

GRP tanks and vessels for use above ground —

Part 3: Design and workmanship

ICS 23.020.10

National foreword

This British Standard is the UK implementation of EN 13121-3:2008+A1:2010, incorporating corrigendum May 2011. It supersedes BS EN 13121-3:2008 which is withdrawn.

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

The start and finish of text introduced or altered by corrigendum is indicated in the text by tags. Text altered by CEN corrigendum May 2011 is indicated in the text by AC1 AC1.

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.

BS EN 13121 is published in four parts.

- BS EN 13121-1:2003, *GRP tanks and vessels for use above ground — Raw materials — Specification conditions and acceptance conditions*
- BS EN 13121-2:2003, *GRP tanks and vessels for use above ground — Composite materials — Chemical resistance*
- BS EN 13121-3:2008, *GRP tanks and vessels for use above ground — Design and workmanship*
- BS EN 13121-4:2005, *GRP tanks and vessels for use above ground — Delivery — Installation and maintenance*

The scope of this Part 3 covers those tanks and vessels that work up to a 10 bar pressure, for above ground use only. This standard has therefore been prepared under the European Commission Mandate 83/139/EEC, the Pressure Equipment Directive (PED), which has been in force since May 2002.

The design and manufacture of tanks and vessels in GRP can involve a number of different materials to produce a suitable construction, and employ combinations of different types of reinforcement materials. This allows designers to select laminate constructions that are best suited for their purpose and the most cost effective in terms of production.

With the publication of BS EN 13121-3:2008, the current British Standard BS 4994:1987 for the design and construction of tanks and vessels in reinforced plastics will be declared obsolescent as of 2009-12-31 as it can still be used to cover those tanks and vessels that are still in service at that time, since equipment designed, constructed and maintained to that standard is considered to have a long working life.

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

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

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Partie 3: Conception et fabrication

Oberirdische GFK-Tanks und -Behälter - Teil 3: Auslegung
und Herstellung

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Foreword

This document (EN 13121-3:2008+A1:2010) has been prepared by Technical Committee CEN/TC 210 “GRP tanks and vessels”, the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by August 2010, and conflicting national standards shall be withdrawn at the latest by August 2010.

This document includes Amendment 1, approved by CEN on 2010-01-11.

This document supersedes EN 13121-3:2008.

The start and finish of text introduced or altered by amendment is indicated in the text by tags **A1** **A1**.

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

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

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, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and the United Kingdom.

Introduction

EN 13121 consists of the following parts under the general title "*GRP tanks and vessels for use above ground*":

- Part 1: Raw materials — Specification conditions and acceptance conditions
- Part 2: Composite materials — Chemical resistance
- Part 3: Design and workmanship (this standard)
- Part 4: Delivery, installation and maintenance

These four parts together define the responsibilities of the tank or vessel manufacturer and the materials to be used in their manufacture.

Part 1 of this standard 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 Part 2 and the mechanical, thermal and design properties determined in Part 3. Together with the workmanship principles determined in Part 3, requirements and acceptance conditions for raw materials ensure that the tank or vessel will be able to meet its design requirements. Part 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 tanks and vessels conforming to this standard should be made only by manufacturers who are competent and suitably equipped to fulfil all requirements, 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.

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 ^(AC1)thermoplastics^(AC1) lining for storage or processing of fluids, factory made or site built, non pressurised or pressurised up to 10 bar, for use above ground.

The terms vessels and tanks as used in this European Standard 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. In addition to the definitive requirements, this European Standard also requires the items in Clause 5 to be fully documented.

This European Standard covers vessels and tanks subject to temperatures between – 40 °C and + 120 °C.

NOTE 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 wishes to take advantage of such developments, then all other requirements of the standard shall be maintained and such tanks and vessels shall only be designed in accordance with the advanced design method given in 7.8.3.

Excluded from this European Standard 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;
- 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 13280:2001).

2 Normative references

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

EN 59, *Glass reinforced plastics — Measurement of hardness by means of a Barcol impressor*

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

EN 1993-1-2, *Eurocode 3: Design of steel structures — Part 1-2: General rules — Structural fire design*

EN 1993-1-3, *Eurocode 3 — Design of steel structures — Part 1-3: General rules — Supplementary rules for cold-formed members and sheeting*

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

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

EN 13121-4:2005, *GRP tanks and vessels for use above ground — Part 4: Delivery, installation and maintenance*

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, ebonite and long-fibre-reinforced composites (ISO 75-2:2004)*

EN ISO 291, *Plastics — Standard atmospheres for conditioning and testing (ISO 291:2005)*

EN ISO 527-4, *Plastics — Determination of tensile properties — Part 4: Test conditions for isotropic and orthotropic fibre-reinforced plastic composites (ISO 527-4:1997)*

EN ISO 527-5, *Plastics — Determination of tensile properties — Part 5: Test conditions for unidirectional fibre-reinforced plastic composites (ISO 527-5:1997)*

EN ISO 899-1, *Plastics — Determination of creep behaviour — Part 1: Tensile creep (ISO 899-1:2003)*

EN ISO 899-2, *Plastics — Determination of creep behaviour — Part 2: Flexural creep by three-point loading (ISO 899-2:2003)*

EN ISO 1172, *Textile-glass-reinforced plastics — Prepregs, moulding compounds and laminates — Determination of the textile-glass and mineral-filler content — Calcination methods (ISO 1172:1996)*

EN ISO 2592, *Determination of flash and fire points - Cleveland open cup method (ISO 2592:2000)*

EN ISO 3915, *Plastics — Measurement of resistivity of conductive plastics (ISO 3915:1981)*

EN ISO 7500-1, *Metallic materials — Verification of static uniaxial testing machines — Part 1: Tension/compression testing machines — Verification and calibration of the force-measuring system (ISO 7500-1:2004)*

EN ISO 9513, *Metallic materials — Calibration of extensometers used in uniaxial testing (ISO 9513:1999)*

EN ISO 14125:1998, *Fibre-reinforced plastic composites — Determination of flexural properties (ISO 14125: 1998)*

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

ISO 4901, *Reinforced plastics based on unsaturated polyester resins — Determination of residual styrene monomer content*

3 Terms and definitions

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

3.1

manufacturer

the organisation that designs, manufactures and tests the vessel or tank in accordance with this European Standard

3.2

purchaser

the organisation or individual that buys the finished vessel or tank and specifies the process requirements

3.3

authorised inspecting authority

the body or organisation that may be required to check that the design, materials and construction comply with this European Standard when $PS \leq 0,5$ bar

3.4

vessel

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

3.5

tank

a 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

3.6

laminate

resin reinforced with glass fibre

3.7

gel coat

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

3.8

cure

the chemical reaction resulting in the polymerised laminate

3.9

post cure

the application of heat to take the polymerisation to a final stage

3.10

maximum allowable pressure (PS)

the maximum pressure for which the equipment is designed, as decided by the manufacturer

3.11

differential pressure

the difference of pressure on both sides of a component

3.12

[AC₁] design pressure (p_D) [AC₁]

the design pressure used in the calculations for a component

3.13

maximum/minimum allowable temperature (TS)

the maximum or minimum temperature for which the equipment is designed, decided by the manufacturer

3.14

test temperature

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

3.15

test pressure (TP)

the pressure to which the tank or vessel is tested

4 Symbols and abbreviations

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

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/mm ²	Modulus of elasticity = $\frac{X}{t}$
ε	%	Strain
F	-	Buckling design factor
ϕ	°	Half the angle at the apex of the cone
$\sphericalangle_{AC1} \theta \sphericalangle_{AC1}$	°	Support saddle angle
g	m/s ²	Gravity
h	mm	Height of dished end
H	mm	Height of cone
I	mm ⁴	Second moment of area
k	-	Correction factor
K	-	Overall design factor
l	mm	Length
L	mm	Overall length

Table 1 (continued)

Symbol	Unit	Definition
m	kg/m ²	Mass per unit area
M	Nmm	Bending moment
u	N/mm	Unit load = load/width
ν	—	Poissons ratio
P	N	Direct load
p	N/mm ²	Pressure
Q	N	Shear load
r	mm	Knuckle radius
R	mm	Radius
ρ	kg/m ³	Density of liquid
σ	N/mm ²	Load = $\frac{U}{t}$ and $\frac{q}{t}$
t	mm	Thickness
τ	N/mm ²	Shear load
T	°C	Temperature
TS	°C	Design temperature
all. U_{lam}	N/mm	allowable unit load for the laminate
U	N/mm per kg/m ² glass	Ultimate tensile unit strength of the laminate (UTUS)
V	m ³	Volume
W	kg	Weight
χ	—	Coordinate in axial direction
X	N/mm	Unit modulus = Load/width x strain
X_i	N/mm per kg/m ² glass	Unit tensile-modulus of the lamina per kg/m ² glass
q	N/mm	Applied unit load

Table 1 (continued)

Abbreviations		
CSM	-	Chopped strand mat
ECTFE	-	Ethylene-chlorotrifluoroethylene copolymer
all.	-	Allowable
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, unplasticised
PVDF	-	Polyvinylidene fluoride
UP	-	Unsaturated polyester
VE	-	Vinyl ester
WR	-	Woven rovings
CRL	-	Chemical Resistant Layer, see EN 13121-2
VL	-	Veil Layer, see EN 13121-2
TPL	-	Thermoplastics Liner, see EN 13121-2
Supp.	-	Support
lam	-	Laminate
S.G	-	Specific Gravity (Relative Density)
O.D	-	Outside Diameter
I.D	-	Inside Diameter

5 Information and requirements to be supplied and to be documented

5.1 General

The definitive requirements specified throughout the standard and the documented items 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 manufacturer shall obtain from the purchaser or his agent sufficient information to undertake the product design construction and hazard assessment (when required).

- a) Details of fluids to be handled;
- b) Design pressure (or vacuum) and design temperature including test requirements;
- c) Operating conditions;
- d) Details of any imposed loads (personnel/agitation, etc.);
- e) Support requirements;
- f) Information which may already be available on suitability of resins or thermoplastics for the stated conditions;
- g) All the geometrical details of proposed product and required fillings;
- h) Applicable regulations e.g. laws, statutory orders and decrees;
- i) Site conditions including ambient conditions with reference to extremes of temperature and superimposed loads, e.g. wind, snow, seismic and associated pipe-work.

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 [\[AC1\]](#) Tables 18 and 19 [\[AC1\]](#) 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.

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 Figure 34 a).

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 15.3.

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 **[AC1]** (see Table 24) **[AC1]**, 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. 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 4.4 of EN 13121-2:2003 and the minimum thickness of the lining material shall be as given in Table 2.

Table 2 — Thickness of thermoplastics sheets and tubes

Material	Thickness of sheets mm	Thickness of tubes mm
PVC-U	3,0 to 4,5	3,0 to 4,5
PVDF	3,0 to 6,0	2,4 to 4,0
PP-H,-B,-R	3,0 to 6,0	3,0 to 6
ECTFE	min.1,7	min.1,7 to 4,0
FEP	min.1,7	min.1,7 to 4,0
PFA	min.1,7	min.1,7 to 4,0

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.

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 AC_1 ECR AC_1 glass.

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

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

6.3 Flammability

When required or specified, the external surface layer(s) shall be modified to have the appropriate surface spread of flame characteristic.

NOTE It may be that in some locations where the tank or vessel is to be used there are local or national fire regulations which have to be taken into account.

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 $10^6 \Omega$, or the volume resistivity $10^6 \Omega\text{m}$, when tested in accordance with test method 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 test methods 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 [AC1](#) 7.8.3 [AC1](#).

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.

When $TS \leq 60\text{ °C}$

$$(HDT - 20\text{ °C}) \geq TS$$

When $TS > 60\text{ °C}$

$$(HDT - 40\text{ °C}) \geq TS$$

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 U_i N/mm per kg/m ² glass	Unit tensile modulus X_i N/mm per kg/m ² glass	Shear strength τ N/mm ²	Shear modulus G N/mm ²
CSM	All		200	14 000		
CSM (furane/phenolic)	All		140	14 000		
WR	Warp	$\xi \geq \frac{1}{6}$	$500 \times \xi$	$4\,000 + 24\,000 \times \xi$		
		$\xi < \frac{1}{6}$	60	4 000		
	Weft	$\xi \leq \frac{5}{6}$	$500 \times (1 - \xi)$	$4\,000 + 24\,000 \times (1 - \xi)$	50	2 200
		$\xi > \frac{5}{6}$	60	4 000		
WR (furane/phenolic)	Warp	$\xi \geq \frac{1}{6}$	$320 \times \xi$	$4\,000 + 24\,000 \times \xi$		
		$\xi < \frac{1}{6}$	40	4 000		
	Weft	$\xi \leq \frac{5}{6}$	$500 \times (1 - \xi)$	$4\,000 + 24\,000 \times (1 - \xi)$		
		$\xi > \frac{5}{6}$	40	4 000		
FW	Fibre direction	$85^\circ < \theta < 90^\circ$	500	28 000		
FW (furane/phenolic)	Fibre direction	$85^\circ < \theta < 90^\circ$	280	28 000		

where:

ξ 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 $\boxed{\text{AC}_1}$ lamina $\overline{\text{AC}_1}$ type i, expressed as a force per unit width per unit weight;

X_i is the $\boxed{\text{AC}_1}$ unit tensile modulus $\overline{\text{AC}_1}$, 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 Lamina thickness

The thickness of an individual lamina layer t_i shall be determined using Equation (1) which is represented graphically in Annex B.

$$\boxed{AC1} t_i = \left(\frac{1}{\rho_g} + \frac{(100 - m_g)}{m_g \times \rho_r} \right) \times 10^3 \boxed{AC1} \quad (1)$$

Where:

- t_i thickness of lamina layer type i (mm), of mass 1 kg/m²;
- m_g is the glass content by mass, expressed in %, of the layer i;
- 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 can be determined from $\boxed{AC1}$ basic lamina properties $\boxed{AC1}$ using the methods given in Annex B.

7.6 Inter-laminar shear strength

7.6.1 Laminate

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

Table 4a — Minimum inter-laminar shear strengths

Type of reinforcement	Inter-laminar shear strength N/mm ²
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 4b when tested in accordance with test method D.8.

Table 4b — Minimum bond shear strengths for thermoplastics linings

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

7.7 Peel strength

7.7.1 Peel strength of laminates

The peel strength of laminates shall have a minimum value of 5 N/mm width, when tested in accordance with the procedure given in test method D.9.

7.8 Selection of physical properties of materials and allowable design factors

7.8.1 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 7.8.2 and is designated the basic design method, or by carrying out an extended mechanical test program establishing higher mechanical properties for the particular laminate configuration to be used (see 7.8.3), which is designated the advanced design method.

7.8.2 Basic design

The minimum specified properties shall be verified by carrying out tests on five individual samples, see 15.6, for:

- a) glass content (loss on ignition), test method D.2;
- b) unit tensile modulus (based on load carried at 0,25 % strain), test method D.6;
- c) ultimate tensile unit strength [test in (2) above continued to failure], test method D.5;
- d) inter-laminar shear test (based on max. shear load over a specified shear length), test method D.7;
- e) Barcol hardness test, test method D.11;
- f) short term creep test, test method D.10;
- g) flexural strength of laminate, test method D.20.

When a thermoplastics lining material is utilised, 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), test method D.8;

- i) peel strength (to establish the bond strength in peel between liner and laminate), test method D.9;
- j) UTUS of lining material, test method D.3;
- k) UTUS of lining welds test method 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:

- a) the arithmetic average of the 5 test results;

or

- b) 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 minimum specified properties given in Table 3 in order to use the values of Table 3.

7.8.3 Advanced design

Higher values for material properties, based on the tests detailed in Annex D can be used, provided that a minimum of 15 specimens are used for all mechanical tests.

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 $N \geq 15$) each having a result of value J , the standard deviation, s , from the mean of the test results may be obtained from:

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

Where:

- s is the standard deviation;
- N is the number of tests;
- J is the actual test result;
- $\bar{J}$ is the arithmetic mean of the test results.

The characteristic value to be input into the design equation is $\bar{J} - k \times s$

where

$$k = 1,6 + \frac{4}{N} \quad (3)$$

When authenticated historical test data is already available, the characteristic value shall be verified by testing a further 5 samples and taking the average of these test results, or the average of 3 test results where the max. and min. is discarded. The lowest figure thus calculated shall be greater than the advanced design characteristic value $\bar{J} - k \times s$.

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

7.8.4 Design factors

7.8.4.1 General

Design factors shall be applied to the values of mechanical properties obtained in accordance with the requirements of 7.8 as follows:

7.8.4.2 Overall design factors K and F

The overall design factor K shall be determined from Equation (4):

$$K = 2 \times A_1 \times A_2 \times A_3 \times A_4 \times A_5 \quad (4)$$

The maximum and minimum values of the partial design factors are given in Table 6.

The buckling design factor F shall be determined from Equation (5).

$$F = 2 \times A_1 \times A_2 \times A_3 \times A_4 \sqrt{A_5} \quad (5)$$

NOTE The partial design factor A_5 varies according to the nature of the loading, different values being obtained for loadings in tension or Flexural and for Short-term or Long-term loading conditions, see 7.8.4.7.

Accordingly different K and F factors may have to be derived depending upon the load case(s) being considered, as given in Clause 9.

These factors will be used to determine the allowable design strains using the method given in 8.2 in order to establish the allowable design loads (8.3), which will be used in the overall design analysis as detailed in Clause 10.

7.8.4.3 Derivation of partial design factor A_1

A_1 is the partial design factor relating to the test verification of material properties and shall be determined as follows and as detailed in Table 6.

$A_1 = 2$ When the maximum allowable load is determined from the properties given in Table 3 and verified by valid historical test data 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 7.8.2.

$A_1 = 1,2$ 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 7.8.2.

$A_1 = 1,1$ When the maximum allowable load is determined by testing sample laminates in accordance with 7.8.3.

$A_1 = 1,0$ When the maximum allowable load is determined by testing actual samples from the vessel or tank in accordance with 7.8.3.

7.8.4.4 Derivation of partial design factor A_2

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

7.8.4.5 Derivation of partial design 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 AC1 Equations (6a) and (6b) AC1 :

$$A_3 = 1,0 + 0,4 \frac{T_D - 20}{HDT - 40} \quad \text{AC1} (6a) \quad \text{AC1}$$

For insulated tanks:

$$A_3 = 1,0 + 0,4 \frac{T_D}{HDT - 40} \quad \text{AC1} (6b) \quad \text{AC1}$$

NOTE A_3 should always be $> 1,0$ and $\leq 1,4$.

7.8.4.6 Derivation of partial design factor A_4

A_4 is the partial design 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.

7.8.4.7 Derivation of partial design 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 5 or by testing in accordance with D.16.

In the absence of test data, A_5 shall be taken from Table 5.

Table 5 — The value of partial design factor A_5

	Short term	A_5 Tension		A_5 Flexural	
	Loading	Life of tank or vessel		Life of tank or vessel	
Reinforcement-resin system Polyester- and Vinylester	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 are to be used, the value of A_5 shall be taken for the major constituent.

For intermediate lifetimes 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 test D.16.

An early assessment of the partial design factor A_5 can be determined using the short term creep test (see method D.10), but the final value used in the design shall be that determined from the long term creep test (see method D.16).

The partial design factor A_5 shall not be less than 1,20, other than for short term loads (see Table 5).

For the calculation of the buckling Factor F (see 7.8.4), only the A_5 value for Flexural shall be used.

For the calculation of the overall design Factor K (see 7.8.4) 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.

The different A_5 factors for different types of load, may result in a range of K and F factors (see 7.8.4) and allowable design strain levels and subsequent design unit loads having to be evaluated (see 8.2.4 and 8.3). However simplification of the design analysis can be achieved if the largest applicable value of the A_5 factor is used for all calculations in the design analysis.

Table 6 — Summary of design methods and partial design factors

	Permissible design approach		
	Advanced design	Basic design	
		either	or
Derivation of mechanical properties (test)	User-defined material properties may be used based on rigorous testing (15 samples minimum)	Minimum specified properties as defined in this standard supported by limited testing (5 samples)	Minimum specified properties as defined in this standard supported by limited testing (5 samples).
Historical test data	Historic data not acceptable without support from a limited production test programme	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 design factor relating to the level of the test verification of material properties	$A_1 = 1,0$ (vessel cut- outs) $A_1 = 1,1$ (sample laminates) (For mechanical properties) $A_1 = 1,1$ when using historic test data and verifying tests (7.8.3)	$A_1 = 1,2$ (vessel cut- outs) $A_1 = 1,3$ (sample laminates) $A_1 = 1,5$ (If no additional testing is carried out and historic test data is 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)	A_2 (from EN 13121-2)	A_2 (from EN 13121-2)
Partial design factor relating to the design temperature of the vessel and resin HDT	A_3 (7.8.4.5)	A_3 (7.8.4.5)	A_3 (7.8.4.5)
Partial design factor relating to cyclical loading	A_4 (7.8.4.6) = 1	A_4 (7.8.4.6) = 1	A_4 (7.8.4.6) = 1
Partial design factor relating to long term behaviour	A_5 (7.8.4.7)	A_5 (7.8.4.7)	$A_5 = 2,4$
Minimum design factor K	K (minimum) = 4 K (minimum) = 5 if A_5 is not determined by test program D.16.of Annex D	K (minimum) = 6	K (minimum) = 8
Minimum buckling design factor F	$F \geq 2,7$	$F \geq 3,0$	$F \geq 4,0$

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 Allowable design strains

8.2.1 General

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

8.2.2 Allowable resin strain ε_{ar}

The allowable strain ε_{ar} for each type of resin used shall be determined from Equation (7)

$$\varepsilon_{ar} = 0,1 \times \varepsilon_R \quad (7)$$

where

ε_R is the elongation at break of the unreinforced resin.

8.2.3 Limiting strain for laminate ε_L or lamina ε_i

The limiting strain for a laminate shall be determined from Equation (8A); and for a lamina from Equation (8B).

$$\varepsilon_L = \frac{U_{lam}}{K \times X_{lam}} \quad (8A)$$

$$\varepsilon_i = \frac{U_i}{K \times X_i} \quad (8B)$$

where U_{lam} and X_{lam} are $\overline{AC1}$ obtained from Equations (10a) and (10b) $\overline{AC1}$, using the material's ultimate properties as determined from the test programme values detailed in Clause 7, or taken from Table 3 in accordance with 7.1.

The design factor K shall be determined from Equation (4) or be the maximum value given in Table 6 for the design method to be used, whichever is the higher, using where necessary different values of A_5 (see 7.8.4.7).

8.2.4 Maximum allowable lamina design strain ε_d

The lamina design strain ε_d shall be the least of

- a) 0,10 % strain for furane resin,
- 0,23 % strain for polyester resin lamina,
- 0,27 % for Vinylester lamina,
- 0,20 % PVC - U Thermoplastics Liners.

- b) For PVDF, PP, ECTFE and PFA Thermoplastics liners, the design strain shall be the design strain of the lamina.
- c) The allowable strain determined from Equation (7).
- d) The limiting minimum CSM lamina strain determined from Equation (8A) but when a thermoplastics liner is used, the limiting minimum CSM lamina strain determined from Equation (8b) shall be taken.

NOTE 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 %.

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.

8.2.5 Allowable test strain ϵ_{test}

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

- 0,133 % for Furane resin systems,
- 0,30 % for Polyester resin systems,
- 0,35 % for Vinyl ester resin systems,
- 0,26 % PVC-U thermoplastics liners.

For PP, PVDF, ECTFE and PFA Thermoplastics liners, the maximum test strain shall be the maximum strain of the resin system.

8.3 Laminate design loadings

The allowable design unit loading of the laminate shall be determined from the allowable unit loading for lamina which is given in Equation (9).

$$\text{all. } u_i = \epsilon_d \times X_i \quad (9)$$

These lamina values shall then 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 design analysis given in Clause 10.

Where U_{lam} is from Equation (10) and X_{lam} is given by Equation (10a).

8.4 Laminate design

The laminate construction shall where ever possible be symmetrical.

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 (normative). These allowable loadings shall be related to the unit loads to be carried by the region of the structure concerned.

$$\boxed{\text{AC1}} \text{all. } U_{\text{lam}} = u_1 \times m_1 \times n_1 + u_2 \times m_2 \times n_2 \dots u_i \times m_i \times n_i \quad (10a) \boxed{\text{AC1}}$$

For the proposed laminate construction the X_{lam} is given by Equation (10a):

where

$$\boxed{\text{AC1}} X_{\text{lam}} = X_1 \times m_1 \times n_1 + X_2 \times m_2 \times n_2 + \dots + X_i \times m_i \times n_i. \quad (10b) \boxed{\text{AC1}}$$

If the condition $q > \text{all. } U_{\text{lam}}$, where q is the applied unit load, then the proposed laminate shall be redesigned.

where:

$\text{all. } U_{\text{lam}}$ is the allowable tensile load carrying capacity of a laminate, N/mm;

u_i $\boxed{\text{AC1}}$ is the tensile unit load carrying capacity of lamina layer I $\boxed{\text{AC1}}$, N/mm per kg/m² glass from Equation (9);

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;

NOTE For filament winding, a layer shall consist of two helixes wound at $\pm \Theta$ where $< 85^\circ \leq \Theta \leq 90^\circ$.

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

X_{lam} is the unit tensile modulus of laminate, $\boxed{\text{AC1}}$ N/mm $\boxed{\text{AC1}}$ glass;

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 vessel, see Annex H (informative) for detailed method of analysis.

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.

The thickness of each lamina layer, for design purposes, shall be determined from the glass content for that layer using Equation (1) in 7.4.

The minimum laminate thickness shall be 3 mm excluding any chemical barrier.

The structural laminate shall be symmetrical about the mid point 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

The vessel or tank shall be designed for the most severe combination of conditions which may include:

- 1) internal pressure or external pressure;
- 2) static head of contents (working and test conditions);
- 3) weight of vessel or tank and contents;
- 4) design temperature;
- 5) superimposed and wind loads;
- 6) flexural moments due to eccentric loads;
- 7) localised loads acting at the supports, lugs and other attachments;
- 8) shock loads;
- 9) loads due to heating or cooling and thermal gradients;
- 10) loads applied during transport on rail, road or ship and on erection;
- 11) loads imposed by personnel during erection and operation;
- 12) fatigue;
- 13) any requirements for fire resistance of attached vessel or tank supports, e.g. skirt, legs.

The design analysis given in Clause 10 shall be used to determine the applied unit load at each region of the tank or vessel for the most severe combination of loading conditions.

Equation (10) shall be used to assess the suitability of the proposed laminate design.

Two assessments shall be carried out, namely:

- a) Long-term loads only, where the total applied unit load shall be assessed using the allowable laminate design unit loading calculated using the long-term value for A_5 in the determination of their maximum allowable design strain;
- b) Long-term and short-term loads, where the total applied unit load shall be assessed using the allowable laminate design unit loading as calculated using the short-term value of A_5 used in the derivation of the maximum allowable design strain.

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

NOTE 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 the local recommended loading data.

NOTE Reference can be made to EN 1991-1-3.

9.2.2 Wind

The wind velocities shall be taken from the local recommended conditions where the vessel or tank is to be located.

Consideration shall be given to open top tanks, 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.

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

$p_{\text{wind}} = 0,6 \times \text{dynamic maximum wind pressure for closed vessels};$

$p_{\text{wind}} = 1,6 \times \text{dynamic maximum wind pressure for open vessels}.$

The rim of open top tanks requires to be stiffened either with a flange or stiffener to prevent ovalizing. Annex J (informative) gives the method for design of a shell of varying sections under wind loading.

 NOTE Reference can be made to EN 1991-1-4. 

9.2.3 Seismic loads

Seismic loading - when specified the tank should be designed to withstand seismic loads derived from the relevant local seismic data. Seismic and wind load shall not be considered to act at the same time.

9.2.4 Insulation loads

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

Where 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

The loads resulting from pipes, valves and other items connected to the tank or vessel should be considered in the design as per local load analysis in accordance with Annex G (informative).

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 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:

$$P_{\text{access}} = 1,5 \text{ kN/m}^2 \text{ over the total area, and/or}$$

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

AC1 Snow and access loads shall not be considered to act together. AC1

9.3 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 15.3.

9.4 Design details

9.4.1 Design temperature TS

Shall be as defined in 3.13.

9.4.2 Pressure

The calculation pressure AC1 p_D AC1, 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 shall take into account the following pressure loads:

PS	maximum allowable pressure (+ or -)	short or long term
p_{wind}	see 9.2.2	short term
p_{liquid}	$\rho \times g \times h_{\text{liquid}}$	long term
p_{snow}	see 9.2.1	short or long term
p_{access}	see 9.2.7	short term

AC1 p_D AC1 shall be the worst values of the combination of the individual pressure loads. AC1 Text deleted AC1

10 Design analysis

10.1 Symbols and units

Symbol	Unit	Definition
α	1/°C	thermal expansion coefficient
λ	-	shell parameter
		AC1 Text deleted AC1
D	mm	internal diameter of tank/vessel
D_{pc}	mm	pitch circle diameter of anchorage bolts
D_m	mm	mean diameter of gasket
D_s	mm	neutral axis of stiffener ring
E_R	N/mm ²	modulus of elasticity, ring
E_s	N/mm ²	modulus of elasticity of stiffener
G_{shell}	N/mm ²	shear modulus of shell
h_{Liquid}	mm	height of liquid
I_s	mm ⁴	moment of inertia of stiffener
l_{over}	mm	length overlapping laminate
L_c	mm	length of local thickening since this symbol also applies to junctions without knuckles as shown on Figure 4b)
L_j	mm	length of overlay/side of a joint
L_s	mm	distance between two stiffeners or supports
M	Nmm	bending moment
M_D	Nmm	calculation of bending moment
M_H	Nmm	maximum flexural moment at saddle horn of horizontal vessel support
M_S	Nmm	flexural moment in stiffening ring
q_c	N/mm	unit load, cut out
q_{over}	N/mm	unit load, overlapping laminate
$q_{x,w}$	N/mm	unit load, axial direction, due to weight
N_b	-	number of anchorage bolts
N_S	N	normal load in the stiffener ring
p_D	N/mm ²	calculation pressure
p_c	N/mm ²	pressure causing instability failure
AC1 t	mm	thickness of shell AC1
		AC1 Text deleted AC1
u_c	N/mm	unit load causing axial instability failure
		AC1 Text deleted AC1
t_s	mm	thickness of stiffener
		AC1 Text deleted AC1
W_D	N	calculation weight
Z	mm ³	section modulus of ring
W	N	weight
X	N/mm	unit modulus
AC1 PS	N/mm ²	maximum allowable pressure AC1

Subscripts		
ΔT		due to temperature difference
ϕ		circumferential direction
b		flexural
bk		bottom knuckle area
D		design
c		critical
cyl		cylinder
e		short term
f		flexural
H		saddle horn
k		knuckle area
lam		laminate
l		load
M		due to flexural moment
N		due to normal load
p		due to pressure
R		ring
s		stiffener
Sk		skirt
Sku		upper part of skirt
T		due to tensile load
w		due to weight
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 q_ϕ shall be determined from Equation (11)

$$q_\phi = \frac{p_D \times D}{2} \quad (11)$$

where $p_D = PS + \text{hydrostatic pressure}$.

The laminate selected using Equation (10) shall have a circumferential load bearing capacity equal to or greater than that given by Equation (11).

10.2.2 Combined axial loading

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

a) Pressure:

$$\text{Axial unit load } q_{x,p} = \frac{p_D \times D}{4} \quad (12)$$

$$\text{For stability case } p_D = PS + \frac{p_e}{(A_5)^{0,5}}$$

$$\text{and } p_D = PS + \frac{p_e}{A_5} \text{ for tension case}$$

where p_e = any short term pressure load.

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

$$\text{Axial unit load } q_{x,M} = \frac{4 \times M_D}{\pi \times D^2} \quad (13)$$

$$\text{For stability case } M_D = M + \frac{M_e}{(A_5)^{0,5}}$$

$$\text{and } M_D = M + \frac{M_e}{A_5} \text{ for tension case}$$

where M_e = any short term flexural moment.

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

$$\text{Axial unit load } q_{x,w} = \frac{W_D}{\pi \times D} \quad (14)$$

$$\text{where } W_D = W + \frac{W_e}{(A_5)^{0,5}} \text{ for stability case}$$

$$\text{and } W_D = W + \frac{W_e}{A_5} \text{ for tension case}$$

where W_e = any short term weight loading.

The combined axial unit loading q_x is the sum of the values obtained from Equations (12) to (14) inclusive, having due regard for the direction of loading.

For shell stability (i.e. compressive loading):

$$q_{x,c} = q_{x,M} + q_{x,w} + q_{x,p} \quad (15)$$

where $q_{x,w}$ is the axial load from the weight of that part of the vessel, fittings, attachments and applied load acting above the point under consideration.

If $q_{x,p}$ is from a overpressure, then

$$q_{x,c} = q_{x,M} + q_{x,W} - q_{x,p} \quad (16)$$

For the shell in tension:

$$q_{x,c} = q_{x,p} + q_{x,M} + q_{x,W} \quad (17)$$

where $q_{x,W}$ is the axial unit load from the weight of that part of the vessel, fittings, contents, attachments and applied loads acting below the point considered.

The laminate selected using Equation (10a) shall have an axial load bearing capacity, all U_{lam} , equal to or greater than that given by Equation (15), (16) and (17).

The maximum value of $q_{x,c}$ shall also be checked against the stability criteria as given in 10.3.

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 and circumferential compressive loadings and 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. Equation (18) gives the compressive buckling unit load for the shell.

$$u_c = k \times \sqrt{E_{\phi b} \times E_x} \times \frac{t^2}{D} \quad (18)$$

Where:

E_{ϕ} = Flexural modulus in circumferential direction;

E_x = Axial modulus.

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

t is the wall at the cut-out

In all cases $\frac{u_c}{q_{xc}} \geq F$, where F shall be taken from Table 6 or Equation (5) whichever is the higher.

Regarding shell sections or skirt supports with cut outs, k for such sections is given by Equations (19) and (20)

when

$$\frac{d_{co}}{\left(\frac{D \times t}{2}\right)^{0.5}} \leq 3,5 \quad k = \frac{0,78}{\sqrt{1 + \frac{D}{200 \times t}}} \quad (19)$$

and

when

$$\frac{d_{co}}{\left(\frac{D \times t}{2}\right)^{0.5}} > 3,5 \quad k = \frac{0,54}{\sqrt{1 + \frac{D}{200 \cdot t}}} \quad (20)$$

where d_{co} = dia. of cut-out.

10.3.3 Critical circumferential buckling pressure

For short cylinders $L_s \leq 6 \times D$

$$\boxed{AC1} p_c = 2,40 \times \sqrt[4]{E_{\phi b}^3 \times E_x} \times \frac{D}{L_s} \times \left(\frac{t}{D}\right)^{2,5} \boxed{AC1} \quad (21)$$

where L_s is the effective length of the cylinder or the distance between two stiffeners, see Figure 1.

For long cylinders i.e. L_s or $L > 6 \times D$

$$\boxed{AC1} p_c = 2,1 \times E_{\phi b} \times \left(\frac{t}{D}\right)^3 \boxed{AC1} \quad (22)$$

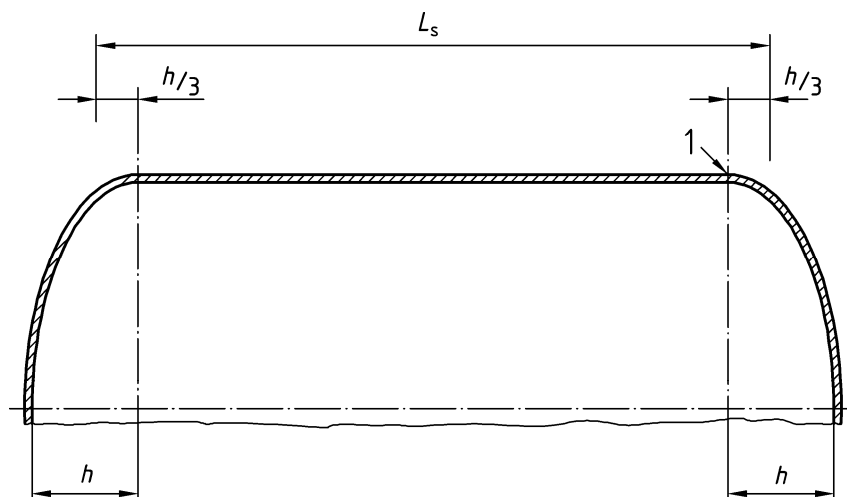
In all cases $\frac{p_c}{p_D} \geq F$, where F shall be taken from Table 6 or Equation (5) whichever is the higher.

10.3.4 Combined axial and radial compressive loadings

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

$$\left(\frac{q_{xc} \times F}{u_c}\right)^{1,25} + \left(\frac{p_D \times F}{p_c}\right)^{1,25} \leq 1 \quad (23)$$

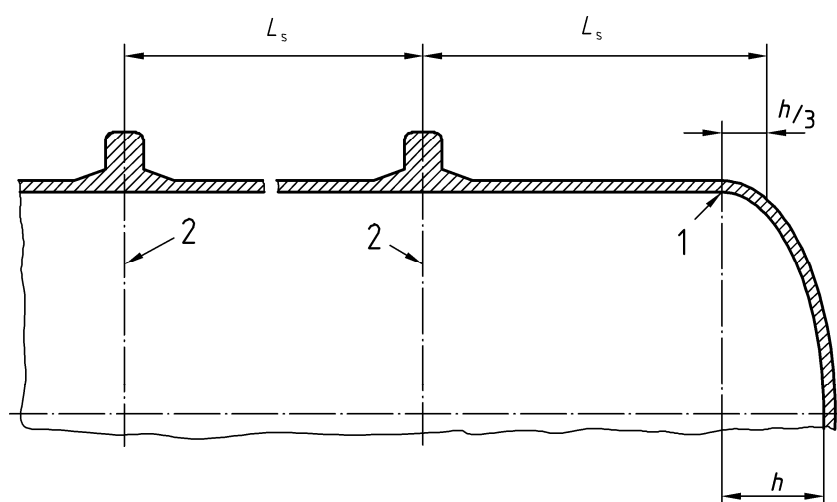
where q_{xc} is given by Equation (15), u_c by Equation (18) and p_c by Equation (21) or (22). F shall be taken from Table 6 or Equation (5) whichever is the higher.



Key

- 1 tangent point

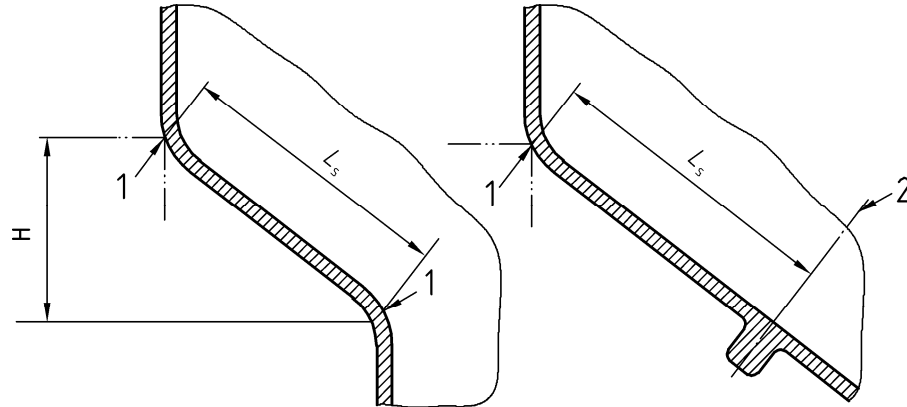
Figure 1a) — Effective length for unstiffened cylinders



Key

- 1 tangent point
2 C_L of stiffener

Figure 1b) — Effective length between stiffeners for cylinder



Key

- 1 tangent point
- 2 C_L of stiffener

Figure 1c) — Effective length between stiffeners for cones under external pressure

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

When the thickness obtained from Equations (21) or (22) results in an unacceptably high value, the shell may be subdivided and recalculated using a shorter effective length using Equation (24a).

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 fully bonded to the shell.

The critical general instability pressure p_c is given by Equation (24).

$$\boxed{\text{AC1}} p_c = \left[\left(E_{\phi b}^3 \times E_x \right)^{0,25} \times \frac{2 \times t_c}{D} \times \frac{\lambda^4}{\left(m^2 - 1 + \frac{\lambda^2}{2} \right) \times (m^2 + \lambda^2)^2} + \frac{8 \times (m^2 - 1) \times E_s \times I_s}{L_s \times D_s^3} \right] \quad (24a) \boxed{\text{AC1}}$$

Using $m = 2, 3$, etc. to find the minimum value of p_c . If $L > 20 \times D$ or the contribution from the shell is ignored, the ring stiffness shall be given by (24a).

$$E_s \times I_s \geq \frac{p_D \times L_s \times D_s^3 \times F}{24} \quad \boxed{\text{AC1}} (24b) \boxed{\text{AC1}}$$

- m is the circumferential buckling wave number;
- E_s is the flexural modulus of the stiffener, in the hoop direction;
- λ shell parameter;
- I_s is the second moment of area of the stiffener, see Figures 2 and 3;
- L_s is the distance between two stiffeners. If the stiffener spacing is not equal, then L_s is the average value;
- t_c is the minimum shell thickness of t_{c1} or t_{c2} in the area of the stiffener, see Figure 2.

$$\lambda = \frac{\pi \times D}{2 \left\{ L_S + \frac{2}{3} h \right\}}$$

where F shall be taken from Table 6, or Equation (5) whichever is the greatest.

In all cases $\frac{p_c}{p_D} \geq F$.

- a) For a solid GRP stiffener the basic dimensions to be used in Equation (24) are given as follows and shown in Figure 2. Where the effective width of the shell used in this calculation equals $b_s + 1,15 \times \sqrt{D \times t_c}$

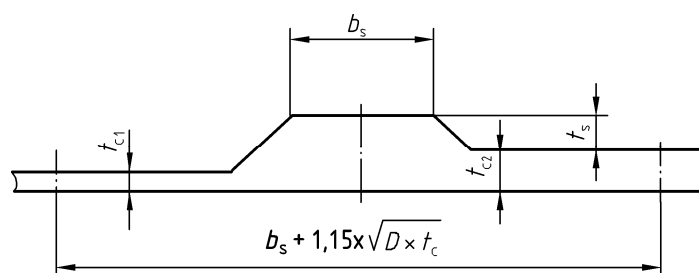


Figure 2 — Solid GRP stiffener configurations

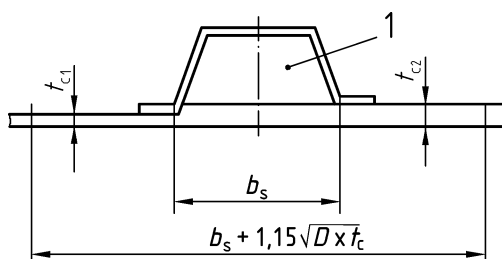
where:

$$5 \times t_c \leq b_s \leq 20 \times t_s;$$

$$\text{and } 1,5 \times t_c \leq t_s \leq 4 \times b_s;$$

$$\text{and } b_s \leq 300 \text{ mm.}$$

- b) For other GRP-stiffener configurations, AC1 *Text deleted* AC1 the basic dimensions to be used in Equation (24) are as shown in Figure 3.



Key

1 infill (foam) or open

NOTE t_c = average thickness

Figure 3 — 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

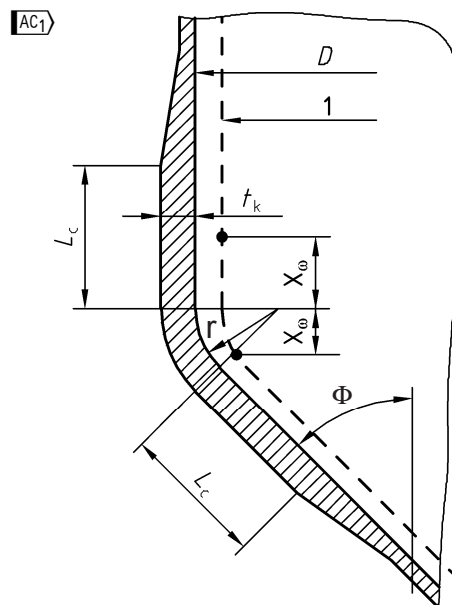
The geometry of conical shells shall be to one of the forms shown in AC1 Figure 4a) and 4b). AC1

Figure 4a) shall be used for all materials including fabric backed AC1 thermoplastics liners, except as noted below. The knuckle radius r AC1 should preferably be not less than $0,1 D$, but shall not be less than $0,06 D$, where D is the adjacent shell diameter.

Figure 4b) may only be used 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 cone angle of 120°.

The maximum included angle of the cone at its apex shall be 150° for all cones subject to pressure or vacuum having a knuckle radius.

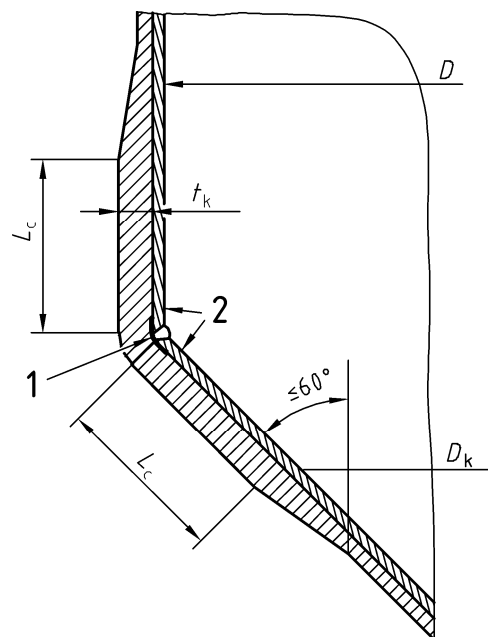
Conical covers of storage tanks not subject to internal or external pressure manufactured without a knuckle radius shall be designed in accordance with 10.4.5. A knuckle radius is not required for conical covers when the applied pressure is less than 65 mbar positive or 6 mbar negative.



Key

- 1 liner $\chi_w > 80$ mm, i.e. position of welds

Figure 4a) — Conical section with knuckle, with or without thermoplastics liner AC1



Key

1 conductive layer behind weld

2 no voids here behind welded area

Figure 4b) — 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 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 given by Equation (25).

Circumferential unit load

$$\boxed{AC1} q_{\Phi} = \frac{p_D \times D_k}{(2 \cos \Phi)} \boxed{AC1} \quad (25)$$

where Φ is half the angle at the apex of the cone and D_k is defined in Figure 4.

The laminate selected using $\boxed{AC1}$ Equation (10a) $\boxed{AC1}$ shall have a circumferential load bearing capacity equal to or greater than that given by Equation (25).

10.4.3.2 Axial unit load in cone to knuckle junction

a) For ends of the form shown in Figure 4a), the axial unit load shall be given by Equation (26):

$$q_{x1} = \frac{p_D \times D_k \times K_{c1}}{2} \quad (26)$$

where K_{c1} is obtained from Table 7.

The laminate selected using $\overline{AC_1}$ Equation (10a) $\overline{AC_1}$ shall have a load bearing capacity equal to or greater than that given by Equation (26).

Table 7 — Concentration factor K_{c1} for conical shells with knuckle $\overline{AC_1}$

$\frac{r}{D}$	K_{c1} for ϕ					
	10°	20°	30°	45°	60°	75°
0,06	1,57	2,18	2,55	3,22	4,1	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	1,2	1,2	1,26	1,53	2,79
0,3	1	1,06	1,13	1,2	1,33	1,86

b) For ends of the form shown in Figure 4b the axial unit load shall be given by (27).

$$q_{x2} = \frac{p_D \times D_k \times K_{c2}}{2} \quad (27)$$

where K_{c2} is obtained from Table 8.

The laminate selected using $\overline{AC_1}$ Equation (10a) $\overline{AC_1}$ shall have a load bearing capacity equal to or greater than that given by Equation (27).

Table 8 — Concentration factor K_{c2} for conical shells without knuckle

$\overline{AC_1} \frac{t_k}{D} \overline{AC_1}$	K_{c2} for ϕ			
	15°	30°	45°	60°
0,002	2,94	5,62	8,9	13,6
0,005	2,05	3,7	5,8	8,7
0,01	1,6	2,75	4,12	6,3
0,02	1,24	2	3	4,4
0,04	1	1,55	2,2	3,2
0,05	1	1,45	2	2,75

Any calculated increase in construction of the knuckle region shall extend onto the shell and cone a distance L_c given by Equation (28).

$$L_c = \sqrt{\frac{D \times t_k}{\cos \Phi}} \quad (28)$$

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

The longitudinal unit load used to determine the laminate shall not be less than q_ϕ , q_{x1} or q_{x2} , as appropriate from $\boxed{\text{AC1}}$ Equation (10a). $\boxed{\text{AC1}}$

10.4.4 Conical ends subject to external pressure

10.4.4.1 Strength requirement

The circumferential unit load shall be computed using $\boxed{\text{AC1}}$ Equation (25). The laminate selected using Equation (10a) shall have a load bearing capacity equal to or greater than that given by Equation (25) to (27). $\boxed{\text{AC1}}$

10.4.4.2 Elastic stability

10.4.4.2.1 General

The cylinder shall be checked to ensure that it is of sufficient thickness to resist collapse due to compressive and circumferential loading. It shall also be ensured that the cylinder will resist collapse under the combined action of axial and circumferential loading.

10.4.4.2.2 Critical radial buckling pressure p_c

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

$$\boxed{\text{AC1}} p_c = 2,40 \times 4 \sqrt[4]{E_{\phi b}^3 \times E_x} \times \frac{D_m}{\cos \Phi \times L_s} \times \left(\frac{\cos \Phi \times t}{D_m} \right)^{2,5} \boxed{\text{AC1}} \quad (29)$$

where:

$L_s = \frac{H}{\cos \Phi}$ is the effective length of the conical cylinder, or the distance between stiffeners, see Figure 1;

D_m is the mean diameter of the cone section being designed = $\frac{(D_1 + D_2)}{2}$.

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

$$\boxed{\text{AC1}} p_c = 2,1 \times E_{\phi b} \left(\frac{\cos \Phi \times t}{D_m} \right)^3 \boxed{\text{AC1}} \quad (30)$$

In all cases $\frac{p_c}{p_D} \geq F$, where F shall be taken from Table 6 or Equation (5) whichever is the higher.

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 using Equation (31)

$$\boxed{\text{AC1}} u_c = k \times \sqrt{E_{\phi b} \times E_x} \times \frac{t^2 \times \cos \Phi}{D_m} \boxed{\text{AC1}} \quad (31)$$

where

$$k = \frac{0,84}{\sqrt{1 + \frac{D_m}{200 \times t \times \cos \Phi}}}.$$

In all cases

$$\frac{u_c}{q_x} \geq F \quad (32)$$

where F shall be taken from Table 6 or Equation (5), whichever is the higher.

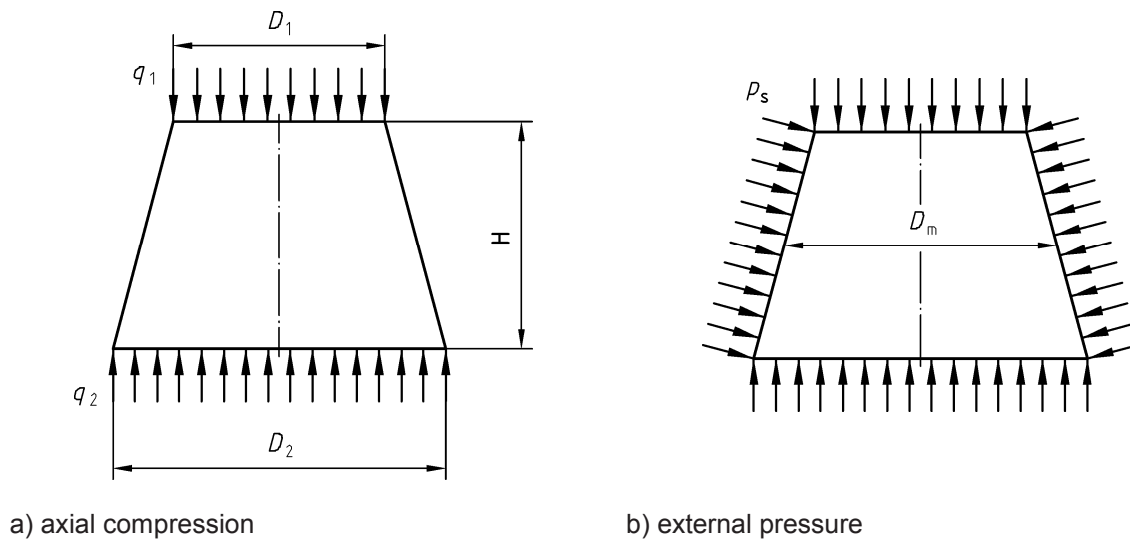


Figure 5 — Conical shells under external pressure

Where q_1 and q_2 are the normal unit axial loads at the change of geometry, under axial load N_{x1} and N_{x2}

$$q_1 = \frac{N_{x1}}{\pi \times D_1} \quad q_2 = \frac{N_{x2}}{\pi \times D_2} \quad (33)$$

10.4.4.2.4 Combined axial and radial compressive loadings

For combined axial and radial loadings, the following criterion (34) shall be met:

$$\boxed{\text{AC1}} \left(\frac{q_x \times F}{u_c} \right)^{1.25} + \left(\frac{p_D \times F}{p_c} \right)^{1.25} \leq 1 \quad \boxed{\text{AC1}} \quad (34)$$

p_c is given by Equation (29) or (30)

u_c is given by Equation (31)

10.4.5 Shell conical covers

10.4.5.1 Covers subjected to internal pressure

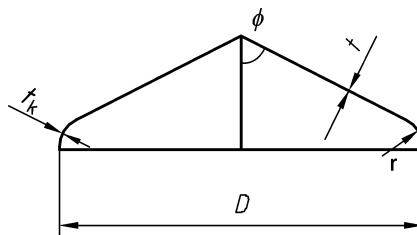


Figure 6 — Conical covers

For conical covers when $60^\circ \leq \phi \leq 75^\circ$ and where $0 \leq \frac{r}{D} \leq 0,1$, the unit load in the axial direction in the knuckle is given by Equation (35). $\boxed{\text{AC1}}$ If $\phi > 75^\circ$ the covers $\boxed{\text{AC1}}$ shall be designed as a flat plate in accordance with 10.9.

$$\boxed{\text{AC1}} q_x = \alpha_b \times p_D \times \frac{1}{\sin \phi \times \cos \phi} \times \left(\frac{D}{t_k} \right)^{1+\beta_b} \times t_k \quad \boxed{\text{AC1}} \quad (35)$$

where

$$\boxed{\text{AC1}} \alpha_b = -64 \times \left(\frac{r}{D} \right)^2 + 7,6 \times \left(\frac{r}{D} \right) + 0,13 \quad \boxed{\text{AC1}} \quad (36a)$$

$$\boxed{\text{AC1}} \beta_b = 51,6 \times \left(\frac{r}{D} \right)^2 - 8,18 \times \left(\frac{r}{D} \right) + 0,52 \quad \boxed{\text{AC1}} \quad (36b)$$

The laminate selected using $\boxed{\text{AC1}}$ Equation (10a) $\boxed{\text{AC1}}$ shall have an axial load bearing capacity equal to or greater than that given by Equation (35).

10.4.5.2 Conical covers subject to external pressure.

The stability of the cover is given by $\boxed{\text{AC1}}$ Equation (37a) $\boxed{\text{AC1}}$

$$\boxed{\text{AC1}} p_c = 13,58 \times E_b \times \sin \phi \times \cos^{1,5} \phi \times \left(\frac{t}{D} \right)^{2,5} \quad \boxed{\text{AC1}} \quad (37a)$$

where E_b is the unit flexural modulus (minimum) of the conical cover construction.

In all cases

$$\boxed{AC1} \frac{p_c}{p_D} \geq F \quad (37b) \boxed{AC1}$$

where F shall be taken from Table 6 or Equation (5), whichever is the greater.

10.5 Dished end

10.5.1 General requirements

Dished ends shall be one of the following shapes:

Hemispherical end see Figure 7 or Torispherical end see Figure 8. The limitations of this type of end shall be $0,8 D \leq R < D$ and the knuckle radius shall be a minimum of $0,1 D$ and a maximum of $0,25 D$.

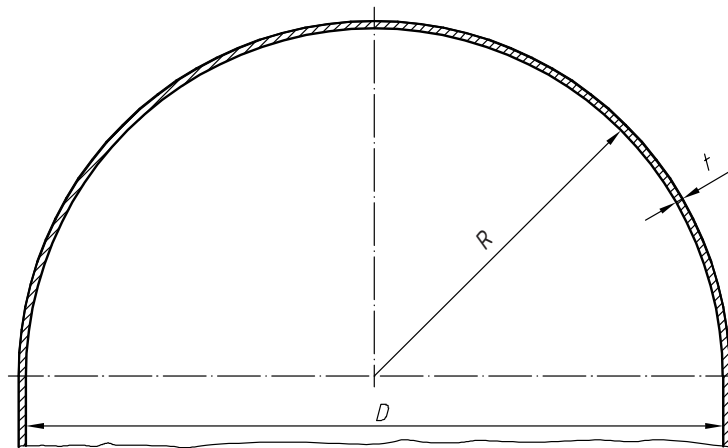


Figure 7 — Hemispherical dished ends

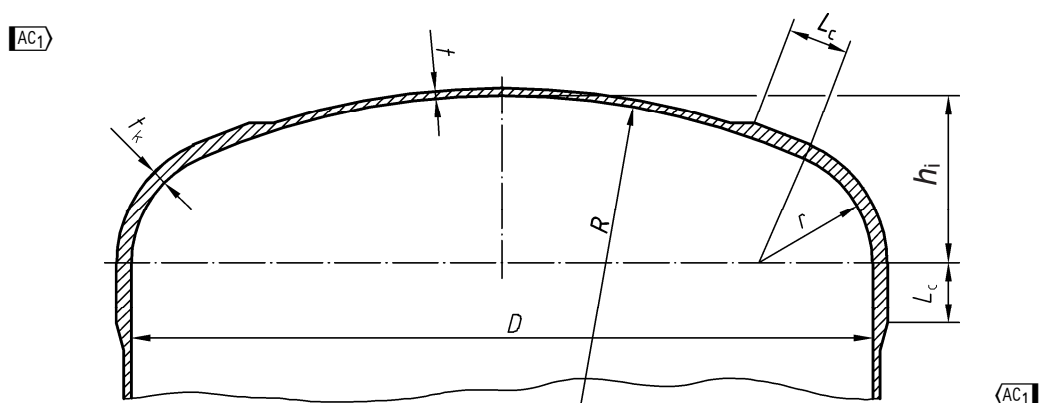


Figure 8 — Torispherical dished ends

10.5.2 Dished ends subject to internal pressure

The unit loading in an ellipsoidal end and the knuckle region of torispherical ends shall be given by Equation (38):

$$q_{k,p} = \frac{p_D \times D \times K_d}{2} \quad (38)$$

The value of K_d shall be determined from Table 9 for trial thicknesses until the allowed laminate loading exceeds the value given by AC1 Equation (38). AC1

The unit loading in the crown region of torispherical ends and hemispherical ends shall be determined from Equation (39):

$$q_p = 0,6 \times p_D \times R \quad (39)$$

where R is the radius of the crown region.

In the case of torispherical ends that may require a greater laminate in the knuckle region than on the crown, the extra laminate shall extend a distance L_c determined from Equation (40) onto both the crown and shell.

$$L_c = \sqrt{D \times t_k} \quad (40)$$

where t_k is the thickness of the knuckle, determined from the value of $q_{k,p}$ derived from Equation (38).

The laminate selected using AC1 Equation (10a) AC1 shall have a load bearing capacity equal to or greater than that given by Equation (38) and (39).

Table 9 — Concentration factors K_d for torispherical dished end knuckles

$\frac{h_i}{D}$	$\frac{t}{D}$	Torispherical 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	AC1 0,005 AC1	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

10.5.3 Stability for dished ends subject to external pressure

The critical buckling pressure shall be given by Equation (41)

$$p_c = 0,242 \times E_b \left(\frac{t}{R} \right)^2 \quad (41)$$

In all cases

$$\frac{P_c}{P_D} \geq F \quad (42)$$

where F shall be taken from Table 6 or Equation (5) whichever is the greater.

10.6 AC₁ Bottoms AC₁

10.6.1 Fully supported, flat-bottom tanks

10.6.1.1 General

Continuous support shall be provided over the whole area of the flat bottom except where sumps or bottom run offs have to be accommodated. The unsupported region of the base shall be designed as a flat plate in accordance with the relevant subclauses of 10.9.

The gaps in the supports to allow for bottom branches shall be sized so that there is room for gussets (see Figure 15) and so that high local loads are not imposed on the additional reinforcement which is used for compensation of the branch opening.

Anchorage 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 12.5 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.

10.6.1.2 When $r > 30$ mm, or $\frac{r}{D} > 0,05$

the maximum axial unit load $q_{xk,1}$ in the knuckle is given by the following equations:

- a) unit load $q_{x,1}$ from internal pressure (hydrostatic plus overpressure)

$$q_{xk,1} = 3 \times k_p \times p_D \times D \quad (43)$$

where

$$k_p = 0,22 + \left(0,6 + 0,0566 \frac{D}{t_k} \right) \times \left(\frac{2 \times r}{D} - 4,44 \left(\frac{t_k}{D} \right)^{1,15} - 0,04 \right) \quad (44)$$

and k_p shall always be $\geq 0,22$.

- b) unit load $q_{xk,2}$ from loads at the cylindrical wall in the axial direction, $\Sigma q_{x,i}$ from dead loads, wind, weight, etc

$$q_{xk,2} = 6 \times k_n \times \sum q_{x,i} \quad (45)$$

where

$$k_n = \left| 1,38 + 0,41 \frac{r}{D} \left(\frac{D}{t_k} \right)^{1,15} - 0,077 \left(\frac{r}{t_k} \right)^2 \right| \quad (46)$$

The maxima of these loads occur in different positions and the interaction of these loads is given by Equation (47).

$$q_{xk} = q_{xk,1} + 0,3 \times q_{xk,2} \quad (47)$$

or

$$q_{xk} = q_{xk,2} + 0,3 \times q_{xk,1} \quad (48)$$

The maximum value of q_x shall be used in the design.

The laminate selected using $\boxed{\text{AC1}}$ Equation (10a) $\boxed{\text{AC1}}$ shall have a load bearing capacity equal to or greater than that given by Equation (49).

$$q_{xk \max} = -\frac{W_D}{\pi \times D} \pm \frac{4 \times M_D}{\pi \times D^2} \pm q_{xk} \quad (49)$$

Also the circumferential unit load given by Equation (11) shall be checked to ensure that it is less than the load bearing capacity in the circumferential direction.

10.6.1.3 When $r \leq 30$ mm, or $\frac{r}{D} \leq 0,05$

the maximum axial unit load in the knuckle region from internal pressure (hydrostatic plus overpressure) is given by the following equations:

a) for $t_{b1} \leq t_k$

$$\boxed{\text{AC1}} q_{xk1} = 0,72 \times p_D \times D \boxed{\text{AC1}} \quad (50)$$

b) for $t_{b1} > t_k$

$$\boxed{\text{AC1}} q_{xk1} = 0,90 \times p_D \times D \boxed{\text{AC1}} \quad (51)$$

The maximum unit load is given by Equation (52).

$$q_{xk \max} = -\frac{W_D}{\pi \times D} \pm \frac{4 \times M_D}{\pi \times D^2} \pm q_{xk,1} \quad (52)$$

The laminate selected using Equation (10) shall have a load bearing capacity equal to or greater than q_{xk} , given by Equation (52). Also the circumferential unit load given by Equation (11) shall be checked to ensure that it is less than the load bearing capacity in the circumferential direction.

Any increase in thickness over the bottom section of the shell or base, shall extend a distance L_c from the end of the knuckle determined from Equation (53), see Figure 9,

where