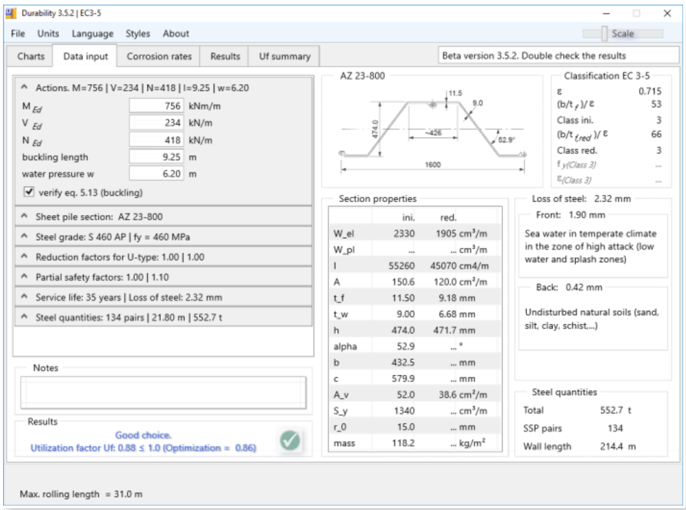
Durability 3.5.2 | User manual | August 2017

Durability is a software that simplifies the choice of a steel sheet pile section taking into account the durability of steel in different environments and the service life of the sheet pile structure. It is a simple tool, yet quite powerful in case the design is based on **Eurocode 3 – Part 5** (EC 3-5) or the **Allowable Stress Design** (ASD) method.



It is a free software that can be downloaded from ArcelorMittal's website, and it is updated on a regular basis (mainly when a sheet pile range is launched or replaced). It was developed for internal use by the technical department of ArcelorMittal Commercial RPS in Luxembourg.

Please read the disclaimer at the end of the document before using this software.

1 Purpose of the software

The software *Durability* has been developed by civil engineers for civil engineers. The key objective of the design engineer is to select the most cost-effective steel sheet pile taking into account every aspect that has an influence on the safety of the steel structure during its service life.

The geotechnical design of the structure is influenced mainly by the soil conditions, the geometry of the structure and the load combinations on the retaining structure. Depending on the chosen design method, the main parameters required for the choice of a sheet pile wall are

- bending moment
- compression load
- shear forces
- deformation and / or deflection (depends partially on the selected section)
- reduced section properties in case of loss of steel thickness

Other parameters may need to be taken into account in certain cases (for instance, buckling length in case of high compression stresses, …).

Driveability, especially in compact soils, may be an additional key parameter in the choice of the section.

The software ***Durability* has several options that will simplify the choice of the sheet pile section**.

It is limited to 'regular' hot rolled sheet piles Z- and U-type (i.e. box-piles and combined wall systems are out of scope).

Following chapters enumerate the main options and assumptions that have been implemented.

2 Design approach

Corrosion of steel is a natural phenomenon that occurs under certain conditions. In the case of steel sheet piles, the main factor having an influence on *overall* corrosion in water is the oxygen. Corrosion of steel in natural soils is almost negligible, with some exceptions, such as peat for instance. However, corrosion of steel should be considered for permanent structures in contact with water.

The best approach to estimate the loss of steel over the service life is to extrapolate from measurements on adjacent structures in similar conditions. This is possible in major ports that have been monitoring their existing steel sheet pile structures for decades, but quite often this data is not readily available or is not reliable enough.

An acceptable source for estimating the loss of steel thickness can be found in the European standard **EN 1993-Part 5, Chapter 4**. The values shown in those tables are valid for temperate climates.

There are several ways to deal with corrosion of steel. Either you try to prevent the steel from corroding, at least during a certain period, for instance by using coatings, cathodic protection. Or you **estimate the loss of steel during the service life and take it into account by reducing the section properties of the steel sheet pile**. This last approach is sometimes also referred to as *statical reserve* of steel.

In marine environment, a new steel grade *AMLoCor* can significantly reduce the corrosion rates in the *Low Water Zone* and in the *Permanent Immersion Zone*.

It is of utmost importance to understand the difference between the ASD and EC 3-5 design methods. ASD considers the effective efforts and resistances, with different global safety factors on soil and steel, whereas EC 3-5 considers an ultimate limit state (ULS) approach, as well as a serviceability limit state (SLS), with partial safety factors at ULS: different partial safety factors on actions (combinations of loads and soil actions), as well as different partial safety factors on resistances (soil resistance and steel resistance). Do not mix both methods! *Characteristic* values and *design* values only apply to EC 3-5!

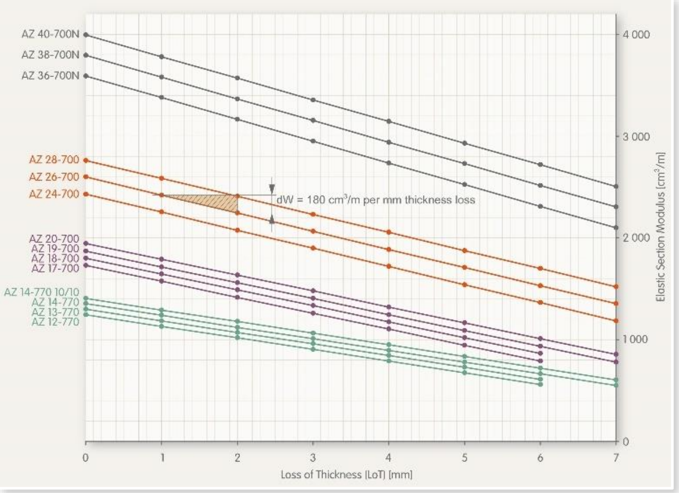
3 Assumptions & simplifications

Following assumptions have been made

- *overall corrosion* leading to an uniform loss of steel thickness over the whole cross-section (see § 4.2. (1) of EN 1993-5:2007)
- reduced section properties calculated with a CAD software for a double sheet pile
- reduced section properties calculated with total loss of steel thickness on one side of the wall [1]
- no corrosion occurs inside the interlocks [2]
- maximum loss of steel for all sections: 7.0 mm (covers most of the normal structures)
- minimum thickness of flange and web of a profile: 2.5 mm

Note: some thin sections cannot cope with losses of 7 mm due to their initial low thickness of the flange / web.

Below a **graph of the reduced section properties** $W_{el,red}$ of Z-piles (as a sample)



[1] This simplification yields in most cases unfavourable section properties. Compared to a loss of steel thickness on both sides, the difference for most sections is less than 2%.

[2] Corrosion inside the interlocks can be neglected. This is based on several structures where the sheet piles were pulled out after the service life and the thickness of the flanges and webs were measured. No corrosion was apparent inside the interlocks.

4 Design method ASD

The software calculates the safety factor based on the 'Allowable Stress Design' (ASD), using a **global safety factor approach**, for the initial conditions ($S_{f,ini}$) or for the end of the service life ($S_{f,red}$). The steel stresses are calculated with following formula[3]

$$\sigma_{el} = \frac{M}{W_{el}} + \frac{N \cdot e}{W_{el}} + \frac{N}{A_x} \leq \sigma_{allowable}$$

and

$$\sigma_{allowable} = \frac{f_y}{S_f}$$

where

σ_{el}	steel stress in the cross-section
M	bending moment (usually the maximum bending moment)
N	compression load (usually vertical loads from the superstructure and anchors)
e	deformation of the sheet pile section (simplification: use the maximum value)
W_{el}	elastic section modulus of the sheet pile section
A_x	cross-sectional area of the sheet pile section
$\sigma_{allowable}$	allowable steel stress
f_y	yield strength of the steel
S_f	safety factor
ini	stands for *initial*
red	stands for *reduced*

As the loss of steel generally varies by elevation, the verification of the safety factor may have to be carried out at different elevations.

In most countries, a global safety factor of 1.50 for the service life is required in normal load cases. This implies $S_f \geq 1.50$.

For exceptional load combinations, like seismic design phase, a lower safety factor may be acceptable, but should in any case be at least equal to 1.0.

Some design codes accept different safety factors for permanent and temporary structures.

[3] this formula may not be applicable to class 4 sections (see EN 1993-Part 5 for definition of the classes)

5 Design method EC 3-5

The first impression when reading the standard is that this design approach is much more complex, probably because it considers the interaction between bending moments, shear forces and compression loads, as well as buckling length when applicable, and so on. However, in most cases, the governing parameter will be the bending moment M_{Ed} because the interaction between the effects can be neglected in most cases or does not have a significant influence on the result.

Please be aware that the values that have to be entered are **design values**, which have already been multiplied in the geotechnical design by the applicable partial safety factors.

There is a myriad of formulas, simple ones and more complex ones. For more information, please refer to the standard.

EC 3-5 considers both plastic as well as elastic sections modulus, depending on the classification of the section, and several reduction factors. For instance, for U-piles, a reduction of the section modulus may have to be considered. Each (European) country may determine the reduction factors in their National Application Document (NAD).

High water pressure on AZ sections may also reduce the resistance of the structure, but this is quite rare.

The most important formula is probably the first one from 5.2.2 (1) and (2):

$$M_{Ed} \leq M_{c,Rd}$$

where

M_{Ed}	design bending moment, derived from a calculation according to the relevant case of EN 1997-1
$M_{c,Rd}$	design moment resistance of the cross-section

Class 1 & 2 profiles

$$M_{c,Rd} = \frac{\beta_B W_{pl} f_y}{\gamma_{M0}}$$

Class 3

$$M_{c,Rd} = \frac{\beta_B W_{el} f_y}{\gamma_{M0}}$$

with

W_{pl}	plastic section modulus determined for a continuous wall
W_{el}	elastic section modulus determined for a continuous wall
γ_{M0}	partial safety factor
β_B	factor that takes account of a possible lack of shear force transmission in the interlocks and has the following values $\beta_B = 1.0$ for Z-piles and triple U-piles[4] $\beta_B \leq 1.0$ for single and double U-piles

Class 4 sections do not achieve the elastic bending moment resistance because local buckling affects the cross-sectional resistance. The software considers in that case a reduced yield strength $f_{y,red}$ so that the section fulfils the class 3 criteria. This simplified approach is quite conservative in some situations, but is a good estimation in a first step. If the difference between f_y and $f_{y,red}$ is significant, then a more rigorous approach should be checked, for instance as described in Annex A of the Eurocode.

[4] For triple U-piles, only applicable provided that the common interlocks are crimped or welded !!

6 Options and results

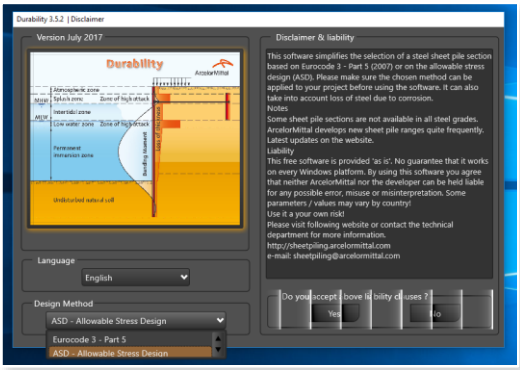
Screenshots in this chapter are common to both design approaches (except for the text in the title bar). In the next chapters, features specific to each approach are highlighted.

6.1 Launch of the software

When you launch the software, you have two options

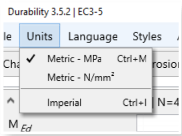
- choose a language. You can also change the language later
- choose the design method. You cannot switch the design method later!!

Then you have to accept the liability clauses, otherwise the software simply closes.

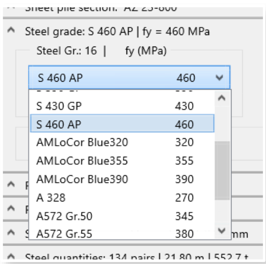


6.2 Tab ‘Data Input’

- **Units**: choice between *metric* and *imperial* units. German engineers prefer the metric units *N/mm²*, but usually *MPa* is used.

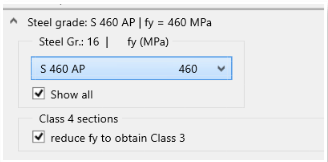


- **Steel grades**: choice between European steel grades according to **EN 10248**, American standards **ASTM** or ArcelorMittal mill specific steel grades (**S 460 AP**, **AMLoCor**).

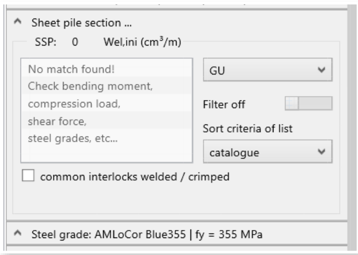


Note: a **higher yield strength f_y will usually lead to a lighter section and consequently lead to a more cost-effective solution**. The premium for higher steel grades varies but it is usually offset by the savings in weight of a lighter section. However, it should be checked if the residual thickness of the sheet pile and if the deflections still fit the purpose of the structure. Driveability must also be analysed.

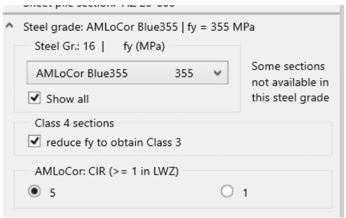
- Some sheet pile sections are not available in all the steel grades. If the *Show all* checkbox is not checked, then the number of steel grades available for the selected sheet pile is shown in the caption.



Checking the *Show all* checkbox resets the list of steel grades to all the steel grades. If you choose a steel grade that is not available for the selected sheet pile, then the range of steel sheet piles is also reset. For example, GU sections are not available in AMLoCor Blue 355. The list with the available sheet piles is automatically reset in that case.

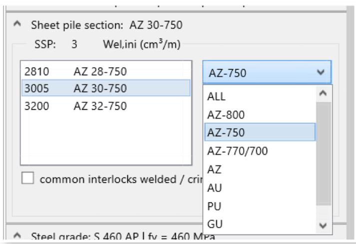


- ***CIP*** (*Corrosion Impediment Factor* = **reduction factor of the loss of steel thickness**) **for AMLoCor or ASTM A690**. This option is only available if the user chooses values from EN 1993-5 in combination with the proper exposure zone, or chooses *project specific rates*.

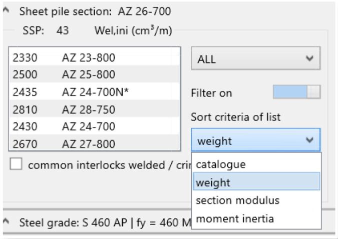


- **Service life**: you can choose the service life, and a period during which the steel surface is protected on the front and/or in the back side, for instance by using a coating, cathodic protection, …A protection will reduce the loss of steel thickness proportionally to the service life. You can either select a value from the drop-down list of the combo-box, or type a value.

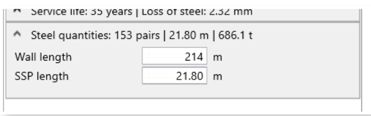
- The user can reduce the range of the sheet pile sections shown in the list box *Sheet pile section* by choosing a specific type of sheet pile (AZ-750 range for instance).

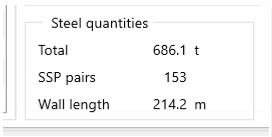


- The user can also filter the sheet piles so that only the sections that match all the design criteria are shown in the list box. Toggle the switch *Filter* on and off.
  The user can also filter the list by name, weight, section modulus or moment of inertia.
  This is valid for a specific steel grade. The lightest solution can usually be found by choosing the highest steel grade available, for instance S 460 AP.



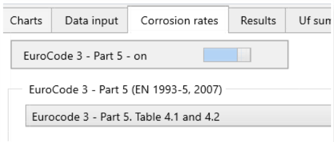
- Steel quantities*:* a simplified bill of quantity can be calculated for a straight wall: type the length of the wall and the length of the sheet piles (or the average of the length over the wall length) in *Steel quantities*. This gives a rough estimation of the total quantity of steel (without special piles and / or corner piles).



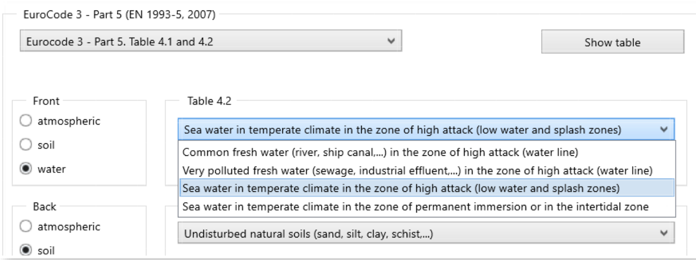


6.3 Tab '*Corrosion rates*'

- Select the switch *Eurocode 3 – Part 5* to toggle between predefined corrosion rates from *Eurocode*, or *project specific rates*.



  ➢ select the loss of steel from the tables from *EuroCode 3 – Part 5* rates (EN 1993-5). Some tables from the *NAD* ('National Application Document' of the original standard) have been implemented. In this case, the number of years selected in the *Service life* will automatically determine the loss of steel thickness.

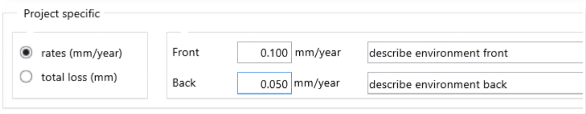


- click on *Show table* to view the corresponding table

Eurocode 3 - Part 5. Table 4.1 and 4.2. Loss of steel thickness [mm]

YEARS	0	5	25	50	75	100
**** ATMOSPHERIC ****						
Normal atmospheres	0.00	0.05	0.25	0.50	0.75	1.00
Locations close to the Sea	0.00	0.10	0.50	1.00	1.50	2.00
**** SOIL ****						
Undisturbed natural soils (sand, silt, clay, schist,...)	0.00	0.00	0.30	0.60	0.90	1.20
Polluted natural soils and industrial grounds	0.00	0.15	0.75	1.50	2.25	3.00
Aggressive natural soils (swamp, marsh, peat,...)	0.00	0.20	1.00	1.75	2.50	3.25
Non-compacted and non-aggressive fills (clay, schist, sand, silt,...)	0.00	0.18	0.70	1.20	1.70	2.20
Non-compacted and aggressive fills (ashes, slag,...)	0.00	0.50	2.00	3.25	4.50	5.75
Compacted and non-aggressive fills (clay, schist, sand, silt,...)	0.00	0.09	0.35	0.60	0.85	1.10
Compacted and aggressive fills (ashes, slag,...)	0.00	0.25	1.00	1.63	2.25	2.88
**** WATER ****						
Common fresh water (river, ship canal,...) in the zone of high attack (water line)	0.00	0.15	0.55	0.90	1.15	1.40
Very polluted fresh water (sewage, industrial effluent,...) in the zone of high attack (water line)	0.00	0.30	1.30	2.30	3.30	4.30
Sea water in temperate climate in the zone of high attack (low water and splash zones)	0.00	0.55	1.90	3.75	5.60	7.50
Sea water in temperate climate in the zone of permanent immersion or in the intertidal zone	0.00	0.25	0.90	1.75	2.60	3.50

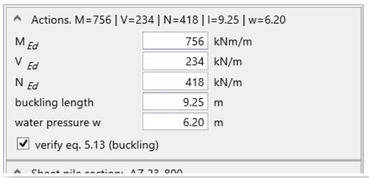
- provide the loss of steel (*Project specific*), either a rate in *mm/year* or the total loss in *mm* (same option in imperial units). If you provide a rate per year, please select also the corresponding service life in the tab *Data input*.



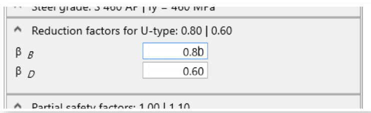
7 EC 3-5: specific features and calculation

7.1 Tab '*Data input*'

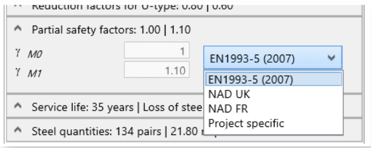
- The data to be provided are **design values**, starting with the actions. Please refer to the European standard for the definition of the data. Bending moment, shear forces, compression loads, buckling length and water pressure are the main actions.
  In case of significant compression loads, ArcelorMittal recommends that the influence of the deformation of the sheet pile on the resulting bending moment should be considered in the geotechnical design, for instance with a subgrade reaction model combined to a second order calculation. Hence, the deformation of the sheet pile is not a parameter in *Durability*.



- **Reduction factors for U-piles**. Please refer to the national annex of your country to determine the values. Depending on the country, soil conditions, amount of supports (bracing, anchors), water pressure, and so on can have an influence on these two factors.



  - β_B applies to the bending moment resistance
  - β_D applies to the moment of inertia
- **Partial safety factors**. Please refer to the national annexes to determine these values. Pre-defined values are available in the drop-down box. Project specific values can be typed into the boxes. The values must be geater or equal to 1.0.



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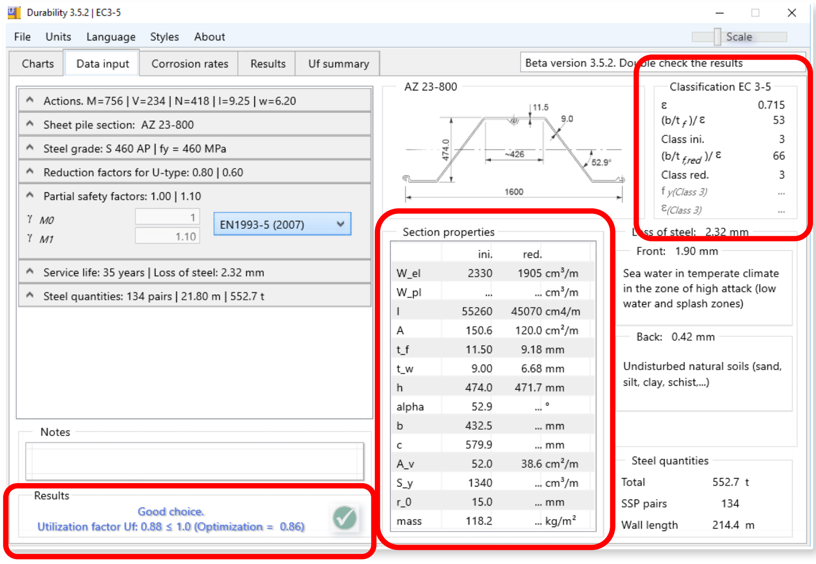
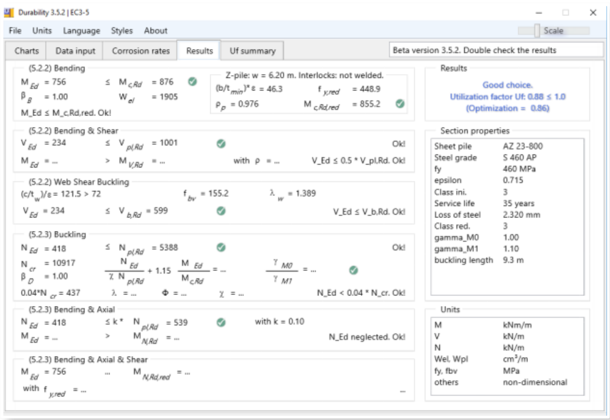
- The main results for the chosen section are summarized in this tab: reduced section properties, classification, optimization factor.

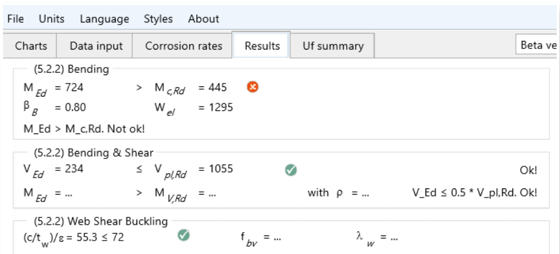


The *utilization factor* checks all criteria (formulas) and shows the highest ratio of action / resistance. An utilization factor of 1.0 means that the selected combination sheet pile section / steel grade has reached the limit for at least one of the design criteria. This is theoretically the optimum result for the specific combination, but it does not imply that the chosen section is the most cost-effective of all the possible combinations!

7.2 Tab '*Results*'

- Detailed results are summarized in the tab *Results*. A red cross besides a result indicates that this criterion is not met with the chosen combination section / steel grade. A greyed field means that this criterion does not need to be considered (for instance, no interaction between the actions).



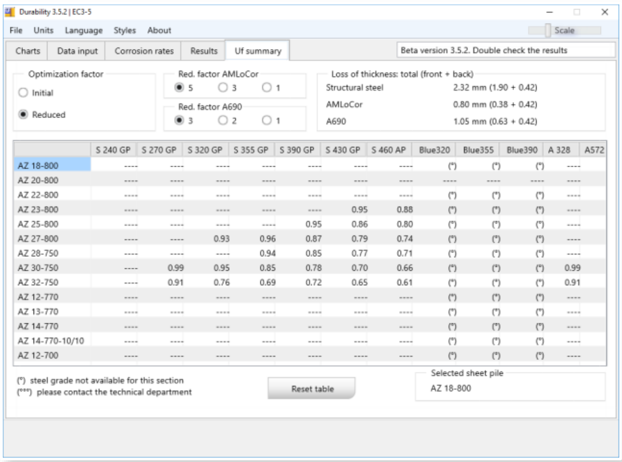


7.3 Tab '*Uf summary*'

This tab summarizes the *utilisation factor* for all the steel sheet pile sections (or a reduced range if the corresponding filter is on). This is the best tool to choose the most cost-effective solution, for the initial and for corroded phase.

To be even more flexible, the reduction factors for AMLoCor and A690 can be selected independently of the initial choice in the tab *Data input*.

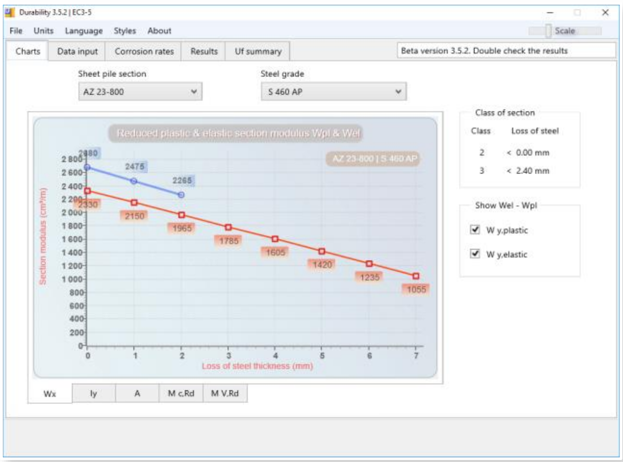
Combinations section / steel grade that do not match the criteria have an optimization factor above 1.0 and consequently are not shown ('---'). Note that sometimes this factor is only slightly above 1.0 and it might be wise to recheck the actions.

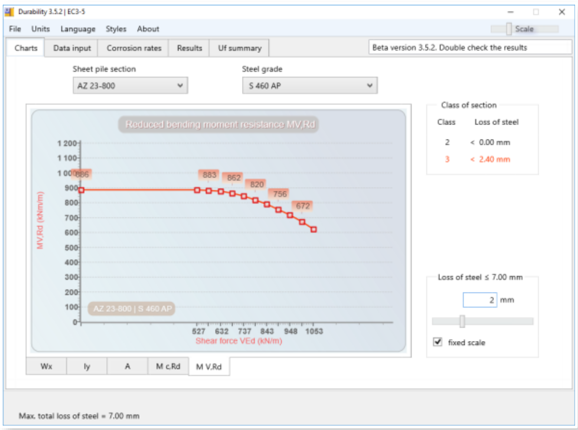


7.4 Tab '*Charts*'

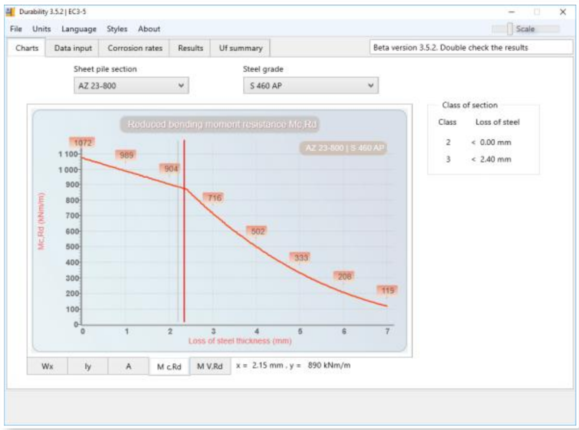
The chart is a nice tool to analyse the behaviour of a section based on loss of steel thickness and steel grades. One can also compare different sections. There are several tabs inside the graph: moment of inertia, cross-sectional area, bending moment resistance, as well as the interaction between bending moment and shear forces.

Note that these are the values used internally for the calculations, and that they are rounded.





Durability 3.5.2 | EC3-5
File Units Language Styles About
Scale
Charts Data input Corrosion rates Results Uf summary
Beta version 3.5.2. Double check the results
Sheet pile section
AZ 23-800
Steel grade
S 460 AP
Reduced bending moment resistance MV,Rd
MV,Rd (kNm/m)
Shear force VEd (kN/m)
AZ 23-800 | S 460 AP
Class of section
Class Loss of steel
2 < 0.00 mm
3 < 2.40 mm
Loss of steel ≤ 7.00 mm
2 mm
fixed scale
Wx Iy A M c,Rd M V,Rd
Max. total loss of steel = 7.00 mm

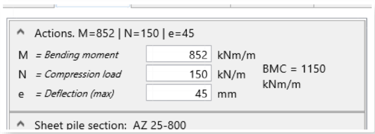


Durability 3.5.2 | EC3-5
File Units Language Styles About
Scale
Charts Data input Corrosion rates Results Uf summary
Beta version 3.5.2. Double check the results
Sheet pile section
AZ 23-800
Steel grade
S 460 AP
Reduced bending moment resistance Mc,Rd
Mc,Rd (kNm/m)
Loss of steel thickness (mm)
AZ 23-800 | S 460 AP
Class of section
Class Loss of steel
2 < 0.00 mm
3 < 2.40 mm
Wx Iy A M c,Rd M V,Rd
x = 2.15 mm , y = 890 kNm/m

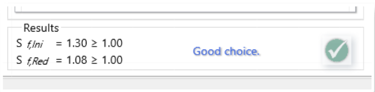
8 ASD: specific features and calculation

8.1 Tab '*Data input*'

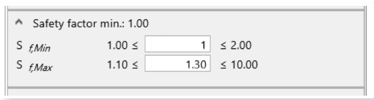
- The data to be provided are **unfactored values**, starting with the actions. The Bending Moment Capacity (BMC) is given for information only.



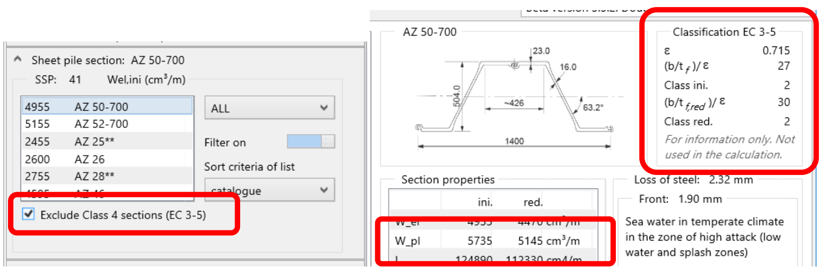
- The software calculates $S_{f,ini}$ and $S_{f,red}$. Note that usually $S_{f,min} \geq 1.50$, except in specific situations such as seismic actions.
  A green check in this group box means that the combination section / steel grade fulfills the design criteria. It does not imply that it is the most cost-effective solution!



- The user can reduce or increase the number of solutions shown in the table in the tab *Sf summary* by choosing an adequate range for the safety factor $S_{f,max}$. in the tab *Data input*.
  For practical reasons, the edit box $S_{f,min}$ is limited to values greater or equal to 1.0, and the difference between $S_{f,min}$ and $S_{f,max}$ must be higher than an arbitrary predefined range.

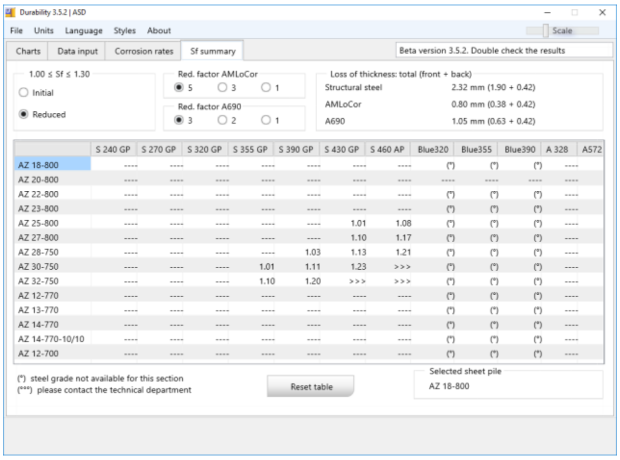


- Some values are given only for information and are not used in the calculations.
  For instance, to avoid using very thin sheet piles that may buckle before reaching the elastic section modulus, the user may verify the classification according to EC 3-5, or even prevent showing class 4 section in the list-box (when the filter switch is on) and summary table. Check the box *Exclude Class 4 sections (EC 3-5)*.
  For instance, the plastic section modulus cannot be used in the ASD method, but is given nevertheless for information.



8.2 Tab '*Sf summary*'

The software summarizes in a table the safety factors (initial or reduced) for all the possible combinations steel sheet pile / steel grades, taking into account above pre-defined safety factor limits. These limits enhance the readability of the table.



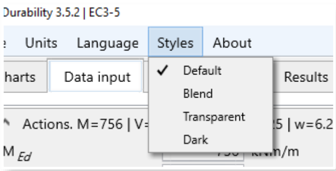
8.3 Tab '*Charts*'

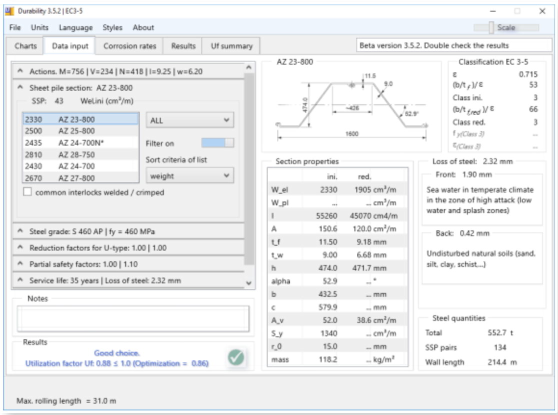
- Similarly to the EC 3-5 version, there are four different graphs that show the reduction of the section properties with the loss of steel thickness. The BMC is shown in one graph. The classification according to EC 3-5 is only given for information. In the case highlighted below, class 4 would be achieved for a loss of steel thickness of 3.40 mm.
- Modifications to the selected sheet pile section and/or steel grade are replicated in the tab *Data input*.

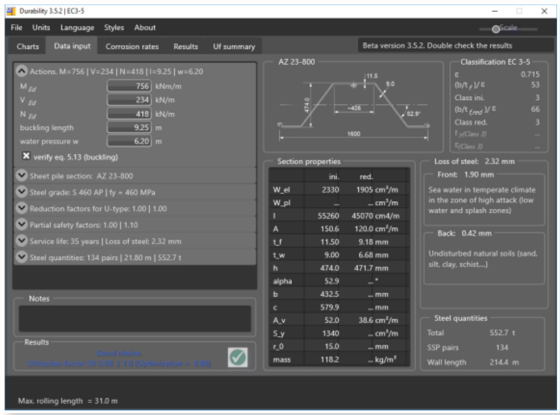
9 Miscellaneous

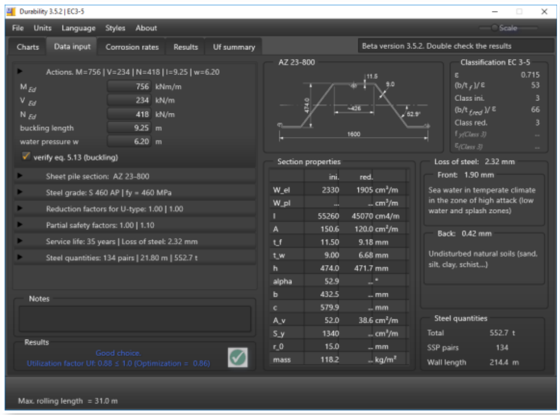
9.1 Menu ‘*Styles*’

Four different styles for the form are available from the menu *Styles*, which affects the background and text colours. Depending on the OS version, you may have to click on an active item to repaint the whole user interface (the sketch and some lines may not be shown in the correct colour).



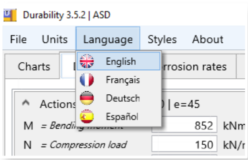






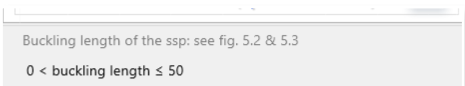
9.2 Menu ‘*Languages*’

Several languages are available. You can switch between languages at any time.



9.3 Status bars

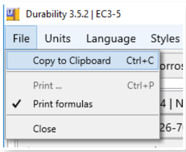
The status bar at the bottom of the form can provide additional information on some parameters or error messages. For instance, the maximum rolling length of the selected sheet pile, the definition of some abbreviations, etc… Note that some parameters are limited to arbitrary values, based on logical and practical aspects.



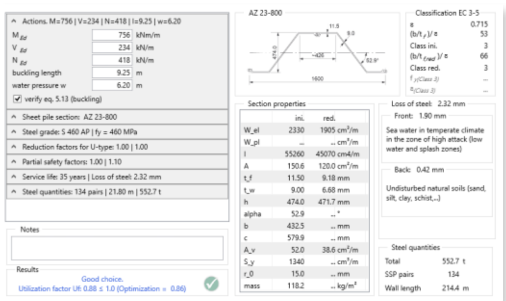
'*Copy / paste*' is not specifically supported by the application. You may try to paste values or text into the edit boxes but some edit boxes do not support unformatted text or numbers. In that case, an error message will appear in the status bar at the bottom of the form.

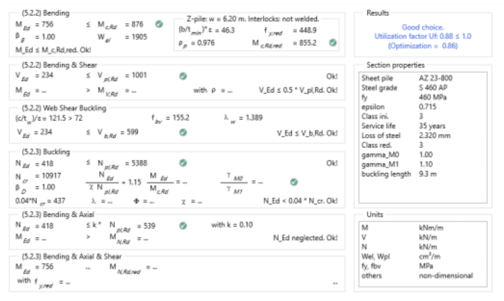
9.4 Screenshots of the form

The user can copy part of the form (tabs) shown on the screen to the *Clipboard* of the operating system with the sub-menu *Copy to Clipboard* in the *File* menu, and then paste in another file such as a word processing file.



The information contained in the bitmap varies based on the relevant results. Below two screenshots from EC 3-5.





9.5 Software crashes and issues

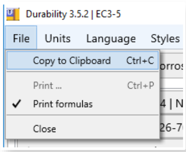
Depending on the operating system and the regional parameters, an error might occur when you launch the software the first time (the software did not recognize the *decimal point*). In that case, simply close the application (through the *Task Manager* if necessary) and launch again the software. If this does not solve the problem, please contact ArcelorMittal.

10 Printing

As printing of the results was not a key aspect for the developers of the software, printing options are quite limited. Printing is possible as a simplified text on a DIN A4 page. Printing on other page formats might be incomplete or lead to unexpected results.

The sub-menu *Print formulas* allows to print the formulas with the results (available for EC 3-5).

Printing is only possible when a valid sheet pile is chosen and when the tab *Result* is active, otherwise the menu item is greyed.



11 Disclaimer

Some assumptions that have been implemented in this software might not be fully in line with local standards.

The sketches and screenshots in this document are only for illustration purposes and might contain errors (screenshots from a beta-version).

The data and commentary contained within this document is for general information purposes only. It is provided without warranty of any kind.

The software *Durability* is provided ‘as is’, without warranty of any kind (no guarantee that it works flawlessly on every Windows® operating systems).

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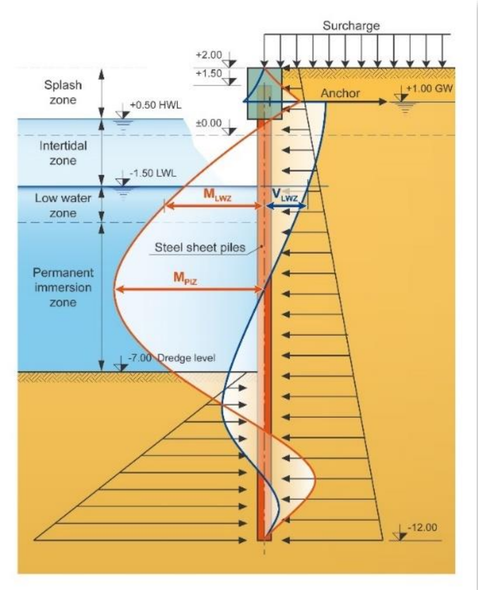
Please contact ArcelorMittal’s technical department for any questions / comments / suggestions, or to report a bug: sheetpiling@arcelormittal.com.

12 Example

12.1 Design assumptions

Quay wall in a marine environment. Service life of the structure: 50 years.



The design of the sheet pile wall can be done with different design methods

- **LEM** (Limit Equilibrium Method). Simplest method, based on an equilibrium of the retaining wall. Can be used for cantilever and single supported retaining walls
- **Subgrade Reaction Modulus** or SSIM (Soil Structure Interaction Model) with soil springs. Interaction between soil and structure. This design method is nowadays the standard in European countries
- **FEM** (Finite Element Method). Usually reserved for rather complex structures or special soil geometries / properties

In a LEM design, the moment of inertia I_x of the sheet pile wall has no influence on the bending moments and anchor forces, whereas in the two more complex methods, there is almost always a slight influence on the bending moments (due to the soil / structure interaction). A stiff retaining wall will be submitted to higher bending moments than a more flexible structure.

The deflection / deformation with the LEM design method is proportional to the stiffness I_x of the wall. In the more elaborate design methods, the deflection / deformation is rarely strictly proportional to the stiffness.

The design of a sheet pile wall is an interactive process, as the stiffness may have an influence on the deflection e, which may have an influence on the steel stresses.

Assumptions

Unfactored design method (ASD). Chosen section in the design with a LEM method (for instance with *Prosheet 2.2*): **AZ 32-750 in S 460 AP**.

Bending moment	$M_{max} = M_{PIZ}$	800	kNm/m
Compression loads	N	150	kN/m
Deflection	e	70	mm

Assume no surface protection and allow the steel to corrode.

Consider corrosion rates from EN 1993-5, Table 4.1 and 4.2: *PIZ* (Permanent Immersion Zone) on the front face, *natural soil* on the back face.

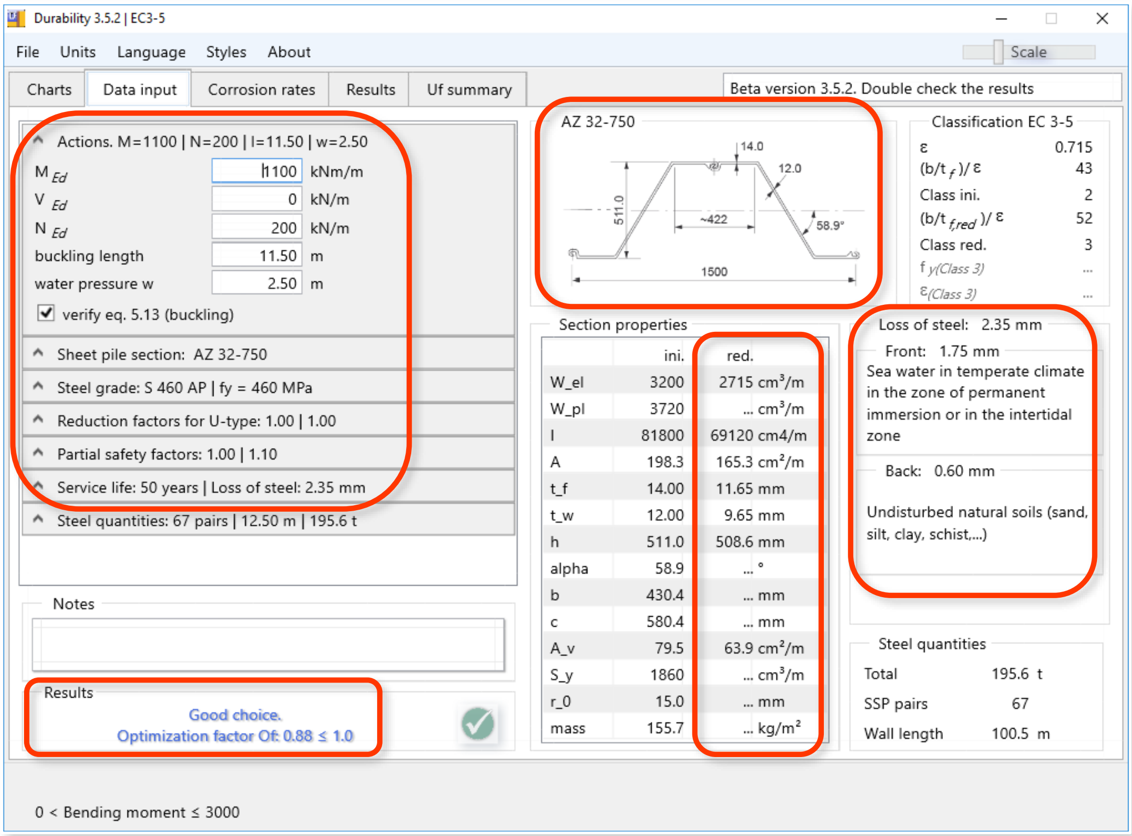
Total loss of steel thickness: 2.35 mm with a standard steel grade.

12.2 EC 3-5

For this illustrative purpose, let us consider the **design values** found with Prosheet and multiplied by a factor of say 1.35 approximately (this is not necessarily the case in reality!).

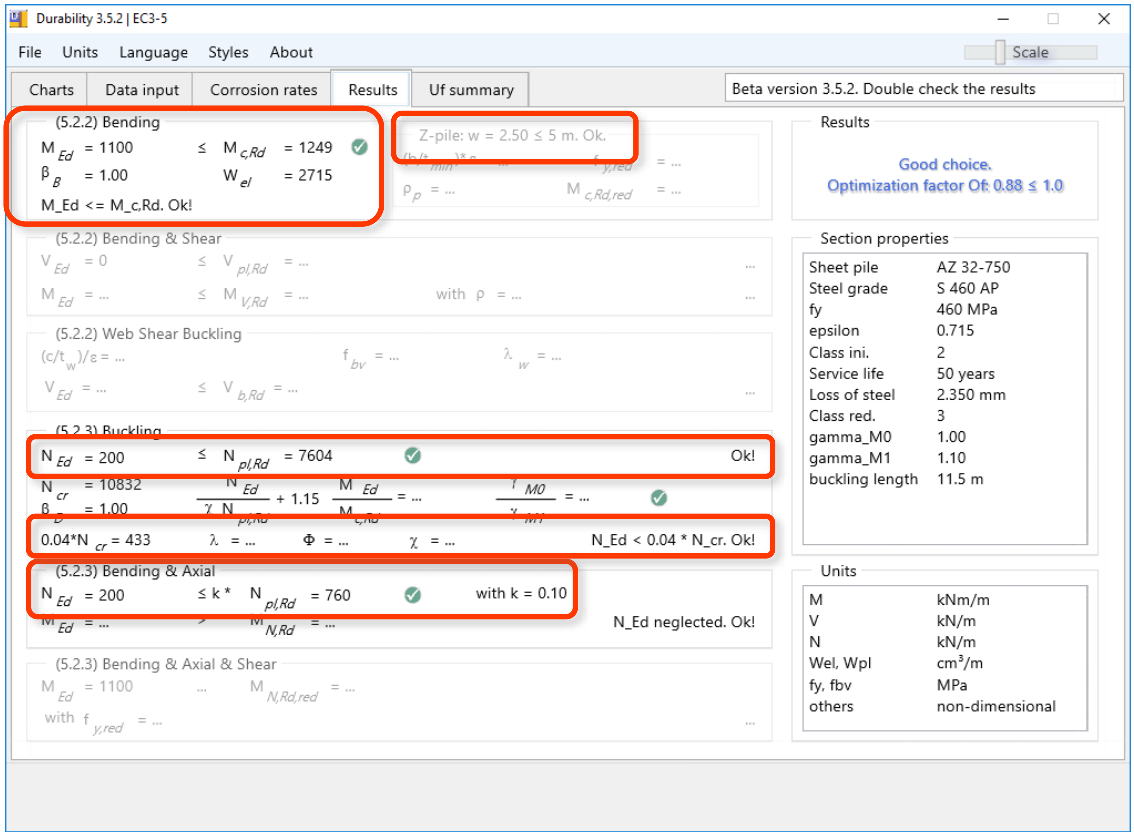
Bending moment	$M_d = M_{PIZ}$	1100	kNm/m
Compression loads	N_d	200	kN/m
Shear forces	V_d	≈ 0	kN/m (elevation of maximum bending moment)
Water pressure difference		2.5	m
Buckling length	l	11.0	m

Below a screenshot of the solution.



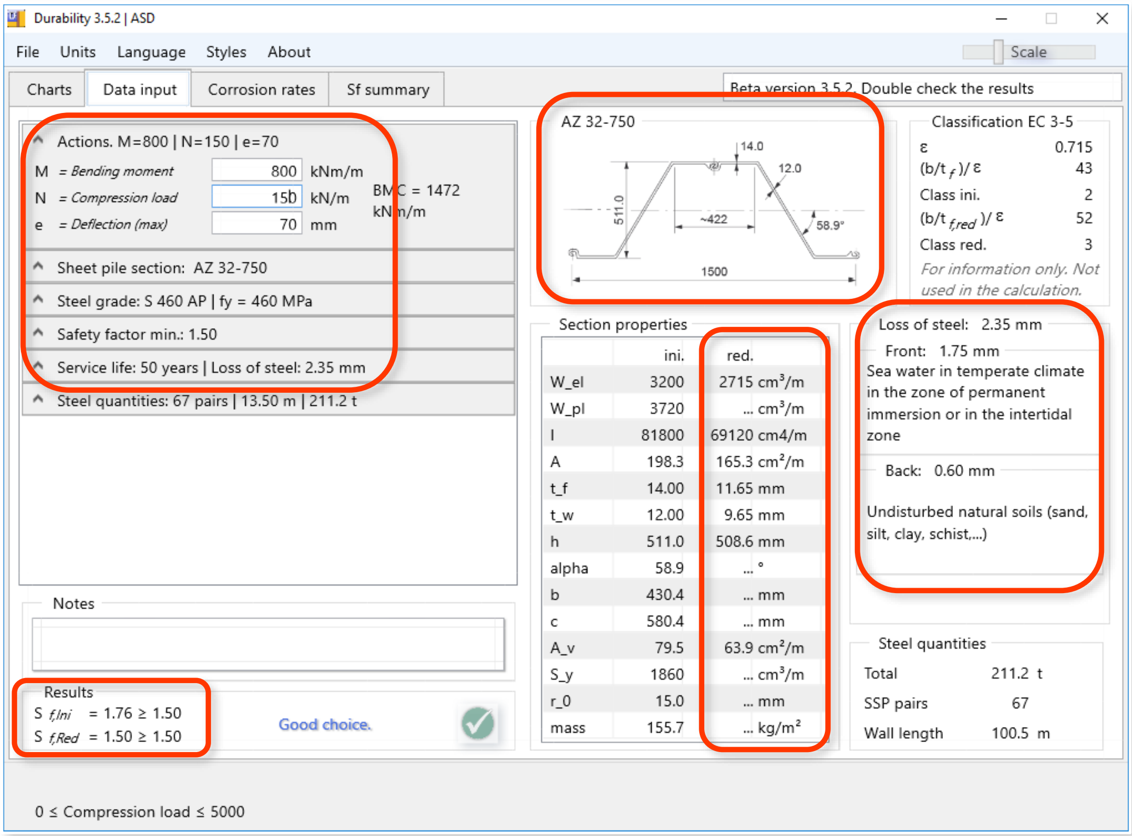
Minimum thickness after service life: 9.65 mm in the web.

Optimization factor of 0.88. Note: an AZ 30-750 in S 460 AP would also work.



12.3 ASD

Below a screenshot of the solution.



Minimum thickness after service life: 9.65 mm in the web.

Safety factor

$$\sigma_{el} = \left(\frac{800}{2\,715} + \frac{150 \cdot 0.07}{2\,715}\right) \cdot 1000 + \frac{150}{165.3} \cdot 10 = 307.6\ MPa$$

$$S_{f,red} = \frac{f_y}{\sigma_{el}} = \frac{460}{307.6} = 1.50 \geq 1.50 = S_{f,min}$$

The verification at the LWL (Low Water Level) should also be performed.