Statical Calculation of a SeaWall

AC3 - Seismic design

Data:

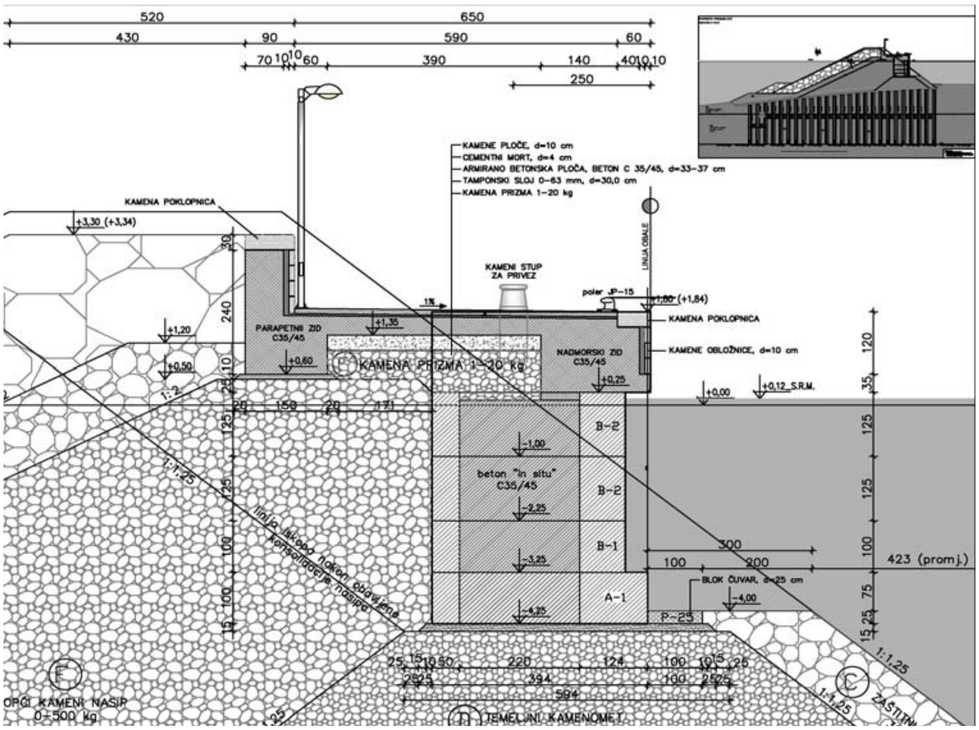

Figure 1. Structure.

1. Characteristics of the soil:

$\gamma_s =$ 19.00 [kN/m^3]

$\gamma_{s'} =$ 10.00 [kN/m^3]

$\gamma_w =$ 10.25 [kN/m^3]

$\beta =$ 0º = 0.00 rad

$\alpha =$ 90º = 1.57 rad

Loads in the structure are caused by:		
	Self Weight	• Permanent action
	Soil	• Permanent action
	Water	• Varible action
	Near foundations	• Permanent action
	Additional loads[1]	• Variable action
	[1]Traffic load and ship load	
	Seismic loads	

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2. Partial factors for ultimate limit states and recommended values:

	Set		Symbol	Coefficient
Actions	A1	Permanent		
		Unfavorable	γ_G	1.00
		Favorable		1.00
		Variable		
		Unfavorable	γ_Q	1.30
		Favorable		0
Soil Parameter	M2	Shearing Resistance	$\gamma_{\varphi}{}^{1}$	1.25
		Effective Cohesion	$\gamma_{c'}$	1.25
		Undrained Strength	γ_{cu}	1.40
		Unconfined Strength	γ_{qu}	1.40
		Weight Density	γ_{γ}	1.00
Resistance	R3	Bearing	γ_{Rv}	1.00
		Sliding	γ_{Rh}	1.00

[1]This *factor is applied* to tan(φ')

	k[1]	d[2]	
φ'	40º	34º	0.59 rad
δ	27º	22º	0.38 rad

[1]Characteristical [2]Design

Combination factors

ψ_{wave}	0.1
ψ_{ship}	0.5
ψ_q	0.3

3. Coefficient of active earth pressure:

$$K_a = \frac{\sin^2(\alpha+\varphi)}{\sin^2(\alpha)\sin(\alpha-\delta)\left(1+\sqrt{\frac{\sin(\varphi+\delta)\sin(\varphi-\beta)}{\sin(\alpha-\delta)\sin(\alpha+\beta)}}\right)^2}$$

	Ka
EC8$^{(Coloumb)}$	0.256

4. Wave characteristics

H_s= 0,5m

H_{max}= 1m

L_w= 10m

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Permanent Actions:

1. Produced by structures:

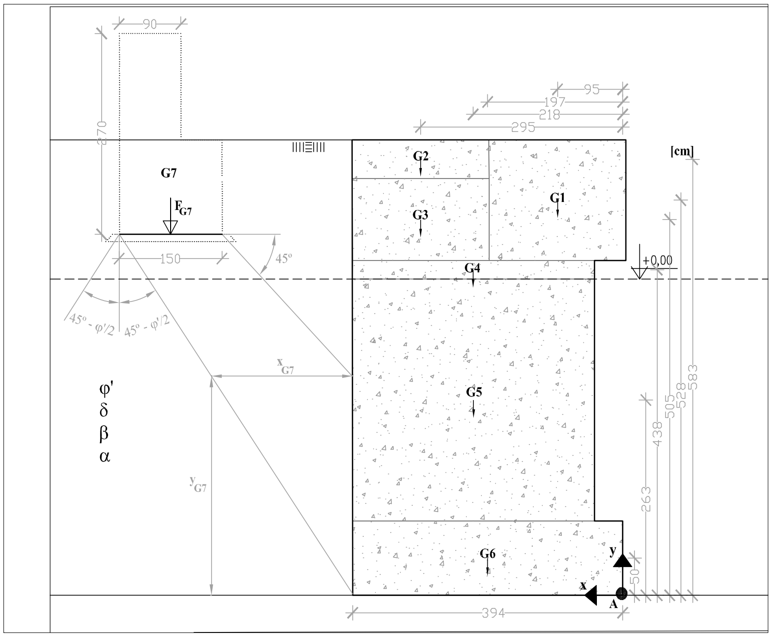

Figure 2. Calculation scheme and load distribution derived from nearby foundations.

Block G7:	Area	Volume	F	x_{G7}	y_{G7}	F/x
	[m^2]	[m^3]	[kN]	[m]	[m]	[kN/m]
	3.19	3.19	79.80	2.06	2.94	38.73

	Dimensions [m]			V	γ	γ'	G	G_u	x	y
	H	L	d	[m^3]	[kN/m^3]	[kN/m^3]	[kN]	[kN]	[m]	[m]
G1	1.55	2.00	1.00	3.10	25.00	-	77.50	77.50	0.99	5.28
G2	0.45	1.94	1.00	0.87	25.00	-	21.83	21.83	2.95	5.83
G3	1.10	1.94	1.00	2.13	19.00	-	40.55	40.55	2.95	5.28
G4	0.25	3.59	1.00	0.90	24.00	-	21.51	21.51	2.18	4.38
G5	3.25	3.59	1.00	11.65	24.00	14.00	279.63	163.12	2.18	2.63
G6	1.00	3.94	1.00	3.94	24.00	14.00	94.56	55.16	1.97	0.50

$\Sigma(G) = G_{uk} =$ 535.57 kN/m $x_G =$ 2.06m

$\Sigma(G_u) = G_{uk,u} =$ 379.66 kN/m $y_G =$ 3.04m

$M_{guk,A} =$ 1103.10 kNm

$M_{Guk,U,A} =$ 781.97 kNm

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2. Produced by soil:

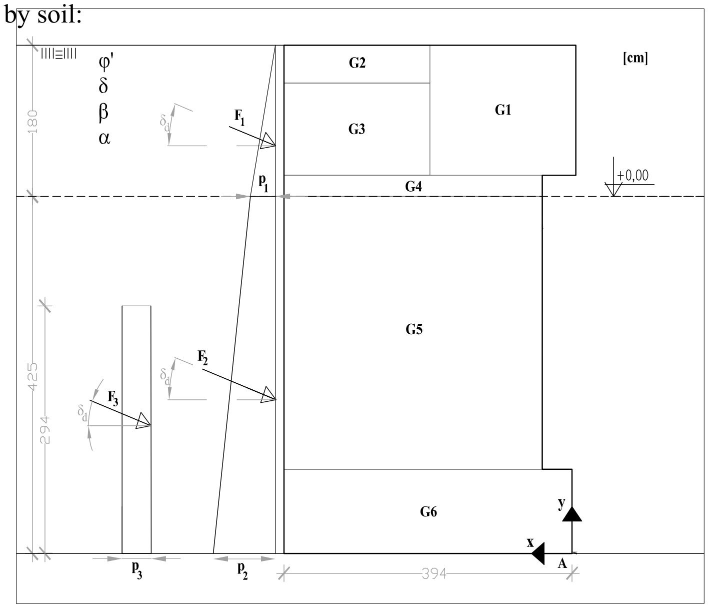

Figure 3. Calculation scheme and pressure distribution of soil.

$p_1 = K_a \times \gamma_s \times h_1$
$p_2 = p_1 + \gamma_s' \times h_2 \times K_a$
$p_3 = K_a \times (F/x)$

$F_1 = ½ \times p_1 \times h_1$
$F_2 = ½ \times (p_1 + p_2) \times h_2$
$F_3 = p_3 \times h_3$

$F_{i,h} = F_i \times \cos(\delta_d)$
$F_{i,v} = F_i \times \sin(\delta_d)$

- Soil Above Water
- Soil Below Water
- Nearby Foundation

Dimensions:

$h_1 =$ 1.80m
$h_2 =$ 4.25m
$h_3 =$ 2.94m
L = 3.94m

Type of soil pressure	i	p [kPa]	F_i [kN/m]	$F_{i,h}$ [kN/m]	$F_{i,v}$ [kN/m]	$h_{i,F}$ [m]	$M_{i,h}$ [+] [kNm/m]	$M_{i,v}$ [+] [kNm/m]
Active	1	8.74	7.87	7.30	2.93	4.85	-35.42	11.56
Active	2	19.61	60.25	55.91	22.46	1.85	-103.63	88.50
Active	3	9.90	29.11	27.01	10.85	1.47	-39.71	42.76
					$\Sigma(M_{Fi(h;v)})$ =		-178.76	142.82

- Soil Pressure Above WL
- Soil Pressure Below WL
- Soil Pressure Produced by Near Foundation

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Variable Actions:

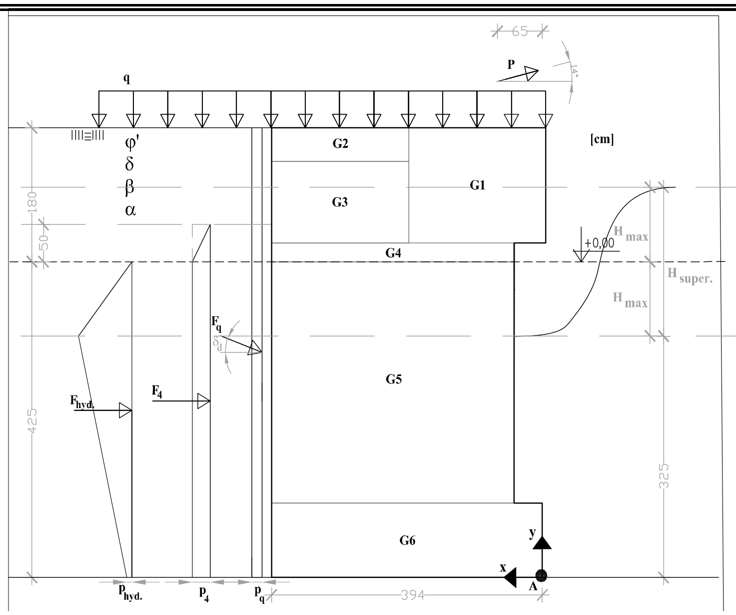


Figure 4. Calculation scheme and pressre distribuition of variable actions.

1. Trafic Load:

   $q =$ 5 [kN/m^2] $p_q = K_a \times q$ $F_q = p_q \times (h_1 + h_2)$

2. Ship Load:

   $P =$ 6.44 [kN/m^2]

3. Water:

□ Residual Water Pressure:

$p_4 = \gamma_w \times (h_s)$ $F_4 \cong p_4 \times (h_2 + h_s)$

□ Hydrodynamic Pressure:

$p_{hydrodynamic} = \gamma_w \times (H_{max}) / \cosh(2\pi \times (h_2)/L_w{}^1)$

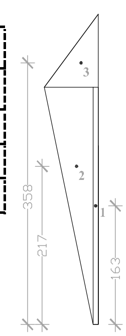
[1]L_w=10m (wave lenght of characteristic incoming waves)

-clapotis mean level uplift is neglected

$F_{hid} = ½ \times (p_{hyd.} + \gamma_w \times H_{max}) \times (h_2 - H_{max}) + ½ \times (\gamma_w \times H_{max})$

$h_{hydrodynamic,F} = \Sigma(h_i \times A_i)/\Sigma(A_i)$

i	A_i [m^2]	h_i [m]	$A_i \times h_i$
1	4.59	1.63	7.46
2	6.03	2.17	13.07
3	2.56	3.58	9.18
	Σ=13.19		Σ=29.71



Dimensions:

$H_{super.}$ = 2.00m

H_{max} = 1.00m

h_s = 0.50m

h_2 = 4.25m

L = 3.94m

□ Wave Height

□ Residual Water Behind The Wall

Name	p [kPa]	F_i [kN/m]	$F_{i,h}$ [kN/m]	$F_{i,v}$ [kN/m]	$h_{i,F}$ [m]	$x_{i,F}$ [m]	$M_{i,h}$ [+] [kNm/m]	$M_{i,v}$ [+] [kNm/m]
4	5.13	24.34	24.34	-	2.38	-	-57.82	-
hyd.	1.41	24.08	24.08	-	2.25	-	-54.25	-
q	1.28	7.73	7.18	2.88	3.03	3.94	-21.71	11.36
P	-	-	6.25	-1.56	6.23	0.70	-38.94	-1.09
						$\Sigma(M_{Fi(h;v)})$=	-172.72	10.27

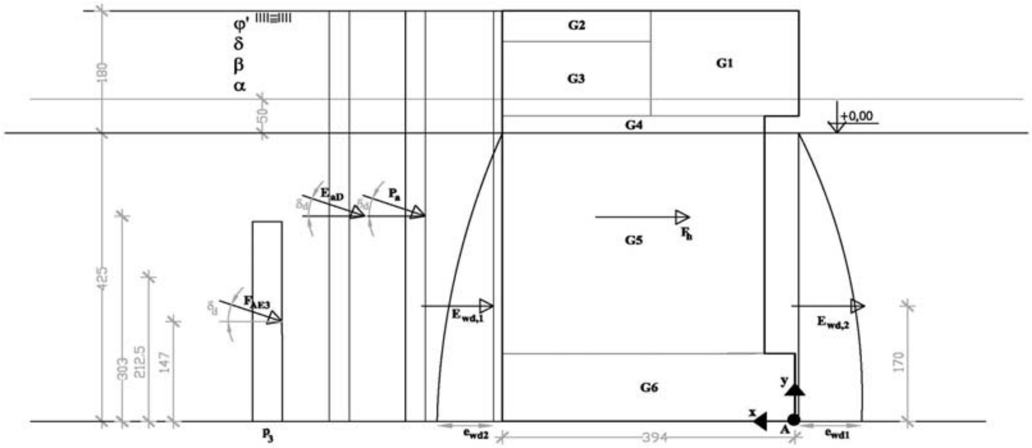
□ Water Pressure

□ Hydrodynamic Pressure

□ Traffic Load

□ Ship Load

Seismic Actions:



Seismic zone: 7

a_g=	0.5	[m/s^2]	• design ground acceleration
α=	0.05		• ratio a_g/g
S=	1		• soil parameter for ground type A
r=	1.5		• factor depending on the type of retaining structure

Seismic coefficients:

Horizonta	$k_h=\alpha\times S/r$=	0.034	
Vertical	k_V=	0.000	• assumption made for simplicity in design practice

1. Seismic Inertial Force
   $F_h = k_h \times G_{uk}$

2. Seismic Hydrodynamic Pressure

Landward side of the wall: $e_{wd1}(z)=7/8\times k_h\times y_w\times\sqrt{(h\times z)}$ [kN/m^2] $E_{wd1}=7/12\times k_h\times\gamma_w\times H'^2$

$H'=h_2$= 4.25m • height of the water table

Outer side of the wall: $e_{wd2}(z)=7/8\times k_h\times y_w\times\sqrt{(h\times z)}$ [kN/m^2] $E_{wd2}=7/12\times k_h\times\gamma_w\times h_w^2$

$h_w=h_2$= 4.25 • free water height

r=1 → k_h= 0.05 • k_h for the outer side of the wall must be calculated for r=1

3. Seismic Earth Pressure Force

$h_1 << h_2 \rightarrow$ • calculations are made with γ_s'

$E_{a(S+D)} = 0.5 \times \gamma^* \times (1 \pm k_v) \times K \times (h_1 + h_2)^2$

For $\beta \leq \varphi'_d - \theta$:

$$K = \frac{\sin^2(\psi + \varphi_d' - \theta)}{\cos\theta \sin^2\psi \sin(\psi - \theta - \delta_d)\left(1 + \sqrt{\frac{\sin(\varphi_d' + \delta_d)\sin(\varphi_d' - \beta - \theta)}{\sin(\psi - \theta - \delta_d)\sin(\psi + \beta)}}\right)^2} = 0.275$$

• earth pressure coefficient (static+dynamic)

$\beta =$ 0º = 0.00 rad

$\psi = \alpha =$ 90º = 1.57 rad

$\gamma^* = \gamma_s' =$ 10.00 [kN/m³]

$$\tan\theta = \frac{k_h}{1 \mp k_v} = 0.034$$

	rad	°
θ	0.03	1.95

$E_{a(S+D)} =$ 50.41

$E_{aD} = E_{a(S+D)} - E_{aS}$ • dynamic component of earth pressure force

4. Seismic Earth Pressure Force due to Traffic Load

$p = K \times q =$ 1.38 $Pa = p \times (h_1 + h_2)$

5. Seismic Earth Pressure due to Near foundation

$p_{AE3} = K \times (F/x)$ $F_{AE3} = p_3 \times h_3$

Name	F_i [kN/m]	$F_{i,h}$ [kN/m]	$F_{i,v}$ [kN/m]	$h_{i,F}$ [m]	$x_{i,F}$ [m]	$M_{i,h}$ [+] [kNm/m]	$M_{i,v}$ [+] [kNm/m]	
F_h	12.90	12.90	0.00	3.04	2.06	-39.19	0.00	• inertial force
E_{wd1}	3.67	3.67	-	1.7	-	-6.24	-	• hydrodynamic force
E_{wd2}	5.50	5.50	-	1.7	-	-9.36	-	• hydrodynamic force
E_{aD}	-17.71	-16.43	-6.60	3.03	3.94	49.71	-26.01	• earth pressure force
P_a	8.33	7.73	3.11	3.03	3.94	-23.39	12.24	• seismic traffic load
F_{AE3}	31.36	29.10	11.69	1.47	3.94	-42.78	46.07	• near foundation

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Overturning around point A:

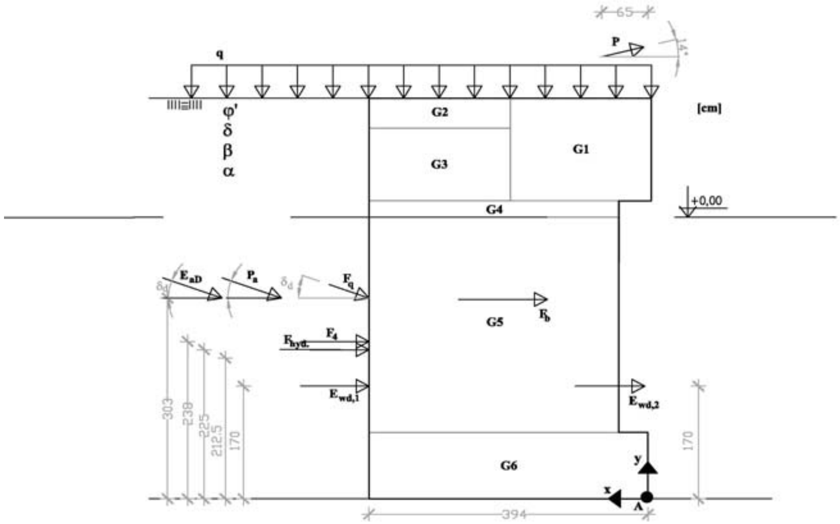

Figure 6. Calculation scheme and forces location on the structure.

	i	$M_{h,k}$ [+] [kNm/m]	γ_G	$M_{v,k}$ [+] [kNm/m]	γ_G	$M_{h,d}$ [+] [kNm/m]	$M_{v,d}$ [+] [kNm/m]
Permanent Actions (G)	$G_{uk,U}$	0.00	1.00	781.97	1.00	0.00	781.97
	1	-35.42	1.00	11.56	1.00	-35.42	11.56
	2	-103.63	1.00	88.50	1.00	-103.63	88.50
	3	-39.71	1.00	42.76	1.00	-39.71	42.76

	i	$M_{h,k}$ [+] [kNm/m]	γ_Q	$M_{v,k}$ [+] [kNm/m]	γ_Q	$M_{h,d}$ [+] [kNm/m]	$M_{v,d}$ [+] [kNm/m]
Variable Actions (Q)	4	-57.82	1.30	-	-	-75.16	-
	hyd.	-54.25	1.30	-	-	-70.53	-
	q	-21.71	1.30	11.36	0.00	-28.22	0.00
	P	-38.94	1.30	-1.09	1.30	-50.62	-1.42

	i	$M_{h,k}$ [+] [kNm/m]	γA	$M_{v,k}$ [+] [kNm/m]	γA	$M_{h,d}$ [+] [kNm/m]	$M_{v,d}$ [+] [kNm/m]
Seismic Actions (A_{Ed})	F_h	-39.19	1.00	0.00	1.00	-39.19	0.00
	E_{wd1}	-6.24	1.00	-	1.00	-6.24	-
	E_{wd2}	-9.36	1.00	-	1.00	-9.36	
	E_{aD}	49.71	1.00	-26.01	1.00	49.71	-26.01
	P_a	-23.39	1.00	12.24	1.00	-23.39	12.24
	F_{AE3}	-42.78	1.00	46.07	1.00	-42.78	46.07

1. Persistent and Transient Design Situation

Using $M_{hyd.}$ as the dominant variable action:

$M_{dst} = \Sigma(\gamma_{G,dst} \times M_{G,i}^{-}) + \gamma_{Q,dst} \times M_{Q,i}^{-} + \Sigma(\Psi_{2i} \times \gamma_{Q,dst} \times M_{P,i}^{-})=$ -306.32 [kNm/m]

$M_{stb} = \Sigma(\gamma_{G,stb} \times (M_{Guk,U}^{+} + M_{G,i}^{+})) + \gamma_{Q,stb} \times M_{Q,i}^{+} + \Sigma(\Psi_{2i} \times \gamma_{Q,stb} \times M_{P,i}^{+})=$ 924.79 [kNm/m]

$F_{spr} = (M_{stb}/M_{dst})/\gamma_R =$ 3.0190

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2. Seismic Design Situation

$M_{dst} = \Sigma(M_{G,i}^{-}) + \Sigma(\Psi_{2i} \times \gamma_{Q,dst} \times M_{Q,i}^{-}) + M_{AEd,i}^{-} =$ -398.89 [kNm/m]

$M_{stb} = \Sigma(\gamma_{G,stb} \times (M_{Guk,U}^{+} + M_{G,i}^{+})) + \Sigma(\Psi_{2i} \times \gamma_{Q,stb} \times M_{Q,i}^{+}) + M_{AEd,i}^{+} =$ 1032.81 [kNm/m]

$F_{spr} = (M_{stb}/M_{dst})/\gamma_R =$ 2.5892

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Sliding:

	i	F_h [kN/m]	γ_G	F_v [kN/m]	γ_G	$F_{h,d}$ [kN/m]	$F_{v,d}$ [kN/m]
Permanent Actions (G)	$G_{uk,U}$	0.00	1.00	379.66	1.00	0.00	379.66
	1	7.30	1.00	2.93	1.00	7.30	2.93
	2	55.91	1.00	22.46	1.00	55.91	22.46
	3	27.01	1.00	10.85	1.00	27.01	10.85

	i	F_h [kN/m]	γ_G	F_v [kN/m]	γ_G	$F_{h,d}$ [kN/m]	$F_{v,d}$ [kN/m]
Variable Actions (Q)	4	24.34	1.30	-	-	31.65	-
	hyd.	24.08	1.30	-	-	31.30	-
	q	7.18	1.30	2.88	0.00	9.33	0.00
	P	6.25	1.30	-1.56	1.30	8.13	-2.03

	i	F_h [kN/m]	γA	F_v [kN/m]	γA	$F_{h,d}$ [kN/m]	$F_{v,d}$ [kN/m]
Accidental (Seismic) Actions (AEd)	Fh	12.90	1.00	0.00	1.00	12.90	0.00
	Ewd1	3.67	1.00	-	1.00	3.67	-
	Ewd2	5.50	1.00	-	1.00	5.50	-
	E_{aD}	-16.43	1.00	-6.60	1.00	-16.43	-6.60
	Pa	7.73	1.00	3.11	1.00	7.73	3.11
	F_{AE3}	29.10	1.00	11.69	1.00	29.10	11.69

1. Persistent and Transient Design Situation

Using $F_{hyd.}$ as the dominant variable action:

$H_d = \Sigma(\gamma_G \times F_{Gh,i}) + \gamma_Q \times F_{Qh,i} + \Sigma(\Psi_{2i} \times \gamma_Q \times F_{Qh,i}) =$ 137.88 [kN/m]

$V_d = \Sigma(\gamma_G \times F_{Gh,i}) + \gamma_Q \times F_{Qh,i} + \Sigma(\Psi_{2i} \times \gamma_Q \times F_{Qh,i}) =$ 414.89 [kN/m]

$R_d = V_d \times tg(\delta_d)/\gamma_{R;h} =$ 166.69 [kN/m]

$H_d \leq R_d$ - VERIFIED $F_{spr} = (R_d/V_d) =$ 1.21

2. Seismic Design Situation

$H_d = \Sigma(F_{Gh,i}) + \Sigma(\Psi_{2i} \times \gamma_Q \times F_{Qh,i}) + \Sigma F_{Ah} =$ 157.15 [kN/m]

$V_d = \Sigma(\gamma_G \times F_{Gv,i}) + \Sigma(\Psi_{2i} \times \gamma_Q \times F_{Qv,i}) + \Sigma F_{Av} =$ 424.77 [kN/m]

$R_d = V_d \times tg(\delta_d)/\gamma_{R;h} =$ 170.66 [kN/m]

$H_d \leq R_d$ - VERIFIED $F_{spr} = (R_d/V_d) =$ 1.09