mathbf{s,d,R}} = \frac{K_{11} \cdot W_1 \cdot D_\mathbf{s} \cdot A_5 \cdot \gamma_{F,w}}{2 \cdot \pi} \quad or \quad M_{\mathbf{s,d},\varepsilon} = \frac{K_{11} \cdot W_1 \cdot D_\mathbf{s}}{2 \cdot \pi} \tag{207}$$

K_{11} is given in Table 22 and K_{10} in Formula (214).

Table 22 — Design factor K_{11} [17]

shell-parameter	**soft saddle** K_{11}
$K_{10} \leq 0{,}1$	0,012 5
$0{,}1 \leq K_{10} \leq 10$	$0{,}017\,5 \times \log(K_{10}) + 0{,}03$
$K_{10} \geq 10$	0,047 5

Normal load N_s in the stiffener ring is given by:

$$N_{\mathbf{s,d,R}} = \frac{W_1 \cdot A_5 \cdot \gamma_{F,w1}}{4} \quad or \quad N_{\mathbf{s,d},\varepsilon} = \frac{W_1}{4} \tag{208}$$

and the maximum unit load in the stiffener ring is given by:

$$n_{\mathbf{s,d,R}} = \pm \frac{M_{\mathbf{s,d,R}}}{W_\mathbf{s}} \cdot t_{\mathbf{eff,B}} - \frac{N_{\mathbf{s,d,R}}}{b_\mathbf{s}} \quad or \quad n_{\mathbf{s,d},\varepsilon} = \pm \frac{M_{\mathbf{s,d},\varepsilon}}{W_\mathbf{s}} \cdot t_{\mathbf{eff,B}} - \frac{N_{\mathbf{s,d},\varepsilon}}{b_\mathbf{s}} \tag{209}$$

For W_s, b_s and t_{eff} refer to 10.10.4.3.1.

b) Special case, rings are arranged at dome end position:

Dimensions in millimetres

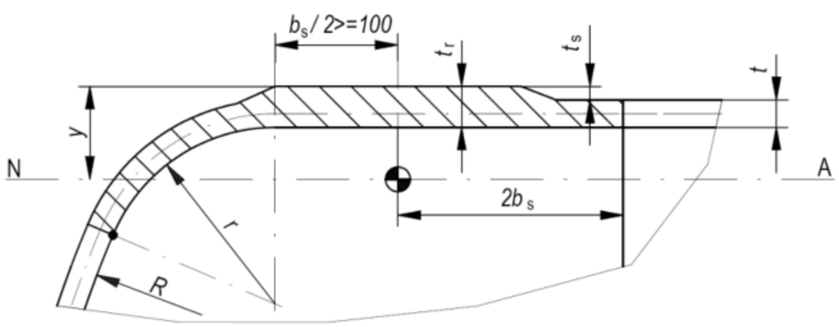


Figure 44 — Effective dimension of the stiffener at the dome end position

The axial load $n_{x,d,R}$ in the ring is determined by:

$$n_{\mathbf{xR,d,R}} = \frac{0{,}53 \cdot W_1 \cdot A_5 \cdot \gamma_{F,w}}{t_R^{1{,}5} \cdot D^{0{,}5}} \quad or \quad n_{\mathbf{xR,d},\varepsilon} = \frac{0{,}53 \cdot W_1}{t_R^{1{,}5} \cdot D^{0{,}5}} \tag{210}$$

where

t_R is the ring thickness and equals $t + t_s$.

For the selected laminate use 9.3.2 to proof the load bearing capacity.

10.10.4.3.4 Localized effects at saddle or stiffener ring positions due to pressure

In the transition areas at the stiffener ring to cylinder attachment the following additional unit loads occur in the axial direction due to the internal pressure and are given by the following formula:

$$\Delta n_{x,p,d,R} = 0{,}48 \cdot p_{d,R} \cdot D \quad or \quad \Delta n_{x,p,d,\varepsilon} = 0{,}48 \cdot p_{d,\varepsilon} \cdot D \tag{211}$$

where

$$p_{d,R} = PS_{op} \cdot A_5 \cdot \gamma_{F,p} + \rho \cdot g \cdot D \cdot A_5 \cdot \gamma_{F,w} \quad or \quad p_{d,\varepsilon} = PS_{op} + \rho \cdot g \cdot D$$

and from the direct bearing of the vessel on the support, an additional unit load in the axial direction arises and is given by the following formula:

$$\Delta n_{x,1,d,R} = \frac{1{,}10 \cdot K_{12} \cdot Q_{d,R}}{t} \quad or \quad \Delta n_{x,1,d,\varepsilon} = \frac{1{,}10 \cdot K_{12} \cdot Q_{d,\varepsilon}}{t} \tag{212}$$

where

Q_d is the maximum shear load at the support

$$K_{12} = \frac{(1 - \log K_{10})^3}{640} \tag{213}$$

and

$$K_{10} = 3{,}4 \cdot \frac{I_{\mathbf{R}}}{t_{\mathbf{R}}^3} \cdot \sqrt{\frac{t}{D_{\mathbf{S}}^3}} \tag{214}$$

where

I_R is the second moment of area of the stiffener ring;

D_S mean diameter of stiffener ring;

t_R total thickness (shell + reinforcement) at support;

t thickness of shell.

10.10.5 Unit loads for horizontal loads at the vessel

For horizontal loads, such as wind or earthquake, acting on a horizontal vessel, the formulae for the unit loads from 10.10.3.2 shall apply accordingly. w shall be replaced by w_h. All other loads are contained in the above formulae.

$$w_h = \frac{W_{h,totalload}}{L + \frac{4 \cdot h}{3}} \tag{215}$$

For more than two saddles the moment should be:

$$w_h = \frac{W_{h,totalload}}{L + \frac{4 \cdot h}{3}} \tag{216}$$

If the loads can operate simultaneously, the respective unit loads shall be superimposed in the axial direction as follows:

$$n_x = \sqrt{{n_{x,v}}^2 + {n_{x,h}}^2} \tag{217}$$

If horizontal loads are working, for example by wind or earthquake, ring-stiffeners are necessary. The maximum flexural moment at the stiffener occurs near to the saddle horn.

The most unfavourable loading case at the saddle position shall be used designing the saddle area.

The load at the saddle for vessels supported on two saddles is given by the following formula:

$$W_h = \frac{W_\mathbf{t}}{2} \tag{218}$$

and when supported on more than two saddles, the load is given by a continuous beam analysis, however for the ring design, a more conservative value of saddle load is taken, which is given by:

$$W_h = \frac{W_\mathbf{t}}{n-1} \tag{219}$$

where

n is the number of saddles.

For the moment in the ring stiffener, see EN 13445-3:2014, 16.9, Horizontal vessels on ring supports,

$$M_{h,d,R} = \frac{K_h \cdot W_{h,d,R} \cdot D}{2} \quad or \quad M_{h,d,\varepsilon} = \frac{K_h \cdot W_{h,d,\varepsilon} \cdot D}{2} \tag{220}$$

where

K_h is given in Table 23 and

$$W_{h,d,R} = W_h \cdot A_5 \cdot \gamma_{F,w} \qquad or \qquad W_{h,d,\varepsilon} = W_h \tag{221}$$

Table 23 — Design factor K_h [17]

Θ	120°	135°	150°	165°	180°
K_h	0,1010	0,0824	0,0666	0,0532	0,0418

If the loads can operate simultaneously, the respective moments at the ring stiffener shall be superimposed as follows:

$$M_{ring} = M_s + 0{,}5 \cdot M_h \tag{222}$$

10.11 Large diameter pipes and pipe fittings

10.11.1 General

This standard covers large diameter piping (DN > 600) bonded directly to the shell of tanks and vessels up to the point of connection to pipework. For pressure pipes in the plants or between individual vessels, especially for elbows and tees, some special considerations are required. This applies to both design and the execution of the laminates.

10.11.2 Joints

The joints are designed as "butt and wrap" joints with laminates one both sites or as a tapered "butt and wrap" connections. A tapered overlap connection is better than a one-sided "butt and wrap", since the additional stresses are negligibly small due to the centricity of the connection laminate. A "butt and wrap" can give considerable additional stresses at the joint laminate. To minimize this, the laminate should be applied symmetrically as an inner and an outer joint laminate.

a) Internal pressure:

Axial unit load $n_{x,p,d,R} = \frac{p_{d,R} \cdot D}{4}$ *or* $n_{x,p,d,\varepsilon} = \frac{p_{\mathbf{d},\varepsilon} \cdot D}{4}$ (223)

where

$$p_{d,R} = PS_{op} \cdot A_{5,i} \cdot \gamma_{F,p}$$

respectively $p_{d,\varepsilon} = PS_{op}$

b) Flexural moment due to content, wind, snow or seismic loads (determined to an applicable local code):

Axial unit load $n_{\mathbf{x,M,d,R}} = \frac{4 \cdot M_{\mathbf{d,R}}}{\pi \cdot D^2}$ *or* $n_{\mathbf{x,M,d},\varepsilon} = \frac{4 \cdot M_{\mathbf{d},\varepsilon}}{\pi \cdot D^2}$ *or* $n_{\mathbf{x,M,d,cr}} = \frac{4 \cdot M_{\mathbf{d,cr}}}{\pi \cdot D^2}$ (224)

where

$$M_{d,R} = M_{content} \cdot A_{5,i} \cdot \gamma_{F,w} + \sum \left(M_{e,i} \cdot A_{5,i} \cdot \gamma_{F,i} \right)$$

respectively $M_{d,\varepsilon} = M_{content} + \sum M_{e,i}$

For axial stability $M_{d,cr} = M_{content} \cdot \sqrt{A_{5,i}} \cdot \gamma_{F,f} + \sum \left(M_{e,i} \cdot \sqrt{A_{5,i}} \cdot \gamma_{F,i} \right)$

where

$M_{e,i}$ = any other flexural moment and

$M_{content}$ = Moment due to content.

For joint laminate:

tension: $n_{joint,d,R} = n_{x,p,d,R} + n_{x,M,d,R}$ (225)

strain: $n_{joint,d,\varepsilon} = n_{x,p,d,\varepsilon} + n_{x,M,d,\varepsilon}$ (226)

For the selected laminate use 9.3.2 to proof the axial load bearing capacity.

The lap shear load in the joint is given by Formula (227):

$\tau_{\mathbf{over,d}} = \frac{n_{\mathbf{joint,d,R}}}{\ell_{\mathbf{over}}}$ and $\tau_{\mathbf{over,d}} \leq \frac{\tau_k}{(\gamma_M \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4)}$ (227)

and

$$\ell_{\mathbf{over}} \leq 16 \cdot t_{\mathbf{over}} \tag{228}$$

where

l_{over} is the length with tapered end.

10.11.3 Elbows

The elbows may be smooth or mitred. Depending on the chosen design or manufacturing method different stresses occur and the unit loads in the elbows shall be multiplied with a stress factor. The factors for the internal pressure are listed below. For bending loads, EN ISO 14692-3:2002, Annex D shall be used.

The following factors shall be applied, if the bend radius is 1,5·DN:

elbow angle		smooth	mitred (30° single mitre)	
			hoop pipe	axial for joint laminate
≤ 30°	m_{psb}	1,0	1,0	1,0
≤ 90°	m_{psb}	1,0	1,3	1,15

Pressure:

circumference unit load only for the pipe:

$$n_{\varphi,p,d,R} = m_{psb} \cdot \frac{p_{d,R} \cdot (D+t)}{2} \quad or \quad n_{\varphi,p,d,\varepsilon} = m_{psb} \cdot \frac{p_{\mathbf{d},\varepsilon} \cdot (D+t)}{2} \tag{229}$$

where

$$p_{d,R} = PS_{op} \cdot A_{5,i} \cdot \gamma_{F,p}$$

respectively $p_{d,\varepsilon} = PS_{op}$

axial unit load for the joint laminate:

$$n_{joint,d,R} = m_{psb} \cdot \frac{p_{d,R} \cdot (D+t)}{4} \quad or \quad n_{joint,p,d,\varepsilon} = m_{psb} \cdot \frac{p_{\mathbf{d},\varepsilon} \cdot (D+t)}{4} \tag{230}$$

For the selected laminate use 9.3.2 to proof the load bearing capacity.

The laminates shall be divided equally between the interior and exterior surface of the pipe. The minimum number of layers shall be more than 3 × 450 g/m².

The lap shear load in the joint is given by:

$$\tau_{\mathbf{over,d}} = \frac{n_{\mathbf{joint,d,R}}}{l_{\mathbf{over}}} \quad \text{and} \quad \tau_{\mathbf{over,d}} \leq \frac{\tau_k}{(\gamma_M \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4)} \tag{231}$$

and

$$l_{\mathbf{over}} \leq 16 \cdot t_{\mathbf{over}} \tag{232}$$

10.11.4 Large cut-outs and Tees

Analysis of the stresses and their directions in a tee is quite complex. EN ISO 14692-3:2002, Annex D and data from experiments are used. Only the influence of the internal pressure is given, if additional loads from moments are applied to the tee EN ISO 14692-3:2002, Annex D shall be used. The computational procedure below is valid only if $D_b \geq 0{,}5 \cdot D_i$. For the smaller T-pieces and cut-outs use 10.8.3.

For tees with $D_b \geq 0{,}5 \cdot D_i$ the thickness of the main pipe shall be calculated with $m_{ps} \geq 1{,}5$.

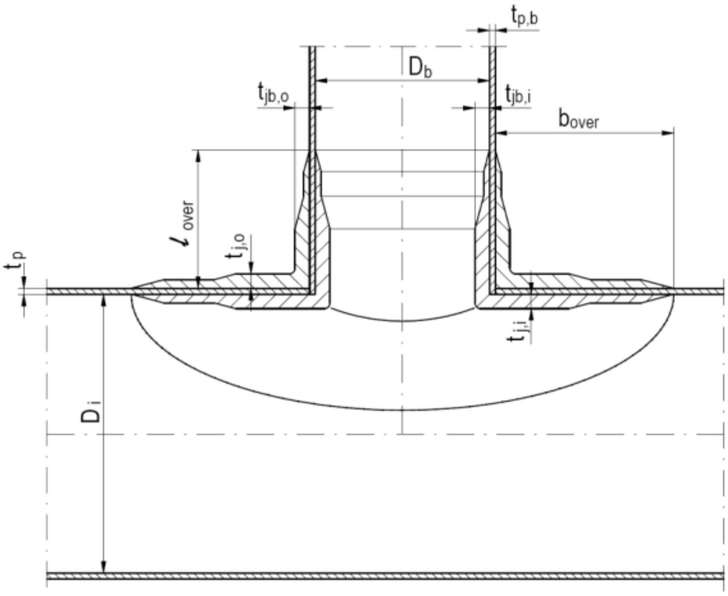


Figure 45 — T-piece

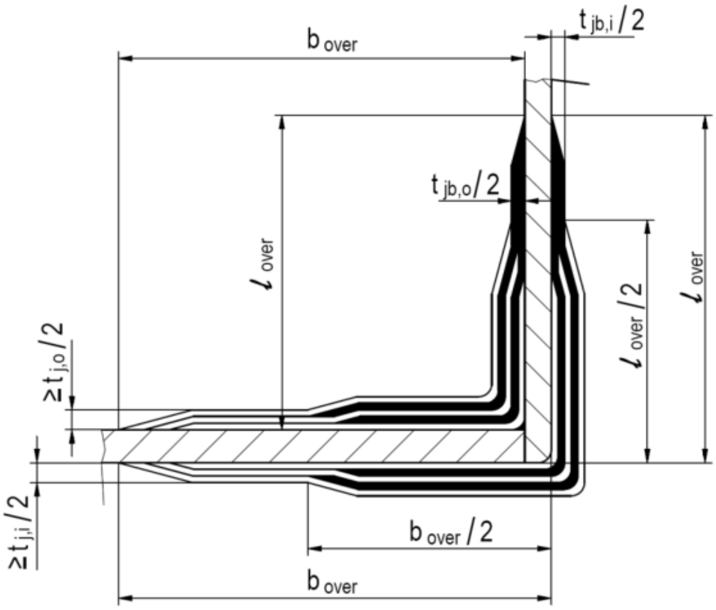


Figure 46 — Detail of the T-piece joint lamination

Circumference unit load:

$$n_{\varphi,p,d,R} = m_{ps} \cdot \frac{p_{d,R} \cdot (D_i + t_p)}{2} \quad or \quad n_{\varphi,p,d,\varepsilon} = m_{ps} \cdot \frac{p_{\mathbf{d},\varepsilon} \cdot (D_i + t_p)}{2} \tag{233}$$

where

$$p_{d,R} = PS_{op} \cdot A_{5,i} \cdot \gamma_{F,p}$$

respectively $p_{d,\varepsilon} = PS_{op}$

axial unit load $$n_{x,p,d,R} = m_{ps} \cdot \frac{p_{d,R} \cdot (D_i + t_p)}{4} \quad or \quad n_{x,p,d,\varepsilon} = m_{ps} \cdot \frac{p_{\mathbf{d},\varepsilon} \cdot (D_i + t_p)}{4} \tag{234}$$

For the selected laminate use 9.3.2 to proof the load bearing capacity.

The pressure stress multiplier for the reinforced laminates, m_{pst}, is given as a function of the pipe factor λ_t:

$$m_{pst} = \frac{1{,}4}{(\lambda_t)^{0{,}25}} \leq 3 \tag{235}$$

and

$$\lambda_t = \frac{\left(2 \cdot \frac{t_{br}}{D_b}\right)^2}{2 \cdot \frac{t_t}{D_i}} \tag{236}$$

where

D_i is the inner diameter of the main pipe

t_t $= (t_p \cdot E_{pipe,\phi} + t_{joint} \cdot E_{jointlam}) / E_{jointlam}$; ($t_{joint} = t_{j,i} + t_{j.o}$ at the main pipe)

$= (U_{lam,pipe,\phi} + U_{lam,jointlam}) / E_{jointlam}$

D_b is the inner diameter of the branch of the tee

t_{br} $= (t_{p,b} \cdot E_{branch,\phi} + t_{joint,b} \cdot E_{jointlam}) / E_{jointlam}$; ($t_{joint,b} = t_{jb,i} + t_{jb,o}$ at the branch)

$= (U_{lam,branch,\phi} + U_{lam,jointlam}) / E_{jointlam}$

with subscripts:

pipe,ϕ is the main pipe in circumferential direction

branch,ϕ is the branch pipe in circumferential direction

jointlam is the joint laminate

ATTENTION — The proof below is valid only if the overlay laminate is equal inside and outside, $t_{joint,inside} = t_{joint,outside}$.

Pressure:

unit load for the joint lamination of the main pipe for $t_{joint} = t_{j,i} + t_{j,o}$ at the main pipe

$$n_{p,d,R} = m_{pst} \cdot \frac{p_{d,R} \cdot (D_i + t_t)}{2} \quad or \quad n_{p,d,\varepsilon} = m_{pst} \cdot \frac{p_{\mathbf{d},\varepsilon} \cdot (D_i + t_t)}{2} \tag{237}$$

where

$$p_{d,R} = PS_{op} \cdot A_{5,i} \cdot \gamma_{F,p}$$

respectively $p_{d,\varepsilon} = PS_{op}$

For the selected joint laminate, t_{joint}, use 9.3.2 to proof the load bearing capacity.

The width of the additional laminate at the main pipe is including the tapered end

$$b_{\mathbf{over}} \leq \sqrt{(D_i + t_t) \cdot t_t} \tag{238}$$

unit load for the joint lamination to the branch of the tee, $t_{joint,b} = t_{jb,i+}\ t_{jb,o}$ at the branch,

$$n_{p,d,R} = \frac{p_{d,R} \cdot (D_b + t_{br})}{2} \quad or \quad n_{p,d,\varepsilon} = \frac{p_{\mathbf{d},\varepsilon} \cdot (D_b + t_{br})}{2} \tag{239}$$

where

$$p_{d,R} = PS_{op} \cdot A_{5,i} \cdot \gamma_{F,p}$$

respectively $p_{d,\varepsilon} = PS_{op}$

For the selected joint laminate, $t_{joint,b}$, use 9.3.2 to proof the load bearing capacity.

The limit strains at the reinforcement laminate are shown in Table 9.

The length of the joint lamination at the branch of the tee is with tapered end

$$l_{\mathbf{over}} \leq \sqrt{D_b \cdot t_{jb,i}} \quad or \quad = \sqrt{D_b \cdot t_{jb,o}} \tag{240}$$

The laminates can be stepped on its width and length in two different thicknesses, $l_{over}/2$ and $b_{over}/2$. All ends of lamination shall be tapered.

All laminates used to connect the branch pipe shall continue out on the main pipe.

11 Bolted flange connections

11.1 General

Standard flanged connections shall be used wherever possible and these are basically designated as

Type 1, Full face flanges with or without a backing ring;

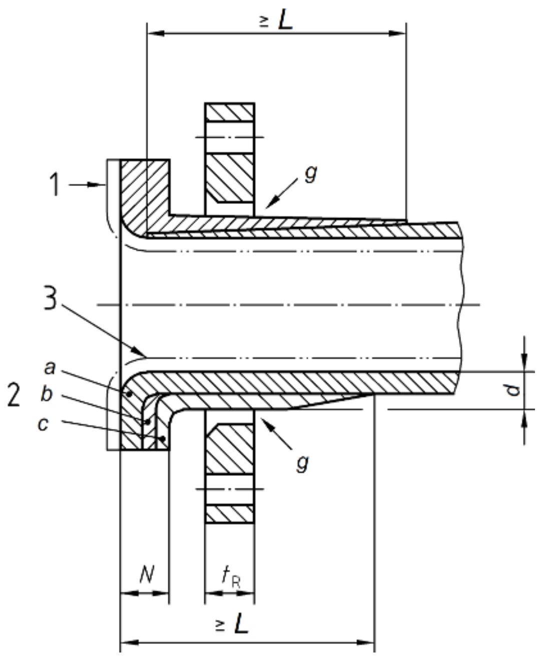
Type 2, Stub flanges complete with backing rings (metallic or GRP).

The basic design requirements of these flanges are given in 11.2 and Figures 48 and 49 for type 1 flanges and in 11.3 and Figure 47 for type 2 flanges. The requirements for the important feature of the chemical barrier for the flanges are given in Figure 49 and Figure 50.

The relevant flange or stub thickness requirements of these classifications are for a design strain level of ε_d = 0,25 %.

Where standard flanges cannot be used, the flange shall be designed in accordance with the requirements of 11.2, 11.3 and 11.4 where applicable.

Where pre-moulded flanges are used of the type shown schematically in Figure 52, they shall be designed and manufactured to the performance requirements.



Key

1 performed stub or full face flange

2 integrally moulded stub or full face flange

3 weld all liners

Branches without a backing ring:

a pipe wall reinforcement continuing into flange face

b additional glass fibre reinforcement to give flange thickness, to be tapered onto the hub

c final overlay of 1,2 kg/m² CSM across flange into hub

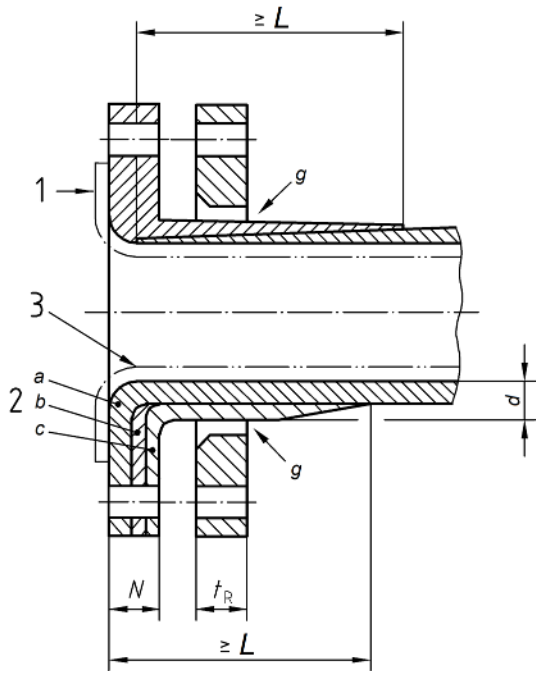
d hub thickness which is to extend for a minimum distance of (N+6xt) along the branch or shell

e When an optional steel backing flange is used, thickness shall be not less than 6 mm.

f all radii minimum 3 mm

g The clearance between the bore of backing flange and the outside diameter of the hub should be as small as practicable.

Figure 47 — Integral stub and backing ring



Key

1 performed stub or full face flange

2 integrally moulded stub or full face flange

3 weld all liners

Branches without a backing ring:

a pipe wall reinforcement continuing into flange face

b additional glass fibre reinforcement to give flange thickness, to be tapered onto the hub

c final overlay of 1,2 kg/m2 CSM across flange into hub

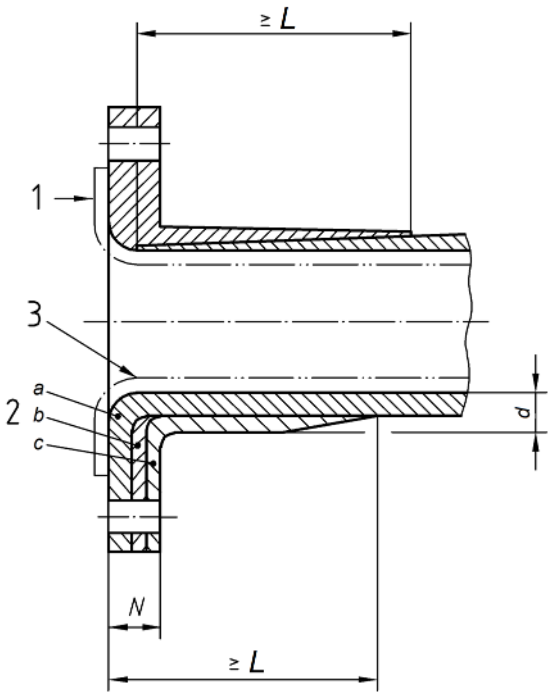
d hub thickness which is to extend for a minimum distance of (N+6xt) along the branch or shell

e When an optional steel backing flange is used, thickness shall be not less than 6 mm.

f all radii minimum 3 mm

g The clearance between the bore of backing flange and the outside diameter of the hub should be as small as practicable.

Figure 48 — Full face flange and backing ring



Key

1 performed stub or full face flange

2 integrally moulded stub or full face flange

3 weld all liners

Branches without a backing ring:

a pipe wall reinforcement continuing into flange face

b additional glass fibre reinforcement to give flange thickness, to be tapered onto the hub

c final overlay of 1,2 kg/m² CSM across flange into hub

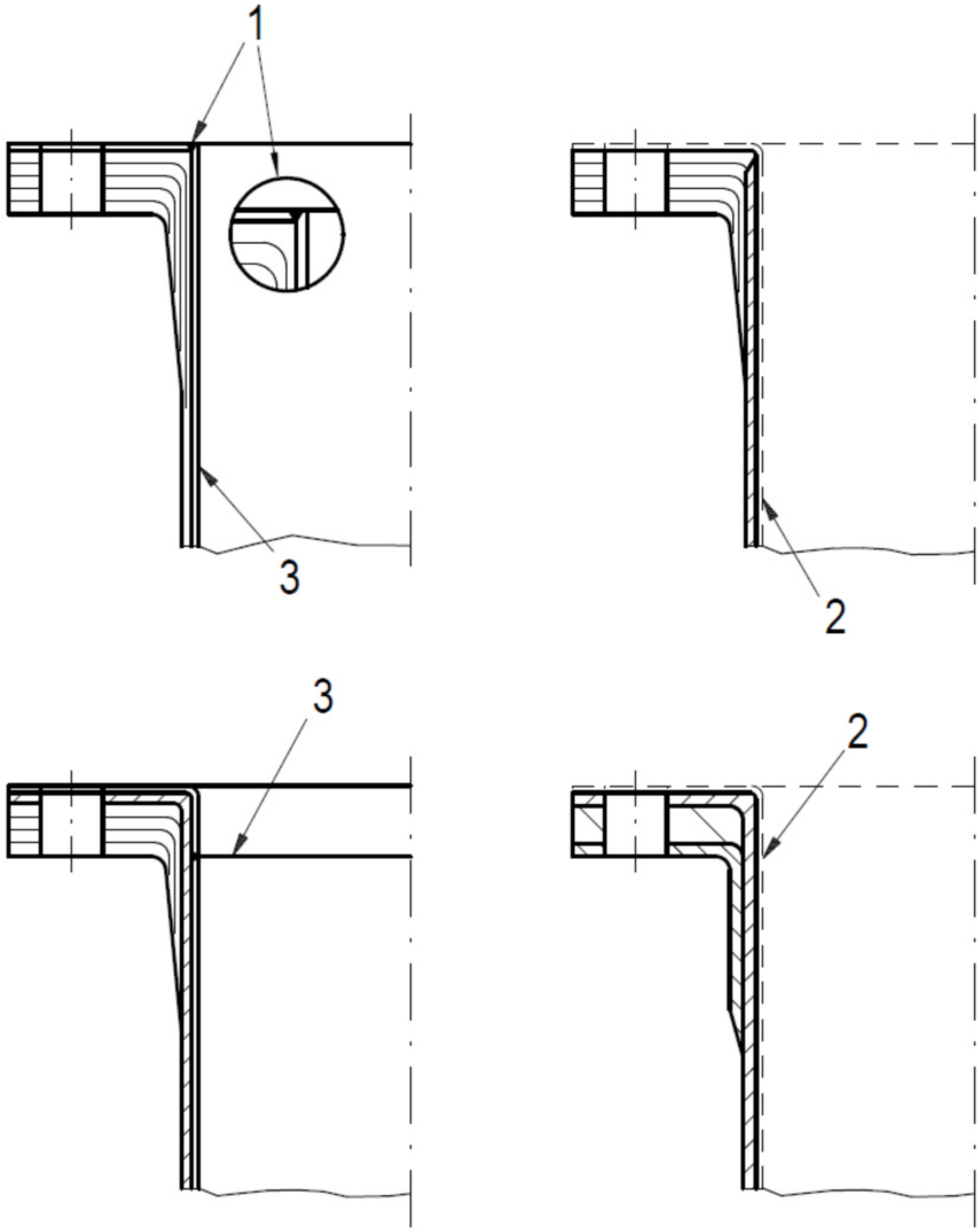
d hub thickness which is to extend for a minimum distance of (N+6xt) along the branch or shell

e When an optional steel backing flange is used, thickness shall be not less than 6 mm.

f All radii minimum 3 mm

g The clearance between the bore of backing flange and the outside diameter of the hub should be as small as practicable.

Figure 49 — Full face flange without backing ring



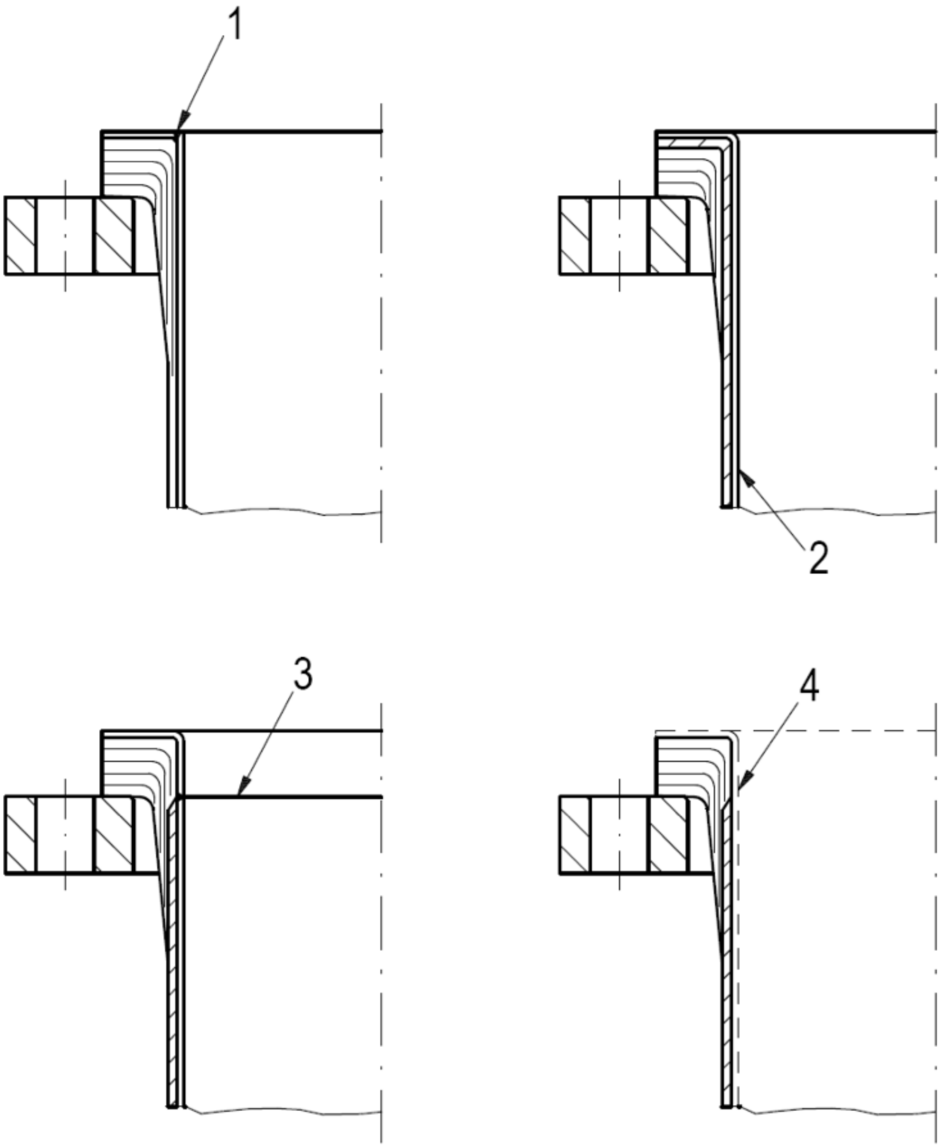
Key

1 normal liner weld position for all materials

2 corrosion barrier continuous over flange

3 weld line position for all materials if the liner should formed over flange (necked from a plate)

Figure 50 — Full face flange requirements for thermoplastics or corrosion barrier



Key

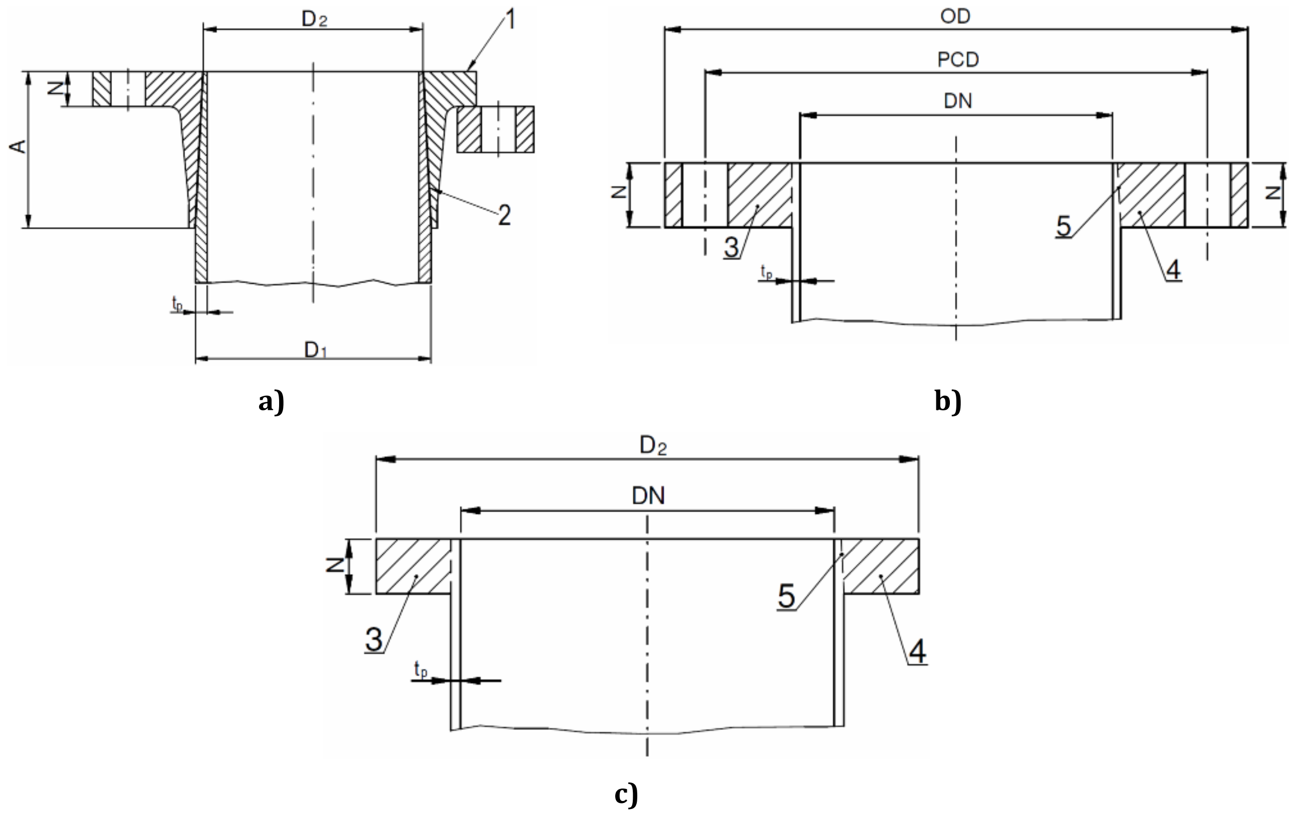
1 normal liner weld position for all materials

2 liner formed over stub flange for flanges with a diameter less than 300 mm

3 weld line position for all materials if the liner should formed over flange (necked from a plate)

4 corrosion barrier continuous over stub flange

Figure 51 — Stub flanges requirements for thermoplastics liner and corrosion barrier



Key

1 pre-moulded flange

2 $\frac{D_1}{D_2} \geq 1{,}05$ *and* $A \geq L$ where L = Flange hub length

3 flange or stub end wound directly to the pipe

4 wound flange or stub end glued to the pipe

5 pasted seam tapered 2° (thickness ≥ 0,5 mm but ≤ 2 mm)

Figure 52 — Pre-moulded and wound flanges

11.2 Full face flanges design

11.2.1 General

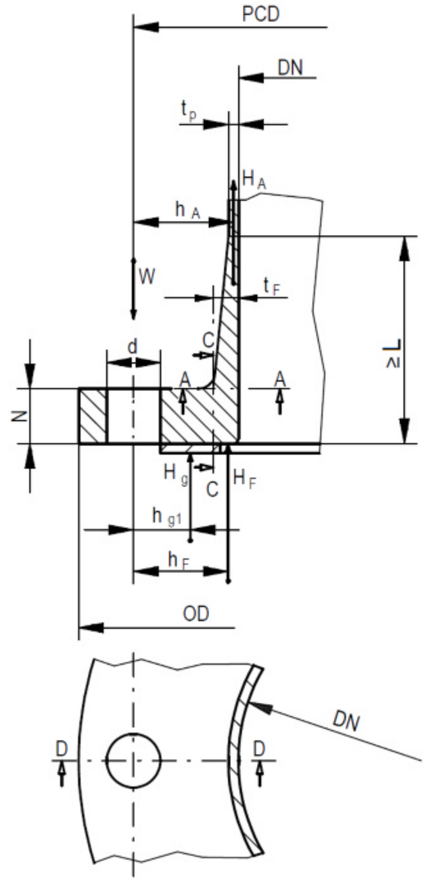
Two conditions shall be considered:

a) bolting up condition;

b) operating condition.

In all cases the flange materials of construction shall be of adequate crushing strength to resist the applied bolt and joint loads.

Only rubber gaskets without fabric or fibre fillers of 50 IRHD to 65 IRHD and above, measured in accordance with test method D.16 shall be used. Gaskets with low bearing pressure to prefer, for example flat-gaskets with O-ring.



Key

Levers:

$$h_A = \frac{PCD - DN - t_P}{2} \qquad h_F = \frac{2 \cdot PCD - DN - \mathrm{D_G}}{4}$$

$$h_{g1} = \frac{PCD - \mathrm{D_G}}{2}$$

Figure 53 — Full face flange

11.2.2 Symbols

A_b Actual single bolt area

A_G Effective gasket area; may be determined by using EN 1591

d^* Diameter of bolt holes for calculation purpose; d* = $\begin{cases} 2 \cdot d \cdot \left(1 - \frac{DN}{1000mm}\right), DN < 500mm \\ d\ ,\ \mathrm{DN} \geq 500\mathrm{mm} \end{cases}$

d_{Bolt} Bolt diameter

d_C Diameter of cross section centroid

D_1 Inside diameter of the backing ring

D_2 Outside diameter of the stub flange

D_G Average diameter of gasket

DN Inside diameter of flange

E	The laminates bending modulus of elasticity in circumferential direction
$f_{m,k}$	Characteristic bending strength for the corresponding laminate
$f_{\mathrm{i,k}}$	Characteristic strength of a material
$f_{\mathrm{s,k}}$	Characteristic seating strength
$f_{v,k}$	Characteristic shear strength for the corresponding laminate
$f_{v,i,,k}$	Characteristic interlaminar shear strength for the corresponding laminate
$H_{A,d}$	$A_5 \cdot \gamma_F$-fold total axial force; $H_{\mathrm{A,d}} = H_{\mathrm{P,d}} + H_{\mathrm{R,d}}$
$H_{g0,d}$	$A_5 \cdot \gamma_F$-fold compression load on gasket for bolting up conditions
$H_{g1,d}$	$A_5 \cdot \gamma_F$-fold compression load on gasket for operating conditions
$H_{R,d}$	$A_5 \cdot \gamma_F$-fold axial force due to additional forces on the flange (thermal expansion, ground displacement, moments…); $H_{R,d} = \sum \left(H_{R,i} \cdot A_{5,i} \cdot \gamma_{F,i} \right)$
$H_{p,d}$	$A_5 \cdot \gamma_F$-fold axial force due to internal pressure
$H_{F,d}$	$A_5 \cdot \gamma_F$-fold force due to pressure on flange face
h_A	Radial distance from bolt circle to circle on which H_A acts
h_B	Lever between PCD and flange (only for stub flanges)
h_C	Lever between PCD and cross section C-C
h_F	Radial distance from bolt circle to circle on which H_F acts
h_{g1}	Radial distance from bolt circle to circle on which H_{g1} acts
I	Second moment of area
K	Safety factor
L	Flange hub length; $L = N + \sqrt{DN \cdot \left(t_F - t_p \right)}$
M	Carding moment
$M_{0,d}$	$A_5 \cdot \gamma_F$-fold total bending moment for bolting up conditions
$M_{C,d}$	$A_5 \cdot \gamma_F$-fold outer bending moment in cross section C-C
$M_{1,d}$	$A_5 \cdot \gamma_F$-fold total bending moment for operating conditions
N	Stub flange thickness (GRP)
n	Number of bolts
OD	Outside diameter of flange/backing ring
p	Pressure due to flange [$\mathrm{N/mm^2}$]
PCD	Bolt circle diameter
Q_{min}	Minimum required surface pressure on gasket for bolting up conditions (see EN 13555)
$Q_{Smin(L)}$	Minimum required surface pressure on gasket for operating conditions (see EN 13555)
$t*$	Required thickness to compensate $\mathrm{H_A}$; $t^* = \dfrac{H_{A,d}}{\pi \cdot (DN + t_P) \cdot f_{m,k} / \left(\gamma_M \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4 \right)}$
t_f	Thickness of hub at back of flange
t_p	Thickness of hub at small end

t_R Thickness of the steel backing ring, see Table 27

t_S Thickness of the backing flange

Z Section modulus

σ_B Bearing stress

σ_R Backing ring stress

σ_S Seating stress between backing ring and stub flange

$W_{m,d}$ Flange design bolt load, based on actual size bolts used to provide greater of $W_{\mathrm{m1,d}}$ and $W_{\mathrm{m2,d}}$

$W_{m1,d}$ Minimum required bolt load for operating conditions

$W_{mo,d}$ Minimum required bolt load for bolting up conditions

11.2.3 Pipe loads on flanges

For the design the following are defined:

Pressure on flange

$$p_{d,R} = PS_{op} \cdot A_{5,i} \cdot \gamma_{F,p} + p_{hp} \cdot A_{5,i} \cdot \gamma_{F,w}$$

respectively $p_{d,\varepsilon} = PS_{op} + p_{hp}$

Loads due to pressure and additional forces or moments:

$$H_{p,d,R} = p_{d,R} \times \frac{\pi}{4} \times DN^2 \quad or \quad H_{p,d,\varepsilon} = p_{d,\varepsilon} \times \frac{\pi}{4} \times DN^2 \qquad (241)$$

$$H_{R,d,R} = \sum H_{R,i} \cdot A_5 \cdot \gamma_F \quad or \quad H_{R,d,\varepsilon} = \sum H_{R,i} \qquad (242)$$

$H_{R,i}$ = loads from additional axial loads H or moment $H_M = \frac{4 \cdot M}{DN + t_p}$ to flange

$$H_{A,d,R} = H_{p,d,R} + H_{R,d,R} \quad or \quad H_{A,d,\varepsilon} = H_{p,d,\varepsilon} + H_{R,d,\varepsilon} \qquad (243)$$

$$H_{F,d,R} = p_{d,R} \cdot \frac{\pi}{4} \cdot (D_G^2 - DN^2) \quad or \quad H_{F,\varepsilon} = p_{d,\varepsilon} \cdot \frac{\pi}{4} \cdot (D_G^2 - DN^2) \qquad (244)$$

11.2.4 Gasket load and bolt torque

The torque settings are based on a free running well lubricated nut.

The operating and bolting up conditions shall be as follows:

a) Operating conditions:

The gasket load for the operating conditions, $H_{\mathrm{g1,d}}$, shall be determined from the following formula:

$$H_{g1,d,R} = p_{g1} \cdot A_G \cdot A_5 \cdot \gamma_F \cdot D_G \cdot \pi \quad or \quad H_{g1,d,\varepsilon} = p_{g1} \cdot A_G \cdot D_G \cdot \pi \qquad (245)$$

$p_{\mathrm{g1}} = Q_{\mathrm{Smin(L)}}$ compression on gasket for operating condition

b) Bolting up conditions:

The gasket load for bolting up conditions, $H_{g0,d}$, shall be determined from the following formula:

$$H_{g0,d,R} = p_{g0} \cdot A_G \cdot A_5 \cdot \gamma_F \cdot D_G \cdot \pi \qquad or \qquad H_{g0,d,\varepsilon} = p_{g0} \cdot A_G \cdot D_G \cdot \pi \tag{246}$$

p_{g0} = Q_{min} compression on gasket for bolting up condition

$$M_{bolt} = \frac{\mu \cdot H_{g0,d,\varepsilon} \cdot d_{bolt}}{n} \qquad where \quad 0{,}15 \leq \mu \leq 0{,}20 \tag{247}$$

This bolt torque moment M_{bolt} shall be noted on the assembly drawing.

11.2.5 Summary of loads

The operating and bolting up conditions shall be as follows:

a) Operating conditions:

The minimum bolt load for the operating conditions, $W_{m1,d}$, shall be determined from the following formula:

$$W_{m1,d,R} = H_{A,d,R} + H_{F,d,R} + H_{g1,d,R} \ or \ W_{m1,d,\varepsilon} = H_{A,d,\varepsilon} + H_{F,d,\varepsilon} + H_{g1,d,\varepsilon} \tag{248}$$

b) Bolting up conditions:

The minimum total bolt load for gasket seating, $W_{m0,d}$, shall be determined from Formula (249):

$$W_{m0,d,R} \geq H_{R,d,R} + H_{g0,d,R} \qquad or \qquad W_{m0,d,\varepsilon} \geq H_{R,d,\varepsilon} + H_{g0,d,\varepsilon} \tag{249}$$

11.2.6 Total bending moment

The operating and bolting up conditions shall be as follows:

a) Operating conditions:

The total bending moment for the operating conditions, $M_{1,d}$, shall be determined from following formula:

$$M_{1,d,R} = H_{A,d,R} \cdot h_A + H_{F,d,R} \cdot h_F + H_{g1,d,R} \cdot h_{g1} \qquad \text{or} \tag{250}$$

$$M_{1,d,\varepsilon} = H_{A,d,\varepsilon} \cdot h_A + H_{F,d,\varepsilon} \cdot h_F + H_{g1,d,\varepsilon} \cdot h_{g1}$$

b) Bolting up conditions:

The total bending moment for the bolting up conditions, $M_{0,d}$, shall be determined from following formula:

$$M_{0,d,R} = W_{m0,d;R} \cdot h_{g1} \qquad or \qquad M_{0,d,\varepsilon} = W_{m0,d;\varepsilon} \cdot h_{g1} \tag{251}$$

11.2.7 Flange design

There are three cross sections, which shall be proved: The cross section A-A, C-C and D-D in Figure 53. The section modulus of A-A is defined by following formula:

$$Z_{A-A} = \frac{\pi}{6} \cdot \left[\left(OD - DN - d^* \right) \cdot N^2 + \left(DN + t_F \right) \cdot \left(t_F^2 - t^{*2} \right) \right] \quad DN \le 1000\,mm$$

$$Z_{A-A} = \frac{1{,}2 \cdot \pi}{6} \cdot \left[\left(OD - DN - d^* \right) \cdot N^2 + 0{,}8 \cdot \left(DN + t_F \right) \cdot \left(t_F^2 - t^{*^2} \right) + 0{,}1 \cdot t_F \cdot \left(DN + t_F \right) \cdot N \right] \quad DN > 1000\,mm \tag{252}$$

The following formula shall be fulfilled for bolting up and operation conditions:

$$\sigma_{A,d,R} = \frac{M_{i,d,R}}{Z_{A-A}} \quad or \quad \sigma_{A,d,\varepsilon} = \frac{M_{i,d,\varepsilon}}{Z_{A-A}} \tag{253}$$

For the selected laminate use the following formula for bearing capability or strain limit:

$$\frac{\sigma_{A,d,R}}{\dfrac{f_{i,k}}{\gamma_M \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4}} \le 1 \quad \text{respectively} \quad \frac{\sigma_{A,d,\varepsilon}}{E_{i,m}} \le \varepsilon_{\lim} \tag{254}$$

The section modulus of C-C is defined by the following formula:

$$Z_{C-C} = \frac{\pi}{6} \cdot N^2 \cdot (OD - d^*) \tag{255}$$

The bending moments for this section is equal to section A-A:

$$\sigma_{C,d,R} = \frac{M_{i,d,R}}{Z_{C-C}} \quad or \quad \sigma_{C,d,\varepsilon} = \frac{M_{i,d,\varepsilon}}{Z_{C-C}} \tag{256}$$

For the selected laminate use the following formula for bearing capability or strain limit

$$\frac{\sigma_{C,d,R}}{\dfrac{f_{i,k}}{\gamma_M \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4}} \le 1 \quad \text{respectively} \quad \frac{\sigma_{C,d,\varepsilon}}{E_{i,m}} \le \varepsilon_{\lim} \tag{257}$$

The section modulus of D-D is defined by the following formula:

$$Z_{D-D} = 2 \cdot \pi \cdot \frac{\mathrm{I}_{xx}}{y_s} \tag{258}$$

where:

$$\mathrm{I}_{xx} = \frac{N^3 \left(OD - DN \right)}{24} + \frac{N \cdot \left(OD - DN \right) \cdot \left(\dfrac{N}{2} - y_s \right)^2}{2} + \frac{l_F^3 \cdot \left(t_p + t_F \right)}{36} + \frac{l_F \cdot \left(t_p + t_F \right) \cdot \left(\dfrac{l_F}{2} + N - y_s \right)^2}{2}$$

$$y_s = \frac{N^2 \cdot \left(OD - DN \right) + l_F \left(t_p + t_F \right) \cdot \left(l_F + 2 \cdot N \right)}{2 \cdot \left[N \cdot \left(OD - DN \right) + l_F \cdot \left(t_p + t_F \right) \right]}$$

$$l_F = \sqrt{DN \cdot \left(t_p + t_F \right) / 4}$$

The bending moments for this section is equal to formula section A-A:

$$\sigma_{D,d,R} = \frac{M_{i,d,R}}{Z_{D-D}} \quad or \quad \sigma_{D,d,\varepsilon} = \frac{M_{i,d,\varepsilon}}{Z_{D-D}} \tag{259}$$

For the selected laminate use the following formula for bearing capability or strain limit:

$$\frac{\sigma_{D,d,R}}{\dfrac{f_{i,k}}{\gamma_M \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4}} \le 1 \qquad \text{respectively} \qquad \frac{\sigma_{D,d,\varepsilon}}{E_{i,m}} \le \varepsilon_{\text{lim}} \tag{260}$$

For wound or glued flanges or stub ends, Figure 52, following verifications shall be performed:

$$\tau_{d,R} = \frac{W_{i,d,R}}{\pi \times (DN + t_F) \times N}$$

For the glued seam use the following formula for bearing capability:

$$\frac{\tau_{R,d,R}}{\dfrac{\tau_{i,k}}{\gamma_M \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4}} \le 1$$

$\tau_{R,d,R}$ shear strength from ($A_5 \cdot \gamma_{F,I}$) - loads

$\tau_{i,k}$ characteristic shear strength is 7,0 N/mm² for wound flange/stub ends and 5,0 N/mm²for glued flange/stub ends

11.2.8 Flange slope

The flange slope shall be determined from the following formula:

$$\phi = \frac{M \cdot d_C}{2 \cdot E \cdot I_{XX}} \le 1{,}5^\circ \text{ for flanges} \le \text{DN } 1000 \tag{261}$$

where

$$d_c = DN + 2 \cdot x_s \tag{262}$$

$$x_s = \frac{N \cdot (OD - DN)^2 + l_F \cdot (t_p + t_F)^2}{4 \cdot \left[N \cdot (OD - DN) + l_F \cdot (t_p + t_F) \right]}$$

$$M = \frac{H_{A,d,\varepsilon}}{\pi \cdot D} \cdot \frac{(PCD - DN - 2 \cdot x_s)}{2} \cdot \frac{d_c}{2} \tag{263}$$

for flanges > DN 1000 larger deflections can be accepted if tightness is guaranteed.

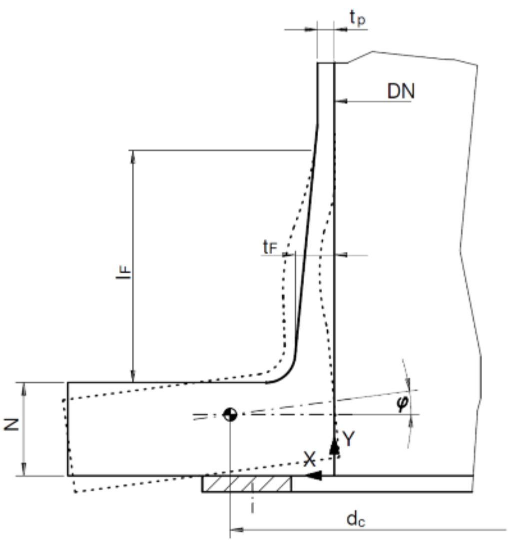
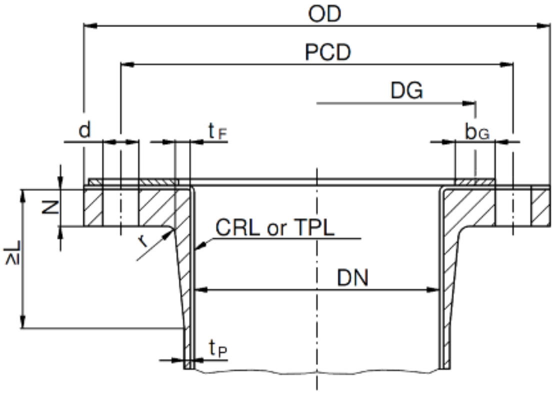


Figure 54 — Flange slope

Table 24 — Full face flange and bolt details

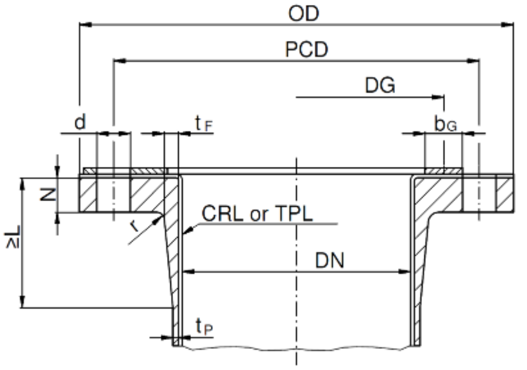


Branch nominal size	thickness N			connection size										
				Classification 150 (ASME B16.5/16.47)						Classification 10 (EN 1092–1 PN 10)				
DN	pressure 10 bar	t_F	t_P	DN	OD	PCD	*d*	Bolts		OD	PCD	*d*	Bolts	
mm	mm	mm	mm	in	mm	mm	mm	No	Size inch	mm	mm	mm	No	Size mm
25	18	9	3	1	110	79,4	16	4	1/2	115	85	14	4	M12
32	18	11	3	1 1/4	115	88,9	16	4	1/2	140	100	18	4	M16
40	18	11	3	1 1/2	125	98,4	16	4	1/2	150	110	18	4	M16
50	18	11	3	2	150	120,7	19	4	5/8	165	125	18	4	M16
65	20	11	3	2 1/2	180	139,7	19	4	5/8	185	145	18	8	M16
80	20	12	3	3	190	152,4	19	4	5/8	200	160	18	8	M16
100	23	12	3	4	230	190,5	19	8	5/8	220	180	18	8	M16
125	26	12	3	5	255	215,9	23	8	3/4	250	210	18	8	M16
150	31	12	3	6	280	241,3	23	8	3/4	285	240	22	8	M20
200	36	15	4	8	345	298,5	23	8	3/4	340	295	22	8	M20
250	44	15	5	10	405	362	26	12	7/8	395	350	22	12	M20
300	50	17	6	12	485	431,8	26	12	7/8	445	400	22	12	M20
350	55	21	7	14	535	476,3	29	12	1	505	460	22	16	M20
400	60	22	8	16	595	539,8	29	16	1	565	515	26	16	M24
450	65	23	9	18	635	577,9	32	16	1 1/8	615	565	26	20	M24
500	70	25	10	20	700	635	32	20	1 1/8	670	620	26	20	M24
600	85	25	12	24	815	749,3	35	20	1 1/4	780	725	30	20	M27
700	100	27	14	28	925	863,6	35	28	1 1/4	895	840	30	24	M27
800	110	32	16	32	1 060	977,9	42	28	1 1/2	1 015	950	33	24	M30
900	120	33	18	36	1 170	1 085,8	42	32	1 1/2	1 115	1 050	33	28	M30
1 000	135	35	20	40	1 290	1 200,2	42	36	1 1/2	1 230	1 160	36	28	M33

NOTE The pressure rating is based on:

1 design stress of flange laminate $f_{m,k}$ / K = 30 N/mm² and pipe laminate 25 N/mm²;
2 the gasket seating stress $Q_{min} \leq 2,5$ N/mm²;
3 maximum of $\varphi = 1,2°$ flange deformation;
4 $r \geq 3$ mm.

Table 25 — Full face flange and bolt details

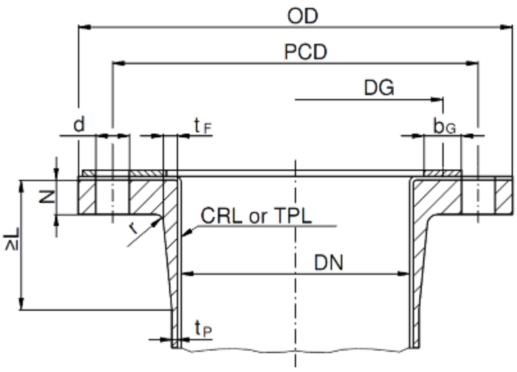


Branch nominal size DN	thickness N pressure 6 bar	t_F	t_P	connection size										
				Classification 150 (ASME B16.5/16.47)						Classification 10 (EN 1092–1 PN 10)				
				DN	OD	PCD	*d*	Bolts		OD	PCD	*d*	Bolts	
mm	mm	mm	mm	in	mm	mm	mm	No	Size inch	mm	mm	mm	No	Size mm
25	14	9	3	1	110	79,4	16	4	1/2	115	85	14	4	M12
32	14	11	3	1 1/4	115	88,9	16	4	1/2	140	100	18	4	M16
40	14	11	3	1 1/2	125	98,4	16	4	1/2	150	110	18	4	M16
50	14	11	3	2	150	120,7	19	4	5/8	165	125	18	4	M16
65	18	11	3	2 1/2	180	139,7	19	4	5/8	185	145	18	8	M16
80	18	12	3	3	190	152,4	19	4	5/8	200	160	18	8	M16
100	20	12	3	4	230	190,5	19	8	5/8	220	180	18	8	M16
125	20	12	3	5	255	215,9	23	8	3/4	250	210	18	8	M16
150	23	12	3	6	280	241,3	23	8	3/4	285	240	22	8	M20
200	26	15	3	8	345	298,5	23	8	3/4	340	295	22	8	M20
250	31	15	3	10	405	362	26	12	7/8	395	350	22	12	M20
300	36	17	3,6	12	485	431,8	26	12	7/8	445	400	22	12	M20
350	41	21	4,2	14	535	476,3	29	12	1	505	460	22	16	M20
400	46	22	4,8	16	595	539,8	29	16	1	565	515	26	16	M24
450	51	23	5,4	18	635	577,9	32	16	1 1/8	615	565	26	20	M24
500	56	25	6	20	700	635	32	20	1 1/8	670	620	26	20	M24
600	65	25	7,2	24	815	749,3	35	20	1 1/4	780	725	30	20	M27
700	76	27	8,4	28	925	863,6	35	28	1 1/4	895	840	30	24	M27
800	85	32	9,6	32	1 060	977,9	42	28	1 1/2	1 015	950	33	24	M30
900	94	33	11	36	1 170	1 085,8	42	32	1 1/2	1 115	1 050	33	28	M30
1 000	105	35	12	40	1 290	1 200,2	42	36	1 1/2	1 230	1 160	36	28	M33

NOTE The pressure rating is based on:

1 design stress of flange laminate $f_{m,k}$ / K = 30 N/mm² and pipe laminate 25 N/mm²;
2 the gasket seating stress Q_{min} ≤ 2,5 N/mm²;
3 maximum of φ = 1,2° flange deformation;
4 r ≥ 3 mm.

Table 26 — Full face flange and bolt details

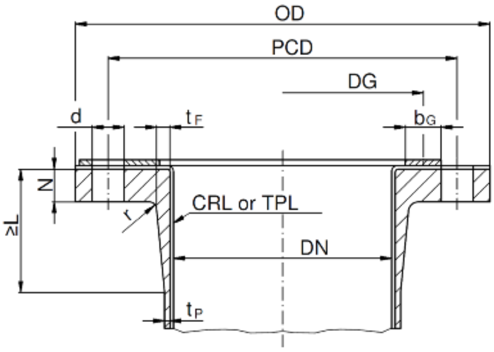


Branch nominal size DN	thickness N pressure 4 bar	t_F	t_P	connection size: Classification 150 (ASME B16.5/16.47) DN	OD	PCD	*d*	Bolts No	Bolts Size	Classification 10 (EN 1092–1 PN 10) OD	PCD	*d*	Bolts No	Bolts Size
mm	mm	mm	mm	in	mm	mm	mm	No	inch	mm	mm	mm	No	mm
25	14	9	3	1	110	79,4	16	4	1/2	115	85	14	4	M12
32	14	11	3	1 1/4	115	88,9	16	4	1/2	140	100	18	4	M16
40	14	11	3	1 1/2	125	98,4	16	4	1/2	150	110	18	4	M16
50	14	11	3	2	150	120,7	19	4	5/8	165	125	18	4	M16
65	16	11	3	2 1/2	180	139,7	19	4	5/8	185	145	18	8	M16
80	16	12	3	3	190	152,4	19	4	5/8	200	160	18	8	M16
100	16	12	3	4	230	190,5	19	8	5/8	220	180	18	8	M16
125	18	12	3	5	255	215,9	23	8	3/4	250	210	18	8	M16
150	18	12	3	6	280	241,3	23	8	3/4	285	240	22	8	M20
200	21	15	3	8	345	298,5	23	8	3/4	340	295	22	8	M20
250	26	15	3	10	405	362	26	12	7/8	395	350	22	12	M20
300	30	17	3	12	485	431,8	26	12	7/8	445	400	22	12	M20
350	35	21	3	14	535	476,3	29	12	1	505	460	22	16	M20
400	39	22	3,2	16	595	539,8	29	16	1	565	515	26	16	M24
450	43	23	3,6	18	635	577,9	32	16	1 1/8	615	565	26	20	M24
500	47	25	4	20	700	635	32	20	1 1/8	670	620	26	20	M24
600	53	25	4,8	24	815	749,3	35	20	1 1/4	780	725	30	20	M27
700	65	27	5,6	28	925	863,6	35	28	1 1/4	895	840	30	24	M27
800	73	32	6,4	32	1 060	977,9	42	28	1 1/2	1 015	950	33	24	M30
900	80	33	7,2	36	1 170	1 085,8	42	32	1 1/2	1 115	1 050	33	28	M30
1 000	90	35	8	40	1 290	1 200,2	42	36	1 1/2	1 230	1 160	36	28	M33

NOTE The pressure rating is based on:

1 design stress of flange laminate $f_{m,k}$ / K = 30 N/mm² and pipe laminate 25 N/mm²;
2 the gasket seating stress $Q_{min} \leq 2{,}5$ N/mm²;
3 maximum of $\varphi = 1{,}2°$ flange deformation;
4 $r \geq 3$ mm.

Table 27 — Full face flange and bolt details

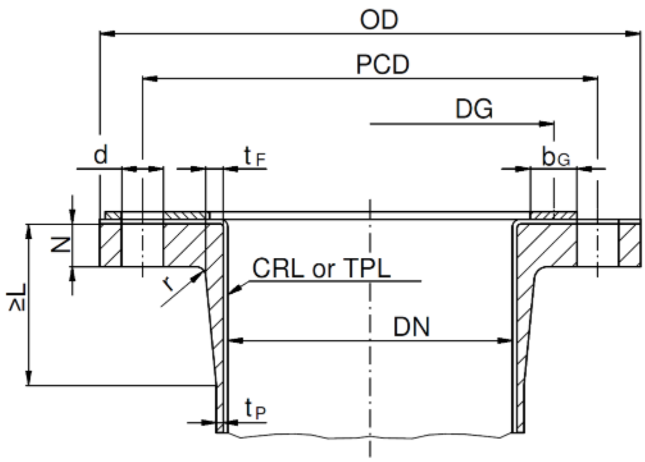


Branch nominal size DN	thickness N pressure 2,5 bar	t_F	t_P	connection size Classification 150 (ASME B16.5/16.47) DN	OD	PCD	*d*	Bolts		Classification 10 (EN 1092–1 PN 10) OD	PCD	*d*	Bolts	
mm	mm	mm	mm	in	mm	mm	mm	No	Size inch	mm	mm	mm	No	Size mm
25	14	9	3	1	110	79,4	16	4	1/2	115	85	14	4	M12
32	14	11	3	1 1/4	115	88,9	16	4	1/2	140	100	18	4	M16
40	14	11	3	1 1/2	125	98,4	16	4	1/2	150	110	18	4	M16
50	14	11	3	2	150	120,7	19	4	5/8	165	125	18	4	M16
65	16	11	3	2 1/2	180	139,7	19	4	5/8	185	145	18	8	M16
80	16	12	3	3	190	152,4	19	4	5/8	200	160	18	8	M16
100	16	12	3	4	230	190,5	19	8	5/8	220	180	18	8	M16
125	18	12	3	5	255	215,9	23	8	3/4	250	210	18	8	M16
150	18	12	3	6	280	241,3	23	8	3/4	285	240	22	8	M20
200	18	15	3	8	345	298,5	23	8	3/4	340	295	22	8	M20
250	22	15	3	10	405	362	26	12	7/8	395	350	22	12	M20
300	26	17	3	12	485	431,8	26	12	7/8	445	400	22	12	M20
350	30	21	3	14	535	476,3	29	12	1	505	460	22	16	M20
400	33	22	3	16	595	539,8	29	16	1	565	515	26	16	M24
450	37	23	3	18	635	577,9	32	16	1 1/8	615	565	26	20	M24
500	41	25	3	20	700	635	32	20	1 1/8	670	620	26	20	M24
600	47	25	3	24	815	749,3	35	20	1 1/4	780	725	30	20	M27
700	55	27	3,5	28	925	863,6	35	28	1 1/4	895	840	30	24	M27
800	62	32	4	32	1 060	977,9	42	28	1 1/2	1 015	950	33	24	M30
900	70	33	4,5	36	1 170	1 085,8	42	32	1 1/2	1 115	1 050	33	28	M30
1 000	78	35	5	40	1 290	1 200,2	42	36	1 1/2	1 230	1 160	36	28	M33

NOTE The pressure rating is based on:

1 the gasket seating stress $Q_{min} \leq 2,5$ N/mm²;
2 design stress of flange laminate $f_{m,k}$ / K = 30 N/mm² and pipe laminate 25 N/mm²;
3 maximum of $\varphi = 1,2°$ flange deformation;
4 $r \geq 3$ mm.

Table 28 — Full face flange and bolt details



Branch nominal size	thickness N			connection size										
				Classification 150 (ASME B16.5/16.47)						Classification 10 (EN 1092–1 PN 10)				
DN	pressure 1 bar	t_F	t_P	DN	OD	PCD	*d*	Bolts		OD	PCD	*d*	Bolts	
									Size					Size
mm	mm	mm	mm	in	mm	mm	mm	No	inch	mm	mm	mm	No	mm
500	30	25	3	20	700	635	32	20	1 1/8	670	620	26	20	M24
600	35	25	3	24	815	749,3	35	20	1 1/4	780	725	30	20	M27
700	41	27	3,5	28	925	863,6	35	28	1 1/4	895	840	30	24	M27
800	46	32	4	32	1 060	977,9	42	28	1 1/2	1 015	950	33	24	M30
900	51	33	4,5	36	1 170	1 085,8	42	32	1 1/2	1 115	1 050	33	28	M30
1 000	56	35	5	40	1 290	1 200,2	42	36	1 1/2	1 230	1 160	36	28	M33

NOTE The pressure rating is based on:

1 design stress of flange laminate $f_{m,k}$ / K = 30 N/mm² and pipe laminate 25 N/mm²;
2 the gasket seating stress Q_{min} ≤ 2,5 N/mm²;
3 maximum of φ = 1,2° flange deformation;
4 r ≥ 3 mm;
5 in the case of flanges for manholes (with blind flanges) reduced bolt size and hole diameter are possible if they are calculated separately.

11.3 Stub flange design with backing ring

11.3.1 General

This method concerns flanges incorporating a stub with a metallic or GRP backing ring, which may be fabricated in one piece with a nozzle, pre-moulded and joined to a nozzle, see Figure 47 and Figure 55.

In all cases any metal backing ring shall be calculated as a loose flange using the design rules EN 13445-3 or other appropriate pressure vessel standard. The relevant dimensions used in the calculations for stub thickness are given in Figure 55.

11.3.2 Loads, bending moment and design for backing ring made of steel or GRP

The operating and bolting up conditions shall be as follows:

$$H_{p,d,R} = p_{d,R} \cdot \frac{\pi}{4} \cdot DN^2 \tag{264}$$

where

$$p_{d,R} = PS_{op} \cdot A_{5,i} \cdot \gamma_{F,p} + p_{hp} \cdot A_{5,i} \cdot \gamma_{F,w}$$

$$H_{R,d,R} = \sum H_{R,i} \cdot \gamma_F \tag{265}$$

where

$H_{R,i}$ = loads from additional axial loads H or moment $H_M = \frac{4 \cdot M}{DN + t_p}$ to flange

$$H_{A,d,R} = H_{p,d,R} + H_{R,d,R} \tag{266}$$

$$H_{F,d,R} = p_{d,R} \cdot \frac{\pi}{4} \cdot (D_G^2 - DN^2) \tag{267}$$

$$H_{g0,d,R} = p_{g0,R} \cdot A_G \cdot \gamma_F \tag{268}$$

p_{g0} = compression on gasket for bolting up condition

$$H_{g1,d,R} = p_{g1,R} \cdot A_G \cdot \gamma_F \tag{269}$$

p_{g1} = compression on gasket for operating condition

Operating conditions:

The minimum moment operating conditions, $M_{1,d,R}$, shall be determined from the following formula:

$$M_{1,d,R} = (H_{A,d,R} + H_{F,d,R} + H_{g1,d,R}) \cdot h_B \tag{270}$$

Bolting up conditions:

The minimum moment for gasket seating, $M_{0,d,R}$, shall be determined from the following formula:

$$M_{0,d,R} \geq (H_{R,d,R} + H_{g0,d,R}) \cdot h_B \tag{271}$$

For backing rings manufactured as full rings, the thickness of the ring, t_R, shall be given by the appropriate steel flange standard.

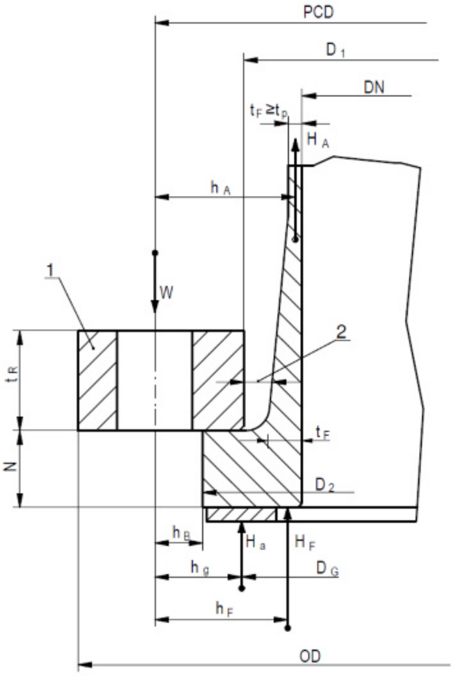
$$\sigma_{d,R} = \frac{M_{i,d,R}}{\frac{\pi}{6} \cdot \left(OD - D_1 - d^*\right) \cdot t_R^2} \tag{272}$$

For bearing capability use Formula (273):

$$\frac{\sigma_{d,R}}{f_{i,k} / \gamma_M} \leq 1 \tag{273}$$

Where the ring is split the backing flange thickness, t_s, is given by Formula (274):

$$t_{\mathrm{s}} = t_{\mathbf{R}} \cdot \sqrt{2} \tag{274}$$



Key

Lever: $h_B = \dfrac{PCD - D_2}{2}$

1 metal ring

2 clearance between the bore of the backing flange and the outside diameter of the hub shall be as small as practicable

Figure 55 — Stub flange details

11.3.3 Stub flange loadings

The stub flange loadings are equal to the flange loadings defined in 11.2.5.

11.3.4 Stub shear interface design

The shear stress at the stub as follows:

$$\tau_{d,R} = \frac{W_{i,d,R}}{\pi \cdot \left(DN + t_F\right) \cdot N} \tag{275}$$

For the select laminate use the following formula for bearing capability

$$\frac{\tau_{d,R}}{\dfrac{f_{i,k}}{\gamma_M \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4}} \le 1 \tag{276}$$

11.3.5 Stub end or flange design

The bending moments for this section are:

$$M_{A0,d} = W_{m,d} \cdot (h_A - h_B) \qquad (277)$$

$$M_{A1,d} = W_{m1,d} \cdot (h_A - h_B) \qquad (278)$$

The section modulus of A-A is defined by Formula (279):

$$Z_{A-A} = \frac{\pi}{6} \cdot \left[\left(D_2 - DN\right) \cdot N^2 + \left(DN + t_F\right) \cdot t_F^2 \right] \qquad DN \leq 1000\,mm$$
$$Z_{A-A} = \frac{1{,}2 \cdot \pi}{6} \cdot \left[\left(D_2 - DN\right) \cdot N^2 + 0{,}8 \cdot \left(DN + t_F\right) \cdot \left(t_F^2 - t_p^2\right) + 0{,}1 \cdot t_F \cdot \left(DN + t_F\right) \cdot N \right] \qquad DN > 1000\,mm \qquad (279)$$

The following stresses result for bolting up and operation conditions:

$$\sigma_{A,d,R} = \frac{M_{i,d,R}}{Z_{A-A}} \qquad (280)$$

$$\sigma_{A,d,\varepsilon} = \frac{M_{i,d,\varepsilon}}{Z_{A-A}} \qquad (281)$$

For the select laminate use the following formula for bearing capability or strain limit

$$\frac{\sigma_{A,d,R}}{\dfrac{f_{i,k}}{\gamma_M \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4}} \leq 1 \qquad \textit{respectivly} \qquad \frac{\sigma_{A,d,\varepsilon}}{E_{i,m}} \leq \varepsilon_{\lim} \qquad (282)$$

The section modulus of C-C is defined by Formula (283):

$$Z_{C-C} = \frac{\pi}{6} \cdot N^2 \cdot (D_2 - d^*) \qquad (283)$$

The bending moments for this section is equal to Formulae (284) and (285):

$$\sigma_{C,d,R} = \frac{M_{i,d,R}}{Z_{C-C}} \qquad (284)$$

$$\sigma_{C,d,\varepsilon} = \frac{M_{i,d,\varepsilon}}{Z_{C-C}} \qquad (285)$$

For the select laminate use the following formula for bearing capability or strain limit

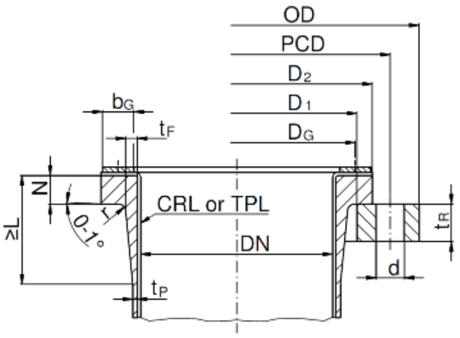
$$\frac{\sigma_{C,d,R}}{\dfrac{f_{i,k}}{\gamma_M \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4}} \leq 1 \qquad \textit{respectively} \qquad \frac{\sigma_{C,d,\varepsilon}}{E_{i,m}} \leq \varepsilon_{\lim} \qquad (286)$$

11.3.6 Seating stress

The seating stress between the backing ring and stub flange is given by Formula (287):

$$\sigma_{S,d} = \frac{(W_{\mathbf{m}1,d}) \text{ or } (W_{m2,d})}{\frac{\pi}{4} \cdot (D_2{}^2 - D_1{}^2)} \text{ where } \frac{\sigma_{S,d}}{f_{S,k} / \left(\gamma_M \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4\right)} \leq 1 \text{ with } f_{s,k} = 150 \text{ N/mm}^2 \qquad (287)$$

Table 29 — Stub flange



Branch nominal size DN	thick-ness N	t_F	FRP t_R	steel t_R	t_P	connection size: Classification 150 (ASME B16.5/16.47) D1	D_2	OD	PCD	Classification 10 (EN 1092–1 PN 10) D_1	D_2	OD	PCD
Mm	mm	mm	mm	mm	mm	mm	mm	in	mm	mm	mm	in	mm
10 bar													
25	12	9	14	12	3	58	63	110	79,4	58	69	115	85
32	14	9	15	12	3	69	73	115	88,9	69	80	140	100
40	14	10	16	12	3	77	82	125	98,4	77	90	150	110
50	14	11	18	14	3	87	102	150	120,7	87	105	165	125
65	15	11	20	14	3	102	120	180	139,7	102	125	185	145
80	16	12	22	14	3	121	133	190	152,4	121	140	200	160
100	18	12	24	17	3	141	171	230	190,5	141	160	220	180
125	20	13	27	17	3	166	193	255	215,9	166	190	250	210
150	22	14	30	18	3	191	218	280	241,3	191	216	285	240
6 bar													
200	25	14	32	20	3	251	275	345	298,5	251	271	340	295
250	28	17	34	22	3	301	336	405	362	301	326	395	350
300	30	17	36	26	3,6	355	406	485	431,8	355	376	445	400
4 bar													
350	32	14	38	28	3	413	447	535	476,3	413	436	505	460
400	35	16	42	32	3,2	465	511	595	539,8	465	487	565	515
450	36	17	44	34	3,6	517	545	635	577,9	517	537	615	565
500	38	17,5	47	38	4	571	603	700	635	571	592	670	620
2,5 bar													
600	45	20	47	36	3	671	714	815	749,3	671	693	780	725
700	53	25,5	53	40	3,5	775	826	925	863,6	775	808	895	840
800	57	25	60	44	4	885	936	1060	977,9	885	915	1 015	950
900	60	26	65	48	4,5	987	1044	1170	1085,8	987	1 015	1 115	1 050
1 000	64	26	70	52	5	1 091	1 158	1 290	1 200,2	1 091	1 122	1 230	1 160

NOTE The pressure rating is based on:

1 design stress of flange laminate $f_{m,k}$ / K = 30 N/mm² and pipe laminate 25 N/mm²;
2 the gasket seating stress Q_{min} ≤ 2,5 N/mm²;
3 maximum of φ = 1,2 degrees flange deformation;
4 r ≥ 3 mm;
5 the ring inner diameter D_1 is not true for flanges with DN in inch and edges rounded;
6 steel S235JR in accordance with EN 10025–2.

11.4 Butt and strap jointed flanges at vessels or tanks

When pre-manufactured or pre-moulded flanges are joined to the branch nozzle at the shell from a tank or vessel, the overlay laminate shall be designed to meet the requirements of the following formula and the relevant details given in 10.8.

Axial unit load for the joint laminate:

$$n_{joint,d,R} = \frac{p_{d,R} \cdot (d_b + t)}{4} \quad or \quad n_{joint,p,d,\varepsilon} = \frac{p_{\mathbf{d},\varepsilon} \cdot (d_b + t)}{4} \tag{288}$$

For the selected laminate using 9.3.2 to proof the load bearing capacity.

The laminates are needed equally between the interior and exterior side. The minimum number of layers shall be more than 3 × 450 g/m².

The lap shear load in the joint is given by:

$$\tau_{\mathbf{over,d}} = \frac{n_{\mathbf{joint,d,R}}}{l_{\mathbf{over}}} \quad \text{and} \quad \tau_{\mathbf{over,d}} \le \frac{\tau_k}{(\gamma_M \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4)} \tag{289}$$

and

$$l_{\mathbf{over}} \le 16 \cdot t_{\mathbf{over}} \tag{290}$$

where

L_j overall length of overlay = $2 \cdot l_{over}$;

d_b internal diameter of branch;

τ_k characteristic interlaminar shear strength of laminate

$p_{d,R}$ $p_{d,R} = PS_{op} \cdot A_{5,i} \cdot \gamma_{F,p} + p_{hp} \cdot A_{5,i} \cdot \gamma_{F,w}$

When a measured value of τ_k is available, this value can be used in the formula in place of the value given in Table 4.

The overlaying laminate shall have a minimum length of 100 mm for branches having a wall thickness (excluding any liner) < 6 mm and 150 mm for branches having a wall thickness (excluding any liner) > 6 mm.

The design and construction requirements of such joints shall be the same as those given in 10.7 for circumferential seam joints for tanks and vessels

12 Supports for vessels and tanks

12.1 General

Attention shall be given to the design of supports for vessels and tanks in reinforced plastics, so as to avoid excessive loads at points of support. All supports shall be designed to accommodate temperature changes and to permit free expansion and contraction. Particularly attention shall be given to the design of supports using metallic materials whether attached directly or not on to the shell because of their different coefficients of thermal expansion.

Vessels and tanks fitted with an agitator shall have supports designed with a load multiplication factor of 1,25.

Continuous support shall be provided for flat bottom tanks over the whole area of the flat bottom except where sumps or bottom run offs shall be accommodated (see Figure 31).

The gaps in the supports to allow for bottom branches shall be sized to allow room for a conical wedge to be fitted to preclude high local loads being imposed on the additional reinforcement which is used for compensation of the branch opening (see Figure 30).

Anchorages shall be provided if there is a tendency for the base of the tank or vessel to lift off its foundation; a design method for tank anchorage is given in Clause 14 and typical hold down arrangements are shown in Figures 59 and 60. Requirements for foundation and installation are given in EN 13121-4.

12.2 Supports and mountings for tanks and vessels

12.2.1 General considerations for supports

This subclause and 12.2.2 are related to the supports for vessels and the supports for fittings carried from the shell or ends of the vessel, with regard to their effect on the vessel only. The structural design of supports is not included because they can be dealt with by the usual methods of structural design.

The supports of vessels and of fittings carried by the shell produce local moments and membrane forces in the vessel wall which shall be analyzed by the methods given in Clause 16.

The supports of a vessel shall be designed to withstand all the external loads likely to be imposed on them in addition to the dead weight of the vessel and contents. These loads may include:

a) directly superimposed loads;

b) wind loads on exposed vessels;

c) thrusts or moments transmitted from connecting pipe work or equipment;

d) shock loads due to liquid hammer or surging of the vessel contents;

e) forces due to differential expansion between the vessel and its supports.

12.2.2 Supports for vertical vessels

12.2.2.1 Leg supports

Individual leg supports attached directly to the tank or vessel are only allowed on equipment up to a maximum of 1 500 mm diameter and 2 000 mm high and density of liquid up to 1 200 kg/m^3.

For vessels outside of these dimensions the vessel shall only be supported on legs when attached to a ring girder or angle ring see Figure 56 and Figure 57.

Legs shall not be directly attached to the bottom of dished vessels, see Figure 57.

When the legs are directly attached to the shell, the eccentricity of the legs shall be kept to a minimum and the cylindrical shell shall be analyzed for the effects of the loads and moments arising.

12.2.2.2 Integral ring supports

It is often desirable to support vertical vessels by means of an integral ring/load shoulder at a convenient position on the shell as shown in Figure 56 and Figure 57.

The ring may be determined by using the formulae below and associated figures.

All ring supports of this type shall rest on a continuous support or steel work as indicated in Figure 56 and Figure 57 or equivalent.

12.2.2.3 Ring girders

The supporting legs of large vertical vessels are often connected to a ring girder that supports the vessel shell. In some designs the lower part of a skirt support is reinforced to form a ring girder. A typical ring girder is shown in Figure 56, such girders are subject to torsion as well as bending and require special consideration as follows and should be of a closed section design wherever possible. If a closed section ring is not used then the torsional stiffness of the ring requires to be checked to ensure that imposed loads are not causing local buckling of the shell.

Calculation for the concentrated load from the legs at the above shell can be neglected if the maximum deflection of the ring between any two support feet shall be 1 mm.

When the supporting columns are equally spaced, the flexural and twisting moments in the ring girder can be found using the coefficients given in Table 30 — and the following formulae.

Table 30 — Flexural and torsion coefficients for ring girder analysis

No of legs	4	6	8	12
Load on each leg	$\frac{W}{4}$	$\frac{W}{6}$	$\frac{W}{8}$	$\frac{W}{12}$
Maximum shear in ring girder	$\frac{W}{8}$	$\frac{W}{12}$	$\frac{W}{16}$	$\frac{W}{24}$
C_{m1}	- 0,0342	- 0,0148	- 0,00827	- 0,00365
C_{m2}	+ 0,0176	+ 0,00751	+ 0,00415	+ 0,00190
C_x	0,335	0,222	0,166	0,111
C_t	0,0053	0,0015	0,00063	0,000185

where

W = Total weight of tank and contents × $\gamma_{F,i}$

The flexural moment at the support position is M_1

$$M_1 = C_{\mathbf{m1}} \cdot W \cdot R_2 + 0{,}16 \cdot W \cdot e_p \quad (291)$$

where

R_2 = Radius to neutral axis of the ring (see Figure 56);

e_p = Distance of the loading point to the neutral axis of the ring.

The flexural moment midway between the supports is M_2

$$M_2 = C_{\mathbf{m2}} \cdot W \cdot R_2 + 0{,}16 \cdot W \cdot e_p \quad (292)$$

The distance either side of the support where maximum torsion occurs and the flexural moment is zero is given by Formula (293), see Figure 56.

$$x = C_{\mathbf{x}} \cdot R_2 \quad (293)$$

The maximum value of torsion is given by Formula (294):

$$T = C_t \cdot W \cdot R_2 \quad (294)$$

If the support not directly in z-axis of the profile an additional torsion moment at the leg region is given.

$$T_{add} = 0{,}5 \cdot W \cdot e_e / number\ of\ legs \quad (295)$$

A flexural moment causing tension in the underside of the girder is taken as positive. Torsion in the girder is zero at the supports and midway between them.

Stresses in the ring girder:

The flexural stresses in the ring girder shall be computed using Formula (296) for each position

$$\sigma_{\mathbf{b}} = \frac{M}{Z_{\mathbf{yy}}} \tag{296}$$

where

Z_{yy} is the section modulus about axis y-y.

The equivalent shear stress developed in the ring flange due to torsion loads shall be determined from Formula (297) with $T_i = T + T_{add}$

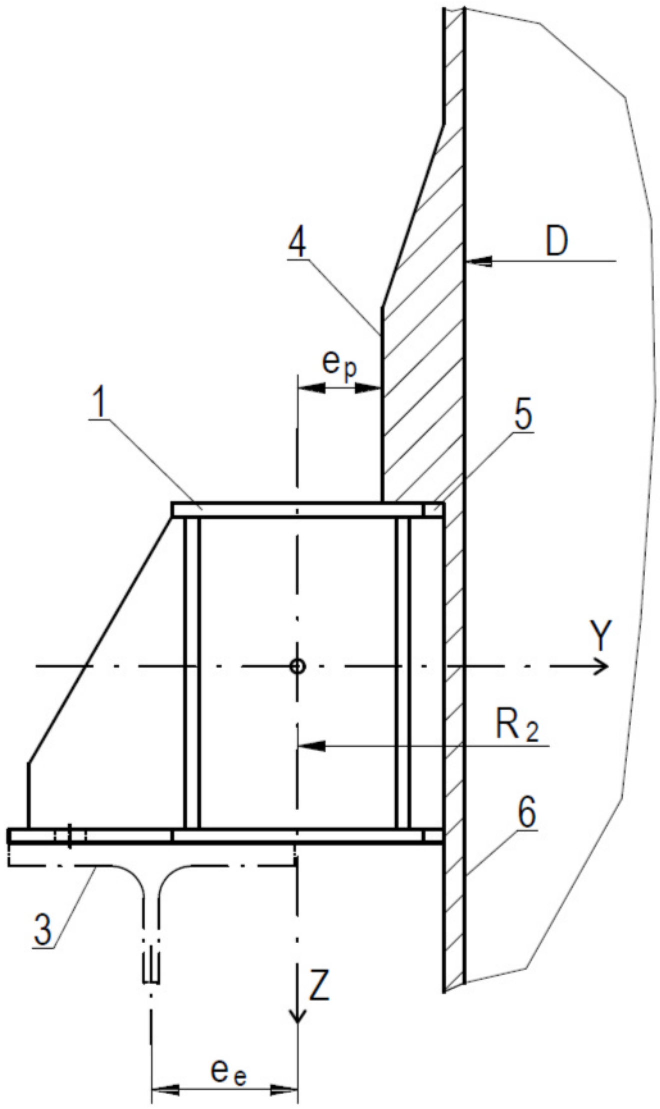
$$\tau_{\mathbf{t}} = \frac{\Sigma T_i}{Z_{\mathbf{xx}}} \tag{297}$$

where

Z_{xx} is the section modulus for torsion about axis x-x.

12.2.2.4 Skirt support

The design of vessels supported on an integral skirt is given in 10.6.4.3.



Key

1 ring girder

2 centre line of the ring grider

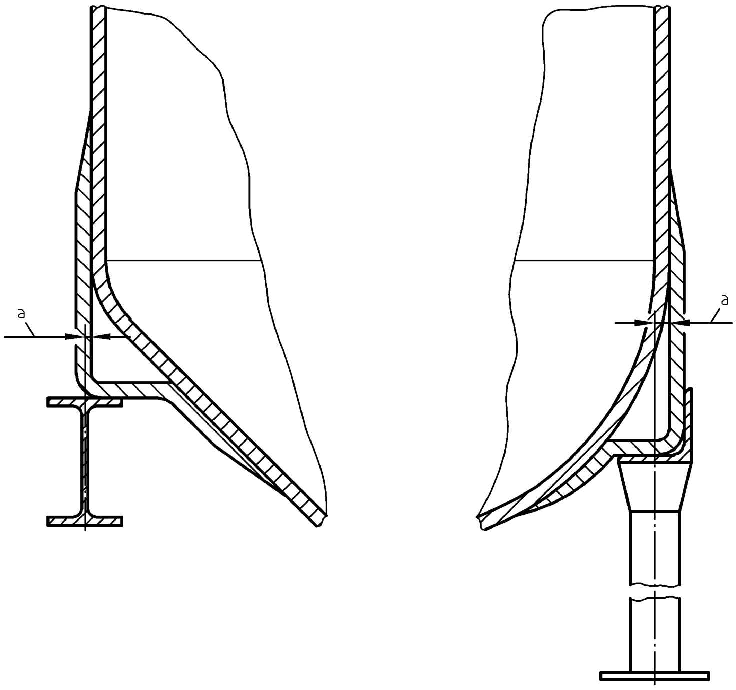
3 steelwork

4 load shoulder

5 minimum practicable clearance here

6 vessel or tank wall

Figure 56 — Support for drop-through vessels and tanks



Dimension (a) shall be as small as practically possible in order to avoid imparting high local flexural moments to the shell.

Figure 57 — Typical ring girder supports for conical and domed ends

12.2.2.5 Steel support without ring girder

The tanks or vessels can also be supported by the steel structure shown in Figure 58. This support shall be designed in accordance to the EN 1993 series. The lower part of the tank or vessel and the skirt can be designed as follows (n = number of legs):

a) Load for the legs due to wind, seismic, or snow loads (determined to an applicable local code):

$$F_{x,M,d,cr} = \frac{4 \cdot M_{d,cr}}{n \cdot D} \text{ axial load } F_{x,M,d,R} = \frac{4 \cdot M_{d,R}}{n \cdot D}, \text{ or } F_{x,M,d,\varepsilon} = \frac{4 \cdot M_{d,\varepsilon}}{n \cdot D} \quad (298)$$

where

$$M_{d,R} = M_{wind} \cdot \gamma_{F,p} + \sum M_{e,i} \cdot A_{5,i} \cdot \gamma_{F,i}$$

$$M_{d,\varepsilon} = M_{wind} + \sum M_{e,i}$$

$$M_{d,cr} = M_{wind} \cdot \gamma_{F,p} + \sum M_{e,i} \cdot \sqrt{A_{5,i}} \cdot \gamma_{F,i} \text{ for axial stability case}$$

and M_e = any other flexural moment.

b) Weight of vessel, fittings, contents, attachments applied and personnel loads:

$$\text{axial load } F_{x,W,d,R} = \frac{W_{d,R}}{n}, \; F_{x,W,d,\varepsilon} = \frac{W_{d,\varepsilon}}{n} \text{ or } F_{x,W,d,cr} = \frac{W_{d,cr}}{n} \quad (299)$$

where

$$W_{d,R} = W \cdot A_{5,i} \cdot \gamma_{F,W} + \sum W_{e,i} \cdot A_{5,i} \cdot \gamma_{F,i}$$

$$W_{d,\varepsilon} = W + \sum W_{e,i}$$

$$W_{d,cr} = W \cdot \sqrt{A_{5,i}} \cdot \gamma_{F,W} + \sum W_{e,i} \cdot \sqrt{A_{5,i}} \cdot \gamma_{F,i} \text{ for axial stability case}$$

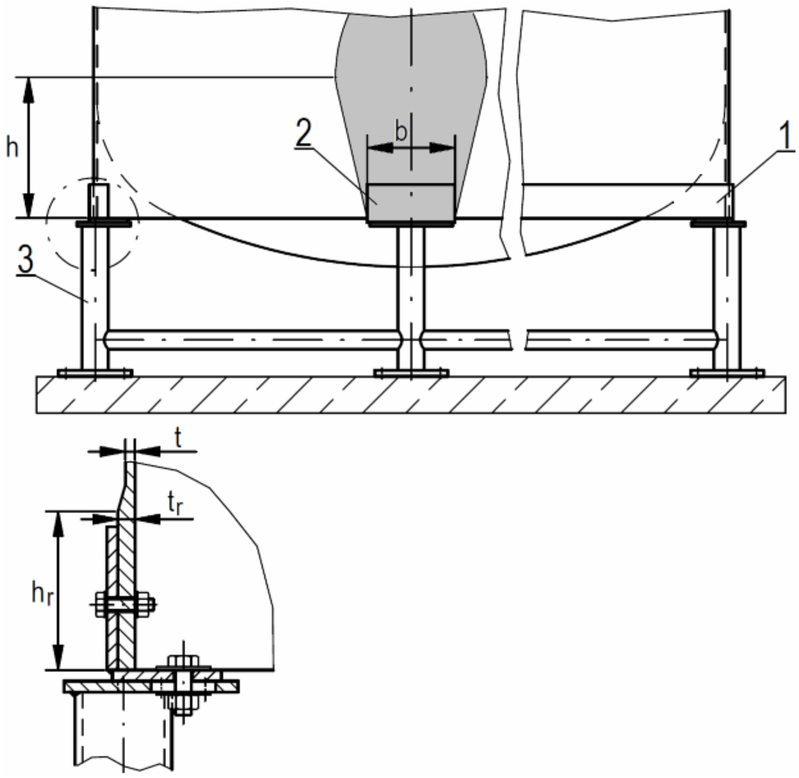
and W_e = any other weight load.

For the skirt

axial compression: $n_{x,d,R} = \left(F_{x,M,d,R} + F_{x,W,d,R}\right)/b$ (300)

strain: $n_{x,d,\varepsilon} = \left(F_{x,M,d,\varepsilon} + F_{x,W,d,\varepsilon}\right)/b$ (301)

For the selected laminate use 9.3.2 to proof the axial load bearing capacity.



Key

1 circumference steel ring grider

2 single support legs

3 steelwork

Figure 58 — Typical steel supports for all bottom designs

For the shell stability above the skirt and bottom region the load is given in Formula (302):

$$F_{x,d,cr} = F_{x,M,d,cr} + F_{x,W,d,cr} \qquad (302)$$

$$n_{x,d,cr} = F_{x,d,cr} \cdot \left[\left(\frac{0{,}0216}{h_R \cdot t_R \cdot D \cdot b} \right)^{0,25} \cdot \left(1 - \frac{t_R}{150 \cdot t} \right) \right] \text{ compressive load} \qquad (303)$$

where

$h = h_R + 1{,}2 \cdot \sqrt{D \cdot t_R}$ position of n_{cr}

t is shell thickness at position h

h_R is the height of the stiffness region

For calculation n_{cr} see 10.3.2.

For support on a circumference steel ring the following should be considered. Calculation for the concentrated load from the legs at the above shell can be neglected if the maximum deflection of the steel ring between any two support feet should be less than 1 mm.

13 Seismic loading

Tanks and vessels subject to the risk of seismic loads shall be designed to meet the requirements of the National Code relevant to the tank or vessel location. Principle formulae are given in 9.2.3.

14 Design calculation for tank and vessel anchorage

14.1 General

This section applies to tanks or vessels where there may be tendency for the base to lift off its support.

14.2 Design for uplift

The design uplift on the anchorage shall take into account the following conditions:

a) hydrostatic head and/or internal pressure;

b) wind overturning load;

c) seismic force. The anchorage shall be designed with a full liquid load if applicable, the effects of both vertical and horizontal accelerations but excluding the effect of pressure and wind loadings, shall apply to both the contents and weight of the tank or vessel;

d) weight of cylindrical shell, roof and associated structure;

e) weight of shell and roof insulation where fitted;

f) test pressure.

14.3 Design for anchor bolts

The overturning force due to wind loading shall be calculated in according to EN 1991-1-4.

The anchorage shall be designed to withstand the maximum overturning moment due to wind loads and other causes. The number and size of anchorage bolts shall be calculated by taking the total resisting moment as equal to the maximum overturning moment.

The minimum number of anchorage points shall be four and shall be spaced evenly around the diameter. Anchorage point spacing shall not exceed 1500 mm.

The contribution from the contents in resisting the overturning moment shall be ignored. The load required to be resisted by each anchor bolt shall be determined from the following formula.

$$N_{E,d} = \left(\frac{4 \cdot M_{d,R}}{D_{pc}} - 0{,}9 \cdot W_k + \frac{p_d \cdot \pi \cdot D^2}{4} \right) \cdot \frac{1}{N_b} \leq N_{R,d} \quad (304)$$

where

$N_{E,d}$ is the acting anchor bolt load;

$N_{R,d}$ is the design anchor bolt load;

$M_{d,R}$ is the total overturning moment, see 9.2;

D_{pc} is the pitch circle diameter of anchorage bolts

W_k is the characteristic dead load of empty vessel (by seismic loads: For vessels and tanks with skirt and hanging vessels and tanks the filling weight can be recognized as resetting);

N_b is the number of anchorage bolts;

p_d design pressure

For seismic conditions the bolt loads for flat bottom tanks are given by the following formula:

$$N_{E,d} = \left(\frac{4 \cdot M_{\mathbf{AE}}}{D_{\mathbf{pc}}} - 0{,}9 \cdot W_k + \frac{p_d \cdot \pi \cdot D^2}{4} \right) \cdot \frac{1}{N_{\mathbf{b}}} \leq N_{R,d} \tag{305}$$

$$V_{E,d} \leq 2 \cdot \frac{H_{AE}}{N_{\mathbf{b}}} \tag{306}$$

where

M_{AE} is the total seismic moment derived from the National Rules applicable to the tank or vessel, principle moment see 9.2.3;

H_{AE} is the total seismic horizontal load derived from the National Rules applicable to the tank or vessel, principle load see 9.2.3.

To prevent buckling of the skirt due to a radial load, transfer of the anchor shear forces into the shell as a tangential load shall be ensured. Otherwise the skirt shall be stiffened by a ring or similar.

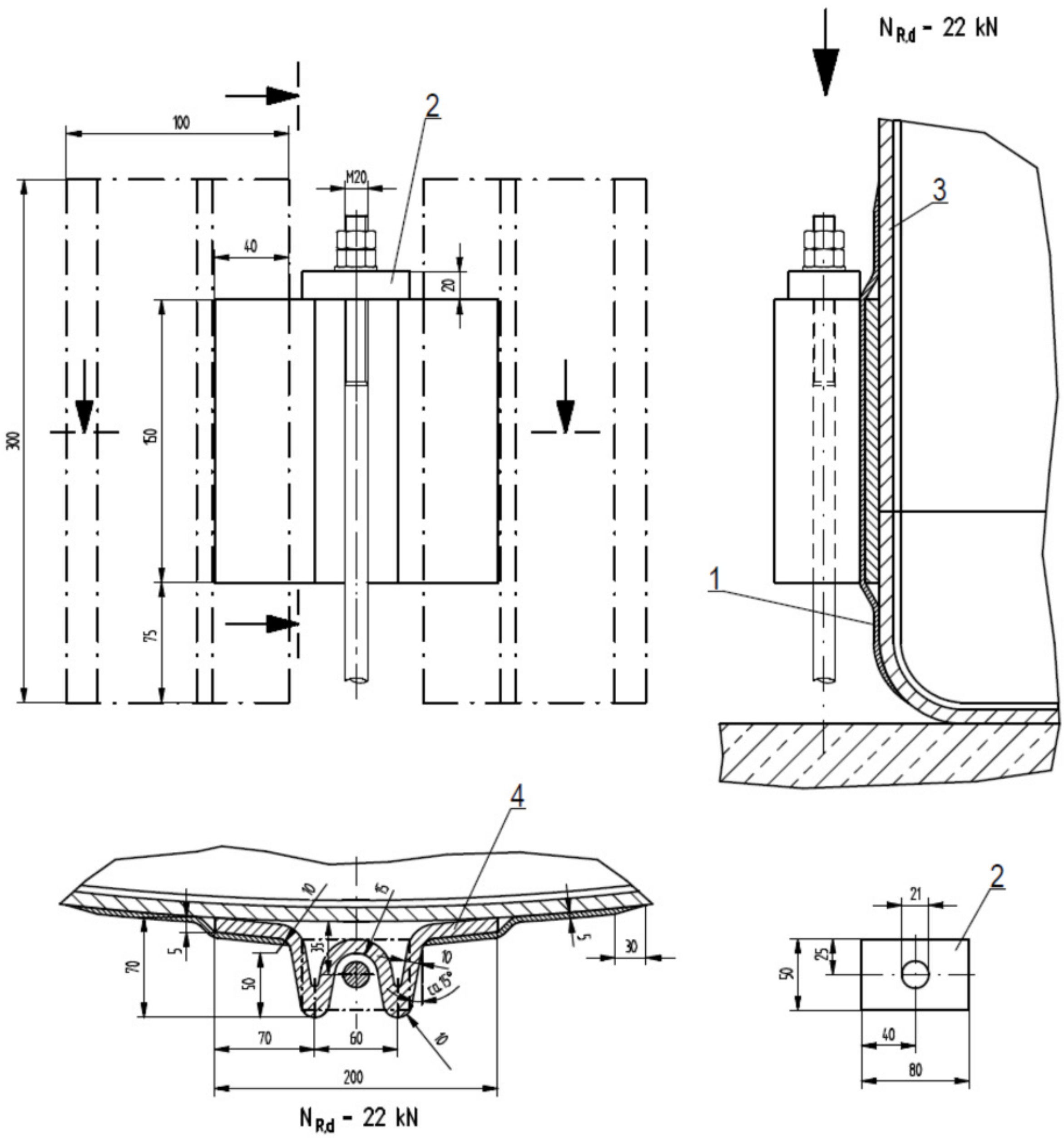
The anchors shown in Figures 59 and 60 are not suitable for seismic loads unless friction load can be taken in consideration.

The quality of steel shall be S235JR in accordance with EN 10025-2 or equal.

To minimize loads to the hold down feet the bolts should only be hand tightened plus half a turn during the tank installation when the tank is empty. All nuts shall be locked by a counter nut.

The design temperature of the anchorage and anchorage attachments shall be the ambient temperature of the tank or vessel location.

Dimensions in millimetres

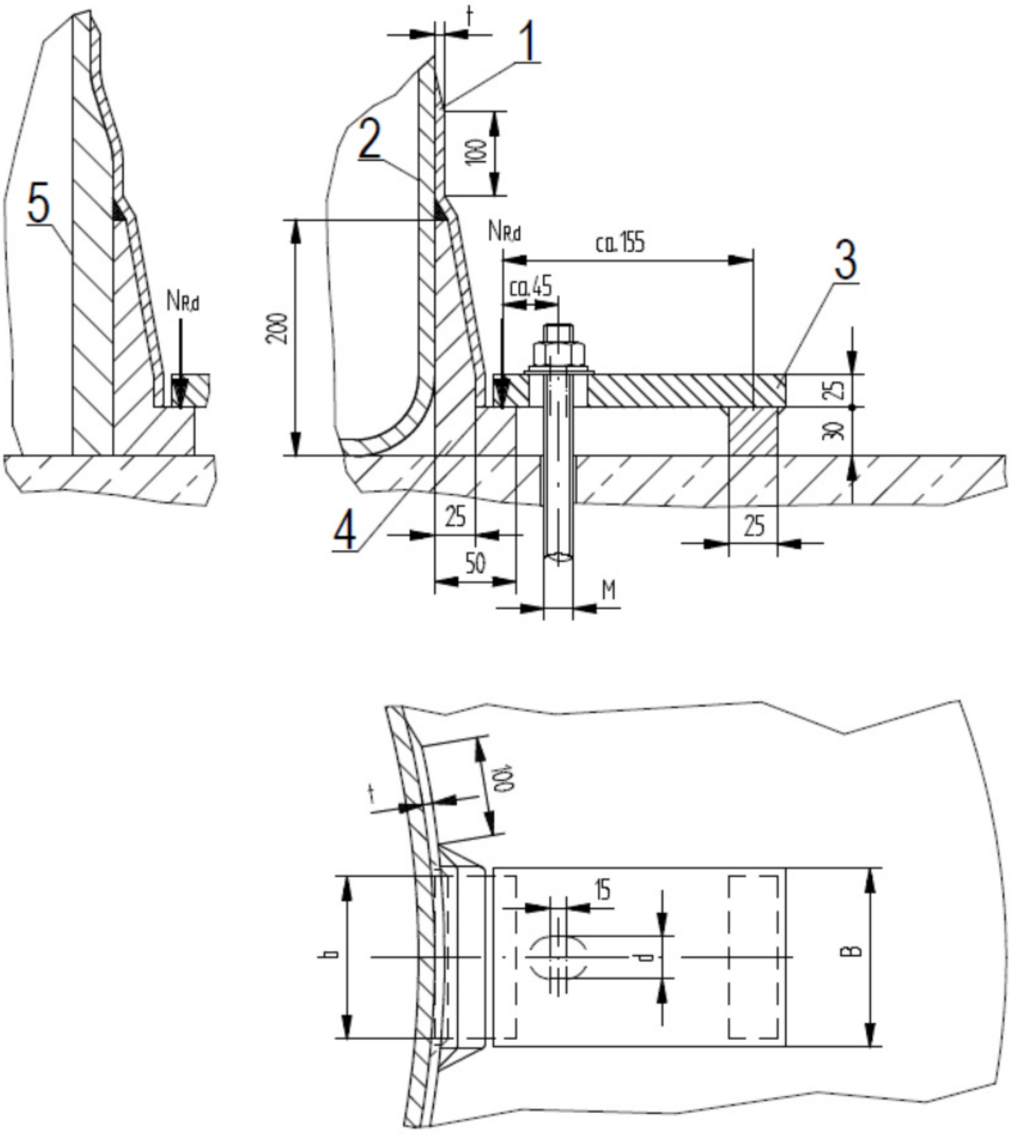


Key

1	GRP tank	2	GRP support
3	mixed laminate	4	mixed laminate

Figure 59 — Typical anchorage arrangement for flat bottom tanks

Dimensions in millimetres



Type	M	$N_{R,d}$ kN	b mm	B mm	d mm	t mm
1	M16	30	100	110	18	4
2	M20	45	150	160	22	5
3	M20	60	200	210	22	7

Key

1 mixed laminate

2 tank with flat bottom

3 steel plate

4 GRP bracket

5 tank with skirt

Figure 60 — Typical anchorage arrangement for tanks or vessels with flat bottoms or skirts

15 Structures and fittings

15.1 General

All structures and fittings shall be arranged as far as practicable to avoid imposing local concentrated loads on the walls of the vessel or tank. The design shall be such that the local strain does not exceed the allowable strain.

15.2 Internal structures and fittings

The material used for internal fittings shall be suitable for the conditions of service.

Fittings carrying load, such as tray supports and all fittings in vessels and tanks fitted with agitators, shall be designed to ensure adequate strength for the service conditions.

15.3 External structures and fittings

Vessels and tanks shall be provided with lifting lugs or other suitable attachments for safe handling for loading and installation on site. See EN 13121-4 for general details.

Where an agitator and drive, or other external equipment, e.g. walkways, are fitted, they shall be supported, either:

a) preferably independently of the vessel or tank (for example over steel cross beam);

b) on integral supports for vessel or tank, design temperature up to 60 °C.

In the case where integral supports, which also act as strengthening members, are used they shall be designed to have adequate strength and rigidity for both simultaneous purposes.

15.4 Lifting devices

The number, position, orientation and type of lifting fittings, i.e. lugs, shall be determined to ensure safe lifting of the empty tank, or vessel, under all circumstances.

The highest load on each fitting shall be calculated taking into account the load direction. When more than two fittings are to be used, the load shall be calculated on the basis that the full load will only be carried on any two fittings and the fittings designed for this load.

Any steel plate forming part of the fitting which shall be attached to the tank or vessel shall be free from loose scale and shall have no sharp edges.

All attachment plates shall be bonded to the tank or vessel so that there are no gaps beneath the plate and shell wall and shall be fitted onto a new uncured laminate or putty.

The overlay laminate shall be designed to withstand the design shear and peel loads in accordance with the requirements of 7.6 and 7.7.

In the following several types of fittings with their corresponding limit lifting loads are shown. The steel used is S235JR in accordance with EN 10025-2 or equal.

The limit loads are determined by the following formula. They already include γ_M, γ_F and the dynamic shock factor β.

$$N_{Ek} = \frac{N_{R,k}}{\gamma_M \times \gamma_F \times \beta} \quad (307)$$

where

β is the dynamic shock factor = 1,5;

γ_F is the partial safety factor for variable actions = 1,5;

γ_M is the partial safety factor for material (depends on material);

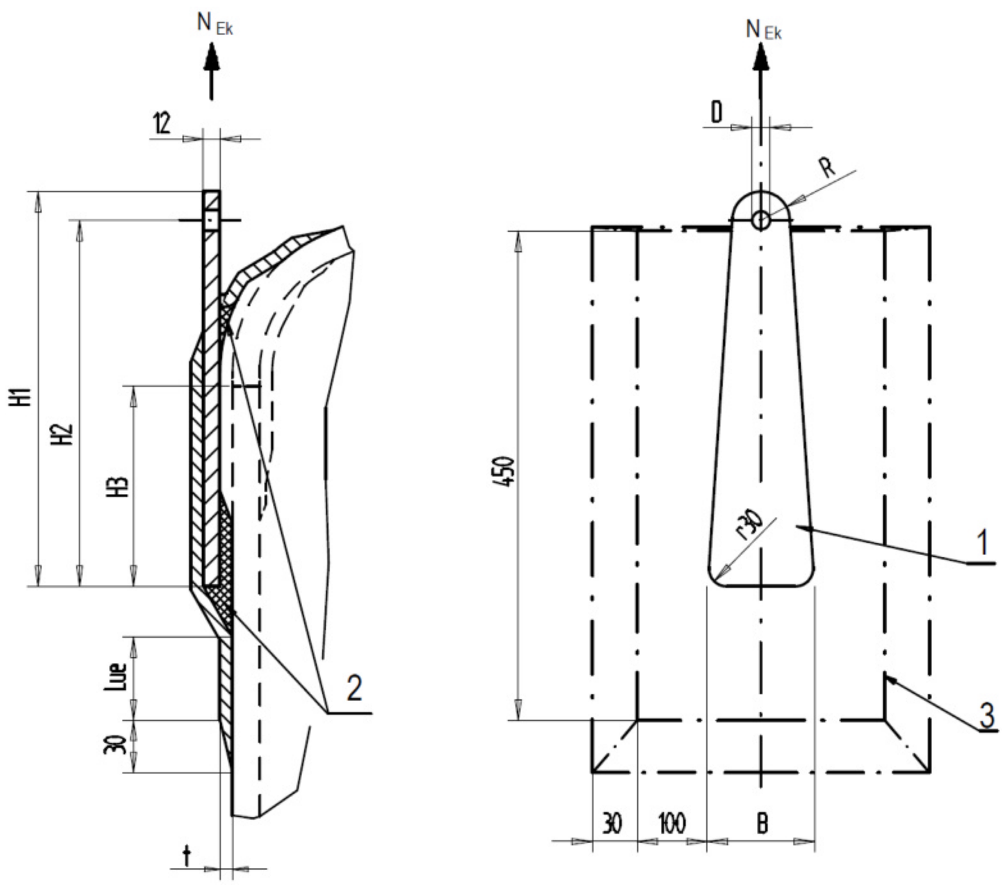
$N_{R,k}$ is the characteristic value for the resisting load of the lifting lug;

N_{Ek} is the characteristic value of the maximum acting load on the lifting lug.

The following criteria shall be fulfilled:

$$\frac{Lifting\,load}{2} \leq N_{Ek}$$

Dimensions in millimetres



Key

1 steel lug

2 putty

3 laminate

Dimensions

Type	H1 mm	H2 mm	H3 mm	R mm	D mm	B mm	Laminate type	Lue mm	t mm	N_{EK} kN
01	455	400	200	55	28	160	mixed laminate	100	5,9	12
02	580	500	300	80	38	250	mixed laminate	150	7,7	33

Figure 61 — Lifting lugs for vertical tanks and vessels

The trunnions shown in Figures 62 and 63 and for which the following conditions are fulfilled, the minimum wall thickness of the cylinder in the area of the trunnions shall be:

$$t_{ct} \geq \sqrt{\frac{M \cdot D}{f_{m,k} \cdot D_a^2}} \tag{308}$$

where

$$M = N_{Ek} \times b$$

$$b_{ct} \geq D_a + 16 \times t_{ct}$$

D is the diameter of the vessel or tank;

D_a is the backing plate diameter of the trunnion;

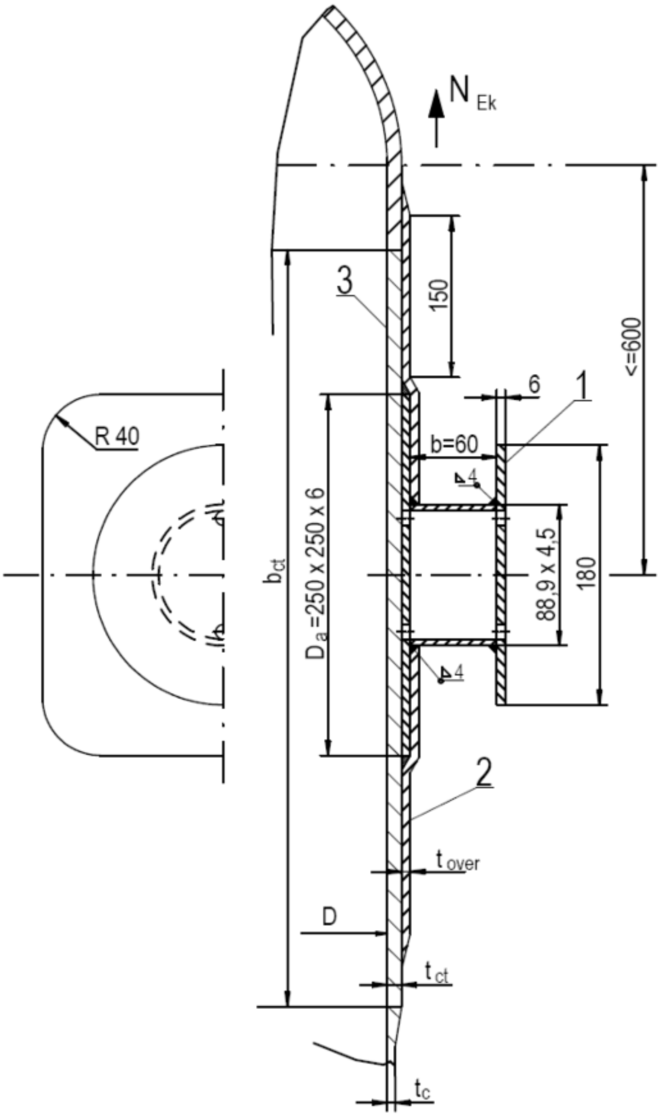
t_{ct} is the thickness of the cylinder in the area of the trunnion;

b_{ct} is the width of t_{ct} on the cylinder, full circumference;

$f_{m,k}$ is the characteristic bending strength of laminate in circumference direction;

b is the cantilever length of the trunnion.

Dimensions in millimetres



Key

1 steel lug

2 mixed laminate

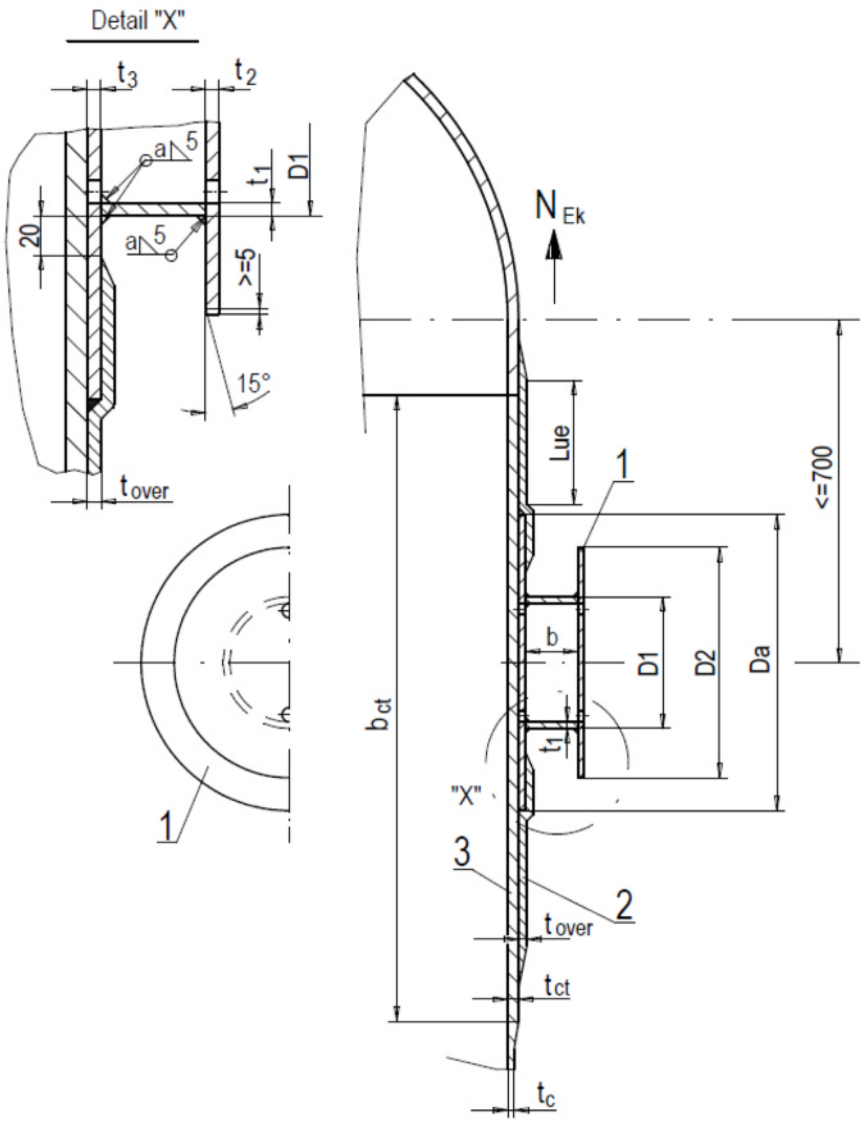
3 cylinder

Dimensions

Type	**Laminate type**	**t** mm	**N$_{EK}$** kN
01	mixed laminate	5,9	20

Figure 62 — Trunnions for vertical tanks and vessels for N_{Ek} ≤ 20 kN

Dimensions in millimetres



Key

1 steel lug

2 mixed laminate

3 cylinder

Dimensions

Type	D1 mm	t1 mm	D2 mm	t2 mm	t3 mm	Da mm	b mm	e mm	f mm	a mm	Laminate type	L_{ue} mm	t_{over} mm	N_{EK} kN
01	219, 1	8	300	8	8	380	≤ 60	80	60	5	mixed laminate	180	7.7	30
02	219, 1	8	300	8	8	380	≤ 60	80	60	5	mixed laminate	180	9.4	60
03	219, 1	8	350	8	8	480	≤ 80	100	80	5	mixed laminate	200	9.4	80

Figure 63 — Trunnions for vertical tanks and vessels for N_{EK} ≤ 80 kN

16 Local load analysis

For the proof of local loads to shells a design method may be found in [7] and [8].

17 Quality Control

17.1 General

The manufacturer shall establish and maintain a quality control system as a means of ensuring that the product conforms to this standard. The following aspects shall be considered:

— The preparation or the availability of documented procedures and instructions covering all aspects of design, procurement of materials, manufacturing, inspection, testing and final delivery of the product.

— The means by which the documented procedures and instructions are effectively implemented.

The manufacturer shall establish and maintain procedures for the training of all personnel in activities affecting quality. Personnel performing specific assigned tasks shall be qualified on the basis of appropriate education, training and/or experience as required. Appropriate records of training shall be maintained.

17.2 Works requirements

17.2.1 General

The place of manufacture shall be designed so that it can be divided into designated areas for the storage of materials, preparation of resins, preparation of reinforcement, laminating, welding, assembly and grinding.

17.2.2 Raw materials storage

All raw materials shall be stored in accordance with manufacturers' instructions.

When not in use resins, curing agents and additives shall be stored in a cool place and protected from heat.

Textile glass products and surfacing non-woven shall be kept dry at all times.

Semi-finished thermoplastics goods shall be protected from direct sunlight.

Sheet and tube materials shall be placed on adequate supports to avoid distortion.

The storage area shall be subdivided for the storage of the different types of materials, particularly peroxides.

Provision shall be made to allow materials which have been in storage to reach the ambient workshop conditions before they are used.

17.2.3 Manufacturing area

The manufacturing area shall be subdivided to provide separate areas for the preparation of reinforcements, measuring and mixing of resins, application of the laminate, trimming and finishing.

17.2.4 Conditions for laminating

Laminating shall be done under controlled environmental conditions compatible with producing a satisfactory vessel or tank, i.e. the control of temperature, humidity, air movement and light.

When laminating is being carried out the ambient temperature in the working area shall be maintained at a minimum of 10 °C. In no case shall the maximum proportion of curing agents exceed the resin manufacturers’ specifications.

Precautions shall be taken to avoid condensation when working at low temperatures. When the temperature falls to within 3 °C of the dew point, all laminating shall be halted until working conditions have improved to eliminate the risk of condensation.

The section where laminating is done shall be provided with suitable ventilation. All ventilation systems shall be designed to minimize loss of styrene from the laminate, e.g. which could occur by local forced draughting, and the ventilation system shall be arranged so that the risk of contamination by dust is kept to a minimum.

17.3 Documentation to be prepared by the manufacturer

17.3.1 Technical documentation

Documentation requirements for design and installation shall be as listed below:

Design calculations or verification and service conditions
General arrangement drawing, laminate specification and mechanical values of laminates for the used laminate types
Detail drawings and material/parts lists (Including method of manufacture)
Operating instructions
Installation and handling procedures
For pressure equipment according to Directive 2014/68/EU (PED): The manufacturer is under an obligation to analyze the hazard in order to identify those which apply to his equipment on account of pressure; he shall then design and construct it taking account of his analysis, i.e. when *PS* > 0,5 bar (see Annex ZA)
Essential safety requirements check list, when *PS* > 0,5 bar (see Annex ZA)
Verification of technical documentation, when *PS* > 0,5 bar (see Annex ZA)

17.3.2 Records and documentation requirements for raw materials

Documentation requirements for raw materials shall be given as follows:

Resin group, name and source certificate
Glass types and mass, name and source certificate
Chemical barrier design, in accordance with EN 13121–1
Raw material documentation in accordance with EN 13121–1

17.3.3 Manufacturing documentation requirements

Documentation requirements for manufacturing shall be given as follows:

Laminating procedures (including cure details)
Laminating operator qualifications
Laminator's record sheets
Weld procedure (for thermoplastics linings)
Welder certification (for thermoplastics linings)
Any repair procedures used
List of all samples, showing cross sections of branches, seams cut-outs, if carried out

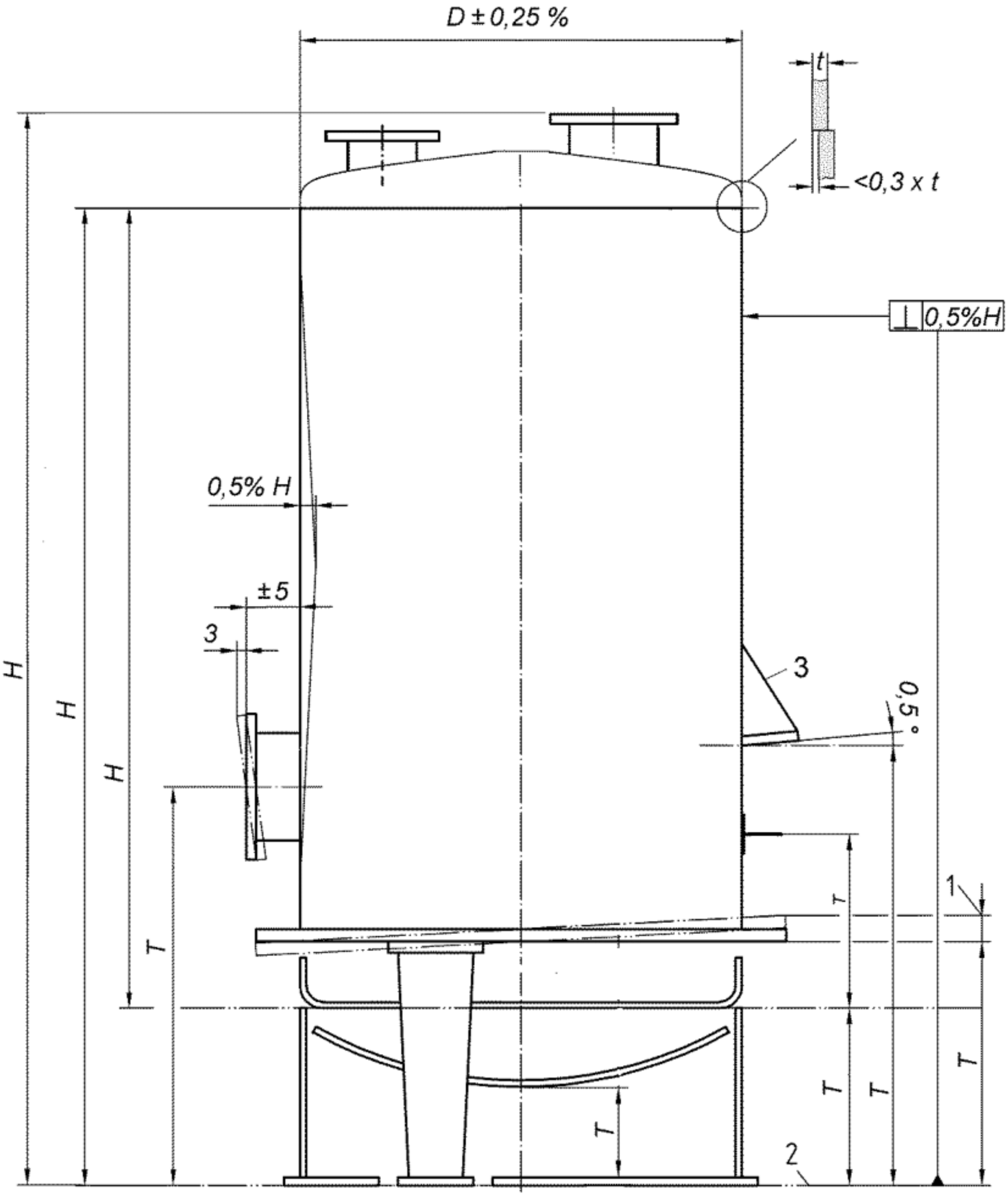
17.3.4 Quality control documentation requirements

Inspection and Test documentation requirements shall be given as follows:

Spark test on thermoplastics liners
All mechanical property records of the laminate used.
Production test coupons required if advanced design properties are used (see 7.9.3)
Visual examination of nozzle cut-outs
Ash test on nozzle cut-outs
Thickness measurement (particularly around discontinuities)
Barcol hardness measurement
Short-term creep test
Weld strength and bond strength (thermoplastics linings) (from previous production test samples if similar work has been undertaken within 12 months of last test)
Weld strength and bond strength (Thermoplastics linings) (Production test samples required if no acceptable records are available)
Resistivity check (if required by specification) resistivity < 10^6 Ohms
Manufacturing tolerances (Figures 64 to 67, Table 31 — Out of roundness related to thickness/diameter ratio (t/D) and Table 32 — Permissible imperfections in laminate) dimensional imperfection report "as built drawing"
Test records/certificates
CE marking and ID number, when *PS* > 0,5 bar
Declaration of conformity, *PS* > 0,5 bar
Certificate of conformity, *PS* > 0,5 bar

[mm]	**≤ 1000**	**> 1000 ≤ 2000**	**> 2000 ≤ 4000**	**> 4000 ≤ 8000**	**> 8000 ≤ 11000**
T, U, N	±6 mm	±8 mm	±11 mm	±14 mm	±18 mm
H, L	±8 mm	±12 mm	±16 mm	±21 mm	±27 mm

Dimensions in millimetres



Key

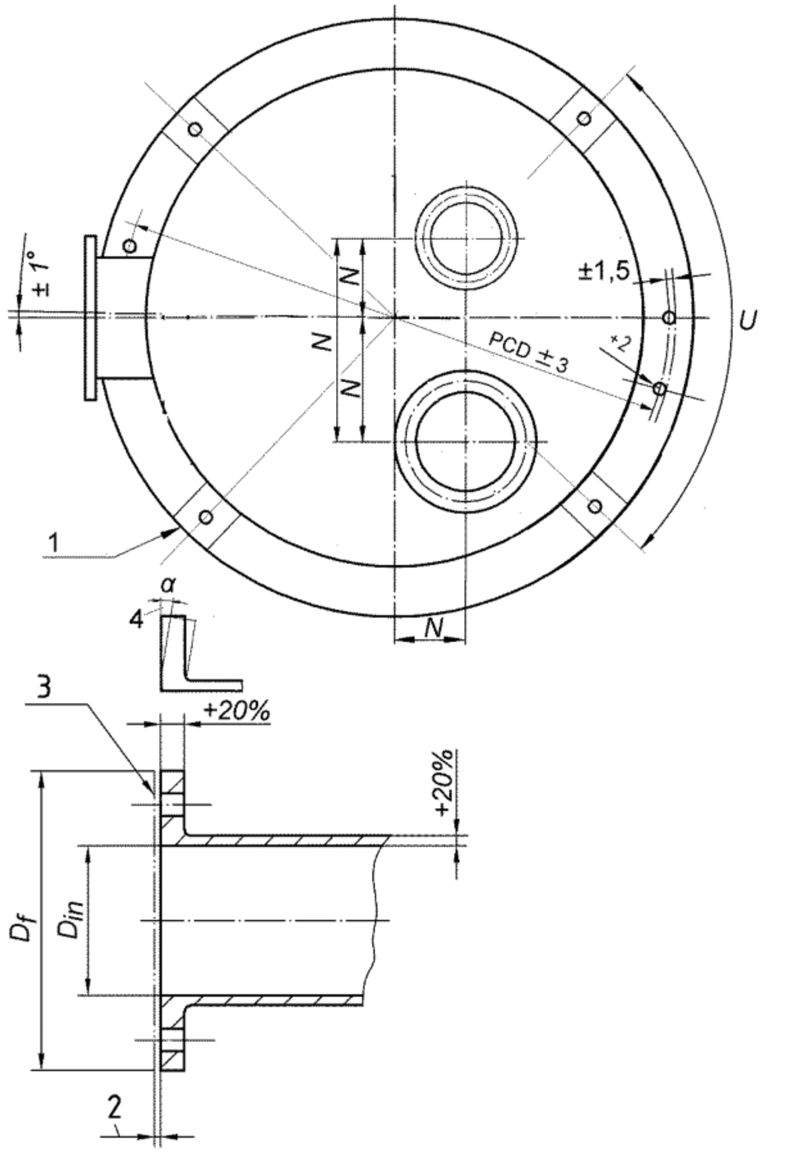
1 3 mm for *D* ≤ DN1600, 6mm for D > DN1600

2 tangent line reference

3 support

Figure 64 — Dimension tolerances for vertical tanks or vessels

Dimensions in millimetres



Key

1 support lugs

2 flatness:
1,0 mm for D_{in} ≤ 450
1,5 mm for 450 < D_{in} ≤ 1000
3,0 mm for D_{in} > 1000

3 local faults on mating surfaces < 0,8mm

4 flange drawback

D_{in} ± 1,5 mm for DN 25 to DN 80

D_{in} ± 4 mm for DN 100 to DN 350

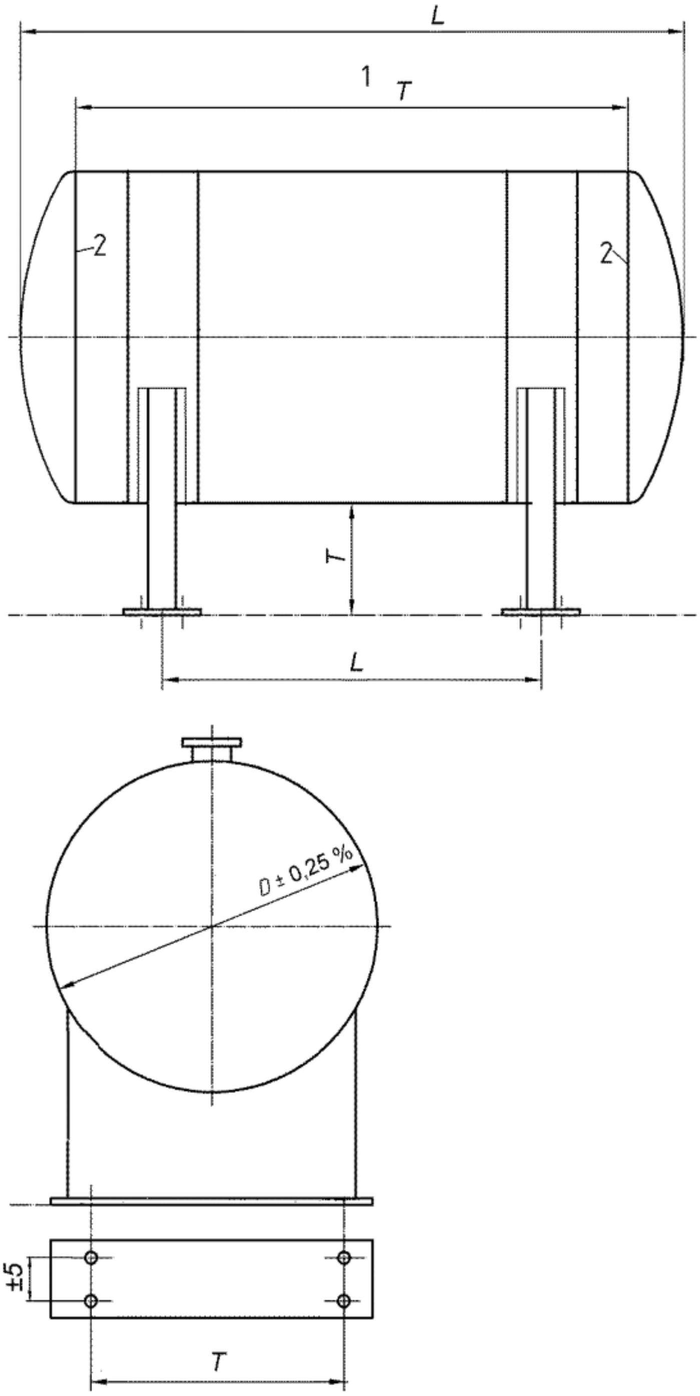
D_{in} ± 6 mm for DN 400 to DN 1000

α ≤ 1° for D_{in} ≤ 1000; for DN > 1000 according to the requirements

Reverse drawback is not allowed.

Figure 65 — Dimension tolerances

Dimensions in millimetres



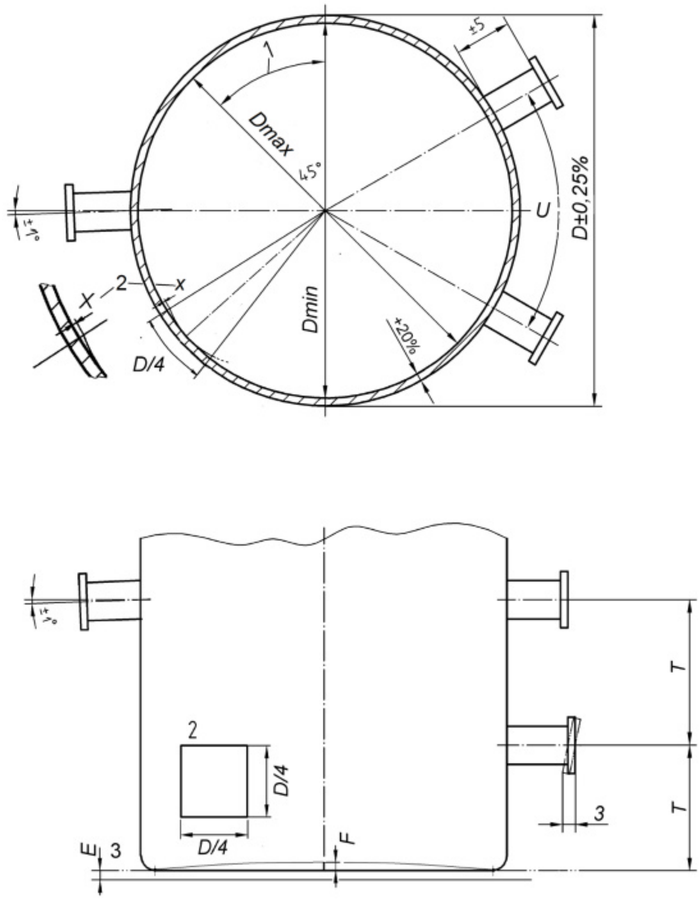
Key

1 length between tangent lines

2 tangent line

Figure 66 — Dimension tolerances for horizontal tanks or vessels

Dimensions in millimetres



Key

1 out of roundness see Table 31

2 flat spot cylinder of maximum width D/4

Maximum departure (X) from designed form

D ≤ 2500; X ≤ 1,2 %D

D > 2500; X ≥ 8mm or X ≥ 0,2 % D whichever is greater

3 evenness flat bottom

Knuckle area:

Evenness in comparison to a plan parallel level. E ± 3mm local width < 600 mm in circumferential direction

Center point flat bottom:

Allowable deflection F: F ≤ 2 %D for membrane flat bottoms F ≤ 1 %D for others if t_b < 10 mm

Figure 67 — Dimension tolerances for tanks or vessels

Table 31 — Out of roundness related to thickness/diameter ratio (t/D)

t/D	**Out of roundness**	
	I.D (Inside Diameter)	**O.D (Outside Diameter)**
0,01 <	2,0 %	1,5 %
0,01 to 0,1	1,5 %	1,5 %
given in % by $= 2 \cdot \frac{(D_{max} - D_{min})}{(D_{max} + D_{min})} \cdot 100$		

Table 32 — Permissible imperfections in laminate

A) Imperfection	B) Description	C) Inner surface (SPL) (CRL)	D) Structural laminate	E) Outer surface
Blisters	elevation of the surface of varied contour and dimensions, with a cavity beneath it	none	N.A.	maximum diameter 6 mm Height from surface not to be greater than 3 mm
Chip	a small piece broken off an edge or surface	none	N.A.	maximum 6 mm providing it does not penetrate reinforcing laminate
Crack surface	fine crack existing only on the surface of the laminate	none	N.A.	maximum length 6,5 mm. See NOTE.
Dry spot	area where the reinforcement has not been wetted with resin	none	maximum diameter 10 mm and less than 10 / m²	maximum diameter 10 mm and less than 10 / m²
Air bubble (void)	air entrapment within and between the plies of reinforcement, usually spherical in shape	maximum diameter 3 mm See NOTE.	maximum diameter 10 mm or width less than 6 mm	N.A.
Foaming	many very small bubbles in the laminate with an diameter less than 3 mm, as nest in shape (hand laminate) or as stripes in shape (winding laminate)	not more than 10 % of the surface See NOTE.	N.A	N.A.
Foreign inclusion	particles of substance included in a laminate which seem foreign to its composition.	none See NOTE.	See NOTE.	N.A
Pit/crazing/ porosity	small crater in the surface of a laminate, with its width approximately of the same order of magnitude as its depth. The crater can be closed with a layer of veil or pure resin	maximum 3 mm dia. 0,5 mm deep. Number shall not exceed 1 per 100 mm × 100 mm	N.A.	maximum diameter 3 mm and maximum depth 1,5 mm
Scratch/Score	shallow mark, groove, furrow or channel caused by improper handling or storage	maximum 0,2 mm deep	N.A.	maximum 0,5 mm deep
Delamination	separation of the layers of material	none	See NOTE.	N.A
Wrinkle	in a laminate an imperfection that has the appearance of a wave moulded into one or more plies of fabric or other reinforcement material	Maximum deviation 20 % of the wall thickness, but not exceeding 3 mm	minimum wall thickness shall be in the tolerance.	minimum wall thickness shall be in the tolerance.
Whitish stain	Small area of white colour resulting from traces of humidity	none	diameter less than 10 mm or less than 1 % of the area	N.A.
NOTE Such imperfections can be acceptable if the chemical or mechanical influences are not affected.				

17.4 Manufacture

17.4.1 General

All aspects of manufacture shall be supervised by staff having suitable technical knowledge and training for laminates see Annex E, and all materials used in the construction shall have full traceability (see 17.3).

17.4.2 Fabrication of thermoplastics liners

The details of the fabrication process shall be chosen to suit the selected thermoplastics liner.

The manufacturer should use the fabrication instruction of thermoplastic suppliers for performing and welding.

All welders shall be qualified in accordance with EN 13067.

The layout of the lining sheet should be arranged to avoid welds in corners. Longitudinal welds should be staggered as far as it is practicable. All welds should be located so as to avoid areas of high local strain, e.g. nozzles, knuckle radii and supports.

All sheet forming operations requiring high deformation such as right angled bends or small radius bends shall be performed hot at a temperature recommended by the manufacturer of the sheet.

Before welding of the sheet material commences, the edges to be welded, together with the filler rod, shall be cleaned.

In the case of glass or fabric backed materials the backing shall be stripped away for a distance of 3 mm to 6 mm on either side of the weld in order to ensure that no glass filaments are included in the weld.

Sheet welding shall be done by hot gas, heated tool, electro fusion or extrusion.

Lap welds are not permitted.

For hot gas welding an inert gas, or air (provided it is free from moisture, dirt and oil) can be used.

In all cases, the grade of filler rod shall be fully compatible with the grade of sheet being welded.

In the case of welds made using a filler rod the root run shall be tested for discontinuities and repaired if necessary before the weld is completed. A temporary earthing strip shall be provided to enable the testing to be done.

All welds shall be fully penetrating and free from notches and pin holes and shall have at least 85 % of the strength of the parent material in the case of welds made from two sides and 70 % of the strength of the parent material when made from one side, when tested in accordance with test method D.3.

The weld stand out on the side to be laminated shall not exceed 1,0 mm.

On completion all weld shall be tested for discontinuities.

There shall be adhesion between the thermoplastics liner and the laminate as specified in 7.6.2. The bond shall be achieved by one of the following methods:

a) chemical etching and priming;

b) use of selected resins;

c) use of glass, polyester or other suitable fabric backed material;

d) thermal treatment which does not degrade the parent material.

The manufacturer shall state the method to be employed in the technical specification.

17.4.3 Fabrication of laminates

The lay-up of the reinforcement i.e. the number of layers and type shall be as specified.

The total mass (g/m^2) of glass in the laminate shall be as specified but not less than - 5 %.

Laminators shall be familiar with the resin systems used by the manufacturer.

Laminators shall be familiar with the details of the lay-up required for different features e.g. nozzles, used in the fabrication of tanks and vessels.

All laminators shall be qualified by an internal or external inspection authority in accordance with Annex E. The requirements for laminators in case of PS > 0,5 bar see Annex ZA.

When reinforcement is used where the orientation of the glass fibres is not balanced, care shall be taken to ensure that high strength fibres are adequately aligned in the correct direction to give the required strength.

There shall be no addition of fillers or pigments to the laminating resin which might interfere with visual inspection of the laminate. The only exception to this requirement shall be in a case of conductive laminates.

A conducting laminate shall be applied to the back of all welds before the main laminate is applied.

A filled or pigmented resin flow coat may be required on the outside surface of the tank or vessel and this shall be applied only after inspection has been completed.

The requisite amounts of resin and curing agents and any other additive, such as accelerators or permitted filler, shall be accurately measured and thoroughly mixed. The amounts of mixed resin and reinforcement used in each laminate and the number and type of layers shall be recorded. The records shall be available as required.

Good rolling is essential but shall not disturb the distribution of the reinforcement or break the fibre strands.

It shall be ensured that good adhesion is obtained between successive layers of the laminate and between the shell and added fittings either by appropriate scheduling of the manufacturing operation or by removing the surface of any cured resin to expose the fibres.

In the case of laminates used as a chemical barrier, adjacent pieces of reinforcement shall be overlapped by not less than 25 mm. In the case of al structural laminates, adjacent pieces of laminate, including feather edged reinforcement, shall be overlapped by not less than 50 times the layer thickness but not less than 25 mm. So far as is practicable, all joints shall be staggered through the thickness of the laminate and in no case shall joints coincide in adjacent layers.

When roving is chopped for spray application, the length of individual strands shall not be less than 16 mm. For spray-up laminates with fibre lengths of 16 mm to 32 mm, the mechanical properties deviate from Table 3.

17.4.4 Imperfections in laminates

The limits for imperfections in the laminate shall be as given in Table 32. Imperfections outside the limits given in Table 32 can be repaired following an accepted specified repair procedure. Repair procedures shall be technically endorsed, recorded in the manufacturing document and made available for inspection as required.

17.4.5 Curing

All tanks and vessels shall be cured in accordance with resin manufacturers' instructions and the manufacturing schedule and shall be carried out at the manufacturers' works. Where this is not possible due to size limitations, the curing procedure shall be determined according to the design requirements and the resin system used, but before going into service. Post cure as required.

17.5 Inspection and testing after completion of fabrication

17.5.1 Visual and dimensional inspection

The general arrangement and overall dimensions shall be in accordance with the technical specification.

The thickness of any item shall not be less than that specified or on the drawing.

Details of dimensions, out of roundness, flat spots, straightness, the setting in of nozzles, squareness of flanges and flatness of faces shall be within the dimensional tolerances detailed in Table 31 and in Figures 64 to 67.

All changes of contour shall be smooth and free from irregularities and have a minimum taper of 1 in 6.

A visual survey of the tank or vessel shall be made to establish that the dimensional tolerance do not exceed the limits specified in Table 31 and Figure 64 to Figure 67, and the imperfections limitations given in Table 32.

17.5.2 Physical test to be carried out

A survey shall be of the Barcol hardness of the inner and outer surfaces to establish that the resin has reached the appropriate level of cure.

All thermoplastics linings shall be subject to a spark test before and after the static head test or pressure test as appropriate and shown to be free from discontinuities. Should discontinuities be found repairs may be carried out by removal of the damaged area and re-welding. The minimum length of any repair weld shall be 50 mm.

Vessels and tanks shall be subjected to the appropriate hydraulic pressure or static heat test at ambient temperature in accordance with Annex C.

17.5.3 Coupon testing

Coupons taken from cut-outs for branch openings shall be made available for inspection and appropriate testing provided that they are typical of the laminate they represent.

NOTE In the majority of cases such coupons will not be flat and therefore there will be difficulty in carrying out all the mechanical tests which would normally be done on a flat coupon. The properties of laminates are determined to a considerable extent by the type of glass reinforcement, the type of resin and the glass resin ratio as given in Clause 7 and the construction of the laminate as indicated in 8.4.

What is required from the production coupons is a clear indication that the properties of the laminate produced, match the properties used in design.

As an alternative to using cut outs for test coupons or in addition, specimen laminates shall be prepared by the operators on the production laminate. These specimens shall be laid up at the same time with the same materials and in the same manner as the laminate they represent and cured under the same conditions as the tank or vessel laminate.

The following tests shall be carried out on representative samples (bottoms, cylinder, etc.) to verify laminate construction and determine that the minimum properties are as used in the design calculations. When cut-outs are removed from a tank or vessel, tests shall not be done until the resin is fully cured:

a) visual examination of the cut out or coupon;

b) thickness of the laminate;

c) lap shear strength of bond where a thermoplastics liner is used (see Clause D.8);

d) glass content (see Clause D.2);

e) number of layers of glass, type and arrangement;

f) in the cases where advanced design properties are use a short term creep test (see Clause D.10);

g) Barcol hardness of the inner and outer surfaces (see Clause D.11);

h) unit tensile modulus (see Clause D.6) or flexural modulus (see Clause D.10);

i) flexural strength of laminate (see Clause D.19).

In the case of polyester type resins and vinyl ester resins the Barcol hardness of the cured resin shall be not less than 80 % of the value quoted by the resin manufacturer for the particular grade of resin used for the laminate.

If the result of the Barcol hardness test gives doubt about the state of cure of the resin a test in accordance to Clause D.13 shall be made.

17.6 Experimental Design Verification Method for pressure vessel

17.6.1 General

Where a particular design aspect cannot be fully quantified by design formulae, an experimental verification system as given below can be used.

The design of the equipment may be validated, in all or in part, by an appropriate test programme carried out on a sample representative of the equipment or category of equipment. The sample may be in the form of a vessel prototype or represent the section geometry under consideration.

This method can be used:

a) if the design temperature, *TS*, does not exceed (HDT –20 °C);

b) where documentary evidence of past experience using similar geometries and operating parameters is available;

c) as an alternative to design by formula;

d) as a complement to design by formula;

e) for cases and geometries not covered by formulae in this standard;

f) where it can be demonstrated that the maximum strain under test conditions does not exceed the strain level given in 8.2.3 for the material being used, or;

g) the vessel can withstand a pressure test of at least 5 times the design pressure, without major structural failure;

h) where all the above is subject to verification by the Inspection Authority;

i) for vessels having $PS > 0{,}5$ bar, when the product of the maximum allowable pressure *PS* and the volume *V* is less than 6000 bar*litres.

The properties of permanent joints shall meet the minimum mechanical properties specified for the materials to be joined. For all pressure equipment, permanent jointing of components which contribute to the pressure resistance of equipment and components which are attached to them shall be carried out by laminators approved in accordance to Annex E or in accordance with operating procedures specified by the manufacturer.

17.6.2 Manufacture of the prototype vessel

The prototype vessel consists of one of the following:

a) a complete vessel identical in design and manufacture to the vessel or vessels proposed;

b) a specially made test vessel designed to withstand repeated test procedures, into which any novel details can be incorporated for test purposes; or

c) the first of a series of identical production vessels.

When a manufacturer produces vessels of varying design and size the sample vessel shall incorporate details of construction representative of the range, including in particular:

d) materials and laminates;

e) dimensions;

f) methods of construction;

g) liners/chemical barrier design.

17.6.3 Tests to be applied to prototype vessels

The tests shall demonstrate resistance to specified modes of failure, and may include one or more of the following:

a) determination of general and local strains, by measurement, strain gauges or other suitable means, when the vessel is hydraulically pressurized to the required pressure;

b) determination of the fatigue strength of the vessel or detail, by cyclic variations of pressure or detail, by cyclic variations of pressure or temperature or both between stated limits;

c) determination of the factor of safety to failure which shall be a minimum of five and the mode of failure.

At high test pressures the laminate may be permeable and due consideration to this fact shall be taken into account when detailing the test procedure and determination of the failure mode.

When it is required to verify the mechanical properties of the test laminate the following tests shall be carried out:

d) ultimate tensile unit strength (see Clause D.5);

e) unit modulus (see Clause D.6);

f) Inter-laminar shear strength of the laminate (see Clause D.7);

g) bond shear and peel strength of the bond of thermoplastics lining to the laminate when used (see Clauses D.8 and D.9)

Tests on laminates of mixed types of reinforcement may not achieve the full unit load capacity of $u \times K$ due to the different strain to failure values of the individual layers of reinforcement. (Where K is the overall design factor and u is the limit unit load.)

18 Marking

Each vessel and tank designed and fabricated in accordance with this standard shall be marked according to the following:

a) manufacturer's name;

b) year of manufacture;

c) manufacturer's serial number and inspection stamp;

d) max. allowable pressure *PS*;

e) test pressure *PT*;

f) maximum/minimum allowable temperature;

g) capacity;

h) contents (main);

i) tare weight of tank or vessel;

j) CE-Marking if necessary supplemented with the number of the notified body;

k) materials of construction;

l) stamp of inspection authority where applicable.

Annex A
(informative)

Product testing for serial or batch production process

A.1 Initial type testing (ITT)

Items forming the first new product of a serial or batch production process should be subject to type testing.

In order to demonstrate that the items are fit for the intended use, tests according to Table A.1 should be carried out. Whenever there is a change in design, material or production methods (other than routine in-process adjustments) and appropriate tests should be undertaken.

Table A.1 — Typical characteristics requiring ITT

Characteristics	Tests / Requirements
Raw materials / Chemical resistance	Certificates / test records, see EN 13121–1:2003, Clause 9 for details
Composition	Specifications / laminator's record sheets / welder certificates
Laminate / Protective Liner	Destructive tests on test specimens
Fitting strength	Test on sample of similar geometry
Static electricity	Resistivity < 10^6 Ω (EN ISO 3915)
Lifting system loading	Lift test
Appearance / Surface condition	Visual acceptance criteria report
Non-visual examinations	Acoustic emission testing, spark testing, ultrasonic reports
Dimensions	Dimensions survey report
Leak tightness	Leak test report
Pressure containment	Hydraulic test report

A.2 Testing of samples

A.2.1 General

The following indicate the procedure for sample testing of serial or batch production processes (see Table A.2).

A.2.2 Batch release tests (BRT)

A.2.2.1 General

Those characteristics which are normally be batch released tested are detailed in Table A.2. Two together with the relevant minimum sampling frequency.

A batch or lot should only be released for supply after all relevant tests and inspections have been met.

If one or more items fail one or more tests or inspections, the batch or lot is rejected or the retest procedures given in A.2.3 should be performed and only if these are complied with should the batch or lot be released. If they are not complied with then the batch or lot should be rejected except in circumstances where a non-conformance can be accepted through a properly documented concession application to the purchaser/end user/approved certification body.

Table A.2 — Characteristics and minimum sampling frequencies

Characteristics	Tests / Requirements	Sampling Frequency
Raw materials/Chemical resistance	Certificates / test records	100 %
Composition	Specifications/laminator's record sheets / welders certificate	Every 12 months
Laminate / Protective layer	Destructive tests on test specimens	10 % of batch
Fitting strength	Test on sample of similar geometry	10 % of batch
Static electricity	Resistivity < 10^6 Ω (EN ISO 3915)	100 %
Lifting system loading	Lift test	10 % of batch
Non-visual examinations	Acoustic emission testing, spark testing	As required by specification
Dimensions, tolerances, out of roundness	Tolerance and dimensional survey report	100 %
Leak tightness	Leak test report	100 %
Pressure containment	Hydraulic test report	100 %
Visual inspection	Visual inspection of outer and inner surfaces with detailed report for acceptance criteria	100 %

A.2.2.2 Retesting procedures for batch release tests

The retest procedure should be to find the last product which satisfies the requirements. All products produced after that point should be rejected unless satisfactory concession request documentation can be produced together with non-conformance certification issued and endorsed by the fabricator and approved by the purchaser/end user/approved certification body.

These items may not be released onto the open market and cannot be described or designated as satisfying the requirements of this standard.

A.2.3 Process control tests

If one or more items fail one or more of the process control tests, the retest procedures detailed in the manufacturer's quality plan should be performed, given in A.2.2.2. If the retests are not complied with then the process should be investigated and corrected. If any sample fails one or more of the second retests, then the manufacturer should not mark the product as conforming to this standard until all necessary corrective actions show that all samples pass and then the marking can re-commence. Completed items produced by a non-conforming process can only be accepted by the end user in full knowledge of the non-conformance and they may not be released onto the open market. (See also A.2.2 above.)

A.3 Inspection and test records

A.3.1 General

Unless otherwise specified all records should be maintained for a minimum of 10 years.

A.3.2 Marking

See Clause 17.

A.3.3 Delivery, installation, maintenance

For guidance see EN 13121-4.

Annex B
(informative)

Derivation of laminate properties from laminate properties

B.1 General

Basic laminate properties can be determined mathematically from lamina properties as given in this annex for symmetrical laminates. When a laminate is unsymmetrical, the property values used in any analysis shall be measured.

Properties may require to be evaluated for both the axial and circumferential direction of the tank or vessel.

Woven roving cloth can only be considered when the warp or weft directions are coincident with either the meridional or circumferential direction of the tank or vessel.

B.2 Lamina/laminate thickness

The thickness of a lamina layer is given by the following formula and is shown graphically in Figure B.1.

$$t_{\mathbf{i}} = \left(\frac{1}{\rho_{\mathbf{g}}} + \frac{\left(100 - m_{\mathbf{g}}\right)}{m_{\mathbf{g}} \cdot \rho_{\mathbf{r}}} \right) \cdot 10^{3} \tag{B.1}$$

where

t_{i} is the thickness of lamina layer type *i*, mm; of mass 1 kg/m²;

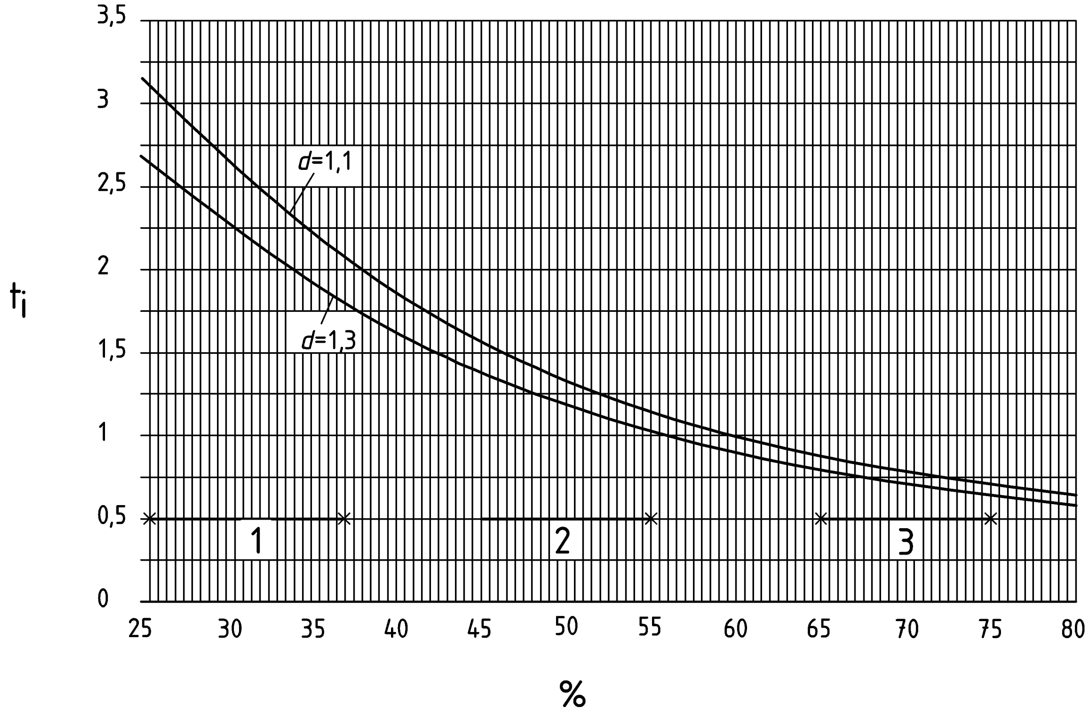
m_{g} is the percentage of glass content by mass in layer *i*, kg/m²;

ρ_{r} is the density of resin cured, kg/m³;

ρ_{g} is the density of glass (kg/m³).

The thickness, *t*, of a laminate is given by the following formula:

$$t = \sum_{i=1}^{n} t_{i} \tag{B.2}$$



Key

1 normal range for chopped strand mat

2 normal range for woven roving cloth

3 normal range for filament wound rovings

Y t_i = thickness (mm per kg/m² of glass)

X % = glass content

Figure B.1 — Relationship between thickness and glass content

B.3 Laminate modulus

The various laminate moduli can be determined as follows, if the influence of the Poisson's ratio is neglected:

$$E_{\mathbf{T}}=\frac{1}{t}\cdot\sum_{\mathrm{i}=1}^{\mathrm{n}}E_{\mathbf{i}}\cdot t_{\mathrm{i}}=\frac{1}{t}\cdot\sum X_{\mathrm{i}} \tag{B.3}$$

$$E_{\mathbf{c}}=\frac{1}{t^2}\cdot\sum_{i=1}^{n}E_{\mathbf{i}}\cdot t_{\mathbf{i}}\cdot h_{\mathbf{i}}=\frac{1}{t}\cdot\sum X_{\mathbf{i}}\cdot h_{\mathbf{i}} \quad \text{sym. laminate } E_c = 0 \tag{B.4}$$

$$E_{\mathbf{B}}=\frac{1}{t^3}\cdot\sum_{\mathrm{i}=1}^{\mathrm{n}}X_{\mathbf{i}}\cdot(12\cdot h_{\mathbf{i}}^2+t_{\mathrm{i}}^2) \tag{B.5}$$

where

E_t is the tensile young modulus of laminate, N/mm²;

E_c is the coupling modulus of laminate, N/mm²;

E_b is the flexural modulus of laminate, N/mm²;

E_i is the young modulus of the i-th layer, in N/mm²;

t_i is the thickness of the i-th layer;

n	is the number of lamina layers in laminate;
h_i	is the distance of the i-th layer from the mid plane of laminate; see Figure B.2
index Φ	designates the property in the circumferential direction;
index x	designates the property in the axial direction;
X_i	is the unit tensile modulus of laminate N/mm.

The values for the modulus of the individual layers E_i shall be derived from the values given in Table 3 or measured values determined in accordance with 7.9.

B.4 Determination of laminate flexural stiffness

The laminate flexural stiffness parameter B is given by the genera following formula:

$$B = \sum E_{\mathbf{i}} \cdot t_{\mathbf{i}} \cdot \left(\frac{t_{\mathbf{i}}^2}{12} + h_{\mathbf{i}}^2 \right) = \sum X_{\mathbf{i}} \cdot \left(\frac{t_{\mathbf{i}}^2}{12} + h_{\mathbf{i}}^2 \right) \tag{B.6}$$

To obtain the flexural stiffness in the circumferential direction B_Φ the individual values of E_i, t_i in the circumferential direction are used. To obtain the flexural stiffness in the axial direction B_x, then the individual properties in the axial direction are used.

B.5 Determination of laminate strains from load resultants

B.5.1 For isotropic constructions, the relevant strains in the laminate are given by the following formulae:

$$\varepsilon_\Phi = \frac{q_\Phi}{E_\Phi \cdot t} \pm \frac{6 \cdot M_\phi}{E_\Phi \cdot t^2} \tag{B.7}$$

and

$$\varepsilon_{\mathbf{x}} = \frac{q_{\mathbf{x}}}{E_{\mathrm{x}} \cdot t} \pm \frac{6 \cdot M_{\mathbf{x}}}{E_{\mathbf{x}} \cdot t^2} \tag{B.8}$$

B.5.2 For a shell laminate constructed from lamina layers having anisotropic properties, the maximum strains are given by,

$$\varepsilon_\Phi = \frac{q_\Phi}{E_\Phi \cdot t} \pm \frac{6 \cdot M_\Phi}{E_\Phi \cdot t^2} \cdot \left(\frac{2 \cdot E_{\mathbf{c}\Phi}}{E_\Phi} \pm 1 \right) \tag{B.9}$$

and

$$\varepsilon_{\mathbf{x}} = \frac{q_x}{E_x \cdot t} \pm \frac{6 \cdot M_{\mathbf{x}}}{E_{\mathbf{x}} \cdot t^2} \cdot \left(\frac{2 \cdot E_{\mathbf{cx}}}{E_{\mathbf{x}}} \pm 1 \right) \tag{B.10}$$

where

q_x	is the force per unit length in the axial direction, N/mm
q_Φ	is the force per unit length in the circumferential direction, N/mm
M_x	is the moment resultant per unit length in the axial direction, Nmm/mm
M_Φ	is the moment resultant per unit length in the circumferential direction, Nmm/mm
ε_x	is the strain in the axial direction
ε_Φ	is the strain in the circumferential direction

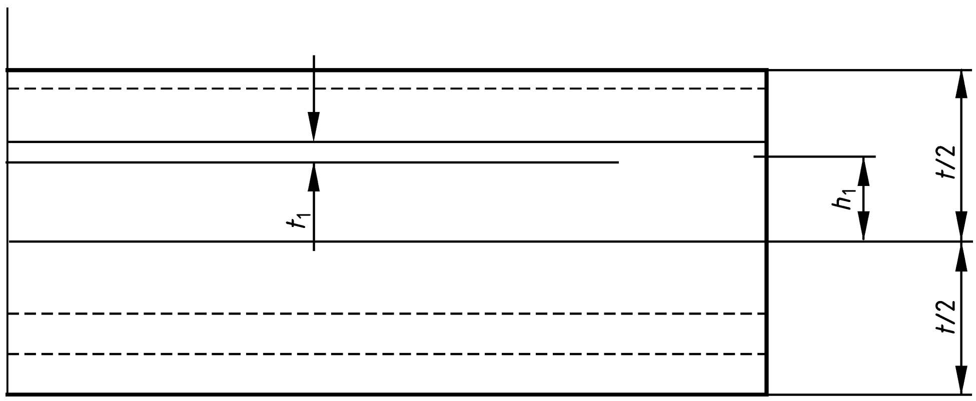


Figure B.2 — n-ply laminated beam details

Annex C
(normative)

Pressure and leak testing

C.1 General

C.1.1 With the approval of the inspecting authority where appropriate, all individually designed tanks and vessels shall be subject to a static head test or a pressure test as required in the design specification.

C.1.2 The completed tank, or vessel shall be tested at the manufactures works. However, regardless of whether or not such testing has been carried out at the manufacturer's works, the tank or vessel shall be tested after delivery and installation.

C.1.3 During testing no part of the tank or vessel shall be subject to strain levels greater than the limiting values determined from Clause 8.

C.1.4 Adequate support shall be provided for tanks and vessels during testing. Flat bottomed tanks and vessels shall be placed on a smooth, flat horizontal surface capable of carrying the full load of the tank or vessel and contents. When necessary, arrangements shall be made to hold the tank down during the test.

C.1.5 All pressure gauges shall be accurate to ± 2 %.

C.1.6 All vessels subject to a pressure test shall be subject to an examination for leaks before the start of the pressure test.

C.1.7 All pressure tests shall be done in a controlled fashion such that the pressure is increased gradually.

C.1.8 In all cases the minimum duration of the test shall be 12 h for static head test and one hour for hydraulic pressure test

C.1.9 During the tests the outside of the tank or vessel shall be inspected for evidence of leaks and abnormal deformation of the shell. The position of any defect shall be recorded.

C.1.10 At the conclusion of a static head test or pressure test the inside surface shall examined for cracking or crazing of the resin.

One completion of static head tests or pressure tests Thermoplastics liners shall be examined for damage and subject to a spark test.

C.1.11 With the approval of the inspecting authority defects found during testing may be repaired. Following repairs the tank or vessel shall be retested.

C.2 Open top tanks

C.2.1 All openings e.g. nozzles shall be sealed prior to the test.

C.2.2 Depending upon the intended duty the tank shall be filled with water or an appropriate solution of higher density than water to the highest operating level. A commercial dye may be added to the liquid to facilitate the identification of leaks.

C.3 Static head test of closed tanks and vessels

C.3.1 Contents having a specific gravity up to 1,0

In the factory under the responsibility of the tank manufacturer the tank shall be filled with water to the highest point of the tank including all flanged connections for a period of at least 12 h. The tank shall be leak tight and an internal and external visual inspection shall reveal no defects. Alternatively, with the agreement of the tank operator this test may be performed at the site under the responsibility of the tank operator or installation company.

C.3.2 Contents having a specific gravity greater than 1,0

With the agreement of the tank operator, the tank may be tested as follows;

Option A

The tank shall be filled with water to the highest point of the tank including all flanged connections. A standpipe will be attached to the top of the tank and filled with water to a level that equates to the specific gravity of the content. The water filling will be maintained for a period of at least 12 h. The tank shall be leak tight and an internal and external visual inspection shall reveal no defects.

Option B

This test may be performed without the standpipe in two steps as follows:

a) In the factory under the responsibility of the tank manufacturer, or on site under the responsibility of the tank operator:

   Fill the tank with water to the highest point of the tank for a period of 12 h. The tank shall be leak tight and an internal and external visual inspection shall reveal no defects.

b) At the site under the responsibility of the tank operator:

   Fill the tank with the chemical to be stored for a period of 12 h. The tank shall be leak tight and an external visual inspection shall reveal no defects. The tank manufacturer should state the need for the 'on site' test in the order confirmation and in the operating manual/drawing of the tank.

In the case of flat bottomed tanks and vessels, the holding down arrangement for the test shall conform to Clause 14.

C.4 Hydraulic pressure test

C.4.1 Test done in the working attitude

Vessels subject to pressure shall be hydraulically tested to 1,3 times the calculation pressure and carried out at 20 °C or ambient temperature.

NOTE The influence of temperature is neglected in this test, due to the associated increase, in the short-term, of the allowable elongation of the resin as the temperature increases.

C.4.2 Tests done in other than the working attitudes

Vertical vessels may have to be pressure tested in a horizontal position. In such cases consideration shall be given to the method of supporting the vessels during test and to the resulting static and pressure loading on the various parts of the vessel.

During the test in no part of the vessel the existing strain shall exceed the limit strain given in 8.2.3.

C.4.3 Pneumatic testing

Pneumatic testing shall be used only when hydraulic testing is not possible.

Gas pressure tests shall only be allowed up to a test pressure of PT ≤ 0,7 bar or limited by PT × V ≤ 6 000 bar·dm^3.

A pressure relief valve shall be fitted to the vessel during the test to avoid the risk of over pressurization.

Due precautions shall be taken for the protection of personnel and equipment in the event of a failure of the vessel during such a test.

C.4.4 Vacuum test

Vessels designed to operate under vacuum conditions shall, where possible, be tested under vacuum or applied external pressure to simulate the vacuum conditions. In either case the resulting external pressure on the vessel shall be 1,3 times the design external pressure, and the strain values given in 8.2.3 shall not be exceeded. The maximum vacuum test shall be limited to full vacuum.

Annex D
(normative)

Methods of tests

D.1 General

D.1.1 Tests

This Annex describes methods for the testing of resins, laminates and thermoplastics for vessels and tanks in reinforced plastics.

Test	Property to be determined
D.2	Loss on ignition
D.3	Tensile strength of thermoplastics welds
D.4	Bend test for thermoplastics welds
D.5	Ultimate unit tensile strength of laminates
D.6	Unit tensile modulus of laminates
D.7	Inter laminar shear strength of laminates
D.8	Lap shear strength of bond between thermoplastics lining and laminate/or between laminates
D.9	Peel strength of bond between laminate layers
D.10	Short-term creep test
D.11	Barcol hardness
D.12	Determination of electrical resistivity
D.13	Glass transition temperature of cured resins
D.14	Spark test of thermoplastic welds
D.15	Long term flexural creep test (or unit flexural modulus E_{1h} and E_{24h} test)
D.16	Hardness of rubber
D.17	Flash point test
D.18	Heat deflection temperature test
D.19	Ultimate unit flexural strength of laminates (bending test)
D.20	Pull off strength (Adhesion) test

When controlled conditions are required for testing then EN ISO 291 shall apply.

D.1.2 Accuracy of test equipment

Testing machines shall be calibrated in accordance with EN ISO 7500-1.

Extensometers, including ancillary or autographic equipment, shall be calibrated in accordance with EN ISO 9513.

D.2 Loss on ignition

The form and the number of test pieces and the test procedure shall be as specified in EN ISO 1172.

D.3 Tensile strength of thermoplastics welds

The form and number of test pieces and the test procedure shall be as specified in EN ISO 527-4.

D.4 Bend test for thermoplastics welds

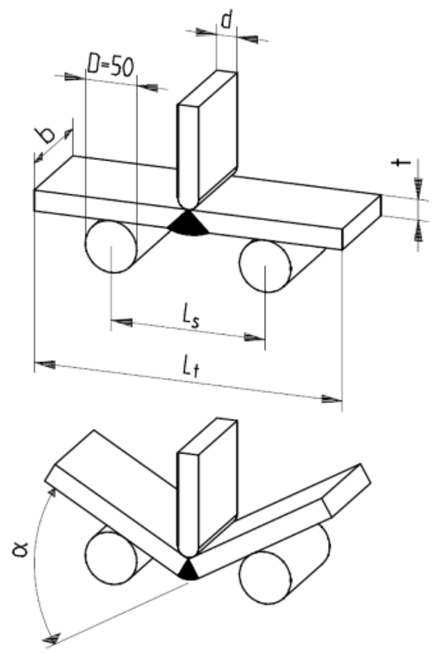
D.4.1 Introduction

The bend test is used in conjunction with other tests to assess the quality of welds in thermoplastics sheets.

D.4.2 Test arrangement

The schematic arrangement for the test is illustrated in Figure D.1.

Dimensions in millimetres



Key

- α flexural angle
- b width of the test plate
- d thickness of the loading beam which has a semi-circular end, radius = 0,5·d
- D diameter of rod, 50 mm
- t thickness of the test plate
- L_s distance between supports
- L_t total length of test piece

Figure D.1 — Schematic diagram of the bend test

D.4.3 Test pieces

Five test pieces shall be prepared from each weld being tested. The dimensions of the test pieces shall be in accordance with Table D.1. The thickness of the flexural beam is also defined which has a semi-circular end; d w which has a semi-circular end; radius 0,5 d.

Table D.1 — Dimension of test pieces

Test pieces mm			**Distance between supports** mm	**Thickness of flexural beam** mm
Thickness *t*	Width *b*	Length L_t	L_s	*d*
3 < *t* ≤ 5	20	150	80	4

D.4.4 Method of test

The test pieces shall be conditioned according to EN ISO 291.

A load shall be applied to the centre of the root of the weld. The rate of application of that load shall be in accordance with Table D.2.

Table D.2 — Test speeds for some thermoplastics

Material	**Test speed** mm/min
PE, PP-B, PP-R	50
PP-H, PVDF, ECTFE	20
PVC-U and PVC-C	10

D.4.5 Requirements from flexural test

The minimum flexural angles for the respective materials given in Table D.3, shall be reached without any cracking occurring in the weld or weld area for all samples tested.

Table D.3 — Requirements for the flexural angle α

Lining material	**Thickness** t (mm)	**Hot gas welding** α	**Heated tool welding** α
PVC-U and PVC-C	3	≥ 30°	≥ 75°
PP-H, PP-B	3 to 6	≥ 50°	≥ 85°
PP-R	3 to 6	≥ 85°	≥ 160°
PVDF, ECTFE, FEP, PFA	2,3 to 3	≥ 80°	≥ 80°

D.4.6 Test report

The test report shall contain the following information:

a) standard used;

b) origin of the test pieces;

c) date of preparation of the test pieces;

d) dimensions of the test pieces;

e) visual assessment of the welds;

f) conditioning of the test pieces;

g) speed of application of the load;

h) flexural angle;

i) visual assessment of the test pieces after the test including any fractures;

j) date of the test.

D.5 Ultimate tensile unit strength of laminates

D.5.1 Test pieces and procedure

The form and number of test pieces and the test procedure shall be in accordance with EN ISO 527-4.

D.5.2 Simple laminates

If comparison with the values given in Table 3 is required, then each type of reinforcement shall be tested individually and computed by using the following formula:

$$U = \frac{F}{b \cdot m} \tag{D.1}$$

where

b	is the mean initial width of test specimen gauge length, in mm;
F	is the maximum tensile force, in N;
m	is the mass of the single type of reinforcement of the glass specimen, in kg/m^2;
U	is the ultimate tensile strength, in N/mm per kg/m^2 glass.

D.5.3 Combined laminates

Where only combined laminates are available (e.g. when testing cut outs from a vessel) the specimen may not achieve the full tensile unit strength as indicated by the individual layers.

The minimum properties of Table 3 can then be assessed by determination of the minimum load that the test specimen shall carry without failure.

NOTE The different strain capabilities of each type of layer will cause failure in one type before full load is achieved in other types of reinforcement. The resulting load transfer will cause premature failure of the specimen.

For each type of layer the strain ε_i of a layer of type i at the minimum ultimate unit strength shall be determined from the following formula:

$$\varepsilon_i = \frac{U}{X_i} \tag{D.2}$$

where

X_i is the unit modulus of layer type i, N/mm per kg/m^2

The lowest strain ε_{min} shall then be used to determine the tensile unit strengths of the other types of reinforcement at this strain level from:

$$U = X_i \cdot \varepsilon_{min} \qquad \text{(D.3)}$$

The resulting tensile unit strength of each layer shall then be multiplied by the total mass of each type of reinforcement and the width of the specimen to obtain the minimum required load.

D.6 Unit tensile modulus of laminates

The form and number of test specimens shall be in accordance with EN ISO 527-4 and the speed of separation shall be 2 mm/min.

Apply a small initial tensioning force (not exceeding 10 % of the expected force at 0,25 % strain) to straighten the test piece and at this force set the indicating device to zero.

Increase the strain steadily until an extension, Z_x of 0,1 mm is reached on the specimen gauge length of 50 mm (0,25 % strain) and note the value of P_x at this point.

Where it is expected that 0,25 % strain may give rise to danger of fracture of the test piece, it is permissible to carry out the test at 0,1 % strain (corresponding to an apparent extension of 0,05 mm over the 50 mm gauge length).

Reduce the initial force to straighten the specimen correspondingly.

The unit modulus of the laminate, X_{lam} shall be determined from Formula (D.4):

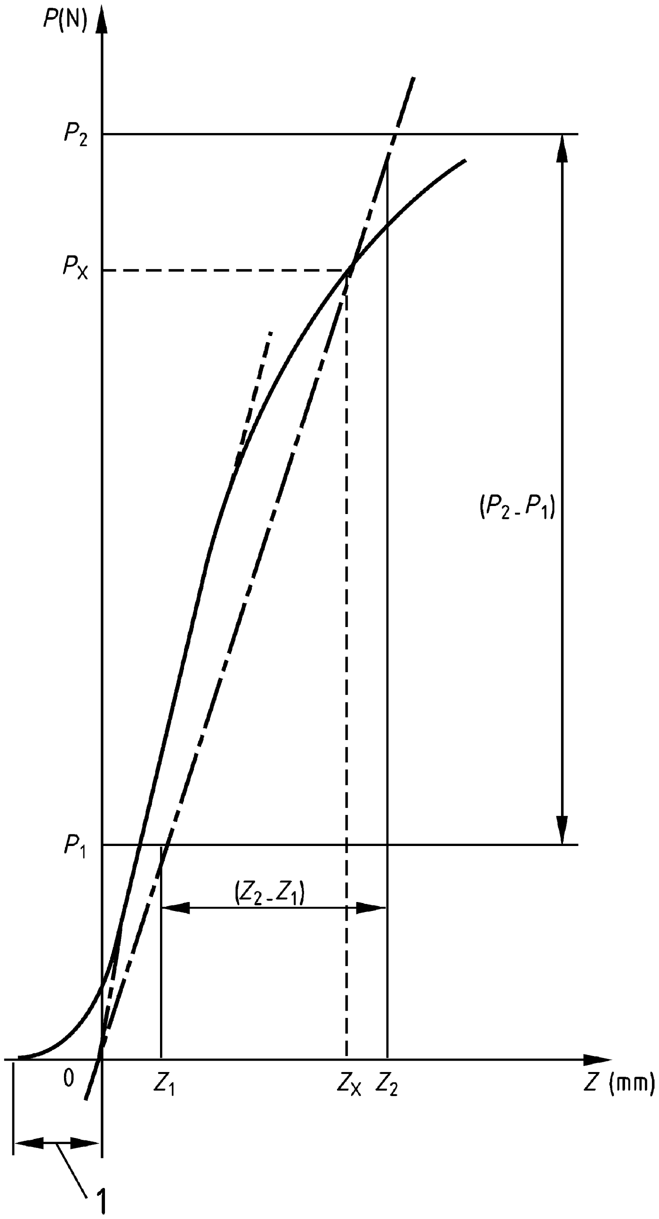
$$X_{\mathbf{lam}} = \frac{(P_2 - P_1)}{(Z_2 - Z_1)} \cdot \frac{L}{b} \qquad \text{(D.4)}$$

where

b is the mean width of the test specimen over the gauge length (mm);

L is the gauge length of the specimen, 50 mm;

$(Z_2\text{-}Z_1)$ is the change in apparent extension, corresponding to a change in applied force $(P_2\text{-}P_1)$ (see Figure D.2), in millimetres.



Key

1 eventual adjustment of the position of the origin

Figure D.2 — Chart of apparent extension, *Z*, versus force *P*

For a laminate consisting of a single type of reinforcement the value of X_i, in N/mm per kg/m² glass, is given by Formula (D.5):

$$X_i = \frac{X_{lam}}{m} \qquad (D.5)$$

where

m is the mass of the single type of reinforcement of glass in the specimen, in kg/m².

D.7 Inter laminar shear strength of laminates

D.7.1 Form of test specimen

Test specimens shall be of the form and dimensions shown in Figure D.3. They shall have a minimum thickness of 3 mm and the length of the specimens may be varied to accommodate the requirements of the available testing equipment. The edges of the specimen shall be smooth but not round or bevelled. Two parallel cuts, one in each opposite face and between 5 to 12 mm apart, shall be sawn across the entire width of the specimen. They shall be as narrow as practicable and shall be parallel within 0,8 mm. The incision shall be half the laminate thickness plus the thickness of one layer or half the laminate thickness + 0,1, – 0 mm if the number of layers or thickness per layer is unknown.

D.7.2 Number of test specimens

Five specimens shall be tested when they consist of laminates made entirely from CSM or by spraying. Whenever the laminates contain woven roving or other directional reinforcement, 10 specimens, five parallel with each principal axis of anisotropy, shall be tested.

D.7.3 Procedure

Condition the specimens according to EN ISO 291.

Insert the specimen in the testing machine and load it until rupture occurs in the form of a shear-type failure with some peeling at the interlaminate bond.

Ensure that the speed of testing, i.e. the relative rate of motion of the grips or test fixtures during the test, is within the range of 5,0 mm/min to 6,5 mm/min.

D.7.4 Results

The inter-laminar shear strength, τ_s (in N/mm^2), shall be determined from the following formula:

$$\tau_s = \frac{W}{a \cdot b} \quad \text{(D.6)}$$

where

W	is the determined load, in N
a	is the distance between saw cuts, (5 mm ≤ a ≤ 12 mm)
b	is the width of the specimen, (10 mm ≤ b ≤ 25 mm)

The inter-laminar shear strength of the laminate under test shall be reported as the arithmetic mean of the lap shear strengths of the specimens in accordance with 7.6.

D.7.5 Report

The report shall state:

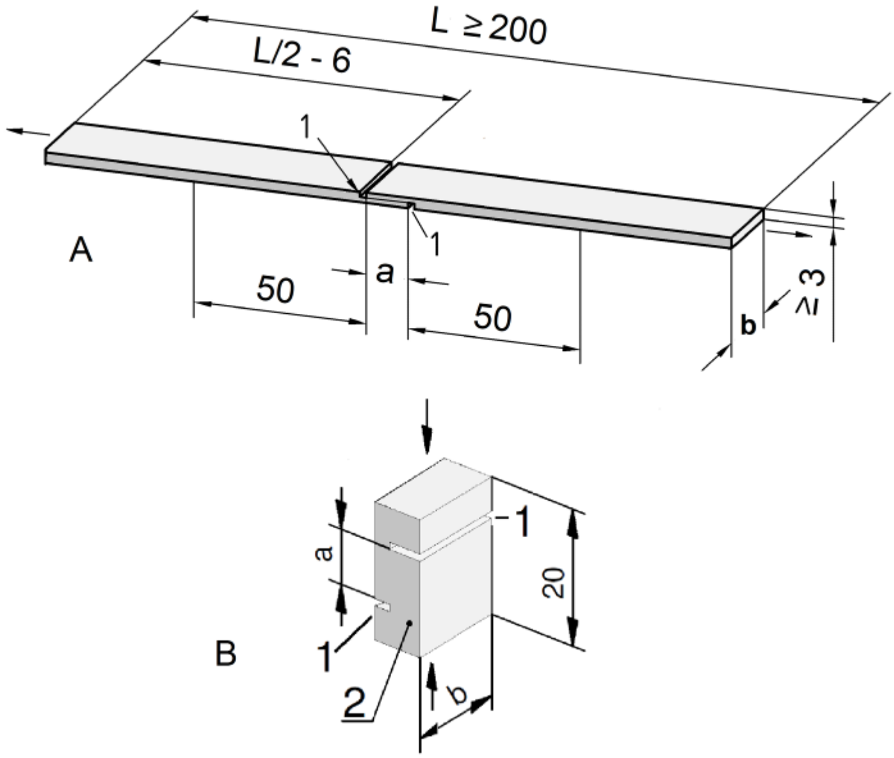
a) standard used;

b) the inter-laminar shear strength of the laminate;

c) the individual test results;

d) the conditioning of the specimens.

Dimensions in millimetres



Key

1 thin saw cut

2 laminate

Figure D.3 — Test specimen for the determination of inter laminar shear strength of a laminate, A specimen for tensile test and B for compression test

D.8 Lap shear strength of bond between thermoplastics lining and laminate or between laminates

D.8.1 Form of the test specimen

The specimen shall be cut from the full thickness of the laminate and lining and shall be of the form and dimensions shown in Figure D.4.

D.8.2 Number of test specimens

A minimum of five specimens shall be used.

D.8.3 Procedure

Make two thin saw cuts in the specimen at right angles to the major axis, 5-12 mm apart and symmetrically about the transverse centre line. Make one cut through the full thickness of the thermoplastics material but not into the laminate and the second through the full thickness of the laminate but not into the thermoplastics material.

Condition the specimens and carry out the tests according to EN ISO 291.

Clamp the specimen in the serrated jaws of a suitable testing machine and in axial alignment with the direction of pull. Strain the specimen at a constant rate of (25 ± 6) mm/min.

The shear strength of the bond shall be calculated from the maximum load and the area under shear and expressed in N/mm^2. The bond shear strength of the material under test shall be reported as the arithmetic mean of the bond shear strength of the specimens in accordance with requirements of 7.6.

D.8.4 Report

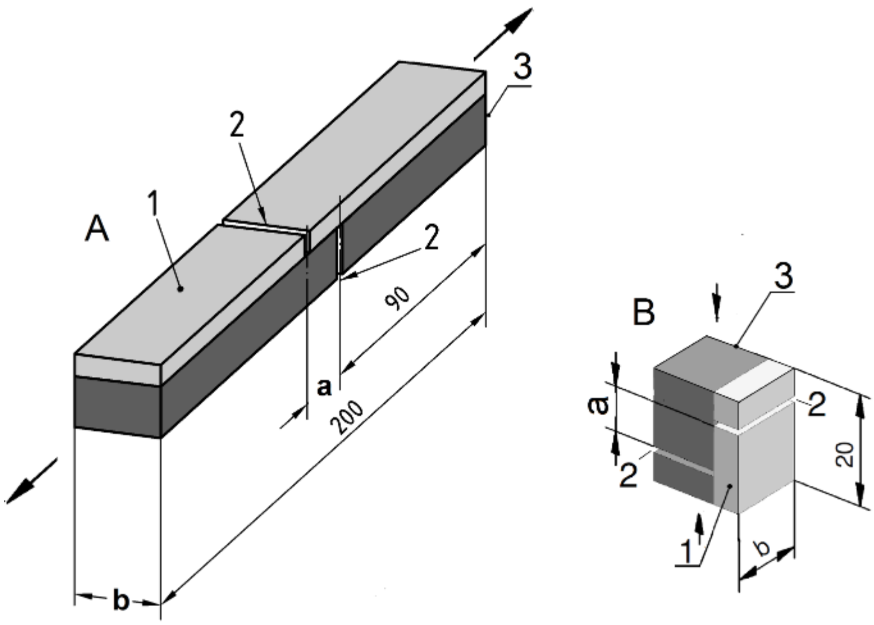
The report shall state:

a) standard used;

b) the bond shear strength of the thermoplastics lining-laminate combination;

c) the individual test results.

Dimensions in millimetres



Key

1 lining or laminate material

2 thin saw cut

3 base laminate

Figure D.4 — Test specimens for the determination of bond strength between thermoplastics lining and laminate, or between laminates. A specimen for tensile test and B for compression test

D.9 Peel strength of bond between laminate layers

D.9.1 Form of the specimen

The specimen shall be cut from the full thickness of the laminate and shall be of the form and dimensions shown in the figures. The saw cut shall be as thin as possible and shall be made along the interface between the two laminate layers whose peel strength is required (for example, between a main and an overlay laminate).

D.9.2 Number of specimens

The number of specimens used shall be in accordance with the requirements of 7.6 or 7.7.

D.9.3 Procedure

The test specimens shall be conditioned and the tests carried out in accordance with EN ISO 291.

Grip the main laminate horizontally in the jaws of a vice or a clamp and apply the load to the secondary laminate by means of weights or a suitable testing machine until the load is just sufficient to peel the two laminate layers apart. During this operation ensure that the plane of the load remains normal to the laminate interface, see Figure D.5. The peel strength of the load shall be calculated from the total load at peel and the measured width of the specimen and expressed in Newton per millimetre width. The bond peel strength shall be reported as the arithmetic mean of the bond peel strengths to the test specimens in accordance with the requirements of 7.6 and 7.7.

D.9.4 Report

The report shall state:

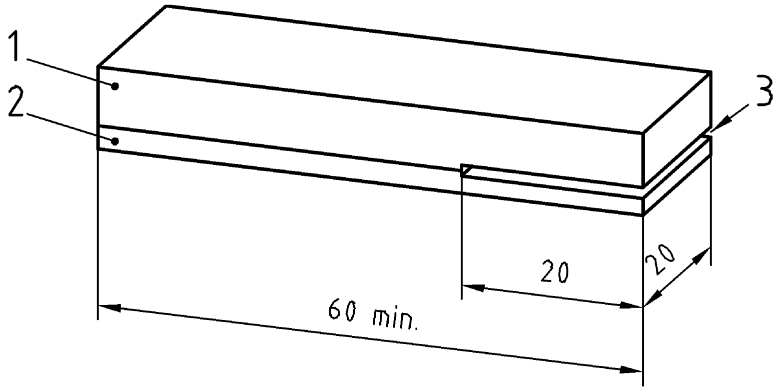
a) standard used;

b) the bond peel strength of the laminate;

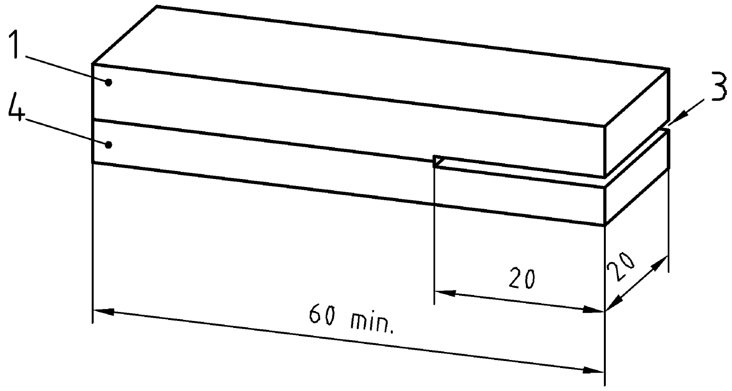
c) the lay-up of the laminates incorporated in the test specimens;

d) the individual test results.

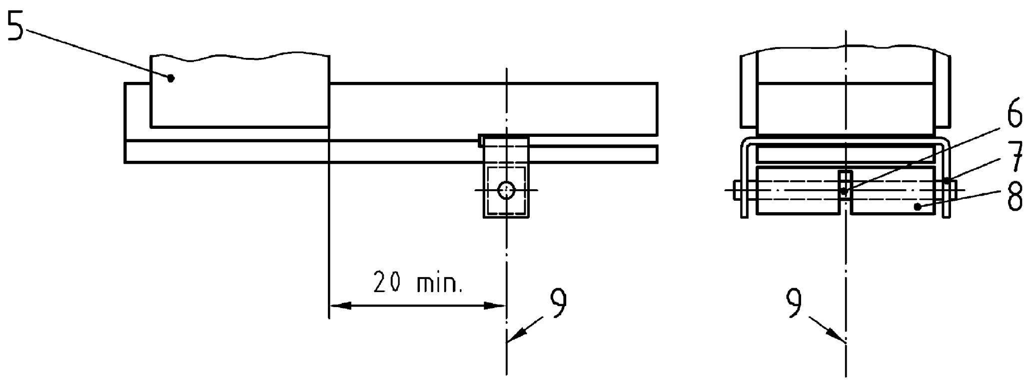
Dimensions in millimetres



a) Thermoplastics-lined laminate specimen



b) Laminate/laminate specimen



c) Assembly

Key

1	laminate	2 thermoplastics lining
3	thin saw-cut	4 secondary laminate
5	vice jaw or clamp	6 stirrup
7	pin	8 yoke
9	load (scale pan and weights or testing machine) machine)	

Figure D.5 — Test for determination of peel strength of bond

D.10 Flexural short-term creep test (flexural modulus E_{1h} and E_{24h} test)

D.10.1 General

The flexural short-term creep test shall be used in the production control to quickly verify the factor A_5 as given by Table 7 or as determined by the long term creep test in accordance with Clause D.15. The short-term creep test does not supersede the long term creep test specified by Clause D.15 to determine the factor A_5 for the advanced design (see 7.9.5.6). The short-term creep test is based on EN ISO 899-1 and EN ISO 899-2 and on EN ISO 14125, which are methods of determining the flexural properties of a laminate by three point loading. Evaluation of the short-term creep properties is determined by loading freely supported beams loaded at mid span over a period of 24 h in order to verify the suggested long term behaviour of the laminate under static load.

D.10.2 Definitions

Deflection: The distance, *d*, over which the top or bottom of surface of the test piece at mid span has deviated under static flexural load from its original position.

Creep rate: The creep rate, $f_{c,\,24\,h}$, defines a representative part of the creep curve within 1 h and 24 h, suggested to be characteristic for long term behaviour of the laminate, and shall be calculated by the formula given in D.10.6.

D.10.3 Test device

Standard testing device with the position of test piece, shown schematically in Figure D.6, which can be operated to apply a constant load. The supports and the loading nose shall be parallel to each other.

The radius, r_1, of the loading nose and the radius, r_2, of the supports shall be as follows:

$$r_1 = (5 \pm 0{,}1)mm,$$

$$r_2 = (2 \pm 0{,}2)mm$$

The distance between supports, *L*, shall be adjustable as required.

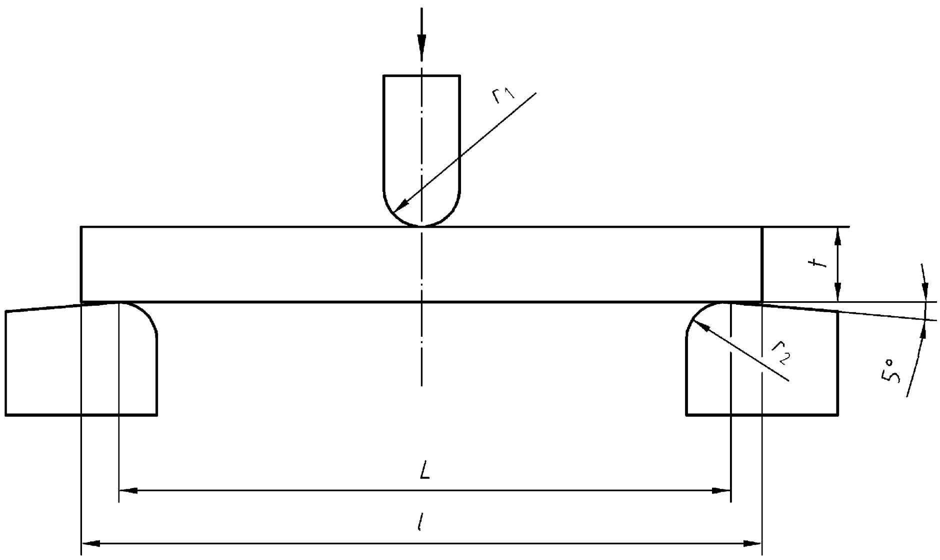


Figure D.6 — Detail of testing device

D.10.4 Test pieces

The test pieces shall be taken from coupons of cut outs from the finished laminate or from prepared specimen (see 17.6.3). The test pieces may be with or without chemical barrier.

The thickness t of the test piece shall be the thickness of the structural laminate, any chemical corrosion barrier or lining having been removed.

The width b of the test piece shall be equal $(2,5 \pm 0,5) \cdot t$. The length l of the test piece shall be equal $L + 4 \cdot t$. The distance L between supports shall be equal $(18 \pm 2) \cdot t$.

In the case of laminate type test a minimum of five test pieces shall be prepared.

In the case of production control tests, a minimum of three test pieces shall be prepared.

If the laminate has a significant difference in flexural properties in two principal directions test pieces shall be prepared for each direction.

All test pieces shall be in the same state of cure as the completed tank or vessel and shall be conditioned in accordance with EN ISO 291.

D.10.5 Procedure

The test pieces shall be placed symmetrically across the parallel supports (see Figure D.6) ensuring that the length of the test pieces is at right angles to the supports. The distance between the supports, L, shall be as required in D.10.4.

The flexural stress from the load N applied shall be 20 ± 2 % of the ultimate flexural strength of the laminate as determined from Test D.19. Where historical data of the flexural strength of the laminate is available, this value may be used in place of carrying out a specific flexural test.

The deflections of the test pieces shall be measured when the load is first applied within 0,1 h, then after 1 h, and then after 24 h and recorded to three decimal places.

D.10.6 Calculation

The creep rate in % shall be calculated using the following formula. The result may be expressed graphically as shown in Figure D.7.

$$f_{c,24h} = 100 \cdot \frac{(d_{24} - d_1)}{d_1} \quad \text{(D.7)}$$

where

d_0 is the initial deflection under static load;

d_1 is the deflection after 1 h under static load;

d_{24} is the deflection after 24 h under static load.

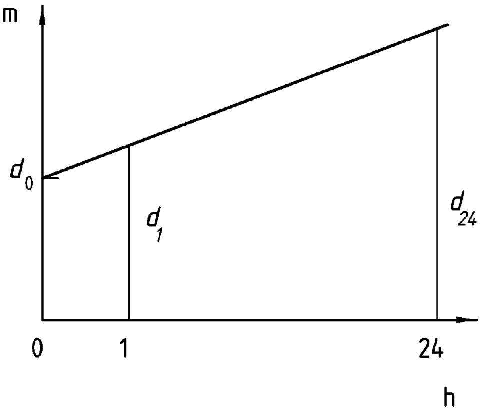


Figure D.7 — Diagram of short-term creep test

The corresponding numbers of creep rate and factor A_5 are given in Table D.4.

Table D.4 — Corresponding numbers of creep rate and factor A_5

A_5	1,25	1,30	1,40	1,50	1,60	1,70	1,80	1,90	2,00	2,20	2,40
$f_{c,24,\ 6min}$ %	5,00	5,92	7,65	9,29	10,84	12,33	13,74	15,10	16,40	18,85	21,14

The above table has the following relationship: $A_5 = (1+f_{c,24\ h}/100)^{4,565}$ based on the 6 min.–value = 0,10 h

$$E_{24h} = \frac{N \cdot L^3}{4 \cdot b \cdot t^3 \cdot d_{24}} \quad ; \quad E_{1h} = \frac{N \cdot L^3}{4 \cdot b \cdot t^3 \cdot d_1} \qquad \text{(D.8)}$$

D.11 Barcol hardness

The test procedure shall be in accordance with EN 59.

D.12 Determination of electrical resistivity

The test procedure shall be in accordance with EN ISO 3915.

D.13 Glass transition temperature by DSC of cured resin

The test procedure shall be in accordance with EN ISO 11357-2.

D.14 Spark testing of thermoplastics welds

D.14.1 General

The purpose of this test is to establish that the welds in thermoplastics liners after fabrication are free from discontinuities.

The approach to continuity testing is to consider the thermoplastics lining as an electrical insulator and search for holes or cracks by trying to make electrical contact through the lining to an earth.

The dielectric properties of the thermoplastic liners can change over the course of the operation time of the tank or vessel.

Attention: For this reason the spark test method is not reliable once a tank has been in service.

D.14.2 Apparatus

The test equipment shall be a high frequency instrument with an AC source for PVC-U and PVC-C, PVDF and PP and a DC or AC source for FEP, PFA and E-CTFE materials. DC voltage is more accurately controllable for such materials where lower voltage are required, see D.14.3.

D.14.3 Procedure

The earth contact at the back of the weld may be a temporary metal strip, which shall be removed after test and before any reinforcement is applied to the liner or a conducting layer of resin, which may contain carbon veil.

High frequency instruments have a single probe from which there is a corona discharge. The DC instruments have a probe but also require an earth return. When a fault is located the circuit is closed and an alarm is trigged.

The test voltage for the different materials shall be:

— For PVC-U and PCV-C: 5 kV/mm thickness for all liner thicknesses;

— For PP, PVDF, FEP, PFA and ECTFE: 4 kV/mm thickness for liner thickness > 3mm;

— For PP, PVDF, FEP, PFA and ECTFE: 3,5 kV/mm thickness for liner thickness ≤ 3mm.

Any retesting of such welds shall be carried out at a reduced voltage in accordance with the recommendations of the sheet/tube manufacturer.

The rate of travel of the probe over the surface of the weld shall be between 100 mm/s and 200 mm/s. and care shall be taken to prevent dwelling of probe at one location for too long.

D.15 Long term flexural creep test

D.15.1 General

The test is for the evaluation of the creep behaviour of freely supported beams loaded at mid span over a period of minimum 1 000 h and is based on method A under three-point loading of EN ISO 14125. This evaluation is representative of the long term behaviour of laminates under permissible static load at room temperature.

D.15.2 Definitions

Deflection: The distance, *d*, over which the top or bottom of surface of the test pieces at mid span has deviated during flexure under static load from its original position.

Creep factor: The creep factor, $f_{c,2x10^5}$, is defined by the creep line within 10^{-1} and 10^3 h plotted in log ε / log *t*-chart, and linear extrapolated to 2×10^5 h. The creep factor $f_{c,2x10^5}$ shall be calculated by the formula given in D.15.6.

D.15.3 Test device

The standard testing device with the position of test pieces, shown schematically in Figure D.6, can be operated to apply a constant load. The supports and loading nose shall be at least as wide as the test piece and shall be parallel to each other. The radius, r_1, of the loading nose and the radius, r_2, of the supports shall be as follows:

— r_1 = (5 ± 0,1) mm,

— r_2 = (2 ± 0,2) mm.

The distance between supports, L, should be adjustable.

D.15.4 Test pieces

The test pieces shall be taken from coupons of cut outs from the finished laminate or from prepared specimen (see 17.6.3). The test pieces may be with or without chemical barrier.

The thickness t of the test piece in shall be the thickness of the structural laminate, ignoring any chemical barrier when present.

The width of the test piece shall be equal $(2{,}5 \pm 0{,}5)\cdot t$.

The length l of the test piece shall be equal $L + 4\cdot t$.

The distance L between supports shall be equal $(18 \pm 2)\cdot t$.

In the case of laminate type test or for advanced design a minimum of five test pieces shall be prepared.

If the laminate has a significant difference in flexural properties in two principal directions test pieces shall be prepared for each direction.

All test coupons shall be in the same state of cure as the completed tank or vessel and shall be conditioned in accordance with EN ISO 291.

D.15.5 Procedure

The test piece shall be placed symmetrically across the parallel supports (see Figure D.6) ensuring that the length of the test piece is at right angles to the supports. The distance between the supports, L, shall be as required in D.15.4.

The load applied shall be (20 ± 2) % of the ultimate flexural strength of the laminate as determined from test D.20 or historical data and shall be maintained for a minimum of 24 h.

The deflection of the test piece shall be measured first after 0,1 h (6 min) after load apply, then after 1 h, 24 h (1 d), 96 h (4 d), 168 h (1 week), 336 h (2 weeks), 672 h (4 weeks) and 1 000 h (6 weeks) and recorded in three decimal point numbers.

The ambient test temperature shall be controlled within the test time and recorded.

D.15.6 Calculation

The creep factor shall be calculated as follows.

Plot a log-log graph of the deflection δ (mm) versus time t (hours) as shown in Figure D.8.

Draw a least squares line to fit the data.

Read off the log deflections at $10^{-1}$and 10^{3}h and convert deflections into mm.

Let deflection at 10^{-1}h = a (mm).

Let deflection at 10^{3}h = b (mm).

Calculate a design value for the long term deflection c (mm), using Formula (D.9):

$$\log c = \log a + 1{,}575 \cdot \left(\log b - \log a\right) \qquad \text{(D.9)}$$

where

1,575 = 6,301/4 being $\log 2 \times 10^{6}$ divided by $\log 10^{4}$

The value for A_5 is given by the following formula:

$$A_5 = \frac{c}{a} \qquad \text{(D.10)}$$

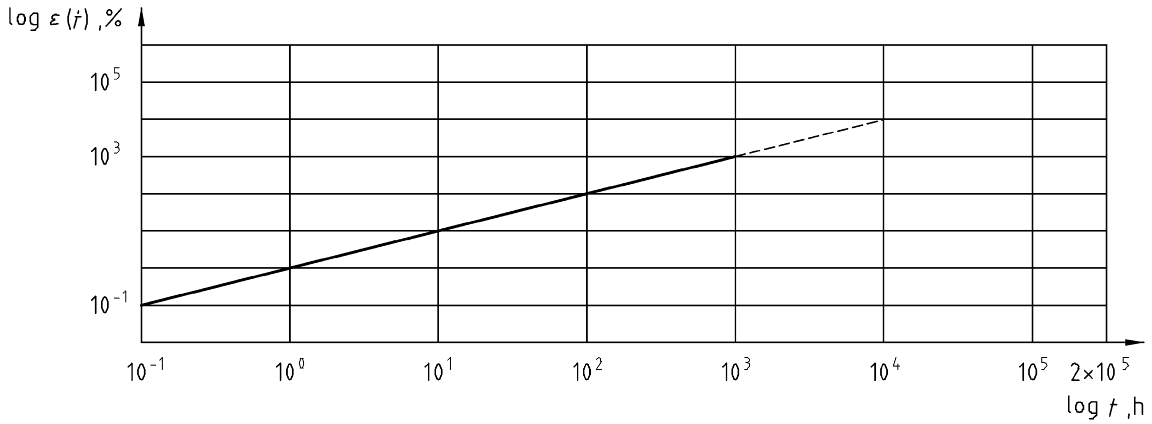


Figure D.8 — Results of long-term creep test (schematically)

D.16 Hardness of rubber

The hardness of rubber gaskets shall be measured in accordance with ISO 48.

D.17 Flash point test

The flash point test shall be determined in accordance with EN ISO 2592.

D.18 Heat deflection temperature test

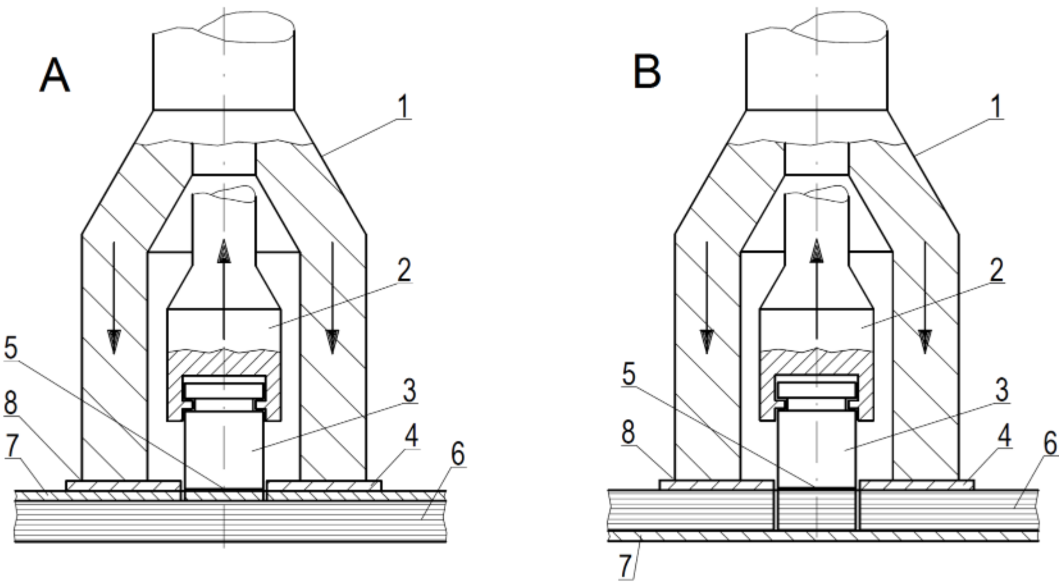
The form and number of test pieces and the test procedure shall be in accordance with EN ISO 75-2.

D.19 Flexural strength of laminate

The flexural strength of laminate shall be determined in accordance with EN ISO 14125.

D.20 Pull-off strength from laminates

The procedure for evaluating the pull-off strength from laminates shall be determined in accordance with ASTM D4541-09.



Key

1	detaching assembly	2 central grip
3	loading fixture	4 annular ring
5	adhesive	6 structural laminate
7	laminate (A) or liner (B) to be tested	8 base

Figure D.9 — Testing device

Annex E
(normative)

Approval testing of laminators

E.1 General

The quality of laminating work depends on the skill and knowledge of the laminator.

An examination of the skill of the laminator is essential for the assurance of the quality of the laminating work.

This annex specifies the method of testing the knowledge and skill of laminators who are required to carry out work on GRP tanks with or without thermoplastic lining and vessels constructed to this standard. The requirement applies to repair work as well as new work.

This annex details the test procedure by which a laminator is assessed.

All applicants shall have experience as a laminator or have completed a training course.

E.2 Assessment of the laminator

The assessment of the laminator shall include the following tests:

a) flat hand laminate;

b) seam joint;

c) branch connection;

d) resin rich layer type;

e) theory exam.

E.3 Procedure

During the assessment the laminator shall demonstrate practical skill and complete test pieces for the laminate shapes and chemical barriers which will be used in production, in accordance with relevant laminating procedure.

The laminator shall demonstrate knowledge of the techniques for obtaining a bond between laminates and thermoplastics liners.

The test pieces shall be made in the presence of an inspector. Before the commencement of the test the inspector shall check the identity of the laminator, the materials to be used, equipment and procedure.

The test pieces shall be made in accordance with the manufacturer’s laminating procedure.

Details of the laminator, laminate procedure and testing shall be recorded. The inspector shall stop the test if the laminating conditions are not in compliance with the laminating procedure.

The fabrication of the test pieces shall take place under the same conditions as normal production practice. Approval testing in the shop shall be permitted for laminators who will be carrying out work on site.

The equipment used for the preparation of the test pieces shall be similar to that used in production.

E.4 Theory exam

The theory exam should be done in written form in presence of an inspector. The exam should have minimum of 30 questions about the following sections:

a) basic information on materials;

b) storage and processing of materials;

c) preparation of the laminating process;

d) conditions during the laminating process and repair of laminates;

e) environmental influence during the laminating process (humidity, dew point etc.);

f) standard safety rules and environmental protection.

The assessment is passed if minimum of 60 % of the questions are correct. An additional oral examination is acceptable.

E.5 Test pieces

The test pieces shall consist of a flat hand laminate, a seam joint between two flat hand laminates and a branch connection.

All test pieces shall be made with non-pigmented resin.

The test pieces shall be laid up on a surface with release properties e.g. glass or thermoplastic.

The dimensions of the test pieces and the laminate build up shall be as follows:

a) Flat hand laminates shall be 500 mm × 500 mm and shall consist of 4 layers of chopped strand mat (CSM) alternating with 3 layers of woven roving (WR).

b) Seam joint between flat hand plates. The size of each plate shall be 500 mm × 250 mm. The joint shall be made in accordance with the fabricators standard procedure.

c) The branch connection shall consist of a pipe 100 mm to 150 mm diameter joined to a flat panel which has chemical resistant barrier on one side. The laminate build up shall be in accordance with the fabricators standard procedure.

The test pieces shall be marked and dated by the inspector.

The test pieces shall be cured for 7 days at (21 ± 2) °C before testing.

E.6 Evaluation of test pieces

E.6.1 General

The test pieces shall be subject to following tests:

a) flat hand laminate - test procedure 1;

b) seam joint - test procedure2;

c) branch connection - test procedure 3.

E.6.2 Test procedure 1

The test procedure 1 shall include the following:

a) visual examination;

b) Barcol hardness in accordance with Clause D.11;

c) tensile test in accordance with EN ISO 527-4;

d) glass content in accordance with EN ISO 1172;

e) arrangement of glass reinforcement.

E.6.3 Test procedure 2

The test procedure 2 shall include the following:

a) visual examination;

b) Barcol hardness in accordance with Clause D.11;

c) glass content in accordance with EN ISO 1172;

d) arrangement of glass reinforcement;

e) shear test in accordance with test method D.7.

E.6.4 Test procedure 3

The test procedure 3 shall include the following:

a) visual examination;

b) Barcol hardness in accordance with Clause D.11;

c) arrangement of glass reinforcement.

E.7 Minimum requirements for acceptance

The following minimum requirements shall be met to pass the assessment:

a) The defects found by visual examination shall not exceed the permissible limits given in Table 32.

b) The tensile strength shall be equal to or greater than given in Table 3.

c) The bond shear strength shall be equal to or greater than given in Table 4.

d) The Barcol hardness of the resin shall be the minimum specified by the resin manufacturer for the resin used to prepare the laminate.

e) The glass content shall be between the limits specified in the laminating procedure.

f) The glass residue after the loss by ignition shall be examined to determine if the lay-up conforms to that specified in the laminating procedure.

E.8 Test certificate

A test certificate shall be issued to laminators who pass the test. The test results shall be recorded on a test certificate, e.g. as illustrated in Figure E.1.

Any restrictions and supplementary information shall be recorded on the test certificate.

If a laminator has not passed the test may be repeated after an appropriate period of training.

E.9 Validity and renewal

A laminator's approval certificate shall remain valid for five years, provided it can be shown that the laminator has been employed with reasonable continuity of work.

If a laminator has a period of inactivity of 12 months or more a new approval test shall be required.

E.10 Range of approval

The range of approval and any specific restrictions shall be stated on the test certificate.

A laminator who has passed the test shall be entitled to work on other laminate shapes, laminate specifications and chemical barriers.

<table>
<tr><td colspan="3">Laminator approval test certificate
EN xyz Annex E</td><td colspan="2">Test record
No</td></tr>
<tr><td>Fabricator's name</td><td colspan="3">Laminator's name and identity No</td><td>Issue No</td></tr>
<tr><td colspan="2">Laminating procedure reference</td><td colspan="3">Date of test</td></tr>
<tr><td colspan="2">Test piece details
Flat hand laminate

Seam joint

Branch connection
Theory exam</td><td colspan="3">Test results
Test procedure 1

Test procedure 2

Test procedure 3</td></tr>
<tr><td colspan="5">Resin used</td></tr>
<tr><td colspan="5">Test results
State 'acceptable or non-acceptable (with reasons).</td></tr>
<tr><td colspan="5">Remarks</td></tr>
<tr><td colspan="5">The statements in this certificate are correct. The test laminates were prepared, cured and tested in accordance with EN xyz Annex E.</td></tr>
<tr><td colspan="5">Inspector

Date</td></tr>
</table>

Figure E.1 — Laminator test certificate

Annex F
(informative)

Design by stress analysis

F.1 General

Vessels or vessel structures may contain such structures or structural solutions for the design of which this standard does not provide sufficient guidance. In that case, other methods shall be used in order to obtain a safe structure. This Annex comprises those methods which can be used in the design of vessels or vessel parts.

F.2 Typical methods

Typical methods are the following:

a) the finite element analysis;

b) reverse engineering of the biaxial state of stress using strain gage data;

c) other mathematical and/or experimental techniques that the design and safety responsible persons consider accurate or conservative.

F.3 General requirements

The analysis shall take into consideration the orthotropic characteristic of laminates.

The analysis needs to determine the maximum strains and stresses of the construction and also the instability of the construction.

F.4 Important determination results

The important determination results are:

a) biaxial stress state in the laminate;

b) shear stress;

c) strain level.

F.5 Design factors

As a minimum the design shall be as follows:

a) such that the design factors are determined according to 7.9.4;

b) the strength ratio of a laminate at continuous service conditions is greater or equal to the determined design factor;

c) the strength ratio of a laminate at short term combined load conditions is greater or equal to the determined short term design factor;

d) local strain in any condition does not exceed allowable design strain determined according to 8.2.

Annex G
(normative)

Environmental aspects

G.1 Principle

The environmental aspects at all stages of the life cycle of the tank or vessel shall be considered.

G.2 Design and Manufacturing

a) Design:

The environmental aspects to be considered should be clearly documented in the design and manufacturing schedule or in the manufacturing record. Information of how to dispose of the tank or vessel at the end of its life-cycle should be included.

b) Material and manufacturing method:

The material/method with the lowest environmental impact shall be chosen. Materials shall be used in compliance with the suppliers´ instruction and in accordance with laws and regulations.

c) Storage of materials:

Materials shall be stored in compliance with the suppliers´ instruction and in accordance with laws and regulations.

d) Handling of waste:

Minimize, handle in accordance with laws and regulations.

e) Handling and transportation:

Recyclable packaging material shall be used. The mean of transportation chosen shall have the lowest impact on the environment.

G.3 Effects of materials on water

When used under the conditions for which they are designed, non-metallic material in contact with or likely to come into contact with potable water shall not constitute a toxic hazard, shall not support microbial growth and shall not give rise to unpleasant taste or odour, cloudiness or discoloration of the water.

Concentration of substances, chemicals and biological agents leached from materials in contact with potable water, and measurements of organoleptic/physical parameters shall not exceed the maximum values recommended by the EEC Council Directive of July 1980 relating to the quality of water intended for human consumption (Official Journal of the European Communities L299 pp 11-29) or as required by the Word Health Organization in its publication “Guidelines for drinking water quality” Vol 1 “Recommendations” (WHO, Geneva 1984), whichever in each case is more stringent.

G.4 Effects of materials on food

Plastic materials and articles coming into contact with food may transfer toxic substances to them. In order to prevent any danger to human health, the Commission Regulation (EU) No 10/2011 of 14 January 2011 establishes specific requirements applicable to the manufacture and marketing of plastic materials and articles intended to come into contact with food, and lays down migration limits applicable to substances constituting the materials and articles in question and defines specific conditions of use to guarantee food safety.

These materials and articles and parts thereof may be composed:

a) exclusively of plastics;

b) of several layers of plastics; or

c) of plastics combined with other materials.

Plastic materials and articles intended to come into contact with food will comply with:

d) the requirements for use, labelling and traceability set out in Regulation (EC) No 1935/2004;

e) the good manufacturing practice defined in Regulation (EC) No 2023/2006;

f) the compositional and declaration requirements set out in this Regulation.

Only the substances included in the list set out in Annex I of this Regulation may be intentionally used in the manufacture of plastic materials and articles. The list includes:

g) monomers;

h) additives (excluding colorants);

i) polymer production aids (excluding solvents).

By way of derogation, substances not included on this list may be authorized under certain conditions.

G.5 Recycling

To make recycling possible and effective the marking of materials of construction as well as the content shall be made in accordance with Clause 18.

A recyclable packaging material shall be chosen.

G.6 Storage of substances hazardous to water

When storing substances hazardous to water, national regulations and requirements shall be observed in tanks with a working pressure ≤ 0,5 bar.

Annex ZA
(informative)

Relationship between this European Standard and the essential requirements of Directive 2014/68/EU aimed to be covered

This European Standard has been prepared under a Commission's standardization request "M/071 Mandate to CEN for Standardization in the field of pressure equipment" to provide one voluntary means of conforming to essential requirements of Directive 2014/68/EU of The European Parliament and of the Council of 15 May 2014 on the harmonisation of the laws of the Member States relating to the making available on the market of pressure equipment.

Once this standard is cited in the Official Journal of the European Union under that Directive, compliance with the normative clauses of this standard given in Table ZA.1 confers, within the limits of the scope of this standard, a presumption of conformity with the corresponding essential requirements of that Directive, and associated EFTA regulations.

Table ZA.1 — Correspondence between this European Standard and Directive 2014/68/EU

Essential Requirements of Directive 2014/68/EU, Annex I	**Clause(s)/sub-clause(s) of this EN**	**Remarks/Notes**
2.1	7.9.4, 7.9.5, 8.2	Approprieate safety coefficients
2.2.1	9.1, 9.2, 9.3, 9.4, 9.5	To be designed for loadings appropriate to intended use
2.2.3 (a)	Clause 9, Clause 10, Clause 11, Clause 12, Clause 14, Clause 15	Calculation method calculations with formulae a) Pressure containment and other loading aspects
2.2.3 (b)	7.2, 7.9.5.2 to 7.9.5.7, Clause 8, 9.5.2	Calculation method b) Resistance/load capacity
2.2.4	17.6	Experimental design method
2.6	6.2	Corrosion or other chemical attack
2.9	9.2.7, 9.5.2	Provision for filling and discharge
3.1.2	10.7, 10.8, 17.4.3 Annex E	Permanent joining carried out by - suitably qualified personnel (laminators) - suitable operating procedures for catergories II, III, and IV approved by a competent third party, notified body or if certified according Modul D by **an** internal inspection authority
3.1.3	17.5	Non-destructive tests carried out by

		- suitably qualified personnel - for categorie III and IV approved by a third party (acc. article 13) body or if certified according Modul D by an internal inspection authority
3.1.4	17.4.5	Post curing
3.1.5	17.3	Traceability
3.2.1	17.5	Final inspection
3.2.2	17.5.2 Annex C	Proof test (Modul G with notified body)
3.3	Clause 18	Marking
3.4	17.3.1	Operating instructions
4.1 (b)	6.2, 7.9.5.3	Materials for pressure parts - chemical resistance
4.1 (c)	7.9.5.6	Materials for pressure parts - ageing
4.1 (d)	17.2, 17.4	Materials for pressure parts - suitable for the intended processing procedures
4.2 (b)	7.9.2 or 7.9.3, 8.4	Materials for pressure parts mechanical values: - comply with harmonized standards - or European approval acc. article 15 - or particular appraisal
4.2 (c)	7.9.3, 8.4	Materials for pressure parts mechanical values : For pressure equipment in categories III and IV, a specific assessment of the particular material appraisal shall be performed by the notified body
4.3	17.3.4	Certificate of specific product control
7.4	8.2.3 Annex C (normative)	Hydrostatic test pressure

WARNING 1 — Presumption of conformity stays valid only as long as a reference to this European Standard is maintained in the list published in the Official Journal of the European Union. Users of this standard should consult frequently the latest list published in the Official Journal of the European Union.

WARNING 2 — Other Union legislation may be applicable to the product(s) falling within the scope of this standard.

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In the preparation of this European Standard certain technical information has been derived from published technical papers and international documents and detailed below for further reference.

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[17] Berechnungsempfehlungen für auf Sattelschalen gelagerte Behälter aus glasfaserverstärkten Kunststoffen 40-B2, Deutsches Institut für Bautechnik Berlin, Dezember 2012

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