Second Generation of Eurocode 8

WEBINAR 4: Silos, tanks, pipelines, towers masts and chimneys – Rules for Tanks

Roberto Nascimbene - IUSS Pavia

CB0

30th June 2023

Folie 1

CB0 Only your name ...

Christoph Butenweg; 2023-06-28T04:41:17.875

RULES FOR TANKS - SCOPE

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.

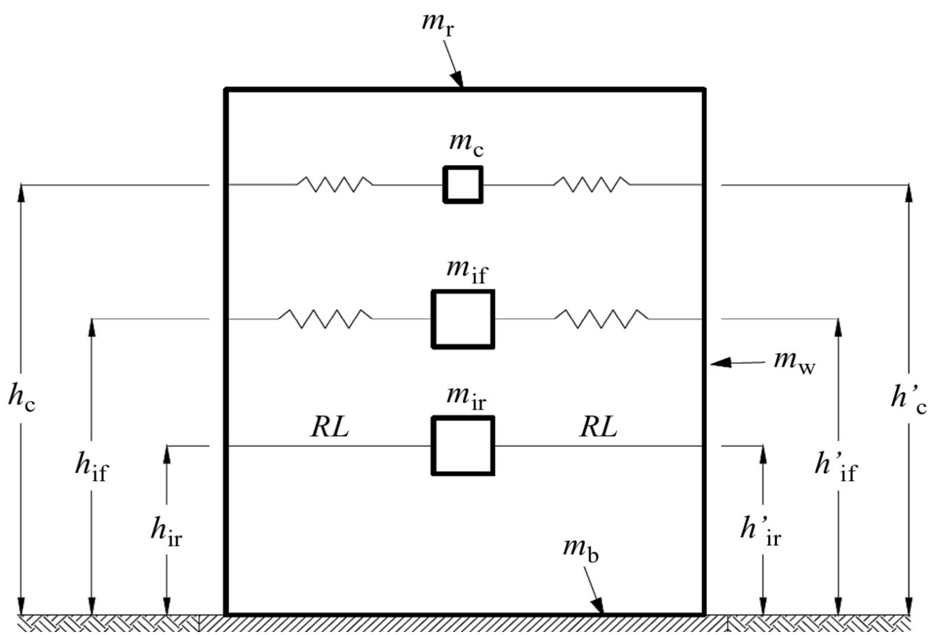
A distinction is made between:
- above-ground.
- underground.
- elevated tanks, supported by substructures.

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)).

MODELLING AND STRUCTURAL ANALYSIS - MODELLING

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.



MODELLING AND STRUCTURAL ANALYSIS - STRUCTURAL ANALYSIS

(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.

BEHAVIOUR FACTOR

Tanks: DC1

- Bolted and welded steel tanks
  $q_R = 1{,}0$, $q_D = 1{,}0$, $q_S = 1{,}2$

- Reinforced concrete or prestressed precast reinforced concrete tanks:
  $q_R = 1{,}0$, $q_D = 1{,}0$, $q_S = 1{,}5$

Substructure: DC1, DC2 and DC3

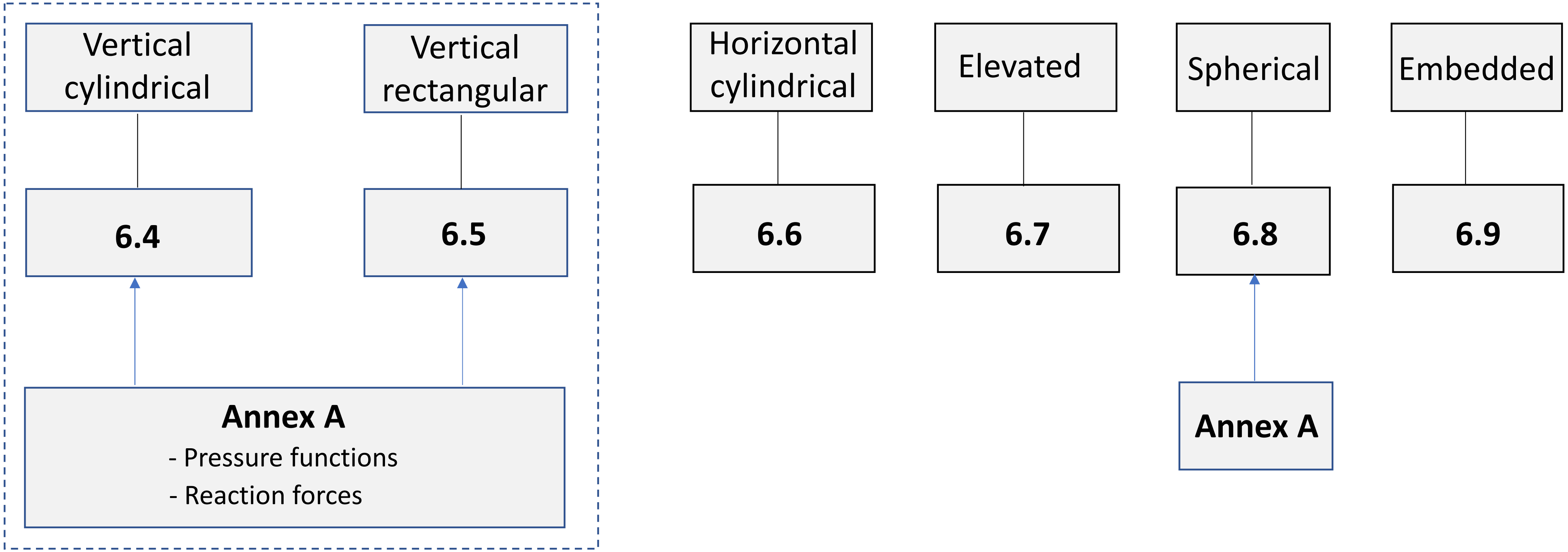
- To be applied as given in the relevant parts of EN 1998-1-2

Behaviour factor for the vertical component

- min(q; 1,5), where q is behaviour factor for the horizontal component

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)



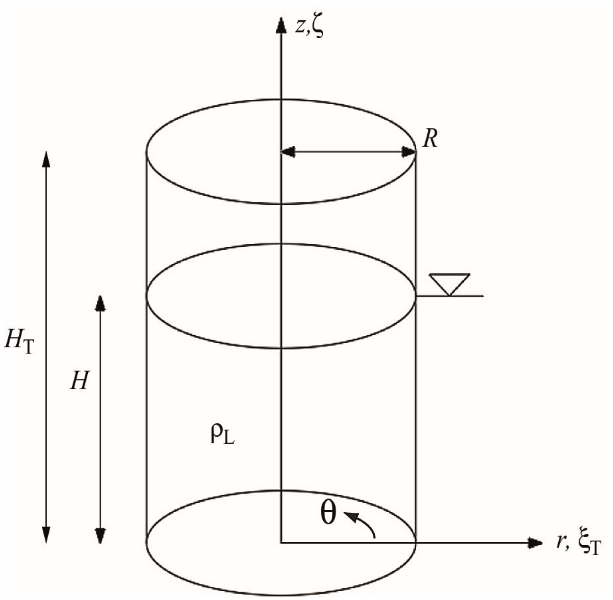
SUBDIVISION OF SECTIONS – GEOMETRY/BEHAVIOUR ORIENTED

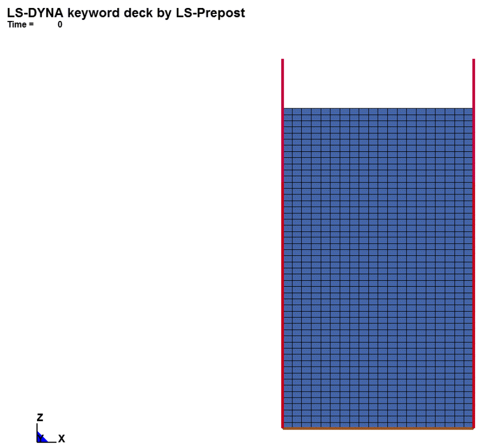
6.4.1.1 Total base shear, overturning moment and vertical reaction force at tank bottom
6.4.1.2 Seismic pressures on tank wall and bottom
6.4.1.3 Fundamental periods of vibrations
6.4.1.4 Impulsive rigid (flexible) and convective masses and lever arms
6.4.1.5 Convective wave height

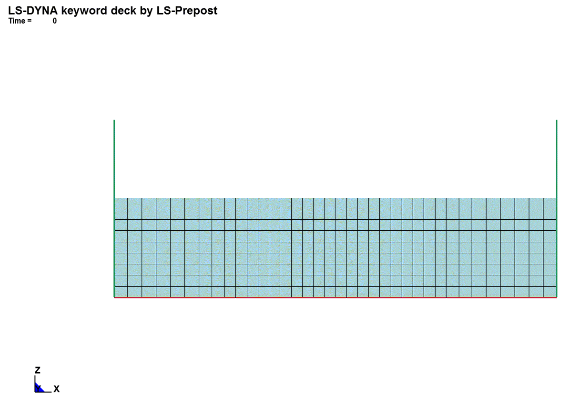
6.10 Superposition of horizontal and vertical seismic pressures
6.11 Superposition of base shear, overturning moment and vertical reaction force
6.12 Verification to limit states

FORCE BASED APPROACH: VERTICAL CYLINDRICAL ABOVE GROUND TANKS

SLENDER VS SQUAT TANK

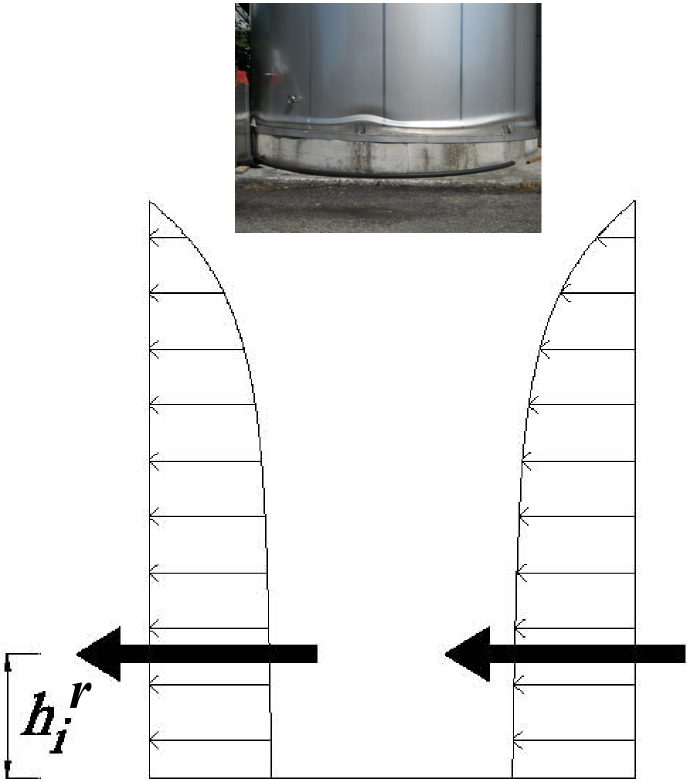




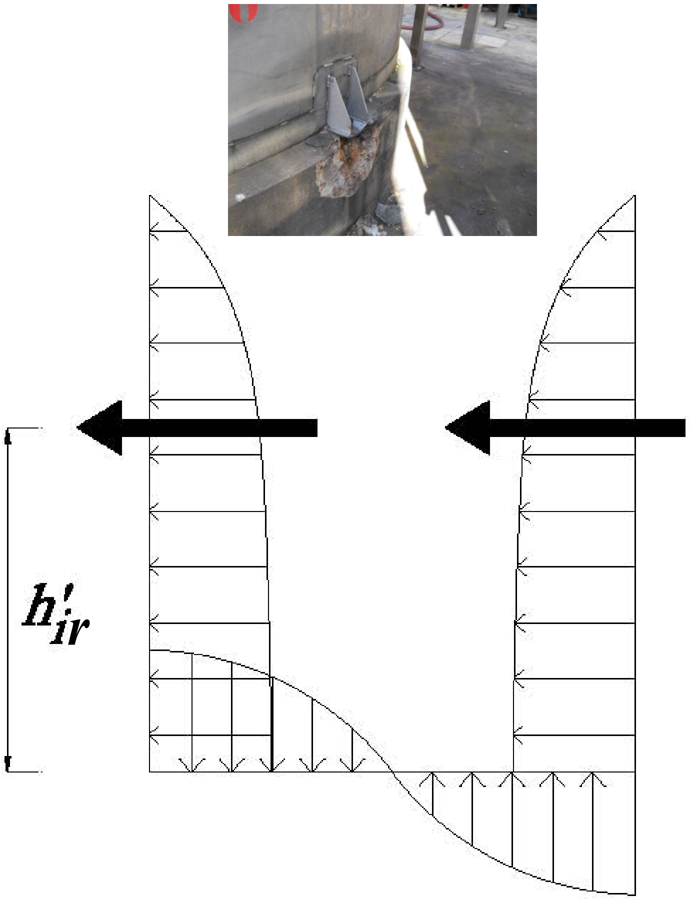


$\gamma = H/R$ is the ratio of filling height to tank radius

IMPULSIVE RIGID SUPPORT REACTIONS



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

CB0 You can reference to my part with Annex A ...

Christoph Butenweg; 2023-06-28T04:46:20.671

IMPULSIVE RIGID SUPPORT REACTIONS

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

CONVECTIVE SUPPORT REACTIONS

$$F_{\mathrm{b,c}} = m_{\mathrm{c}}\, S_{\mathrm{e}}(T_{\mathrm{con}})$$

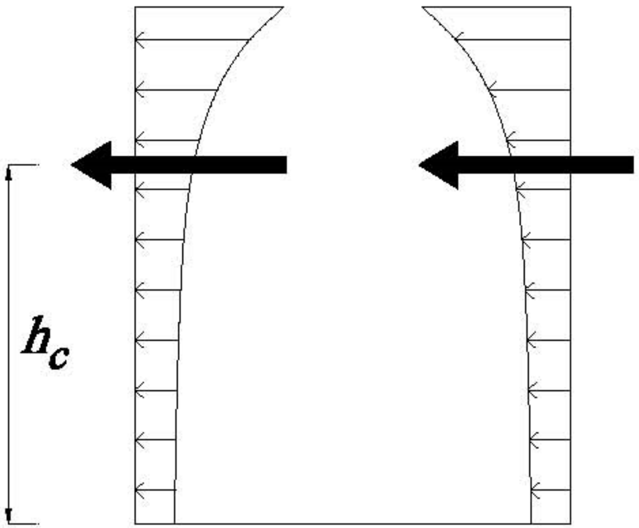
$$M_{\mathrm{W,c}} = F_{\mathrm{b,c}}\, h_{\mathrm{c}}$$

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

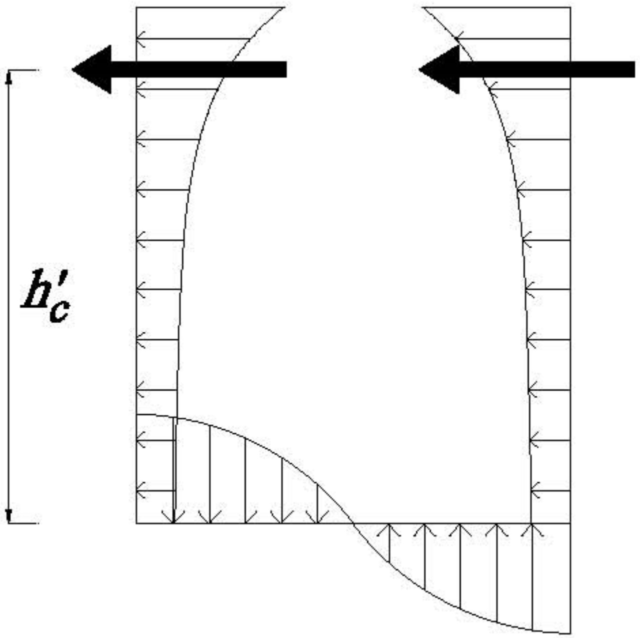
$$F_{\mathrm{b,c}} = C_{\mathrm{F,c}}\, \Gamma_{\mathrm{c}}\, m_{\mathrm{l}}\, S_{\mathrm{e}}(T_{\mathrm{con}})$$

$$M_{\mathrm{W,c}} = C_{\mathrm{MW,c}}\, \Gamma_c\, m_{\mathrm{l}}\, H\, S_{\mathrm{e}}(T_{\mathrm{con}})$$

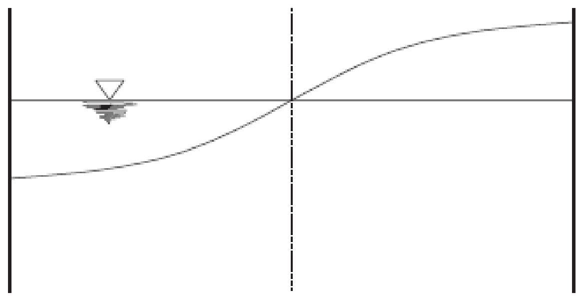
$$M_{\mathrm{G,c}} = C_{\mathrm{M,c}}\, \Gamma_{\mathrm{c}}\, \pi\, R^4\, \rho_{\mathrm{L}}\, S_{\mathrm{e}}(T_{\mathrm{con}})$$



Impulsive rigid pressure on the wall



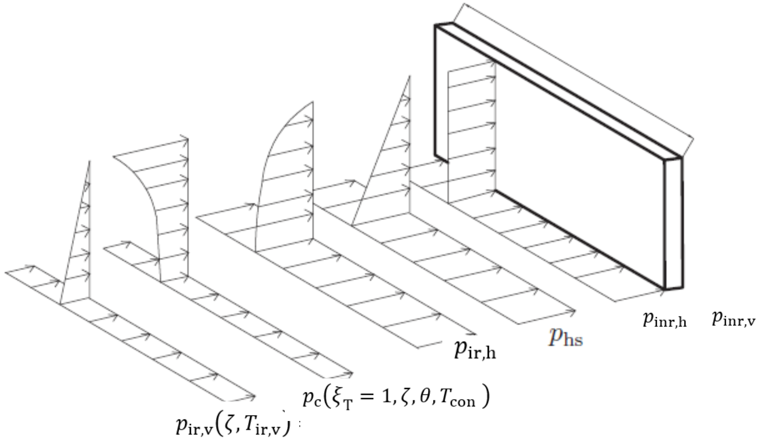
Impulsive rigid pressure on wall and base

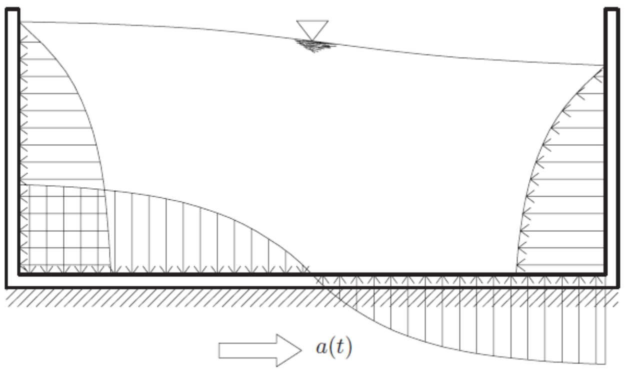


Folie 11

CB0 MAYBE ONLY THE FIRST MODE; AS WE NEGLECT ALL OTHERS: Or you can give an explanation ...
Christoph Butenweg; 2023-06-28T04:47:58.300

SEISMIC PRESSURES ON TANK WALL AND BOTTOM





RIGID

$$p_{\mathrm{ir,h}}(\xi_{\mathrm{T}}=1,\zeta,\theta,T_{\mathrm{ir,h}}) = C_{\mathrm{ir,h}}(\zeta,\gamma)\,\Gamma_{\mathrm{ir,h}}\,\rho_{\mathrm{L}}\,R\cos(\theta)\;S_{\mathrm{r}}(T_{\mathrm{ir,h}})$$

$$p_{\mathrm{ir,v}}(\zeta,T_{\mathrm{ir,v}}) = \Gamma_{\mathrm{ir,v}}\,\rho_{\mathrm{L}}\,[H\,(1-\zeta)]\,S_{\mathrm{rv}}(T_{\mathrm{ir,v}})$$

$$p_{\mathrm{c}}(\xi_{\mathrm{T}}=1,\zeta,\theta,T_{\mathrm{con}}) = C_{\mathrm{c}}(\zeta,\gamma)\;\Gamma_{\mathrm{c}}\,\rho_{\mathrm{L}}\,R\cos(\theta)\;S_{\mathrm{e}}(T_{\mathrm{con}})$$

$$p_{\mathrm{inr,h}} = \rho_{\mathrm{s}}\,s_{\mathrm{w}}\,S_{\mathrm{r}}(T_{\mathrm{ir,h}})$$

$$p_{\mathrm{inr,v}} = \rho_{\mathrm{s}}\,s_{\mathrm{w}}\,S_{\mathrm{rv}}(T_{\mathrm{ir,v}})$$

FLEXIBLE

$$p_{\mathrm{if,h}}(\xi_{\mathrm{T}}=1,\theta,\zeta,T_{\mathrm{if,h}}) = C_{\mathrm{if,h}}(\zeta,\gamma)\,\Gamma_{\mathrm{if,h}}\,\rho_{\mathrm{L}}\,R\cos(\theta)\;S_{\mathrm{r}}(T_{\mathrm{if,h}})$$

$$p_{\mathrm{if,v}}(\xi_{\mathrm{T}}=1,\zeta,T_{\mathrm{if,v}}) = C_{\mathrm{if,v}}(\zeta,\gamma)\,\Gamma_{\mathrm{if,v}}\,\rho_{\mathrm{L}}\,R\,S_{\mathrm{rv}}(T_{\mathrm{if,v}})$$

The pressure function on the tank bottom may be calculated with $\zeta = 0$

SEISMIC PRESSURES ON TANK WALL AND BOTTOM

Table A.1 - Dimensionless function $C_c(\zeta,\gamma)$ for the convective pressure component considering the fundamental natural first mode for sloshing

$\zeta=\frac{z}{H}$	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
1,00	0,8371	0,8371	0,8371	0,8371	0,8371	0,8371	0,8371	0,8371	0,8371	0,8371	0,8371	0,8371	0,8371	0,8371	0,8371	0,8371	0,8371
0,95	0,8318	0,8183	0,8012	0,7838	0,7672	0,7300	0,6965	0,6650	0,6351	0,6065	0,5792	0,5283	0,4818	0,4395	0,4008	0,3656	0,3334
0,90	0,8268	0,8007	0,7679	0,7348	0,7039	0,6369	0,5796	0,5284	0,4819	0,4395	0,4008	0,3334	0,2774	0,2307	0,1919	0,1597	0,1328
0,85	0,8220	0,7841	0,7368	0,6898	0,6466	0,5560	0,4825	0,4198	0,3656	0,3184	0,2774	0,2104	0,1597	0,1211	0,0919	0,0697	0,0529
0,80	0,8176	0,7686	0,7080	0,6485	0,5947	0,4857	0,4017	0,3336	0,2774	0,2307	0,1919	0,1328	0,0919	0,0636	0,0440	0,0305	0,0211
0,75	0,8134	0,7541	0,6814	0,6107	0,5479	0,4247	0,3345	0,2651	0,2105	0,1672	0,1328	0,0838	0,0529	0,0334	0,0211	0,0133	0,0084
0,70	0,8095	0,7407	0,6569	0,5763	0,5057	0,3717	0,2788	0,2107	0,1597	0,1211	0,0919	0,0529	0,0305	0,0175	0,0101	0,0058	0,0033
0,65	0,8059	0,7283	0,6343	0,5449	0,4678	0,3259	0,2325	0,1676	0,1212	0,0878	0,0636	0,0334	0,0175	0,0092	0,0048	0,0025	0,0013
0,60	0,8026	0,7168	0,6137	0,5166	0,4339	0,2863	0,1941	0,1333	0,0920	0,0636	0,0440	0,0211	0,0101	0,0048	0,0023	0,0011	0,0005
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0,50	0,7967	0,6968	0,5780	0,4681	0,3768	0,2228	0,1361	0,0847	0,0531	0,0334	0,0211	0,0084	0,0033	0,0013	0,0005	0,0002	0,0001
0,45	0,7941	0,6883	0,5629	0,4477	0,3532	0,1978	0,1144	0,0676	0,0404	0,0243	0,0146	0,0053	0,0019	0,0007	0,0003	0,0001	0
0,40	0,7919	0,6806	0,5494	0,4298	0,3326	0,1765	0,0967	0,0542	0,0308	0,0176	0,0101	0,0033	0,0011	0,0004	0,0001	0	0
0,35	0,7899	0,6739	0,5377	0,4142	0,3148	0,1586	0,0822	0,0437	0,0236	0,0128	0,0070	0,0021	0,0006	0,0002	0,0001	0	0
0,30	0,7882	0,6681	0,5275	0,4009	0,2996	0,1437	0,0705	0,0355	0,0182	0,0094	0,0049	0,0013	0,0004	0,0001	0	0	0
0,25	0,7867	0,6632	0,5190	0,3897	0,2870	0,1315	0,0613	0,0292	0,0141	0,0069	0,0034	0,0008	0,0002	0,0001	0	0	0
0,20	0,7855	0,6592	0,5121	0,3806	0,2769	0,1219	0,0541	0,0244	0,0112	0,0052	0,0024	0,0005	0,0001	0	0	0	0
0,15	0,7846	0,6561	0,5067	0,3736	0,2690	0,1146	0,0487	0,0209	0,0091	0,0040	0,0018	0,0004	0,0001	0	0	0	0
0,10	0,7839	0,6539	0,5029	0,3686	0,2635	0,1094	0,0450	0,0186	0,0077	0,0032	0,0014	0,0002	0	0	0	0	0
0,05	0,7835	0,6526	0,5006	0,3657	0,2602	0,1064	0,0428	0,0172	0,0069	0,0028	0,0011	0,0002	0	0	0	0	0
0	0,7834	0,6521	0,4998	0,3647	0,2591	0,1054	0,0421	0,0168	0,0067	0,0027	0,0011	0,0002	0	0	0	0	0

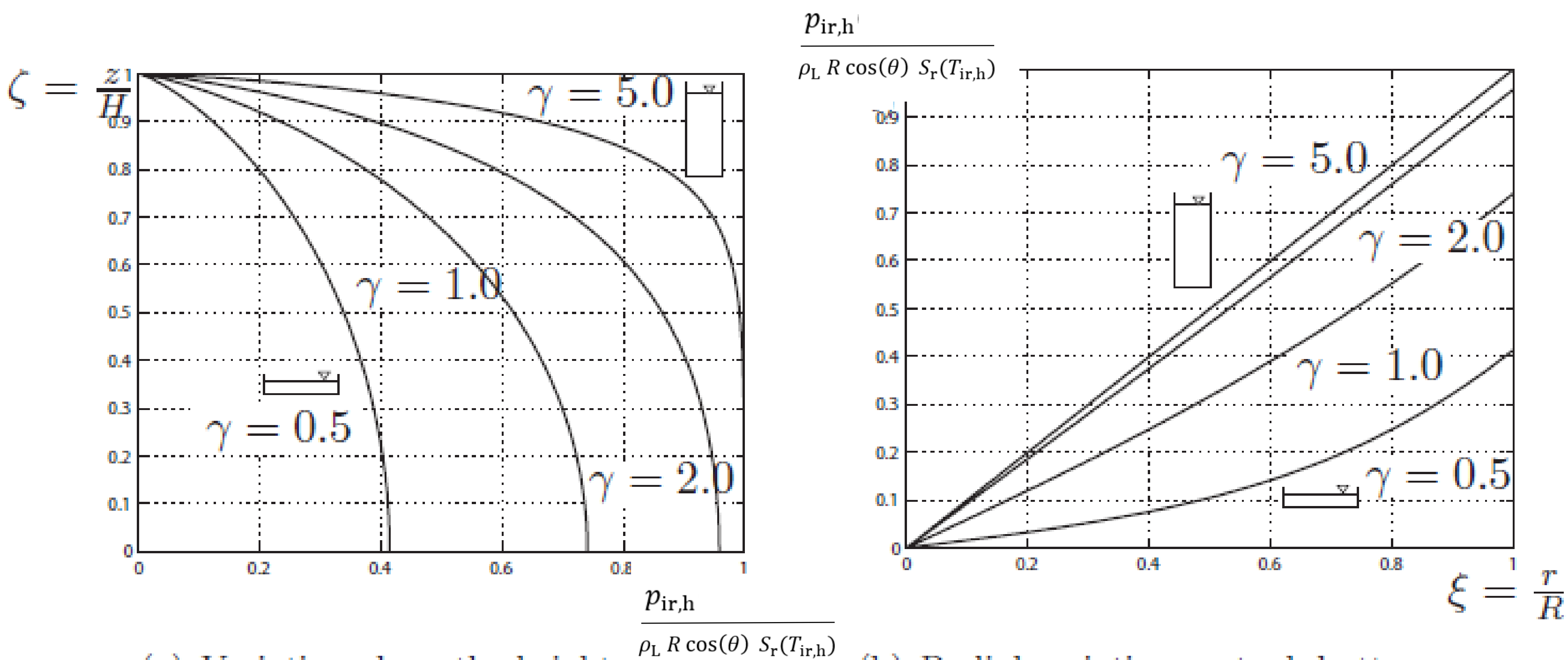
Table A.2 - Dimensionless function $C_{ir,h}(\zeta,\gamma)$ for the impulsive rigid pressure component due to horizontal seismic excitation

$\zeta=\frac{z}{H}$	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
1,00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0,95	0,0277	0,0569	0,0864	0,1138	0,1390	0,1934	0,2401	0,2819	0,3202	0,3556	0,3885	0,4481	0,5007	0,5475	0,5893	0,6270	0,6609
0,90	0,0469	0,0965	0,1458	0,1916	0,2327	0,3184	0,3882	0,4481	0,5008	0,5476	0,5895	0,6611	0,7195	0,7674	0,8070	0,8397	0,8667
0,85	0,0625	0,1289	0,1948	0,2553	0,3088	0,4166	0,5002	0,5691	0,6272	0,6769	0,7196	0,7882	0,8397	0,8786	0,9079	0,9302	0,9470
0,80	0,0759	0,1569	0,2369	0,3098	0,3732	0,4970	0,5887	0,6610	0,7195	0,7675	0,8071	0,8669	0,9080	0,9364	0,9560	0,9695	0,9789
0,75	0,0876	0,1813	0,2738	0,3571	0,4286	0,5642	0,6601	0,7322	0,7882	0,8322	0,8669	0,9161	0,9471	0,9666	0,9789	0,9867	0,9916
0,70	0,0980	0,2030	0,3063	0,3987	0,4770	0,6211	0,7182	0,7879	0,8397	0,8786	0,9080	0,9471	0,9695	0,9825	0,9899	0,9942	0,9966
0,65	0,1072	0,2222	0,3352	0,4355	0,5193	0,6694	0,7658	0,8318	0,8786	0,9121	0,9364	0,9666	0,9825	0,9908	0,9952	0,9974	0,9986
0,60	0,1154	0,2394	0,3610	0,4680	0,5565	0,7107	0,8049	0,8664	0,9079	0,9364	0,9560	0,9789	0,9899	0,9952	0,9977	0,9989	0,9995
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0,50	0,1291	0,2683	0,4041	0,5222	0,6178	0,7759	0,8636	0,9153	0,9469	0,9666	0,9789	0,9916	0,9967	0,9987	0,9995	0,9998	0,9999
0,45	0,1348	0,2803	0,4220	0,5445	0,6427	0,8014	0,8854	0,9324	0,9596	0,9758	0,9854	0,9947	0,9981	0,9993	0,9998	0,9999	1
0,40	0,1399	0,2909	0,4377	0,5640	0,6644	0,8230	0,9033	0,9458	0,9692	0,9824	0,9899	0,9967	0,9989	0,9996	0,9999	1	1
0,35	0,1442	0,3000	0,4512	0,5808	0,6829	0,8411	0,9178	0,9563	0,9764	0,9872	0,9930	0,9979	0,9994	0,9998	1	1	1
0,30	0,1479	0,3078	0,4628	0,5951	0,6986	0,8561	0,9295	0,9645	0,9819	0,9906	0,9951	0,9987	0,9996	0,9999	1	1	1
0,25	0,1510	0,3143	0,4725	0,6070	0,7116	0,8684	0,9388	0,9708	0,9859	0,9931	0,9966	0,9992	0,9998	1	1	1	1
0,20	0,1535	0,3196	0,4803	0,6166	0,7221	0,8781	0,9460	0,9756	0,9888	0,9948	0,9976	0,9995	0,9999	1	1	1	1
0,15	0,1554	0,3237	0,4863	0,6240	0,7301	0,8854	0,9513	0,9791	0,9909	0,9960	0,9982	0,9997	0,9999	1	1	1	1
0,10	0,1568	0,3266	0,4906	0,6292	0,7358	0,8906	0,9550	0,9814	0,9923	0,9968	0,9986	0,9998	1	1	1	1	1
0,05	0,1576	0,3283	0,4932	0,6323	0,7392	0,8936	0,9572	0,9828	0,9931	0,9972	0,9989	0,9998	1	1	1	1	1
0	0,1579	0,3289	0,4940	0,6334	0,7403	0,8946	0,9579	0,9832	0,9933	0,9973	0,9990	0,9998	1	1	1	1	1

The pressure function on the tank bottom may be calculated with $\zeta = 0$

SEISMIC PRESSURES ON TANK WALL AND BOTTOM – IMPULSIVE RIGID TERM

CB0



(a) Variation along the height

(b) Radial variation on tank bottom

CB0 a(t) is in time domain. It is better to be consistent with the force based approach. It should be the spectral acceleration ...

Christoph Butenweg; 2023-06-28T04:52:51.581

ANNEX B - SOIL-STRUCTURE INTERACTION EFFECTS OF TANKS

FUNDAMENTAL PERIODS OF VIBRATIONS

Impulsive rigid vibration mode in horizontal direction

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.

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

CB0

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

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

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

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

CB0 Roberto, these functions are not given in the last versin in graphical form. I suggest to make reference to Annex B and to take the analytical solution. There was a probem with the graphical representation and we corrected it ...

Consider the changes in the formulas ...

Christoph Butenweg; 2023-06-28T05:02:30.406

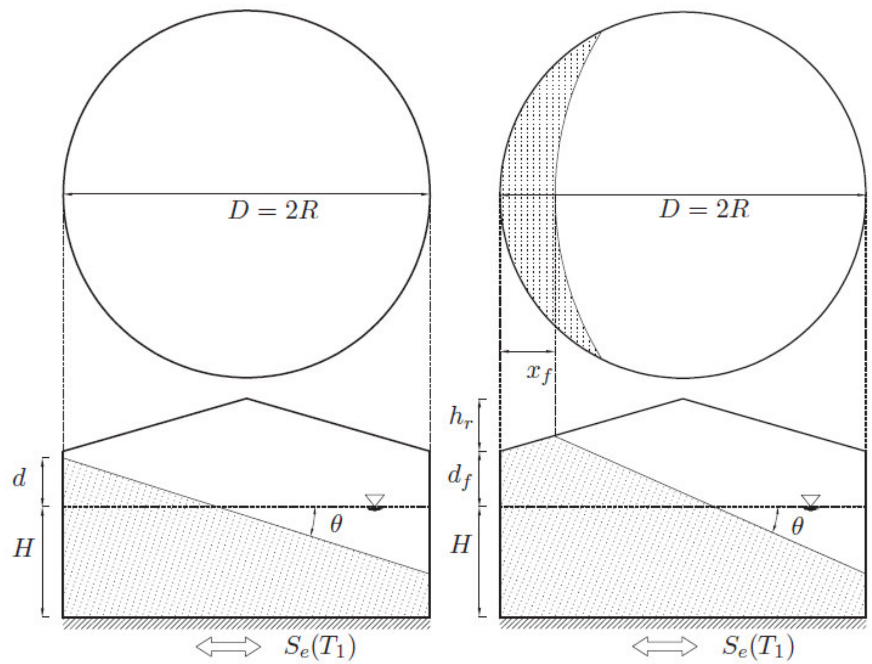
FUNDAMENTAL PERIODS OF VIBRATIONS AND WAVE HEIGHT

Convective vibration mode

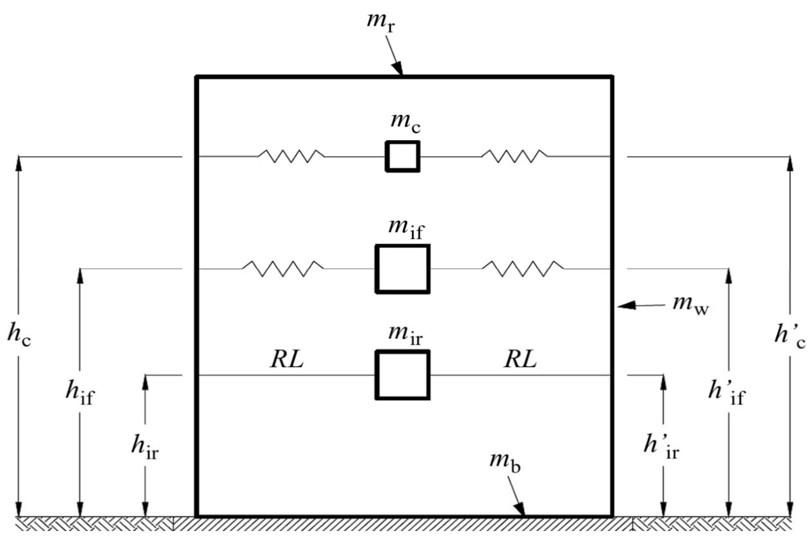
$$T_{\text{con}} = \frac{2\pi\sqrt{\frac{R}{g}}}{\sqrt{1{,}841\tanh\left(\frac{1{,}841H}{R}\right)}}$$

Absolute maximum value of the vertical wave height in cylindrical tanks

$$d_{\max} = 0{,}84\,R\,\frac{S_{\text{e}}(T_{\text{con}})}{g}$$



IMPULSIVE RIGID MASS AND LEVER ARM - WELDED & BOLTED STEEL TANKS



If $\frac{R}{H} \geq 0{,}665$

$$\frac{m_{ir}}{m_l} = \frac{\tanh\left(\sqrt{3}\,\frac{R}{H}\right)}{\sqrt{3}\,\frac{R}{H}}$$

$$\frac{h_{ir}}{H} = \frac{3}{8}$$

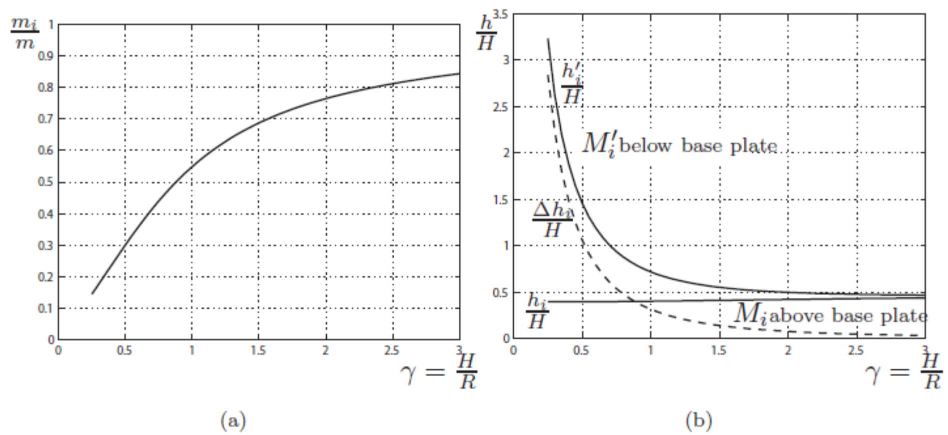
$$\frac{h'_{ir}}{H} = \frac{3}{8}\left[1 + \frac{4}{3}\left(\frac{\sqrt{3}\,\frac{R}{H}}{\tanh\left(\sqrt{3}\,\frac{R}{H}\right)} - 1\right)\right]$$

If $\frac{R}{H} < 0{,}665$

$$\frac{m_{ir}}{m_l} = 1 - 0{,}436\,\frac{R}{H}$$

$$\frac{h_{ir}}{H} = 0{,}5 - 0{,}188\,\frac{R}{H}$$

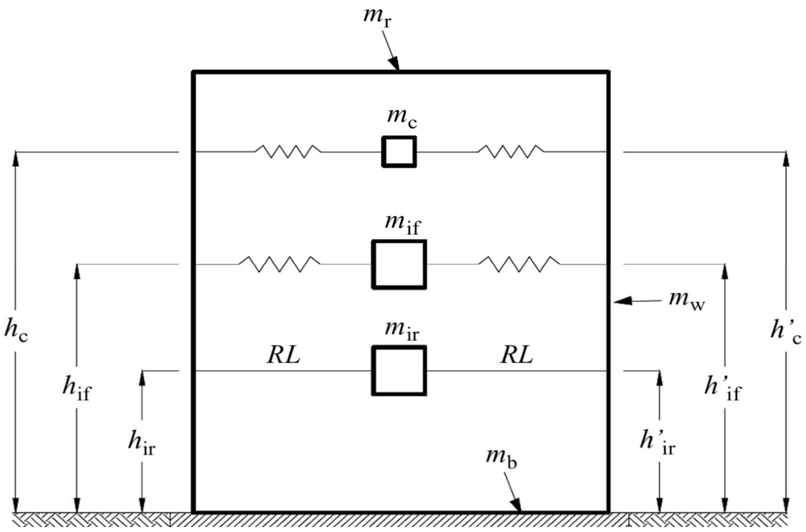
$$\frac{h'_{ir}}{H} = 0{,}5 + 0{,}12\,\frac{R}{H}$$



CB0 Shorter without loosing the content … Decide …

Christoph Butenweg; 2023-06-28T05:12:06.863

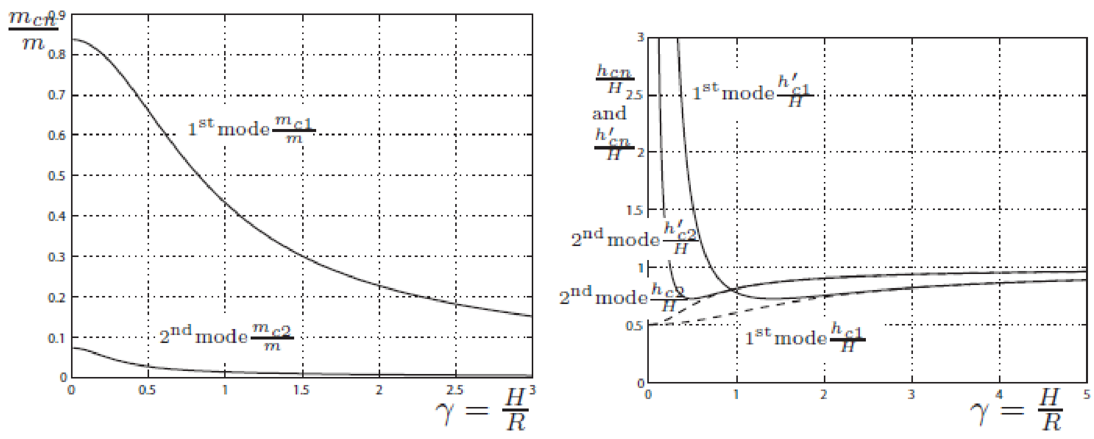
CONVECTIVE MASS AND LEVER ARM - WELDED & BOLTED STEEL TANKS



$$\frac{m_c}{m_l} = \frac{1}{4}\sqrt{\frac{27}{8}}\frac{R}{H}\tanh\left(\sqrt{\frac{27}{8}}\frac{H}{R}\right)$$

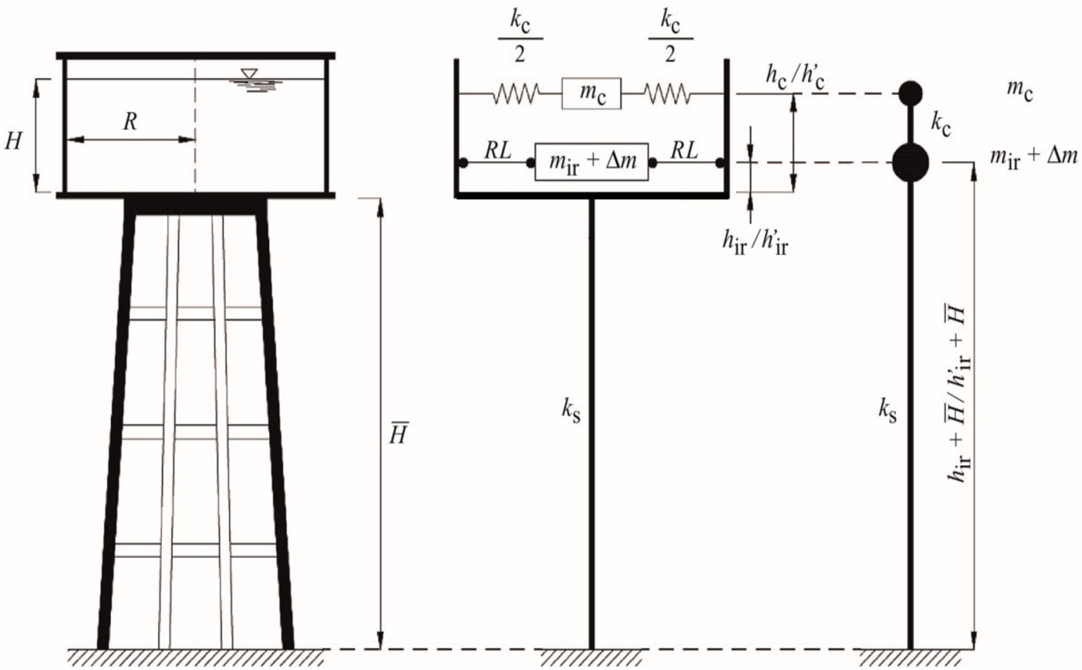
$$\frac{h_c}{H} = 1 - \frac{\cosh\left(\sqrt{\frac{27}{8}}\frac{H}{R}\right) - 1}{\sqrt{\frac{27}{8}}\frac{H}{R}\sinh\left(\sqrt{\frac{27}{8}}\frac{H}{R}\right)}$$

$$\frac{h'_c}{H} = 1 - \frac{\cosh\left(\sqrt{\frac{27}{8}}\frac{H}{R}\right) - \frac{31}{16}}{\sqrt{\frac{27}{8}}\frac{H}{R}\sinh\left(\sqrt{\frac{27}{8}}\frac{H}{R}\right)}$$



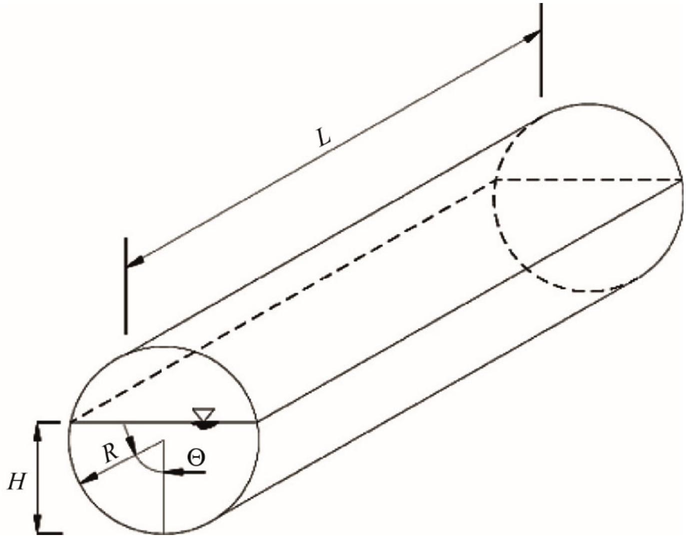
(a) (b)

ELEVATED TANKS



Elevated tanks may be analysed using a two-coupled-mass model representing the convective and the impulsive vibration modes, including the mass and flexibility of the substructure The flexibility of the tank shell may be neglected.

HORIZONTAL TANKS



H filling height

R radius

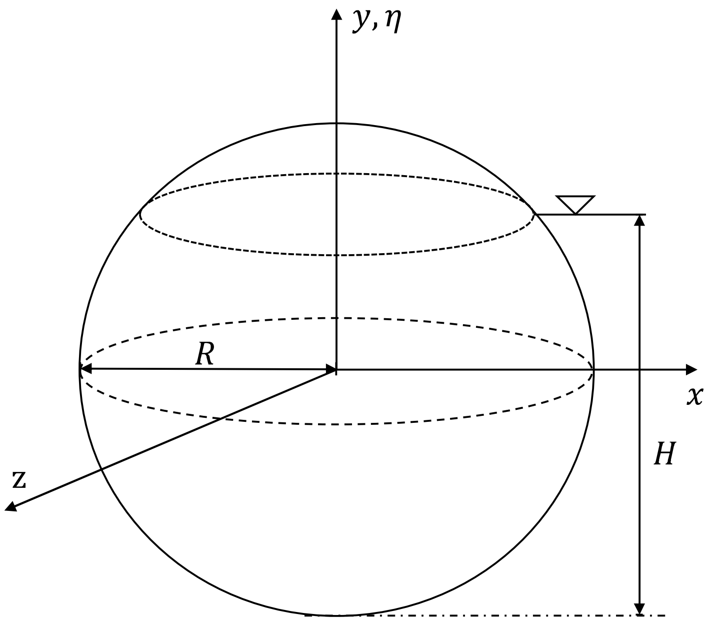
L length in longitudinal direction

Θ circumferential angle

SUPPORT REACTIONS & HYDRODYNAMIC PRESSURES

- May be calculated as for rectangular tanks considering an equivalent rectangular tank
- If H/R exceeds 1,6, the convective pressure component and convective reactions may be neglected

SPHERICAL TANKS



H filling height

η dimensionless coordinate

R radius

First fundamental convective period

$$T_{\mathrm{con}} = \frac{2\pi}{\omega_{con}}$$

ω_{con}: Annex A, Table A.11

Impulsive rigid vibration mode

$$T_{\mathrm{ir,h}} = \frac{2\pi}{\omega_{ir}}$$

$$\omega_{\mathrm{ir,h}}^2 = \frac{k_{\mathrm{sp}}}{m_{\mathrm{ir}} + m_{\mathrm{W}} + \Delta m_{\mathrm{ss}}}$$

Horizontal and vertical reaction forces and moments

$$F_{\mathrm{b},j} = m_j \, S_{\mathrm{r}}\left(T_{1,\mathrm{j}}\right)$$

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

SUPERPOSITION OF HORIZONTAL AND VERTICAL SEISMIC PRESSURES

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

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

3. Superposition of resulting pressures in horizontal and vertical directions (Clause 4) CB0

$$1{,}12\ E_{\mathrm{Edx}}\ \text{"+"}\ 0{,}30\ E_{\mathrm{Edz}}$$

$$0{,}34\ E_{\mathrm{Edx}}\ \text{"+"}\ 1{,}00\ E_{\mathrm{Edz}}$$

Folie 22

CB0 Shorter, as presented in the first part (Basis for design ...)
Christoph Butenweg; 2023-06-28T05:14:23.084

SUPERPOSITION OF BASE SHEAR, OVERTURNING MOMENT AND VERTICAL REACTION FORCE

1. Superposition of base shear

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

2. Superposition of the vertical reaction forces

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

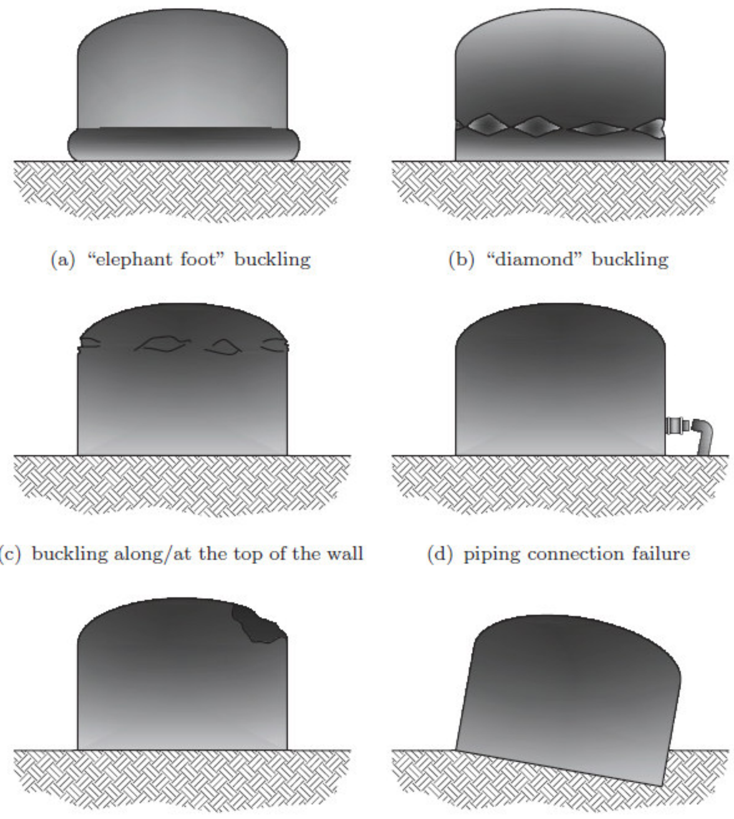
3. Superposition of overturning moments above the base plate

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

4. Superposition of overturning moments below the base plate

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

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

Folie 24

CB0 It would be good to highlight, that we use EC3 for all verifications. That means we are in line with the Eurocode concept, which was not the case before. Maybe you can add a link to the main design codes to underline this fact (EN 1993 and EN 1992)
Christoph Butenweg; 2023-06-28T05:18:36.232