Form 36

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Interested committees:

Title: Draft BS EN 13121-3 GRP tanks and vessels for use above ground. Part 3: Design and workmanship.

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Introduction

This draft standard is based on national and international discussions. Your comments on this draft are invited and will assist in the preparation of the consequent standard.

For international standards, comments will be reviewed by the relevant UK national committee before sending the consensus UK vote and comments to the international committee, which will then decide appropriate action. If the international standard is approved, it is usual for the text to be published as a British Standard.

For national standards, comments will be reviewed by the relevant UK national committee and the resulting standards published as a British Standard.

UK Vote

Please indicate whether you consider the UK should submit a negative (with supporting technical reasons) or positive vote on this draft. Please indicate if you are aware of any reason why this draft standard should not be published as a British Standard.

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Date: xx/xx/20xx	Document: ISO/DIS xxxx

1	2	(3)	4	5	(6)	7
MB	Clause No./ Subclause No./Annex **(e.g. 3.1)**	Paragraph/ Figure/Table/Note	**Type of comment**	**Commend (justification for change) by the MB**	**Proposed change by the MB**	**Secretariat observations on each comment submitted**
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	

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EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

DRAFT
prEN 13121-3

September 2022

ICS 23.020.10

Will supersede EN 13121-3:2016

English Version

GRP tanks and vessels for use above ground - Part 3: Design and workmanship

Réservoirs et récipients en PRV pour applications hors sol - Partie 3 : Conception et fabrication

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

This draft European Standard is submitted to CEN members for enquiry. It has been drawn up by the Technical Committee CEN/TC 210.

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European foreword

This document (prEN 13121-3:2022) has been prepared by Technical Committee CEN/TC 210 “GRP tanks and vessels”, the secretariat of which is held by DIN.

This document is currently submitted to the CEN Enquiry.

This document will supersede EN 13121-3:2016.

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).

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

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

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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 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 document are made only by manufacturers who are competent and suitably equipped to comply with all the requirements of this document, 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 document 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.

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1 Scope

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

EN 59:2016, *Glass reinforced plastics — Determination of indentation hardness by means of a Barcol hardness tester*

EN 1990:2021, *Eurocode — Basis of structural design*

EN 1991-1-3:2010, *Eurocode 1 — Actions on structures — Part 1-3: General actions - Snow loads*

EN 1991-1-4:2010, *Eurocode 1: Actions on structures — Part 1-4: General actions - Wind actions*

EN 1991-4:2010, *Eurocode 1 — Actions on structures — Part 4: Silos and tanks*

EN 1993-1-1:2010, *Eurocode 3: Design of steel structures — Part 1-1: General rules and rules for buildings*

EN 1993-1-6:2017, *Eurocode 3 — Design of steel structures — Part 1-6: Strength and Stability of Shell Structures*

EN 1998-1:2010, *Eurocode 8: Design of structures for earthquake resistance — Part 1: General rules, seismic actions and rules for buildings*

EN 10025-2:2019, *Hot rolled products of structural steels — Part 2: Technical delivery conditions for non-alloy structural steels*

EN 13067:2020, *Plastics welding personnel — Qualification testing of welders — Thermoplastics welded assemblies*

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EN 13121-1:2021, *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 13121-4:2005, *GRP tanks and vessels for use above ground — Part 4: Delivery, installation and maintenance*

EN 13445-3:2021, *Unfired pressure vessels — Part 3: Design*

EN ISO 75-2:2013, *Plastics — Determination of temperature of deflection under load — Part 2: Plastics and ebonite (ISO 75-2)*

EN ISO 291:2008, *Plastics — Standard atmospheres for conditioning and testing (ISO 291)*

EN ISO 527-4:2021, *Plastics — Determination of tensile properties — Part 4: Test conditions for isotropic and orthotopic fibre-reinforced plastic composites (ISO 527-4)*

EN ISO 1172:1998, *Textile-glass-reinforced plastics — Prepregs, moulding compounds and laminates — Determination of the textile-glass and mineral-filler content — Calcination methods (ISO 1172)*

EN ISO 2592:2017, *Petroleum and related products — Determination of flash and fire points — Cleveland open cup method (ISO 2592)*

EN ISO 3915:2022, *Plastics — Measurement of resistivity of conductive plastics (ISO 3915)*

EN ISO 7500-1:2018, *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 9513:2012, *Metallic materials — Calibration of extensometer systems used in uniaxial testing (ISO 9513)*

EN ISO 11357-2:2020, *Plastics — Differential scanning calorimetry (DSC) — Part 2: Determination of glass transition temperature and glass transition step height (ISO 11357-2)*

EN ISO 14125:2011, *Fibre-reinforced plastic composites — Determination of flexural properties (ISO 14125)*

EN ISO 14692-3:2018, *Petroleum and natural gas industries — Glass-reinforced plastics (GRP) piping — Part 3: System design (ISO 14692-3)*

ISO 48-2:2018, *Rubber, vulcanized or thermoplastic — Determination of hardness (hardness between 10 IRHD and 100 IRHD)*

ASTM D4541:2017, *Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers*

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3 Terms and definitions

For the purposes of this document, the following terms and definitions apply. ISO and IEC maintain terminology databases for use in standardization at the following addresses:

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

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

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

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 document

Note 1 to entry: For this document, 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 document, 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

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

3.12
maximum allowable pressure
PS
maximum pressure without consideration of the hydrostatic 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

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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/mm^2	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/s^2	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	mm^4	Second moment of area
k	-	Correction factor
K	-	Overall design factor
l	mm	Length
L	mm	Overall length
m	kg/m^2	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/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	Stress = $\frac{U}{t}$and $\frac{n}{t}$

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Symbol	Unit	Definition
t	mm	Thickness
τ	N/mm^2	Shear stress
T	°C	Temperature
TS	°C	Design temperature
U_{lam}	N/mm	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
x	–	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
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

For laminates with layers deviating from 0° or 90°, the classical laminate theory according to Tsai, Puck or Hyer [5] shall be applied.

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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 document.

The tests as specified in Clause 7 and report along with the definitive documented items and requirements specified in this document shall be satisfied before a claim of compliance with this document 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 document and the documented items shall be satisfied before claim of compliance with this document 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;

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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 13121-4:2005.

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

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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 13121-1:2021.

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 13121-2:2003.

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 0,4 mm and 0,6 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 $10^6\,\Omega$, or the volume resistivity $10^6\,\Omega$m, when tested in accordance with the test method given in D.12.

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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 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/m^2 CSM or continuous filament windings construction, shall be finished with a surface veil.

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Table 3 — Minimum properties of laminate layers

Type of reinforcement	Direction	Applicable criteria	UTUS	Unit Tensile Modulus
			U_i N/mm per kg/m^2 glass	X_i N/mm per kg/m^2 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/mm^2 in plane (τ_{xy}) and transverse (τ_{xz}, τ_{yz}) Interlaminar lap shear strength $f_{lap,k} = \tau_{lap,k} \geq 20$ N/mm^2 Shear modulus $G_{xy} = 3\,300$ N/mm^2				
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*.

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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/m^2;

m_g is the % glass content by mass in layer i kg/m^2;

ρ_r is the density of the cured resin (kg/m^3);

ρ_g is the density of the glass (kg/m^3).

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 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/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 5 when tested in accordance with the test method given in D.8.

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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 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 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 document 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 D.2;

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

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

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

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

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

g) flexural strength of laminate, according to the test method given in 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 D.8;

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

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

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

For the ultimate properties of filament windings refer to EN 13923:2006.

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 (l) or (m) 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 competent testing laboratory for FRP.

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

The document 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:

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

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

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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):

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

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):

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

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.

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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 document, 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 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. Major constituent is the layer type with higher mass per unit area. Designer is allowed to calculate A_5 values as a weighted average of the layers, considered the mass per unit area as the weighing factor.

For intermediate life times between 10 and 50 years, values of A_5 may be determined by linear or logarithmic 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 D.15.

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An early assessment of the partial design factor A_5 can be determined using the short-term creep test (see D.10), but the final value used in the design shall be that determined from the long term creep test (see 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	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	$F \geq 2,7$	$F \geq 3,0$	$F \geq 4,0$

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8 Determination of design strain and loadings

8.1 General

This document 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 or laminate 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

Type of resin	Laminates				
	Chopped strand mat laminate CSM	Mixed laminate WR/CSM	Filament 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.

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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:

$$\varepsilon_{test} \leq 1{,}3 \cdot \varepsilon_{\lim} \tag{8}$$

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):

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

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

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

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

$$F_{\min} \geq (\gamma_M \cdot \gamma_F \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4) \qquad \text{where} \quad \gamma_M \cdot \gamma_F = 1{,}4 \cdot 1{,}5 = 2{,}1$$

$$\text{then shall be} \quad A_1 \cdot A_2 \cdot A_3 \cdot A_4 \geq \frac{F_{min}}{1{,}4 \cdot 1{,}5}$$

$K_{\text{min.}}$ and $F_{\text{min.}}$ 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 (fiber composite materials) are to be regarded as materials in the sense of EU Directive 2014/68 / EC for pressure equipment.

For these materials for the manufacture of pressure equipment, expert reports that correspond to Sections 7.9.3 to 7.9.5 shall be submitted by the manufacturer before the start of manufacture. The material parameters and influence-factors that are decisive for the dimension-ing and design of the components shall be determined. The tests required for this, and the preparation of the reports are to be carried out by an independent test laboratory that is competent in GRP.

In the case of pressure equipment of category III and IV, a special assessment of the report shall be carried out by the responsible notified body (see Annex ZA).

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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.

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

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

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

where

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

U_{i} is the ultimate tensile unit load carrying capacity of lamina layer *i*, N/mm, per kg/m^2 glass from 8.3;

m_{i} is the mass of reinforcement per unit area in one layer of type *i*, kg/m^2 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/m^2 glass.

To assess the design of a filament wound tank or vessels see EN 13923:2006 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 $U_{\text{lam,k}}$ and $X_{\text{lam,k}}$ 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.

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9 Design

9.1 Introduction

According to EN 1990:2021 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 1991-1-3:2010.

9.2.2 Wind loads

The wind loads shall be taken from EN 1991-1-4:2010.

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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. The stiffener / flange shall be calculated using equation (50) for the characteristic wind pressure.

Wind load on roof and catch basin according to EN 1991-4:2010.

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 (see formula 7.4) ;

— p_{wind} = (0,6 + 0,4) · dynamic maximum wind pressure for vessels with ventilation(see formula 7.4 and 7.5)

— 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 1991-1-4:2010 and EN 1991-1-6:2010.

In the case of slim structures with $H/D \geq 6$ or $h_{total} \geq 20$ m, proof of the actual wind pressure distribution (according to EN 1991-1-4:2010, 7.9) on the circumference can be dispensed when the following conditions are met:

$$\sqrt{\frac{20000\ N/mm^2}{E_{\varphi b}}} \cdot \frac{r_m}{t} \leq 150 \text{ and } \frac{l_R}{D} \leq 4$$

The wall thickness in the other areas shall not be less than that determined above.

The bending moments in the circumferential direction are then approximate

$m_y \cong 0{,}2 \cdot {r_m}^2 \cdot q_e$

q_e = wind pressure on the shell according to EN 1991-1-4:2010, 5.1 at the height z

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 1998-4:2006.

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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 1998-1:2010.

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 $T_A = T_B = 0$:

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

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

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

where

a_g is the design ground acceleration $(a_g = \gamma_I \cdot a_{gR})$;

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, $1{,}2 \leq \gamma_I \leq 2{,}0$ (see EN 1998–1:2010 and EN 1998–4:2006);

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):

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

9.2.3.5 Unit loads

For all unit loads the formulae in Clauses 9 to 16 are valid and $\gamma_F = 1{,}0$.

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:

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

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 $h_s = h_{liquid}/2 + h_{skirt}$.

$$M_{AE} = H_{AE} \cdot h_s \quad (19)$$

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:

— $p_{access} = 1{,}5\ kN/m^2$ 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.

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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 1990:2021 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 1990:2021. 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.

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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 1990:2021 all actions shall be classified as follows:

— permanent actions (G), e.g. self-weight of the vessel or tank, fluid weight in design conditions, 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:

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

Combinations of actions for accidental design situations:

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

Combinations of actions for seismic design situations:

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

Verifications of static equilibrium and resistance:

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

$$E_{d,dst} \leq E_{d,stb} \quad (23)$$

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

$$E_d \leq R_d \quad (24)$$

b) Serviceability limit state:

Characteristic combination (used to verify limit strain):

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

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Frequent combination:

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

Quasi-permanent combination:

$$E_{d,perm} = \sum G_{k,j} \oplus \sum \psi_{2,i} \cdot Q_{k,i} \quad (27)$$

Verifications:

It shall be verified that:

$$E_d \leq C_d \quad (28)$$

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, $i \geq 1$

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Table 11 — Ψ-factors based on EN 1990:2021

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 1991–1–1:2010)			
- 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.

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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.

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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 $n{\cdot}1$-matrix *E*.

— Write all *m* possible combinations column by column (in terms of combination values) in an $n{\cdot}m$-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:

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

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 1991-4:2010.

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 1990:2021.

9.3.2 Dimensioning by using ($A_5{\cdot}\gamma_{F,i}$)-factored loads

For the "($A_5{\cdot}\gamma_{F,i}$)-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 ($A_5{\cdot}\gamma_{F,i}$)-factored loads determine the particular tensions $\sigma_{d,R}$ or $n_{d,R}$.

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The following applies:

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

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

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

where

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

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

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

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

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

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

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

$X_{\text{lam,i}}$ 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.

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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/mm^2	modulus of elasticity
E_b	N/mm^2	flexural modulus
E_{s}	N/mm^2	modulus of elasticity of stiffener
E_x	N/mm^2	tensile modulus of laminate in axial direction
$E_{x,b}$	N/mm^2	flexural modulus of laminate in axial direction
E_ϕ	N/mm^2	tensile modulus of laminate in circumferential direction
$E_{\phi,b}$	N/mm^2	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/mm^2	shear modulus of laminates
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
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
M_{H}	Nmm	maximum flexural moment at saddle horn of horizontal vessel support
M_S	Nmm	flexural moment in stiffening ring

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Symbol	Unit	Definition
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/mm^2	design pressure
p_{cr}	N/mm^2	pressure causing instability failure
p_{hp}	N/mm^2	hydrostatic pressure
PS	N/mm^2	maximum pressure (= maximum allowable pressure according to EU Directive 2014/68/EU)
PS_{op}	N/mm^2	maximum internal pressure (overpressure)
PS_{ep}	N/mm^2	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	mm^3	section modulus

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

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10.2 Vertical vessels or tanks, cylinders under loads ($t < 0{,}01 \cdot D$)

10.2.1 Circumferential loadings

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

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

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 $p_{d,cr} = PS_{ep} \cdot \gamma_{F,p} + p_{wind} \cdot \gamma_{F,p}$ (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 $n_{x,p,d,R} = \frac{p_{d,R} \cdot D}{4} \quad or \quad n_{x,p,d,\varepsilon} = \frac{p_{d,\varepsilon} \cdot D}{4}$ (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 $n_{x,M,d,R} = \frac{4 \cdot M_{d,R}}{\pi \cdot D^2} \quad or \quad n_{x,M,d,\varepsilon} = \frac{4 \cdot M_{d,\varepsilon}}{\pi \cdot D^2} \quad or \quad n_{x,M,d,cr} = \frac{4 \cdot M_{d,cr}}{\pi \cdot D^2}$ (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:

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

where

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

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

axial unit load $n_{x,W,d,R} = \frac{W_{d,R}}{\pi \cdot D}$ *or* $n_{x,W,d,\varepsilon} = \frac{W_{d,\varepsilon}}{\pi \cdot D}$ *or* $n_{x,W,d,cr} = \frac{W_{d,cr}}{\pi \cdot D}$ (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:

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

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

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

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

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

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

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:

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

where

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

E_x is the axial modulus

t is the actual shell thickness

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

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:

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

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

when

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

and when

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

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 1993-1-6:2017, D.2 by an equivalent cylinder comprising three sections. t_o and l_o are values for the top section.

$$p_{cr} = 2{,}40 \cdot C_\Theta \cdot \sqrt[4]{E_{\varphi b}^3 \cdot E_x} \cdot \frac{D}{L_S} \cdot \left(\frac{t}{D}\right)^{2,5} \qquad (45)$$

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 $L > 6 \cdot D$

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

the following criterion shall be met:

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

10.3.4 Combined axial and radial compressive loadings

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

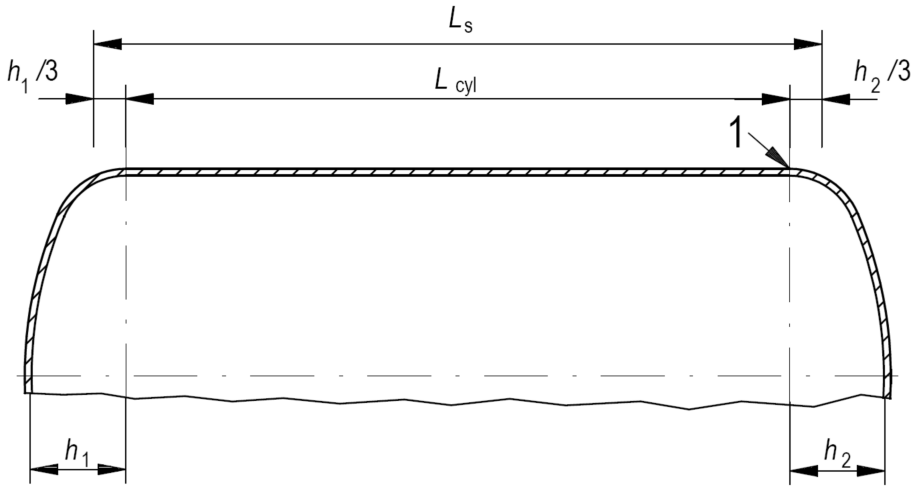
$$\left(\frac{n_{x,d,cr}}{n_{cr}/(\gamma_M \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4)}\right)^{1,25} + \left(\frac{p_{d,cr}}{p_{cr}/(\gamma_M \cdot A_1 \cdot A_2 \cdot A_3 \cdot A_4)}\right)^{1,25} \leq 1 \qquad (48)$$

where

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

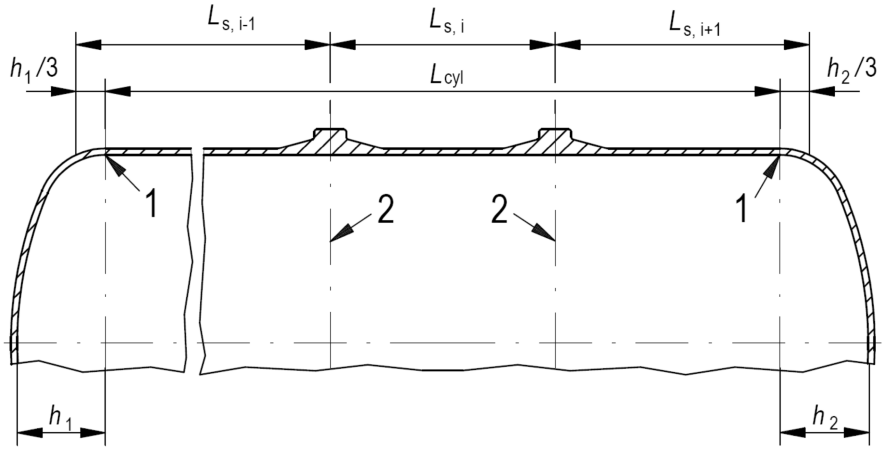


Key

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):

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