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Il nuovo standard europeo per la progettazione sismica

EUCENTRE FOR YOUR SAFETY.

reluis

Materiali e tipologie costruttive

EN1998-4. Silos e serbatoi

Roberto Nascimbene, IUSS Pavia

Pavia - 5 Giugno 2025

Differences

Eurocode 8 — Design of structures for earthquake resistance — Part 4: Silos, tanks, pipelines, towers, masts and chimneys

Eurocode 8 — Auslegung von Bauwerken gegen Erdbeben — Teil 4: Silos, Tankbauwerke, Rohrleitungen, Türme, Maste und Schornsteine

Eurocode 8 — Calcul des structures pour leur résistance au séismes — Part 4: Silos, réservoirs, tuyauteries, tours, mâts et cheminées

1) **Estimated differences**: ~70–80% of the content is **either new or substantially reworked**.

2) The **NEW version** represents **a major structural and technical revision, not just an update.**

3) **Engineers familiar with the 2006 edition should treat the 2025 edition as a fundamentally new document.**

Rules for silos

Section 5 of EN 1998-4 gives rules for the **structural analysis and design** of steel, reinforced concrete and prestressed reinforced concrete silos subjected to seismic actions.

A distinction is made between:

- **on-ground**;

- and **elevated silos, supported on a skirt** extending to the ground or **by substructures**.

The principles of seismic analysis procedures can be applied to aluminium silos, considering the provisions of EN 1999-1-1 for verification.

The dynamic effects of the silo content should be considered by additional structural masses assuming that the **particulate content** moves together with the silo shell.

Rules for tanks

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Section 6 of EN 1998-4 should be used for the **structural analysis and design** of steel, reinforced concrete and prestressed precast reinforced concrete liquid storage tanks with circular and rectangular cross sections subjected to seismic actions. Rules are provided for anchored and unanchored tanks with fixed or floating roofs.

A distinction is made between:

- **above-ground**.
- **underground**.
- **elevated tanks, supported by substructures**.

The principles of the seismic analysis procedures may also be applicable for tanks made of other materials (e.g. glass fibre-reinforced plastic/polymer (GFRP), high density polyethylene (HDPE) or polyethylene (PE)).

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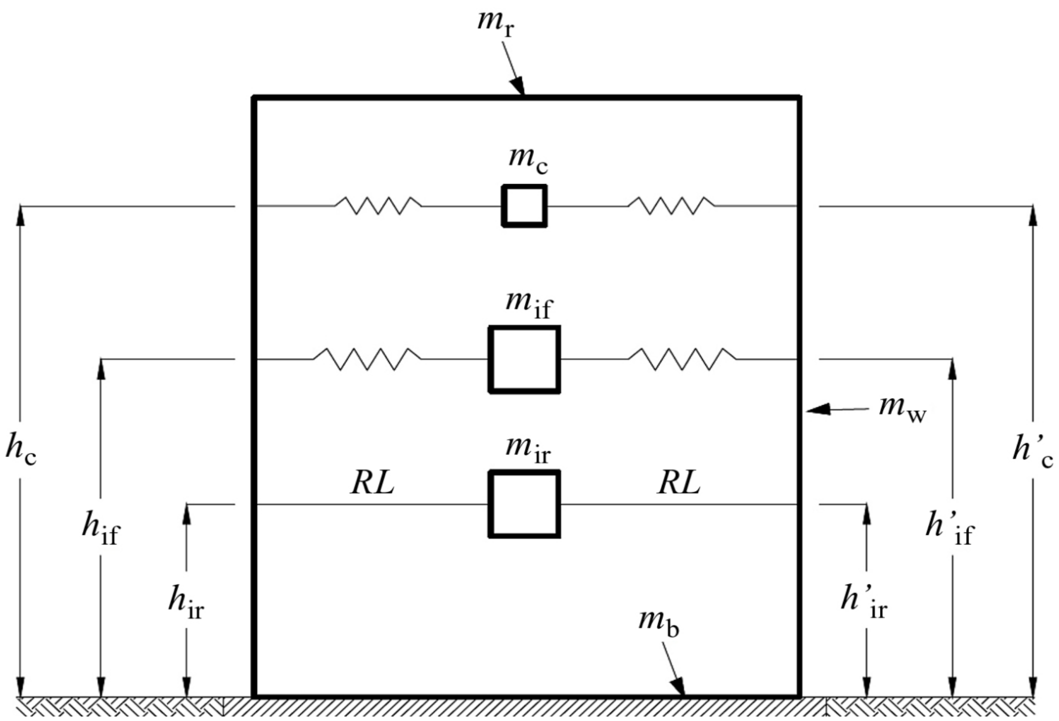
Dynamic calculation models of the tank should reproduce accurately the stiffness, the strength, the damping, the mass and the geometrical properties of the tank structure and should account for the hydrodynamic response of the contained liquid.

The calculation model for tanks under horizontal seismic actions may be represented by **spring-mass models** which describe the hydrodynamic response by impulsive rigid, impulsive flexible and convective masses with corresponding lever arms.



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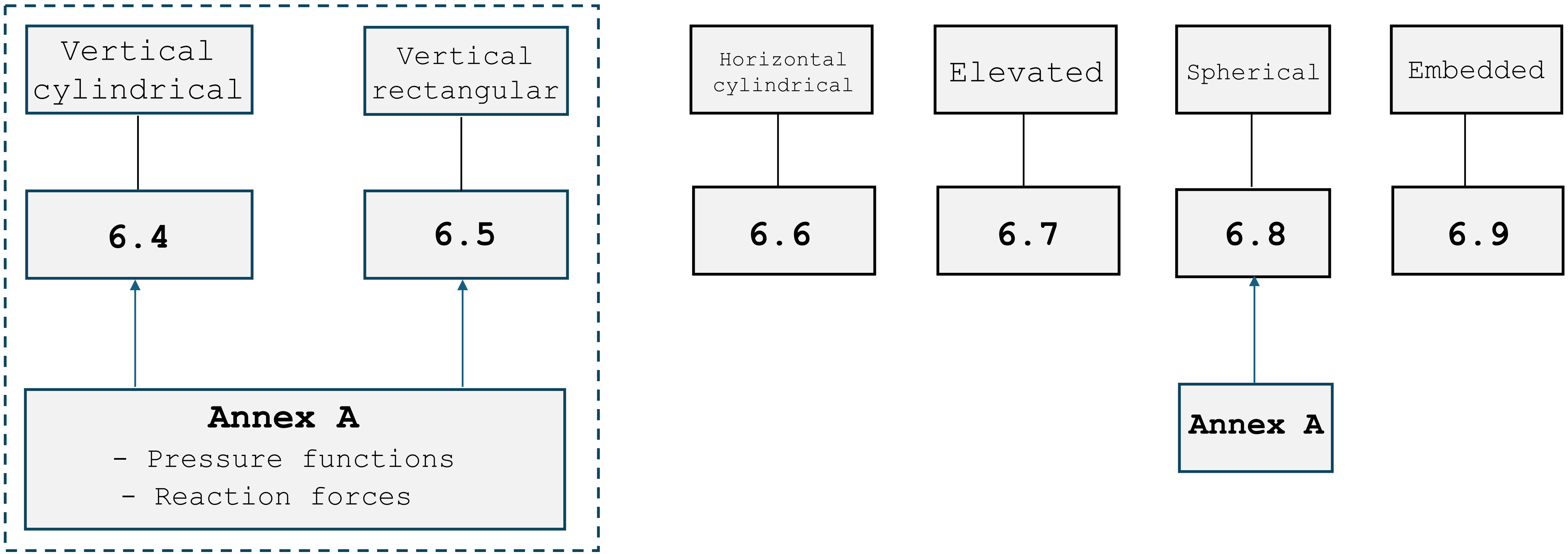
(1) Above-ground and elevated tanks with or without substructures should be analysed with the force-based approach with calculation models specified in previous slide. The dynamic effects of the convective and impulsive modes of vibrations should be described by equivalent static pressure distributions applied on the tank wall and bottom.

(2) Above-ground tanks and elevated tanks with substructures may be analysed with nonlinear approaches according to EN 1993-1-6, using non-linear response-history analysis and application rules given in EN 1998-1-1.

(3) The substructures of elevated tanks may be analysed using non-linear static or non-linear response-history analysis according to EN 1998-1-1.

SUBDIVISION OF SECTIONS – GEOMETRY/BEHAVIOUR ORIENTED

Modelling rules (6.3.1) and structural analysis (6.3.2)
„Distinction‟ between rigid or flexible tanks (Table A.10)



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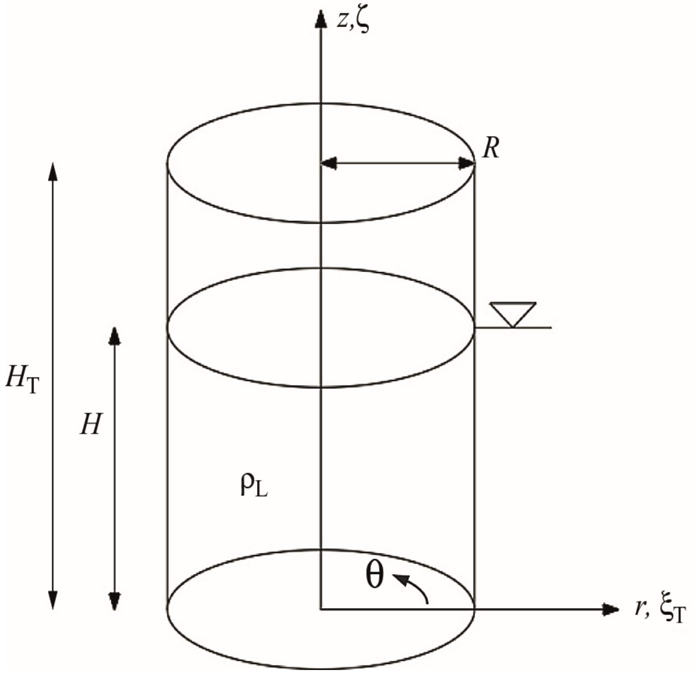
6.4.1.1 Total base shear, overturning moment and vertical reaction force at tank bottom
6.4.1.2 Seismic pressures on tank wall and bottom
6.4.1.3 Fundamental periods of vibrations
6.4.1.4 Impulsive rigid (flexible) and convective masses and lever arms
6.4.1.5 Convective wave height

6.10 Superposition of horizontal and vertical seismic pressures
6.11 Superposition of base shear, overturning moment and vertical reaction force
6.12 Verification to limit states

$\gamma = \frac{H}{R}$ is the ratio of filling height to tank radius



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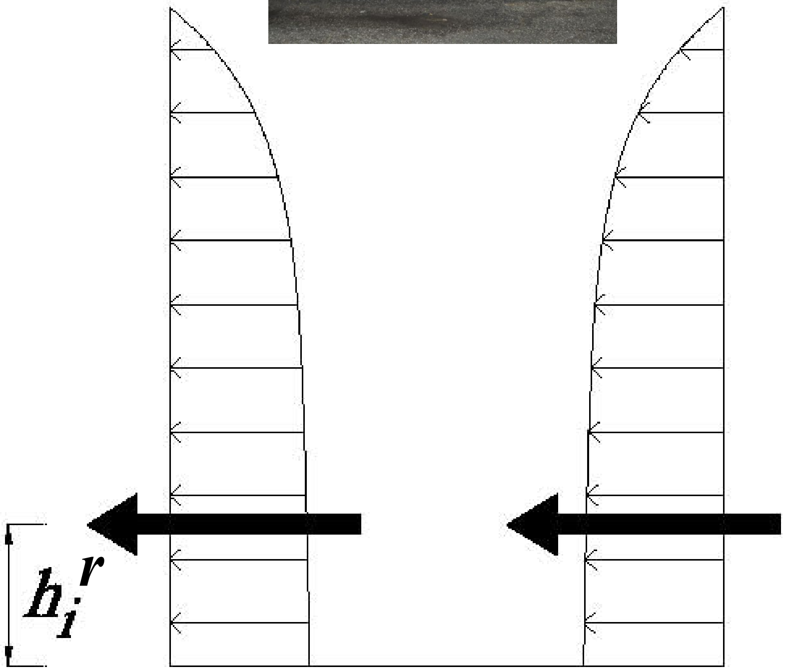
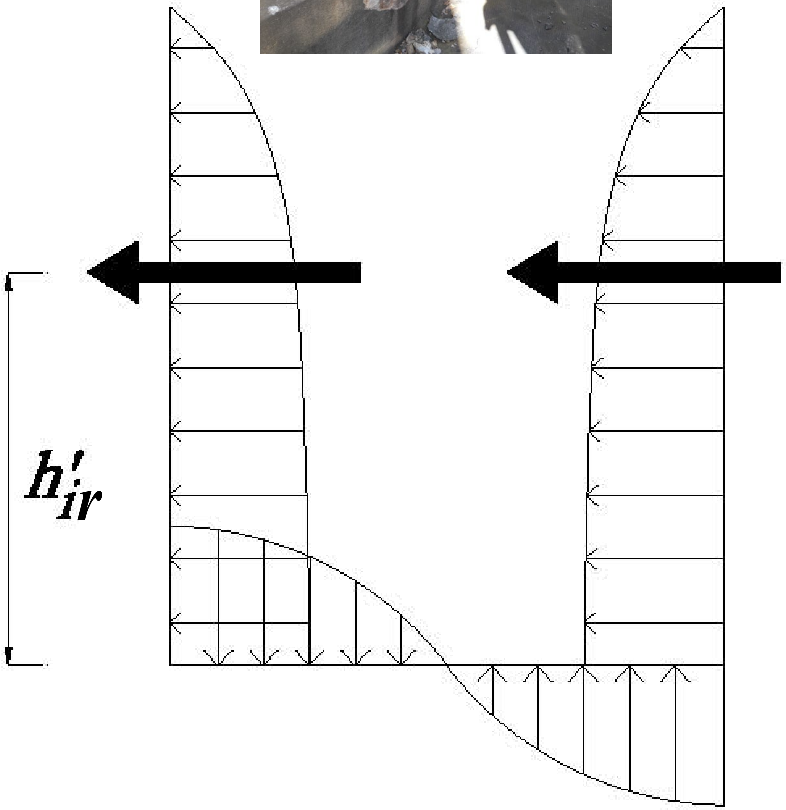
Example



Impulsive rigid pressure on the wall



Impulsive rigid pressure on wall and base

$$F_{\mathrm{b,ir,h}} = m_{\mathrm{ir}}\, S_{\mathrm{r}}(T_{\mathrm{ir,h}})$$

$$F_{\mathrm{b,ir,v}} = m_{\mathrm{l}}\, S_{\mathrm{rv}}(T_{\mathrm{ir,v}})$$

$$M_{\mathrm{W,ir,h}} = F_{\mathrm{b,ir,h}}\, h_{\mathrm{ir}}$$

$$M_{\mathrm{G,ir,h}} = F_{\mathrm{b,ir,h}}\, h'_{\mathrm{ir}}$$

$$F_{\mathrm{b,ir,h}} = C_{\mathrm{F,ir,h}}\, \Gamma_{\mathrm{ir,h}}\, m_{\mathrm{l}}\, S_{\mathrm{r}}(T_{\mathrm{ir,h}})$$

$$F_{\mathrm{b,ir,v}} = \Gamma_{\mathrm{ir,v}}\, \rho_{\mathrm{L}}\, H\, S_{\mathrm{rv}}(T_{\mathrm{ir,v}})\, \pi\, R^2$$

$$M_{\mathrm{W,ir,h}} = C_{\mathrm{MW,ir,h}}\, \Gamma_{\mathrm{ir,h}}\, m_{\mathrm{l}}\, H\, S_{\mathrm{r}}(T_{\mathrm{ir,h}})$$

$$M_{\mathrm{G,ir,h}} = C_{\mathrm{M,ir,h}}\, \Gamma_{\mathrm{ir,h}}\, \pi\, R^4\, \rho_{\mathrm{L}}\, S_{\mathrm{r}}(T_{\mathrm{ir,h}})$$

Coefficients are provided in Annex A

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Table A.7 - Coefficients $C_{F,j}$, $C_{MW,j}$, $C_{M,j}$ and participation factors Γ_j for the convective ($j = c$), impulsive rigid ($i = ir, h$) and impulsive flexible pressure components ($i = if, h$)

Coefficient	γ=0,2	γ=0,4	γ=0,6	γ=0,8	γ=1,0	γ=1,5	γ=2,0	γ=2,5	γ=3,0	γ=3,5	γ=4,0	γ=5,0	γ=6,0	γ=7,0	γ=8,0	γ=9,0	γ=10
	Convective pressure component																
$C_{F,c}$	0,8704	0,7541	0,6360	0,5328	0,4493	0,3120	0,2355	0,1886	0,1572	0,1348	0,1179	0,0943	0,0786	0,0674	0,0590	0,0524	0,0472
$C_{MW,c}$	0,4434	0,3985	0,3520	0,3105	0,2758	0,2147	0,1762	0,1494	0,1297	0,1144	0,1023	0,0843	0,0717	0,0623	0,0551	0,0493	0,0447
$C_{M,c}$	0,2488	0,2561	0,2742	0,3063	0,3523	0,5143	0,7170	0,9388	1,1689	1,4023	1,6372	2,1084	2,5801	3,0520	3,5240	3,9963	4,4689
Γc	1,5101	1,5389	1,5830	1,6371	1,6954	1,8289	1,9173	1,9635	1,9847	1,9938	1,9975	1,9996	1,9999	2,0000	2,0000	2,0000	2,0000
	Impulsive rigid pressure component																
$C_{F,ir,h}$	0,1148	0,2386	0,3591	0,4636	0,5478	0,6861	0,7630	0,8102	0,8418	0,8644	0,8813	0,9051	0,9209	0,9321	0,9406	0,9472	0,9524
$C_{MW,ir,h}$	0,0459	0,0952	0,1435	0,1861	0,2214	0,2834	0,3224	0,3494	0,3694	0,3847	0,3969	0,4150	0,4278	0,4372	0,4445	0,4503	0,4549
$C_{M,ir,h}$	0,0191	0,0723	0,1541	0,2615	0,3950	0,8565	1,5273	2,4290	3,5724	4,9623	6,6008	10,6261	15,6508	21,6749	28,6986	36,7218	45,7444
$\Gamma_{ir,h}$	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
	Impulsive flexible pressure component																
$C_{F,if,h}$	0,0620	0,1286	0,1937	0,2510	0,2982	0,3801	0,4306	0,4647	0,3693	0,3846	0,3968	0,4149	0,4276	0,4371	0,4443	0,3151	0,3194
$C_{MW,if,h}$	0,0283	0,0586	0,0885	0,1157	0,1393	0,1854	0,2190	0,2448	0,2074	0,2211	0,2322	0,2493	0,2616	0,2708	0,2779	0,2204	0,2247
$C_{M,if,h}$	0,0090	0,0352	0,0772	0,1355	0,2118	0,4994	0,9547	1,6012	1,9094	2,7456	3,7493	6,2598	9,4396	13,2871	17,8012	17,8567	22,4761
$\Gamma_{if,h}$	1,6529	1,6581	1,6545	1,6417	1,6226	1,5646	1,5099	1,4656	1,7807	1,7401	1,7087	1,6642	1,6348	1,6141	1,5989	1,7553	1,7393

Impulsive rigid vibration mode in horizontal direction

The period $T_{\mathrm{ir,h}}$ of the impulsive rigid vibration mode of the tank–foundation system including soil–structure interaction may be calculated as

In case of rigid tanks without consideration of soil–structure interaction, the period $T_{\mathrm{ir,h}}$ of the impulsive rigid vibration mode should be taken equal to zero.

$$\alpha_\theta = 1 - a_1 \frac{(a_2\alpha)^2}{1+(a_2\alpha)^2} - a_3\alpha^2 \qquad \alpha_V = 1 - b_1 \frac{(b_2\alpha)^2}{1+(b_2\alpha)^2} - b_3\alpha^2$$

$$T^*_{ir,h} = 2\pi\sqrt{\frac{(m_{\mathrm{ir}}+m_{\mathrm{w}}+m_{\mathrm{r}})+m_{\mathrm{b}}}{K_{\mathrm{x}}} + \frac{(m_{\mathrm{ir}}+m_{\mathrm{w}}+m_{\mathrm{r}})\,h_{\mathrm{ir}}^2}{K_\theta}}$$

$$K_{\mathrm{x}} = \frac{8}{2-\nu_s} G_{\mathrm{s}} R_{\mathrm{b}} \alpha_{\mathrm{x}} \qquad K_\theta = \frac{8}{3(1-\nu_s)} G_{\mathrm{s}} R_{\mathrm{b}}^3 \alpha_\theta$$

Horizontal component

$$T^*_{\mathrm{ir,v}} = 2\pi\sqrt{\frac{m_{\mathrm{l}}+m_{\mathrm{b}}+m_{\mathrm{w}}+m_{\mathrm{r}}}{K_{\mathrm{V}}}}$$

$$K_{\mathrm{V}} = \frac{4}{1-\nu_s} G_{\mathrm{s}} R_{\mathrm{b}} \alpha_{\mathrm{V}}$$

Vertical component

Coefficient	$\nu_s = 0$	$\nu_s = 0,33$	$\nu_s = 0,45$	$\nu_s = 0,5$
a_1	0,8	0,8	0,8	0,8
a_2	0,525	0,5	0,45	0,4
a_3	0	0	0,023	0,027
b_1	0,25	0,35	-	0
b_2	1	0,8	-	0
b_3	0,85	0,75	-	0,85

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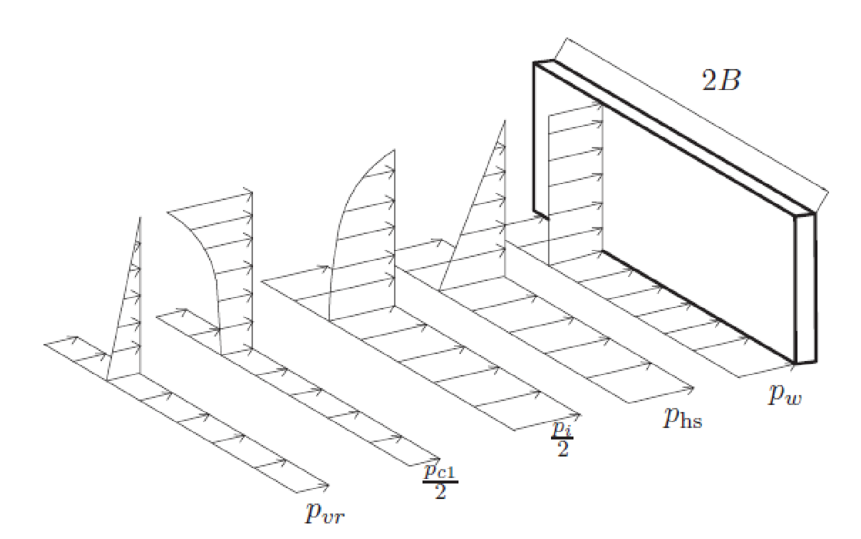
Superposition of base shear, overturning moment and vertical reaction force

1. Superposition of horizontal pressure components due to different modes of response

$$p_{\mathrm{h,res}} = \sqrt{(p_{\mathrm{c}})^2 + (p_{\mathrm{ir,h}} + p_{\mathrm{inr,h}})^2 + (p_{\mathrm{if,h}})^2}$$

2. Superposition of vertical pressure components

$$p_{\mathrm{v,res}} = \sqrt{(p_{\mathrm{ir,v}} + p_{\mathrm{inr,v}})^2 + (p_{\mathrm{if,v}})^2}$$



1. Superposition of base shear

$$F_{\mathrm{bh,res}} = \sqrt{(F_{\mathrm{b,c}})^2 + (F_{\mathrm{b,ir,h}} + F_{\mathrm{b,inr,h}})^2 + (F_{\mathrm{b,if,h}} + F_{\mathrm{b,inf,h}})^2}$$

2. Superposition of the vertical reaction forces

$$F_{\mathrm{bv,res}} = \sqrt{(F_{\mathrm{b,ir,v}} + F_{\mathrm{b,inr,v}})^2 + (F_{\mathrm{b,if,v}} + F_{\mathrm{b,inf,v}})^2}$$

3. Superposition of overturning moments above the base plate

$$M_{\mathrm{W,res}} = \sqrt{(M_{\mathrm{W,c}})^2 + (M_{\mathrm{W,ir,h}} + M_{\mathrm{W,inr,h}})^2 + (M_{\mathrm{W,if,h}} + M_{\mathrm{W,inf,h}})^2}$$

4. Superposition of overturning moments below the base plate

$$M_{\mathrm{G,res}} = \sqrt{(M_{\mathrm{G,c}})^2 + (M_{\mathrm{G,ir,h}} + M_{\mathrm{W,inr,h}})^2 + (M_{\mathrm{G,if,h}} + M_{\mathrm{W,inf,h}})^2}$$

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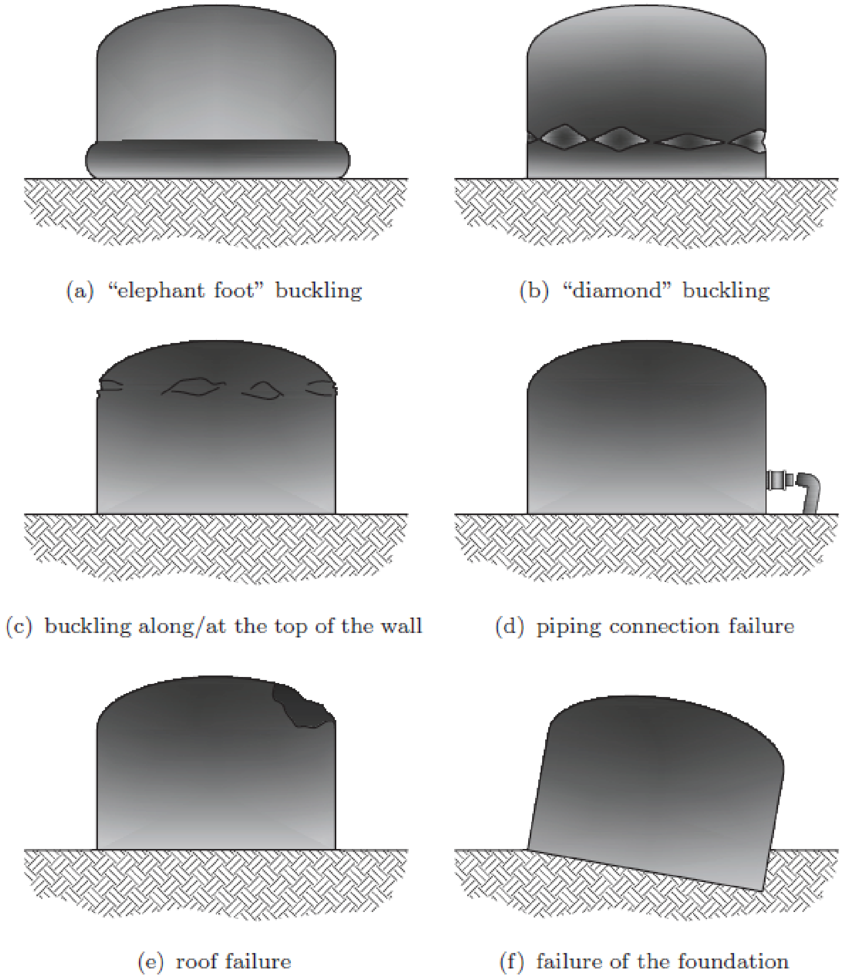
Verification to limit states



(a) "elephant foot" buckling
(b) "diamond" buckling
(c) buckling along/at the top of the wall
(d) piping connection failure
(e) roof failure
(f) failure of the foundation

Verification of Significant Damage (SD) limit state

Global stability
Foundation
Tank shell
Substructures of elevated tanks
Anchorage system
Leak tightness, freeboard and hydraulic systems of the tank
Inlets, outlets and ancillary elements

Verification of Damage Limitation (DL) limit state

Verification of Fully Operational (OP) limit state

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THANK YOU !!!

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