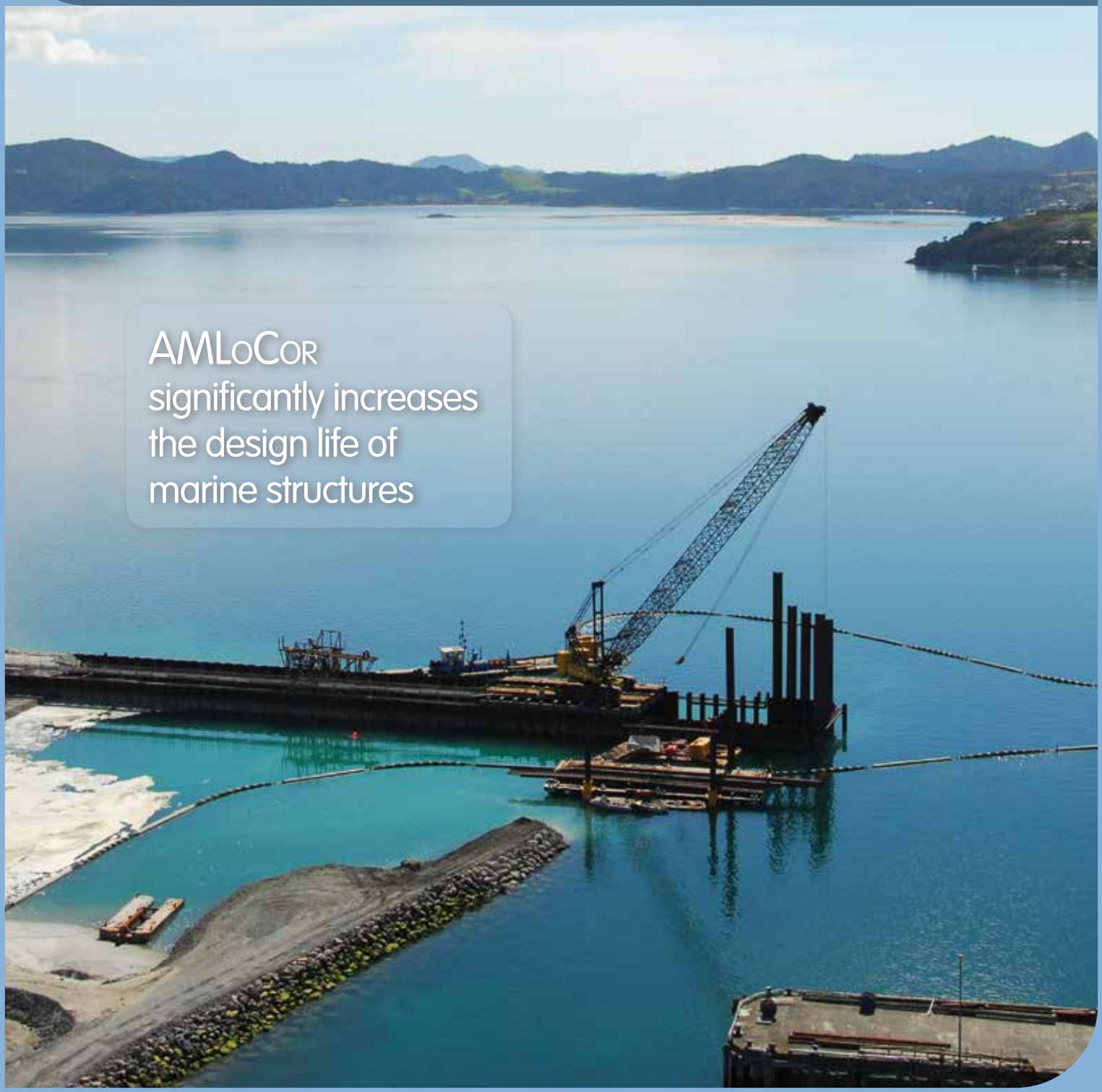
ArcelorMittal Sheet Piling

ArcelorMittal

AMLoCor Steel Grade



Introduction

ArcelorMittal's **'low corrosion' steel grade** will undoubtedly revolutionize the design of maritime infrastructure. As a matter of fact, steel sheet piles have been used for over 100 years to build reliable and cost-effective temporary and permanent structures worldwide. Countless quay walls of major European ports have been constructed with steel sheet piles. One concern of the designers and port authorities was the durability of these marine structures. Corrosion of steel is a natural phenomenon that occurs whenever steel is in contact with humidity or water. However, it has not prevented investors and engineers from using steel in marine applications.

Several methods can be selected to achieve the predefined service life of a steel structure. One way to deal with the corrosion is to consider a certain loss of steel thickness over the service life, sometimes referred to as 'sacrificial thickness' or 'static reserve', and to take it into account in the design by considering reduced section properties of the sheet piles. Quite efficient but generally more expensive solutions are coatings and cathodic protection.

Durability is a challenge, that European manufacturers tackled over 20 years ago. First of all, by surveying many ports by official administrations, and publishing the results of corrosion rates. For instance, in Eurocode 3-Part 5, tables with typical corrosion rates can be found, valid for standard carbon steel in European countries.

But the foremost action was to start investigating into new steel grades that would be less prone to corrosion.

The key challenge was to develop a micro-alloyed steel that would perform better in the different zones to which a typical maritime quay wall is exposed. Several steel grades were tested in various ports over long periods. Many laboratory tests were conducted, to determine the influence of a range of parameters. Furthermore, trials at steel plants and rolling mills were done, to optimize the production of such special steels. The result has been the development of the 'low corrosion' steel grade AMLoCor.

In-situ test specimens have proven that the **loss of steel thickness of AMLoCor is reduced by a factor 3 to 5**, depending on the exposed zones.

Furthermore, a Life Cycle Assessment (LCA) made by ArcelorMittal analysed the environmental impact of steel structures and shows, that it is an excellent 'green solution' compared to alternative construction methods.

ArcelorMittal is working on offering its whole product range in AMLoCor steel grade, which will encompass the combined wall systems in the future. Currently Z sheet piles are offered.

This brochure is limited to **marine structures**, even though the new steel grade will also be efficient in inland waterways and lakes.

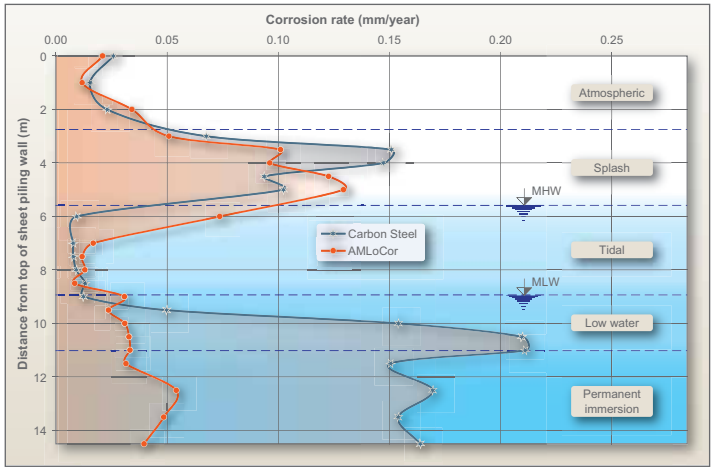
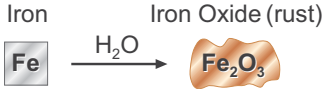


Fig. 1. Corrosion rates measured in a Northern European port.


Fig. 2. Continuous casting of AMLoCor.

Corrosion

Corrosion is a natural electrochemical phenomenon affecting metals and metallic alloys like steel. It leads to transforming the iron atom in the steel into its original state, natural iron oxide (formation of a rust layer).



Coating layers prevent this chemical reaction simply by separating the steel surface from the electrolyte (water). The coating forms a barrier that reduces the transfer of reactants between the steel and the water. A dense and homogeneous rust layer on the steel surface can have a similar protective effect.

Cathodic protection works in a different way: the chemical reaction still occurs, but a less noble metallic element is introduced into the system and corrodes, instead of the steel (galvanic anodes of aluminium for instance), or an electrical system provides the required electrons to protect the steel. Corrosion is a very complex topic depending on a lot of different parameters, that will not be dealt with in more detail in this brochure.
For further information please contact our technical support.

Advantages of AMLoCor

The main advantage of AMLoCor is a significant reduction of the corrosion rates in the Low Water Zone (LWZ) and in the Permanent Immersion Zone (PIZ).

For the verification of the structure, the designer considers average homogeneous corrosion, assuming that the loss of thickness is uniform all over the surface, as opposed to 'pitting' corrosion, which might have more local influence on the serviceability state.

In general, the maximum bending moments, and consequently the steel stresses, are in an area where corrosion rates are relatively low: permanent immersion zone or embedded zone (see Fig. 4). Yet the Low Water Zone sometimes governs the design, because in the permanent immersion zone the reduction of the section properties is offset by the lower thickness loss.

AMLoCor® is backed up with full scale and laboratory tests which have been performed during the last twenty years.

The chemical composition has been slightly improved all along those research projects in order to fulfill the requirements of the product, from durability to fabrication and welding. The excellent performance in the low water zone and in the immersion zone has been confirmed. Although it is not a 'standard' carbon steel used in the construction industry, this micro-alloyed steel can be designed and installed based on standard design procedures and guidelines valid for steel sheet piles, for instance according to EN 1997, EN 1993 Part 5, EN 10248, EN 12063, EAU 2004, etc. The design approach has to be adapted, to take into account the loss of steel thickness. The designer may consider a combination of additional protection methods for zones where the steel is less effective, including coatings, concrete capping beams, etc.

AMLoCor steel grade is slightly more expensive per ton than carbon steel, due to the cost of the additional alloys, just like other special steels as ASTM A690. However the cost-efficiency of any solution needs to consider the overall investment during the whole service life. **AMLoCor** will in many cases **yield the cheapest solution in the long-term.**

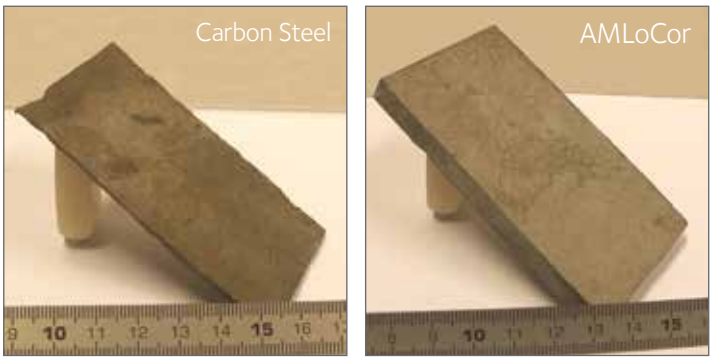


Fig. 3. 15 years old samples exposed in the water of a Northern European port.

In addition, AMLoCor protects steel from ALWC (Accelerated Low Water Corrosion) which is related to biological activity enhancing degradation of steel in the low water zone. The exact mechanism has not yet been scientifically identified, but some seaports in the UK and France have reported this issue.

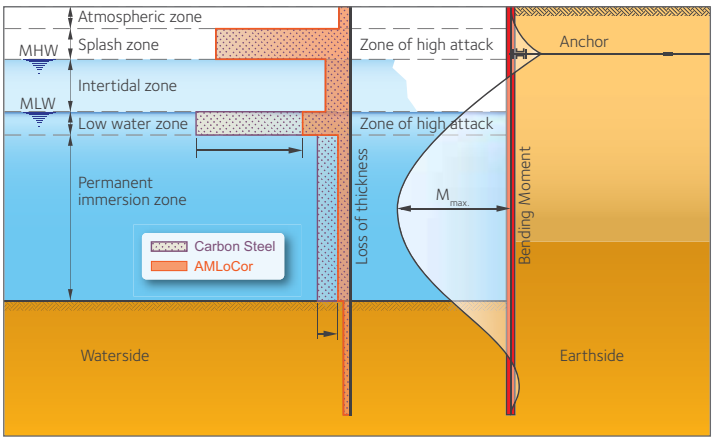


Fig. 4. Typical loss of steel thickness in a marine environment (MHW: Mean High Water; MLW: Mean Low Water).

Properties of AMLoCor

Steel grades with yield strength of 320 MPa and above can be achieved, depending on the sheet pile section. A table, showing the combinations of available steel grades and sheet pile sections, is updated regularly. Please check our website for the latest edition. Welding, splicing and fabrication has been addressed in detail.

By deduction from its behaviour and mechanical properties, AMLoCor can be considered as equivalent to a 'standard' carbon steel used in the construction industry. Hence it can be used in the design of a retaining structure similarly to any standard steel grade applicable to hot rolled steel sheet piles, like EN 10248. Fig. 5 shows two stress-strain diagrams of a S 355 GP and an AMLoCor Blue 355 sample. Both show the typical elastic behaviour of the steel until reaching the yield strength R_{eH}, followed by a long elasto-plastic deformation, and the increase

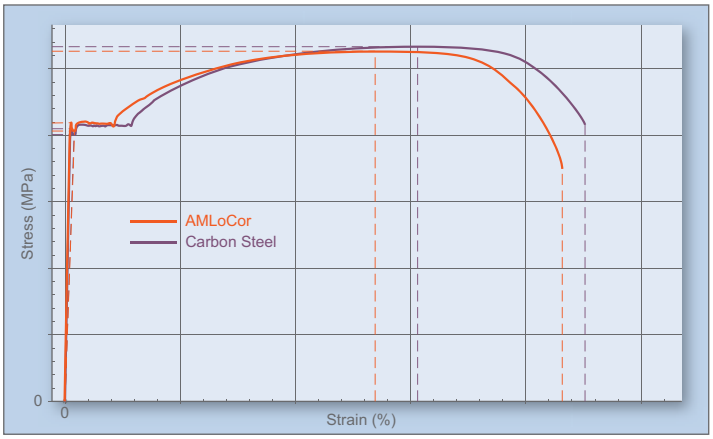


Fig. 5. Stress - strain diagram.

of the resistance until reaching the tensile strength R_m. The ratio R_m/R_{eH} of AMLoCor is quite similar to a standard S 355 GP. The toughness of AMLoCor exceeds the requirement (27J at 0°C) of the future EN 10248.

Steel grades of AMLoCor Blue and related mechanical properties, design, as well as fabrication is approved for sheet piles, tubes and connectors by the German General Technical Approval Z-30.10-55.

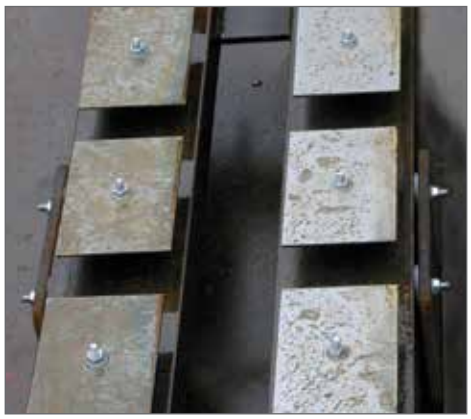


Fig. 6. Samples in a major port, Northern Europe.

Fig. 7. Prototype of an ultrasonic measuring device.

Design considerations

The use of cathodic protection (CP) can avoid any corrosion in the submerged zones: LWZ and PIZ, see Fig. 1. By contrast, if AMLoCor is used, **loss of thickness (LoT)** due to corrosion has to be considered, when designing the structure. The main difference is that LoT will be drastically reduced thanks to the use of AMLoCor when compared with an average carbon steel. For design purposes LoT data for classical steel grades in accordance with EN 10248: 1995 are available, either based on local experience or on recommendations and standards (EAU 2004, EN 1993-5: 2007).

From these, design LoT data for AMLoCor are obtained using the **Corrosion Impediment Ratio (CIR)**

$$CIR = \frac{LoT_{Steel}}{LoT_{AMLoCor}} \Rightarrow LoT_{AMLoCor} = \frac{LoT_{Steel}}{CIR}$$

CIR should be taken from the following table:

Zone	Low Water	Permanent Immersion	Splash
CIR	5	3	1

If limit state design is used, the following design verification approach is recommended:

- at ultimate limit state (ULS), design verification takes into account reduced design resistances $R_{d,cor}$ due to corrosion loss of thickness over the whole structure: $E_d \leq R_{d,cor}$
- at serviceability limit state, the structure is checked against perforation in every zone: LoT < minimum thickness.

As mechanical properties of AMLoCor grades are fully equivalent to normal piling grades, design structural resistances can be determined according to all relevant design codes used for steel sheet piling structures, like EN 1993-5:2007.

Provided the right filler material is used for welding, design verifications for welds also can be done according to these codes. For partial factor verification, it is worth noting, that due to the extreme care required during manufacturing of piling products in AMLoCor, scattering of properties is limited and partial factors for the material properties used for piling steel grades fully apply.

Cost comparison

Compared with the unprotected steel piling solution the use of AMLoCor leads to considerable savings in steel weight, as long as corrosion LoT in the immersion zone is governing the design.

On the other hand, Cathodic Protection (CP) always leads to the minimum weight of the structure. But it generates significant additional cost for both, investment and maintenance. Also galvanic CP has an important environmental impact on the sheet pile solution[1)], and cannot protect the sheet pile wall on the atmospheric and splash zones. The cost for CP is proportional to the projected wet surface of the sheet pile wall, whereas the additional cost for the AMLoCor is proportional to the weight. From this it transpires that the lighter the piling structure, the higher the cost advantage for the AMLoCor solution.

[1)] Hettinger, A.L.; Bourdouxhe, M.P.; Schmitt, A. "Comparative Environmental evaluation of retaining structures made of steel sheet piling or reinforced concrete". ArcelorMittal, 2010.

Fabrication, connections, maintenance

The intrinsic properties of AMLoCor make it a 'special' steel grade with respect to welding. Specific welding procedures have been worked out to ensure state-of-the-art welding. Welders also have to be certified accordingly. The choice of the electrodes is important. Please contact us for more information on the different welding procedures.

Splicing and special piles can be based on EN 12063, except for the welding procedures. Welding procedures are referenced in the German General Technical Approval Z-30.10-55.

The C9 connectors are available in AMLoCor grade. For other special connectors in AMLoCor, please contact us.

In order to avoid damages to connecting devices it is important to design the connection carefully and ensure that the different elements from different steel grades are adequately protected.

One essential parameter is the contact surface of the different steel elements (bolts, walings, etc.).

In very unfavourable conditions, an insulated material at the interface between different elements may be recommended.

AMLoCor is compatible with all coating systems that can be applied on standard sheet piling steel grades. Galvanization is not recommended in combination with AMLoCor, as corrosion protection is already ensured by this steel grade. Coatings shall be compatible with cathodic protection, if CP is foreseen. From an economical point of view, combining AMLoCor with a CP may be a cost-effective solution in certain instances.

Sheet pile walls in AMLoCor do not need any specific maintenance. Depending on the design method used, a regular survey of the coatings and residual thickness of sheet piles is highly recommended.

Fig. 8. AMLoCor beam blank used for rolling sheet piles.

Installation

It is common practice to analyse the driveability of new steel grades during the development stage. Having a good toughness, it was never really an issue, but nevertheless, a driving test in very hard soil conditions was performed in Denmark, in order to compare the behaviour of one section rolled in a 'standard' S 355 GP vs. AMLoCor steel grades. The whole test programme was done under the supervision of an independent body to certify the results of the test. Piles were driven with an impact hammer and a vibratory hammer, and then pulled out for visual inspection and measurement of the section geometry. Additionally, a PDA analysis of the piles was done during the driving. The test confirmed that AMLoCor performed as well as equivalent carbon steel in hard driving conditions.

AMLoCor sheet piles can be installed with all the typical driving equipment: impact hammer, vibratory hammer or hydraulic presses.

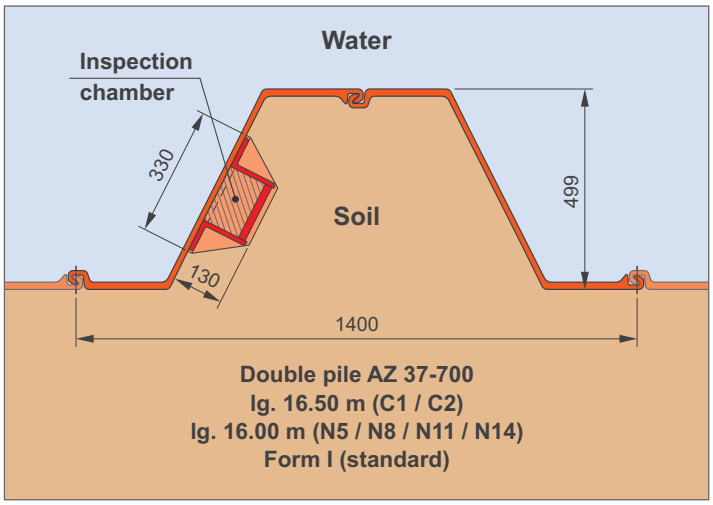


Fig. 9. Detail of a special sheet pile for monitoring the residual thickness.

Services

The expertise of the engineers of our technical department allowed us to become a reference for many design engineers, project owners and contractors seeking professional advice. Our skilled engineers will assist you with any technical issue, free of charge. If you need a welding procedure, or guidance on fabricating special sheet piles, on sealants, on design, layout drawings, etc, do not hesitate to contact us.

The longevity of AMLoCor is key and being tested in different ports. Our Research and development department has created a special measuring device to allow the measurement of the residual thickness at different levels along a structure. This requires special sheet piles being fabricated beforehand and installed as part of the quay wall. A manhole on the quay wall surface allows the introduction of the device behind the sheet pile wall. Traditional inspection methods (ultra sonic sensor), performed from the waterside, require cleansing of the rust layer. Corrosion products are removed, thus activating the steel surface. As a result, corrosion is reinitialized and measurement campaigns are distorted. The new developed method will yield more accurate results and will not damage the corrosion products. Measurements can be done every year, over a period of minimum five years. Our R&D department can assist project owners with this type of additional survey of the structure.

ArcelorMittal can also help with the elaboration of a tender specification for AMLoCor steel grades.

Reference case: Port of Shoreham, UK

Port of Shoreham in the UK installed a pilot wall in 2010. The anchored quay wall is ~30 m long, with one anchor level, and a retained height of 8.7 m. It utilizes sheet piles from a trial rolling, 16.0 m long AZ 37-700 sheet piles in AMLoCor Blue 355, with a yield strength of 355 MPa. The vibratory hammer used to drive the first meters into the ground was a PVE model '2315' with a maximum amplitude of 16 mm and a centrifugal force of 870 kN. If required, the sheets were driven to final elevation with a double acting hydraulic impact hammer, a BSP model 'SL 30' with a 2.5 t ram mass, a drop height of 1.25 m. It can provide 30 kNm of energy per blow at full stroke. The sheets were driven through an alluvial gravel layer (with SPT blow counts up to 25) down into a stiff alluvial clay layer. Some sheets penetrated the chalk layer.

Four sheet piles were installed with the additional channel elements required for the future inspection of the residual thickness, as well as two standard S 355 GP sheet piles. These will serve as reference samples to compare the effective corrosion rates of both steel grades under the exact same conditions.

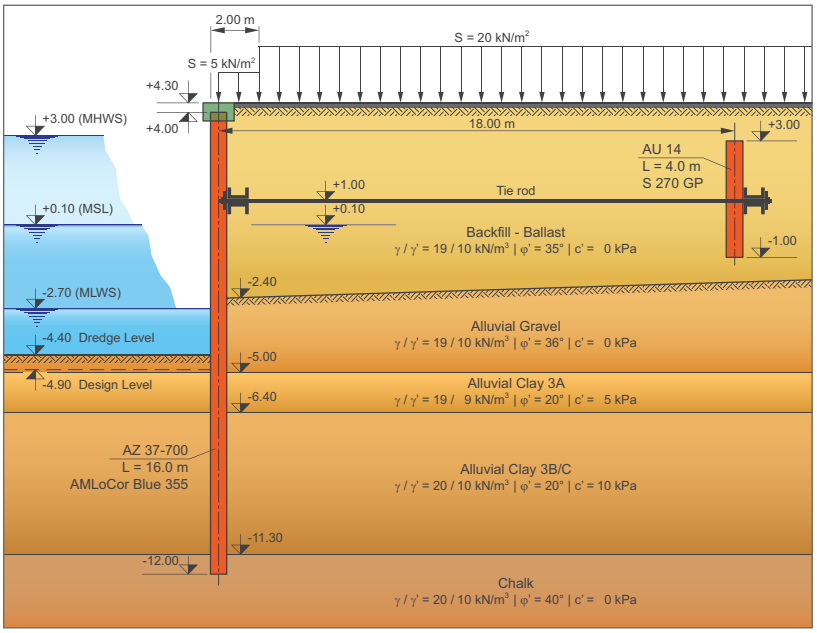


Fig. 10. Port of Shoreham. Cross Section.

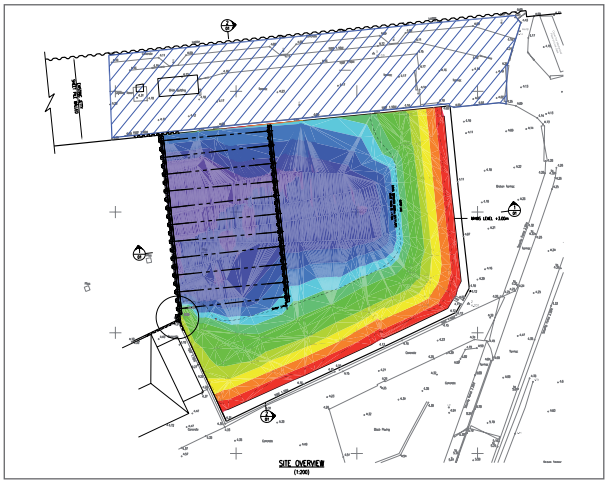


Fig. 11. Port of Shoreham. Layout of the wall.

Fig. 12. Port of Shoreham. AMLoCor steel sheet pile wall.

AMLoCor

The steel solution
for marine structures.

Loss of steel thickness
in seawater reduced
by a factor 3 to 5.

Reference

Spundwandprodukte aus AMLoCor Blue. Allgemeine bauaufsichtliche Zulassung Nr. Z-30.10-55. Deutsches Institut für Bautechnik (DIBt). Berlin, 01.11.2016.

Disclaimer

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