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GRP tanks and vessels for use above ground - Part 5: Example calculation of a GRP-vessel

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GRP tanks and vessels for use above ground - Part 5: Example calculation of a GRP-vessel

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

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EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
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European foreword

This document (FprCEN/TR 13121-5:2016) has been prepared by Technical Committee CEN/TC 210 “GRP tanks and vessels”, the secretariat of which is held by SFS.

This document is currently submitted to the Vote on TR.

Introduction

EN 13121 consists of the following parts:

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

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

— EN 13121-3, *GRP tanks and vessels for use above ground — Part 3: Design and workmanship*

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

— CEN/TR 13121-5, *GRP tanks and vessels for use above ground — Part 5: Example calculation of a GRP-tank (this report)*

These five parts 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 EN 13121-3. 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. EN 13121-4 of this standard specifies recommendations for delivery, handling, installation and maintenance of GRP tanks and vessels. This part of EN 13121 gives guidance in use of the standard. CEN/TC 210 has found it necessary to publish an example calculation of a vessel according to EN 13121-3 due to the standards complexity, and for the understanding of how the standard complies with EN 1990:s principles and requirements for safety, serviceability and durability of structures.

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

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

1 Scope

This Technical Report gives guidance for the design of a vessel using the standard EN 13121-3 GRP tanks and vessels for use above ground. The calculation is done according to the advanced design method given in EN 13121-3:2016, 7.9.3 with approved laminates and laminate properties.

2 General

Vessels or vessel structures may contain such structural elements or solutions for which this standard does not provide sufficient guidance. In that case, other methods shall be used in order to obtain a safe structure.

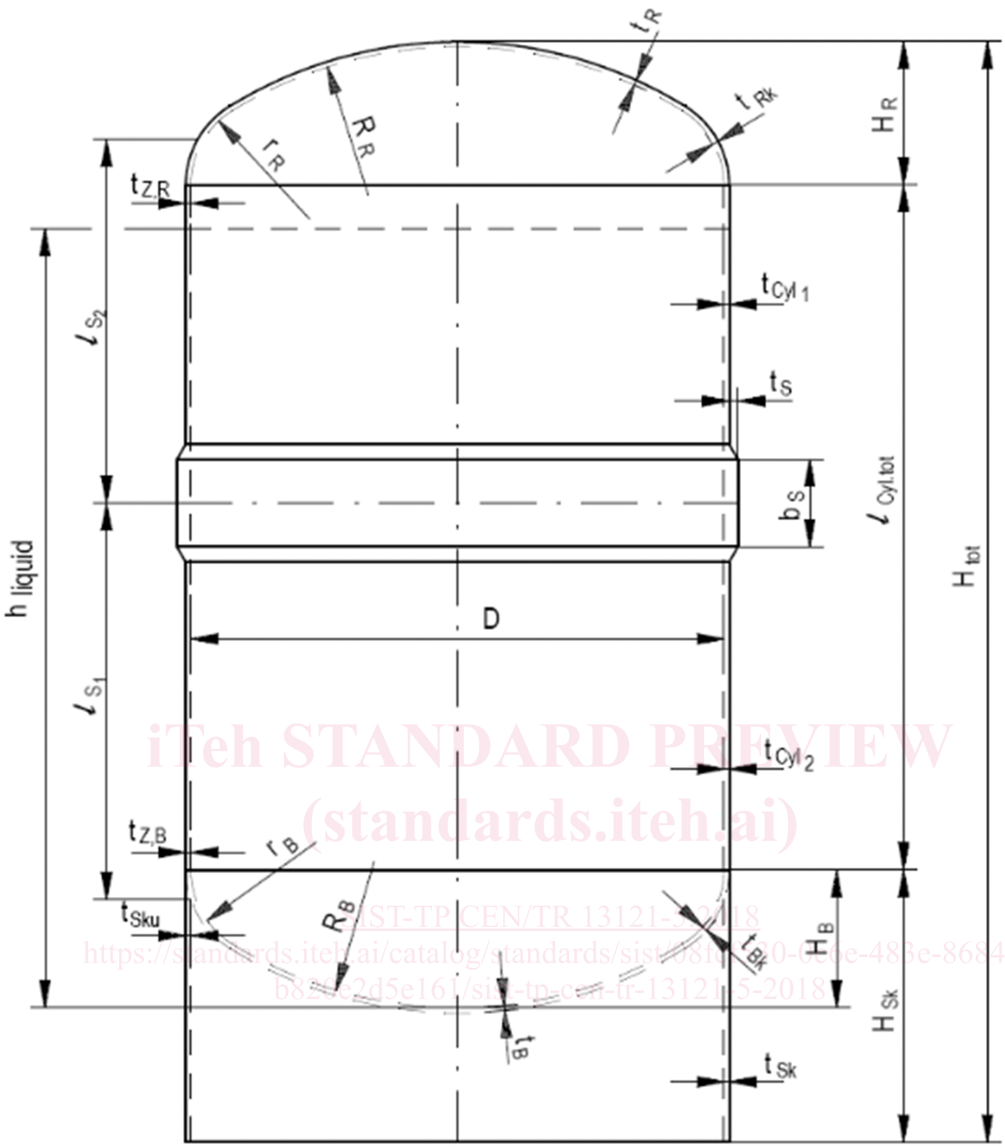
This example calculation is based on a pressurized GRP vessel with an internal diameter of D 3000 mm. The cylindrical parts of the vessel are filament wound. Its bottom and roof are torispherical dished ends that are hand laid up using mixed laminates. Protection against medium attack is obtained by a chemical resistance layer (CRL).

The tank is located outdoors in a seismic area.

IMPORTANT – This example doesn't cover all necessary verifications for the calculation of the GRP tank. Additional verifications have to be performed for the roof, the upper cylinder, etc.

3 Dimensions of the tank

Sketch of the tank dimensions:



General Dimensions:

Diameter: D = 3 000 mm

Total height: H_{tot} = 8 000 mm

Cylinder:

Thickness cylinder 1:	$t_{Cyl,1}$	= t_{C1} = 9,2 mm
Thickness cylinder 2:	$t_{Cyl,2}$	= t_{C2} = 11,7 mm
Thickness cylinder at roof:	$t_{Z,R}$	= 30,0 mm
Thickness cylinder at bottom:	$t_{Z,B}$	= 46,1 mm
Total cylinder length:	$l_{Cyl.tot}$	= 6 610 mm
Distance between stiffeners:	$l_{s.1}$	= 3700 mm $l_{s.2}$ = 3303 mm
Thickness of the stiffener:	t_S	= 20 mm

Width of the stiffener: b_S = 260 mm

Skirt:

Thickness skirt: t_{Sk} = 17,0 mm

Thickness overlay laminate: t_{02} = 7,0 mm

Height of the skirt: H_{Sk} = 890 mm

Roof:

Thickness calotte: t_R = 13,0 mm

Radius calotte: R_R = 3000 mm

Thickness knuckle roof: t_{Rk} = 30,0 mm

Radius knuckle: r_{Rk} = 300 mm

Height of the roof: H_R = 590 mm

Bottom:

Thickness calotte: t_B = 16,5 mm

Radius calotte: R_B = 3 000 mm

Thickness knuckle: t_{Bk} = 45,0 mm

Radius knuckle: r_{Bk} = 300 mm

Height of the bottom: H_B = 590 mm

4 Building materials

Resin type: UP-resin, Resin group 4

5 Loadings (9)

LC 1: Dead load

The assumed dead loads for the separate tank parts are:

Roof:	$W_{R,k}$ = 4 kN	Area load:	$w_{R,k}$ = 0,57 kN/m²
Cylinder + rings:	$W_{C,k}$ = 19 kN		
Bottom:	$W_{B,k}$ = 4 kN	Area load:	$w_{B,k}$ = 0,57 kN/m²
Skirt:	W_{Sk} = 3 kN		

Total dead load of the vessel: W_{tot} = 30 kN

LC 2: Liquid filling

Density of the medium ρ_{liquid} = 1,30 kg/dm³

Filling height h_{liquid} = 7 000 mm

Volume V = 52,0 m³

LC 3: Long time design overpressure

Design pressure $PS_{op.l}$ = 2,000 bar ≡ 0,20 N/mm²

LC 4: Short time design overpressure

Design pressure $PS_{op.s}$ = 2,500 bar ≡ 0,25 N/mm²

LC 5: Long time design negative pressure

Design pressure $PS_{ep.l}$ = 0,000 bar ≡ 0,00 N/mm²

LC 6: Short time design negative pressure

Design pressure $PS_{ep.s}$ = 0,050 bar ≡ 0,005 N/mm²

LC 7: Wind (9.2.2)

Peak velocity pressure q_p = 0,8 kN/m² (EN 1991–1-4)

Force coefficient (cylindrical vessel) c_f = 0,8

External pressure arising from wind load: $p_{wind} = 0{,}6 \cdot q_p = 0{,}6 \cdot 0{,}8 = 0{,}48\ kN/m^2$

LC 8: Snow (9.2.1)

Characteristic snow load s_k = 0,85 kN/m² (EN 1991–1-3)

Shape coefficient μ = 0,80

Snow load $p_{snow} = s_k \cdot \mu = 0{,}85 \cdot 0{,}8 = 0{,}68\ kN/m^2$

LC 9: Personnel loading (9.2.8)

Live load on the roof p_{access} = 1,5 kN/m²

LC 10: Temperature

Design temperature TS = 50°C

Difference in temperature ΔT = 20 K

LC 11: Earthquake (9.2.3.4)

Reference peak ground acceleration	a_{gR} = 1,00 m/s²
Importance factor	γ_1 = 1,4
Design ground acceleration	$a_g = a_{gR} \cdot \gamma_1 = 1{,}00 \cdot 1{,}4 = 1{,}40\, m/s^2$
Ground type according to EN 1998–1	D
Viscous damping	5 %
Control periods of the response spectrum	T_B = 0,20 s T_C = 0,8 s T_D = 2,0 s
Soil factor	S = 1,35
Behaviour factor	q = 1,5
Bending modulus cylinder tangential	$E_{\phi,b}$ = 19 000 N/mm²
Bending modulus cylinder axial	$E_{x,b}$ = 12 000 N/mm²
Modulus of elasticity for short time impact	$E_e = 1{,}5 \cdot \sqrt{E_{\phi,b} \cdot E_{x,b}} = 1{,}5 \cdot \sqrt{19\,000 \cdot 12\,000} = 22\,650 N/mm^2$
Cylinder thickness lower third	$t_{1/2}$ approximately t_{Sk} = 17 mm

Vibration period

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

$$T = \sqrt{\frac{1,33 \cdot 7200}{22650 \cdot 17,0 \cdot 10^3}} \cdot 3,0 \cdot \left[0,628 \cdot \left(\frac{7200}{3000} \right)^2 + \frac{2 \cdot 7200}{3000} + 1,49 \right] = 0,15 \quad s$$

Design spectrum $T \leq T_C$ (plateau area):

$$S_D(T) = a_g \cdot S \cdot \frac{2,5}{q} = 1,40 \cdot 1,35 \cdot \frac{2,5}{1,5} = 3,15\, m / s^2$$

Total mass of the vessel (approximately)

$$W_G = \frac{W_{tot}}{g} + V \cdot \rho_{liquid} = \frac{30}{9,81} + 52 \cdot 1,30 = 70,66\, Tonnen$$

Horizontal load (Base shear)

$$H_{AE} \cong S_D(T) \cdot W_G = 3,15 \cdot 70,66 = 222,6\, kN$$

Overturning moment

$$M_{AE,tot} \cong \left[V \cdot \rho_{liquid} \cdot \left(\frac{h_{liquid}}{2} + H_{Sk} - H_B \right) + \frac{W_{tot}}{g} \cdot \frac{H_{tot}}{2} \right] \cdot S_D(T)$$

$$M_{AE,tot} \cong \left[52 \cdot 1,30 \cdot \left(\frac{7\,000}{2} + 800 - 590 \right) \cdot 10^{-3} + \frac{30}{9,81} \cdot \frac{8\,000}{2} \cdot 10^{-3} \right] \cdot 3,15 = 828,5\, kNm$$

6 Limit strain for laminate (8.2.2)

For the used UP resin is:

The roof is made of a mixed laminate $\varepsilon_{lim,R} = \varepsilon_{d,R} = 0,25$ %

The bottom is made of a mixed laminate $\varepsilon_{lim,B} = \varepsilon_{d,B} = 0,25$ %

The cylinder is made of a wound laminate 0° /90° $\varepsilon_{lim,x,Cyl} = \varepsilon_{d,x,Cyl} = 0,20$ % $\varepsilon_{lim,\phi,Cyl} = \varepsilon_{d,\phi,Cyl} = 0,27$ %

The skirt is made of a wound laminate 0° /90° $\varepsilon_{lim,x,Sk} = \varepsilon_{d,x,Sk} = 0,20$ % $\varepsilon_{lim,\phi,Sk} = \varepsilon_{d,\phi,Sk} = 0,27$ %

7 Influence factors (7.9.5.2)

Influence factor A_1 — $A_1 = 1,0$

Influence factor A_2 — $A_2 = 1,4$ (Table A.4 of EN 13121–2)

Medium category 2, $T_d = 50$°C

HDT of the used resin — HDT = 90 °C

Influence factor A_3

$$A_3 = 1,00 + 0,4 \cdot \left(\frac{TS - 20°C}{HDT - 30°C} \right) = 1,00 + 0,4 \cdot \left(\frac{50 - 20}{90 - 30} \right) = 1,20$$

Influence factor A_4 — $A_4 = 1,0$

Influence factor A_5 — The influence factor A_5 depends on laminate type and is selected separately for each kind of laminate.

8 Partial safety factors (Table 12)

Action	Symbol	Situation	
		P/T	A/AE
Independent permanent actions (s.a):			
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

9 Combination factors (Table 11)

In the following table are shown the relevant Ψ-factors for this example.

Action	ψ_0	ψ_1	ψ_2
Pressures: - Long term pressures - Short-term pressures	 1,0 0	 1,0 0	 1,0 0
Imposed loads in buildings, category (see EN 1991–1-1) - Category H: roofs	0	0	0
Snow loads on buildings (see EN 1991–1-3)[a)]: Remainder of CEN Member States, - for sites located at altitude H ≤ 1000 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

10 Analysis of the cylinder

The cylinder is made of a wound laminate 0° / 90°. For mechanical properties are used historic test data. They are verified with tests in accordance to 7.9.3.

10.1 Influence factor A_5

— For stress analysis

25 years:	a)	Axial	$A_{5B.Cyl.25y.x} = 1{,}60$	b) Tangential	$A_{5B.Cyl.25y.\phi} = 1{,}20$
3 months:			$A_{5B.Cyl.3m.x} = 1{,}40$		$A_{5B.Cyl.3m.\phi} = 1{,}15$
Shorttime:			$A_{5B.Cyl.sh.x} = 1{,}00$		$A_{5B.Cyl.sh.\phi} = 1{,}00$

— For stability analysis

25 years:	a)	Axial	$A_{5I.Cyl.25y.x} = 1{,}60$	b) Tangential	$A_{5I.Cyl.25y.\phi} = 1{,}20$
3 months:			$A_{5I.Cyl.3m.x} = 1{,}40$		$A_{5I.Cyl.3m.\phi} = 1{,}15$
Short time:			$A_{5I.Cyl.sh.x} = 1{,}00$		$A_{5I.Cyl.sh.\phi} = 1{,}00$

Check for minimum design factors K and F:

If the value of K does not reach a minimum of 4 (advanced design) only for longtime loads, the A_{5B} values should be increased.

$$\text{Minimum } A_{5B} = \frac{K}{\left(A_1 \cdot A_2 \cdot A_3 \cdot A_4 \cdot \gamma_M \cdot \gamma_{F,i}\right)} = \frac{4}{\left(1{,}0 \cdot 1{,}4 \cdot 1{,}20 \cdot 1{,}0 \cdot 1{,}4 \cdot 1{,}5\right)} = 1{,}13$$

If the value of F does not reach a minimum of 2,7 (advanced design) only for longtime loads, the A_{5I} values should be increased.

$$\text{Minimum } A_{5I} = \left(\frac{F}{A_1 \cdot A_2 \cdot A_3 \cdot A_4 \cdot \gamma_M \cdot \gamma_{F,i}}\right)^2 \geq 1{,}0 = \left(\frac{2{,}7}{1{,}0 \cdot 1{,}4 \cdot 1{,}20 \cdot 1{,}0 \cdot 1{,}4 \cdot 1{,}5}\right)^2 \geq 1{,}0 = 1{,}0$$

All A_5 values are greater than the minimum A_5 values.

10.2 Characteristic strength values

— For tension

a) Axial $f_{Cyl.x.t.k} = 130$ N/mm² b) Tangential $f_{Cyl.\phi.t.k} = 400$ N/mm²

— For bending

a) Axial $f_{Cyl.x.b.k} = 150$ N/mm² b) Tangential $f_{Cyl.\phi.b.k} = 480$ N/mm²

10.3 Moduli of elasticity

— For tension

a) Axial $E_{Cyl.x.t} = 12500$ N/mm² b) Tangential $E_{Cyl.\phi.t} = 21000$ N/mm²

— For bending

a) Axial $E_{Cyl.x.b} = 12000$ N/mm² b) Tangential $E_{Cyl.\phi.b} = 19000$ N/mm²

10.4 Analysis of the cylinder in axial direction

1. Step) Calculate all characteristic internal forces from the actions, which may cause internal forces in axial direction