Prosheet

B. Technical manual

1. Purpose of the software

Prosheet is a powerful tool for sheet pile design for cantilever, single supported walls (active anchors, passive anchors or struts) and anchors walls.

There are two available calculation methods: Classical and Eurocode.

Classical method consists of wall equilibrium calculation without no ponderation on actions but with possible global factor on passive earth pressure.

Eurocode method consists of wall equilibrium calculation with ponderation on actions and resistances. Design checks requested by French National Standard (NF P4-282) of Eurocode 7 (safety on passive earth pressure, Kranz verification and vertical equilibrium) are implemented. Embankment and berms effects and seismic calculation are also available.

2. Technical specifications

2.1. General

All wall cases integrated in Prosheet assume that:

- Soil behind the sheet pile wall is systematically in active state (limit active earth pressure is considered). Counterreaction (passive earth pressure) will be also taken into account behind the sheet pile if necessary earth support is considered like fixed.
- Soil in front of the sheet pile wall is systematically in passive state (limit passive earth pressure is considered).

Consequently, there is not a direct relation between pressures and displacements at each level of the sheet pile wall like in SSI method.

It is important to note that all calculations will be made under ULS approach for both calculation methods (Classical and Eurocode). Calculation deal with sheet pile wall, multilayer soil, variable natural ground level (berm on the front side or embankment at the back side), supports (struts or anchors) and external loads either applied on the wall or on the soil.

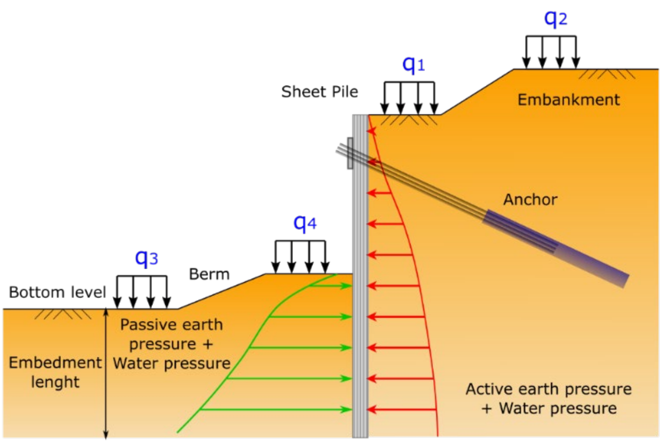


Figure 1. Standard cross-section for an anchored wall

General calculation steps:

1. Compute active and passive earth pressures taken into account appropriate weighting factors.
2. Calculate wall embedment needed for equilibrium and the reactions to the supports (if they exist)
3.
4. Calculate internal loads diagrams:
    a. Shear diagram
    b. Bending diagram
    c. Axial forces diagram
5. Calculate rotation and horizontal displacements diagram.

2.2. Calculation methods

2.2.1. Classical method

The classical method aims to get the wall equilibrium with no ponderation on actions but with minimal global safety on passive earth pressure ($S_{f,min}$ factor). No local standard are used in this method.

In some cases, an increment of embedded length (Δe) may be defined by the user from tip wall level which ensures wall equilibrium. New S_f factor will be deduced and a new equilibrium calculation of the wall will be performed.

Since the passive earth pressure is assumed to be equal to the limit earth pressure, equilibrium may not be reached in some cases due to an excessive passive earth pressure. In this case, it is recommended to increase manually global safety on passive earth pressure to reduce it. This is perfectly consistent with calculation principle because passive earth pressure is a reaction and not an action.

In some cases, equilibrium cannot be reached because passive earth pressure is not enough to compensate global moment generated by the actions applied on the wall. In this case, it is advised to check strength parameters of soil layer on the front side or reduced global safety factor on passive earth pressure.

Horizontal equilibrium forces and global moment equilibrium are used and guaranteed for every case.

2.2.1.1. Cantilever wall

Cantilever wall is submitted to active earth pressure (P_a) applied and other external actions and equilibrated by passive earth pressure (P_b) on the front side. Counter-passive earth pressure (C_h) applied at C level is necessary to compensate horizontal forces generated by the rest of action applied on the wall.

C level is researched rigorously to ensure wall global moment equilibrium. Then, C_h value is taken equal to shear load at C level to guarantee horizontal equilibrium forces. Rotation and displacement are supposed nulls at C level.

It is advised to consider an over-length to guarantee that counter-passive earth pressure is effectively mobilized. This may be done with Δe parameter. New equilibrium calculation will be performed automatically to extend wall length and deduce a new global safety factor on passive earth pressure. The new safety factor will be higher or equal to the minimum safety level defined by the user.

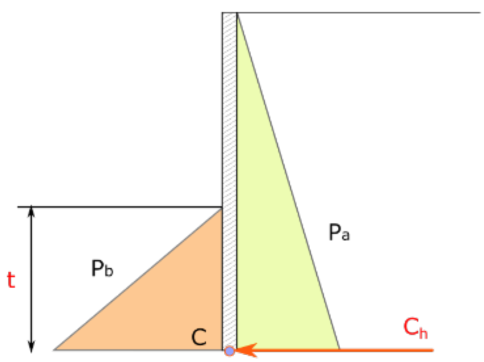


Figure 2. Cantilever wall (classical method)

2.2.1.2. Supported wall: anchored wall or propped wall

There is no difference between anchored wall and propped wall in the classical method.

Supported wall is submitted to active earth pressure (P_a) applied and other external actions and equilibrated by passive earth pressure (P_b) on the front side and support reaction (anchor or strut). Earth support may be defined as Free or Fixed. Global safety on passive earth pressure may be defined (S_f). Over-length is only available for free earth support in order to calculate a new Sf factor and perform a new wall equilibrium. The new safety factor will be higher or equal to the minimum safety level defined by the user.

Indeed, calculation method for fixed earth support doesn't allow to take into account an over-length because equilibrium of the top level (above O level) depends on both the reaction of the support and the safety factor on the passive earth pressure.

- **Free earth support**

Bottom level of the wall (P) is researched rigorously to ensure global momentum equilibrium. Anchor reaction (T_A) is deduced by horizontal force equilibrium. Displacement is supposed null at support level and bottom level of the wall.

- **Fixed earth support**

This case assumes that there is a counter-passive earth pressure at C level, which requires an additional equation: Blum assumption. Blum assumes that null differential pressure level matches with null bending moment level.

Once null differential pressure (O) is reached, support reaction is calculated from global momentum equilibrium of the "top beam" (between top level of the wall until O level). Shear is deduced at O level and is input in "bottom beam" equilibrium. Then, C level of "bottom beam" (OC) is calculated to ensure global momentum equilibrium. Finally, counter-passive earth reaction is calculated to ensure horizontal forces equilibrium.

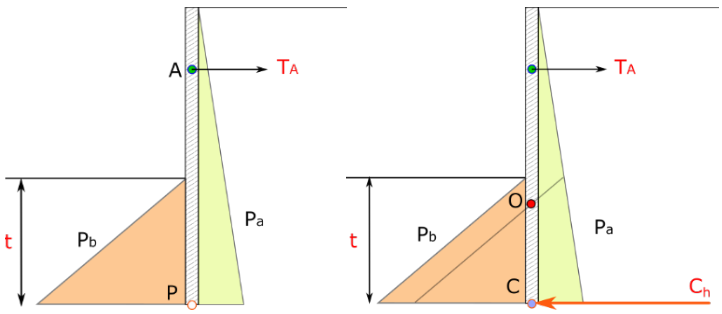


Figure 3. Supported wall (classical method): free earth support (left side) or fixed earth support (right side)

2.2.1.3. Anchor wall

Anchor wall is submitted to support reaction (action), active earth pressure (P_a) applied and other external actions and equilibrated by passive earth pressure (P_b). Global safety on passive earth pressure may be defined as well an over-length to calculate a new Sf factor. Anchor reaction is considered like as an input. Earth support may be defined as Free or Fixed.

- **Free earth support:**

Bottom level of the wall (P) is researched rigorously to ensure horizontal forces equilibrium. Anchor level is recalculated to ensure global momentum equilibrium (z_{A1}).

- **Fixed earth support:**

Bottom level of the wall (C) is researched rigorously to ensure global momentum equilibrium. Counter-passive reaction is calculated to ensure horizontal force equilibrium. Anchor level is not recalculated.

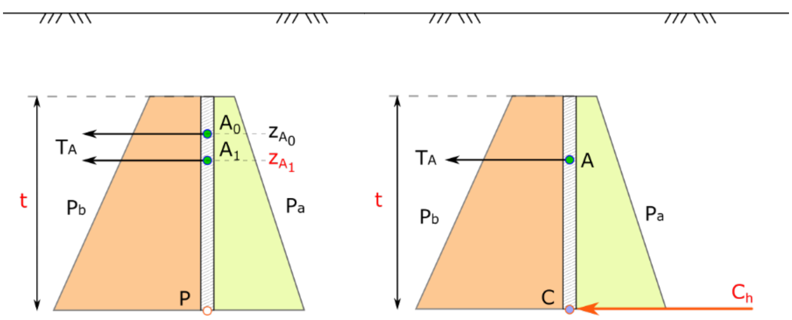


Figure 4. Anchor wall (classical method): free earth support (left) and fixed earth support (right)

2.2.1.4. Head wall & Anchor wall

Main wall will be always considered on the left side and anchor wall on the right side.

- Head wall will be calculated with the same procedure as anchored wall (§2.2.1.2).
- Anchor wall will be calculated with the same procedure as anchor wall (§2.2.1.3)

Head wall equilibrium will provide anchor reaction (T_A). Anchor wall equilibrium will be calculated taking into account this anchor reaction as an input. Therefore, there is no iteration process.

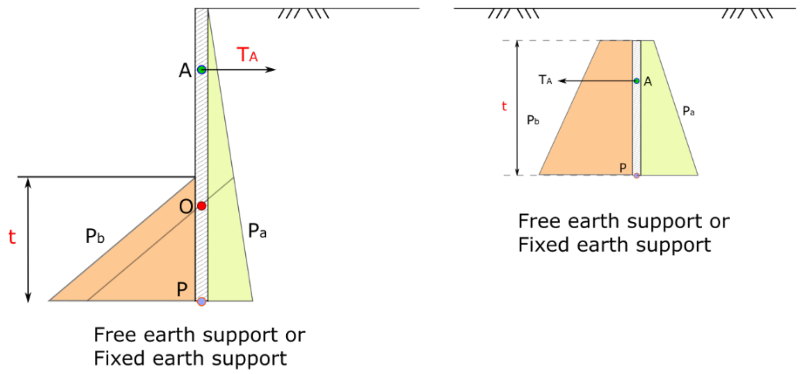


Figure 5. Head wall and anchor wall (classical method)

2.2.2. Eurocode method

Eurocode method consists of applying partial factors on characteristic values of actions and resistances to deduce theirs design values. Following table shows all partial factors values integrated in Prosheet. User has the possibility to define his own partial safety factors with "Custom" option.

				Approach			
			Symbol	1.1	1.2	2*	3
Active earth pressure (destabilizing)			$\gamma_{Pa,dst}$	1.35	1.00	1.35	1.00
Active earth pressure (stabilizing)			$\gamma_{Pa,stb}$	1.00	1.00	1.00	1.00
Passive earth pressure			γ_{Pb}	1.40	1.00	1.40	1.00
Water pressure (destabilizing)			$\gamma_{Pw,dst}$	1.35	1.00	1.35	1.00
Water pressure (stabilizing)			$\gamma_{Pw,stb}$	1.00	1.00	1.00	1.00
Wall weight			γ_{w}	1.35	1.00	1.35	1.35
Loads applied on the soil	Permanent	Unfavourable	$\gamma_{loads,soil,G,dst}$	1.35	1.00	1.35	1.00
		Favourable	$\gamma_{loads,soil,G,stb}$	1.00	1.00	1.00	1.00
	Transient	Unfavourable	$\gamma_{loads,soil,Q,dst}$	1.50	1.30	1.50	1.30
		Favourable	$\gamma_{loads,soil,Q,stb}$	0.00	0.00	0.00	0.00
Loads applied on the wall	Permanent	Unfavourable	$\gamma_{loads,wall,G,dst}$	1.35	1.00	1.35	1.35
		Favourable	$\gamma_{loads,wall,G,stb}$	1.00	1.00	1.00	1.00
	Transient	Unfavourable	$\gamma_{loads,wall,Q,dst}$	1.50	1.30	1.50	1.50
		Favourable	$\gamma_{loads,wall,Q,stb}$	0.00	0.00	0.00	0.00
Drained cohesion			γ_{φ}	1.00	1.25	1.00	1.25
Drained friction angle			γ_{c}	1.00	1.25	1.00	1.25
Undrained cohesion			γ_{φ}	1.00	1.40	1.00	1.40
Undrained friction angle			γ_{c}	1.00	1.40	1.00	1.40
Anchor reaction			γ_{anc}	1.10	1.10	1.00	1.00
Destabilizing force of the anchor block (Kranz)			γ_{krz}	1.00	1.00	1.10	1.00

Tableau 1. Partial factors for every approach of the Eurocode

Earth pressures will be weighted by partial safety factors proposed by Eurocode as a function of design approach

$$P_{ad} = \begin{Bmatrix} \gamma_a P_a(\varphi, c)\ if\ Approach\ 1.1\ or\ 2 \\ P_a\left(\frac{\tan\varphi}{\gamma_\varphi}, \frac{c}{\gamma_c}\right)\ if\ Approach\ 1.2\ or\ 3 \end{Bmatrix} \qquad P_{bd} = \begin{Bmatrix} \frac{P_b(\varphi, c)}{\gamma_b}\ if\ Approach\ 1.1\ or\ 2 \\ P_b\left(\frac{\tan\varphi}{\gamma_\varphi}, \frac{c}{\gamma_c}\right)\ if\ Approach\ 1.2\ or\ 3 \end{Bmatrix}$$

Where φ and c are respectively the characteristic value of frictional angle and cohesion (inputs values).

By default, water pressure is considered as stabilizing at the front side, so factored by $\gamma_{Pw,stb}$, and as destabilizing at the back side, so factored by $\gamma_{Pw,dst}$.

Prosheet offers the possibility to differentiate stabilizing and destabilizing nature of active earth and water pressures for the supported walls. The following figure specifies the areas on which the stabilizing/destabilizing partial factors are applied if the user requests it:

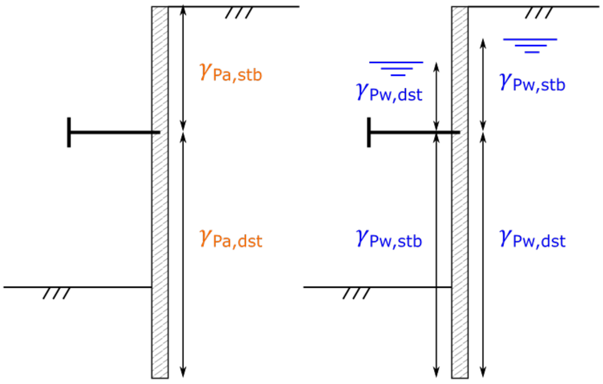


Figure 6. Destabilizing/Stabilizing partial factors on active earth and water pressure applied by region

2.2.2.1. Cantilever wall

Cantilever wall is submitted to active earth pressure ($P_{a,d}$) applied and other external actions and equilibrated by passive earth pressure ($P_{b,d}$) on the front side. Counter-passive earth pressure (C_h) applied at C level is necessary to compensate horizontal forces generated by the rest of action applied on the wall.

C level is researched rigorously to ensure wall global moment equilibrium. Then, C_h value is taken equal to shear load at C level to guarantee horizontal equilibrium forces.

Embedment is measured from null differential pressure level (O):

- f_0 corresponds to the minimal embedment to ensure global momentum equilibrium of the wall
- f_b corresponds to the available embedment (distance between O and P)

Eurocode requires to assure a minimal over-length of 20% on f_0, that's why it is required to respect following condition: $fb/f0 \geq 1.20$. So, once C level is reached, P level is deduced to respect this condition.

Eurocode requires to check that counter-passive reaction needed for the equilibrium ($C_{t,d}$) is less than counter-passive reaction available ($C_{m,d}$) on $0.2f_0$ under C level: $C_{t;d} \leq C_{m;d}$.

Counter-passive reaction is applied over 0.4f0 around C level. The mobilization rate of the counter-passive reaction is obtained from the following relationship: $\alpha = C_{t;d}/C_{m;d}$

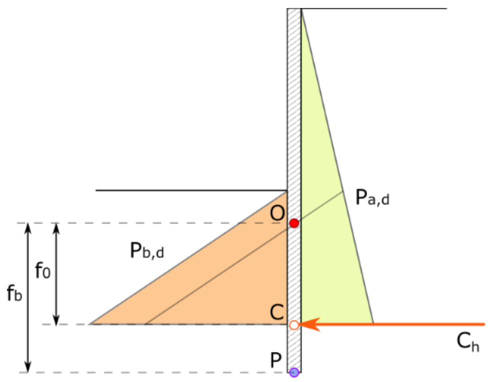


Figure 7. Cantilever wall (Eurocode method)

Supported wall: anchored wall or propped wall Since Eurocode doesn't handle fixed earth support, supported walls are only available with free earth support in Eurocode method.

Equilibrium calculation of the wall is similar to the classical method but taking into account safety partial factors on the actions and on resistances. So, active and passive earth pressures are computed in design values.

Bottom level of the wall (P) is researched rigorously to ensure global momentum equilibrium. Anchor reaction (T_A) is deduced by horizontal force equilibrium. Displacement is supposed null at support level and bottom level of the wall.

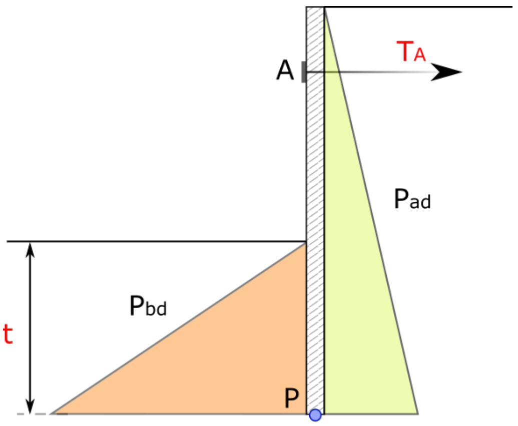


Figure 8. Anchored wall with free earth support (Eurocode method)

2.2.2.2. Anchor wall

Even if Eurocode do not specified fixed earth support for anchor wall, we can handle this case under the same principle as classical method but taking into account weighting factors on the earth pressure. This calculation is possible because T_A is an input, unlike *Anchored wall and Propped wall case* presented before where T_A is a result.

- **Free earth support:**

Bottom level of the wall (P) is researched rigorously to ensure horizontal forces equilibrium. Anchor level is recalculated to ensure global momentum equilibrium (z_{A1}).

In order to ensure the same anchor level at ULS and SLS, the top level of the sheet pile will be searched by iteration between requested top level (user input) and the anchor level calculated at ULS.

- **Fixed earth support:**

Bottom level of the wall (C) is researched rigorously to ensure global momentum equilibrium. Counter-passive reaction is calculated to ensure horizontal force equilibrium. Anchor level is not recalculated.

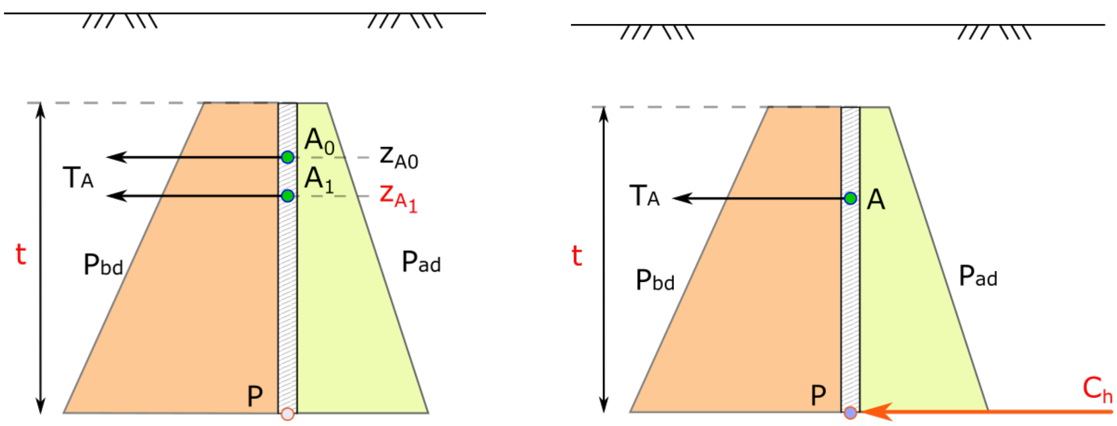


Figure 9. Anchor wall (Eurocode method): free earth support (left) and fixed earth suppor (right)

2.2.2.3. Head wall & Anchor wall

Head wall and anchor wall system equilibrium calculation is similar to the classical method, but taking into account safety partial factors on the actions and on resistances. So, active and passive earth pressures are computed in design values.

Main wall will be always considered on the left side and anchor wall on the right side.

- Head wall will be calculated with the same procedure as anchored wall (§2.2.1.2).
- Anchor wall will be calculated with the same procedure as anchor wall (§2.2.1.3)

Head wall equilibrium will provide anchor reaction (T_A). Anchor wall equilibrium will be calculated taking into account this anchor reaction as an input. Therefore, there is no iteration process.

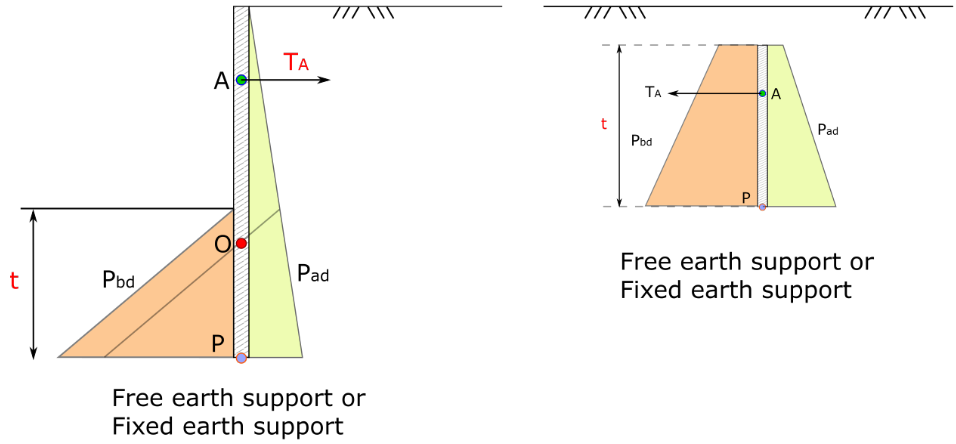


Figure 10. Head wall and anchor wall (Eurocode method)

2.3. Active and passive earth pressures

2.3.1. Horizontal or inclined natural ground level

Limit earth pressures are calculated from effective vertical stress:

- Active earth pressure: $p_a = k_{a\gamma}.\sigma'_v - k_{ac}.c$
- Passive earth pressure: $p_b = k_{p\gamma}.\sigma'_v + k_{pc}.c$

Where:

$k_{a\gamma}$	active earth pressure coefficient applied on γ or γ'
k_{ac}	active earth pressure coefficient applied on c
$k_{p\gamma}$	passive earth pressure coefficient applied on γ or γ'
k_{pc}	passive earth pressure coefficient applied on c
c	soil cohesion

$k_{a\gamma}$, $k_{p\gamma}$ may be defined by the user (custom mode). Automatic mode will take their values from Kerisel-Absi tables for horizontal or inclined natural ground level taking into account the wall inclination (λ) with a limitation of 5°.

According to Eurocode, minimum active earth pressure has to be taking into account to avoid negative values. This will be ensured by considering a minimum active earth pressure coefficient $k_{a\gamma,\min}$ (default value = 0.10).

Active and passive earth pressure coefficients applied on the cohesion are calculated from following expressions:

$$k_{ac} = \frac{1}{\tan\varphi}\left[\frac{\cos\delta_a - \sin\varphi\cos\alpha}{1+\sin\varphi}e^{-(\alpha-\delta_a)\tan\varphi}\cos\delta_a - 1\right]$$

$$k_{pc} = \frac{1}{\tan\varphi}\left[\frac{\cos\delta_p + \sin\varphi\cos\alpha}{1-\sin\varphi}e^{(\alpha+\delta_p)\tan\varphi}\cos\delta_p - 1\right]$$

with $\sin\alpha = \dfrac{\sin\delta}{\sin\varphi}$

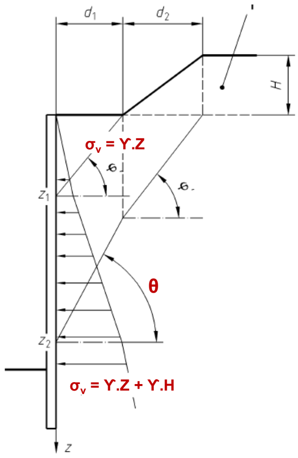
2.3.2. Embankment

Embankment may be defined only at the back side of the main wall. Its effect will be assimilated to an increment of vertical effective stress ($\Delta\sigma_V > 0$). According to the Houy method (NF P 94-282), $\Delta\sigma_V$ will be calculated in three zones:

- Zone 1 (between bottom level and z_1): $\Delta\sigma_V = 0$
- Zone 2 (between z_1 and z_2): $\Delta\sigma_V$ interpolated between zone 1 and 2.
- Zone 3 (beyond z_2): $\Delta\sigma_V = \gamma' H$

with $\theta = \dfrac{\pi}{4} + \dfrac{\varphi}{2}$

Levels z_1 and z_2 are calculated geometrically as a function of position and geometry of embankment. Houy method is designed for a single-layer, but it's adapted for a multilayer.



2.3.3. Berm

Berm may be defined only on the front side of the head wall.

According to the method proposed in NF P 94-262 ("Méthode de la banquette"), passive earth pressure will be calculated, from the top level to the bottom level of berm, as maximum value of shear friction (B_{max}) at each level of the berm. Implicitly, we'll consider a horizontal surface at each level of the berm. Beyond the berm, passive earth pressure will be calculated according to §2.3.1 taken into account berm weight.

$$B_{max} = \frac{1}{2}k_{p\gamma}\gamma H^2 + k_{pc}cH \le W.\tan(\varphi) + c.L_r$$

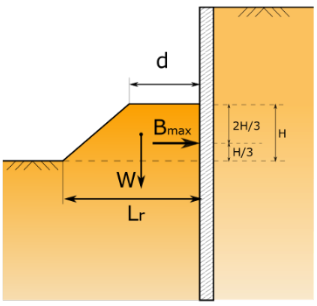


Figure 11. Method proposed in NF P 94-262 ("Méthode de la banquette")

2.3.4. Over-excavation

According to Eurocodes, over-excavation has to be taken into account when excavation level is not controlled in-situ.Its value has to be limited to 0.5 m.

2.4. External loads

2.4.1. Caquot load

Caquot load is a semi-infinite load (q) applied on a side of the sheet pile wall at z_0 level. Its effect is an increment of vertical stress on the soil beyond z_0 level.

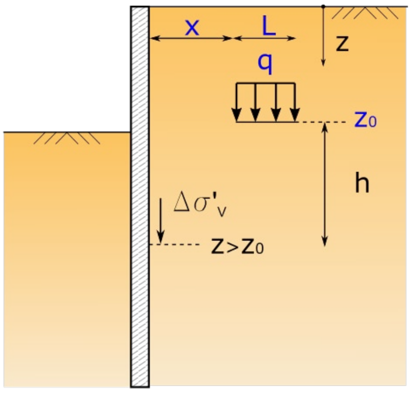
$$\Delta\sigma_v(z) = q \qquad \text{for } z \leq z0$$

2.4.2. Boussinesq load

Boussinesq load is a localised vertical load applied at "z" level over a width L from an x distance from the wall. Its effect is assimilated to an increment of horizontal stress at each level beyond z_0 level. The following expression has been obtained for a semi-infinite and homogenous soil.

$$\Delta\sigma_V = \frac{\alpha_e}{0.5}\frac{q}{\pi}\left(arctan\left(\frac{hL}{x(x+L)+h^2}\right)+\frac{xh}{x^2+h^2}-\frac{(x+L)h}{(x+L)^2+h^2}\right)$$

with $h = z - z_0$



An amplifier factor has to be considered for taking into account the "mirror effect" induced by the sheet wall. Its value can be estimated with following expression:

$$\alpha_e \approx \frac{x+2}{x+1}$$

2.4.3. Linear and distributed loads

Horizontal components from linear and distributed loads will be added systematically at wall horizontal equilibrium. Obviously, they will influence bending moment, shear and axial load as well as horizontal displacements.

Vertical components from linear and distributed loads will be taken into account only for the vertical equilibrium.

2.4.4. Wave load (Sainflou method, PIANC)

Sainflou method for <u>fully reflected standing waves</u> has been integrated into Prosheet. This method is based on PIANC report MarCom/WG 28 -2003). A wizard is available with following input data:

Category / Property		Metric (SI)	Imperial	Description
Geometry				
Top level	Z_{Top}	m	ft	Top level of sheet wall
Water level at the front	$Z_{w,front}$	m	ft	Water level on the front of the wall
Seabed level	Z_{Seabed}	m	ft	Seabed level on the front of the wall
Wave data				
Period	T	s	s	Period of the wave
Height	H	m	ft	Wave height
Angle of incidence	θ	°	°	Angle of incidence of the wave

Computed values:

- Water depth on the front of the wall: $d = z_{w,front} - z_{Seabed}$ m, ft
- Wave length: $L = \frac{gT^2}{2\pi}\sqrt{\tanh\left(\frac{4\pi^2 d}{T^2 g}\right)}$ m, ft
- Rise of water level: $\delta_0 = \pi H^2 \coth(2\pi h_s / L)/L$ m, ft
- Influence of oblique wave incident: $\alpha = 0.50(1+\cos\theta)$ °
- Additional water pressure from wave action: $P_1 = \alpha \frac{(P_2 + \gamma_w h_s)(H+\delta_0)}{(H+\delta_0+h_s)}$ kN/m², ksf
- Pressure increase at seabed level: $P_2 = \alpha \frac{\gamma_w H}{\cosh\left(\frac{2\pi h_s}{L}\right)}$ kN/m², ksf
- Additional water pressure from wave action: $P_3 = \alpha\gamma_w (H - \delta_0)$ kN/m², ksf

Every wave pressure diagram is applied separately.

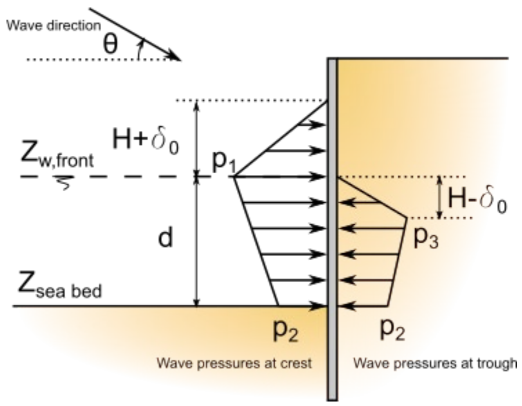


Figure 12. Wave load (Sainflou method, PIANC)

2.5. Seismic conditions

2.5.1. Mononobé-Okabé (1924) approach

Mononobé-Okabé (1924) pseudo-static approach is integrated in Prosheet according to Eurocode 8, which consists to:

- Reassess active (p_a) and passive (p_b) earth pressures on each side of the sheet pile taken into account inertial forces in the soil.
- Reassess water pressure taken into account hydrodynamics effects only where the soil is defined like “open” in seismic situation or where there is no soil but only water.
- Take into account wall inertial forces $F_H = k_H \times W_{wall}$ related to the wall weight $W_{wall.}$ One may choose whether consider this inertial force or not (not taken into account by default).

Input values (Eurocode 8 - §7.3.2.2):

- k_h horizontal seismic coefficient
- k_v vertical seismic coefficient

Four combinations are automatically exanimated:

- $+k_h\ ,\ +k_v$
- $+k_h\ ,\ -k_v$
- $-k_h\ ,\ +k_v$
- $-k_h\ ,\ -k_v$

2.5.1.1. Types of soil behaviour under seismic conditions

According to Eurocode 8 – Part 5, three types or modes of behaviour soil exist in seismic situation: dry soil, “open” soil and “closed” soil. Following table shows the shear stress components to taking into account for each type:

EN 1998-5 Annex E §	**Case**	**Type of behaviour**	**Soil weight**	$tan\theta$
E.5	Water table below retaining wall	Dry	$\gamma^* = \gamma$	$\frac{k_h}{1 \pm k_v}$
E.6	Dynamically imperious soil below the water table	Closed	$\gamma^* = \gamma - \gamma_w$	$\frac{\gamma}{\gamma - \gamma_w} \cdot \frac{k_h}{1 \pm k_v}$
E.7	Dynamically (highly) pervious soil below the water table	Open	$\gamma^* = \gamma - \gamma_w$	$\frac{\gamma_d}{\gamma - \gamma_w} \cdot \frac{k_h}{1 \pm k_v}$

Where:

- θ equivalent seismic obliquity (Eurocode 8 – Annex E - §E.5, E.6 and E.7)
- γ^* γ unit weight of soil
- γ saturated unit weight of soil
- γ_d dry unit weight of the soil (non submerged)
- γ_w unit weight of water

2.5.1.2. Modification of active earth pressure (Eurocode 8 – Annex E - §E.4)

Seismic effect implies a reduction of available shear strength, so a dynamic increase of active earth pressure has to be considered.

- Si $\beta \leq \phi'_d - \theta$:

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

- Si $\beta > \phi'_d - \theta$:

$$K = \frac{\sin^2(\psi + \phi - \theta)}{\cos\theta \sin^2\psi \sin\left(\psi - \theta - \delta_d\right)}$$

Increment of active earth pressure is evaluated as difference of the effect of seismic conditions defined by the user and null seismic conditions. Then, this dynamic increment will be added to the static active pressure.

2.5.1.3. Modification of passive earth pressure (Eurocode 7 – Annex E - §E.4)

Seismic effect implies a reduction of available shear strength, so a dynamic reduction of passive earth pressure has to be considered.

$$K = \frac{\sin^2\left(\psi + \phi'_d - \theta\right)}{\cos\theta \sin^2\psi \sin(\psi + \theta)\left[1 - \sqrt{\frac{\sin\phi'_d \sin\left(\phi'_d + \beta - \theta\right)}{\sin(\psi + \beta)\sin(\psi + \theta)}}\right]^2}$$

Increment of passive earth pressure will be evaluated as difference of the effect of seismic conditions defined by the user and null seismic conditions. Then, this dynamic increment will be added to the static passive pressure.

2.5.1.4. Cohesion effect

Cohesion effect will be evaluated with following expressions:

$$k_{acd} = -2c\sqrt{k_{a\gamma d}} \text{ and } \qquad k_{pcd} = 2c\sqrt{k_{p\gamma d}}$$

$k_{a\gamma d}$ and $k_{p\gamma d}$ will be evaluated with expressions shown in §2.5.1.2 and §2.5.1.3.

2.5.1.5. Hydrodynamic effects (Westergaard model)

Hydrodynamic effects are taken into account where water is considered like "free" (where soil is considered like "open"/"very permeable" or where there is no soil). This effect will be taken into account only for the main wall.

There are 2 checkbox (only available for the main wall in case of double wall project):

- ✓ Hydrodynamic effects on the left side (selected by default)
- ✓ Hydrodynamic effects on the right side (not selected by default, only if the soil is very permeable)

Under seismic conditions, static water pressure is increased only where water is considered like free:

$$u_w\big|_{\text{static+dynamic}} = u_w\big|_{\text{static}} \pm \Delta u_{wd} \qquad \text{with} \qquad \Delta u_{wd}(z) = \frac{7}{8} k_h \gamma_w \sqrt{hz}$$

Where: z distance from the water level to the calculation level

h height of water over all concomitant open soils in contact with each other.

For each "open" soil layer (i), h will be deduced with following expression: $h = h^i_{ref,top} - h^i_{ref,bottom}$

$h^i_{ref,top}$ Maximum level between the first soil layer from group of "open" soil layers and water table (input value)

$h^i_{ref,bottom}$ Bottom level of the last soil layer from group of "open" soil layers (input value)

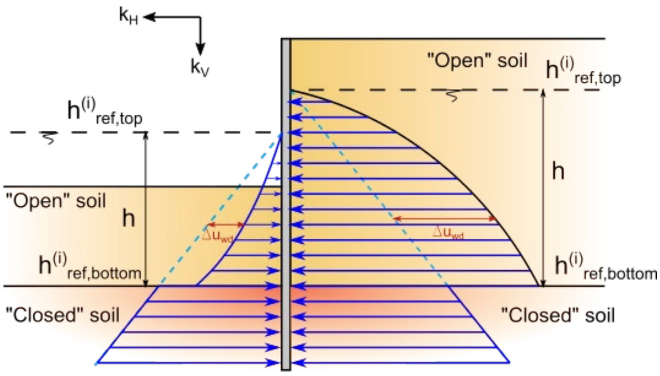


Figure 13. Westergaard model

2.5.2. Lancellotta (2002) approach

Lancelotta (2002) approach is based on the revaluation of active and passive earth pressure coefficients with following formulas. Seismic active earth pressure coefficient will be provided by Mononobe-Okabé formula.

Obliquity: $\theta = \tan^{-1}\dfrac{k_h}{1 \pm k_v}$

Slope of the soil: $\varepsilon^* = \varepsilon - \theta$

Soil weight: $\gamma^* = \gamma\sqrt{(1 \pm k_v)^2 + {k_h}^2}$

Seismic passive earth pressure coefficient: $K_{PE} = \left[\dfrac{\cos\delta}{\cos(\varepsilon-\theta) - \sqrt{\sin^2\phi - \sin^2(\varepsilon-\theta)}} \cdot \left(\cos\delta + \sqrt{\sin^2\phi - \sin^2\delta}\right)\right] e^{2\theta \mathrm{ta}}$

Where: $2\theta = \sin^{-1}\left(\dfrac{\sin\delta}{\sin\phi}\right) + \sin^{-1}\left[\dfrac{\sin(\varepsilon-\theta)}{\sin\phi}\right] + \delta + (\varepsilon - \theta) + 2\theta$

2.6. Verification of the anchor block stability (Kranz)

2.6.1. Calculation method

Single supported walls and anchor wall uses block soil strength to stabilise the system.

Block soil stability has to be checked under anchor action.

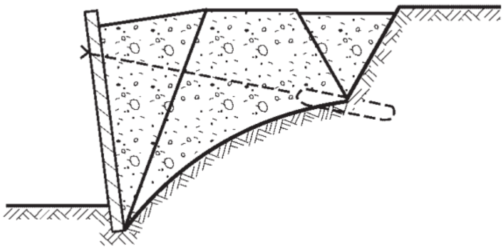


Figure 14. Anchor block soil failure

Kranz method is currently used and proposed by French standard of Eurocode 7 (NF P 94-282). The aim is to calculate the maximal anchor reaction: T value for which limit state is reached. Then, the effective anchor reaction is compared to maximal value. According to the Eurocodes, effective anchor reaction value (effort needed to ensure the wall equilibrium) has to be increased and resistance value (maximal anchor reaction for which limit state is reached) has to be reduced to obtain design values. Finally, safety factor is deduced from the comparison of design values.

Block soil is defined by a polygon ABCD:

- **A** top level of the wall or natural ground top level.
- **D** level where shear is null
- **C** effective anchorage point of anchor
- **B** vertical projection of point C

External loads applied on the block soil:

- T_u anchor reaction
- P_1 wall reaction, equal to earth pressure on [AD]
- P_2 active earth pressure applied at the back of [BC]
- W block weight
- F_e sum of deadweight/permanent external loads applied on the block
- R_c available shear strength generated by cohesion contribution on [CD]
- R_f available shear strength generated by friction contribution on [CD]

In order to calculate T force (maximal anchor reaction for which limit state is reached), we consider horizontal and vertical loads equilibrium.

$$\vec{R_c}+\vec{R_f}+\vec{W}+\vec{F_e}+\vec{P_1}+\vec{P_2}+\vec{T}=\vec{0}$$

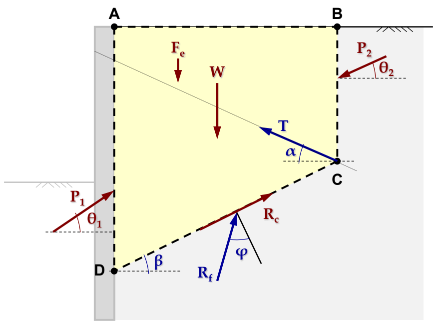


Figure 15. Balance of all efforts applied on the anchorage block soil (Kranz)

2.6.2. Take into account seismic conditions

In order to take into account seismic conditions in the analysis of block soil stability, one may include inertial forces in the equilibrium of block soil, in particular:

- Increase of active earth pressure at the back of [BC]
- Vertical inertial force as a function of block soil weight
- Horizontal inertial force as a function of block soil weight

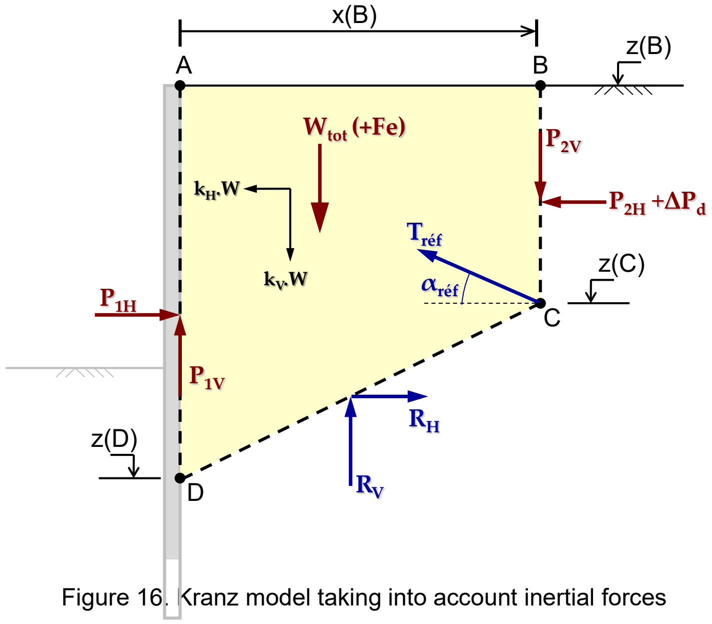


Figure 16. Kranz model taking into account inertial forces

Obviously, equilibrium resolution shows clearly the negative effect of seism on the anchor block soil stability. Consequently, safety factor will be smaller than in static situation.

Absolute values of k_H and k_V are considered as an input. Four combinations are computed automatically:

- $+k_H$, $+k_V$
- $+k_H$, $-k_V$
- $-k_H$, $+k_V$
- $-k_H$, $-k_V$

2.6.3. Anchor wall system case

Kranz model has been adapted to anchor wall system case:

- Geometry: anchor wall will be considered back edge of block soil and point C will be defined by the bottom level of the anchor wall.
- Active earth pressure at the back (P2) is considered as sum of all external loads applied at the back of anchor wall and differential water pressure:

$$\vec{P}_2 = \vec{P}_{2,sol} + \vec{P}_{w,diff}$$

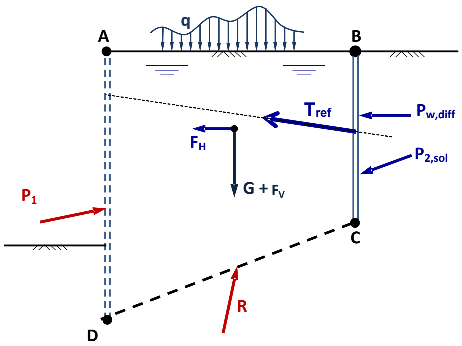


Figure 17. Anchor wall system case (Kranz)

2.7. Vertical equilibrium check

Vertical equilibrium check consists to evaluate the direction of the vertical resulting force applied to the wall, equal to the sum of all vertical components loads applied to the wall. In addition, this check allows validating inclination of active and passive earth pressure.

For cantilever walls, inclination of counter passive earth pressure is modifiable by the user in soil parameters to adapt its value and satisfy vertical equilibrium.

Vertical resulting force direction could be:

- Upwards: in this case, inclination of active and passive earth pressure has to be rectified.
- Downwards: in this case, reached value could be used to check soil-bearing capacity.

Vertical resulting force value will be computed from the following general expression:

$$Rv_d = P_d + Pv_d + Fv_d + Tv_d$$

Where:

P_d total weigh of the wall

P_{Vd} design value of resulting earth pressures

F_{Vd} design value of the resulting external loads applied to the wall

T_{Vd} design value of the resulting anchor reaction