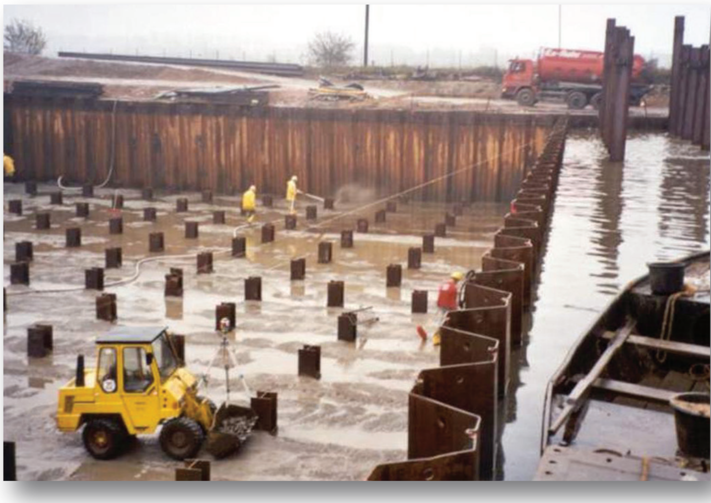
ArcelorMittal Sheet Piling

ArcelorMittal

Impervious steel sheet pile walls
Design & Practical approach



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Rational analysis
of impervious steel sheet pile walls

Until the end of the 1980's, no consistent methodology was available for the assessment of the seepage resistance of steel sheet pile (SSP) walls. The lack of such a methodology can lead to an uneconomic design, especially in cases where the achieved seepage resistance is substantially larger than the specific design requires.

ArcelorMittal, the world's leading producer of sheet piles, carried out in collaboration with Deltares (Delft Geotechnics) an exhaustive research project, on impervious steel sheet pile interlocks.

The aim of the project was to determine the rate of seepage through SSP with Larssen type interlocks for various interlock filler materials, as well as for empty and welded interlocks.

Two key areas of research were addressed:
- Setting up a consistent theory to describe the leakage behaviour through individual interlocks,
- In situ tests on SSP walls.

The research results are deployed to enable the designer to make a rational assessment of the rate of seepage for a specific case. A range of possibilities is discussed: highly permeable unsealed interlocks, sealed interlocks for medium permeability and completely impervious welded interlocks.

The cost involved in each case can be balanced against the seepage resistance requirements and the designer can choose the most appropriate solution based on this analysis.

The concept of interlock resistance

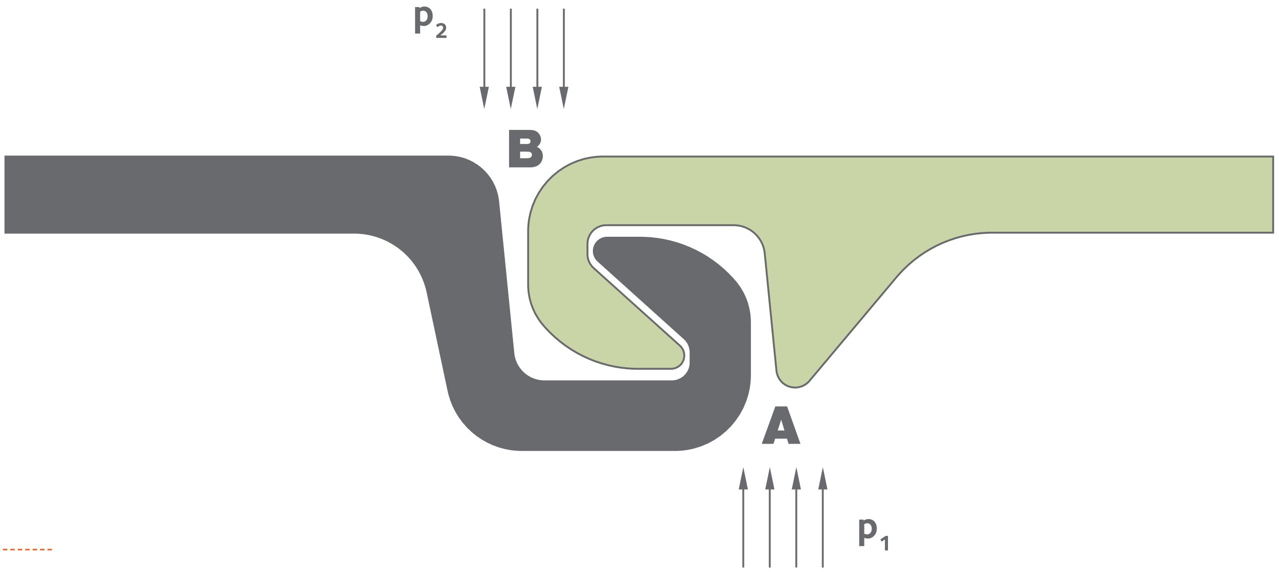


Fig. 1

The steel sheet piles themselves are completely impervious and therefore the only possible route for the fluid to pass through the wall is via the interlocks. For porous medium like slurry walls, the seepage problem can be treated with the aid of Darcy's law with a suitably chosen coefficient of permeability K:

$$v = K \cdot i \qquad (1)$$

where v is the so-called filtration rate and i represents the hydraulic gradient:

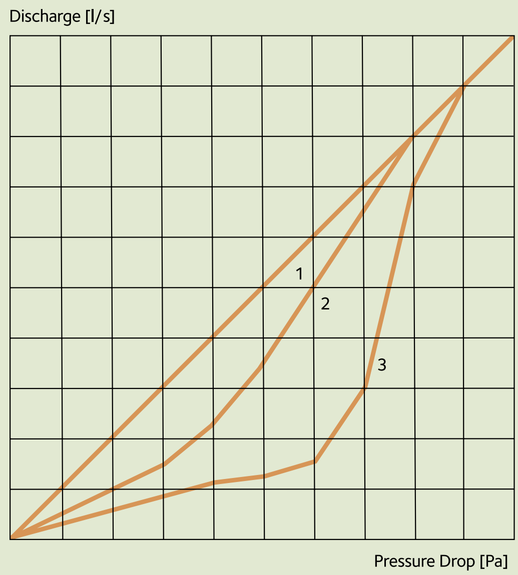
$$i = (\Delta p / \gamma_w)/s \qquad (2)$$

In a horizontal plane, it is defined as the ratio of the difference in pressure height ($\Delta p / \gamma_w$) and the length of the filtration path (s), see reference 4.

The (Fig.1) shows a horizontal cross section of a SSP interlock. The positive pressure difference between the points A and B: $p_2 - p_1$ is associated with a flow from B to A.

The real kind of flow (pipe, potential,...) is difficult to determine, but most likely it will not be a porous media type of flow and consequently Darcy's law is not applicable to seepage through a SSP interlock. To accommodate this difficulty, researchers at Deltares introduced the concept of "Interlock Resistance".

The (Fig.3) shows a typical application of SSP with different water levels on either sides of the wall leading to a pressure difference that depends on (z).
Neglecting the vertical flow inside the interlock, the relation between the discharge through the interlock in the horizontal plane and the related pressure drop p_2-p_1 is roughly as depicted in (Fig. 2). The hypothesis that no discharge occurs in the vertical direction of the interlock is more general than the commonly used Dupuit-Forchheimer assumption for the treatment of these kinds of flows, see reference 2.



1. Empty interlock
2. Interlock filled with Plugged Soil
3. Interlock filled with Filler Material

Fig. 2

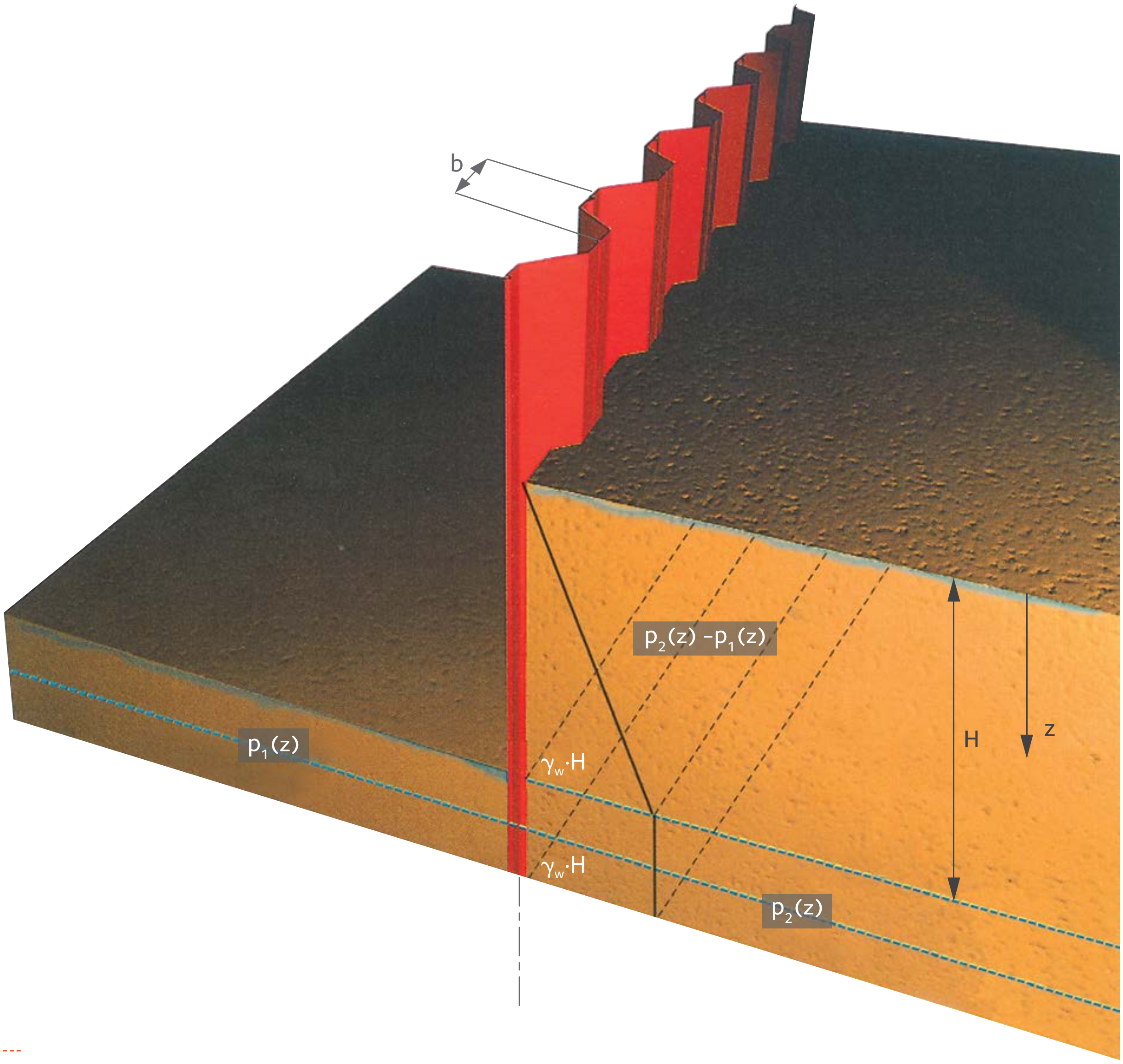


Fig. 3

A straight forward approach is to assume that the discharge is proportional to the pressure drop:

q(z) proportional to $\Delta p(z)$

The proportionality coefficient is denoted by ρ:

$$q(z) = \rho \cdot \Delta p(z)/\gamma_w \quad (3)$$

The meaning of the symbols is as follows:

$q(z)$	discharge per unit of interlock length at level z [$m^3/s/m$]
$\Delta p(z)$	pressure drop at level z [kPa]
ρ	inverse interlock resistance [m/s]
γ_w	unit weight of water [kN/m^3]

Note that (3) does not assume a Darcy type of flow. All interlock properties are encased in ρ and this parameter is determined from in situ tests.
The concept of this theory has been adapted in the EN 12063 (1999).

In situ measurements

In order to allow the design engineer to use equation (3) Deltares and ArcelorMittal carried out field tests on a large number of filler materials. The results of these tests yield values for ρ.

To expose the filler material to extreme site conditions, the sheet piles have been driven in by vibrodriver. Each filler material has been applied in several interlocks.

The discharge through each interlock was measured as a function of the applied pressure drop using a special test apparatus, see (Fig.5). The time dependent behaviour is monitored by taking readings at specific time intervals.

Table 1 shows the relevant criteria for selecting a water sealing system for an SSP wall and the range of values obtained from the tests for different types of filler materials. The results of the empty interlocks are also shown. It is most important to note that the ρ -values obtained for empty interlocks strongly depend on the soil properties, the variations being very large. The test results are plotted in (Fig.4) which generally confirms that the hypothesis which leads up to formula (3) is well-founded (see also Fig.3), at least for a certain pressure range.

The testing programme carried out by Deltares and ArcelorMittal clearly demonstrates that the use of filler products in the interlocks of a SSP wall considerably reduces the seepage rate.

Besides, field tests proved that the filler material introduced into the interlocks is confined inside the interlocks even after installation by a vibratory hammer, provided that the specifications of the manufacturer of the product and the specific application procedures elaborated by ArcelorMittal are adhered to.

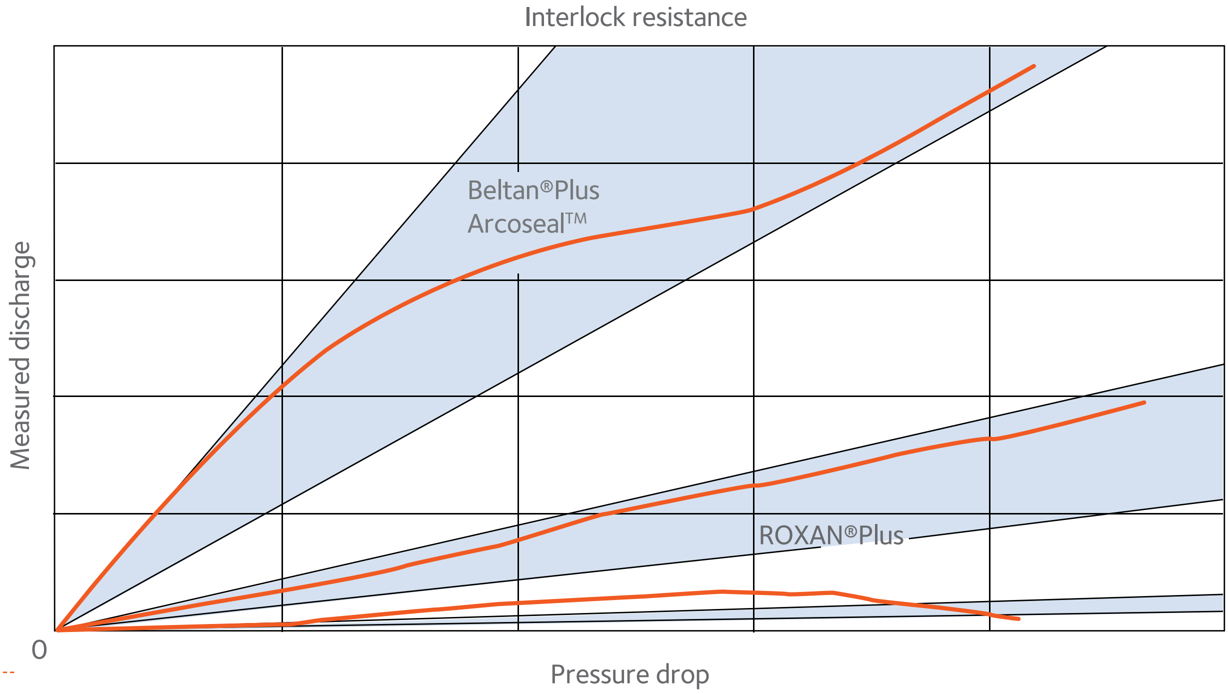
Table 1

Watertightening System	ρ [10^{-10} m/s]			Application of the system	Cost ratio **
Hydrostatic pressure	100 kPa	200 kPa	300 kPa		
Empty interlock*	> 1000	*	-	-	0
Interlock with Beltan® Plus	< 600	-	-	easy	1.0
Interlock with Arcoseal™	< 600	-	-	easy	1.2
Interlock with ROXAN® Plus system	0.5	0.5	-	with care	1.8
Interlock with AKILA® system	0.3	0.3	0.5	with care	2.1
Welded interlock	0	0	0	after excavation for the interlock threaded on jobsite	5.0

* Value available only at 150 kPa : ⩾ 4500

$$\text{** cost ratio} = \frac{\text{cost of the solution}}{\text{cost of the Beltan® Plus solution}}$$

Note: Above "cost ratio" is only an average value. The cost of a sealing system depends mainly on the sealed length (application cost), as well as the weight and the length of the sheet pile (handling costs). Please contact our technical department for a more realistic comparison.



Interlock resistance
Beltan®Plus
Arcoseal™
ROXAN®Plus
Measured discharge
0
Pressure drop

Fig. 4

Fig. 5

Practical use
of the concept

The key design formula is

$$q(z) = \rho \cdot \frac{\Delta p(z)}{\gamma_w} \qquad (3)$$

$q(z)$	discharge per unit of interlock length at level z [$m^3/s/m$]
$\Delta p(z)$	the pressure drop at level z [kPa]
ρ	the inverse interlock resistance [m/s]
γ_w	unit weight of water [kN/m^3]

The geometrical definitions are given in (Fig.1 and 2).

A. Discharge through a SSP wall: simple case

(Fig.6) shows a building pit in which the water table has been lowered about 5 m. The toe of the SSP wall goes right down to the bottom layer; the layer is assumed to be virtually impervious. This assumption allows neglecting the flow around the toe (the value of K required to be able to assume an impervious bottom layer will be dealt with in section C). The resulting hydrostatic pressure diagram is easily drawn (Fig.6): max $(\Delta p) = \gamma_w \cdot H$

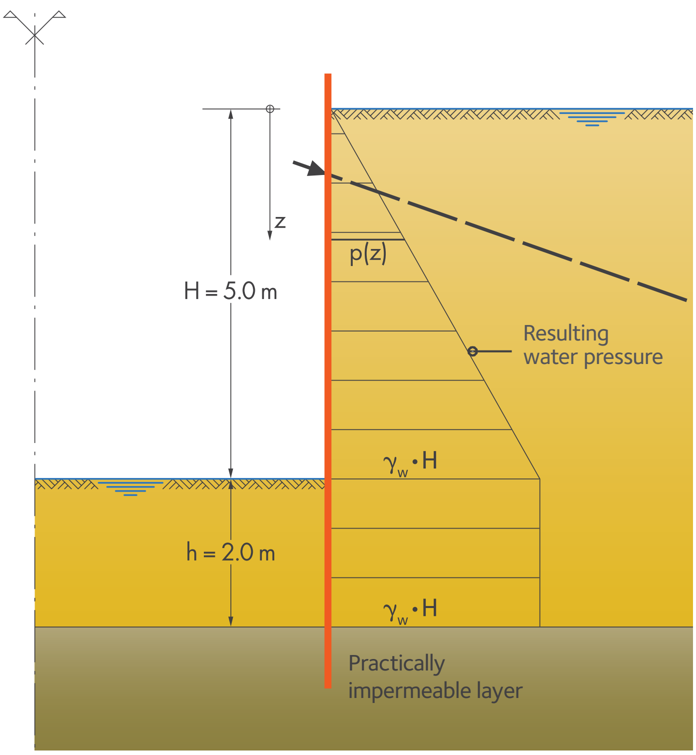


Fig. 6

The total discharge through one interlock is obtained:

$$Q_1 = \int_0^{H+h} q(z) \cdot dz = (\rho/\gamma_w) \cdot \int_0^{H+h} \Delta p(z) \cdot dz \qquad (4)$$

With the pressure drop:

$$\Delta p(z) = \begin{cases} \gamma_w \cdot z & z \leq H \\ \gamma_w \cdot H & H \leq z \leq H + h \end{cases}$$

Thus the integral in (4) yields the area in the pressure diagram and a result for Q1 follows:

$$Q_1 = \rho \cdot H \cdot (0.5\, H + h) \qquad (5)$$

The total number of interlocks in the SSP wall for the building pit is:

$$n = L / b \qquad (6)$$

L: length of the perimeter of the building pit [m]
b: system width of the pile [m]

The total discharge into the pit is:

$$Q = n \cdot Q_1 \qquad (7)$$

(7) represents a safe approximation for the discharge, as certain aspects have been neglected, for example the influence of the flow pattern on the geometry of the water table.

Numerical example

For a building pit with a SSP wall made of AZ18-700, (b = 0.70 m), the perimeter length is L =161m.

The interlocks are filled with a waterswelling filler and described by its inverse interlock resistance ρ value

$$\rho = 0.5 \cdot 10^{-10} \text{ m/s}$$

(Fig.6) shows the geometrical data

H = 5 m and h = 2 m.

Number of interlocks:

$$n = 161 / 0.70 = 230 \qquad (6)$$

Discharge per interlock:

$$Q_1 = 0.5 \cdot 10^{-10} \cdot 5.0 \cdot (0.5 \cdot 5.0 + 2.0) \qquad (5)$$
$$Q_1 = 1.125 \cdot 10^{-9} \text{ m}^3\text{/s}$$

Total discharge into the pit:

$$Q = 230 \cdot 1.125 \cdot 10^{-9} \text{ m}^3\text{/s} \qquad (7)$$
$$Q = 2.587 \cdot 10^{-7} \text{ m}^3\text{/s}$$
$$Q = 0.93 \text{ l/h}$$

B. Comparison with porous media flow

In everyday practice the design engineer often needs to compare the performance (seepage resistance) of a SSP wall with other types of walls, such as a slurry wall (SW); a cut-off wall is an example where such a comparison is relevant.

The slurry wall may be considered as a porous medium and the flow is governed by Darcy's law.

The comparison between the SSP wall and the slurry wall can be carried out by assuming that the discharge per unit wall area is the same. With the definitions given in (Fig.7), Darcy's law (reference 2 and 4) yields a specific discharge:

$$Q_{sw} = K \cdot (\Delta p / \gamma_w)/d \qquad (8)$$

where

d	thickness of the slurry wall [m]
K	permeability of the wall in horizontal direction [m/s]
Δp	pressure drop on both sides of the wall [kPa]

The specific discharge for a SSP wall (Fig.7) follows from (3), (6) and (7) with L = 1m:

$$Q_{ssp} = (1/b) \cdot \rho \cdot (\Delta p/\gamma_w) \qquad (9)$$

Both specific discharges are equal:

$$Q_{sw} = Q_{ssp} \qquad (10)$$

This condition yields:

$$(K/d) = (\rho/b) \qquad (11)$$

For a given SSP wall relation (11) permits the calculation of the properties of a slurry wall with the same seepage properties.

Assuming a slurry wall of a thickness d=1m, the equivalent K-value is:

$$K_e = \rho \cdot (1\text{m})/b \qquad (12)$$

It must be kept in mind however that the nature of the two flows is quite different!

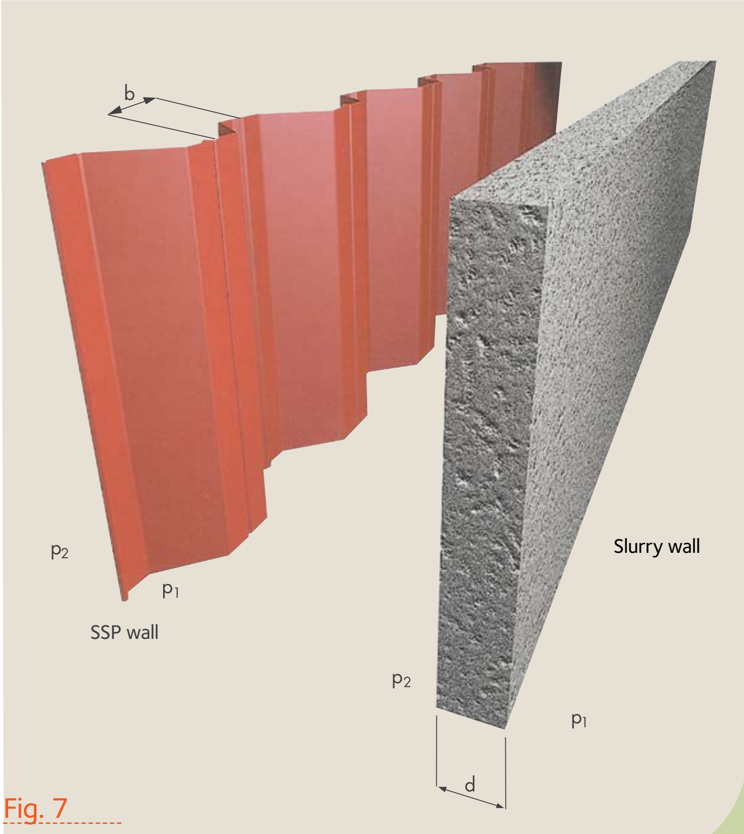


Fig. 7

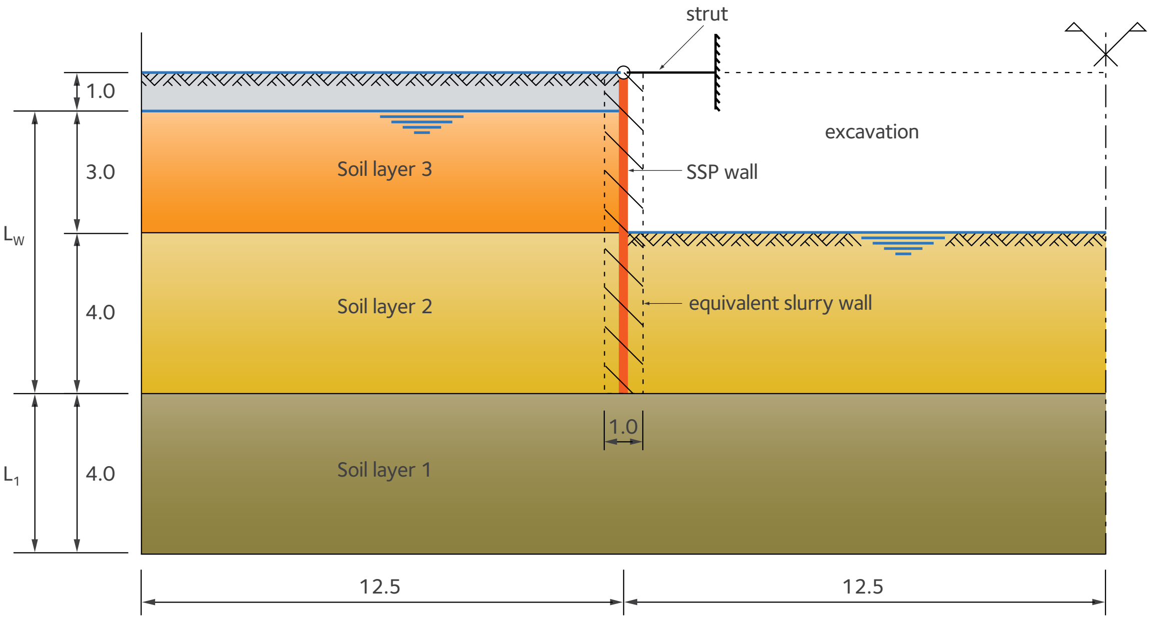


Fig. 8

C. Two dimensional flow around the toe and through an SSP wall

In section A the flow around the toe of the SSP wall was neglected. This is only correct if the bottom layer is much less pervious than the wall. If this is not the case, then the water flow both through and around the wall needs to be considered. This is done with the aid of a 2D-seepage calculation program.

Because this software deals with Darcy type flows only, the behaviour of the SSP wall has to be treated as a porous media flow, using an equivalent slurry wall defined by its thickness d, and its permeability K, according to (11).

In order to show the versatility of this approach and the influence of the bottom layer on the flow, four different cases have been analysed.

All cases pertain to the same situation: an excavation for a building pit (Fig. 8). The SSP wall is used as a retaining structure and is simulated by an equivalent slurry wall with a thickness d = 1m.
The hydraulic conductivity of the slurry wall K_w can be evaluated using (12). The calculations were performed with the PLAXIS finite element code.
(Table 2) summarises the input and output data of the four cases. The resulting flow fields are shown in (Fig. 9, 10, 11 and 12).

row	item	case 1	case 2	case 3	case 4
1	K_i [m/s]: soil layer 1, i=1 soil layer 2, i=2 soil layer 3, i=3	10^{-4} 10^{-4} 10^{-3}	10^{-4} 10^{-4} 10^{-3}	10^{-7} 10^{-4} 10^{-3}	10^{-4} 10^{-4} 10^{-3}
2	equivalent slurry wall: $K_w = \rho/b$ [m/s]	10^{-6}	10^{-5}	10^{-6}	10^{-5}
3	geometry: L_w / L_1	7/4	7/4	7/4	7/8
4	$K_w \cdot L_w / K_1 \cdot L_1$	0.0175	0.175	17.5	0.0875
5	total discharge (wall + bottom layer) according to the PLAXIS Model : D_t [l/h]	518	742	60.5	887
6	discharge through wall according to (section A): D_w [l/h]	59.4	594	59.4	594
7	D_w / D_t [%]	11	80	98	67

Table 2

case 1: $K_w \cdot L_w / K_1 \cdot L_1 = 0.0175$

The wall is much less pervious than the bottom layer. There is hardly any discharge through the wall; most of the flow takes place around the toe (Fig. 9).

case 2: $K_w \cdot L_w / K_1 \cdot L_1 = 0.175$

The discharge through and around the wall is of the same order of magnitude (Fig. 10).

case 3: $K_w \cdot L_w / K_1 \cdot L_1 = 17.5$

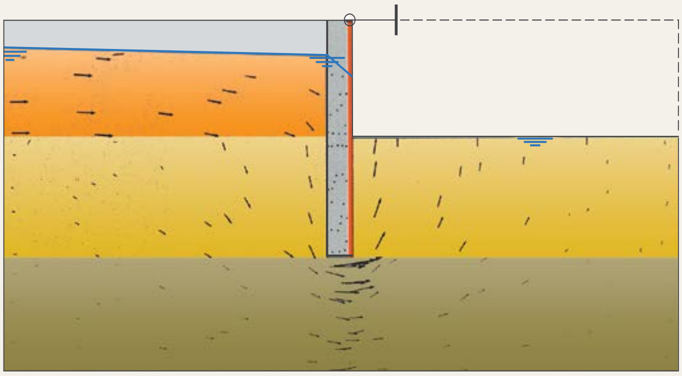
The bottom layer is practically speaking impervious. Seepage through the wall dominates the flow field (Fig. 11).

case 4: $K_w \cdot L_w / K_1 \cdot L_1 = 0.0875$

The K-values are the same as in case 2, but the thickness of the bottom layer has been doubled (Fig. 12). This emphasises the influence of the geometry on the flow field. Compared to case 2, the total discharge has increased due to the extra seepage around the toe and through the bottom layer (Table 2).

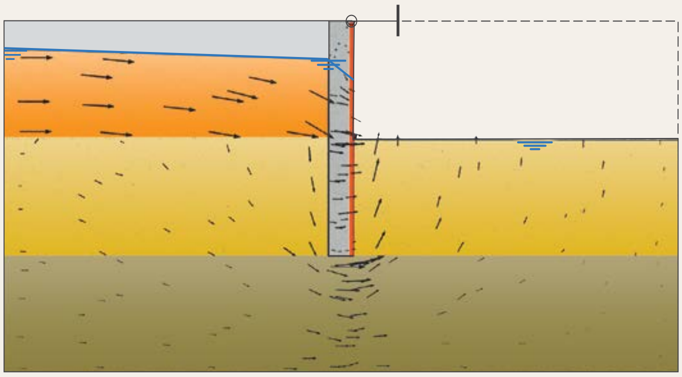
In Table 2, row 5 gives the total discharge (D_t) per linear meter of retaining wall (Fig. 8); row 6 contains the discharge D_w through the wall itself according to the simplified approach of section A.

The ratio D_w / D_t is the ratio of the discharge through the wall compared to the total discharge, while the ratio $K_w \cdot L_w / K_1 \cdot L_1$ encases relevant parameters of the geometry and the permeability of the wall relative to the permeability of the bottom layer.



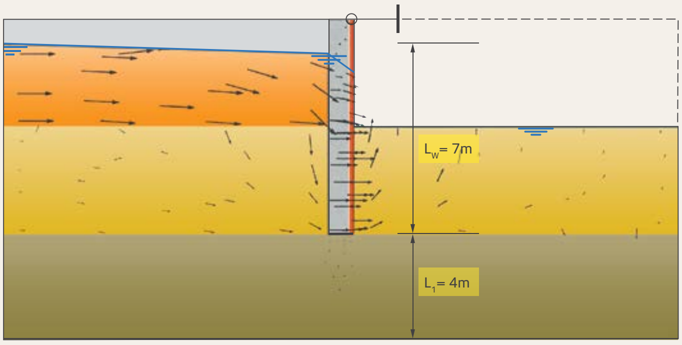
Ultimate flow field with phreatic line
Extreme velocity 6.57E-05 units
Case 1

Fig. 9



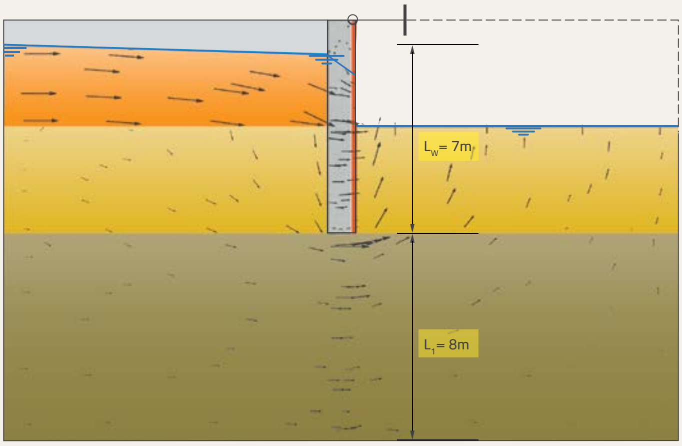
Ultimate flow field with phreatic line
Extreme velocity 4.21E-05 units
Case 2

Fig. 10



Ultimate flow field with phreatic line
Extreme velocity 4.61E-06 units
Case 3

Fig. 11



Ultimate flow field with phreatic line
Extreme velocity 4.74E-05 units
Case 4

Fig. 12

Comparison of both ratios in "Table 2" confirms the assumptions in section A
(Case 3: Kw • Lw/K1 • L1 = 17.50 ⇒ Dw/Dt = 98%).

The diagram of (Fig. 13) warrants the conclusion that for ratios as low as

$K_w \cdot L_w / K_1 \cdot L_1 > 0.175$

80% of the discharge occurs through the wall and therefore the simplified approach yields acceptable results.

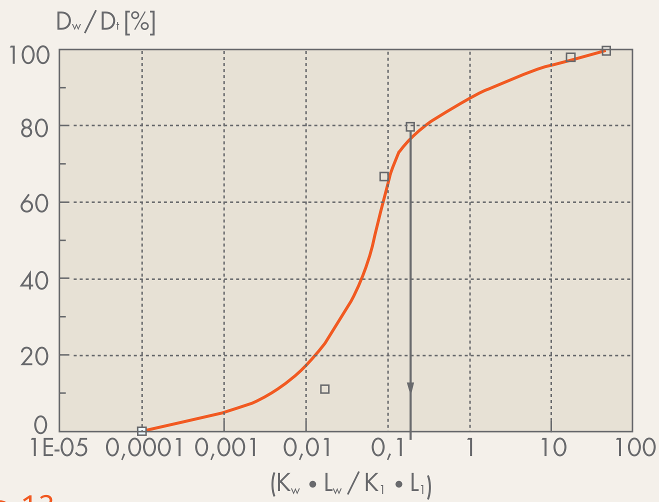


Fig. 13

Summary of the design approach

The imperviousness
of Steel Sheet Pile Walls

For practical design purposes it is advisable to assess the degree of the required seepage resistance in order that a cost effective solution may be selected. Depending on the requirements, there are basically three possible solutions:

1. In applications such as temporary retaining walls a moderate rate of seepage is often tolerable. A SSP wall made of piles with ArcelorMittal's Larssen interlocks provides in most cases sufficient seepage resistance.
2. In applications where a medium to high seepage resistance is required –such as cut-off walls for contaminated sites, retaining structures for bridge abutments and tunnels –double piles with a seal-welded intermediate interlock should be used. The seal-weld made in a workshop is as impervious as the steel itself. The free interlock of the double pile that will be threaded on site is sealed with a filler material. The lower end of the resistance range is adequately served by «Arcoseal™» or «Beltan® Plus» fillers, but it is noted that their use is limited to water pressures up to 100 kPa. For high impervious requirements, as well as water pressures up to 200 kPa, the «ROXAN® Plus» or «AKILA®» system should be utilized. A wall designed in this way is between 100 to 1000 times more impervious than the simple sheet pile wall without filler. The AKILA® system is the only system that resists water pressures up to 300 kPa.
3. A 100% watertightness may be obtained by welding every interlock. Double piles with a seal-welded common interlock, executed in a workshop, are used for the construction of the wall. The interlock that needs to be threaded at the job site has to be welded on site after excavation.

The table below may be used to compare the rate of seepage of a SSP wall and a slurry wall. The hydraulic conductivity which a slurry wall of a thickness D has to provide in order to obtain the same upper limit on the discharge at the same water pressure as the SSP wall, can be determined for a given SSP wall.

Steel sheet pile wall			Hydraulic conductivity K [10^{-11}m/s] of an equivalent slurry wall with a thickness D [(x)]		
Section	Common interlock seal-welded in workshop	Sealing system	D = 600 mm	D = 800 mm	D = 1000 mm
Z (b = 700 mm)	yes	Beltan® Plus or Arcoseal™	2571.4	3428.6	4285.7
	yes	ROXAN® Plus or AKILA®	1.3	1.7	2.1
	no	Beltan® Plus or Arcoseal™	5142.9	6857.1	8571.4
	no	ROXAN® Plus or AKILA®	2.6	3.4	4.3
U (b = 600 mm)	yes	Beltan® Plus or Arcoseal™	2400.0	3200.0	4000.0
	yes	ROXAN® Plus or AKILA®	1.2	1.6	2.0
	no	Beltan® Plus or Arcoseal™	4800.0	6400.0	8000.0
	no	ROXAN® Plus or AKILA®	2.4	3.2	4.0

[(x)] calculated with ρ_m from Table 1 for an hydrostatic pressure of 100 kPa

Example

A SSP wall is made of AZ double piles with a shop welded intermediate interlock and ROXAN® Plus in the interlock to be threaded on site. In order to achieve the same discharge, a slurry wall of 80 cm thickness would require an hydraulic conductivity

$K = 1.7 \cdot 10^{-11} m/s$

To calculate the rate of discharge through the SSP wall (driven into a bottom layer, assumed virtually impervious), the data that need to be provided are (see Fig. 4):

H: the difference in head between the water tables at either side of the wall,

h: the distance from the top of the impervious bottom layer up to the lower water table level.

Discharge through one interlock that is not welded:

$$Q_1 = \rho \cdot H \cdot (H/2 + h)$$

According to the tests the inverse interlock resistance ρ may be assumed to be as follows for a preliminary design approach:

Beltan® Plus or Arcoseal™ filler material
$\rho = 6 \cdot 10^{-8}$ m/s ($p \leq 100$ kPa)

ROXAN® Plus system filler material
$\rho = 0.5 \cdot 10^{-10}$ m/s ($100 \leq p \leq 200$ kPa)

AKILA® system filler material
$\rho = 0.3 \cdot 10^{-10}$ m/s ($p \leq 200$ kPa)
$\rho = 0.5 \cdot 10^{-10}$ m/s ($p \leq 300$ kPa)

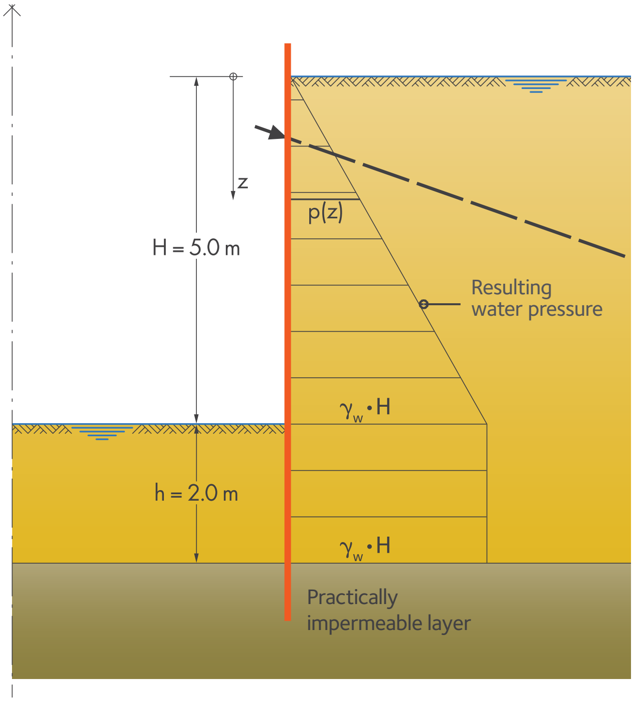


Fig. 14

The following table shows a ballpark figure of the cost per m of sealed interlock for the different solutions. The cost ratio is the ratio of the cost of a particular solution compared to the Beltan® Plus.

These costs cover the filler material and its application inside the interlock.

Value of ρ for a preliminary design approach

Watertightening System	ρ [10^{-10}m/s] 100 kPa	200 kPa	300 kPa	Maximum water pressure difference [kPa]	Cost ratio *
Empty interlocks	> 1000	-	-	100	0
Interlocks with Beltan® Plus	< 600	-	-	100	1.0
Interlocks with Arcoseal™	< 600	-	-	100	1.2
Interlocks with ROXAN® Plus system	0.5	0.5	-	200	1.8
Interlocks with AKILA® system	0.3	0.3	0.5	300	2.1
Welded interlock	0	0	0	-	5.0

$$\text{* cost ratio} = \frac{\text{cost of the solution}}{\text{cost of the Beltan® Plus solution}}$$

Note: Above "cost ratio" is only an average value. The cost of a sealing system depends mainly on the sealed length (application cost), as well as the weight and the length of the sheet pile (handling costs). Please contact our technical department for a more realistic comparison.

Practical approach

Main vertical and horizontal sealing systems

Watertightness of the walls is an important criteria for the selection of the construction process for certain types of projects, like underground car parks, tunnels, confinement of waste, etc...

The theoretical aspects have been explained in the first part of the brochure. However, practical aspects have to be considered when choosing one of the sealing systems.

The installation method, shipment as well as the storage itself might influence the choice of the system.

When dealing with a watertight steel sheet pile wall, two types of sealing must be distinguished:

- Vertical sealing, which consists mainly of making the sheet piling interlocks watertight. According to the requested watertightness degree, several methods can be implemented:
  - products applied in the interlocks either before or after the piles are threaded, for average performance ($\rho = 6 \cdot 10^{-8}$ m/s) to high performance ($\rho = 0.3 \cdot 10^{-10}$ m/s),
  - welding of interlocks for 100% watertightness. Welding of the common interlocks of sheet piles supplied in pairs or triples, is done in the workshop; for interlocks threaded on site, welding is done in situ above excavation level.
- Horizontal sealing, which consists of the sealed junction between the steel sheet pile wall and a horizontal construction element connected to it (for example a concrete slab, a geotextile membrane, etc.). Several examples of watertight connections are treated in this brochure. We differentiate generally two types of sealing:
  - sealing of the base slab which is often under water,
  - sealing of a cover slab.

Note

- *When the project foresees a surface treatment of sheet piling by application of coating, it is essential to inform ArcelorMittal's technical department. Indeed, the choice of the sealing system of interlocks depends not only on the watertightness degree requested by the project. To avoid any problems of adhesion, the system must also be compatible with the coating.*
- *For technical reasons, it is common practice to leave a portion of the interlock at the top and tip of the pile unsealed. The sealer starts usually around 100 mm from the top of the sheet pile unless otherwise instructed in written by the customer.*

Vertical sealing: Sealing products

Sealants with low permeability. Beltan® Plus and Arcoseal™

For applications with average performance requirements, two products are recommended: Beltan® Plus (bitumen based) and Arcoseal™ (wax based) are heated up and then poured in a hot liquid phase inside the interlocks.

		Beltan® Plus	Arcoseal™
Hydrostatic Pressure		≤ 100 kPa	
ρ		$< 600 \cdot 10^{-10}$ m/s	
Features	Composition	bitumen + polymer	mineral oil + paraffin wax
	Density	at 20 °C: 1.05 g/cm^3	at 15 °C: 0.955 g/cm^3
	Softening Point	~ 72 °C (DIN EN 1427)	~ 70 °C
	Colour	black	brown
Packaging		tins of 26 kg	barrels of 12 kg
Conditions of application	Surface covered with standing water	impossible	impossible
	Wet surface	to be avoided	impossible
	Surface temperature	- 10 °C to + 70 °C excellent	0 °C to + 70 °C excellent
Durability	Fresh water	pH 3.5 to pH 11.5 excellent	pH 2 to pH 12 excellent
	Sea water	excellent	excellent
	Mineral oil	low	low to medium
	Petrol*	very low	low
	Crude oil*	very low	low
Consumption**	Leading interlock	0.30 kg/m	0.33 kg/m
	Common & crimped interlock	±0.10 kg/m	±0.15 kg/m

(*) Tested in laboratory on a pure solution. (**) per metre of interlock

Beltan® Plus and Arcoseal™ are certified by the 'Hygiene-Institut des Ruhrgebiets' in Germany as suitable for use in contact with groundwater.

Note

A modified mix of Beltan® Plus can be recommended in some particular situations, for instance when driving sealed steel sheet piles in cold weather, or when the filler material's purpose is to prevent densification of soil particles inside the interlocks (acting more as a 'lubricant' rather than a sealant). Please contact our technical department.

Application of Beltan® Plus or Arcoseal™ in the workshop (Fig. 1 to 5)

The application of these two products in the workshop has to comply with the following requirements:

- the interlocks must be dry and grease free;
- the sheet piles must be laid out in a perfectly horizontal position;
- to achieve the required adherence, cleaning of the interlocks with compressed air, a steel wire brush or high-pressure water jet is necessary;
- to prevent the hot liquid product from flowing out of the ends of the sheet piles when the interlocks are filled, the ends must be clogged-up at the top and bottom by means of a mastic;
- the product is heated uniformly to a predefined temperature, and care must be taken not to overheat it;
- the product is stirred to give a homogeneous mixture;
- the interlocks are filled using an appropriate jug, taking into account the driving direction as well as the position in relation to hydrostatic pressure;
- for single units, only the leading interlock will be filled;
- for paired units, the intermediate interlock must be crimped, and both the intermediate as well as the leading interlock will be filled.

Note

The sealing of intermediate interlocks of double sheet piling (or more) is only achievable with «crimped interlocks». In order to achieve the strength of the crimping points, the products must be applied after crimping.

Operating mode

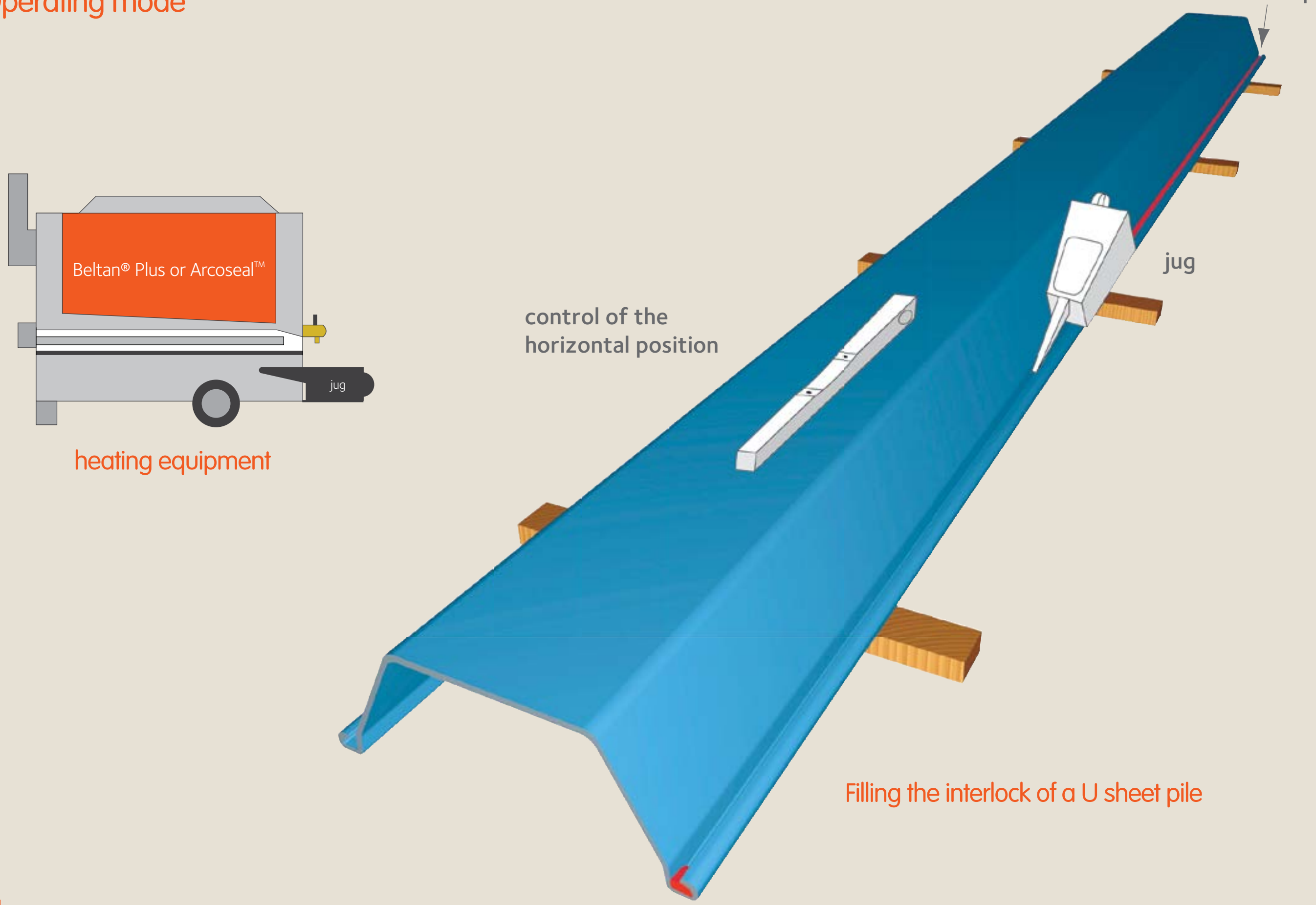


Fig. 1

Detail of application in single Z sheet piles

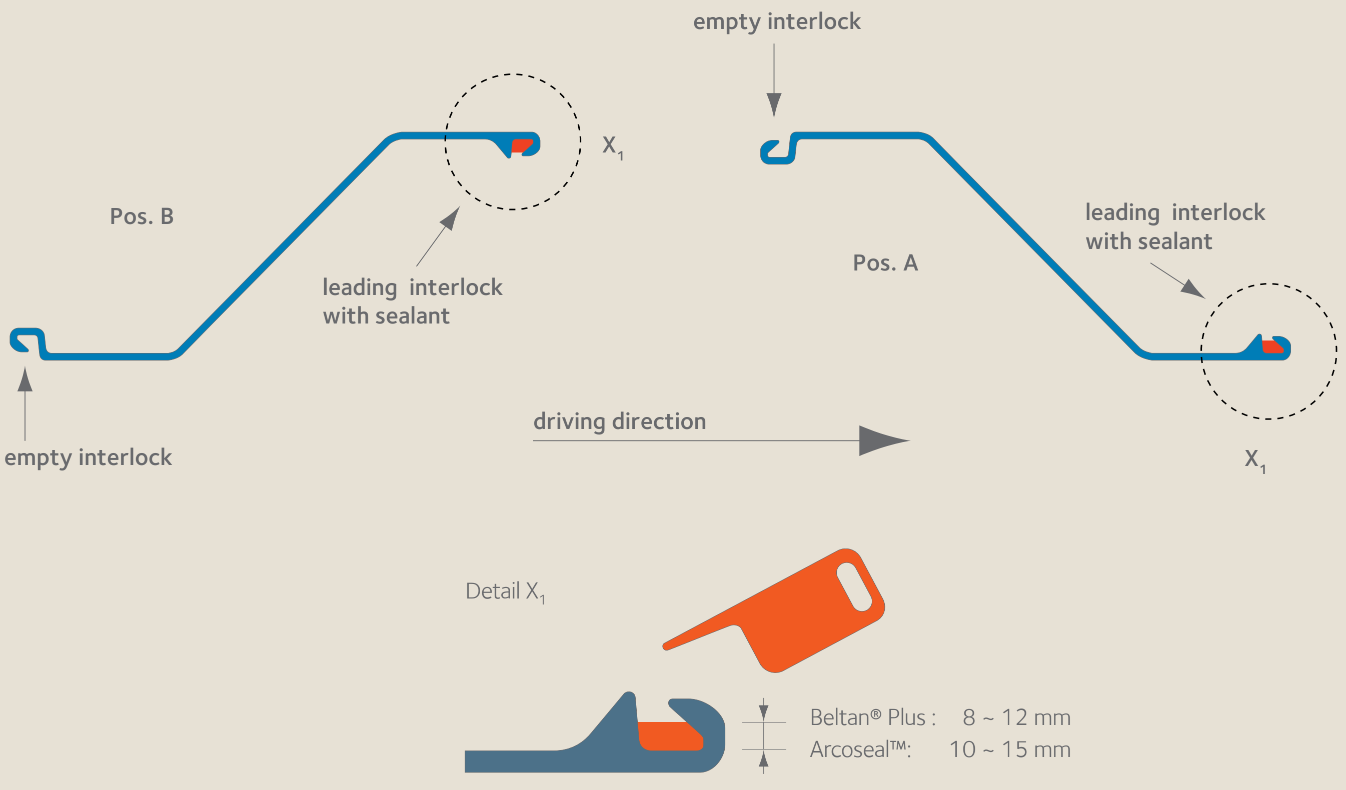


Fig. 2

Detail of application in single U sheet piles

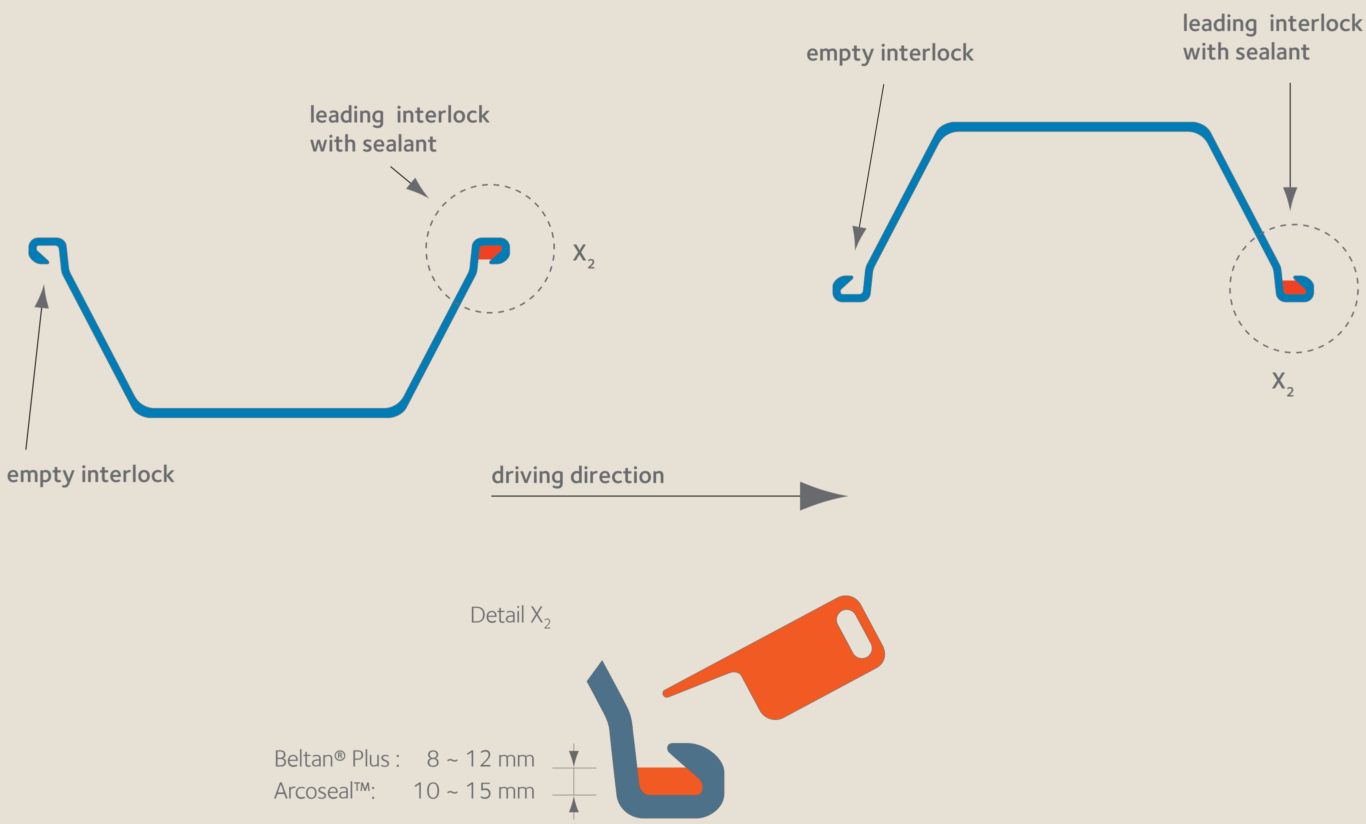


Fig. 3

Detail of application in double Z sheet piles

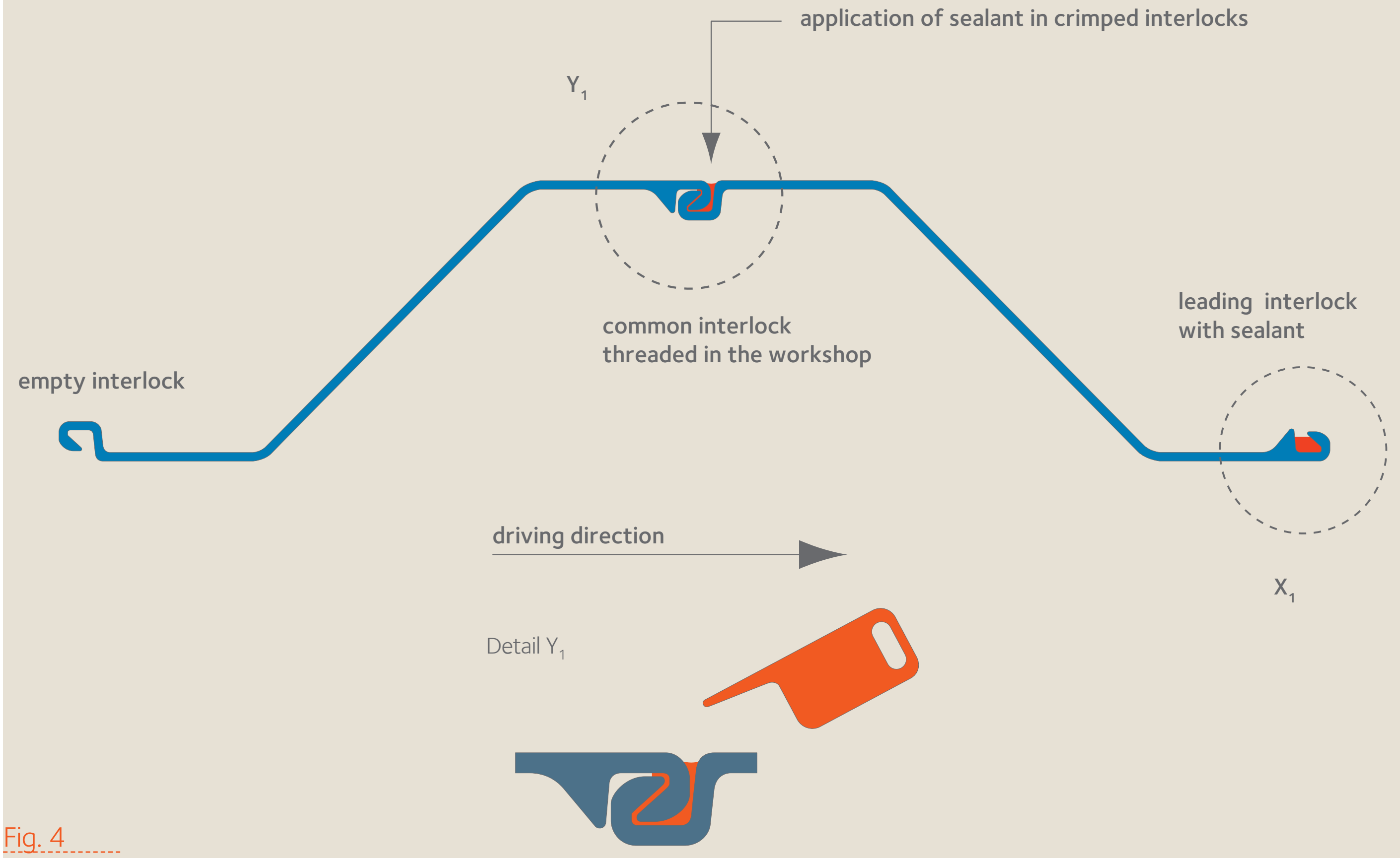


Fig. 4

Detail of application in double U sheet piles

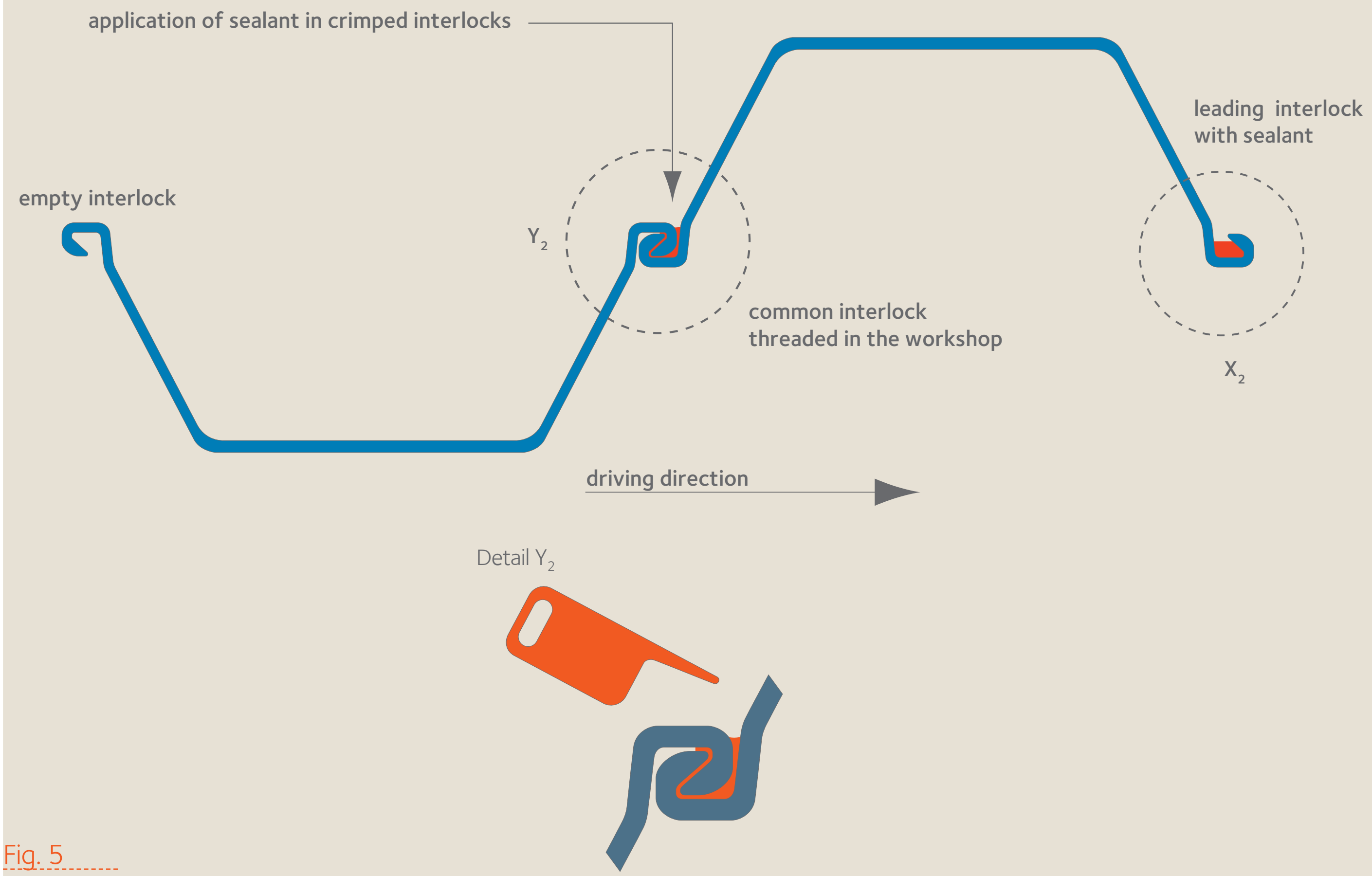


Fig. 5

Application of Beltan® Plus or Arcoseal™ in situ

The application of Beltan® Plus or Arcoseal™ in situ is made in accordance with the same requirements as for the installation in the workshop.

- In dry weather conditions, application in the open air may be acceptable.
- During rainy weather, the application must be made under shelter.

Transport of sealed sheet piles

- If the sealing product has not yet solidified, the sheet piles must be transported horizontally with the openings of the treated interlocks turned upwards.
- Once the product has cooled down, the sheet piles must be protected from high temperatures (see note below) in order to prevent the product from flowing out of the interlock.

Note
Do not exceed the softening point of the product. For instance, it is recommended to avoid exposing sealed interlocks to direct sunlight during summertime.

Driving of sealed sheet piles (Fig. 6)

Sheet piles which have been sealed using Beltan® Plus or Arcoseal™ are installed in a classic way, either by impact hammer, vibrator or by pressing.

As far as installation is concerned, it should be carried out as follows:

- the leading interlock must be the one provided with Beltan® Plus or Arcoseal™;
- when driving sealed sheet piles care must be taken with guiding so as to prevent longitudinally or transversely out of plumb. The use of guides is essential to respect a maximum tolerance of 1% on the verticality;
- when sheet piling is simply installed without driving, it is possible that the sheet pile will not slide down to the required depth if there is an excess of the product in the interlock, or if the product has stiffened at low temperature. In such cases a driving equipment or any other means will be required on site to allow correct installation. Alternatively, the recalcitrant interlock can be heated very gently and carefully with a blowlamp;
- when installing sheet piles in cold atmospheric conditions, a special mix of Beltan® Plus should be used;
- the installation of sealed sheet piles is not recommended with outside temperatures below -10°C (please contact us for more information).

Driving of sheet piles

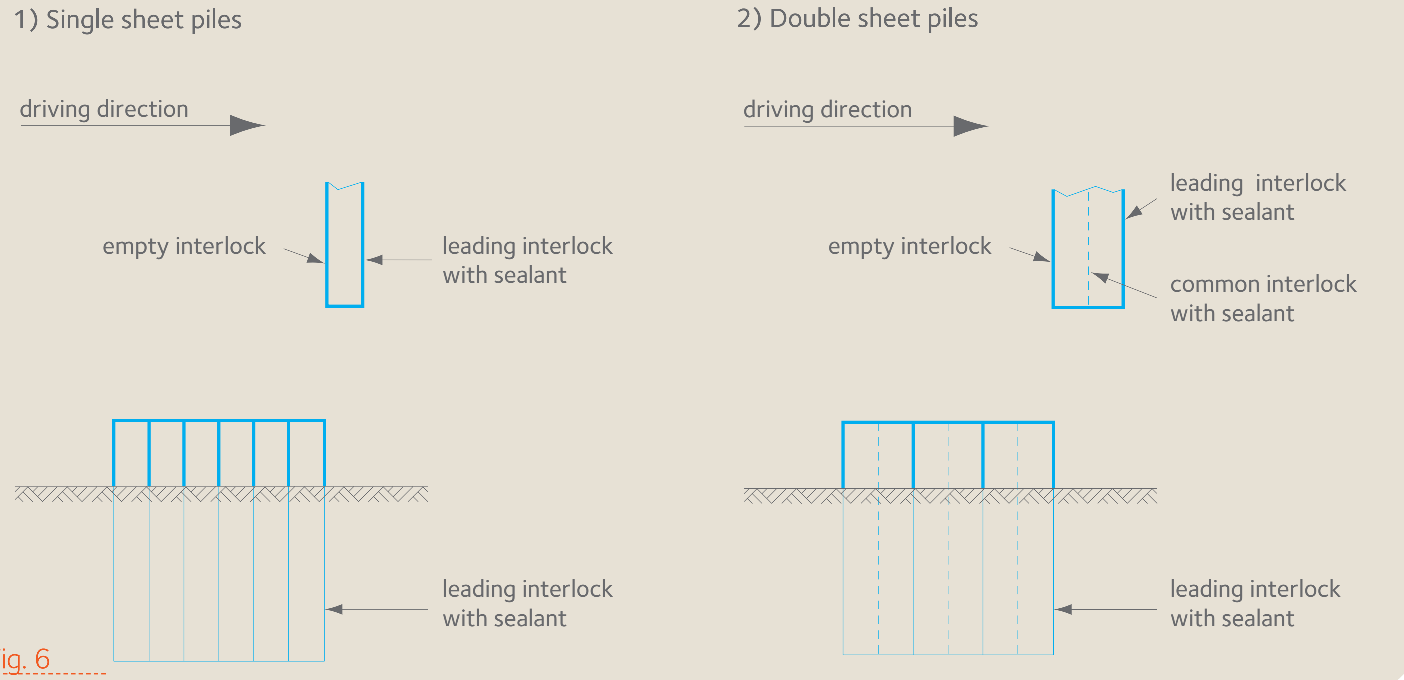


Fig. 6

Sealants with very low permeability. ROXAN® Plus and AKILA® system.

For applications with high performance requirements, it is advised to use the ROXAN® Plus or the AKILA® system.

The ROXAN® Plus system consists of a water-swelling product Sikaswell®-S2 used in the trailing interlock and a Silane Modified Polymer MSP-2 used in the threaded and crimped interlocks of double sheet piles. These two products are applied in the interlock without heating.

		ROXAN® Plus system	
Product		Sikaswell®-S2	MSP-2
Application		Trailing interlock	Common and crimped interlocks
Hydrostatic pressure		$p \leq 200\,kPa$	
ρ		$0.5 \cdot 10^{-10}$ m/s	
Features	Type	waterswelling polyurethane	one component solvent free sealant
	Composition	polyurethane	MS polymer
	Density	at 23 °C: 1.33 g/cm^3	1.48 g/cm^3
	colour	oxide red	oxide red
Packaging		barrels of 30 kg	barrels of 25 kg
Conditions of application	Surface covered with standing water	impossible	impossible
	Wet surface	critical	critical
	Surface temperature	+ 5 °C to + 35 °C	+ 5 °C to + 30 °C
	Polymerization in rain	impossible	to be avoided
	Polymerization in UV light	excellent	excellent
Durability	Fresh water	pH 3.5 to pH 11.5 excellent	pH 3.5 to pH 11.5 excellent
	Sea water	excellent	excellent
	Mineral oil	low	medium
	Petrol*	low to medium	medium
	Crude oil*	low	medium
Expansion features	Alternated cycle saturated in water / dry	excellent	-
	Temperature range -10 °C to +60 °C	excellent	-
	In bentonite slurry	-	-
Consumption	per metre of interlock	± 0.15 kg	± 0.35 kg

(*) Tested in laboratory on a pure solution.

ROXAN® Plus is certified by the 'Hygiene-Institut des Ruhrgebiets' in Germany as suitable for use in contact with groundwater.

Application of ROXAN® Plus system in the workshop (Fig. 7 to 11)

The application of the water-swelling product will always be made **in the trailing interlock** of single or threaded sheet piles, with the following requirements:

- the interlocks must be dry and grease free,
- laying out the sheet piles in a perfectly horizontal position is not necessary, but recommended,
- to achieve the required adherence, cleaning of the interlocks with compressed air, a steel wire brush or high-pressure water jet is necessary,
- application of the product by extrusion using a special template (ArcelorMittal patent LU 88397) which distributes the product properly in the interlock.

Note

Extruding using the special template is essential to ensure the correct shape of the Sikaswell®-S2 sealant.

The application of the MSP-2 product will always be made in the **intermediate interlock** of threaded and crimped sheet piles, with the following requirements:

- the interlocks must be dry and grease free,
- the sheet piles must be laid out in a perfectly horizontal position,
- to achieve the required adherence, cleaning of the interlocks with compressed air, a steel wire brush or high-pressure water jet is necessary,
- to prevent the liquid product from flowing out of the ends of the sheet piles when the interlocks are filled, the ends must be clogged at the top and bottom using a mastic,
- the interlocks are filled using an appropriate jug, taking into account the driving direction as well as the position in relation to hydrostatic pressure.

Note
Standard crimping of the common interlocks of double piles is recommended. However, for combined walls like the HZ®/AZ® system, a special crimping pattern is advisable. Please contact our technical department for detailed information.

Operating mode

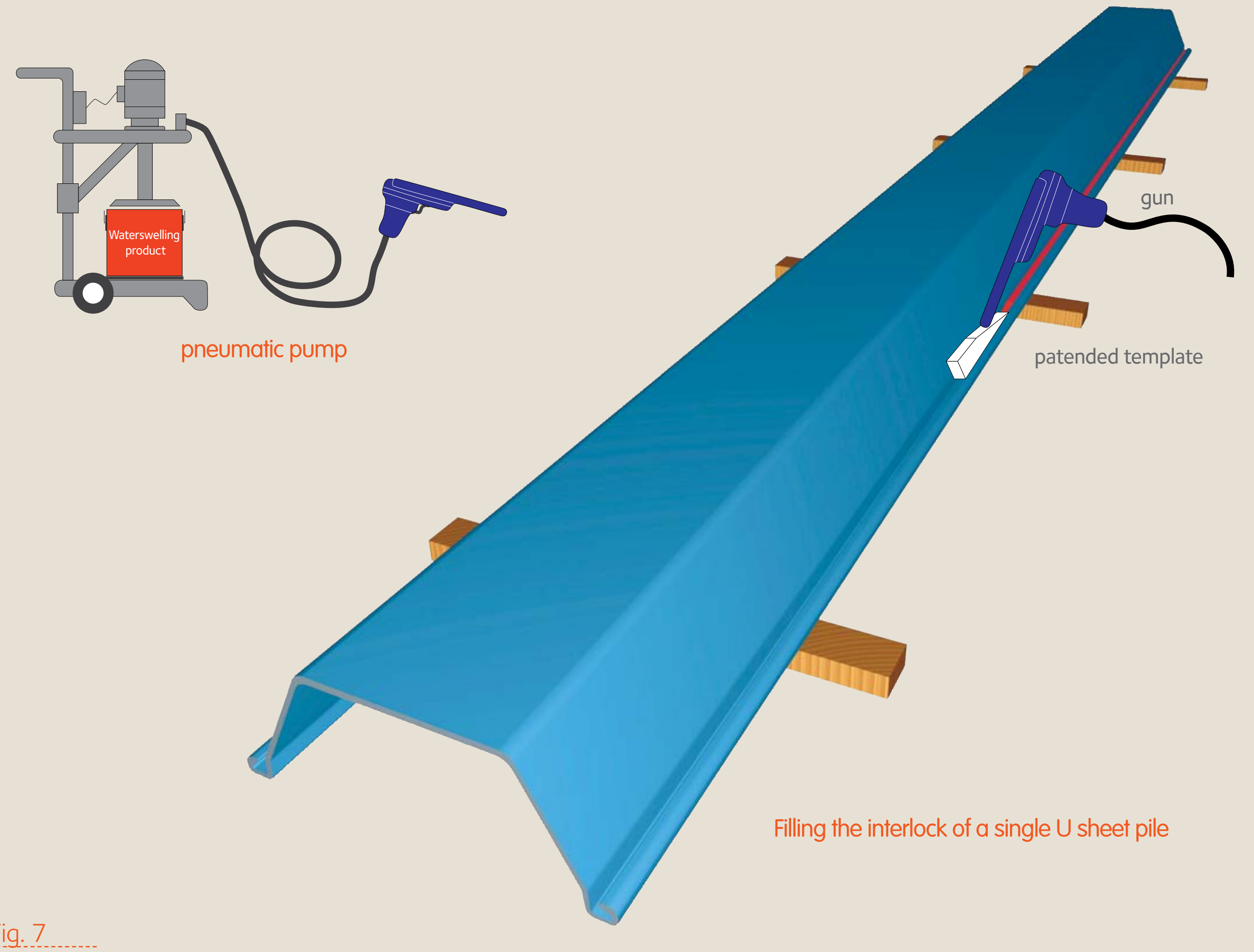


Fig. 7

Application of ROXAN® Plus system in situ

Application of the waterswelling product in situ is not advisable unless the work can be carried out under shelter. It must comply with the same requirements as for the application in the workshop (preferably under supervision of an experienced applicator).

Detail of application in single Z sheet piles

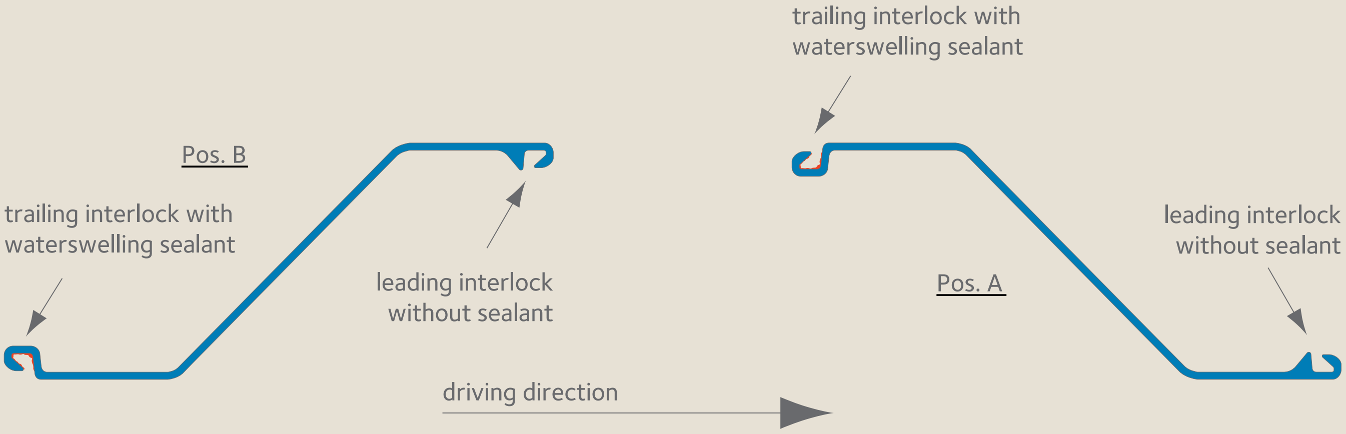


Fig. 8

Detail of application in single U sheet piles

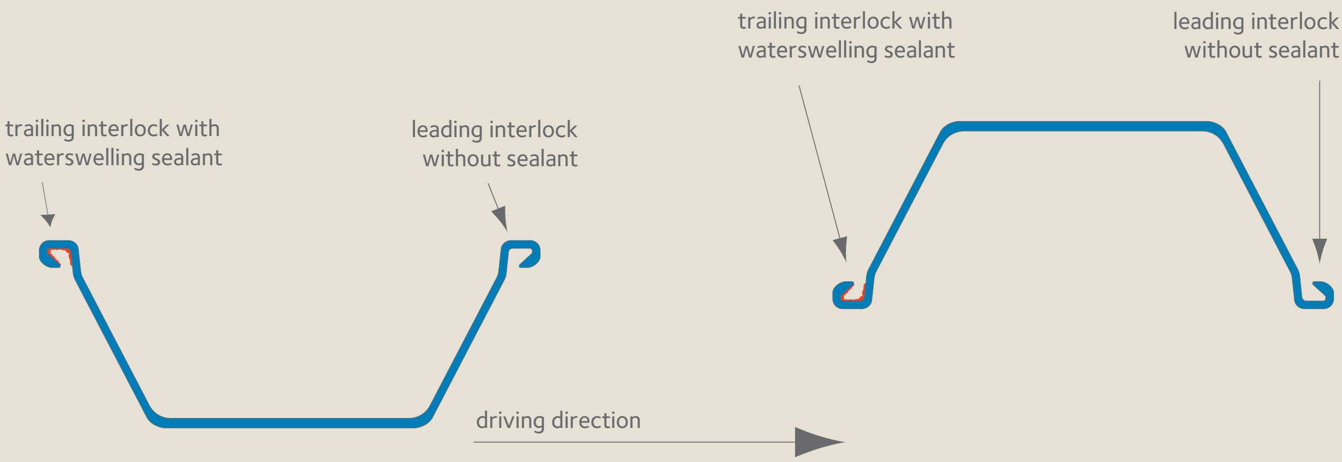


Fig. 9

Detail of application in double Z sheet piles

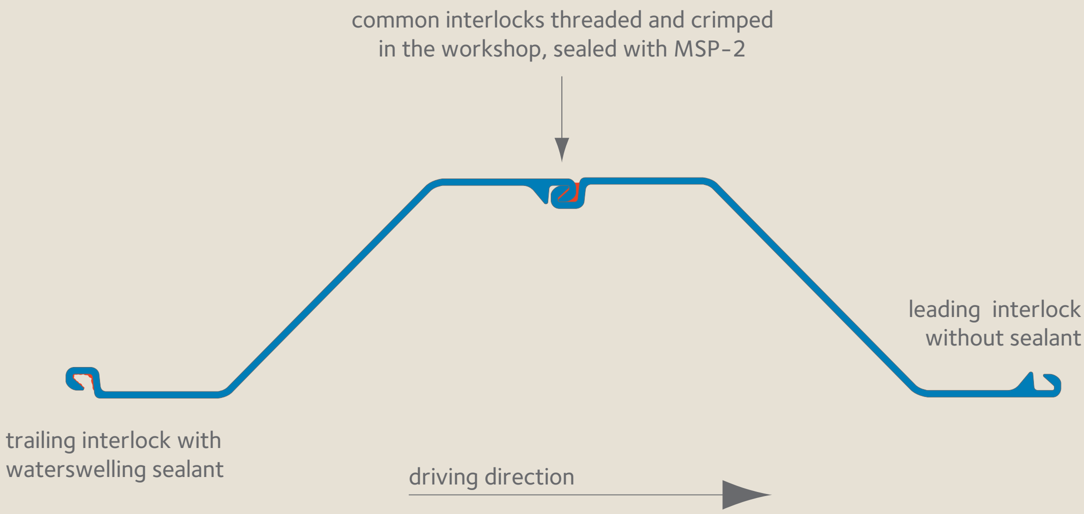


Fig. 10

Detail of application in double U sheet piles

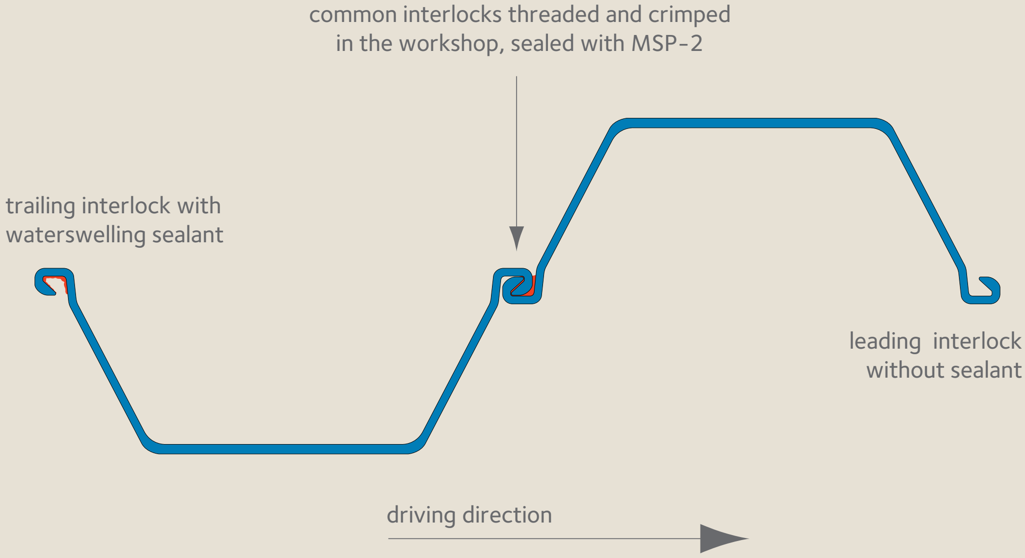


Fig. 11

Transport and storage of sealed sheet piles (Fig. 12)

Sheet piles fitted with the waterswelling product must be transported so that the waterswelling sealant never comes into contact with standing water (risk of expansion of the product after polymerization, and consequently loss of adhesion to steel). Care must be taken therefore to transport the piles with **the openings of the sealed free interlocks facing downwards.**

Transport and storage

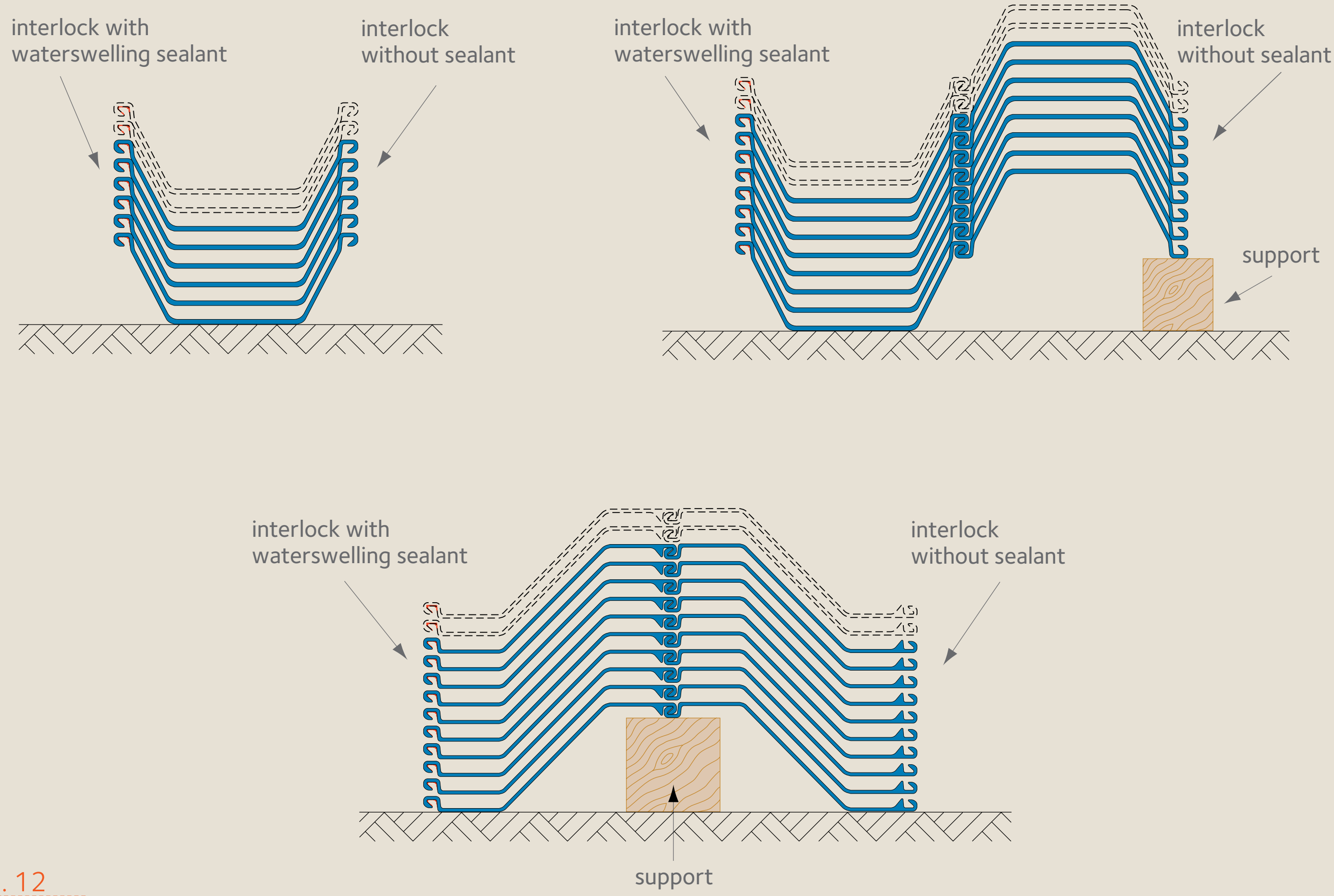


Fig. 12

Driving of sealed sheet piles (Fig. 13a & 13b)

Sheet piles with a waterswelling product are installed in a classic way, either by drop hammer, vibrator or by pressing. As far as installation is concerned, it should be carried out as follows:

- care must be taken with guiding so as to prevent the piles from being longitudinally or transversely out of plumb. The use of guides is absolutely essential and installation must be carried out so that a tolerance of less than 1% on the verticality is respected;
- sealed sheet piling is delivered with the leading interlock chamfered on the top and the trailing interlock (filled with waterswelling product) cut on the toe (Fig. 13b). These two fabricated details allow the cleaning of the leading interlock of the sheet pile already driven by the trailing interlock of the following one, during the driving process. The purpose of this operation is to avoid damaging the waterswelling product;
- the waterswelling product must be lubricated with a commercial soapy product before driving. This product can be spread in the sealed interlock using a paintbrush or by any other means;
- when sheet piling is simply placed in position without driving, it is possible that the piles will not slide down to the required depth because of the product. In such cases, a driving equipment must be provided on the site to allow correct installation;
- when piles are installed using a vibrator, care must be taken that the temperature in the interlocks never exceeds 130°C (risk of damaging the seal);
- during the installation process, **driving to final grade of each pile must be finished in less than two hours after the sealing product gets in contact with standing water** (seawater, ground water, etc). Indeed, expansion of the sealing product would cause it to be torn off if driving is resumed after that period;
- the installation of sealed sheet piles is not recommended with outside temperatures below -10°C (please contact us for more information);
- the layout and driving direction of the sheet pile wall shall be determined before ordering the sheet piles (delivery form of single/double piles, chamfering of interlocks, etc).

Driving of the sheet piles

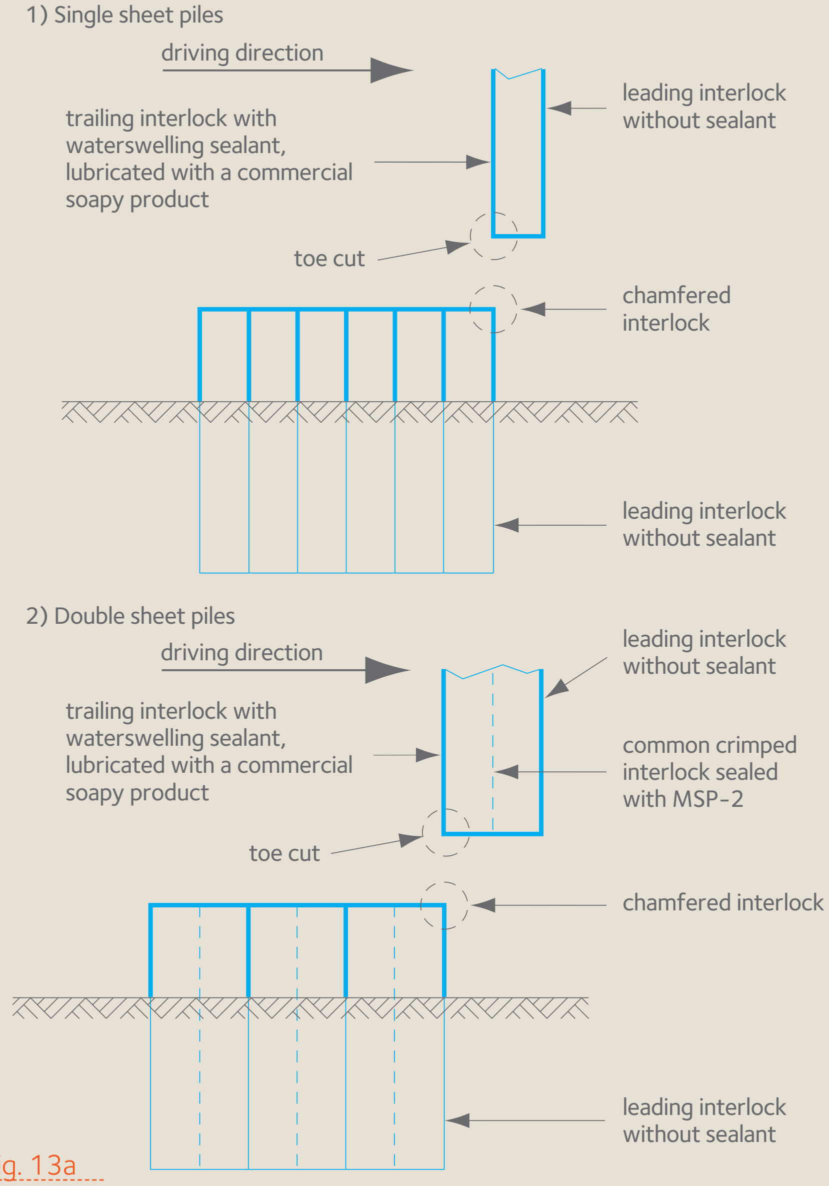


Fig. 13a

Details

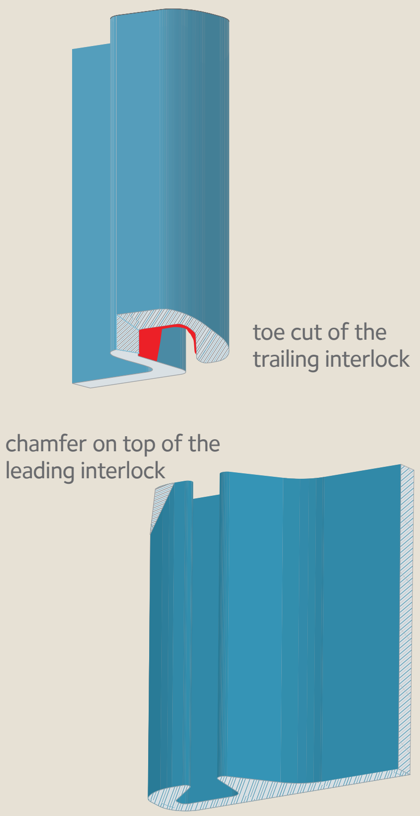


Fig. 13b

AKILA® system is a brand new environmentally friendly high performance sealing system for ArcelorMittal steel sheet piles. The system is based on three sealing 'lips' mechanically extruded into the free interlocks using a product called MSP-1. The common interlock of double piles is sealed with a second product called MSP-2.

		AKILA® system	
Product		MSP-1 +	MSP-2
Application		Trailing interlock	Common and crimped interlocks
Hydrostatic pressure		≤ 300 kPa	
ρ*		$0.5 \cdot 10^{-10}$ m/s	
Features	Type	one component solvent free sealant	one component solvent free sealant
	Composition	MS polymer	MS polymer
	Density	1.41 g/cm^3	1.48 g/cm^3
	colour	oxide red	oxide red
Packaging		barrels of 25 kg	barrels of 25 kg
Conditions of application	Surface covered with standing water	impossible	impossible
	Wet surface	impossible	critical
	Surface temperature	+ 5 °C to + 35 °C	+ 5 °C to + 30 °C
	Polymerization in rain	to be avoided	to be avoided
	Polymerization in UV light	excellent	excellent
Durability	Fresh water	pH 3.5 to pH 11.5 excellent	pH 3.5 to pH 11.5 excellent
	Sea water	excellent	excellent
	Mineral oil	medium	medium
	Petrol**	medium	medium
	Crude oil**	medium	medium
Consumption	per metre of interlock	± 0.15 kg	± 0.35 kg

(*) See Table 1 page 6 for more details.
(**) Tested in laboratory on a pure solution.

AKILA® is certified by the 'Hygiene-Institut des Ruhrgebiets' in Germany as suitable for use in contact with groundwater.

MSP-1 and MSP-2 belong to the family of **silane modified polymers** (MS-Polymers). Both products resist to humidity and weathering. Their main characteristics are:

- **single component elastic sealants,**
- UV-stable,
- **excellent adhesion to steel,**
- resist to temperatures between -40 °C and +90 °C (up to 120 °C for short periods),
- Shore A hardness after complete polymerization
  - 58 for MSP-1,
  - 44 for MSP-2 (after 14 days),
- durable in contact with freshwater, seawater, as well as various hydrocarbons, bases and acids (depending on concentration – a list is available on request).

MS-Polymers are solvent free and do not contain isocyanates. They can be considered **as environmentally friendly** products.

Sketch of MSP-1 product extruded into the trailing interlock

Application, transport and installation of the AKILA® system

Refer to the Roxan® Plus system, except that:

- the sealing products do not swell in contact with water, and hence, there are no restrictions concerning the installation time, nor the position of the sheet pile during handling and storage (once the products have cured),
- the leading interlocks have to be chamfered at the top (see Fig. 14). Penetration of soil into the interlocks during driving should be prevented, for instance by inserting a bolt at the bottom of the interlock (bolt tack welded),
- to improve the sliding of the interlocks, **an environmentally friendly lubricant** must be applied to the sealant in the interlocks prior to driving. The lubricant can be supplied by ArcelorMittal on request,
- ambient temperature during installation must be above 0 °C,
- in case of vibrodriving, sheet piles should be driven continuously at a minimum penetration rate of 3 meters per minute,
- we recommend prior consultation of ArcelorMittal's technical department in case the press-in method is to be used.

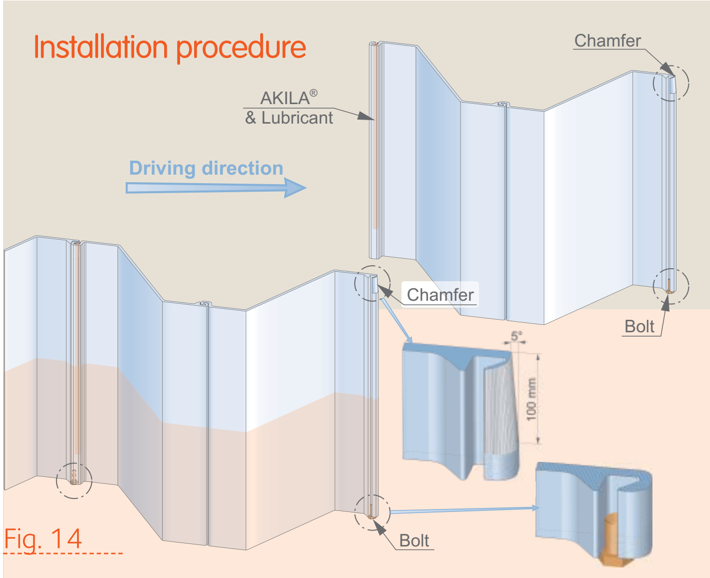


Fig. 14

Note

A series of in-situ tests were carried out in stiff clays and in soft sandy soils. Single and crimped double sheet piles fitted out with the AKILA® system were driven into the ground using an impact hammer as well as a vibratory hammer.

After installation, watertightness was tested at water pressures of 2 and 3 bar.

The testing and the results were witnessed and certified by 'Germanischer Lloyd', an independent third party.

The average inverse joint resistance ρ_m was determined according to EN 12063.

	ρ_m [10^{-10} m/s]	
water pressure	200 kPa	300 kPa
single piles (MSP-1)	0.49	0.86
double piles (MSP-1 & MSP-2)	0.33	0.47

Vertical sealing: Welding

The majority of electric arc welding processes are considered to be valid for sealing the interlocks of sheet piling threaded in the workshop or at the job site.

To prevent problems linked to the quality of welding, it is advised to analyse beforehand the feasibility and the competitiveness of the welding process, which rest on several factors, for example:

- deposition rate in kg/h,
- welding time, ie the time of arc per hour,
- efficiency of the welding product (the weight actually deposited per kg of product),
- preparation of the joint,
- welding position.

In a workshop, working conditions are well known and under control, but outside a workshop above criteria can be influenced by various factors thus particular attention must be paid to the following points:

- accessibility of the pile,
- atmospheric conditions on the site,
- mechanical strength of the weld metal (thickness of seam and penetration to be observed),
- amount of moisture inside the interlocks,
- gap between the interlocks,
- aggressiveness of the environment acting on the welds.

A detailed analysis of the different welding options will determine the most suitable process for the encountered conditions. ArcelorMittal Sheet Piling is at your disposal to advise you on the choice of the best process.

Possible ways of welding the interlocks of sheet piling (Fig. 15 and 16)

A distinction must be made between two ways of fitting together the interlocks of piles and two welding positions for them:

- in the case of piles being supplied to the site in double units, the common interlocks (threaded in the workshop) can be provided with seal-welding carried out at the factory or, possibly, on site before they are driven. This welding should be carried out in a horizontal position;
- interlocks threaded at the job-site can only be welded after the sheet piling has been installed, generally after excavation. This welding is carried out in a vertical position.

Table 1 (p. 33), summarizes the main conditions governing the choice of methods of welding in the various cases.

Note

If interlocks are to be welded on site after driving, a preliminary seal using a bituminous product is recommended. This sealing can be applied either in the factory or on site before driving, and prevents the interlock from becoming too moist which could cause serious problems during welding operations. In this case the positioning of the bituminous sealer must be as shown in Fig. 22 & Fig. 23, detail A, which prevents contact between the weld and the bituminous product! This requirement must be mentioned in the specification.

Choice of site welding process

The choice of possible processes is limited to the following systems:

a) Shielded metal arc welding (SMAW)

Advantages	Disadvantages
well-known process	rather low deposition rate (Fig. 17)
used universally	
easy to carry out	
good quality welding	
influenced very little by atmospheric conditions on the site	
minimum investment in equipment	
robust	

b) Gas shielded arc welding (GMAW)

Advantages	Disadvantages
easy to carry out	requires trained craftsmen
high deposition rate (Fig. 17)	higher investment in equipment
	gas protection lacking in the event of draughts, sometimes causing irregular quality welding

c) Flux cored arc welding (FCAW)

Advantages	Disadvantages
used universally	higher investment in equipment
easy to carry out	requires trained craftsmen
high deposition rate (Fig. 17)	
process combining the efficiency of electrode welding with a semi-automatic process	

Execution of sealing by welding double Z sheet piles

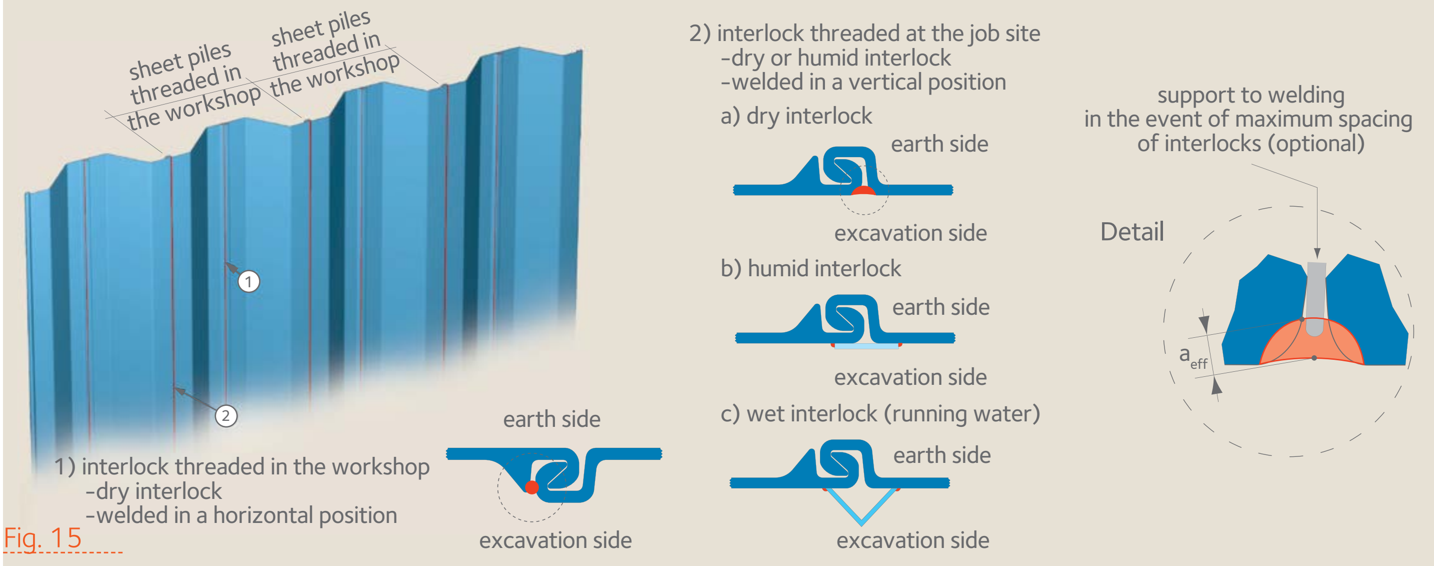


Fig. 15

Execution of sealing by welding double U sheet piles

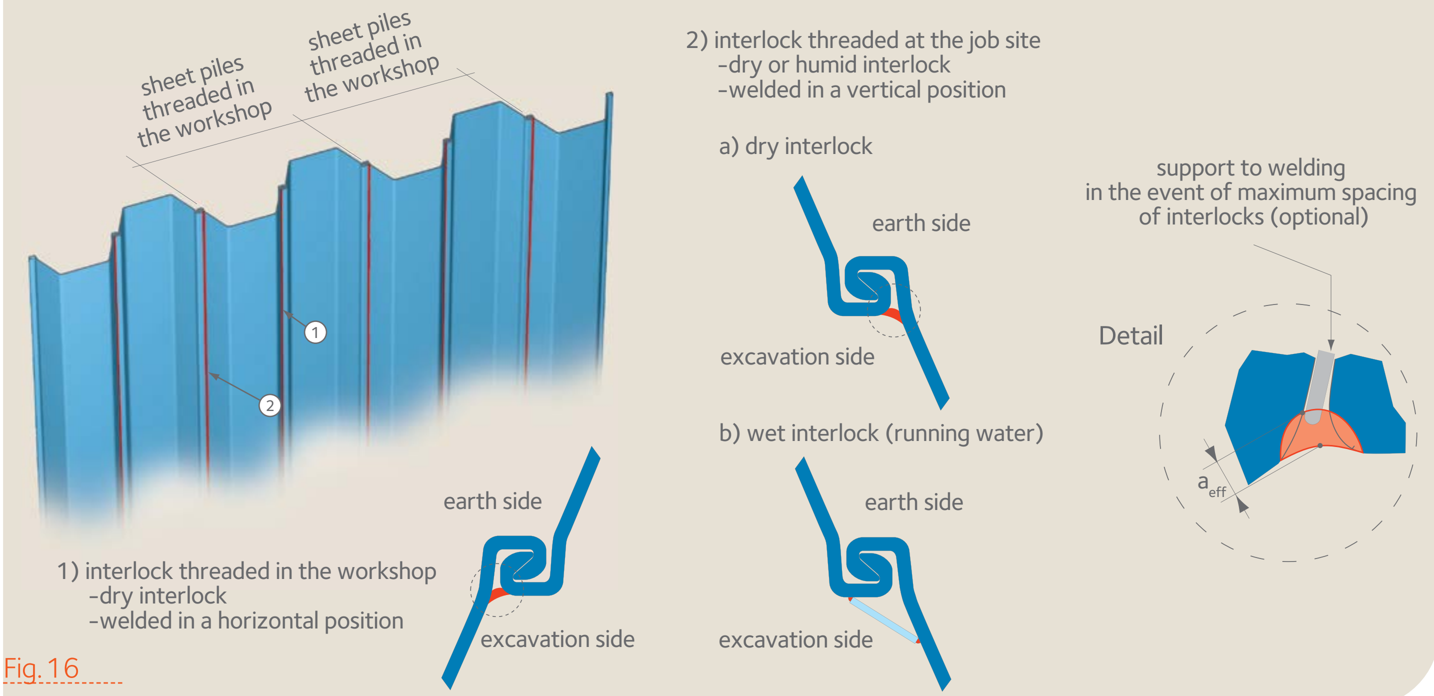


Fig. 16

Automation of welding of sheet piling interlocks on site

Because of the very large number of factors affecting the execution of this work on site, it would be wise to treat this method of working with the greatest reserve, as automation demands considerable consistency in the welding parameters. Because of the different spacing of interlocks and varying site conditions, to achieve a large level of automation would be difficult and of little use. There would not be sufficient return on investment and the equipment would need additional handling which would be likely to increase the welding costs inherent in this type of work.

Welding process (comparison)

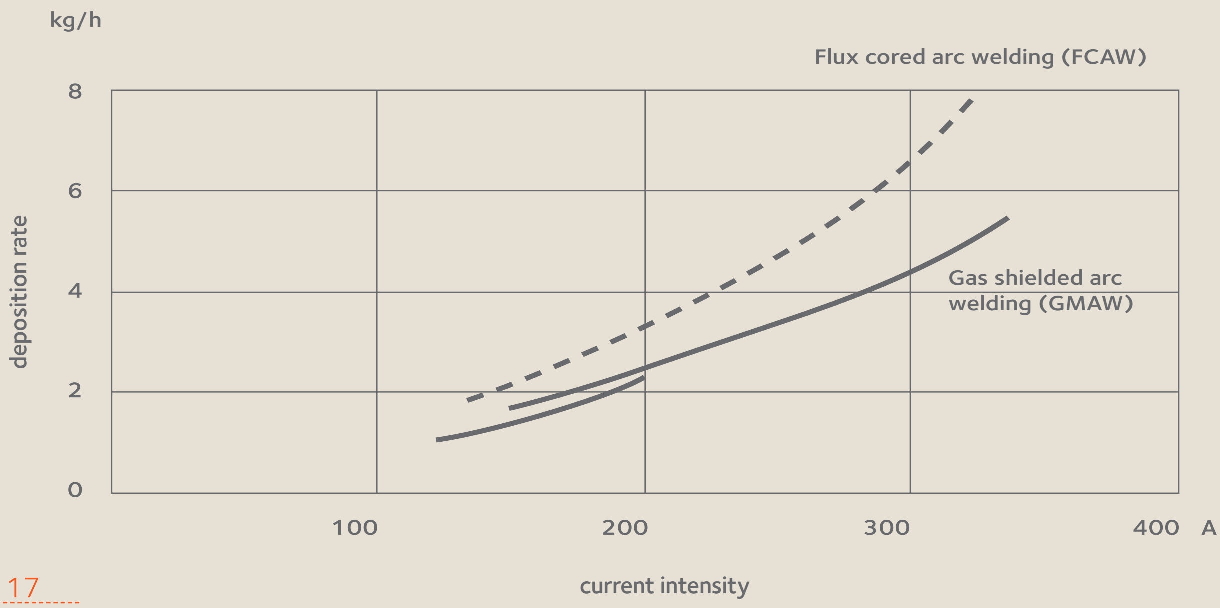


Fig. 17

Table 1: Possible ways of welding interlocks of sheet piles (Summary table)

	Interlock		Type of welding		Welding position			Welding process	Advantages	Disadvantages
					vertical		horizontal			
	dry	humid (1)	in the interlock	with sheet metal covering	upwards welding direction (a_{eff}: > 6 mm)	downwards welding direction (a_{eff}: 3-4 mm)				
Interlock threaded in the workshop + Welding in the workshop	X						X	all	- all the advantage of horizontal welding as opposed to vertical welding	
Interlock connected on site + Welding on site	X		X		To be used: - for any distance between interlocks - when requiring maximum bending in the wall - in a corrosive environment			all	- penetration - guaranteed mechanical characteristics - a single welding pass	- high rate of loading - medium efficiency - cost
	X			X		To be used: - for a minimum spacing between interlocks - when requiring minimum bending in the wall		all	- minimum rate of loading - high speed of execution	- risk of adhesion (low penetration) - minimum mechanical characteristics - sometimes multiple welding passes
	X			X	To be used: - when requiring maximum bending in the wall - in a corrosive environment		see (2)	all	- penetration - guaranteed mechanical characteristics - a single welding pass	- high rate of loading - medium efficiency - cost
	X			X		To be used: - when requiring minimum bending in the wall	see (2)	all	- minimum rate of loading - high speed of execution	- risk of adhesion (low penetration) - minimum mechanical characteristics - sometimes multiple welding passes
		X	X		To be used: - for any distance between interlocks - when requiring maximum bending in the wall - in a corrosive environment			all	- penetration - high mechanical characteristics - higher parts heated by heat rising - a single welding pass (depends on level of humidity)	- high rate of loading - medium efficiency - cost - visual aspect (depends on level of humidity)
		X		X		To be used: - for a minimum spacing between interlocks - when requiring minimum bending in the wall		all	- minimum rate of loading - speed of execution	- limitations according to level of humidity - multiple welding passes necessary (porosity) - risk of adhesion (low penetration) - minimum mechanical characteristics
		X	X		To be used: - when requiring maximum bending in the wall - in a corrosive environment		see (2)	all	- penetration - guaranteed mechanical characteristics - higher parts heated by heat rising - a single welding pass	- high rate of loading - medium efficiency - cost
		X	X			To be used: - when requiring minimum bending in the wall	see (2)	all	- minimum rate of loading - speed of execution	- limitations according to level of humidity - possible multiple welding passes (porosity) - risk of adhesion - minimum mechanical characteristics

Note 1: In the event of the presence of humidity it is advisable to dry the welding area.

Note 2: Concerning sealing using welding with a sheet metal covering: - it is advisable to position the sheet metal so that it fully covers both sides of the sheet pile interlock;
- the size of the spout in the covering should be selected according to the rate of flow of water across the interlock (no effect on the welding on both sides).

Vertical sealing: Alternative solutions

It is possible to seal sheet piles by other processes.

Composite wall with bentonite-cement (Fig. 18)

Composite walls combine the sealing qualities of bentonite with the mechanical strength of steel sheet piling. This system also allows work to be carried out at great depth and in difficult ground. The disadvantage of the technique is the production of excavated material which is considered as polluted material.

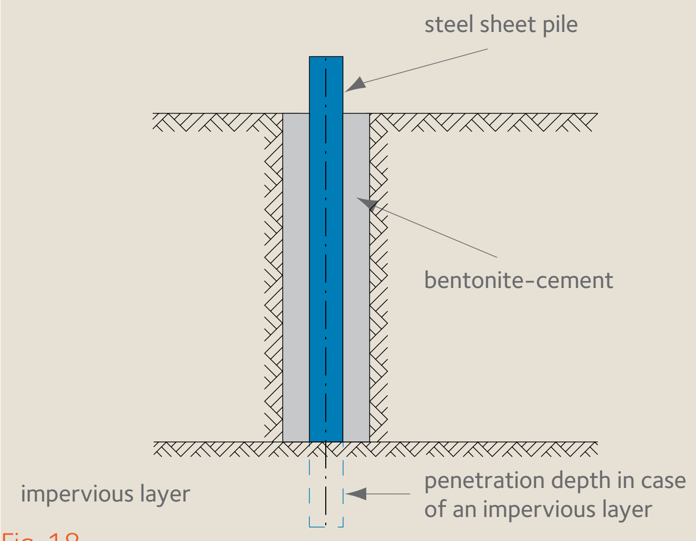


Fig. 18

Vertical pre-drilling on the axis of the leading interlock to be driven (Fig. 19)

A hole is drilled on the axis of the future leading interlock. Drilling diameter: between 300 and 450 mm. Distance between two holes: distance between the outer interlocks of the double pile (1400 mm for AZ-700, 1500 mm for AU). The soil extracted is replaced with bentonite. This method also assists driving and can be combined with a sealed interlock as described previously. The amount of excavated material is limited.

Method for Z sheet piles

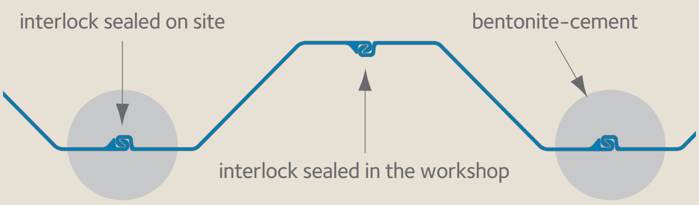


Fig. 19 a

Method for U sheet piles

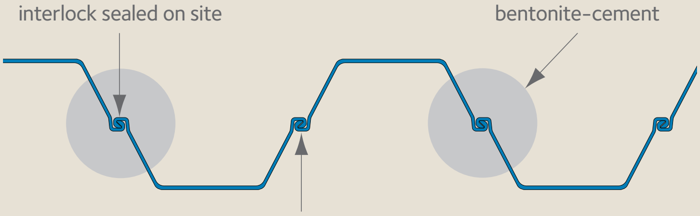


Fig. 19 b

Driving using a special auxiliary section (Fig. 20)

A special auxiliary section of reduced size is locked to the free interlock of the section being driven. The auxiliary section is either driven at the same time as the steel sheet pile or afterwards, if the characteristics of the ground allow it. The auxiliary section is fitted with tubes which push the soil away from the interlocks. Grout is injected through these tubes as the auxiliary section is withdrawn. In this way the soil around the leading interlock is pushed aside and sealed allowing the next pile to be driven with less resistance.

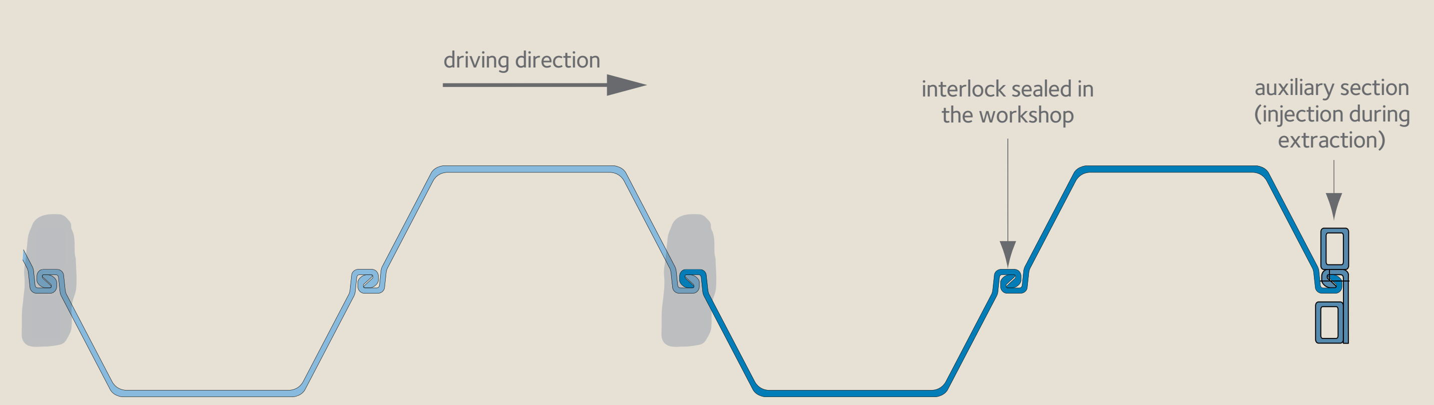


Fig. 20

Driving using a special compression unit (Fig. 21)

For this installation method, two specially made compression units consisting of a standard beam section with steel plates welded to the sides over its full length and fitted with a cutting foot are connected together by a locking system. During the driving operation the adjacent soil is pushed aside. Once the required depth has been reached the compression unit is withdrawn while the formed cavity is filled with bentonite slurry. The steel sheet piles are then positioned or driven into the slurry in suspension. This method avoids the need for the removal of excavated material.

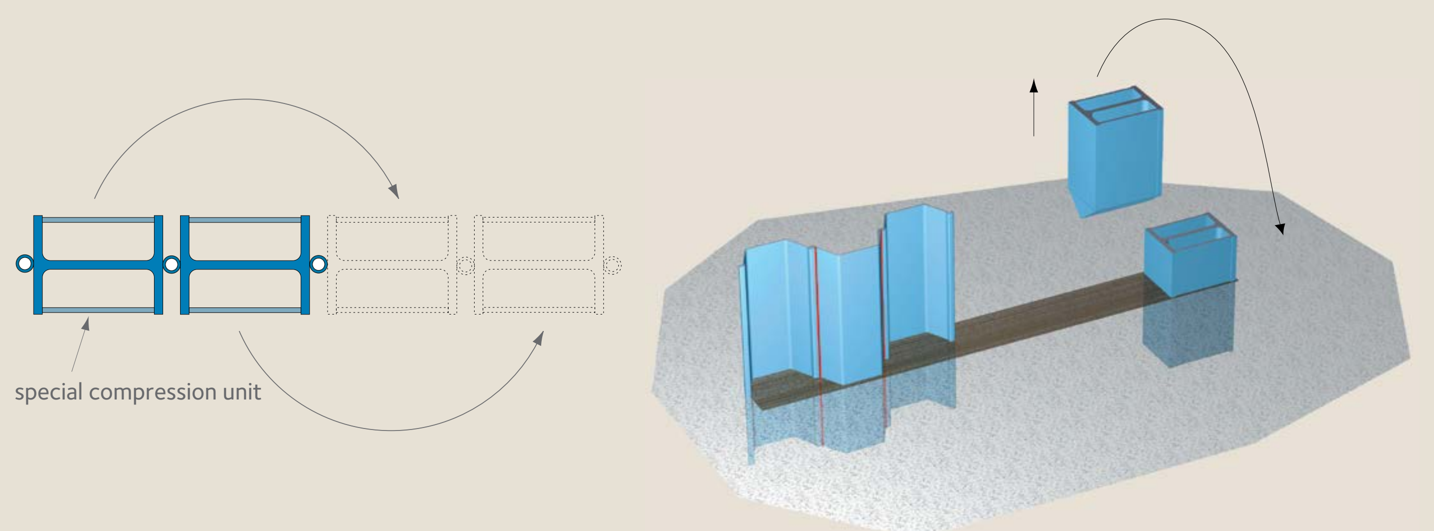


Fig. 21

Injection of slurry behind the steel sheet piling wall

This system of injecting slurry on the land side is very basic and not very reliable, as the distribution of the sealing product (that is the slurry) is not properly controllable and depends on the types of earth encountered.

Vertical sealing:
Repairing defects of the sealing

When a driving incident damages a sealed interlock certain methods can be used as a repair.

The choice of the repair method depends on the following factors:

- type of sealing process (sealing product, welding, etc...);
- location of the sealing joint (see Fig. 22 and 23);
- gap of interlocks (see Fig. 24);
- level of humidity in the interlocks;
- accessibility.

The various methods are summarized below; Table 2 shows the main criteria governing the choice of the proper method.

Location of the sealer (U sheet piles)

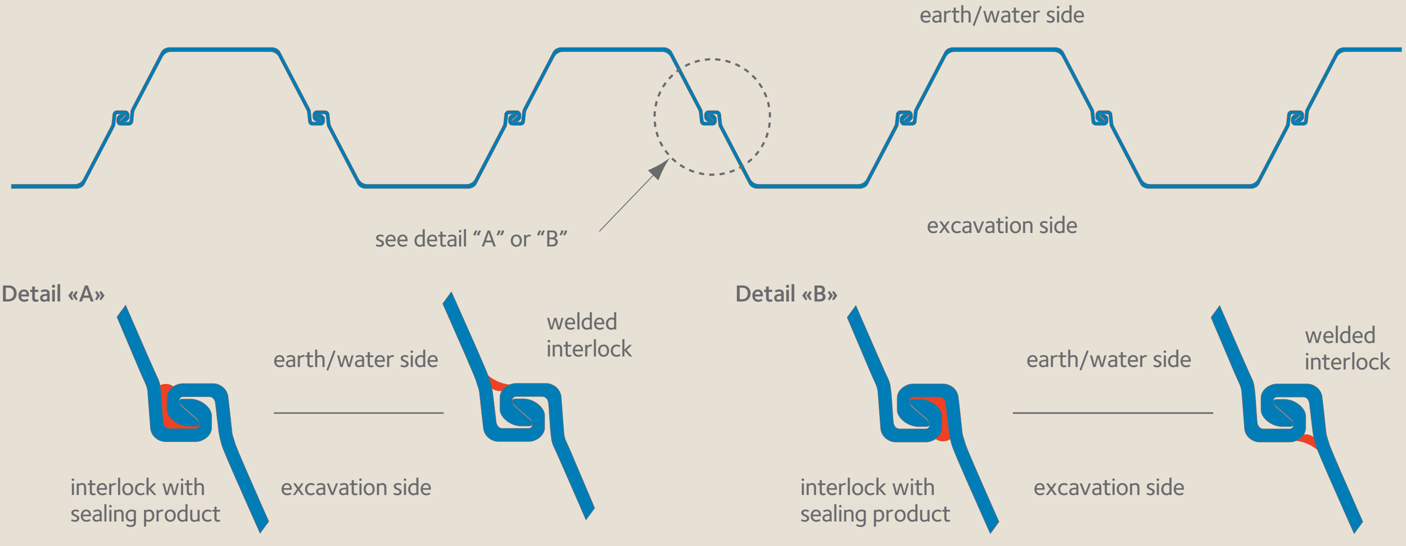


Fig. 22

Location of the sealer (Z sheet piles)

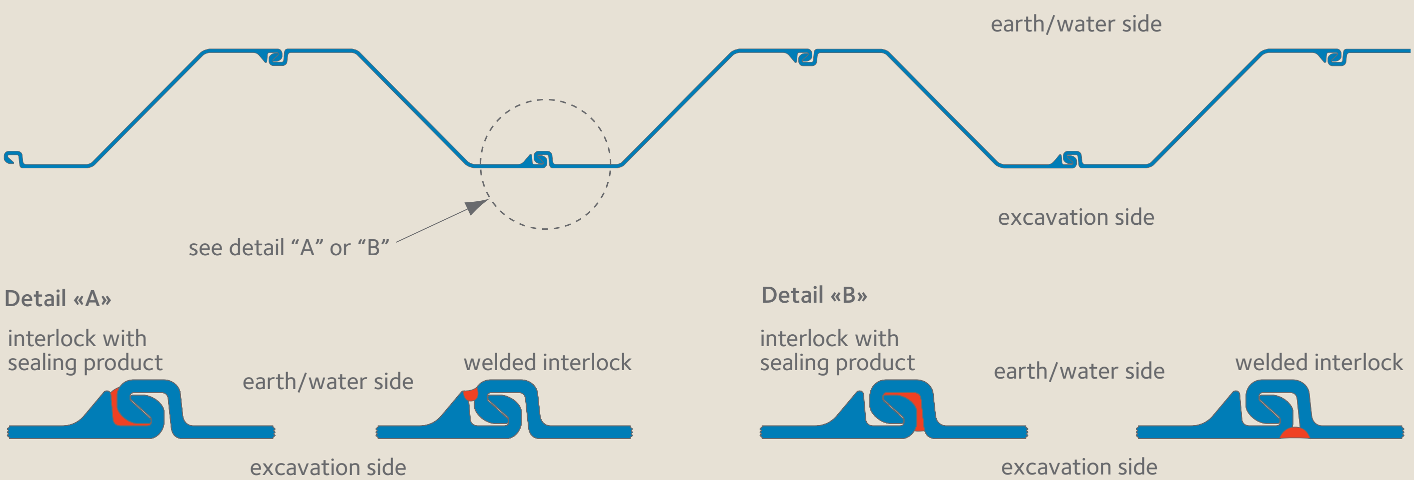


Fig. 23

Spacing of interlock (U sheet piles) | Spacing of interlock (Z sheet piles)

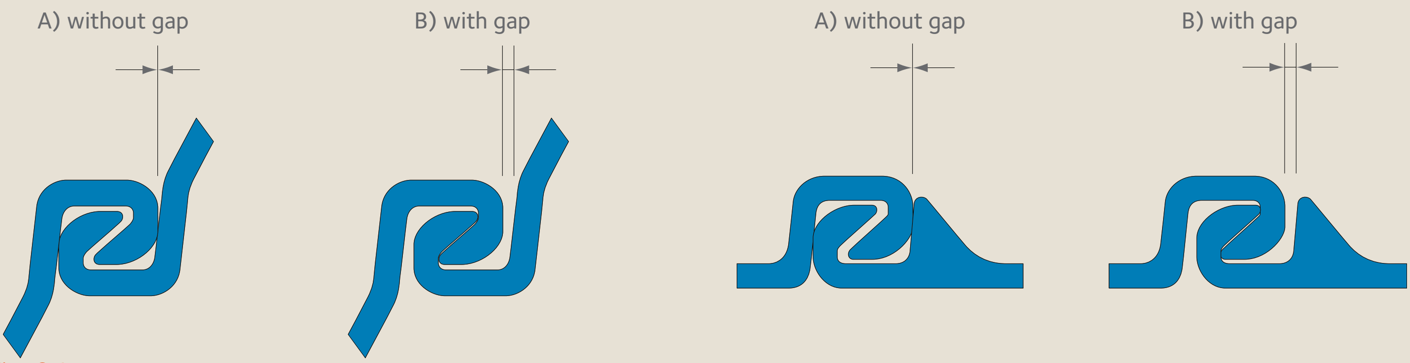


Fig. 24

Table 2: Choice of methods for repairing seals of steel sheet piling

Location of sealing product	Type of sealing product					Spacing of interlocks (see Fig. 24)		Humidity in the interlocks		Accessibility	Method to be used (see Fig. 25 to 27)
	Beltan® Plus	Arcoseal™	ROXAN® Plus system	AKILA® system	Welded interlock	No gap	Gap	Humidity without leakage	Humidity with leakage	Excavation side only	
As detail A (Fig. 22 and 23) (sealing product on water/land side)	X	X	X	X	X	X		X		X	Method 1 or 2
	X	X	X	X	X		X	X		X	Method 1 or 2 or 3
(Example):	X	X	X	X	X		X		X	X	Method 2 or 3
As detail B (Fig. 22 and 23) (sealing product on excavation side)	X	X	X	X		X		X		X	Method 2
	X	X	X	X			X	X	X	X	Method 2 or 3 (intermittently)
					X	X	X	X	X	X	Method 1 (intermittently) or 2

Example:

- sheet pile Z
- ROXAN® Plus system
- located facing water side as figure 23 detail A
- with gap between interlocks
- large water flow across the interlock (with leakage)
- accessibility via the cofferdam.

Repair: method 2 or 3.

Repairs above ground level (interlock accessible on the excavation side)

Method 1

Sealing by applying a seal-weld along the interlock over the required height of the pile (Fig. 25).

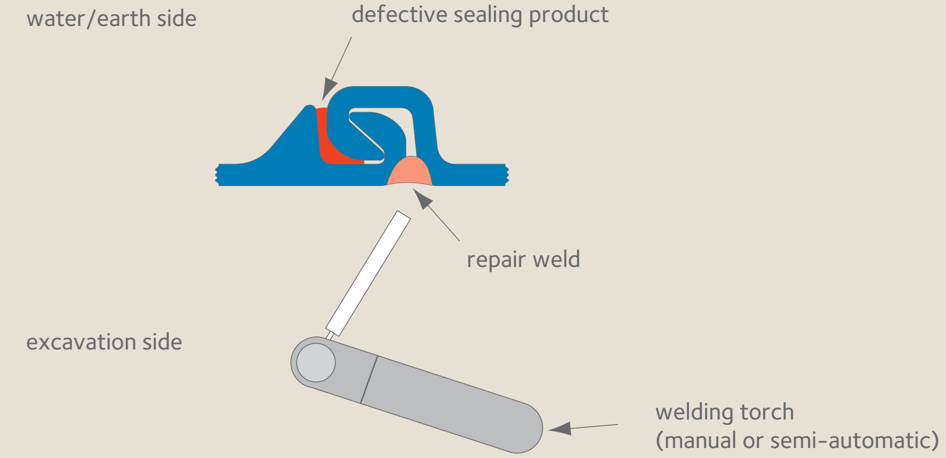


Fig. 25

Method 2

Sealing by welding a plate or an angle over the interlock over the required height of the pile (Fig. 26).

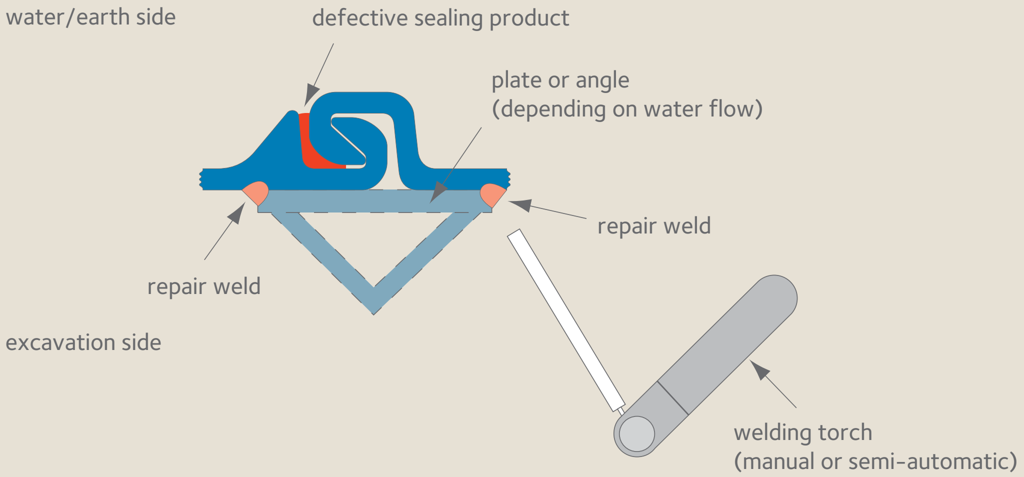


Fig. 26

Method 3

Sealing by filling the gap between the interlocks with plastic sections, strips of waterswelling rubber or prelaminated timber laths over the required height of the pile (Fig. 27).

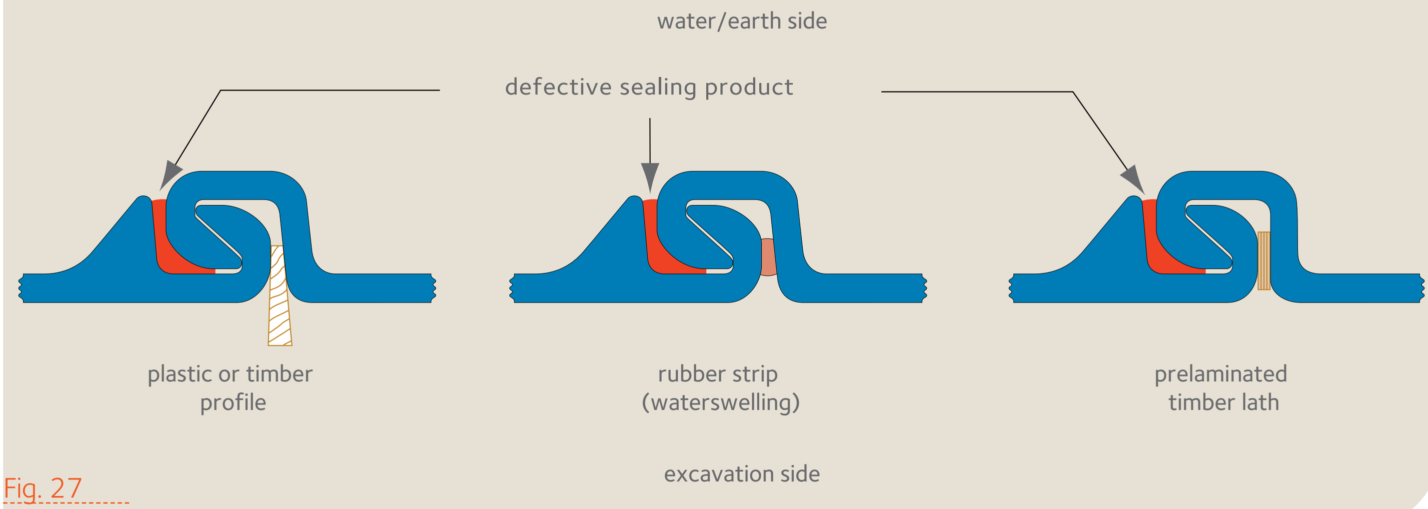


Fig. 27

Repairs below ground level

Method 1

Excavation down the length of the interlock to be sealed and extension of the seal-weld or the interlock repair product down to the necessary depth (Fig. 28).

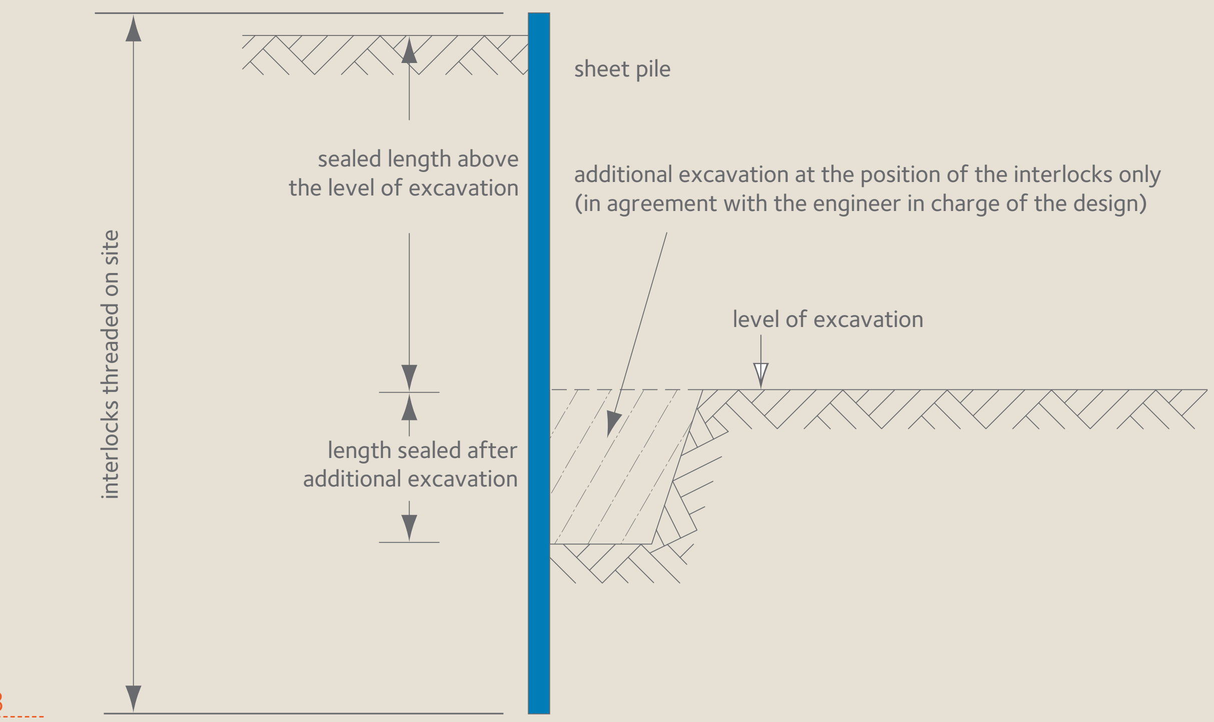


Fig. 28

Method 2

Injection of a product (fast-setting cement or bentonite) behind the wall along the interlock to be sealed (Fig. 29).

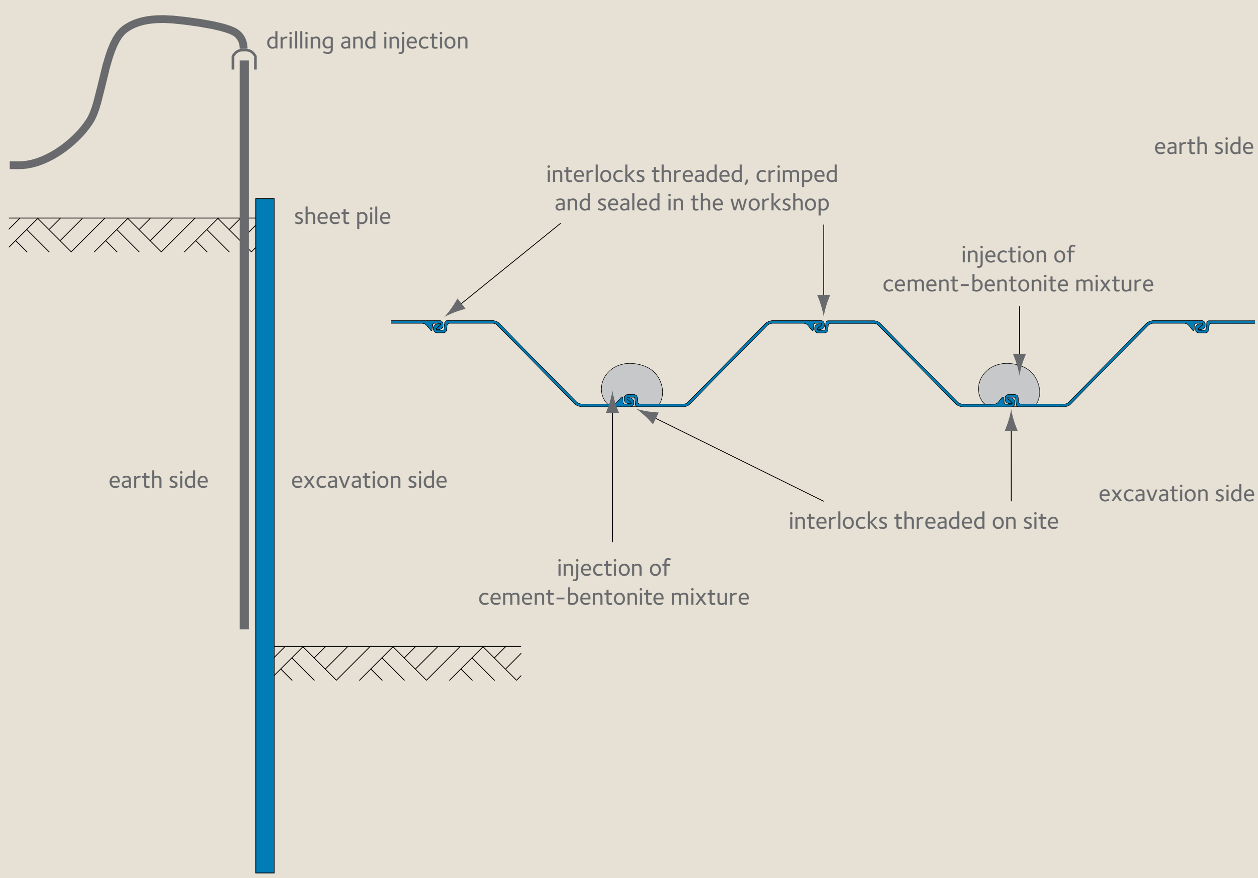


Fig. 29

Method 3

In the event of more serious leaks, form a trench along the bottom of the excavation, install a drainage system and connect to a pumping system (Fig. 30).

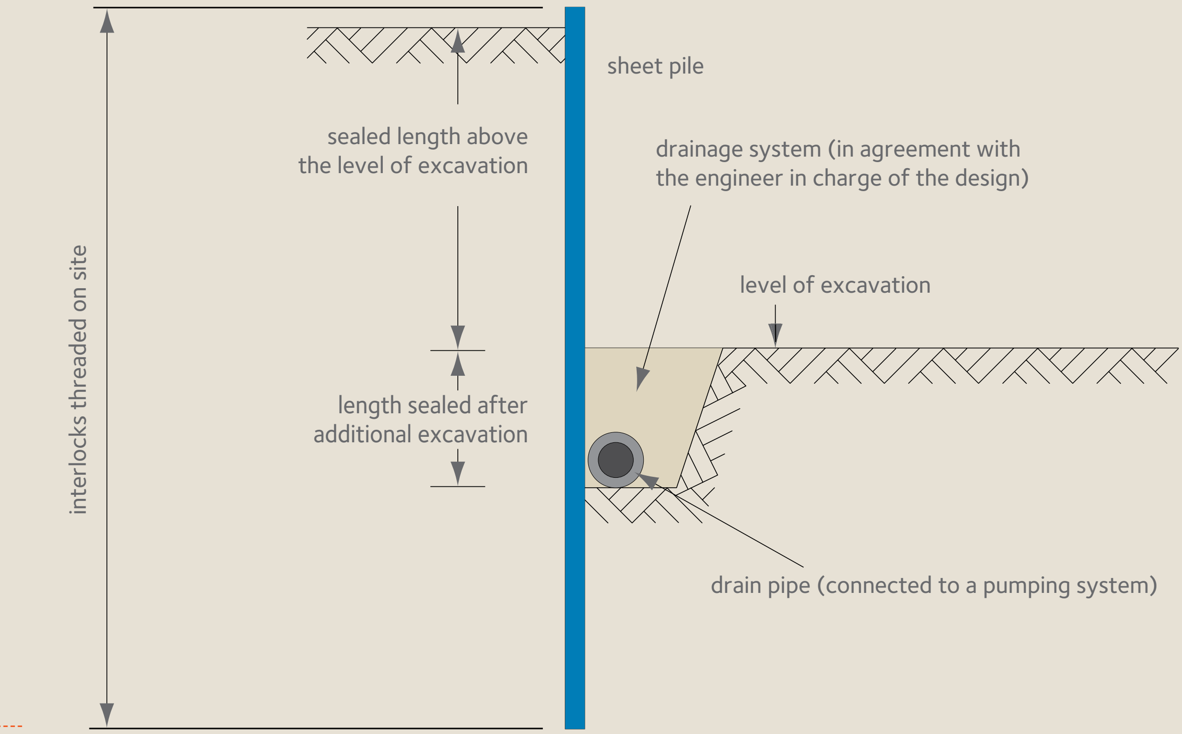


Fig. 30

Repairs in water

In the event that it is required to create or repair a seal on the water side, the examples shown in (Fig. 31a & 31b) may be suitable.

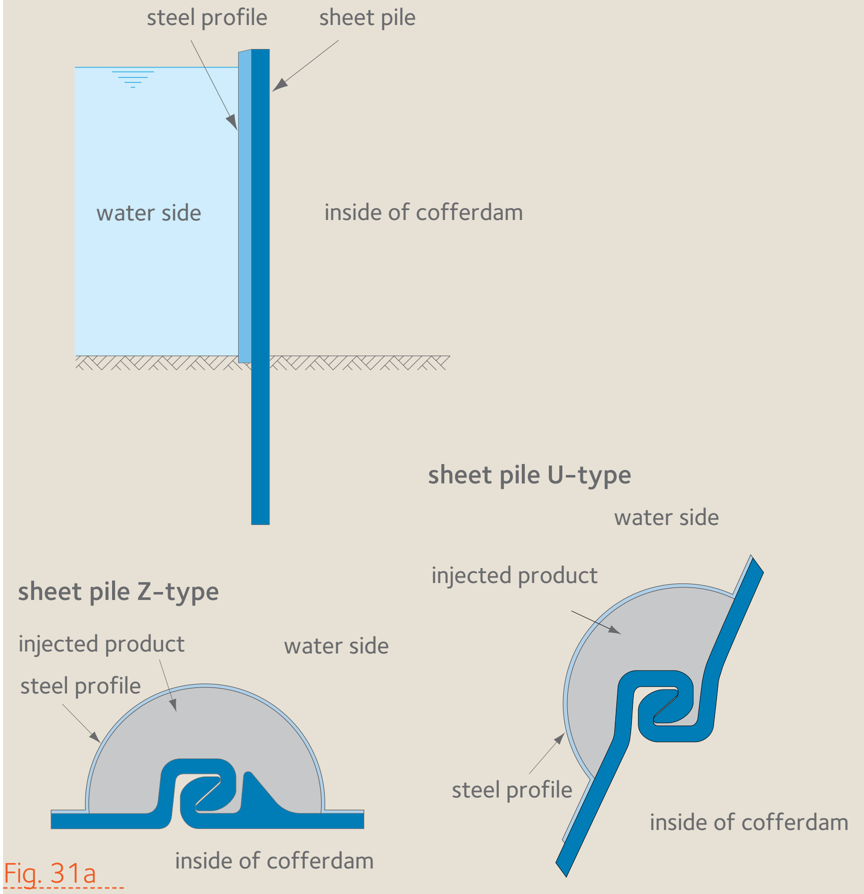


Fig. 31a

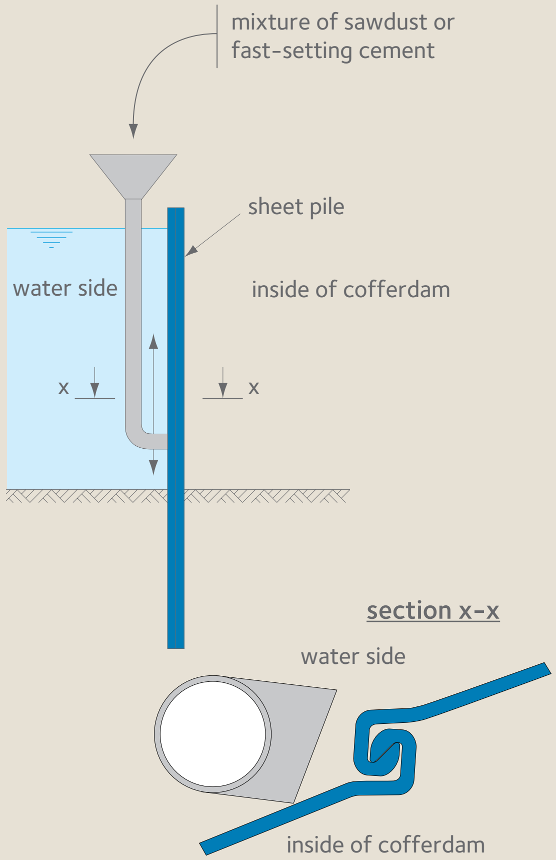


Fig. 31b

Horizontal sealing

Horizontal sealing consists of forming a watertight connection between two types of elements which are essentially different: the steel sheet piling wall which is rigid and corrugated and the horizontal construction element, rigid or flexible and generally flat.

In general, two types of sealing exist:

- sealing of the base slab, ie forming a watertight seal in zones which are often under water;
- sealing the cover slab.

In the case of a sealed connection between a base slab (raft) or a cover slab and steel sheet piling, the connection examples described in the figures below may be useful.

Figures 33-34: connection of a base slab (raft).
Figures 35-37: connection of a cover slab.

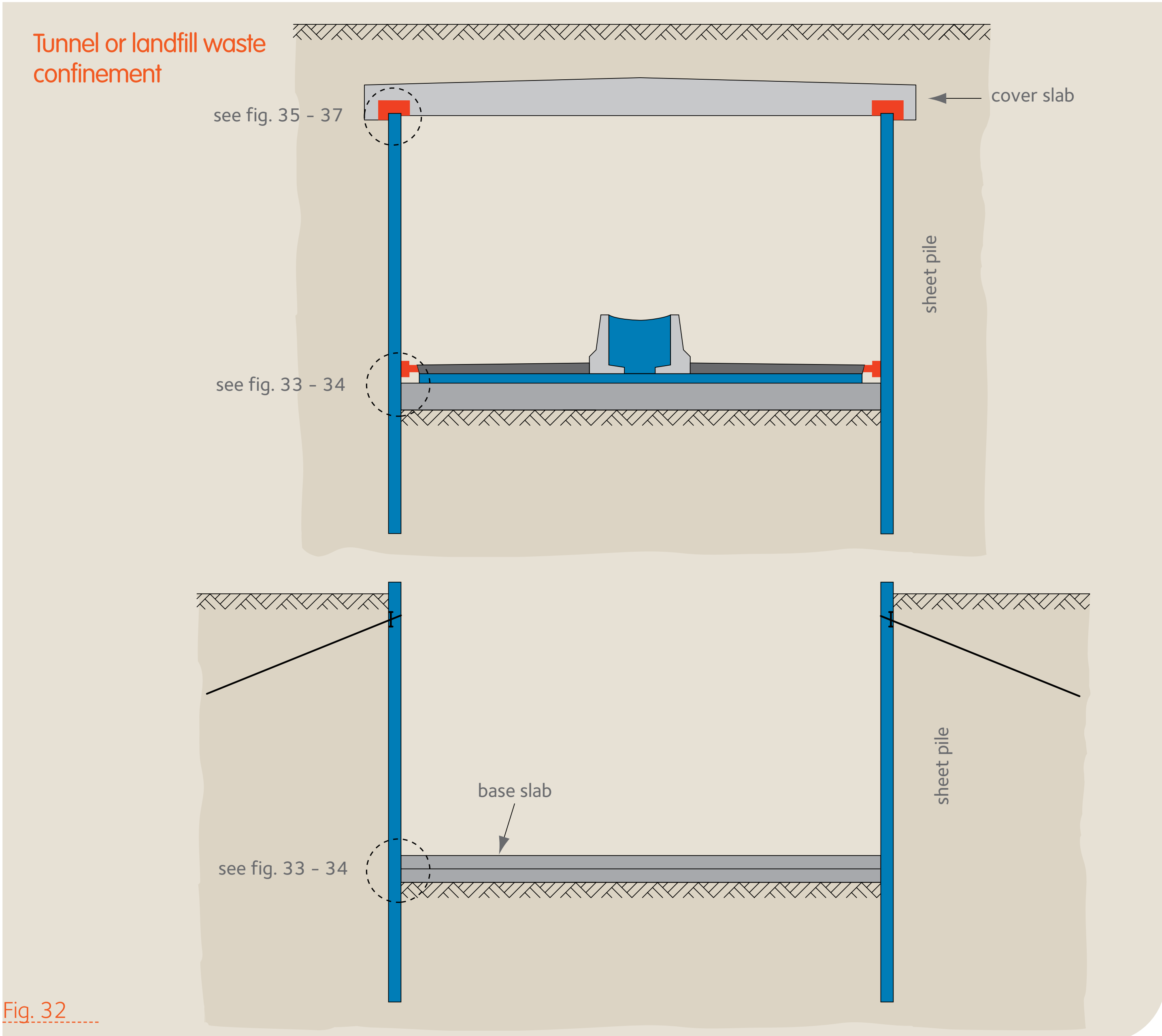
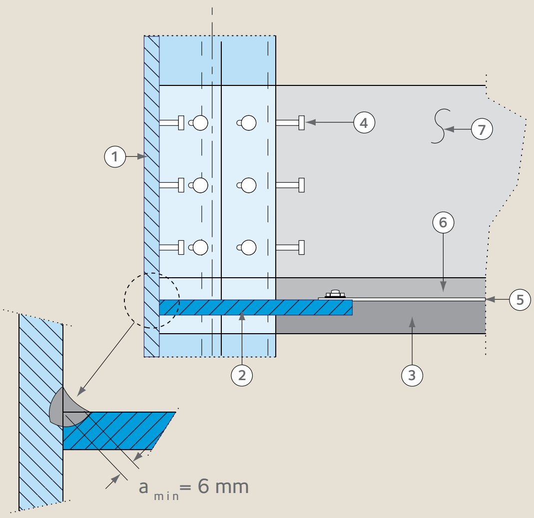
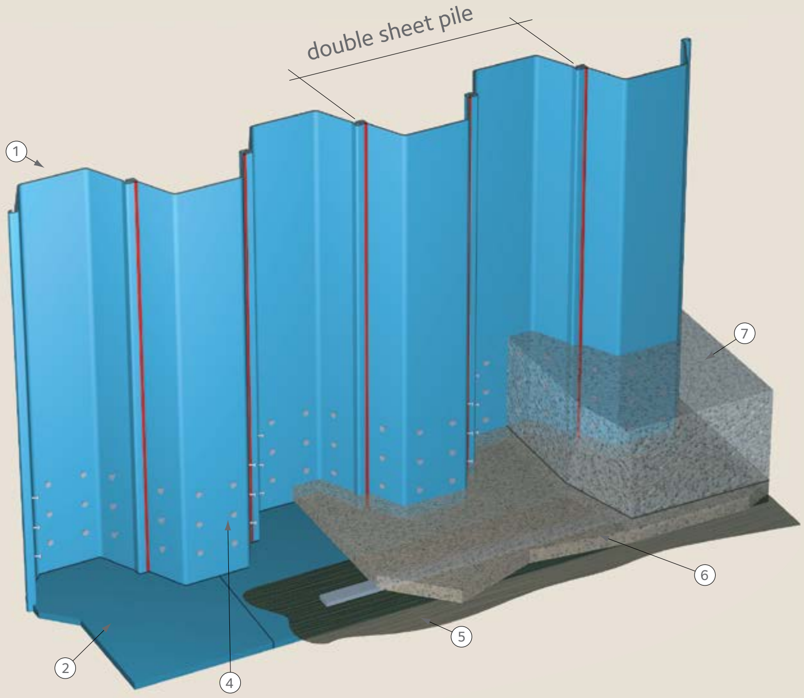


Fig. 32

Horizontal sealing using a steel sheet and a membrane system for low to average stresses



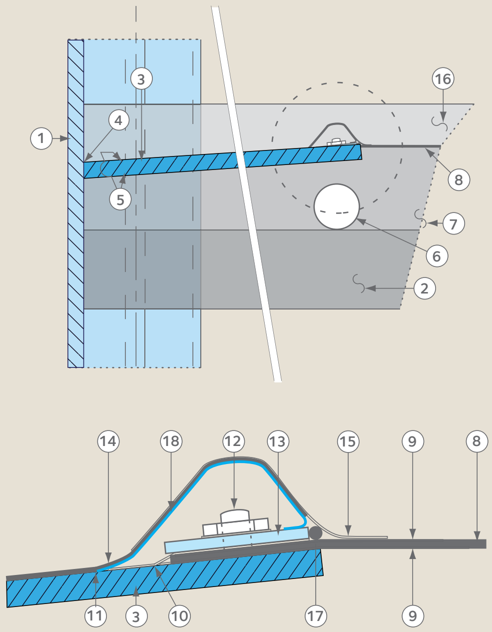


1) sheet pile
2) steel sheet
(fixed by welding)
3) concrete subbase
4) studs
5) sealing membrane fixed either mechanically or with adhesive
6) concrete protection layer
7) concrete base slab

Fig. 33

Horizontal sealing using a steel sheet and a membrane system for high stresses

1) sheet pile
2) tremie concrete
3) steel sheet (8-10 mm thick) fixed by welding
4) weld fillets
5) epoxy resin-based paint
6) drain hole
7) draining concrete
8) sealing membrane
9) sealing membrane (2 mm thick/400 mm wide)
10) pvc sheet (2 mm thick/140 mm wide)
11) pot welding
12) threaded stud with nut for welding
13) steel plate (10 mm thick/100 mm wide)
14) pvc sheet (2 mm thick/400 mm wide)
15) sealing membrane (2 mm thick/350 mm wide)
16) concrete protection
17) sealing gasket
18) shaped steel sheet (2 mm thick/300 mm wide)



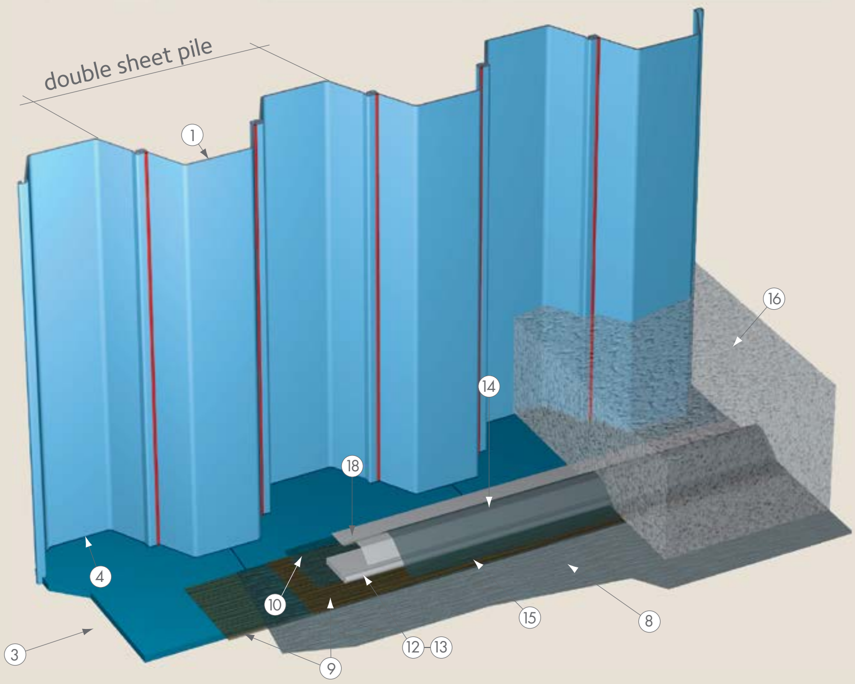
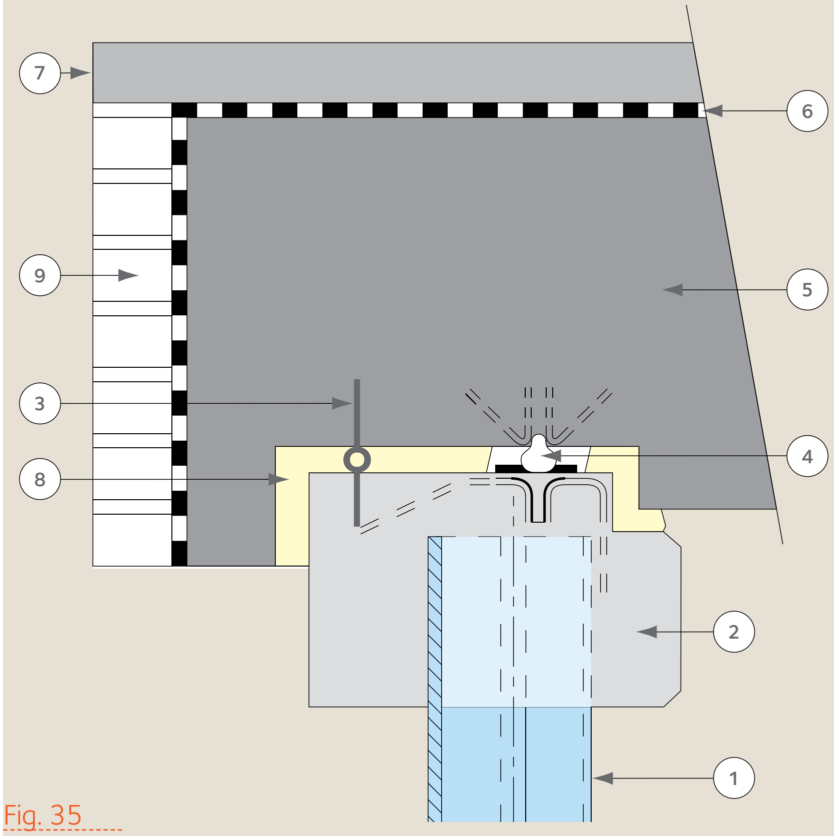


Fig. 34

Horizontal sealing with cover slab
Hinged connection between cover slab and steel sheet piling wall in the presence of water infiltration

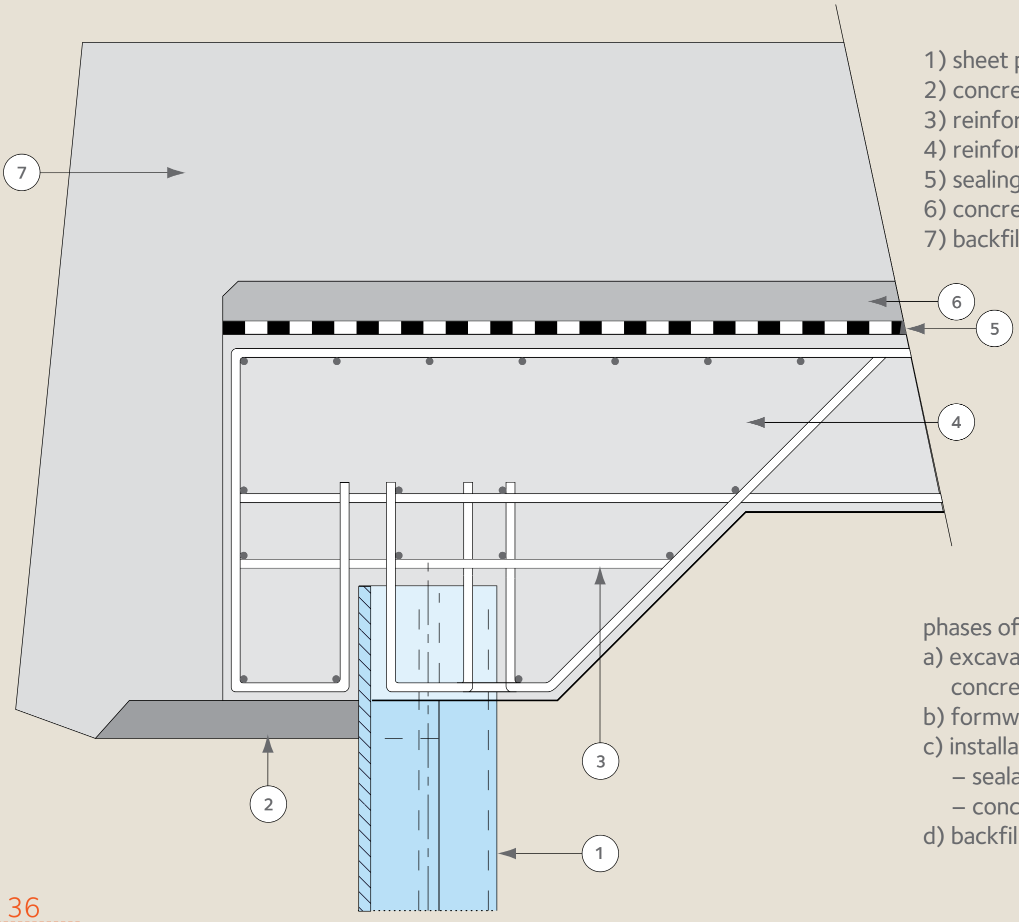


1) sheet pile
2) reinforced concrete
3) elastomer joint (or similar)
4) support
5) reinforced concrete cover slab
6) sealing (membrane or similar)
7) concrete protection or asphalt screed
8) expanded polystyrene (formwork left in place)
9) vertical protection (bricks)

phases of execution:
a) excavation, setting piles to level, cleaning, etc...
b) preparation of the formwork for the reinforced concrete cap, positioning of the lower part of the support, steel reinforcement, positioning of the elastomer joint, concreting.
c) formwork for the cover slab
d) installation of:
   – sealant
   – concrete protection or asphalt cover screed
   – additional vertical protection

Fig. 35

Horizontal sealing with cover slab
Fixed connection between cover slab and steel sheet piling wall in the presence of water infiltration

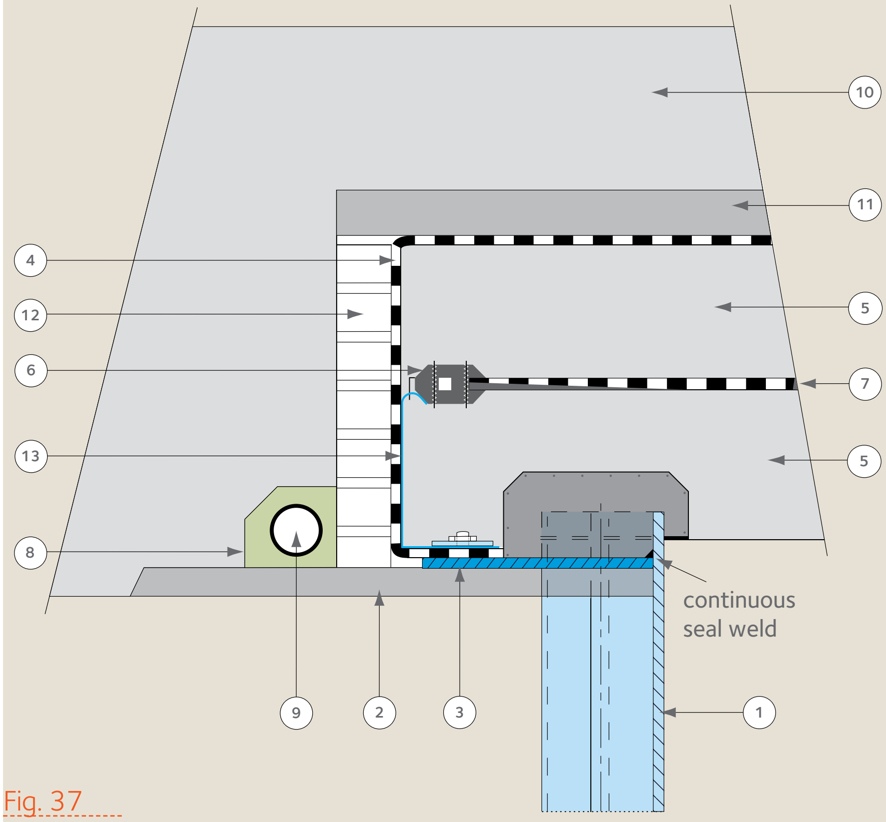


1) sheet pile
2) concrete subbase
3) reinforcement
4) reinforced concrete cover slab
5) sealing
6) concrete protection or asphalt screed
7) backfill, concrete slab

phases of execution:
a) excavation, setting piles to level, concrete subbase, cleaning etc...
b) formwork for the cover slab
c) installation of:
   – sealant
   – concrete protection or asphalt screed
d) backfill, concrete slab

Fig. 36

Horizontal sealing with cover slab
Hinged connection between cover slab and steel sheet piling wall in the presence of water under pressure



1) sheet pile
2) concrete subbase
3) steel sheet (~8 mm thick)
4) sealing membrane (felt layer ~5 mm thick) hot fixed or mechanical fixing with flexible strip
5) reinforced concrete cover slab
6) clamping plate
7) sealing (membrane or similar)
8) filter sheet (geotextile or similar)
9) drainage
10) reinforced concrete cover slab
11) concrete protection or asphalt screed
12) vertical protection (bricks)
13) copper sheet

phases of execution:

a) excavation, setting piles to level, concrete subbase, cleaning etc.
b) preparation of the formwork for the reinforced concrete
c) formwork for the cover slab
d) execution of sealing system, concrete protection or asphalt cover screed including drainage

Fig. 37

Remarks & References

Remarks

It is important to note, that **all ρ values given in this document are characteristic values** (maximum values considered as "cautious estimates") which are results of in-situ tests. **For the determination of design values, a safety factor has to be carefully chosen** in order to balance the scattering of the test results and the imponderables inherent to the installation of the piles, the soil, local defects, etc. Please contact the Technical Department for guidelines on this matter.

References

For additional background information, please refer to:

- Steel Sheet Pile Seepage Resistance, J.B. SELLMEIJER, Fourth International Landfill Symposium, Cagliari, Italy, 1993.
- Joint Resistance of Steel Sheet Piles, Definition, J.B. SELLMEIJER, August 1993 (unpublished).
- The Hydraulic Resistance of Steel Sheet Pile Joints,J.B. SELLMEIJER, J.P.A.E. COOLS, W.J. POST, J. DECKER, 1993 (publication ASCE).
- EAU 2012, Recommandations of the Committee for Waterfront Structures, Harbours and Waterways, Berlin, 2012. (Ernst & Sohn).

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ArcelorMittal Commercial RPS S.à r.l.
Sheet Piling

66, rue de Luxembourg
L-4221 Esch-sur-Alzette (Luxembourg)

T (+352) 5313 3105
sheetpiling@arcelormittal.com
sheetpiling.arcelormittal.com

2-1-14-1-GB