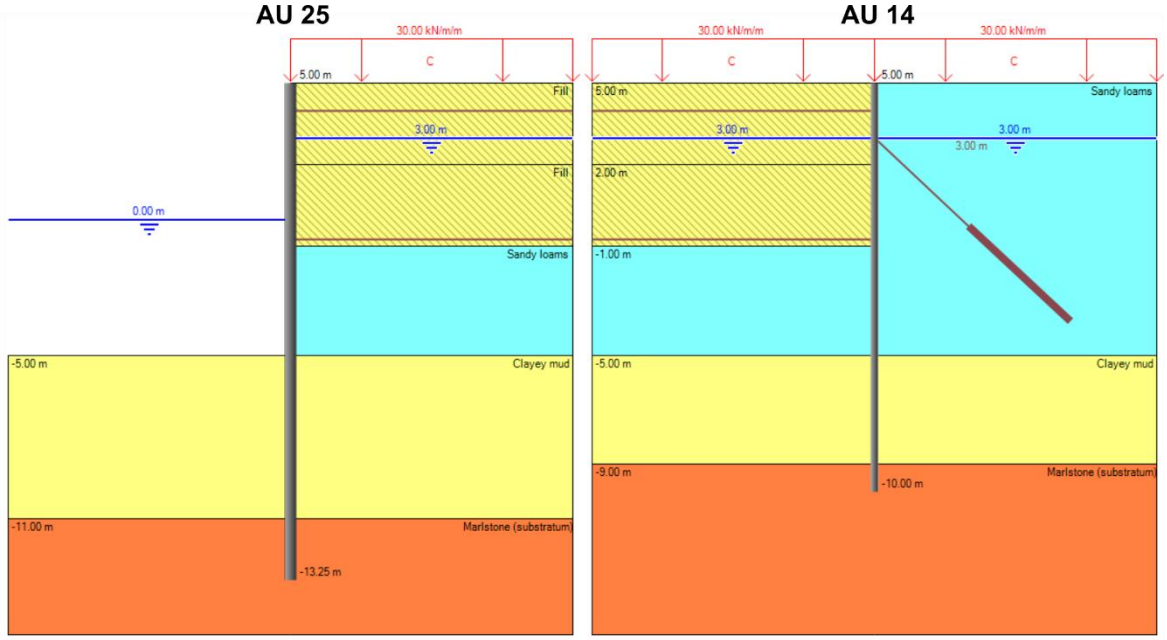
Durability

C. Examples

1. Quay wall in a marine environment

1.1. Description

This example shows a quay wall in a marine environment located in Great Britain. Service life of the structure is 50 years.



AU 25 S 320 GP (head wall) and **AU 14 S 460 AP** (anchor wall) sections have been chosen in the design with a Subgrade Reaction Model (SSIM method implemented on AMRetain). The walls are separated by a distance of 12 m. An anchor is placed at the back of the anchor wall to hold it in place during the temporary stage construction.

The most significant load levels are as follows:

AU 25					AU 14				
z	**M_{Ed}**	**V_{Ed}**	**N_{Ed}**	**e**	**z**	**M_{Ed}**	**V_{Ed}**	**N_{Ed}**	**e**
m	kNm/m	kN/m	kN/m	mm	m	kNm/m	kN/m	kN/m	mm
2.00	37	-5	27	33	3.00	-118	94	97	6.3
-0.75	-191	317	68	38	-0.75	360	275	125	17
-4.40	389	-9	140	41	-7.00	123	2	120	0.3
-11.20	-330	-7	207	2.45					

We assume there is no corrosion protection.

Corrosion rates are according to the EN 1993-5, Table 4.1 and 4.2.

For AU 25:

- Front corrosion zone: *Sea water in temperate climate in the zone of permanent immersion or in the intertidal zone*
- Back corrosion zone: *Undisturbed natural soils*

Total cumulated loss of steel thickness is 1.75 mm (front) + 0.60 mm (back) = 2.35 mm with a standard steel grade.

For AU 14:

- Front corrosion zone: *Undisturbed natural soils*
- Back corrosion zone: *Undisturbed natural soils*

Total cumulated loss of steel thickness is 0.60 mm (front) + 0.60 mm (back) = 1.20 mm with a standard steel grade.

The Sheet Pile steel sections considered in this example will be verified according to ASD (Allowable Stress Design) and Eurocode 3-5.

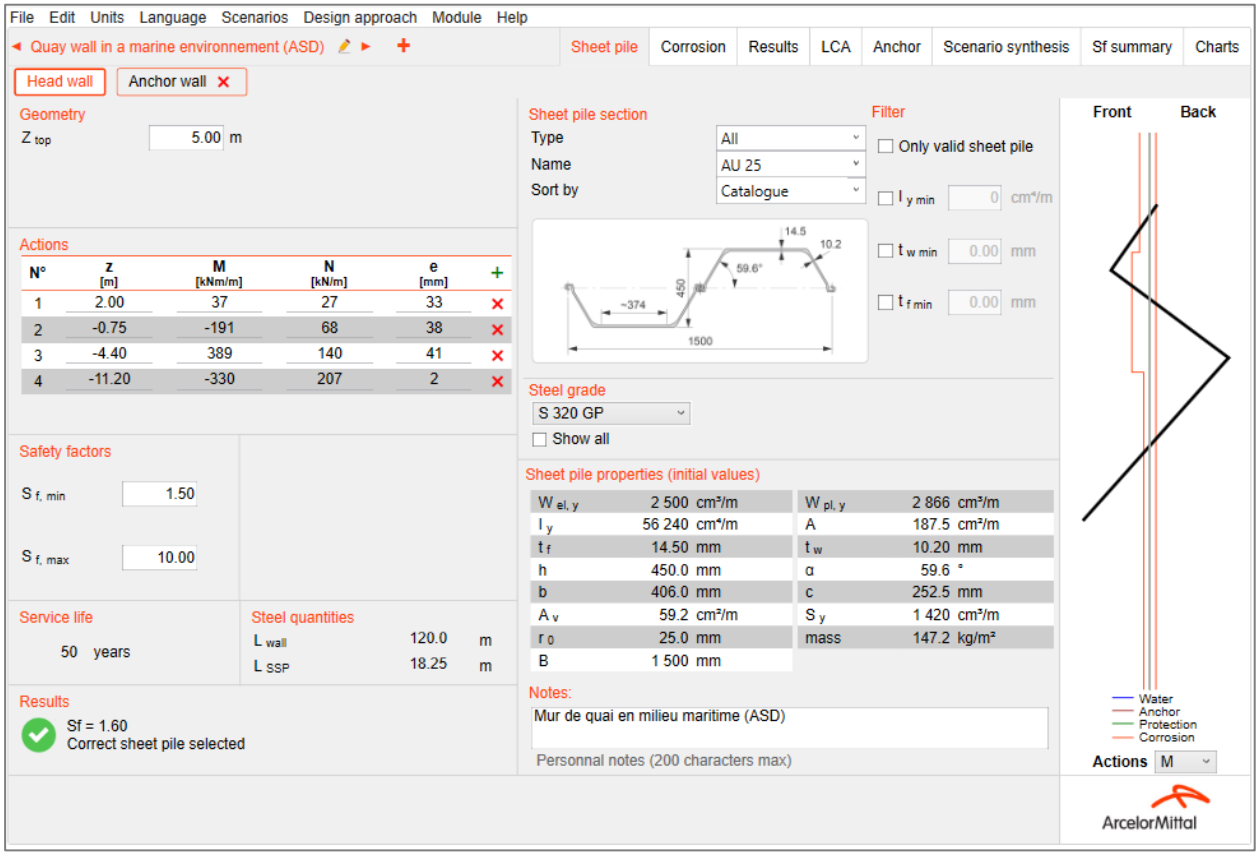
Durability allows to run several calculations simultaneously in the same project, introduced under the form of *Scenarios*, and allows to compare their results. ASD approach will be defined in the first scenario and Eurocode 3-5 in the second one.
Scenario synthesis tab will summarize the results for each scenario.

Definition steps:

1. First of all, one has to choose the project geometry, the sheet pile section and its steel grade, define the loads and partial safety factors in **Sheet pile** tab.
2. After defining the Structure Service Life, one has to define the corrosion to be applied in **Corrosion** tab: either use Eurocode tables or manual definition (rates or total loss)
3. Finally, all numerical results are shown in **Results** tab for each loading level defined previously.

1.2. ASD approach

Head wall definition and calculation:



File Edit Units Language Scenarios Design approach Module Help

Quay wall in a marine environnement (ASD) | Sheet pile | Corrosion | Results | LCA | Anchor | Scenario synthesis | Sf summary | Charts

Head wall | Anchor wall

Corrosion rates

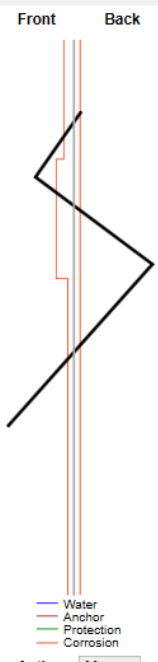
Show table

Eurocode 3 - Part 5

Manual

Eurocode 3 - Part 5. Table 4.1 and 4.2

Zone	z bottom [m]	Corrosion front [mm]	Corrosion back [mm]	Protection Front [years]	Protection Back [years]	Total corrosion Front [mm]	Total corrosion Back [mm]
1	3.00	Atm. Locations close to the se: 1.00	Soil. Compacted and non-aggr 0.60	0	0	1.00	0.60
2	0.00	Atm. Locations close to the se: 1.00	Soil. Compacted and non-aggr 0.60	0	0	1.00	0.60
3	-5.00	Water. Sea water in temperate 1.75	Soil. Compacted and non-aggr 0.60	0	0	1.75	0.60
4	-18.25	Soil. Compacted and non-aggr 0.60	Soil. Compacted and non-aggr 0.60	0	0	0.60	0.60



Actions M

ArcelorMittal

File Edit Units Language Scenarios Design approach Module Help

Quay wall in a marine environnement (ASD) | Sheet pile | Corrosion | Results | LCA | Anchor | Scenario synthesis | Sf summary | Charts

Head wall | Anchor wall

Results

N°	z [m]	ASD	S f
1	2.00	✓	16.79 > 1.50
2	-0.75	✓	3.27 > 1.50
3	-4.40	✓	1.60 > 1.50
4	-11.20	✓	2.04 > 1.50
Synthesis		✓	1.60

Section

Property	Value
f y	320.0

Selected section properties

Property	Ini.	Red.	Unit
W el, y	2 500	2 095	cm³/m
W pl, y	2 866	...	cm³/m
I y	56 240	47 020	cm⁴/m
A	187.5	156.0	cm²/m
t f	14.50	12.15	mm
t w	10.20	7.85	mm
h	450.0	447.6	mm
α	59.6	-	°
b	406.0	-	mm
c	252.5	-	mm
A v	59.2	45.6	cm²/m
S y	1 420	-	cm³/m
r 0	25.0	-	mm

Numerical details : level n°3 (z = -4.40 m)

$$\sigma_{applied} = \frac{M}{W_{el,red}} + \frac{N \cdot e}{W_{el,red}} + \frac{N}{A_{red}}$$

$$\sigma_{applied} = \frac{395\,kNm/m}{2095 \cdot 10^{-6}\,m^3/m} + \frac{140\,kN/m \cdot 0.04\,m}{2095 \cdot 10^{-6}\,m^3/m} + \frac{140\,kN/m}{156.0 \cdot 10^{-4}\,m^2}$$

$$\sigma_{applied} = = 200.1\,MPa$$

$$\sigma_{allowable} = \frac{f_y}{S_f} = \frac{320.0\,MPa}{1.50} = 213.3\,MPa$$

$$\sigma_{applied} = 200.1\,MPa \leq \sigma_{allowable} = 213.3\,MPa$$

$$S_f = 1.60 > 1.50$$

Steel quantities

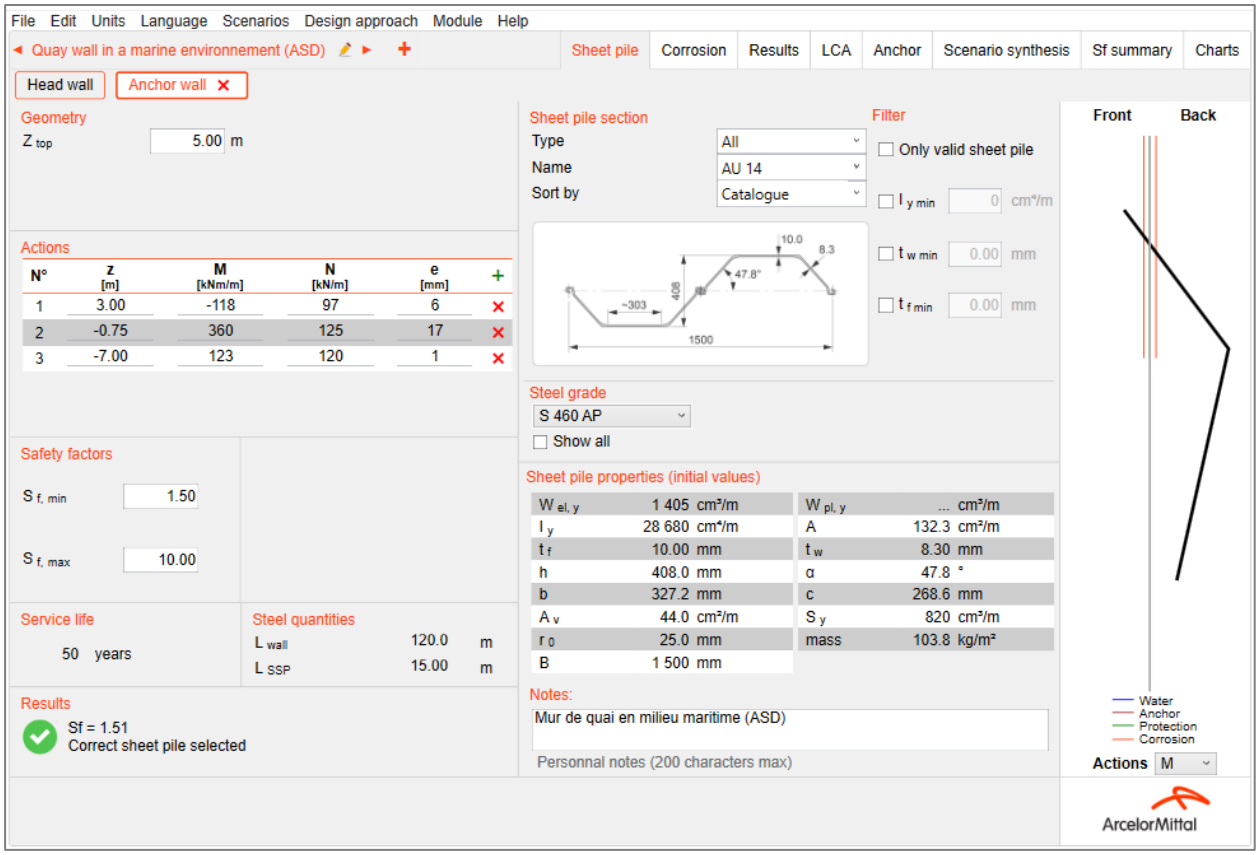
SSP pairs	80
Wall length	120.00 m
Total	322.37 t

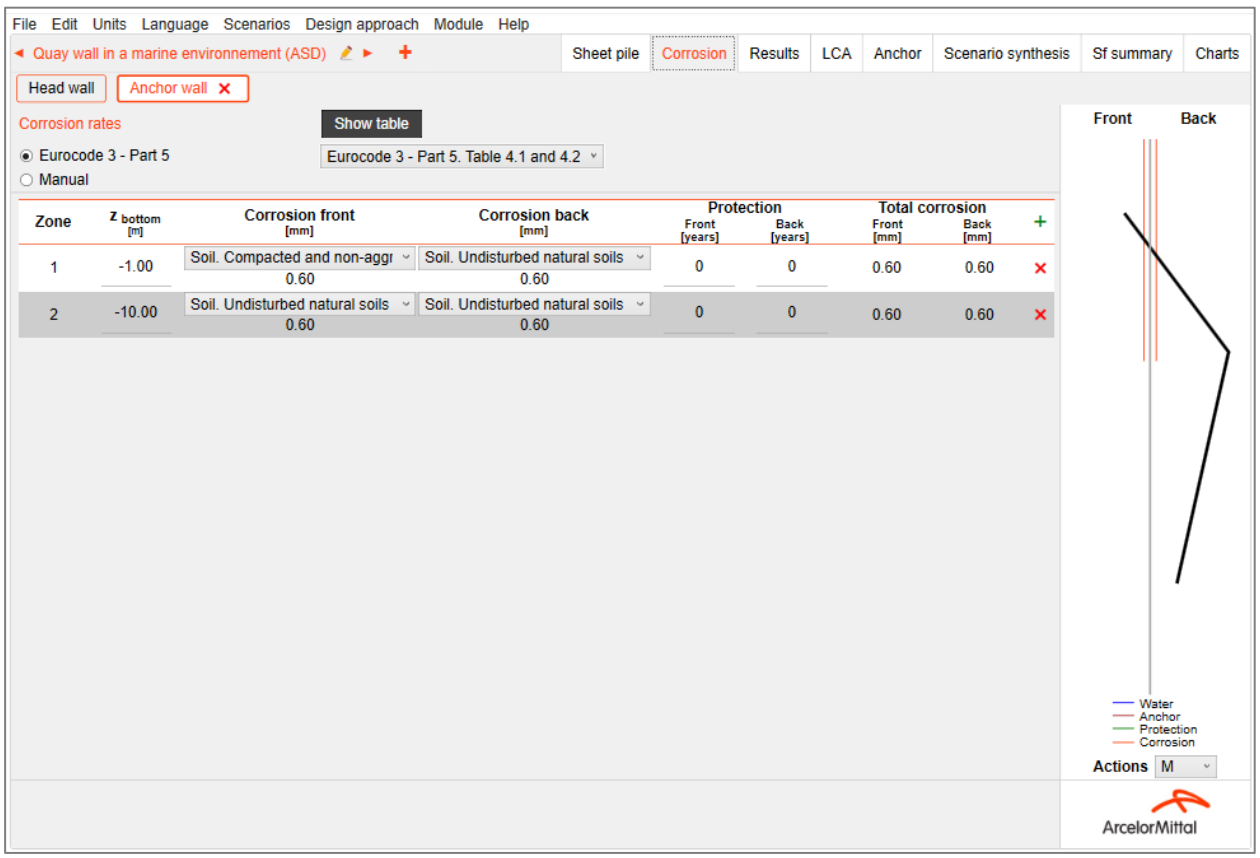
Results

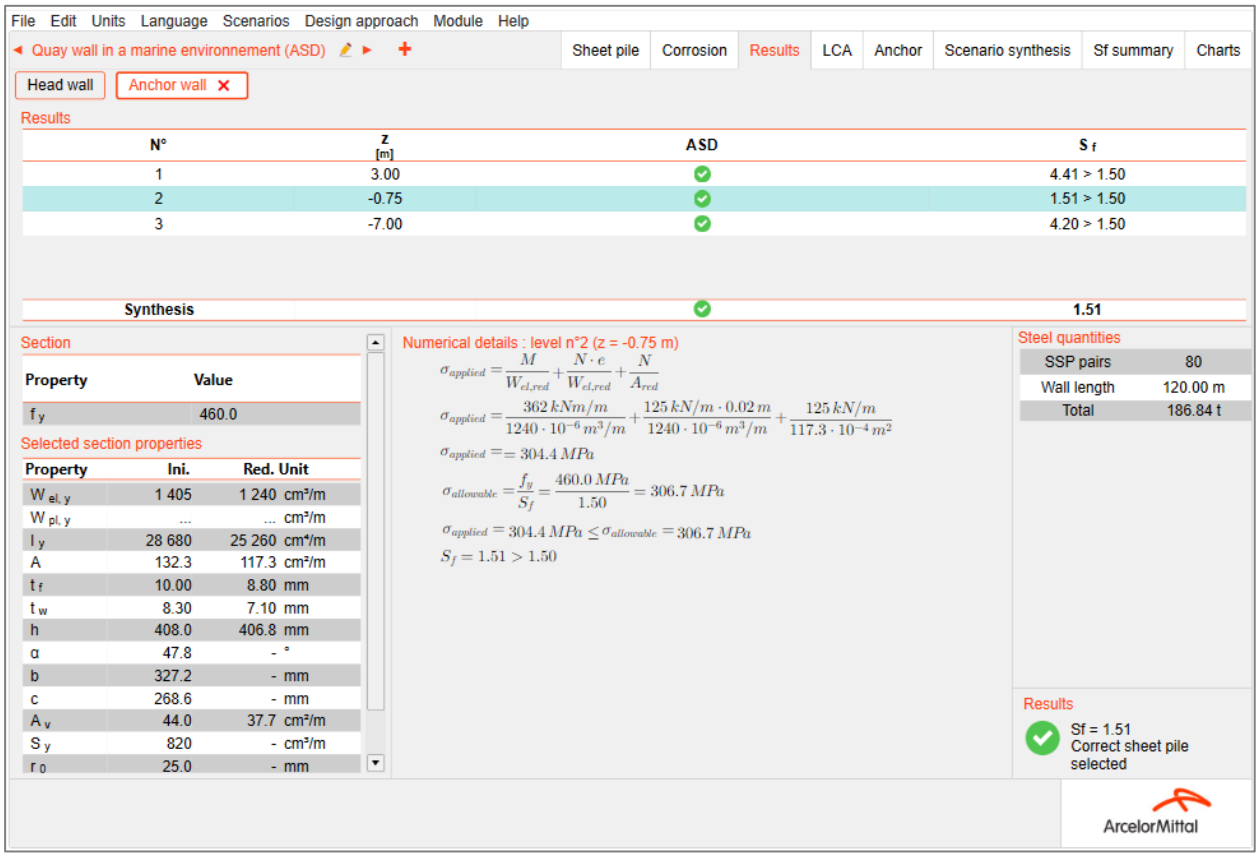
✓ Sf = 1.60
Correct sheet pile selected

ArcelorMittal

Anchor wall definition and calculation:







In conclusion, the proposed structures have a safety factor equal to 1.60 ≥ 1.50 for the head wall after 2.35 mm of loss of steel thickness, and 1.51 ≥ 1.50 for anchor wall after 1.20 mm of loss of steel thickness.

1.3. Eurocode 3 – 5

Eurocode 3-5 approach requires to consider design values of loads, which have already been multiplied in the geotechnical design (calculation done with AMRetain) by the applicable partial safety factor.

Additional calculation parameters required for head and anchor wall:

Partial safety factor	γ_{M0}	1.00
Partial safety factor	γ_{M1}	1.10
Reduction factor	β_B	0.80
Reduction factor	β_D	0.55

Table 1. Partial factors (default values)

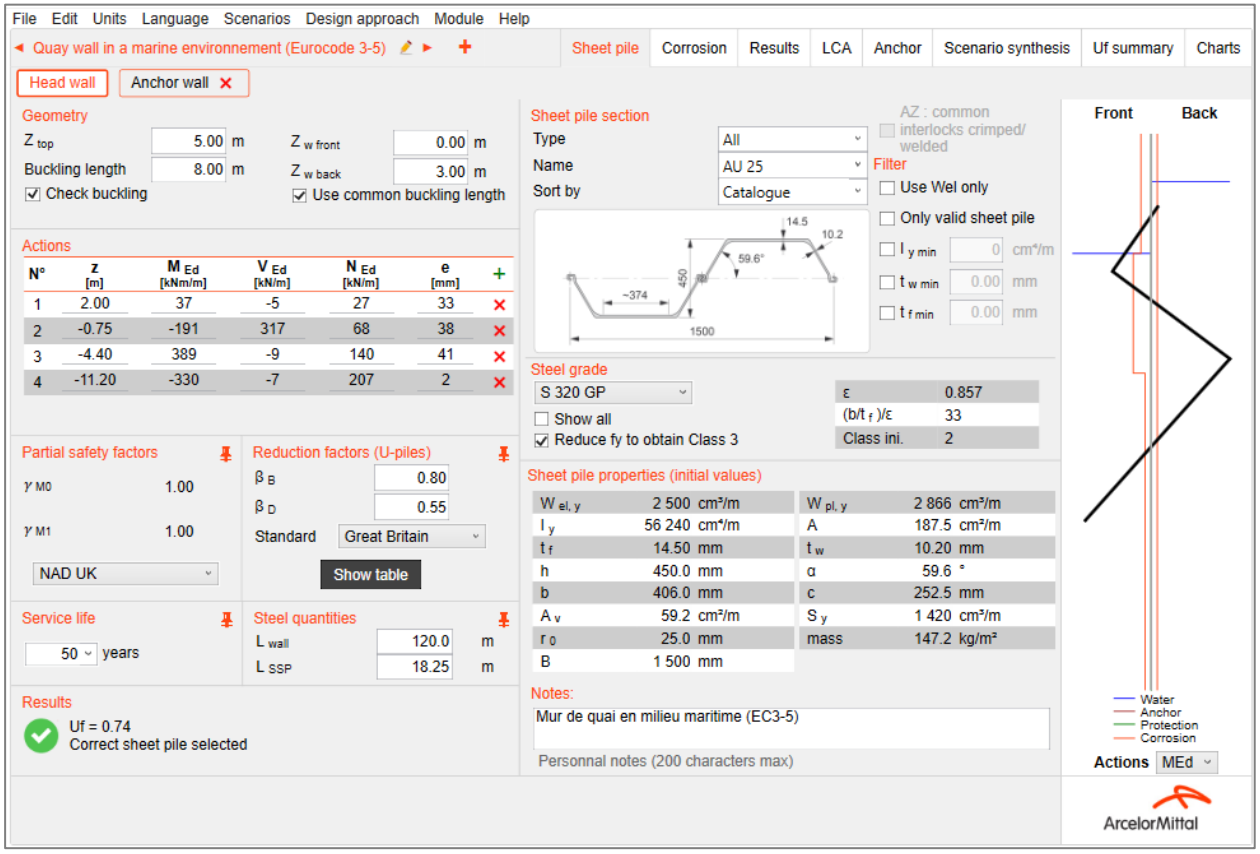
For our specific example located in Great Britain, β_B and β_D values are taken from the British Standard National Annex.

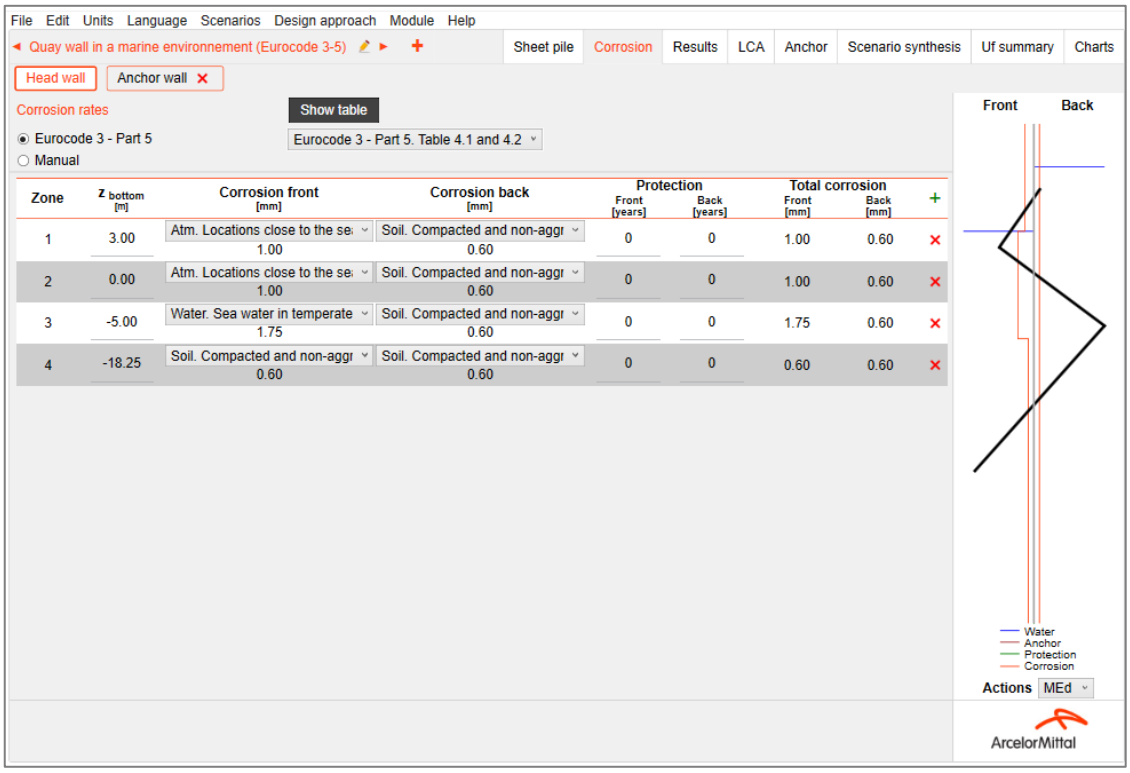
British Standards. NA to BS EN 1993-5:2007. July 2009

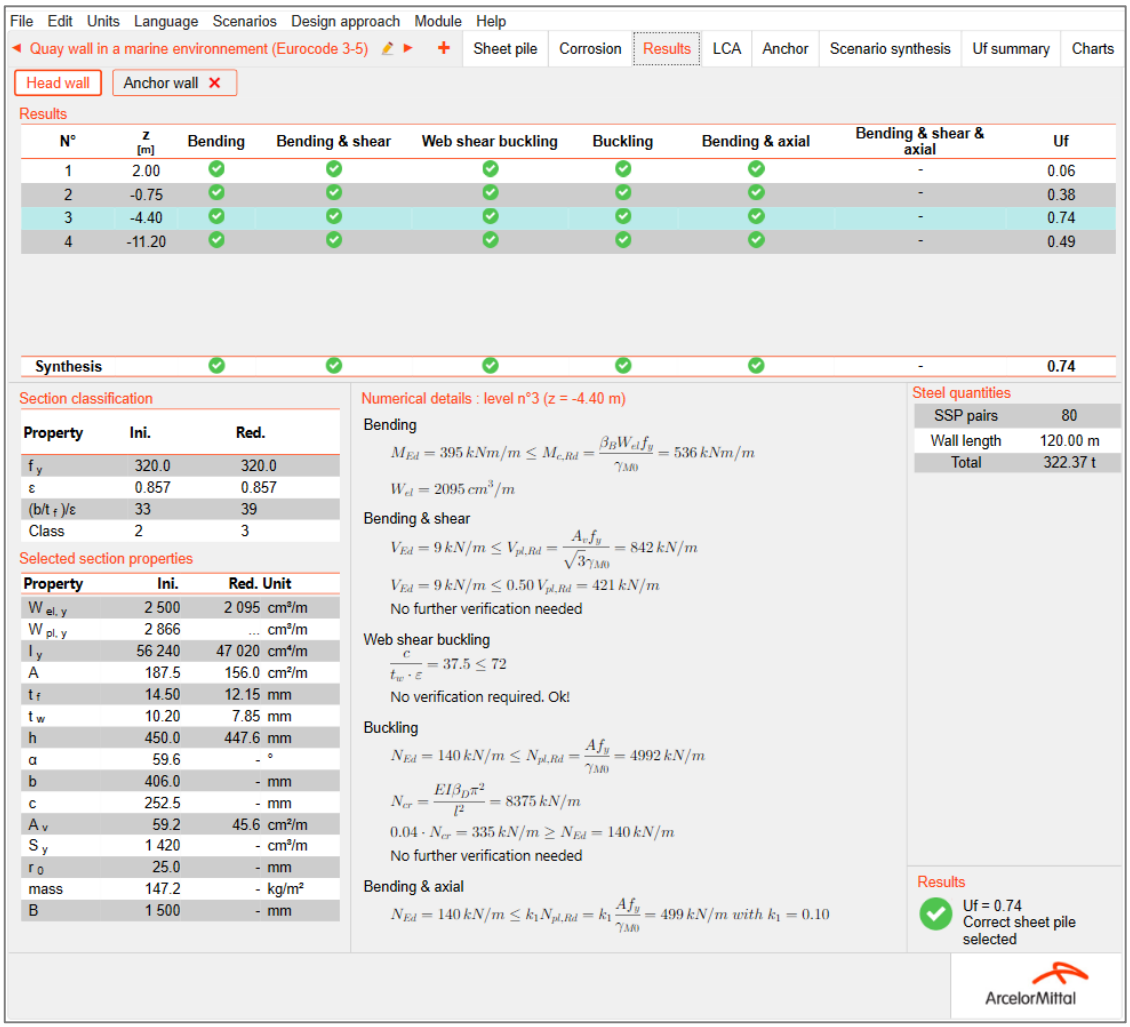
Table NA.2 Reduction factors for U shaped sheet piles.

Type of U-pile unit	Number of structural support levels (see Note 1)	Reduction factors β_B and β_D referred to in 5.2.2 (2); 5.2.2 (9); 5.2.3 (2); 6.4 (3) (see Notes 2, 3, 4, and 5)					
		Highly unfavourable conditions (see Note 6)		Unfavourable conditions (see Note 7)		Favourable conditions (see Note 8)	
		β_B	β_D	β_B	β_D	β_B	β_D
Singles or uncrimped doubles	0	0,40	0,30	0,50	0,35	0,60	0,40
	1	0,55	0,35	0,60	0,40	0,70	0,45
	>1	0,65	0,45	0,70	0,50	0,80	0,55
Crimped or welded doubles	0	0,70	0,60	0,75	0,65	0,80	0,70
	1	0,80	0,70	0,85	0,75	0,95	0,80
	>1	0,90	0,80	0,95	0,85	1,00	0,90

Head wall definition and calculation:

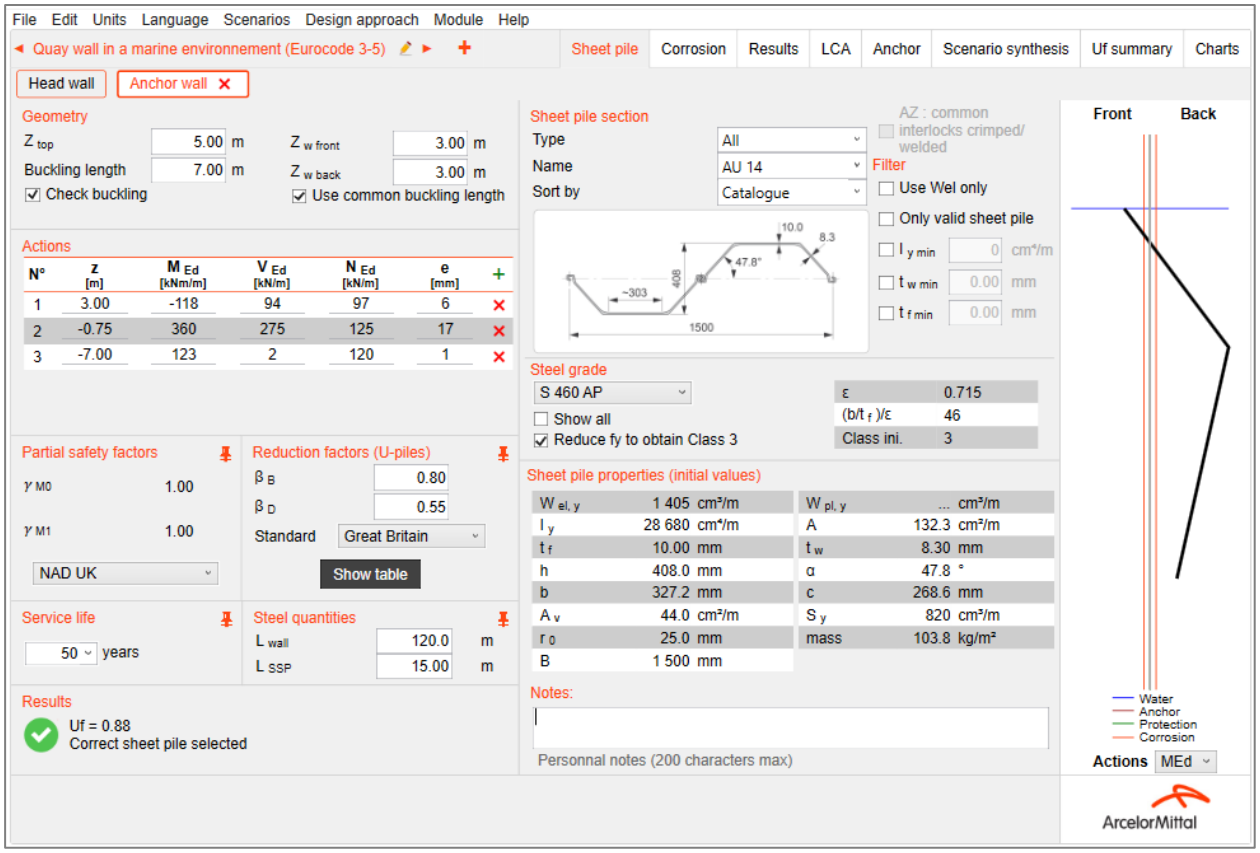


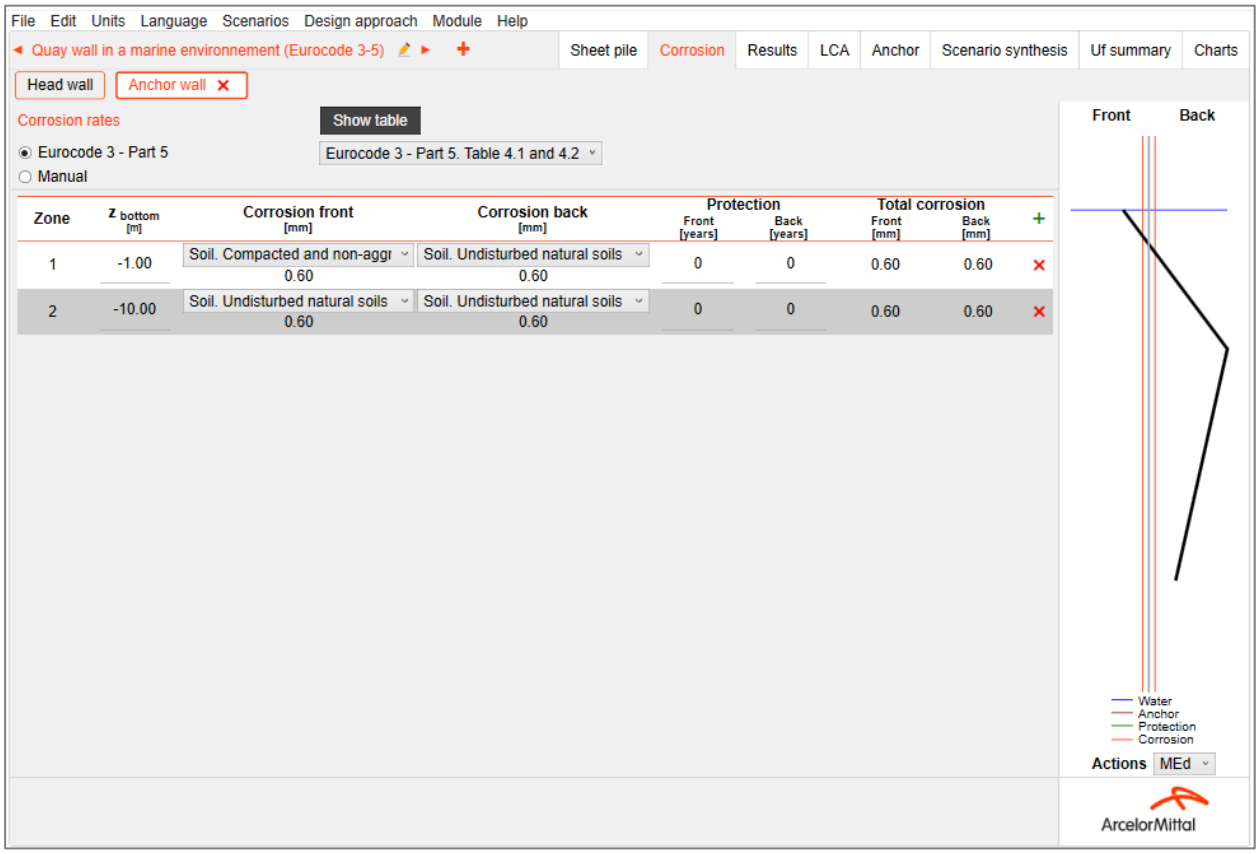




In conclusion, the head wall has an utilisation factor equal to 0.74 ≤ 1.00 after 2.35 mm of loss of steel thickness.

Anchor wall definition and calculation:





File Edit Units Language Scenarios Design approach Module Help

◄ Quay wall in a marine environnement (Eurocode 3-5) ► + | Sheet pile | Corrosion | Results | LCA | Anchor | Scenario synthesis | Uf summary | Charts

Head wall | Anchor wall ✕

Results

N°	z [m]	Bending	Bending & shear	Web shear buckling	Buckling	Bending & axial	Bending & shear & axial	Uf
1	3.00	✓	✓	✓	✓	✓	-	0.29
2	-0.75	✓	✓	✓	✓	✓	-	0.88
3	-7.00	✓	✓	✓	✓	✓	-	0.30
Synthesis		✓	✓	✓	✓	✓	-	**0.88**

Section classification

Property	Ini.	Red.	Red. class 3
f_y	460.0	460.0	416.3
ε	0.715	0.715	0.751
$(b/t_f)/\varepsilon$	46	52	49
Class	3	4	3

Selected section properties

Property	Ini.	Red.	Unit
$W_{el,y}$	1 405	1 240	cm³/m
$W_{pl,y}$	...	...	cm³/m
I_y	28 680	25 260	cm⁴/m
A	132.3	117.3	cm²/m
t_f	10.00	8.80	mm
t_w	8.30	7.10	mm
h	408.0	406.8	mm
α	47.8	-	°
b	327.2	-	mm
c	268.6	-	mm
A_v	44.0	37.7	cm²/m
S_y	820	-	cm³/m
r_0	25.0	-	mm
mass	103.8	-	kg/m²
B	1 500	-	mm

Numerical details : level n°2 (z = -0.75 m)

Bending

$$M_{Ed} = 362\,kNm/m \le M_{c,Rd} = \frac{\beta_B W_{el} f_y}{\gamma_{M0}} = 413\,kNm/m$$

$$W_{el} = 1240\,cm^3/m$$

Bending & shear

$$V_{Ed} = 275\,kN/m \le V_{pl,Rd} = \frac{A_v f_y}{\sqrt{3}\gamma_{M0}} = 906\,kN/m$$

$$V_{Ed} = 275\,kN/m \le 0.50\,V_{pl,Rd} = 453\,kN/m$$

No further verification needed

Web shear buckling

$$\frac{c}{t_w \cdot \varepsilon} = 50.4 \le 72$$

No verification required. Ok!

Buckling

$$N_{Ed} = 125\,kN/m \le N_{pl,Rd} = \frac{A f_y}{\gamma_{M0}} = 4882\,kN/m$$

$$N_{cr} = \frac{EI\beta_D\pi^2}{l^2} = 5877\,kN/m$$

$$0.04 \cdot N_{cr} = 235\,kN/m \ge N_{Ed} = 125\,kN/m$$

No further verification needed

Bending & axial

$$N_{Ed} = 125\,kN/m \le k_1 N_{pl,Rd} = k_1 \frac{A f_y}{\gamma_{M0}} = 488\,kN/m\ with\ k_1 = 0.10$$

Steel quantities

SSP pairs	80
Wall length	120.00 m
Total	186.84 t

Results

✓ Uf = 0.88
Correct sheet pile selected

In conclusion, the anchor wall has an utilisation factor equal to 0.88 ≤ 1.00 after 1.20 mm of loss of steel thickness.

1.4. Additional features

- **Scenario synthesis** tab allows to compare the different scenario results.

Scenario synthesis

Description	Calculation method	Wall	Sheet pile	Steel grade	Wall length [m]	L SSP [m]	Steel weight [t]	S f	Uf	Scenario results	Anchor results	Retained scenarios
Quay wall in a marine environnement (Eurocode 3-5)	Eurocode 3 - 5	Head wall	AU 25	S 320 GP	120.00	18.25	322.37	-	0.74	✓	-	☑
		Anchor wall	AU 14	S 460 AP	120.00	15.00	186.84	-	0.88	✓		
Quay wall in a marine environnement (ASD)	ASD	Head wall	AU 25	S 320 GP	120.00	18.25	322.37	1.60	-	✓	-	☐
		Anchor wall	AU 14	S 460 AP	120.00	15.00	186.84	1.51	-	✓		
Total	-	-	-	-	-	-	**509.21**	-	-	-	-	-

- **Sf/Uf summary** tab allows to check every sheet pile section for each steel grade and calculates either Safety factor (Sf) for ASD approach or Utilisation factor (Uf) for Eurocode 3-5 approach.

File Edit Units Language Scenarios Design approach Module Help

◄ Quay wall in a marine environnement (Eurocode 3-5) ► + | Sheet pile | Corrosion | Results | LCA | Anchor | Scenario synthesis | Uf summary | Charts

Head wall | Anchor wall ✕

Utilization factor

○ Ini.

◉ Red.

Reduction factor for AMLocor

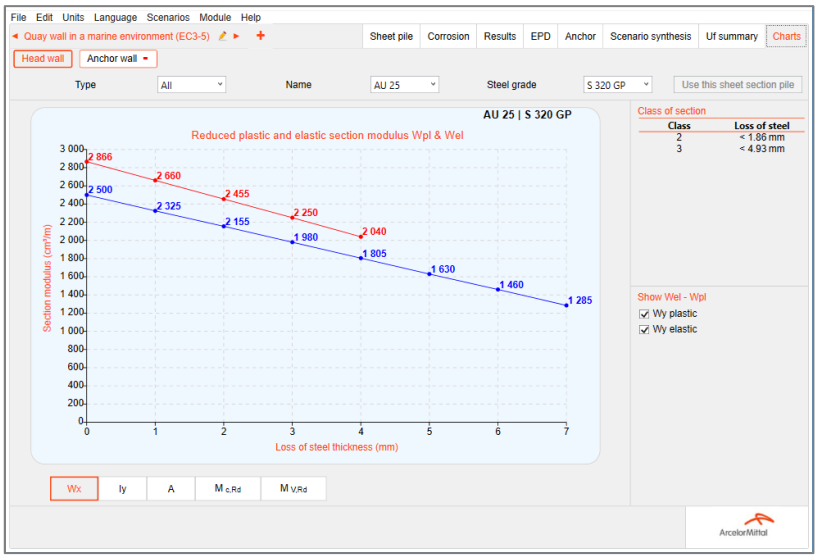
Front 1 Back 1

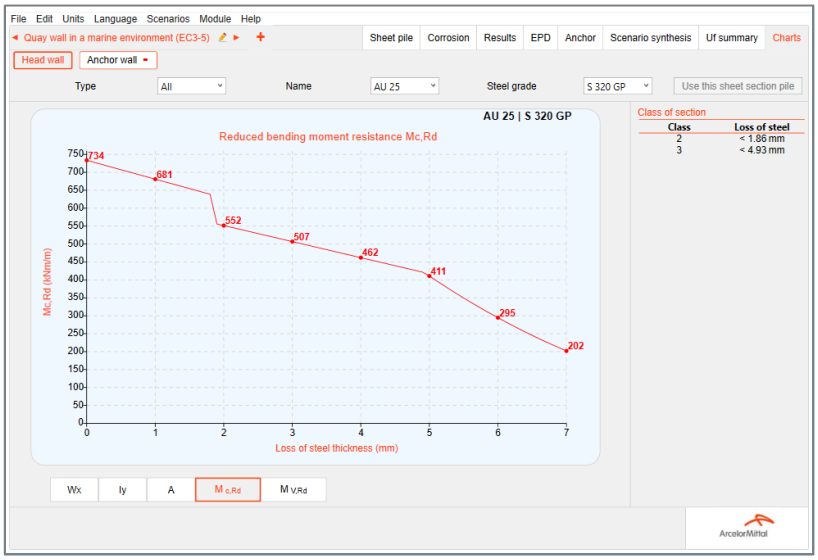
Reduction factor for A690

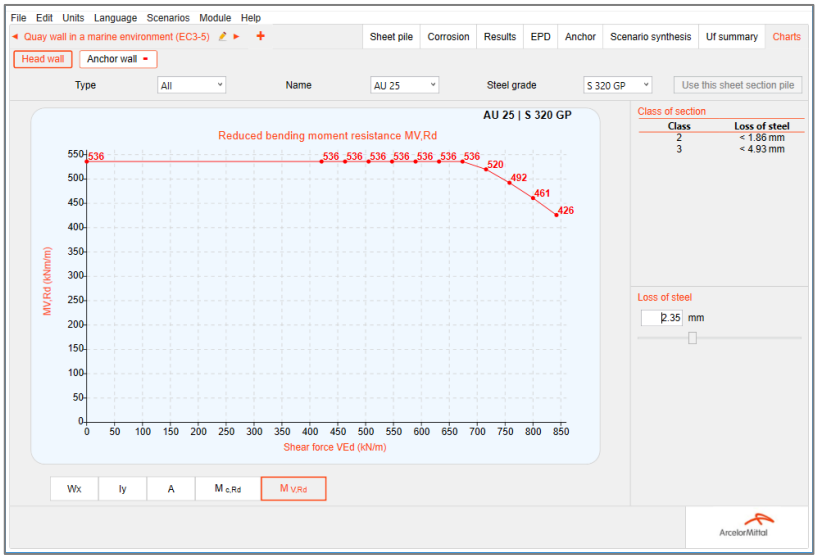
Front 1 Back 1

	S 240 GP	S 270 GP	S 320 GP	European S 355 GP	S 390 GP	S 430 GP	S 460 AP	AMLocor Blue320	AMLocor Blue355	AMLocor Blue390	A 328	A572 Gr.
AZ 18-800	0.93	0.82	0.76	0.76	0.76	0.76	0.76	°	°	°	0.82	0.76
AZ 20-800	0.84	0.75	0.63	0.57	0.54	0.54	0.54	0.63	0.57	0.54	°	0.58
AZ 22-800	0.77	0.69	0.58	0.52	0.47	0.43	0.40	°	°	°	0.69	0.54
AZ 23-800	0.62	0.55	0.54	0.48	0.44	0.40	0.37	°	°	°	0.55	0.50
AZ 25-800	0.57	0.51	0.43	0.45	0.41	0.37	0.34	°	°	°	0.51	0.46
AZ 27-800	0.53	0.47	0.40	0.36	0.33	0.34	0.32	°	°	°	0.47	0.37
AZ 28-750	0.51	0.46	0.44	0.40	0.36	0.33	0.31	°	°	°	0.46	0.41
AZ 30-750	0.47	0.42	0.36	0.32	0.34	0.31	0.29	°	°	°	0.42	0.33
AZ 32-750	0.44	0.39	0.33	0.30	0.27	0.25	0.27	°	°	°	0.39	0.31
AZ 12-770	-	-	1.02	0.92	0.84	0.76	0.73	°	°	°	-	0.95
AZ 13-770	-	-	0.98	0.88	0.80	0.73	0.68	°	°	°	-	0.90
AZ 14-770	1.05	0.93	0.93	0.84	0.76	0.69	0.65	°	°	°	0.93	0.86
AZ 14-770-10/10	1.00	0.89	0.89	0.80	0.73	0.66	0.62	°	°	°	0.89	0.83
AZ 12-700	-	-	1.05	0.95	0.86	0.78	0.77	°	°	°	-	0.98
AZ 13-700	1.09	-	0.96	0.87	0.79	0.72	0.67	°	°	°	-	0.89
AZ 13-700-10/10	1.04	0.93	0.92	0.83	0.76	0.69	0.64	°	°	°	0.93	0.86
AZ 14-700	1.00	0.89	0.75	0.80	0.73	0.66	0.62	°	°	°	0.89	0.82
AZ 17-700	0.98	0.87	0.73	0.66	0.60	0.55	0.53	°	°	°	0.87	0.68
AZ 18-700	0.93	0.83	0.70	0.63	0.57	0.52	0.49	°	°	°	0.83	0.65
AZ 19-700	0.76	0.80	0.67	0.61	0.55	0.50	0.47	0.67	0.61	0.55	0.80	0.62
AZ 20-700	0.73	0.65	0.64	0.58	0.53	0.48	0.45	0.64	0.58	0.53	0.65	0.60
AZ 24-700	0.58	0.51	0.43	0.46	0.42	0.38	0.35	°	°	°	0.51	0.40

- **Charts** tab shows graphically the reduction of the section design parameters, with the increase of the thickness loss due to corrosion. User is able to choose another sheet pile section in this tab and replace initial section previously considered.







2. Checking of the anchorage system

2.1. Description

This example aims to show how to check anchor system with Durability according to Eurocode Standards.

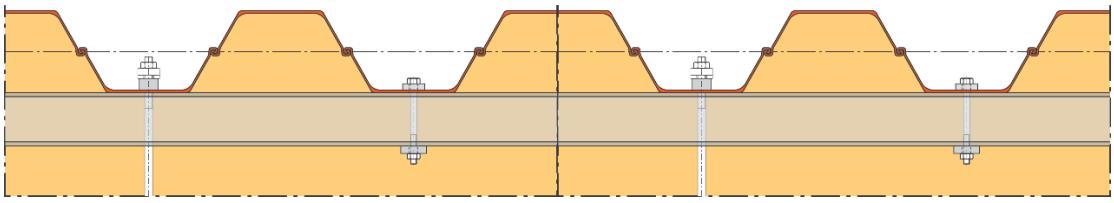
The verification of an anchoring system consists of checking the internal balance of all the steel parts used to take up the force mobilised in the anchorage (tie-rods, waling, plates, swivel plates and forces localised in the sheet pile section).

PU 18+1 S 430 GP has been chosen for head wall. No corrosion is considered.

Anchorage system is composed of:

- Waling behind head wall: **2 x UPN 260 S 235 JR, spacing = 286 mm**
- An horizontal anchor every 2 sheet pile systems: **ASDO355 – M68/52**
  - Front plate
  - Swivel plate supported by bearing plate
- A bolt between 2 anchors fixed to hold sheet pile to the waling : **M45 – ASDO 355**
  - Front plate supported by the sheet pile
  - Back plate supported by the waling

Our case corresponds to Case 7.4 defined by Eurocode 3 – Part 5:

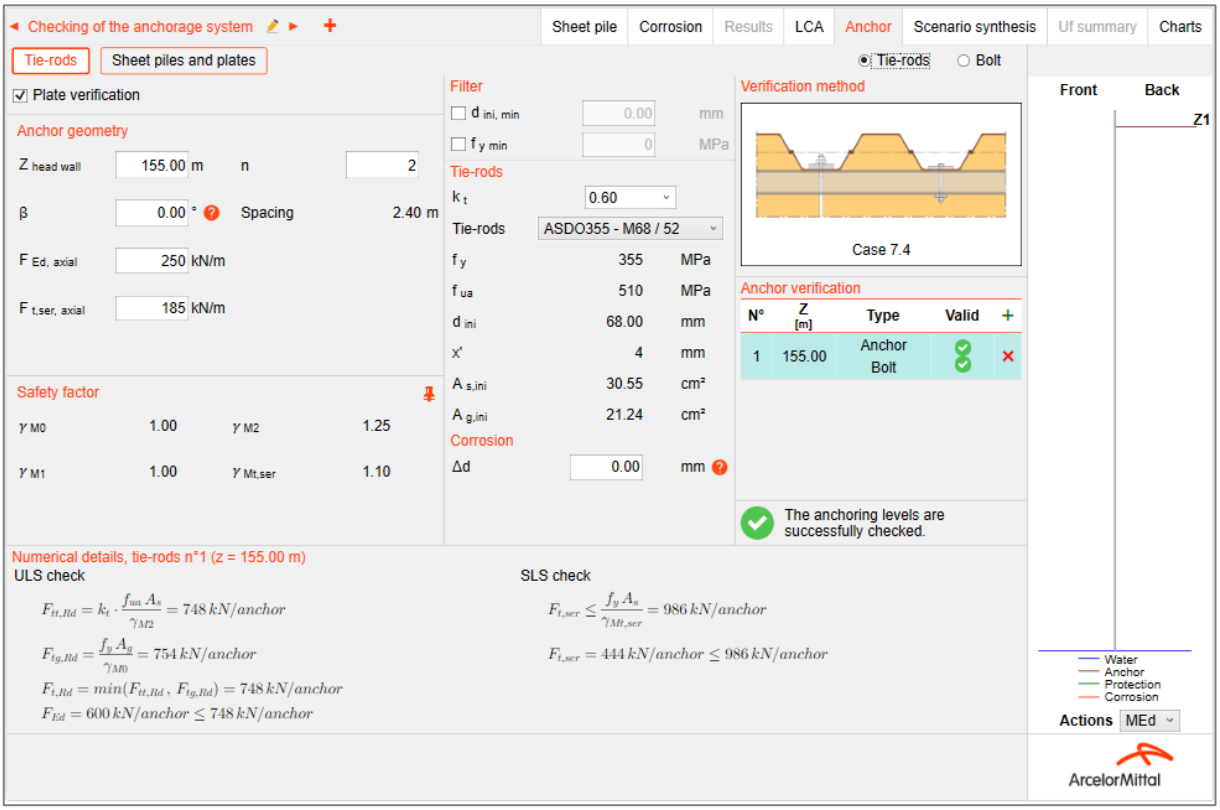


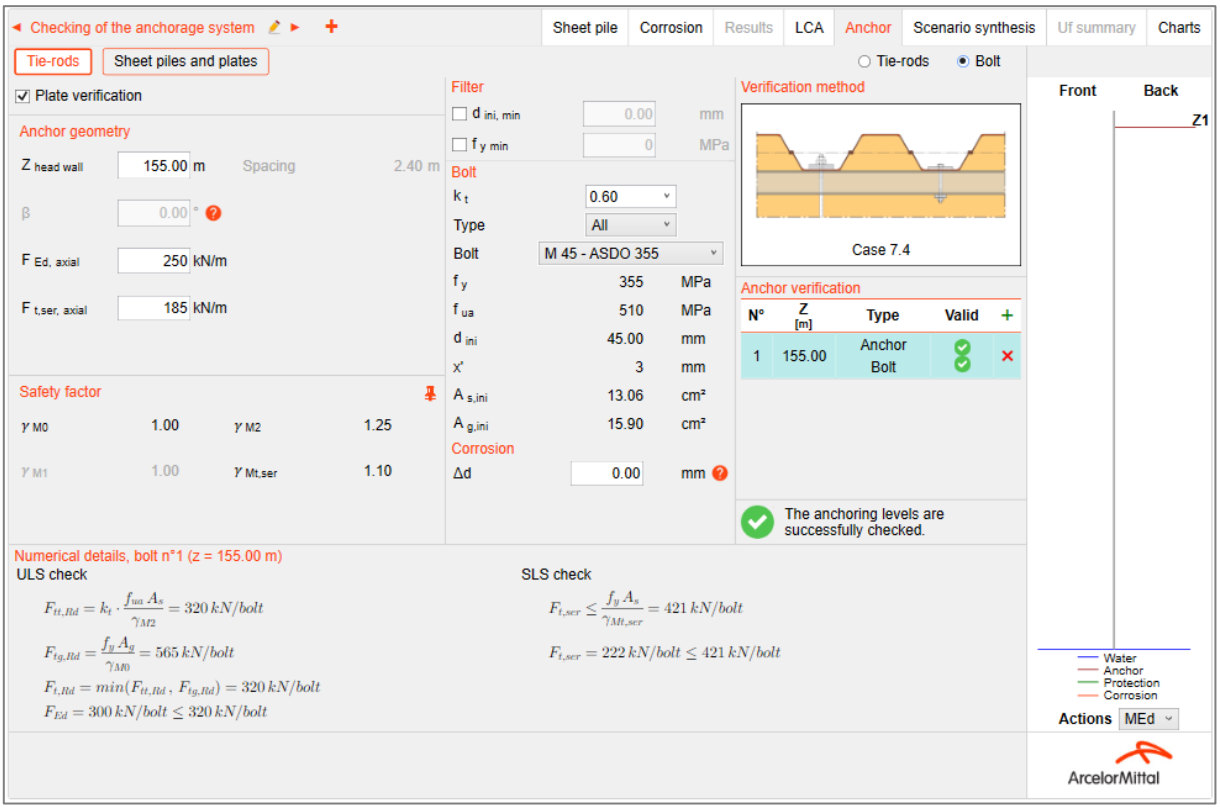
This application considers French standard for safety factor definition.

Geotechnical analysis provides tie-rod axial reaction: 250 kN/m (ULS) and 185 kN/m (SLS).

2.2. Anchor and bolt check

First of all, one has to check the anchor and bolt.



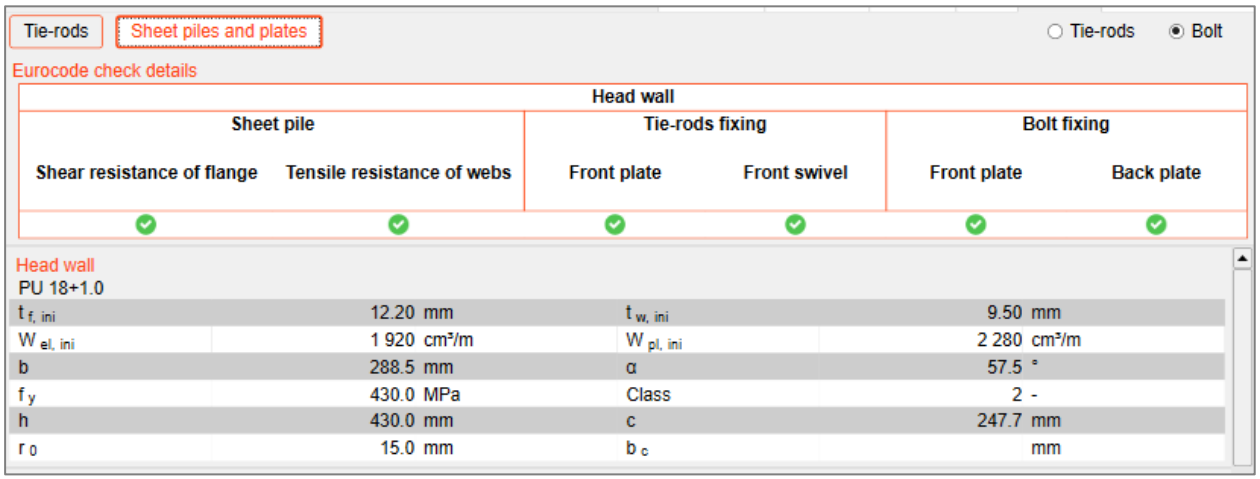


Anchor and bolt are successfully checked.

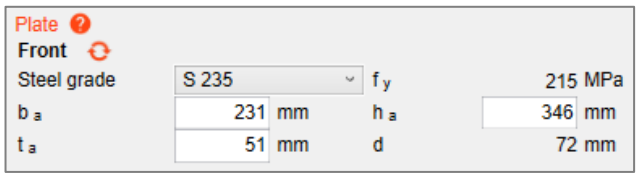
2.3. Sheet pile and plates check

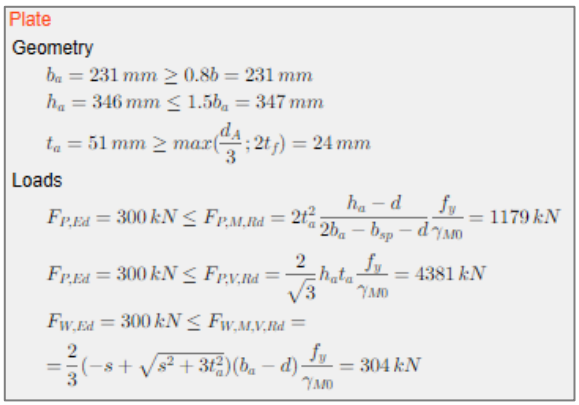
In **Sheet pile and plates** tab, one may find:

- Synthesis of all the checks to be done and sheet pile properties used in calculation:



- Front bearing plate check for anchor:

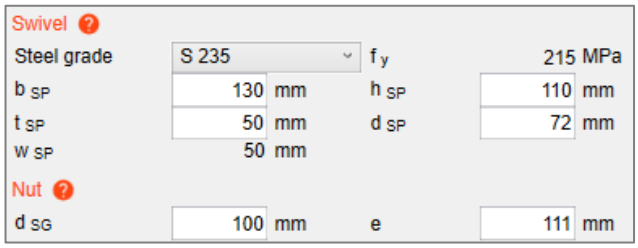


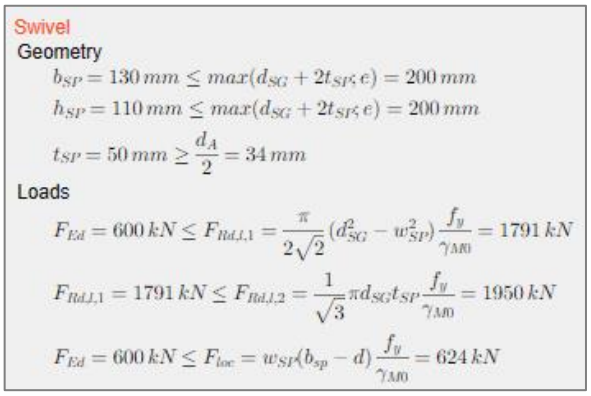


It's important to note that Durability is able to suggest plate dimensions which satisfy all requested criteria ( )

According to EN1993-1-1, steel grade have to be reduced when the plate thickness is greater than 40 mm, that's why f_y=215 MPa whereas steel grade is S 235.

- Swivel plate for anchor check:





- Bearing plates for bolt definition and check:

Plate							
Front					**Back**				
Steel grade	S 235		f_y	235 MPa	Steel grade	S 235		f_y	235 MPa
b_a	231	mm	h_a	346 mm	b_a	231	mm	h_a	346 mm
t_a	28	mm	d	48 mm	t_a	28	mm	d	48 mm
Nut					Nut				
d_{SG}	70	mm			d_{SG}	70	mm		

It's important to note that Durability is able to suggest plate dimensions which satisfy all requested criteria ( )

Front plate

Geometry

$b_a = 231\,mm \geq 0.8b = 231\,mm$

$h_a = 346\,mm \leq 1.5b_a = 347\,mm$

$t_a = 28\,mm \geq max(\frac{d_A}{3}; 2t_f) = 24\,mm$

Loads

$F_{Ed} = 300\,kN \leq F_{M,V,Rd} =$

$= \frac{2}{3}[-(b_a - d') + \sqrt{(b_a - d')^2 + 3t_a^2}](h_a - d)\frac{f_y}{\gamma_{M0}} = 313\,kN$

$F_{Ed} = 300\,kN \leq F_{Rd,1,1} = \frac{\pi}{2\sqrt{2}}(d_{SG}^2 - d^2)\frac{f_y}{\gamma_{M0}} = 678\,kN$

$F_{Rd,1,1} = 678\,kN \leq F_{Rd,1,2} = \frac{1}{\sqrt{3}}\pi \cdot d_{SG} \cdot t_a \frac{f_y}{\gamma_{M0}} = 835\,kN$

Back plate

Geometry

$b_a = 231\,mm \geq 0.8b = 231\,mm$

$h_a = 346\,mm \leq 1.5b_a = 347\,mm$

$t_a = 28\,mm \geq max(\frac{d_A}{3}; 2t_f) = 24\,mm$

Loads

$F_{Ed} = 300\,kN \leq F_{M,V,Rd} =$

$= \frac{2}{3}[-(b_a - d') + \sqrt{(b_a - d')^2 + 3t_a^2}](h_a - d)\frac{f_y}{\gamma_{M0}} = 313\,kN$

$F_{Ed} = 300\,kN \leq F_{Rd,1,1} = \frac{\pi}{2\sqrt{2}}(d_{SG}^2 - d^2)\frac{f_y}{\gamma_{M0}} = 678\,kN$

- Sheet pile check at the anchor level

Sheet pile

Shear resistance of flange (EC3-5 §7.4.3 (3a))

$R_{Vf,Rd} = 2(b_a + h_a)t_f\frac{f_y}{\sqrt{3}\gamma_{M0}} = 3495\,kN$

$F_{Ed} = 300\,kN \leq R_{Vf,Rd} = 3495\,kN$

Tensile resistance of webs (EC3-5 §7.4.3 (3b))

$R_{tw,Rd} = 2h_a t_w \frac{f_y}{\gamma_{M0}} = 2827\,kN$

$F_{Ed} = 300\,kN \leq R_{tw,Rd} = 2827\,kN$