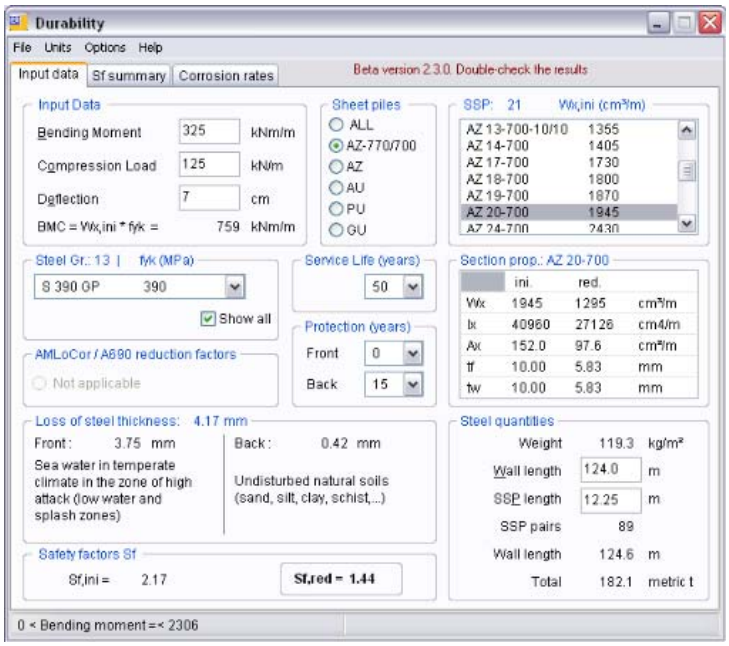
Durability 2.4 | 2012

Introduction



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 quite useful in case the design is based on the **'Allowable Stress Design'** method. It was developed for internal use by the technical department of ArcelorMittal Commercial RPS in Luxembourg.

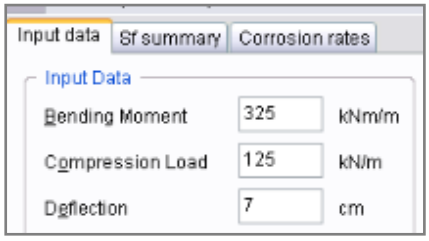
It is a free software that can be downloaded from ArcelorMittal's website, and it is regularly revised (mainly when a new sheet pile section is introduced or removed from the rolling program).

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

Aim of the software

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

The design of the structure will be influenced mainly by the soil conditions, the geometry of the structure and the load combinations that will be applied to the structure. During the design, the main parameters required for the choice of a sheet pile wall are:



- bending moment,
- compression load,
- deflection (depends on the selected section).

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**.

However, it is limited to 'regular' hot rolled sheet piles Z-type and U-type.

Following chapters will show the different options and assumptions that have been implemented in the software.

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, but loss 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 existing nearby structures. This is possible in major ports that have been monitoring their existing steel sheet pile structures, but quite often this data is not readily available or is not reliable enough.

An acceptable source for estimated 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 to corrode, 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**' will significantly reduce the corrosion rates in the 'Low Water Zone' and in the 'Permanent Immersion Zone'.

The software calculates the **safety factor based on the 'Allowable Stress Design' (ASD)**, using a **global safety factor approach**, at the beginning ($S_{f,ini}$) and at the end of the service life ($S_{f,red}$). The steel stresses are calculated with following formula[1]:

$$\sigma_x = \frac{M}{W_x} + \frac{N * e}{W_x} + \frac{N}{A_x} \leq \sigma_{allowable} \quad \text{and} \quad \sigma_{allowable} = \frac{f_y}{S_f}$$

with:

σ_x	steel stress in the section
$\sigma_{allowable}$	allowable steel stress
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_x	elastic section modulus of the sheet pile section
A_x	cross-section of the sheet pile section
S_f	safety factor
f_y	yield strength of the steel
ini	stands for 'initial'
red	stands for 'reduced'

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

In most countries, a global safety factor of 1.50 for the whole service life is required in normal load cases. This implies $\mathbf{S_{f,red} \geq 1.50}$.

For exceptional load combinations, like seismic design phase, a lower safety factor may be acceptable. Some local design codes accept different safety factors for permanent and temporary structures.

[1] this formula should not be used for class 4 sections (see EN 1993-Part 5 for definition of the classes)

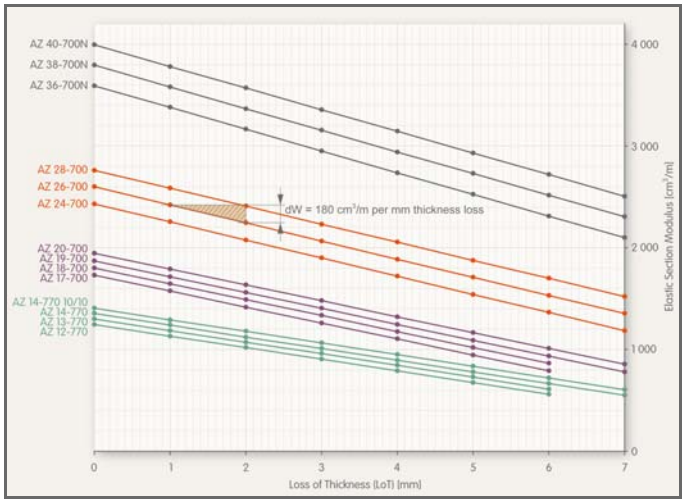
Assumptions / simplifications

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 [2]
- no corrosion occurs inside the interlocks [3]
- maximum loss of steel of a section: 7.0 mm (covers most of the normal structures)
- minimum thickness of flange and web of a profile: 2.5 mm

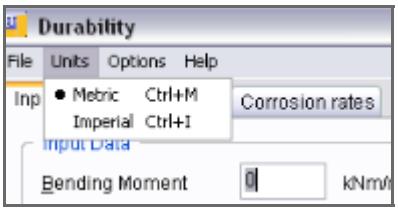
Note: some thin sections cannot cope with losses of 7 mm due to their initial low thickness of the flange / web.

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



Options and results

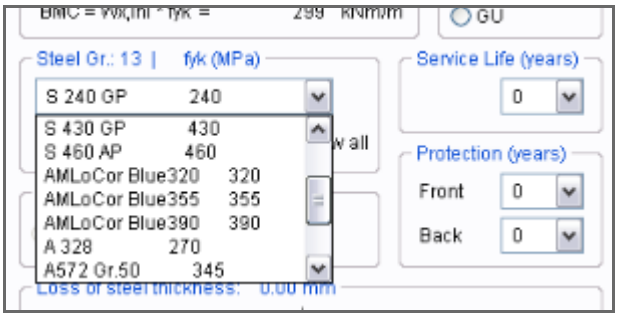
- Choice between 'metric' and 'imperial' units.



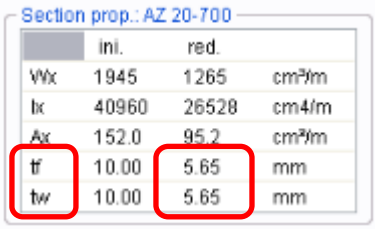
[2] This simplification yields in most cases unfavourable section properties. Compared to a loss of steel thickness on both sides, the difference for most sections is less than 2%.

[3] 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.

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

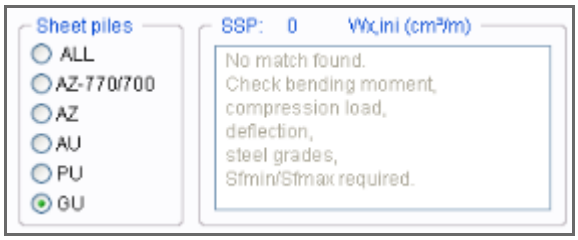


Note: a **higher yield strength f_y of the steel will usually lead to a lighter section and consequently lead to a more cost-effective solution**. The premium for higher steel grades varies but it is usually offset by the savings in weight of a lighter section. However, it should be checked if the residual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

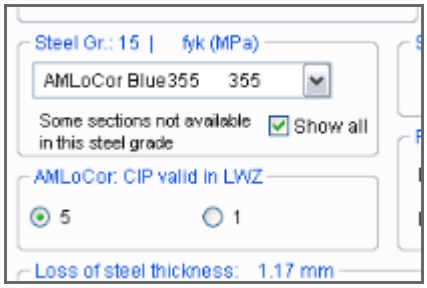


Some sheet pile sections are not available in all the steel grades. If the '*Show all*' checkbox is unchecked, then the number of steel grades available for the selected sheet pile is shown in the caption.

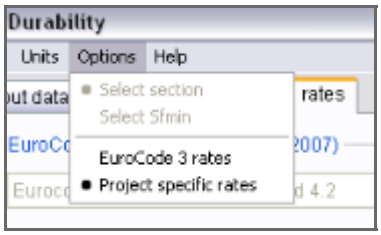
Checking the '*Show all*' checkbox resets the list of steel grades to all the steel grades. If you choose a steel grade that is not available for the selected sheet pile, then the range of steel sheet piles is also reset. For example, GU sections are not available in AMLoCor Blue 320:



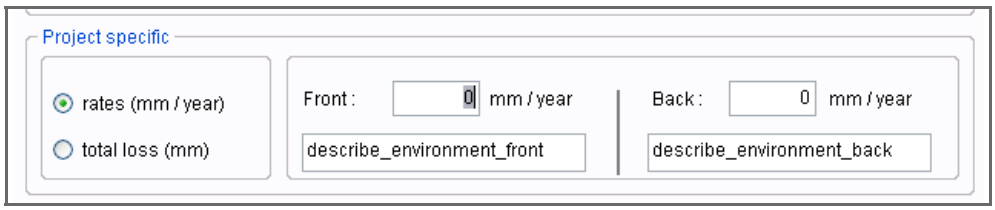
- CIP ('Corrosion Impediment Factor' = **reduction factor of the loss of steel thickness**) **for AMLoCor or ASTM A690**. This option is only available if the user chooses values from EN 1993-5 in combination with the proper exposure zone, or chooses 'project specific rates'.



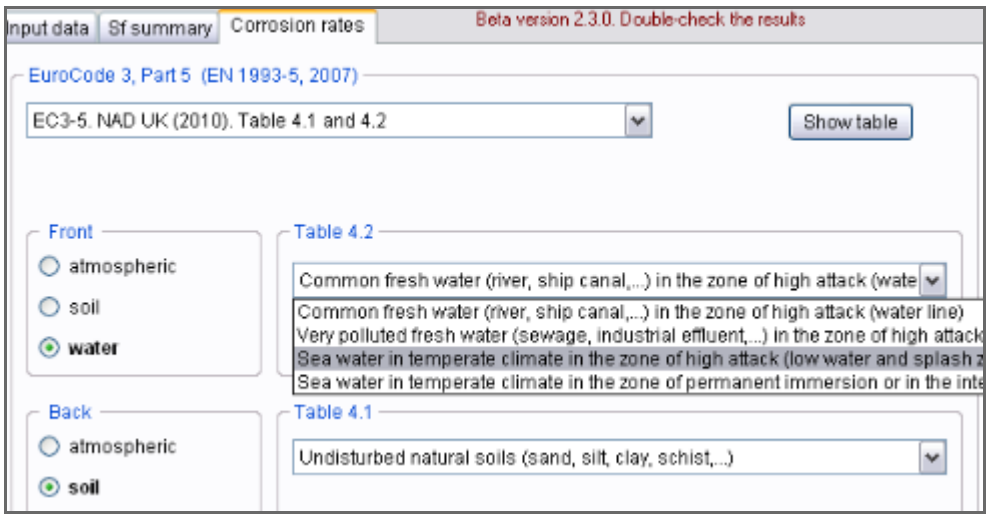
- The user can choose a combination sheet pile section / steel grade, then click on the tab '*Corrosion rates*' and select from the menu '*Options*':



  - estimate the loss of steel ('*Project specific rates*'), either a rate in 'mm/year' or the total loss in 'mm' (similar option in imperial units)

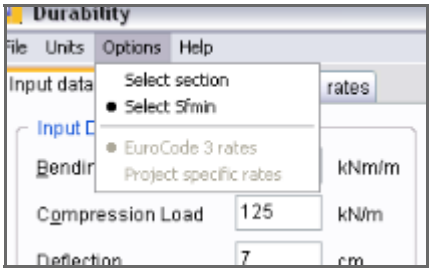


  - select the loss of steel from the tables from '*EuroCode 3 rates*' (EN 1993-5). Some tables from the 'NAD' ('National Application Document' of the original standard) have already been added. In this case, the number of years selected in the '*Service life*' will automatically determine the loss of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

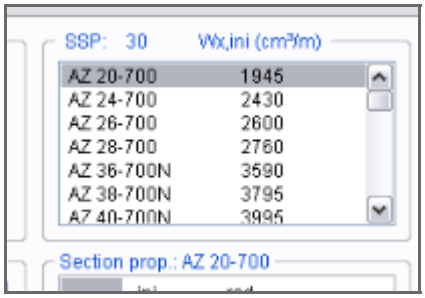


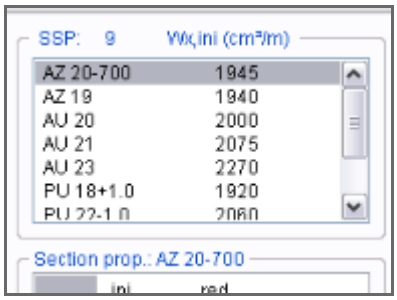
The software calculates $S_{f,ini}$ and $S_{f,red}$ (go back to the tab '*Input data*' to check the result):

- The user chooses a range of $S_{f,red}$ and the software shows all the sheet piles that verify this condition for the selected steel grade.

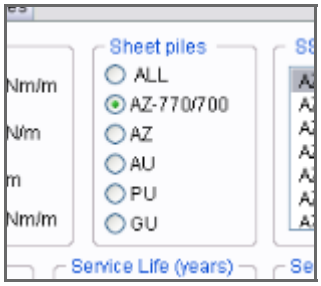


Below two examples: $S_{f,red}$ between 1.5 and 20.0 (30 sections) vs. 1.5 and 2.0 (9 sections).

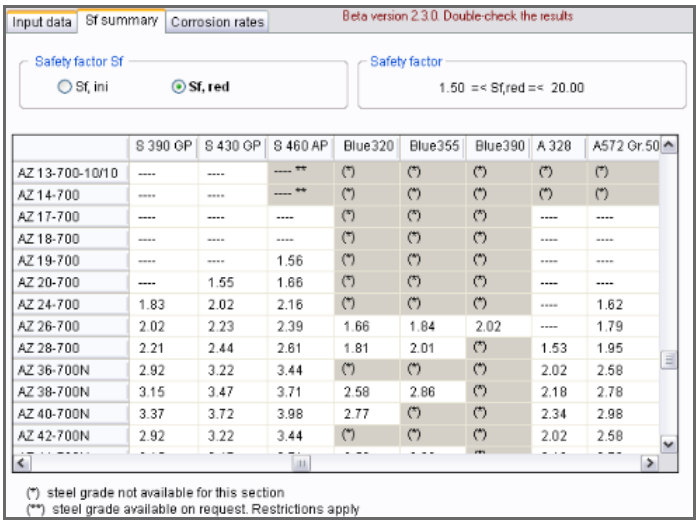




- The user can reduce the range of sheet pile section by choosing a type of sheet pile (AZ-700 range for instance) in the radiogroup '*Sheet piles*'.

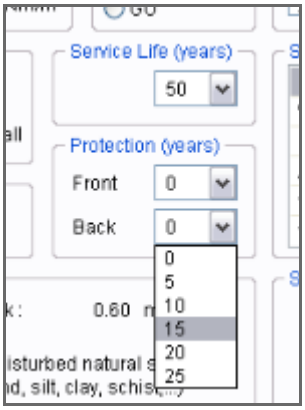


- In the tab '*Sf summary*' the user will find a table with safety factors (initial or reduced) for all the possible combinations sheet pile / steel grades.

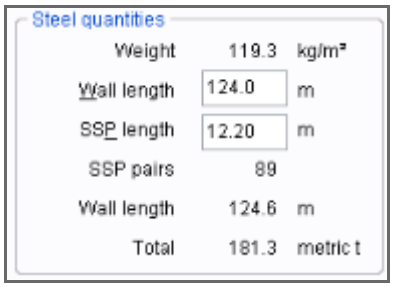


	S 390 GP	S 430 GP	S 460 AP	Blue320	Blue355	Blue390	A 328	A572 Gr.50
AZ 13-700-10/10	----	----	---- **	(*)	(*)	(*)	(*)	(*)
AZ 14-700	----	----	---- **	(*)	(*)	(*)	(*)	(*)
AZ 17-700	----	----	----	(*)	(*)	(*)	----	----
AZ 18-700	----	----	----	(*)	(*)	(*)	----	----
AZ 19-700	----	----	1.56	(*)	(*)	(*)	----	----
AZ 20-700	----	1.55	1.66	(*)	(*)	(*)	----	----
AZ 24-700	1.83	2.02	2.16	(*)	(*)	(*)	----	1.62
AZ 26-700	2.02	2.23	2.39	1.66	1.84	2.02	----	1.79
AZ 28-700	2.21	2.44	2.61	1.81	2.01	(*)	1.53	1.95
AZ 36-700N	2.92	3.22	3.44	(*)	(*)	(*)	2.02	2.58
AZ 38-700N	3.15	3.47	3.71	2.58	2.86	(*)	2.18	2.78
AZ 40-700N	3.37	3.72	3.98	2.77	(*)	(*)	2.34	2.98
AZ 42-700N	2.92	3.22	3.44	(*)	(*)	(*)	2.02	2.58

- In case of values chosen from the tables of EN1993-5, it is possible to take into account a surface protection (coating, cathodic protection) during a few years. Select the years in '*Protection (years)*'. This will reduce the loss of steel proportionally.

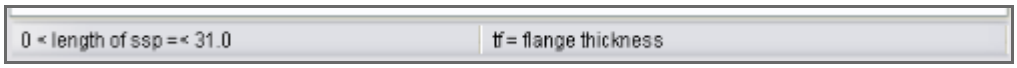


- A simplified bill of quantity can be calculated for a straight wall: enter the length of the wall and length of the sheet piles (or the average of the length over the wall length) in '*Steel quantities*'. This gives a rough estimation of the total quantity of steel (without special piles and / or corner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



Miscellaneous

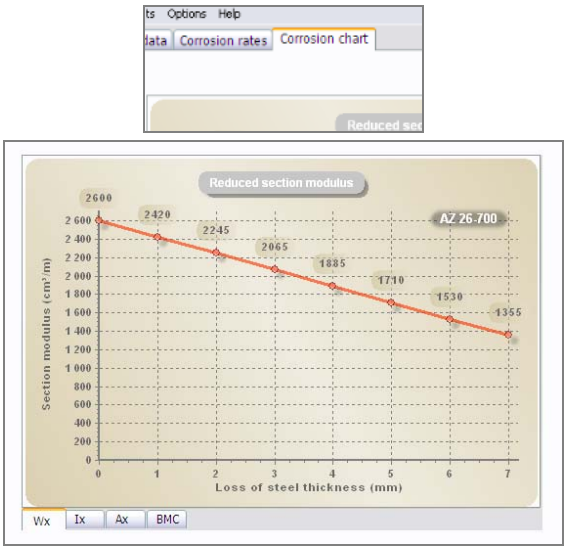
The status bar at the bottom of the form can provide additional information on some parameters or error messages. For instance, the maximum length of the selected sheet pile, or the definition of some abbreviations, etc…



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

Depending on the operating system, an error might occur when you launch the software the first time (it did not recognize the 'decimal point'). In that case, simply close the application (through the 'Task Manager' if necessary) and launch again the software.

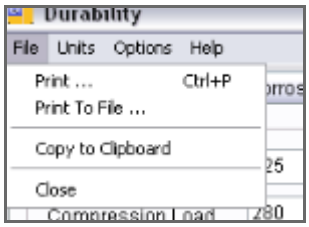
The tab 'Corrosion chart' shows a chart with the reduced section properties of the selected sheet pile section: section modulus, moment of inertia, etc. All the values are rounded. This chart can be printed or copied to the clipboard (right-click on the chart to show the pop-up menu).



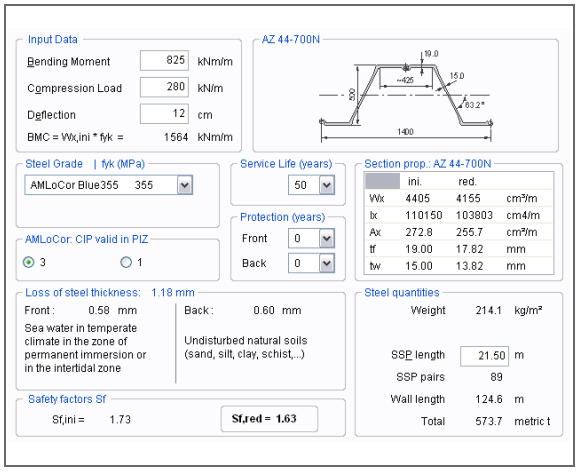
Printing

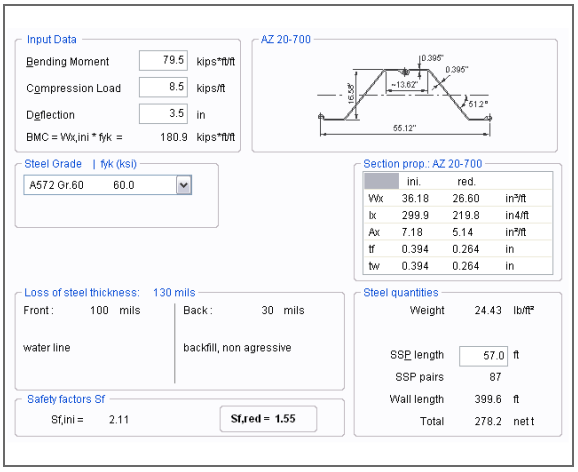
As printing of the results was not an important topic for the developers of the software, the printing options are quite limited. Printing should normally be possible as a simplified text on a DIN A4 page. Printing on other page formats might be incomplete or lead to unexpected results. '*Print To File…*' allows writing the results in a text file (limited feature).

The user can copy part of the form shown on the screen to the 'Clipboard' of the operating system: '*Copy to Clipboard*'.



The information contained in this bitmap varies based on the relevant results:





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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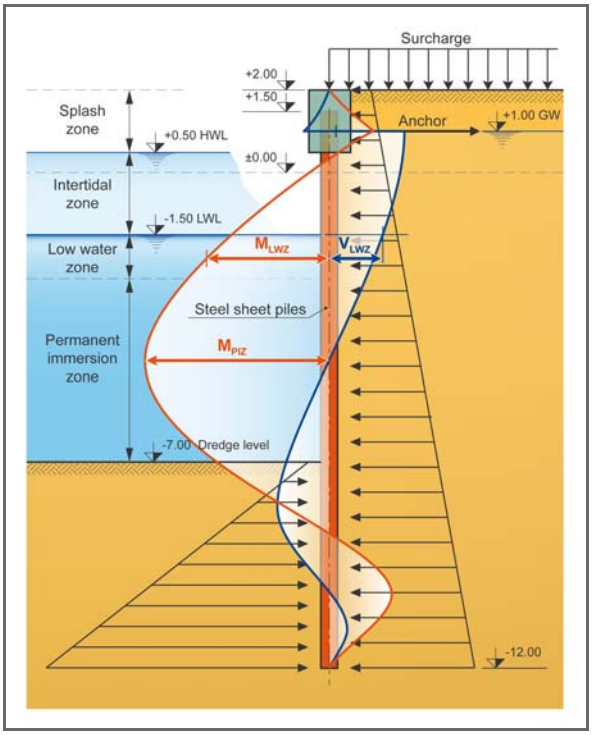
Please contact our technical department for any questions / comments / suggestions, or for more information: sheetpiling@arcelormittal.com.

Example

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,
- '**subgrade reaction modulus**' (SSIM) with soil springs. Interaction between soil and structure. Nowadays almost a standard in most European countries,
- **FEM** (Finite Element Method). Usually reserved for 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 other methods, there is most of the time 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 deflexion/deformation in a LEM design is proportional to the stiffness (I_x) of the wall. In the other design methods, the deflexion/deformation is not necessarily proportional.

Assumption

Chosen section in the design with a LEM method (for instance with Prosheet 2.2): AZ 28-700.

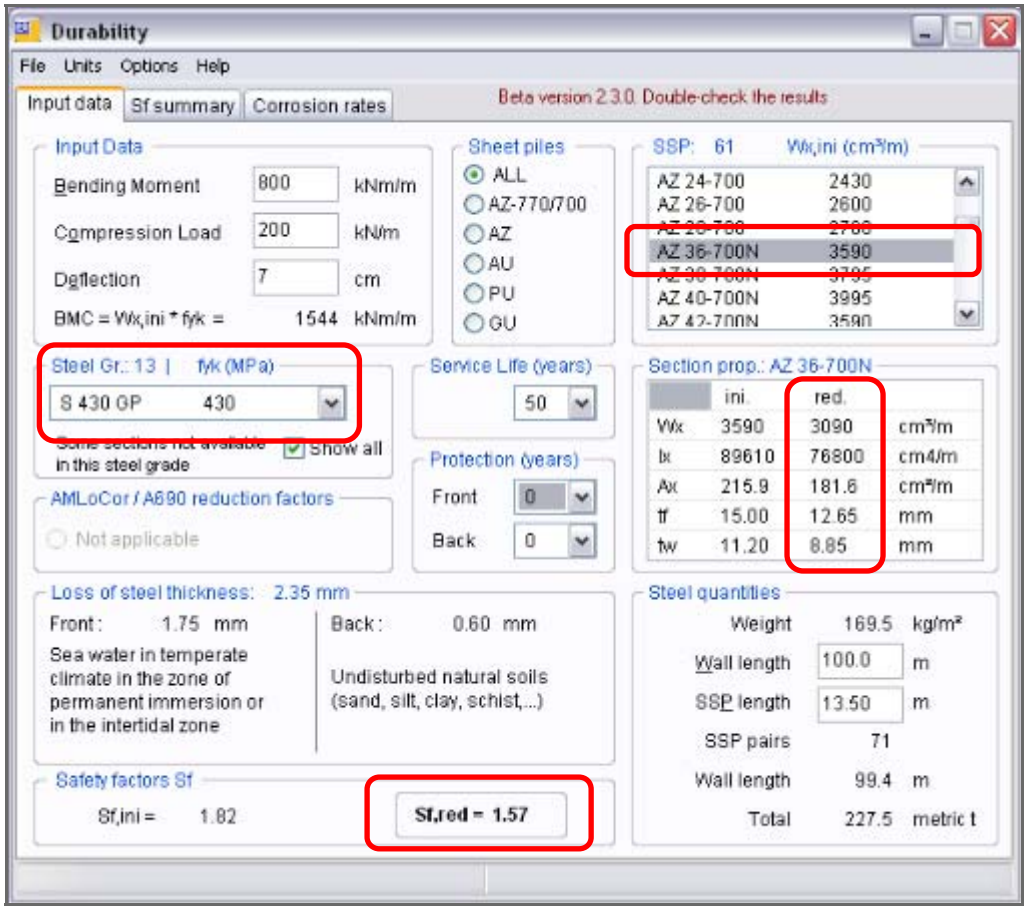
Results from design

Bending moment	M_{max}= M_{PIZ}	800	kNm/m
Compression loads	N	200	kN/m
Deflection	e	10	cm

In the initial conditions, the yield strength f_y required to achieve a safety factor $S_{f,ini}$ of 1.5 is 460 MPa (S 460 AP).

Solution

Assume no need for surface protection. Allow the steel to corrode, and achieve $S_{f,red} \geq 1.5$. Assume corrosion rates from EN 1993-5, Table 4.1 and 4.2: 'PIZ' on the front face, 'natural soil' on the back face. Standard steel grade. Below a screenshot of the solution.



Total loss of steel thickness: 2.35 mm.

Sheet pile: **AZ 36-700N**, **S 430 GP**, deflection of 7 cm. Weight: 169.5 kg/m^2. Minimum thickness after service life: 8.85 mm in the web.

$$\sigma_x = \left(\frac{800}{3090} + \frac{200 * 0.07}{3090}\right) * 1000 + \left(\frac{200}{181.6}\right) * 10 = 274.4\,\text{MPa}$$

$$S_{f,red} = \frac{f_y}{\sigma_x} = \frac{430}{274.4} = 1.57 \geq 1.50 = S_{f,min}$$ ✓

The verification at the LWL (low water level) should also be performed.