



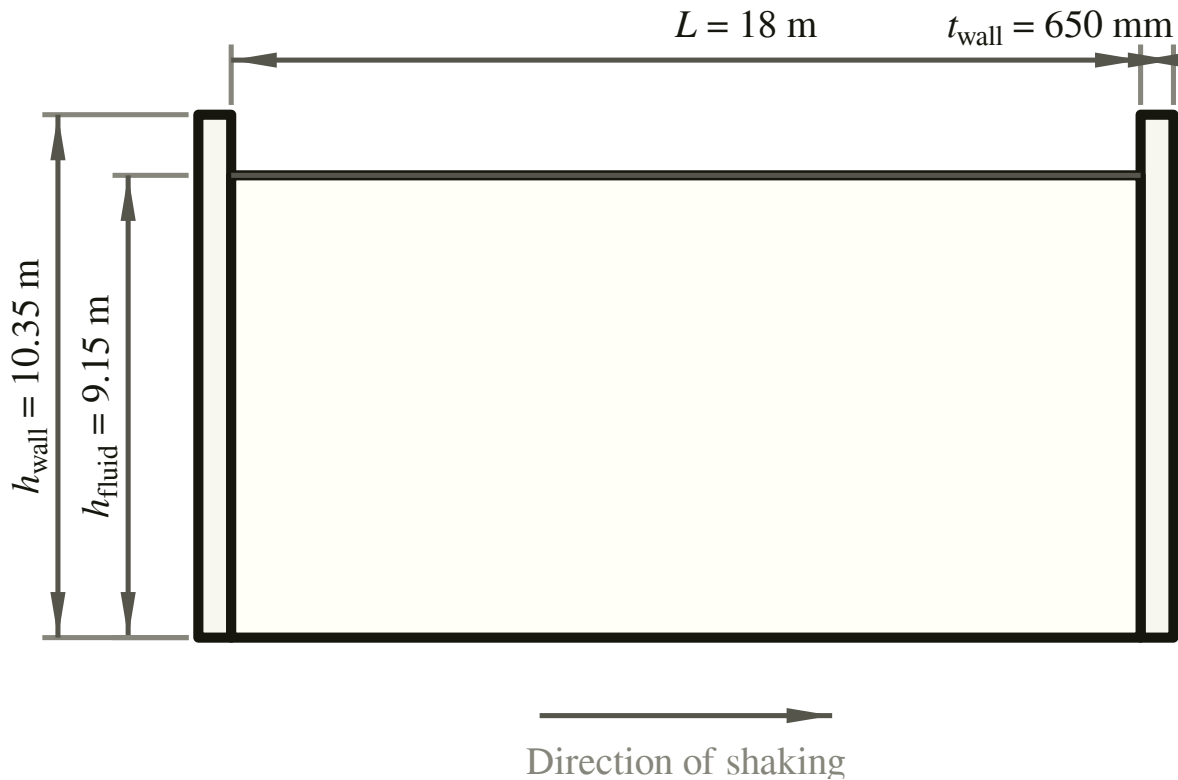
Seismic loads, rectangular tank

Seismic design forces and overturning moments for a rectangular liquid-containing tank.

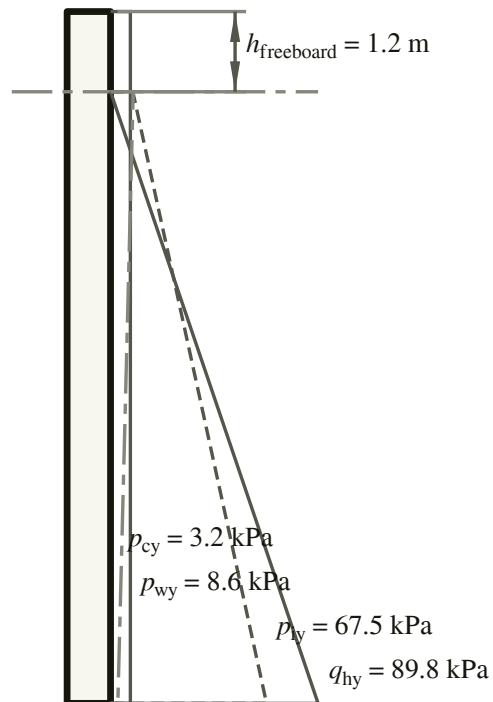
Inputs

Symbol	Value	Unit	Description
L	18	m	Tank length in the direction of shaking
h_{wall}	10.35	m	Wall height
h_{fluid}	9.15	m	Fluid depth
h_{eg}	0	m	Height to earth pressure resultant
t_{wall}	650	mm	Wall thickness
t_{roof}	0	mm	Roof thickness
t_{bottom}	0	mm	Base slab thickness
γ_{fluid}	9.81	kN/m ³	Fluid unit weight
γ_{conc}	23.56	kN/m ³	Concrete unit weight
g	9.78	m · s ⁻²	Gravitational acceleration
I	1.5		Importance factor
S_s	1.06		Short-period spectral response
S_1	0.5		One-second spectral response
F_a	1		Short-period site coefficient
F_v	1		Long-period site coefficient
R_{wi}	2		Impulsive response modification
P_{eg}	0	kN	Earth pressure force
W_r	5	kN	Roof weight

Figures



The tank in section, with the geometry the inputs name.



Section 9.5 wall pressures, each drawn straight between its traced endpoints.

Checks

Name	Check	Result
Freeboard adequate	$h_{\text{freeboard}} \geq 0 \text{ m} \Rightarrow 1.2 \text{ m} \geq 0 \text{ m}$	PASS

Results

Quantity	Description	Value	Unit
V	Total design base shear	894.9	kN
V_t	Fluid design shear at the top of the foundation	715.5	kN
M_s	Overturning moment at the base of the shell	3.44	MN · m
M'_s	Overturning moment including base pressure	6.099	MN · m
T_c	Convective (sloshing) period	4.992	s
$h_{\text{freeboard}}$	Freeboard above the fluid surface	1.2	m

Derivation

$$\begin{aligned}
 \rho_c &= \frac{\gamma_{\text{conc}}}{g} \\
 &= \frac{23.56 \text{ kN/m}^3}{9.78 \text{ m} \cdot \text{s}^{-2}} \\
 &= 2409 \text{ kg} \cdot \text{m}^{-3}
 \end{aligned}$$

$$\begin{aligned}
 \rho_L &= \frac{\gamma_{\text{fluid}}}{g} \\
 &= \frac{9.81 \text{ kN/m}^3}{9.78 \text{ m} \cdot \text{s}^{-2}} \\
 &= 1003 \text{ kg} \cdot \text{m}^{-3}
 \end{aligned}$$

$$B = 1 \text{ m}$$

$$\begin{aligned}
 W_{\text{fluid}} &= L \cdot B \cdot h_{\text{fluid}} \cdot \gamma_{\text{fluid}} \\
 &= 18 \text{ m} \cdot 1 \text{ m} \cdot 9.15 \text{ m} \cdot 9.81 \text{ kN/m}^3 \\
 &= 1.616 \text{ MN}
 \end{aligned}$$

$$\begin{aligned}
 h_{\text{freeboard}} &= h_{\text{wall}} - h_{\text{fluid}} \\
 &= 10.35 \text{ m} - 9.15 \text{ m} \\
 &= 1.2 \text{ m}
 \end{aligned}$$

$$\begin{aligned}
 W_i &= \frac{\tanh\left(0.866 \cdot \frac{L}{h_{\text{fluid}}}\right)}{0.866 \cdot \frac{L}{h_{\text{fluid}}}} \cdot W_{\text{fluid}} \\
 &= \frac{\tanh\left(0.866 \cdot \frac{18 \text{ m}}{9.15 \text{ m}}\right)}{0.866 \cdot \frac{18 \text{ m}}{9.15 \text{ m}}} \cdot 1.616 \text{ MN} \\
 &= 887.6 \text{ kN}
 \end{aligned}$$

$$\begin{aligned}
 W_c &= 0.264 \cdot \frac{L}{h_{\text{fluid}}} \cdot \tanh\left(\frac{3.16 \cdot h_{\text{fluid}}}{L}\right) \cdot W_{\text{fluid}} \\
 &= 0.264 \cdot \frac{18 \text{ m}}{9.15 \text{ m}} \cdot \tanh\left(\frac{3.16 \cdot 9.15 \text{ m}}{18 \text{ m}}\right) \cdot 1.616 \text{ MN} \\
 &= 774.2 \text{ kN}
 \end{aligned}$$

$$\begin{aligned}
 W_{\text{walls}} &= \gamma_{\text{conc}} \cdot 2 \cdot t_{\text{wall}} \cdot h_{\text{wall}} \cdot B \\
 &= 23.56 \text{ kN/m}^3 \cdot 2 \cdot 650 \text{ mm} \cdot 10.35 \text{ m} \cdot 1 \text{ m} \\
 &= 317 \text{ kN}
 \end{aligned}$$

$$\begin{aligned}
 W_{\text{bottom}} &= L \cdot B \cdot \gamma_{\text{conc}} \cdot t_{\text{bottom}} \\
 &= 18 \text{ m} \cdot 1 \text{ m} \cdot 23.56 \text{ kN/m}^3 \cdot 0 \text{ mm} \\
 &= 0 \text{ N}
 \end{aligned}$$

$$\begin{aligned}
 S_{\text{ds}} &= S_s \cdot F_a \\
 &= 1.06 \cdot 1 \\
 &= 1.06
 \end{aligned}$$

$$\begin{aligned}
 S_{d1} &= S_1 \cdot F_v \\
 &= 0.5 \cdot 1 \\
 &= 0.5
 \end{aligned}$$

$$\begin{aligned}
 T_s &= \frac{S_{d1}}{S_{\text{ds}}} \\
 &= \frac{0.5}{1.06} \\
 &= 0.4717
 \end{aligned}$$

$$\begin{aligned}
 C_t &= 0.4 \cdot S_{ds} \\
 &= 0.4 \cdot 1.06 \\
 &= 0.424
 \end{aligned}$$

$$\begin{aligned}
 m_w &= h_{\text{wall}} \cdot t_{\text{wall}} \cdot \rho_c \\
 &= 10.35 \text{ m} \cdot 650 \text{ mm} \cdot 2409 \text{ kg} \cdot \text{m}^{-3} \\
 &= 16206 \text{ kg} \cdot \text{m}^{-1}
 \end{aligned}$$

$$\begin{aligned}
 m_i &= \frac{\frac{W_i}{W_{\text{fluid}}} \cdot L}{2} \cdot h_{\text{wall}} \cdot \rho_L \\
 &= \frac{\frac{887.6 \text{ kN}}{1.616 \text{ MN}} \cdot 18 \text{ m}}{2} \cdot 10.35 \text{ m} \cdot 1003 \text{ kg} \cdot \text{m}^{-3} \\
 &= 51326 \text{ kg} \cdot \text{m}^{-1}
 \end{aligned}$$

$$\begin{aligned}
 T_c &= 2 \cdot \pi \cdot \sqrt{\frac{L}{3.16 \cdot g \cdot \tanh\left(\frac{3.16 \cdot h_{\text{fluid}}}{L}\right)}} \\
 &= 2 \cdot \pi \cdot \sqrt{\frac{18 \text{ m}}{3.16 \cdot 9.78 \text{ m} \cdot \text{s}^{-2} \cdot \tanh\left(\frac{3.16 \cdot 9.15 \text{ m}}{18 \text{ m}}\right)}} \\
 &= 4.992 \text{ s}
 \end{aligned}$$

Branch: $T_c \leq \frac{1.6 \text{ s}}{T_s}$ did not hold

$$\begin{aligned}
 C_c &= \frac{2.4 \cdot S_{ds} \cdot 1 \text{ s}^2}{T_c^2} \\
 &= \frac{2.4 \cdot 1.06 \cdot 1 \text{ s}^2}{(4.992 \text{ s})^2} \\
 &= 0.1021
 \end{aligned}$$

$$\begin{aligned}
 \epsilon &= \min\left(0.0151 \cdot \left(\frac{L}{h_{\text{fluid}}}\right)^2 - 0.1908 \cdot \frac{L}{h_{\text{fluid}}} + 1.021, 1\right) \\
 &= \min\left(0.0151 \cdot \left(\frac{18 \text{ m}}{9.15 \text{ m}}\right)^2 - 0.1908 \cdot \frac{18 \text{ m}}{9.15 \text{ m}} + 1.021, 1\right) \\
 &= 0.7041
 \end{aligned}$$

Branch: $\frac{L}{h_{\text{fluid}}} < 0.75$ did not hold

$$\begin{aligned}
 h'_i &= \left(\frac{\frac{0.866 \cdot L}{h_{\text{fluid}}}}{2 \cdot \tanh\left(\frac{0.866 \cdot L}{h_{\text{fluid}}}\right)} - \frac{1}{8} \right) \cdot h_{\text{fluid}} \\
 &= \left(\frac{\frac{0.866 \cdot 18 \text{ m}}{9.15 \text{ m}}}{2 \cdot \tanh\left(\frac{0.866 \cdot 18 \text{ m}}{9.15 \text{ m}}\right)} - \frac{1}{8} \right) \cdot 9.15 \text{ m} \\
 &= 7.184 \text{ m}
 \end{aligned}$$

$$\begin{aligned}
 h'_c &= \left(1 - \frac{\cosh\left(\frac{3.16 \cdot h_{\text{fluid}}}{L}\right) - 2.01}{\frac{3.16 \cdot h_{\text{fluid}}}{L} \cdot \sinh\left(\frac{3.16 \cdot h_{\text{fluid}}}{L}\right)} \right) \cdot h_{\text{fluid}} \\
 &= \left(1 - \frac{\cosh\left(\frac{3.16 \cdot 9.15 \text{ m}}{18 \text{ m}}\right) - 2.01}{\frac{3.16 \cdot 9.15 \text{ m}}{18 \text{ m}} \cdot \sinh\left(\frac{3.16 \cdot 9.15 \text{ m}}{18 \text{ m}}\right)} \right) \cdot 9.15 \text{ m} \\
 &= 7.763 \text{ m}
 \end{aligned}$$

$$\begin{aligned}
 H_w &= \frac{h_{\text{wall}}}{2} \\
 &= \frac{10.35 \text{ m}}{2} \\
 &= 5.175 \text{ m}
 \end{aligned}$$

$$\begin{aligned}
 h_{\text{roof}} &= h_{\text{wall}} + \frac{t_{\text{roof}}}{2} \\
 &= 10.35 \text{ m} + \frac{0 \text{ mm}}{2} \\
 &= 10.35 \text{ m}
 \end{aligned}$$

Branch: $\frac{L}{h_{\text{fluid}}} < 1.333$ did not hold

$$\begin{aligned}
 h_i &= 0.375 \cdot h_{\text{fluid}} \\
 &= 0.375 \cdot 9.15 \text{ m} \\
 &= 3.431 \text{ m}
 \end{aligned}$$

$$\begin{aligned}
 h_c &= \left(1 - \frac{\cosh\left(\frac{3.16 \cdot h_{\text{fluid}}}{L}\right) - 1}{\frac{3.16 \cdot h_{\text{fluid}}}{L} \cdot \sinh\left(\frac{3.16 \cdot h_{\text{fluid}}}{L}\right)} \right) \cdot h_{\text{fluid}} \\
 &= \left(1 - \frac{\cosh\left(\frac{3.16 \cdot 9.15 \text{ m}}{18 \text{ m}}\right) - 1}{\frac{3.16 \cdot 9.15 \text{ m}}{18 \text{ m}} \cdot \sinh\left(\frac{3.16 \cdot 9.15 \text{ m}}{18 \text{ m}}\right)} \right) \cdot 9.15 \text{ m} \\
 &= 5.357 \text{ m}
 \end{aligned}$$

$$\begin{aligned}P_w &= \frac{I \cdot S_{ds} \cdot \epsilon \cdot W_{\text{walls}}}{R_{wi}} \\&= \frac{1.5 \cdot 1.06 \cdot 0.7041 \cdot 317 \text{ kN}}{2} \\&= 177.4 \text{ kN}\end{aligned}$$

$$\begin{aligned}P_r &= \frac{I \cdot S_{ds} \cdot W_r}{R_{wi}} \\&= \frac{1.5 \cdot 1.06 \cdot 5 \text{ kN}}{2} \\&= 3.975 \text{ kN}\end{aligned}$$

$$\begin{aligned}P_i &= \frac{I \cdot S_{ds} \cdot W_i}{R_{wi}} \\&= \frac{1.5 \cdot 1.06 \cdot 887.6 \text{ kN}}{2} \\&= 705.6 \text{ kN}\end{aligned}$$

$$\begin{aligned}P_c &= C_c \cdot I \cdot W_c \\&= 0.1021 \cdot 1.5 \cdot 774.2 \text{ kN} \\&= 118.5 \text{ kN}\end{aligned}$$

$$\begin{aligned}V_t &= \sqrt{P_c^2 + P_i^2} \\&= \sqrt{(118.5 \text{ kN})^2 + (705.6 \text{ kN})^2} \\&= 715.5 \text{ kN}\end{aligned}$$

$$\begin{aligned}V &= \sqrt{(P_i + P_w + P_r)^2 + P_c^2 + P_{eg}^2} \\&= \sqrt{(705.6 \text{ kN} + 177.4 \text{ kN} + 3.975 \text{ kN})^2 + (118.5 \text{ kN})^2 + (0 \text{ kN})^2} \\&= 894.9 \text{ kN}\end{aligned}$$

$$\begin{aligned}M_w &= P_w \cdot H_w \\&= 177.4 \text{ kN} \cdot 5.175 \text{ m} \\&= 918.3 \text{ kN} \cdot \text{m}\end{aligned}$$

$$\begin{aligned}M_r &= P_r \cdot h_{\text{roof}} \\&= 3.975 \text{ kN} \cdot 10.35 \text{ m} \\&= 41.14 \text{ kN} \cdot \text{m}\end{aligned}$$

$$\begin{aligned}M_i &= P_i \cdot h_i \\&= 705.6 \text{ kN} \cdot 3.431 \text{ m} \\&= 2.421 \text{ MN} \cdot \text{m}\end{aligned}$$

$$\begin{aligned}M_c &= P_c \cdot h_c \\&= 118.5 \text{ kN} \cdot 5.357 \text{ m} \\&= 635.1 \text{ kN} \cdot \text{m}\end{aligned}$$

$$\begin{aligned}M_{\text{eg}} &= P_{\text{eg}} \cdot h_{\text{eg}} \\&= 0 \text{ kN} \cdot 0 \text{ m} \\&= 0 \text{ N} \cdot \text{m}\end{aligned}$$

$$\begin{aligned}M_s &= \sqrt{(M_i + M_w + M_r)^2 + M_c^2 + M_{\text{eg}}^2} \\&= \sqrt{(2.421 \text{ MN} \cdot \text{m} + 918.3 \text{ kN} \cdot \text{m} + 41.14 \text{ kN} \cdot \text{m})^2 + (635.1 \text{ kN} \cdot \text{m})^2 + (0 \text{ N} \cdot \text{m})^2} \\&= 3.44 \text{ MN} \cdot \text{m}\end{aligned}$$

$$\begin{aligned}M'_i &= P_i \cdot h'_i \\&= 705.6 \text{ kN} \cdot 7.184 \text{ m} \\&= 5.069 \text{ MN} \cdot \text{m}\end{aligned}$$

$$\begin{aligned}M'_c &= P_c \cdot h'_c \\&= 118.5 \text{ kN} \cdot 7.763 \text{ m} \\&= 920.2 \text{ kN} \cdot \text{m}\end{aligned}$$

$$\begin{aligned}M'_s &= \sqrt{(M'_i + M_w + M_r)^2 + M'^2_c} \\&= \sqrt{(5.069 \text{ MN} \cdot \text{m} + 918.3 \text{ kN} \cdot \text{m} + 41.14 \text{ kN} \cdot \text{m})^2 + (920.2 \text{ kN} \cdot \text{m})^2} \\&= 6.099 \text{ MN} \cdot \text{m}\end{aligned}$$

$$\begin{aligned}
 q_{\text{hy,base}} &= \gamma_{\text{fluid}} \cdot h_{\text{fluid}} \\
 &= 9.81 \text{ kN/m}^3 \cdot 9.15 \text{ m} \\
 &= 89.76 \text{ kPa}
 \end{aligned}$$

$$\begin{aligned}
 p_{\text{wy}} &= \frac{S_{\text{ds}} \cdot I \cdot \epsilon \cdot \gamma_{\text{conc}} \cdot t_{\text{wall}}}{R_{\text{wi}}} \\
 &= \frac{1.06 \cdot 1.5 \cdot 0.7041 \cdot 23.56 \text{ kN/m}^3 \cdot 650 \text{ mm}}{2} \\
 &= 8.572 \text{ kPa}
 \end{aligned}$$

$$\begin{aligned}
 p_{\text{iy,base}} &= \frac{(4 \cdot h_{\text{fluid}} - 6 \cdot h_i) \cdot \frac{P_i}{2}}{h_{\text{fluid}}^2 \cdot B} \\
 &= \frac{(4 \cdot 9.15 \text{ m} - 6 \cdot 3.431 \text{ m}) \cdot \frac{705.6 \text{ kN}}{2}}{(9.15 \text{ m})^2 \cdot 1 \text{ m}} \\
 &= 67.48 \text{ kPa}
 \end{aligned}$$

$$\begin{aligned}
 p_{\text{iy,top}} &= \frac{(6 \cdot h_i - 2 \cdot h_{\text{fluid}}) \cdot \frac{P_i}{2}}{h_{\text{fluid}}^2 \cdot B} \\
 &= \frac{(6 \cdot 3.431 \text{ m} - 2 \cdot 9.15 \text{ m}) \cdot \frac{705.6 \text{ kN}}{2}}{(9.15 \text{ m})^2 \cdot 1 \text{ m}} \\
 &= 9.64 \text{ kPa}
 \end{aligned}$$

$$\begin{aligned}
 p_{\text{cy,base}} &= \frac{(4 \cdot h_{\text{fluid}} - 6 \cdot h_c) \cdot \frac{P_c}{2}}{h_{\text{fluid}}^2 \cdot B} \\
 &= \frac{(4 \cdot 9.15 \text{ m} - 6 \cdot 5.357 \text{ m}) \cdot \frac{118.5 \text{ kN}}{2}}{(9.15 \text{ m})^2 \cdot 1 \text{ m}} \\
 &= 3.154 \text{ kPa}
 \end{aligned}$$

$$\begin{aligned}
 p_{\text{cy,top}} &= \frac{(6 \cdot h_c - 2 \cdot h_{\text{fluid}}) \cdot \frac{P_c}{2}}{h_{\text{fluid}}^2 \cdot B} \\
 &= \frac{(6 \cdot 5.357 \text{ m} - 2 \cdot 9.15 \text{ m}) \cdot \frac{118.5 \text{ kN}}{2}}{(9.15 \text{ m})^2 \cdot 1 \text{ m}} \\
 &= 9.801 \text{ kPa}
 \end{aligned}$$