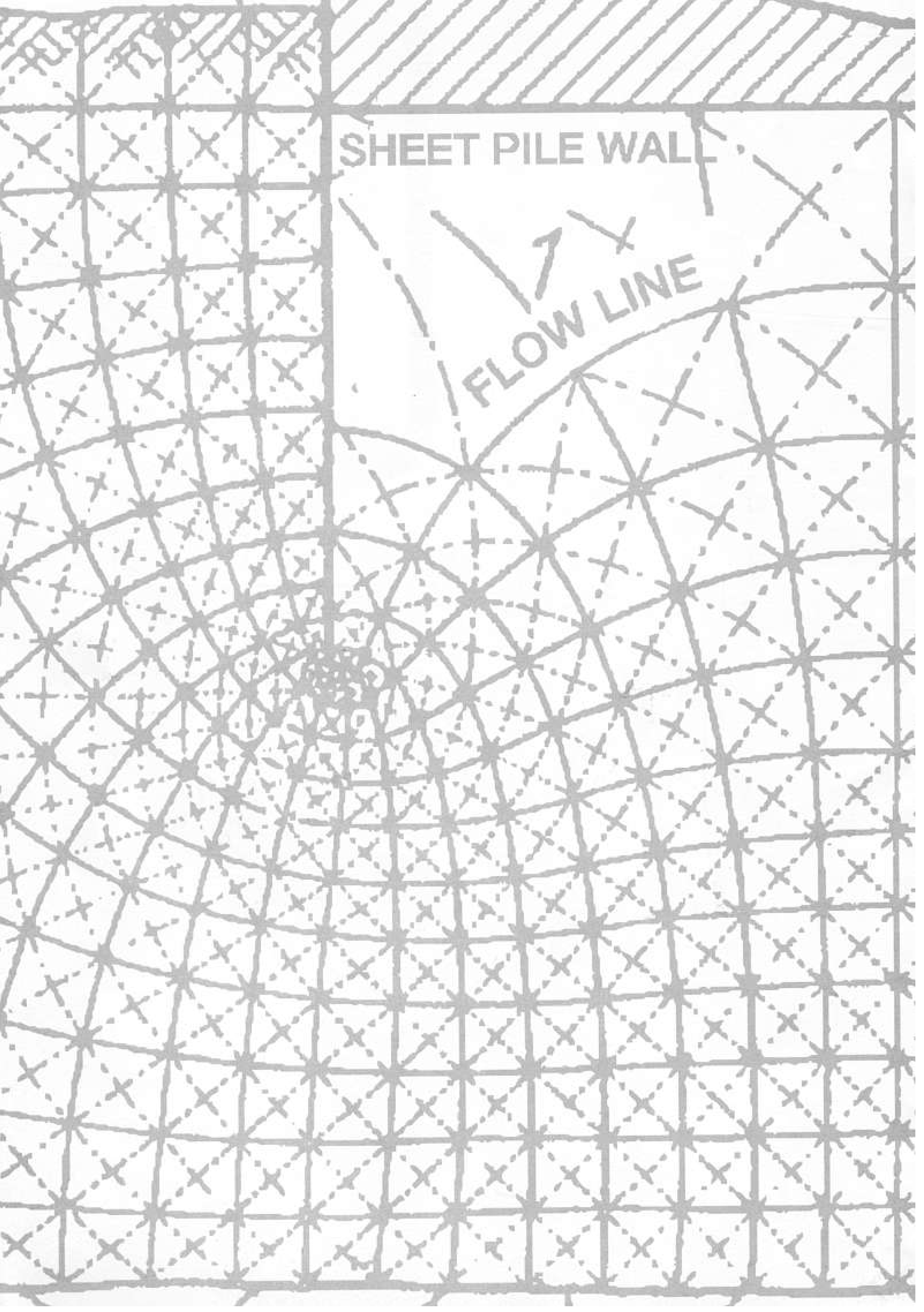
Steel Sheet Piling

The Impervious Steel Sheet Pile Wall • Part 1: Design

Steel solutions for a better world

arcelor


SHEET PILE WALL
FLOW LINE

Rational Analysis of Impervious Steel Sheet Pile Walls

1. Introduction

Until recently no consistent methodology has been available for the assessment of the seepage resistance of steel sheet pile (SSP) walls. The lack of such a methodology can conceivably lead to uneconomic design, especially in cases where the seepage resistance is substantially greater than the specific design requires.

ProfilARBED, the world's leading producer of sheet piles, has carried out an exhaustive research project in collaboration with Delft Geotechnics. The aim of the project was to determine the rate of seepage through SSP walls for various joint filler materials, as well as for empty and welded joints.

Two key areas of research were addressed:

- Setting up a consistent theory to describe the leakage behaviour through individual joints.
- In situ experimentation on SSP walls.

In this paper the research results are deployed to enable the practical designer to make a rational assessment of the rate of seepage for a specific case. A range of possibilities is discussed: highly permeable unfilled joints, filled joints for medium permeability and completely impervious welded joints.

The cost involved in each case can be balanced against the seepage resistance requirements and the most appropriate solution will present itself on the basis of the analysis.

2. The concept of joint resistance

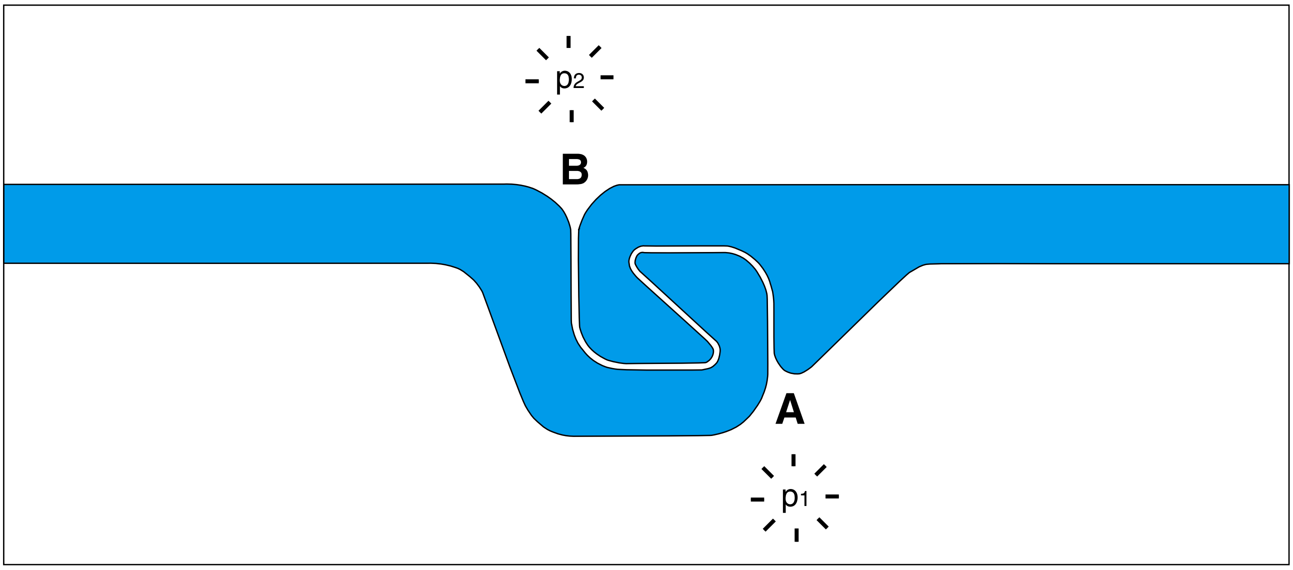


Fig. 1

The steel sheet piles themselves are completely impervious and therefore the only possible route for the fluid to traverse the wall is via the joints. Unlike slurry walls - for which the seepage problem can be treated with the aid of Darcy's law with a suitably chosen coefficient of permeability K:

$$\mathbf{v = K \bullet i} \qquad (1)$$

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

$$\mathbf{i = (\Delta p / \gamma) / s} \qquad (2)$$

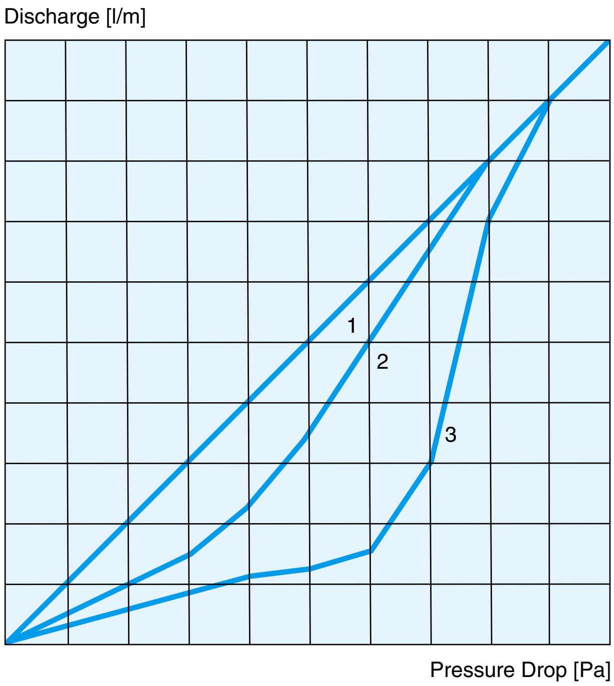
The latter is defined in a horizontal plane as the ratio of the difference in pressure height ($\Delta p/g$) and the length of the filtration path (s), see reference 4.

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

The kind of flow (pipe, potential,...) is difficult to determine, but most likely it will not be a porous media type of flow and Darcy's law does not hold for the local seepage through a SSP joint. To accommodate this difficulty, researchers at Delft Geotechnics have introduced the concept of **Joint Resistance.**

Fig. 2 shows a typical application of SSP with different water levels on either sides of the wall which gives rise to a pressure difference that depends on z.

Neglecting the vertical flow in the joint, the relation between the discharge through the joint in the horizontal plane and the related pressure drop $p_2 - p_1$, is roughly as depicted in Fig. 3. The hypothesis that no discharge occurs in the vertical direction of the joint is rather more general than the commonly used Dupuit-Forchheimer assumption for the treatment of these kinds of flows (see reference 2).



1. Empty
2. Plugged Soil
3. Filler Material

Fig. 3

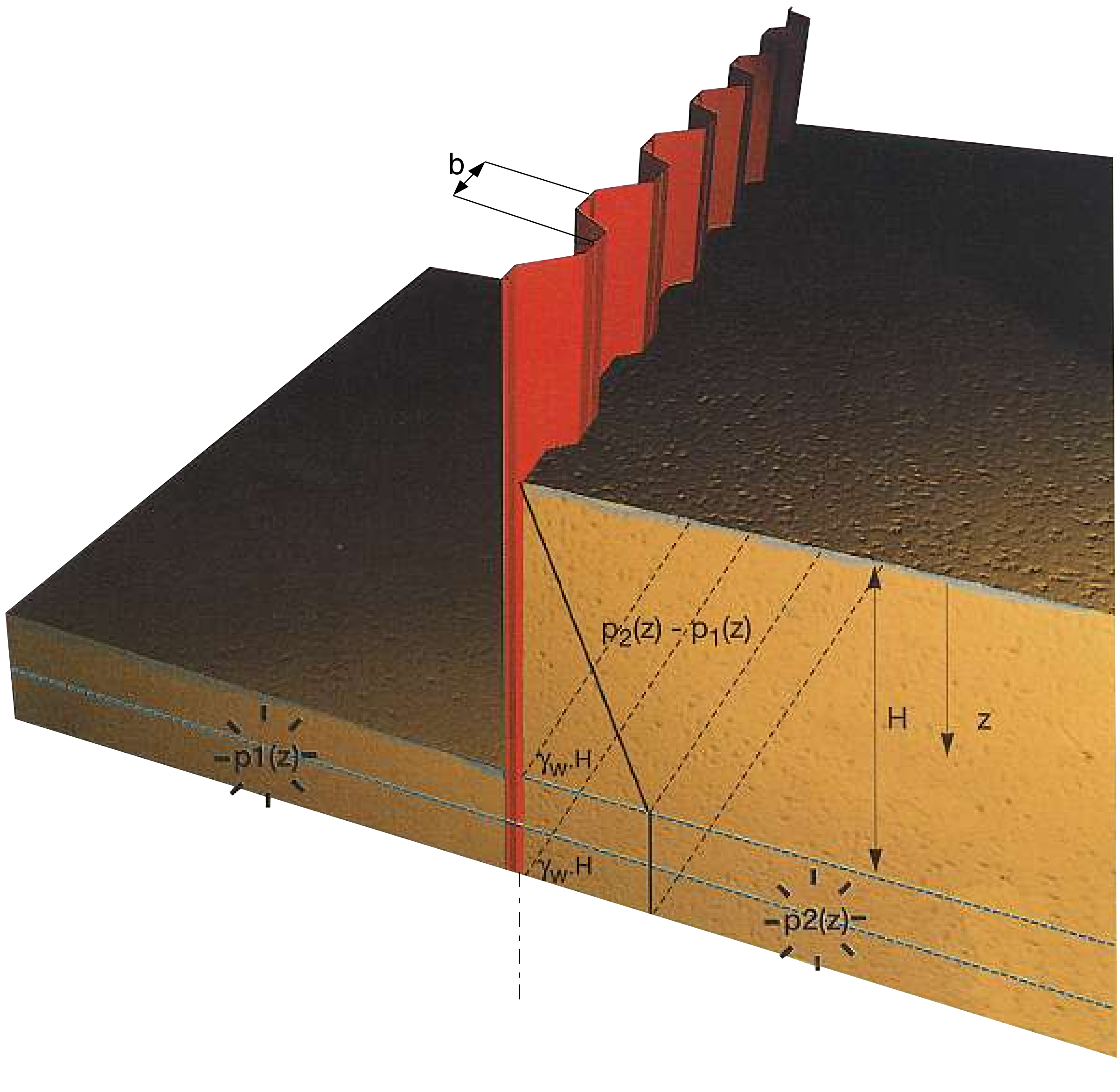


Fig. 2

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

q(z) proportional Δp(z)

The proportionality coefficient is denoted by ρ :

$$\mathbf{q(z)} = \rho \bullet \Delta \mathbf{p(z)} / \gamma \qquad (3)$$

The meaning of the symbols is as follows:

q(z): the discharge per unit of the joint length at level z, [m^3/s/m]

Δp(z): the pressure drop at level z, [kPa]

ρ: the inverse joint resistance, [m/s]

γ: unit weight of water [kN/m^3]

Note that (3) does not suppose a Darcy type of flow. All interlock properties are encased in ρ and this parameter is determined from experiments.

3. In situ measurements

In order to allow the design engineer to make practical use of equation (3) Delft Geotechnics and ProfilARBED have 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 for the test wall have been driven in by vibrohammer. Each filler material has been applied in several joints.

The discharge through each joint was measured as a function of the applied pressure drop using a special test apparatus, see Fig. 4. 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 matrials (bituminous ones as well as water swelling products); the results of the empty joints are also shown. It is most important to note that the r-values obtained for empty joints strongly depend on the soil properties, the variations being very large.

The test results are plotted in Fig. 5 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 Delft Geotechnics and ProfilARBED, clearly demonstrates that the use of filler products in the joints of a SSP wall considerably reduces the seepage rate.

In addition it transpires that the filler material in the joints remains in place, even after the application of a vibrohammer - provided the manufacturer's specifications are strictly adhered to and the special tools, as developed by ProfilARBED for the implantation of the filler materials, are deployed.

Table 1

WATERTIGHTENING SYSTEM	ρ [10^{-9}m/s] 100kPa	200kPa	APPLICATION OF THE SYSTEM	COSTS RATIO **
EMPTY JOINTS	>100	*	-	0
BITUMINOUS FILLER MATERIAL	< 60	not recommended	EASY	1
WATERSWELLING PRODUCT	≤ 0.3	0.3	WITH CARE	2
WELDING OF THE JOINTS	0	0	ONLY AFTER EXCAVATION FOR THE INTERLOCK TO BE THREADED ON JOBSITE	5

* VALUE AVAILABLE ONLY AT 150 kPa: <450

** The costs ratio = $\frac{\text{Costs of the watertightening system}}{\text{Costs of the bituminous filler material solution}}$

Note: See table inside rear cover for values to be used for a first order design approach.

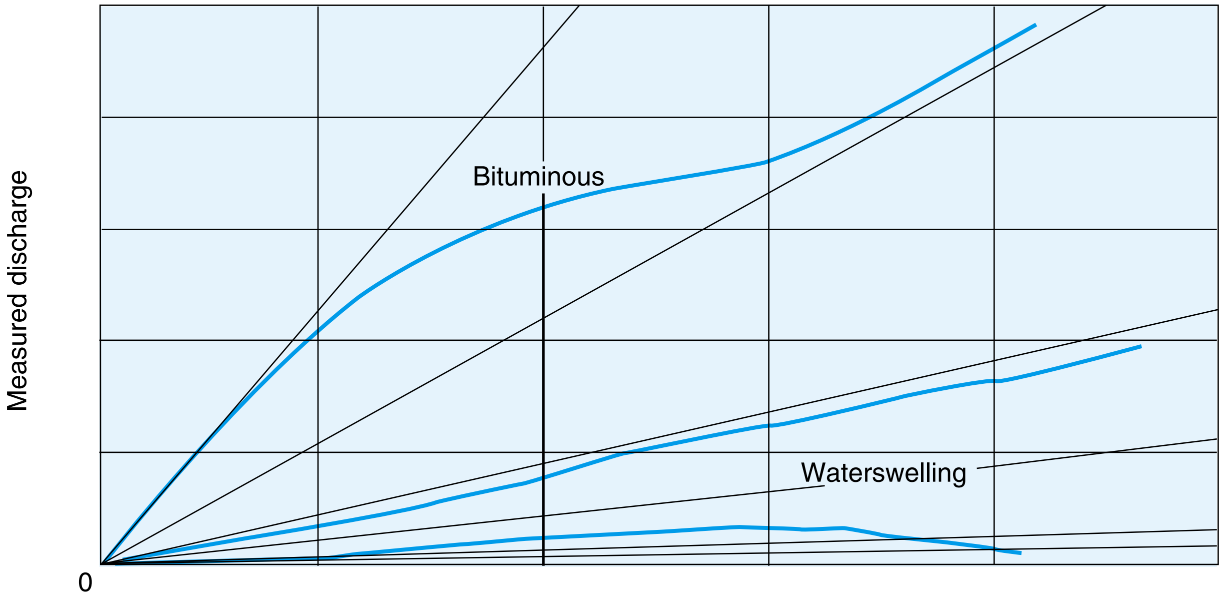

Measured discharge
Bituminous
Waterswelling
0
Pressure drop

Fig. 5

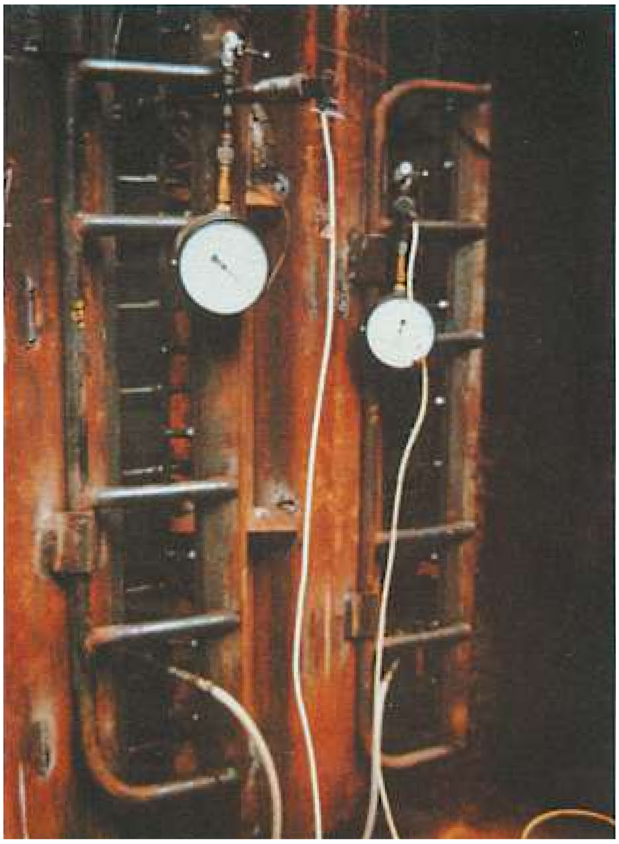


Fig. 4

4. Practical use of the concept

The key design formula is:

$$\mathbf{q(z)} = \rho \bullet \Delta \mathbf{p(z)} / \gamma \qquad (3)$$

q(z): the discharge per unit of the joint length at level z, [$m^3/s/m$]
Δp(z): the pressure drop at level z, [kPa]
ρ: the inverse joint resistance, [m/s]
γ: unit weight of water [kN/m^3]

The geometrical definitions are given in Fig. 1 and 2

4.1. The discharge through a SSP wall The 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 latter is assumed to be virtually impervious.

This assumption allows to neglect the flow around the toe. (The question as to what K value is required to be able to regard the bottom layer as impervious will be dealt with in section 4.3.)

The resulting hydrostatic pressure diagram is easily drawn (Fig. 6): max (Δp) = γ • H, the total discharge through one joint is obtained:

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

With the pressure drop:

$$(\Delta p) = \begin{cases} \gamma \bullet \mathbf{z}, & \mathbf{z <= H} \\ \gamma \bullet \mathbf{H}, & \mathbf{H < z <= H + h} \end{cases}$$

Thus the integral in (4) yields the area in the pressure digramm and a result for Q_1 follows:

$$\mathbf{Q_1} = \rho \bullet \mathbf{H} \bullet (\mathbf{0.5\ H + h}) \qquad (5)$$

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

$$\mathbf{n = L / b} \qquad (6)$$

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

The total discharge into the pit is:

$$\mathbf{Q = n \bullet Q_1} \qquad (7)$$

(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: b = 0.63 m, the perimeter length is L = 160 m.

Fig. 6 shows the geometrical data: H = 5 m and h = 2 m. The joint is fully described by its inverse joint resistance: $\rho = 3.0 \bullet 10^{-10}$ m/s, using a waterswelling filler.

The number of interlocks:

$$n = 160 / 0.63 \cong 254 \qquad (6)$$

Discharge per joint:

$$Q_1 = 3.0 \bullet 10^{-10} \bullet 5.0 \bullet (0.5 \bullet 5.0 + 2.0) \qquad (5)$$
$$Q_1 = 6.75 \bullet 10^{-9}\ m^3 / s$$

Total discharge into the pit:

$$Q = 254 \bullet 6.75 \bullet 10^{-9}\ m^3 / s \qquad (7)$$
$$Q = 1.715 \bullet 10^{-6}\ m^3 / s$$
$$Q = 6.17\ l/h$$

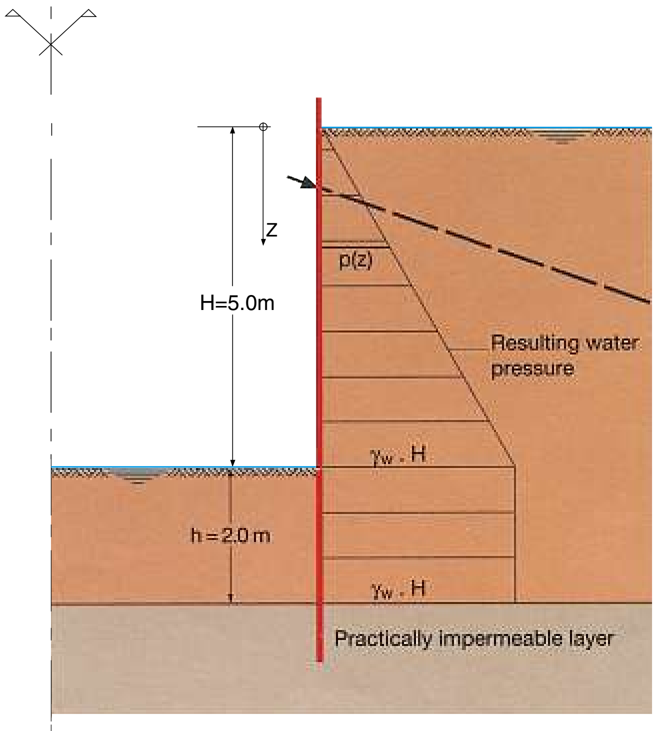


Fig. 6

4.2. 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 wall design, 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:

$$\mathbf{Q_{sw} = K \bullet (\Delta p / \gamma) / d} \qquad (8)$$

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 = 1 m:

$$\mathbf{Q_{ssp} = (1 / b) \bullet \rho \bullet (\Delta p / \gamma)} \qquad (9)$$

Both specific discharges are equal:

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

This condition yields:

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

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:

$$\mathbf{K_e = \rho \bullet (1m) / b} \qquad (12)$$

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

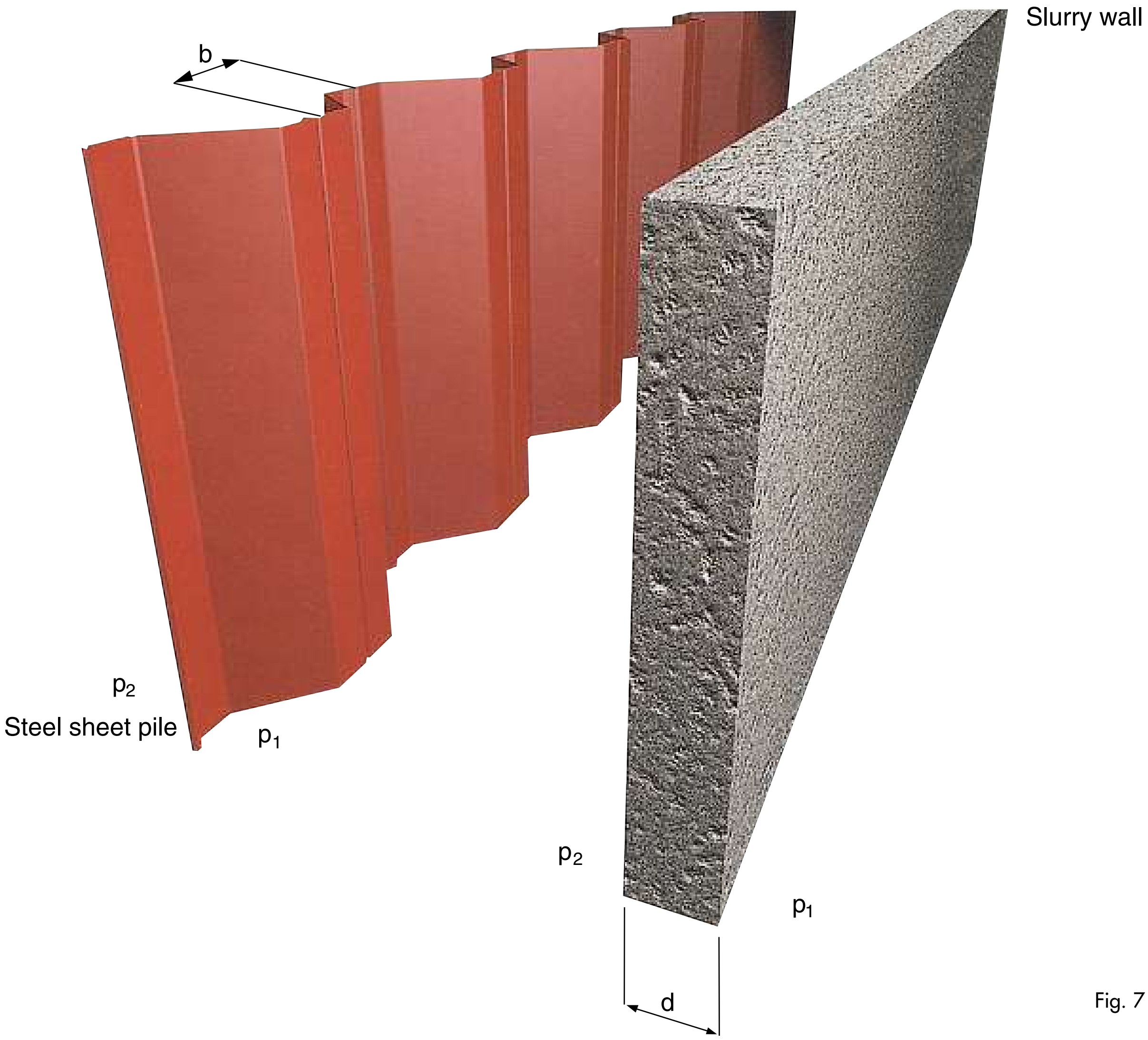


Fig. 7

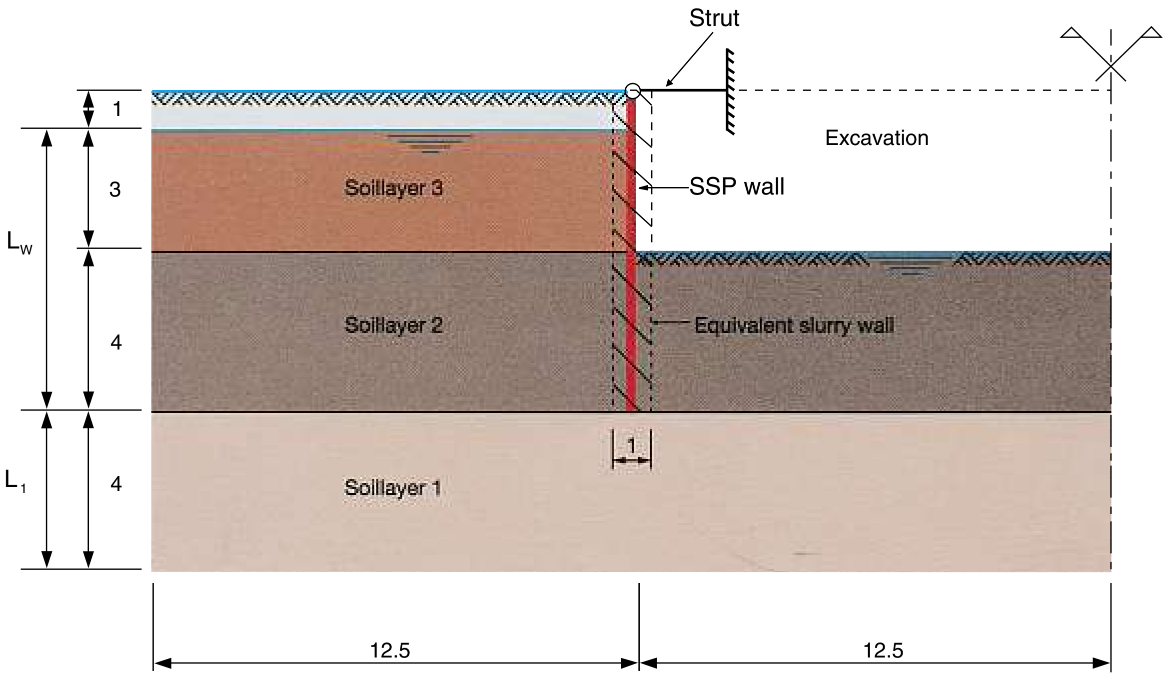


Fig. 8

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

In section 4.1 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 need to be considered. This is done with the aid of a 2D-seepage calculation program - nowadays available for PCs. Because these programs deal 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).

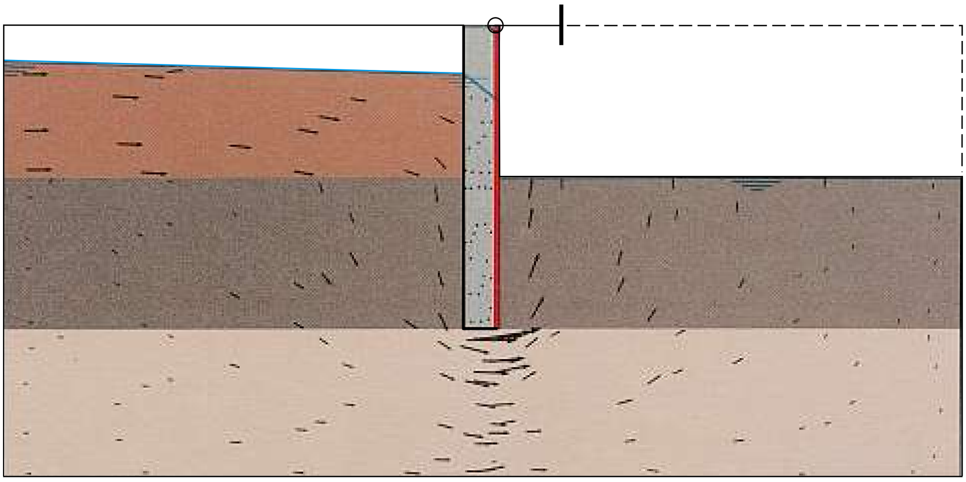
In order to show the versatility of this approach and the influence of the bottom layer on the flow, four different cases have been analysed.

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 Kw can be evaluated using (12).

The calculations are 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 Figs. 9, 10, 11, 12.

TABLE 2

ROW	ITEM	CASE 1	CASE 2	CASE 3	CASE 4
1	Ki [m/s]: SOILLAYER 1, i=1 SOILLAYER 2, i=2 SOILLAYER 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	$K_w \bullet L_w / K_1 \bullet L_1$	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 4.1 D_w [l/h]	59.4	594	59.4	594
7	D_w / D_t [%]	11.5	80	98.2	67



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

Fig. 9

Case 1: $K_w \bullet L_w/K_1 \bullet L_1$ = 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: $K_w \bullet L_w/K_1 \bullet L_1$ = 0.175
The discharge through and around the wall are of the same order of magnitude (Fig. 10).

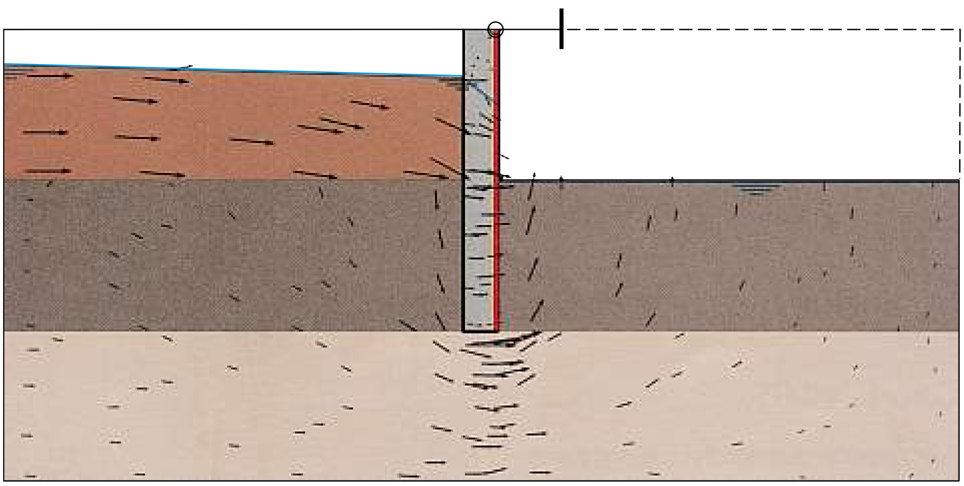
Case 3: $K_w \bullet L_w/K_1 \bullet L_1$ = 17.5
The bottom layer is practically speaking impervious. Seepage through the wall dominates the flow field (Fig. 11).

Case 4: $K_w \bullet L_w/K_1 \bullet L_1$ = 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).

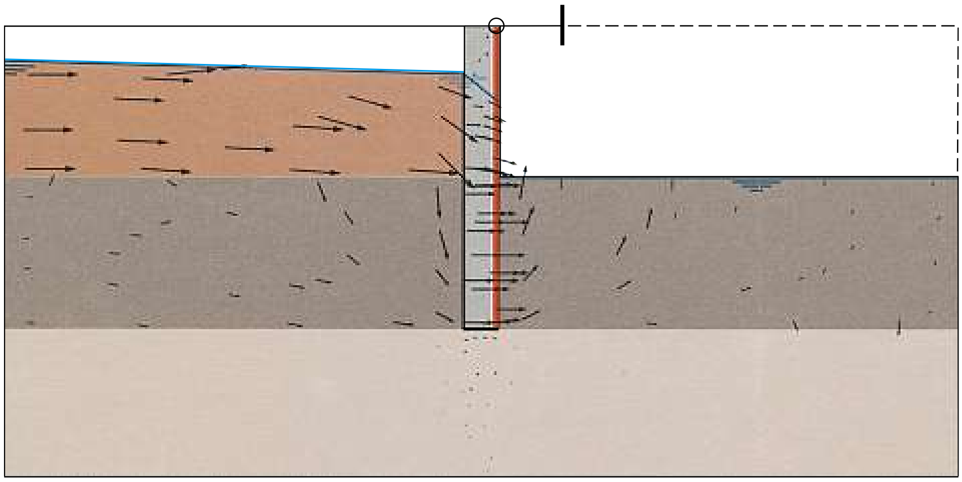
In Table 2, row 5 gives the total discharge (D_t) per m normal to the drawing plane (Fig. 8); row 6 contains the discharge D_w through the wall itself according to the simplified approach of section 4.1.

The ratio D_w / D_t is the ratio of the discharge through the wall compared to the total discharge, while the ratio $K_w \bullet L_w/K_1 \bullet L_1$ encases all that is relevant for the geometry and the permeability of the wall expressed in the permeability of the bottom layer.



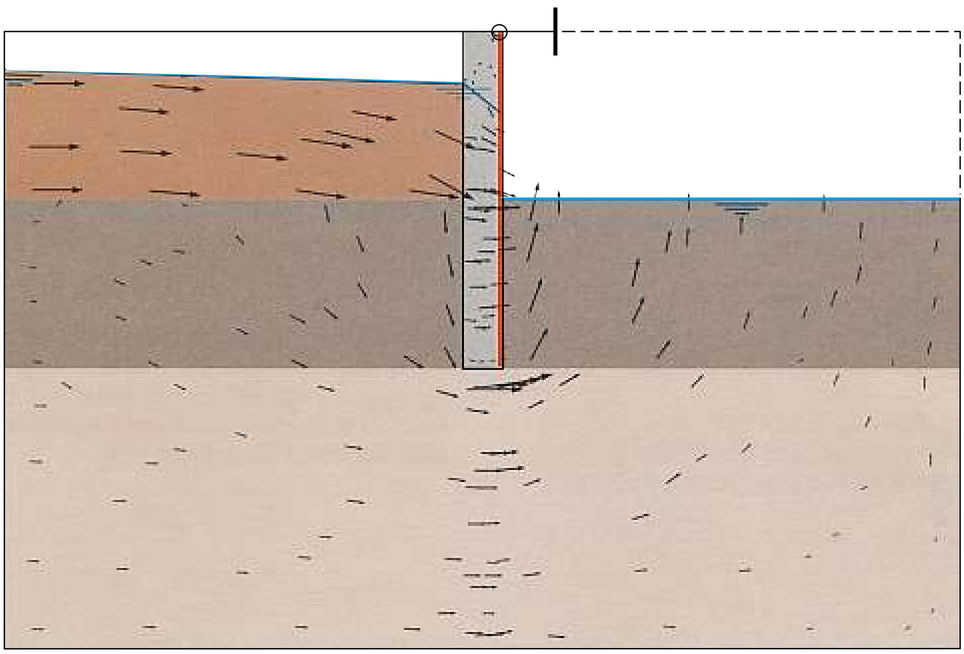
Ultimate flow field with phreatic line
Extreme velocity 4.21E-05 units

Fig. 10



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

Fig.11



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

Fig. 12

Inspection of both ratios in Table 2 confirms the hypothesis of 4.1.
(case 3: $K_w \bullet L_w/K_1 \bullet L_1 = 17{,}5 \Rightarrow D_w/D_t = 98.2\%$).

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

$$\mathbf{K_w \bullet L_w/K_1 \bullet L_1 > 0.175,}$$

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

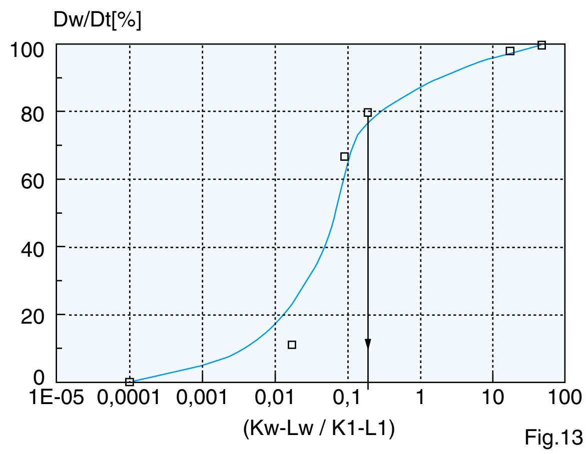


Fig.13

5. Remarks

- It is important to note, that all ρ values given in this document are characteristic values (maximum values as "cautious estimates") which are results of in situ tests.
  For the determination of the 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 Assistance department of Arcelor RPS Sheet Piling for guidelines on this matter.

- All the information included in this brochure has to be considered as informative only and has to be carefully checked by any user.

6. References

For additional background information, please refer to:

1) Steel Sheet Pile Seepage Resistance,
J.B. Sellmeijer, Fourth International Landfill Symposium, Cagliari, Italy, 1993

2) Joint resistance of steel sheet piles, Definition,
J.B. Sellmeijer, August 1993, unpublished

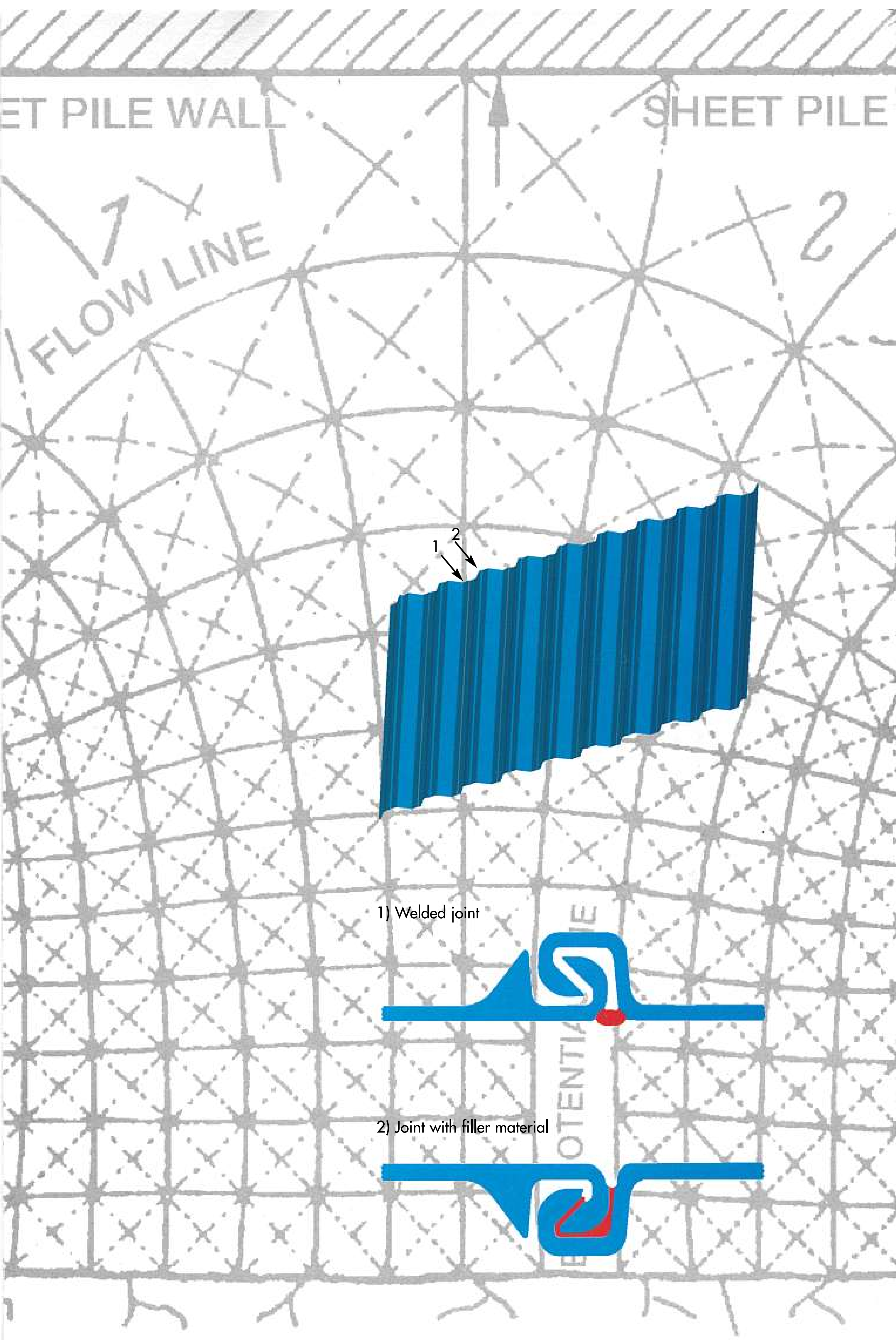
3) The hydraulic resistance of steel sheet pile joints,
J.B. Sellmeijer, J.P.A.E. Cools, W.J. Post,
J. Decker, 1993

4) EAU 1990, Recommendations of the Committee for Waterfront Structures Harbours and Waterways, 1992, Berlin

The practical aspects associated with the sealing of SSP walls such as the implantation of the filler material in the joints, welding procedures, combining vertical and horizontal sealing and pile installation are treated in part 2 of this ISPC brochure.

Part 2: "PRACTICAL ASPECTS"

A resume of the system for ensuring a watertight seal of steel sheet piles is inside the rear cover


ET PILE WALL
SHEET PILE
FLOW LINE
1
2
1) Welded joint
2) Joint with filler material

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. An SSP wall made of piles with the famous Larssen interlock provides 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 workshop welded intermediate joint should be used. The workshop weld is as impervious as the steel itself. The free interlock of the double pile needs to be threaded on site with a filler material. The lower end of the resistance range is adequately served by the various bituminous fillers, but it is noted that their use is limited to water pressures less than 100 kPa.

   For high resistance requirements, as well as water pressures up to 200 kPa, a waterswelling product should be used as a filler material. A wall designed in this way is between 100 to 1000 times more impervious than the simple sheet pile wall with Larssen interlocks.

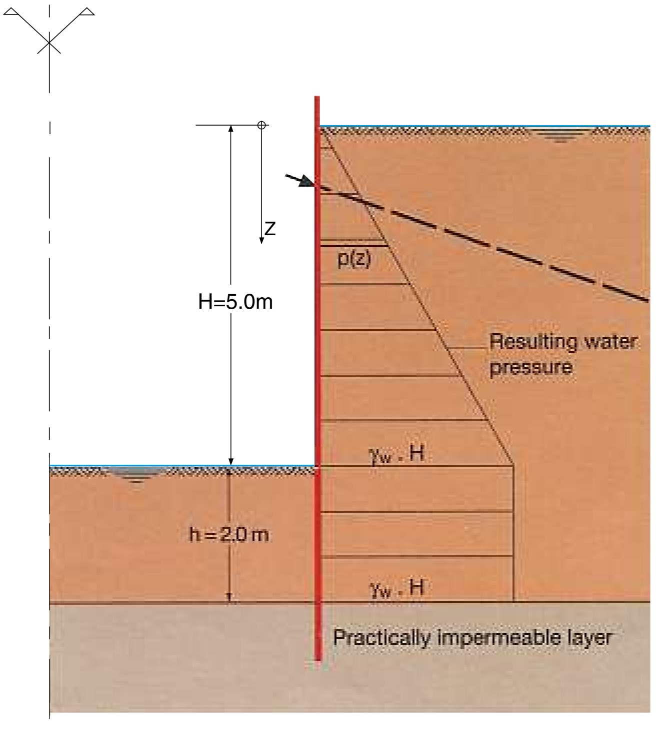
3. A 100% watertightness may be obtained by welding every joint.
   Double piles with a workshop weld are used for the construction of the wall. The interlock that needs to be threaded on the job has to be welded on site after excavation.

If a comparison needs to be made between the rate of seepage of an SSP wall and a slurry wall, the table below may be used. For a given SSP 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.

Example: An SSP wall is selected made of AZ double piles with a shop welded intermediate interlock and a waterswelling filler material in the interlock to be threaded on site.
In order to have the equivalent discharge, a slurry wall of 80 cm thickness has a hydraulic conductivity $K = 1{,}9.10^{-10}$ m/s.

To form an impression of the rate of discharge through the SSP wall the data that need to be provided are (see figure):

STEEL SHEET PILE WALL			**HYDRAULIC CONDUCTIVITY K [m/s] OF AN EQUIVALENT SLURRY WALL WITH A THICKNESS D**		
SECTION	EVERY 2nd INTERLOCK IS SHOPWELDED	FILLER	D = 60 cm	D = 80 cm	D = 100 cm
AZ	YES	BITUMINOUS	2.86 E-08	3.81 E-08	4.76 E-08
	YES	WATERSWELLING	1.43 E-10	1.90 E-10	2.38 E-10
	NO	BITUMINOUS	5.71 E-08	7.62 E-08	9.52 E-08
	NO	WATERSWELLING	2.86 E-10	3.81 E-10	4.76 E-10
PU	YES	BITUMINOUS	3.00 E-08	4.00 E-08	5.00 E-08
	YES	WATERSWELLING	1.50 E-10	2.00 E-10	2.50 E-10
	NO	BITUMINOUS	6.00 E-08	8.00 E-08	1.00 E-07
	NO	WATERSWELLING	3.00 E-10	4.00 E-10	5.00 E-10
LS	YES	BITUMINOUS	3.60 E-08	4.80 E-08	6.00 E-08
	YES	WATERSWELLING	1.80 E-10	2.40 E-10	3.00 E-10
	NO	BITUMINOUS	7.20 E-08	9.60 E-08	1.20 E-07
	NO	WATERSWELLING	3.60 E-10	4.80 E-10	6.00 E-10
JSP	YES	BITUMINOUS	4.50 E-08	6.00 E-08	7.50 E-08
	YES	WATERSWELLING	2.25 E-10	3.00 E-10	3.75 E-10
	NO	BITUMINOUS	9.00 E-08	1.20 E-07	1.50 E-07
	NO	WATERSWELLING	4.50 E-10	6.00 E-10	7.50 E-10



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.

The discharge through one not welded interlock is:

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

According to the tests the inverse joint resistance ρ may be assumed to be as follows for a first order design approach:

bituminous filler material: $= 6 \bullet 10^{-8}$ m/s ($p < 100$ kPa)
waterswelling filler material : $= 3 \bullet 10^{-10}$ m/s ($p \leq 200$ kPa)

For further details please refer to 4.1 of the brochure.

Importantly, this table gives an impression of the cost per m per joint for the different solutions. The cost ratio gives the ratio of the cost of a particular solution to the bituminous filler solution.
These costs cover the filler material including the implantation in the joint.

Seepage resistance solution	Cost ratio
empty joint	0
joint with bituminous filler material	1
joint with waterswelling product	2
welding of the joints	5

Values of ρ for a first order design approach

Watertightening System	ρ [10^{-10} m/s]	maximum differential water pressure [k Pa]
Empty joints	>1000	100
Bituminous filler material	600	100
Waterswelling filler material (Roxan™)	3	200

Roxan™ System (Trademark of ProfilArbed)

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Steel Sheet Piling

The Impervious Steel Sheet Pile Wall • Part 2: Practical Aspects

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The impervious steel sheet pile wall Part 2: Practical Aspects

Contents

Introduction

The watertightness of the walls is one of the important selection criteria for construction processes in certain types of works, as for example: underground parking areas, tunnels, containing of waste, etc.

Steel sheet piling, by definition the separation element between two different types of material, constitutes an ideal solution for resolving the problem of watertight walls provided it is possible to find:

(a) a method of calculating in a precise way the rate of flow through the interlocks;

(b) solutions to the practical problems which arise during the formation of watertight walls.

Paragraph (a) above is dealt with extensively in Part 1: **'Design'**.

Paragraph (b) above is the subject of this publication which explains in detail the various sealing systems as well as all the practical aspects concerning them.

Main vertical and horizontal sealing systems

When we speak of a watertight steel sheet pile wall we must distinguish between two types of sealing:

- vertical sealing, which consists mainly of making the sheet piling interlocks watertight;
- 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).

1. Vertical sealing

Several systems of sealing are proposed, depending on the type of application.

A. Products positioned in the interlocks either before or after the piles are threaded:

- bituminous product (hot applied) for applications where average performance ($\rho = 6 \cdot 10^{-8}$ m/s) is required in respect of watertightness (see para 1.1.1);

- water-swelling product (cold applied) for high performance applications ($\rho = 3 \cdot 10^{-10}$ m/s) (see para 1.1.2).

B. Welding for very high performance applications:

- at the factory for locked interlocks on sheet piling supplied in pairs or triples;

- in situ above ground level or at shallow depth below the bottom of excavation for interlocks threaded on site (see para 1.1.3).

C. Sundry other methods of vertical sealing (see para 1.1.4)

1.1 Features of products and procedures for installing vertical sealing

1.1.1 Hot installed bituminous product

1.1.1.1 Features of the product

Composition:	bitumen-polymers-filler
Density at 25ºC:	1.38-1.48 (ASTM D70)
Softening point:	~ 90ºC (ASTM D36)
Colour:	black-brown

These features are only given as an indication and can be modified by the supplier as required.

1.1.1.2 Packaging

The product can be supplied in barrels or in packets.

1.1.1.3 Conditions of application

The behaviour of the bituminous product when it is installed (hot) is set out below:
- application on a surface covered with standing water: to be avoided

- application on damp metal (dew point): very good, but to be avoided as far as possible

- application on metal at –10 °C to +70 °C: excellent

- hardening in rain: excellent

- drying under UV light: excellent

1.1.1.4 Durability of the product in different environments

ie durability in the installed steel sheet piling:

- water with pH 3.5 to pH 11.5: excellent
- sea water: excellent
- mineral oil: low
- petrol: very low
- crude oil: very low

1.1.1.5 Consumption

a. Application into an open interlock (Figure 1-1):

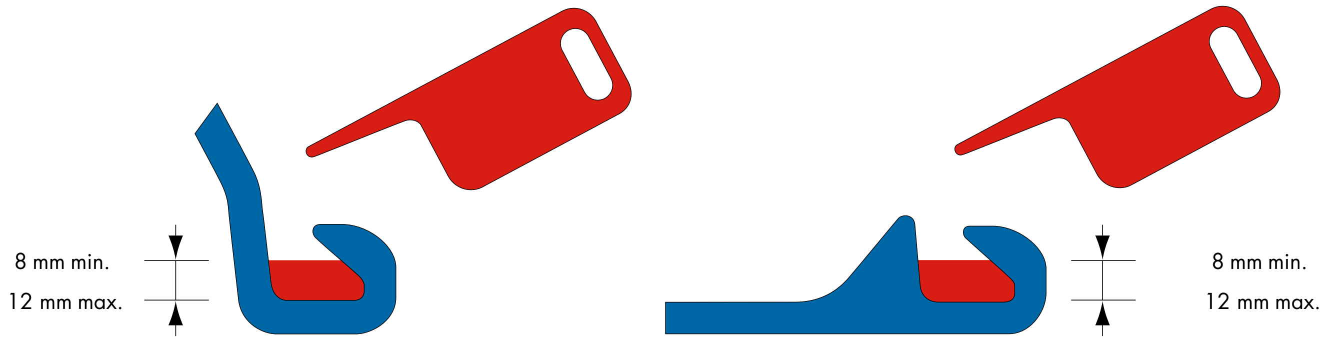
consumption approximately 0.3 l per metre of interlock.

b. Application into threaded interlocks (Figure 1-2):

consumption approximately 0.1 l per metre of interlock on each side of the sheet piling, ie 0.2 l/m if the application is carried out on both sides.

Bituminous product: Hot feeding into the sheet pile interlocks

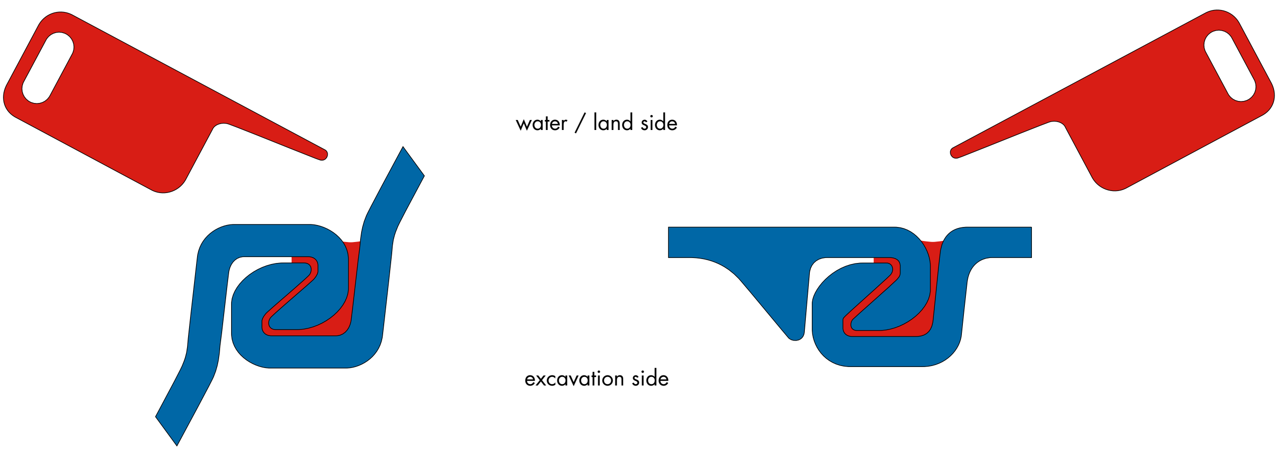
1) Filling the free interlocks:



sheet piles AU/PU/LS/JSP

sheet piles AZ

2) Filling the threaded interlocks taking into account the hydrostatic pressure side



sheet piles AU/PU/LS/JSP

sheet piles AZ

Figure 1

1.1.1.6 Installation of seal at the factory (Figures 2, 3 and 4)

The application of the bituminous product at the factory is carried out to comply with the following requirements:

- the interlocks must be dry but slight dampness is permitted;
- the piling must be laid out in a perfectly horizontal position;
- so that the product can adhere in the interlocks, cleaning with a jet of compressed air, a steel wire brush or high-pressure water jet is recommended if any corrosion is present. Recently rolled piling does not necessitate any particular precautions;
- to prevent the hot liquid product from flowing out of the ends of the piles when the interlocks are filled, the ends must be blocked at the top and bottom using mastic;
- the product is heated to a maximum temperature indicated on the information sheet accompanying the product;
- the product is stirred to give a homogeneous mixture;
- the product is poured into the interlocks using an appropriate pourer;
- the interlocks are filled taking into account the direction of driving and the position in relation to hydrostatic pressure:

  ***** if the piles are supplied in single units:
  fill one free interlock per single pile **(Figure 2)**;

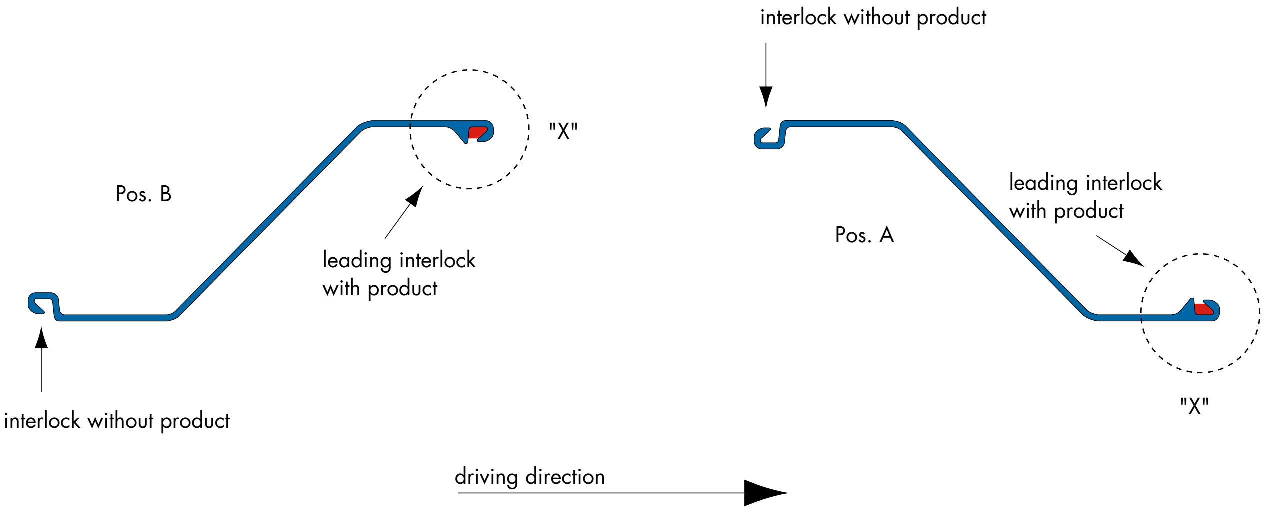
  ***** if the piles are supplied in multiple units (doubles):
  fill the intermediate interlock and one free interlock **(Figure 3)**;
- depth of filling of free interlocks: 8 to 12 mm **(Figure 1-1)**.

Note:

So that the strength of the crimping points is not reduced in the case of threaded and crimped piles, the bituminous product must be applied after the piles are crimped.

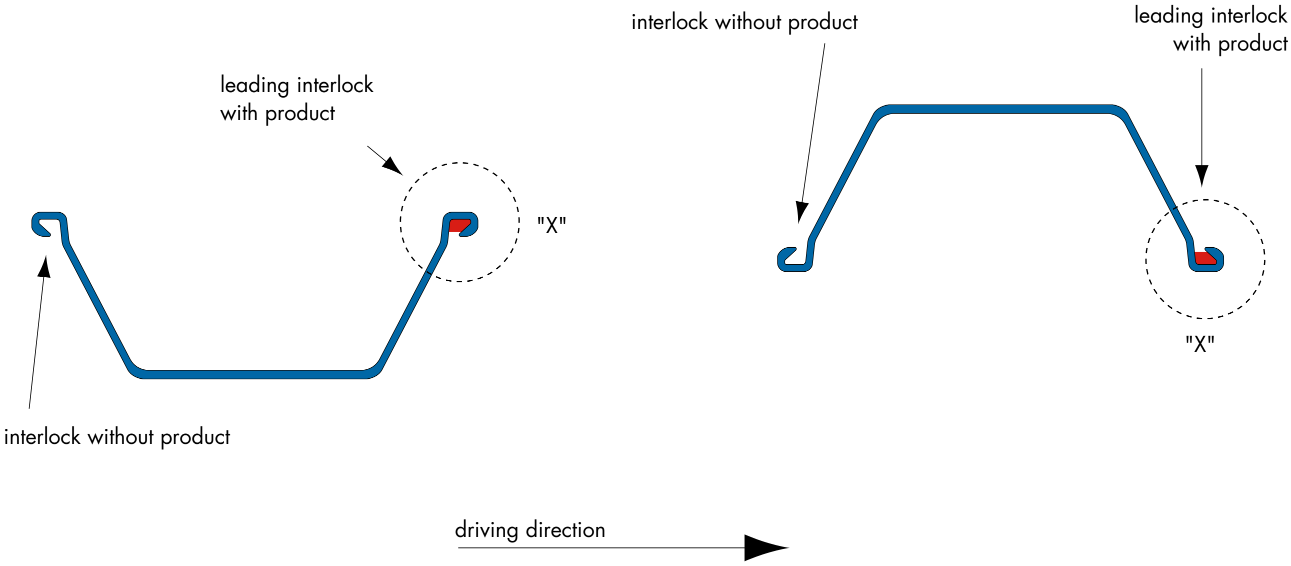
Bituminous product: Hot feeding into the interlocks of single sheet piles

1) Sheet piles AZ



for detail "X" see Fig. 1-1

2) Sheet piles AU/PU/LS/JSP

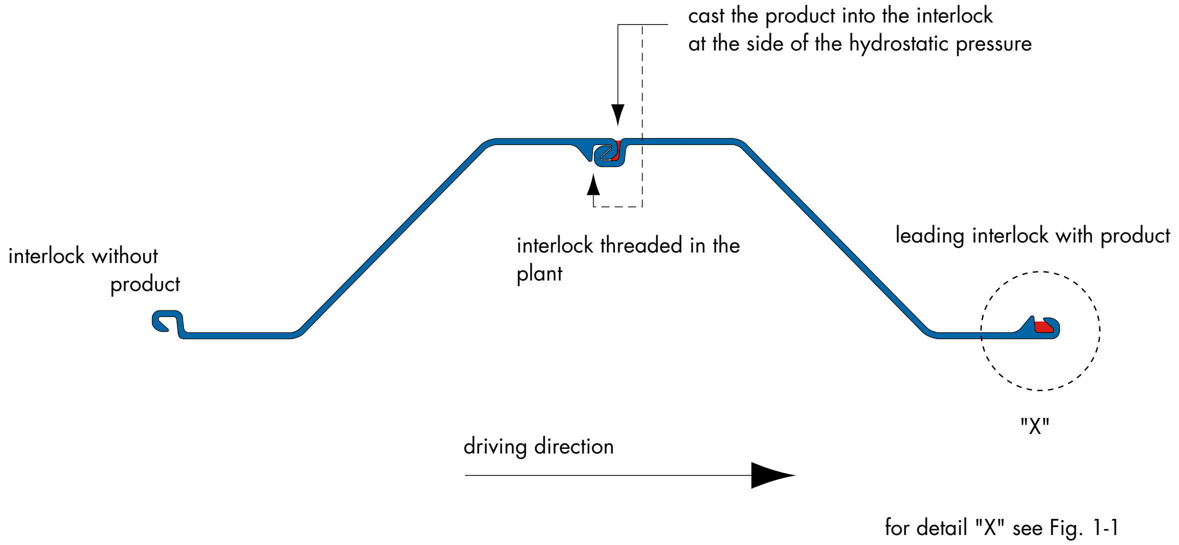


for detail "X" see Fig. 1-1

Figure 2

Bituminous product: Hot feeding into the interlocks of threaded sheet piles

1) Sheet piles AZ



2) Sheet piles AU/PU/LS/JSP

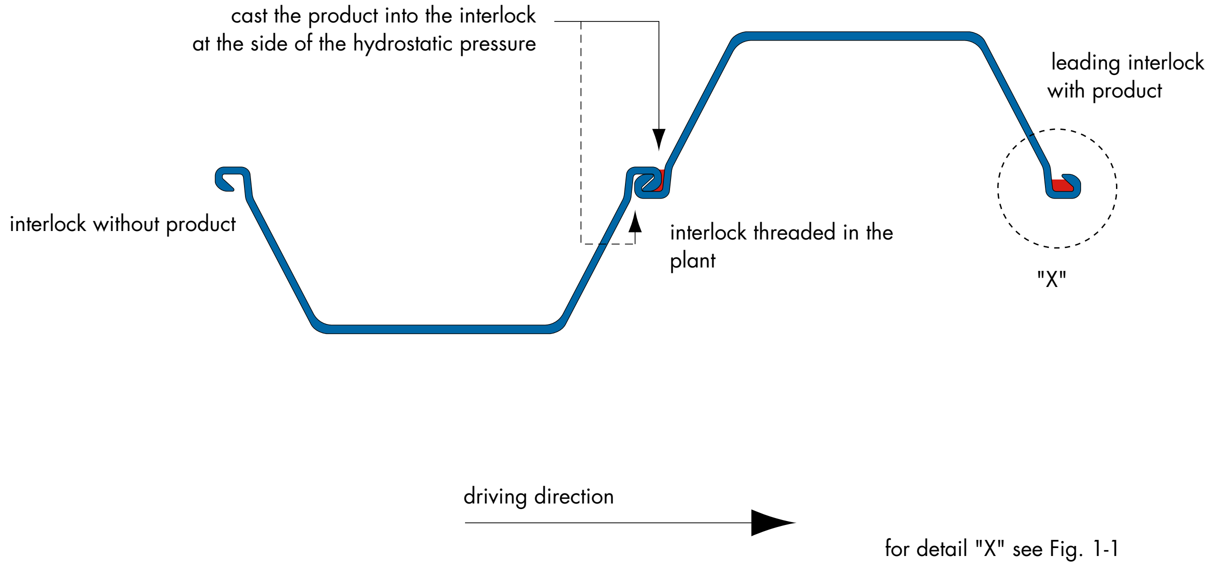
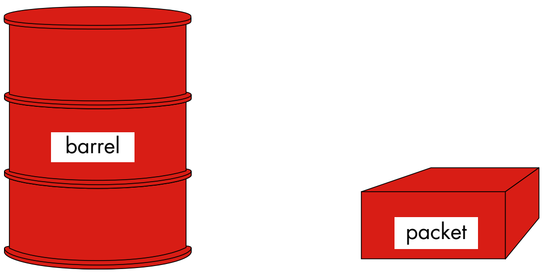


Figure 3

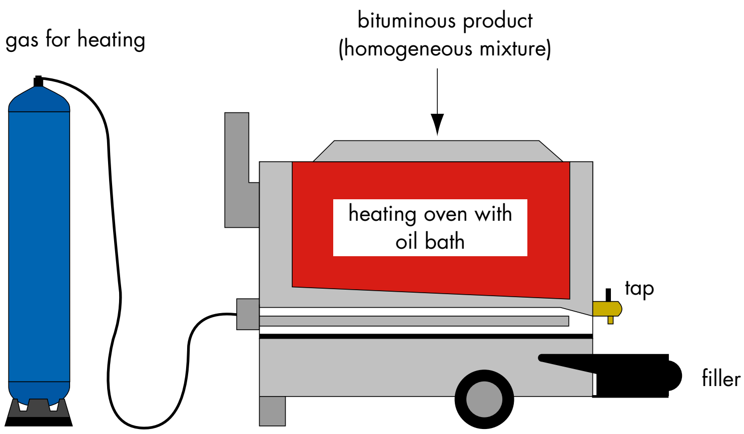
Illustrated description of application of the bituminous product



1) supply of the bituminous product in 200 l barrel or packet. The barrel is cut open and the product taken out in pieces.

2) heating oven for bituminous product

3) stir before use



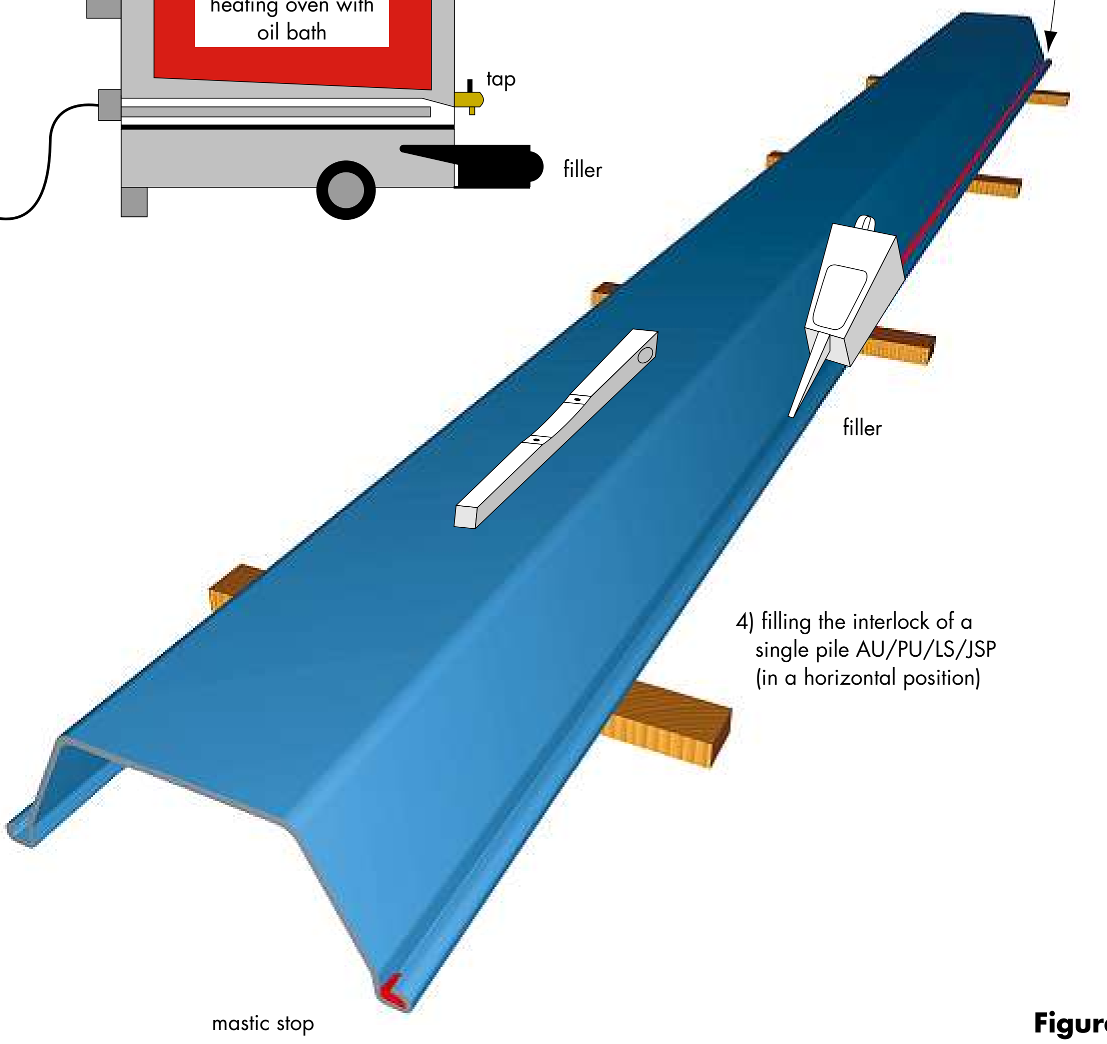


Figure 4

1.1.1.7 Installing the seal in situ

The application of the bituminous product in situ is made in accordance with the requirements stated in 1.1.1.6 for installation at the factory.

In dry weather, installation in the open air does not pose a problem.

In rain, care must be taken, possibly by using a tarpaulin or a plastic sheet, to avoid the presence of water in the interlocks before they are filled with the hot bituminous product.

1.1.1.8 Transport of treated piling

If the bituminous product has not solidified, the treated piles must be transported horizontally with the openings of the treated interlocks turned to face **upwards**.

After the product has cooled, the sheet piling must be protected from getting too hot (softening point of the product: 95 to 110°C) in order to prevent the product from running out of the interlock.

1.1.1.9 Installing the sheet piling (Figure 5)

Piling which has been sealed using a bituminous product is installed in the totally classic way, either by impact hammer, vibrator or by jacking.

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

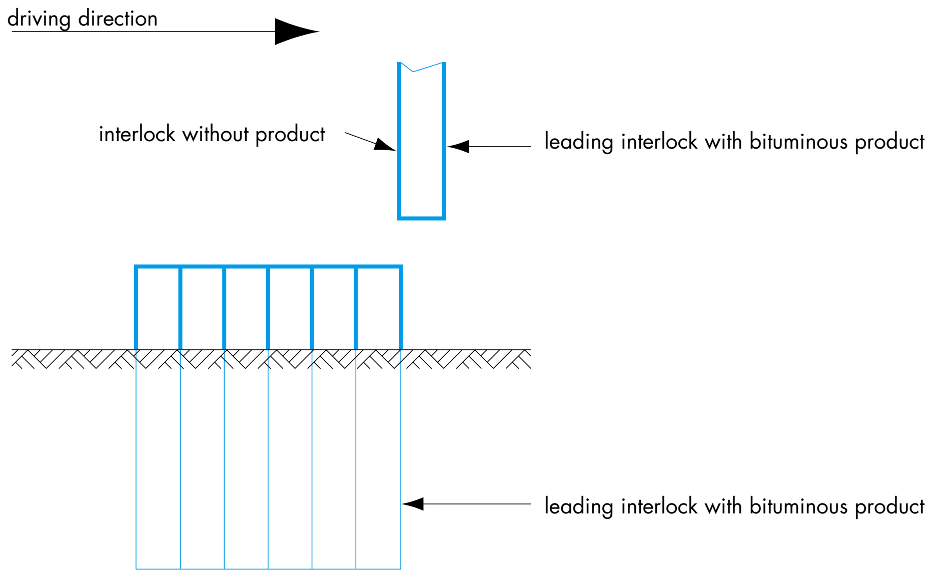
- the leading interlock must be that provided with the bituminous product;

- when driving sealed piles care must be taken with guiding so as to prevent the piling from being longitudinally or transversely out of plumb. The use of guides is absolutely essential to respect a maximum tolerance of 1% (or even less than 1%) on the verticality;
- when sheet piling is simply installed without driving, it is possible that the piling 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 engine must be provided on the site to allow correct installation, or, possibly, the recalcitrant interlock can be heated very gently and carefully with a blow-lamp.

Take care!!
Do not exceed the softening point of the product.

Installing sheet piles sealed with a bituminous product

1) Single sheet piles treated with a bituminous product



2) Double sheet piles treated with a bituminous product

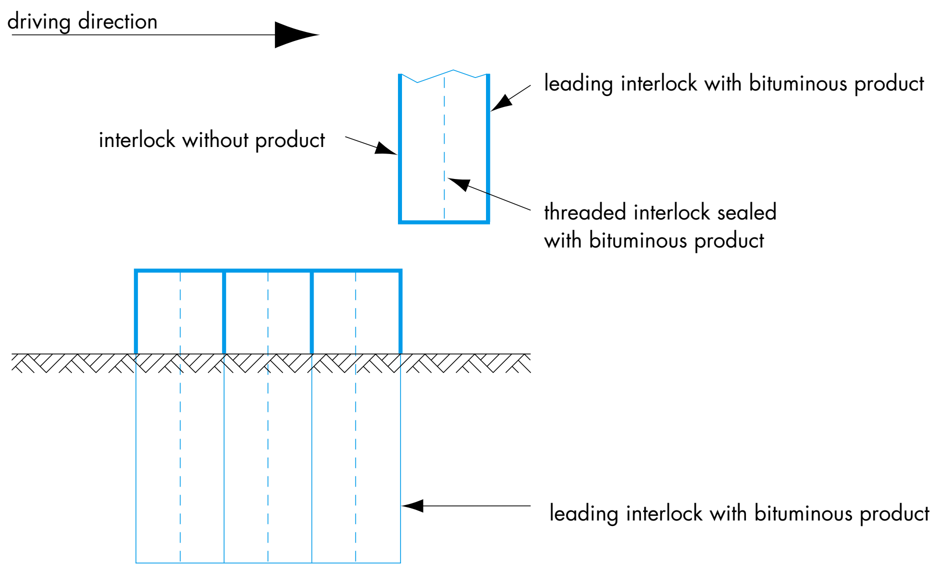


Figure 5

1.1.2 Water-swelling product (Roxan™ System)

1.1.2.1 Features of the product

Composition:	normally urethane prepolymer
Density at 20°C:	1.22
Inflammation point:	500°C
Maximum expansion:	• continuous immersion in drinking water: 115% in sea water: 90% • alternate cycles drinking water: 115% sea water: 90% • no expansion in oil • expansion in alkaline salts: identical to drinking water
Colour:	normally light grey

These features are only given as an indication and can be modified by the supplier as required.

1.1.2.2 Packaging

The product is supplied in cartridges of 320 ml or in barrels of approximately 15 l for extrusion.

1.1.2.3 Conditions of application

The behaviour of the water-swelling product when it is installed is set out below:

- application on a surface covered with standing water: impossible
- application on damp metal (dew point): excellent
- application on metal at –10°C: delicate or critical
- application on metal at +5°C to +70°C: excellent
- polymerization in rain: delicate to critical
- polymerization in UV light: excellent

1.1.2.4 Durability of the product in different environments

ie durability in the installed steel sheet piling:
- water with pH 3.5 to pH 11.5: excellent
- sea water: excellent
- mineral oil: excellent
- petrol: excellent
- crude oil: excellent

1.1.2.5 Consumption

Application into an open interlock **(Figure 6)**: consumption approximately 0.15 l per metre of interlock.

1.1.2.6 Installation of seal at the factory (Figures 7, 8 and 9)

The application of the water-swelling product is made preferably at the factory and must be carried out to comply with the following requirements:

- the interlock must be dry; possible slight humidity is permitted;

- laying out the piling in a perfectly horizontal position is not essential;

- so that the product can adhere in the interlocks, recently rolled piles need to be cleaned with a jet of compressed air. In the event of the presence of corrosion in the interlocks, cleaning with a steel wire brush and/or high-pressure water jet is necessary;

- positioning the product by extrusion and spreading the product using a special template (ProfilArbed patent LU 88397) which distributes the product properly in the interlock;

Take care!! Spreading using the special template is **essential** to ensure the sealing of the interlock.

- filling the interlocks taking into account the direction of driving:

- if the piles are supplied in single units: fill one free interlock per single pile **(Figure 7)**;

- if the piles are supplied in units already fitted together (doubles):

  * either fill the intermediate interlock before they are fitted together, together with one free interlock **(Figure 8)**;

  * or weld the intermediate interlock and fill one free interlock **(Figure 8)**.

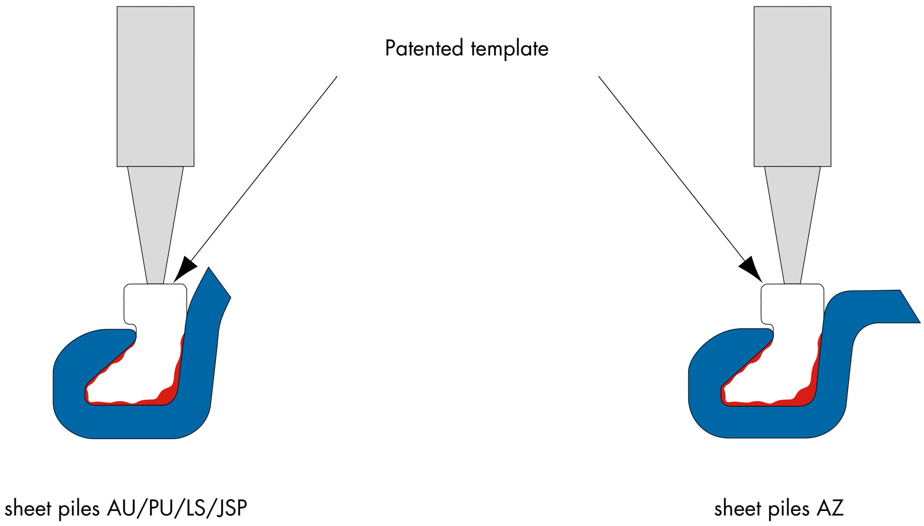
It should be noted that it is possible to crimp the piles once they have been sealed and threaded together.

1.1.2.7 Installing the seal in situ

Application of the water-swelling product in situ is not advised unless the work can be carried out under shelter. It must then be carried out to comply with the same requirements as for application at the factory (with assistance from Arcelor RPS Sheet Piling).

Water-swelling product: Feeding into sheet pile interlocks

1) Filling the free interlock with a water-swelling product



2) Expansion of water-swelling sealer in threaded interlocks

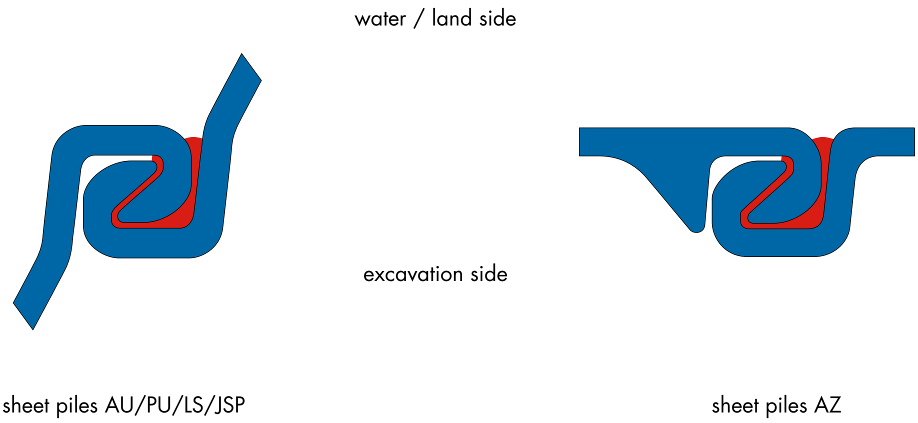
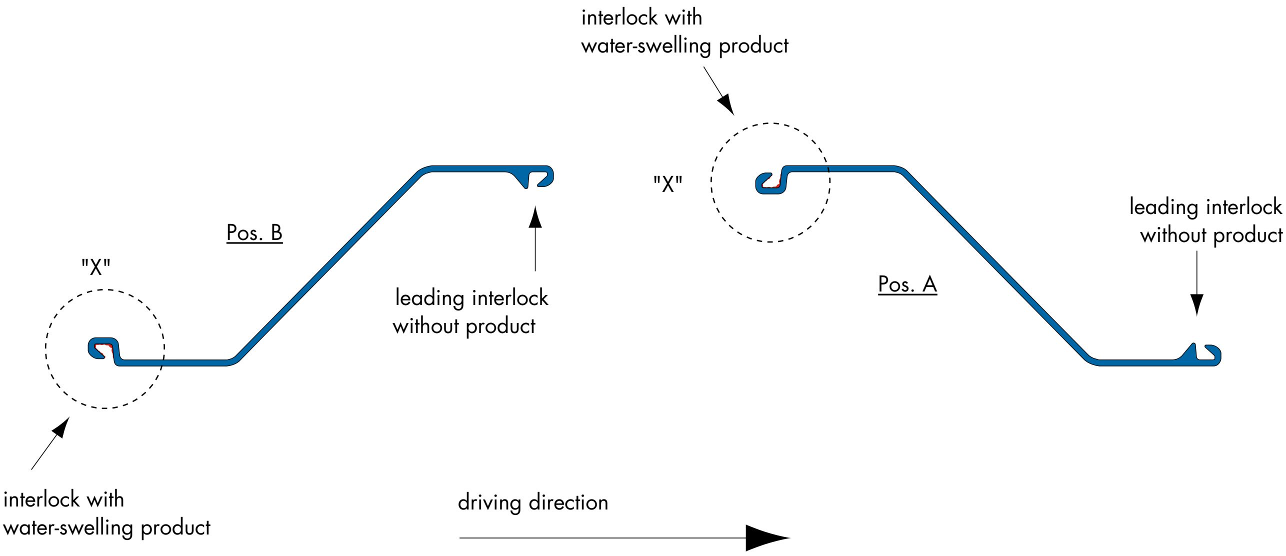


Figure 6

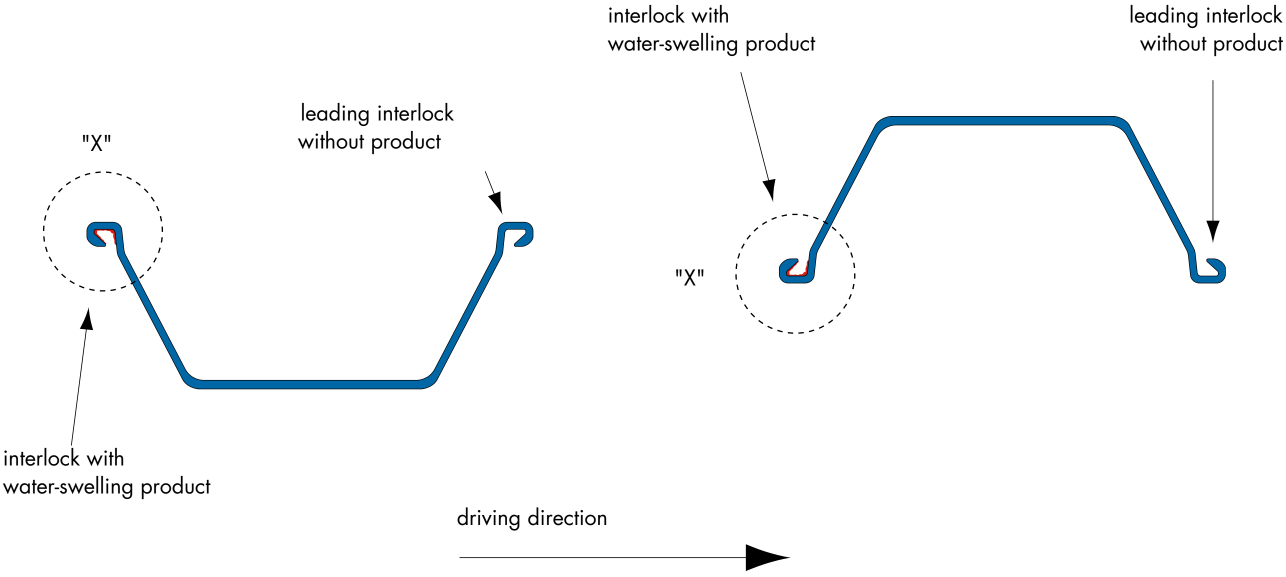
Water-swelling product: Feeding into the interlocks of single sheet piles

1) Sheet piles AZ



for detail "X" see Fig. 6-1

2) Sheet piles AU/PU/LS/JSP

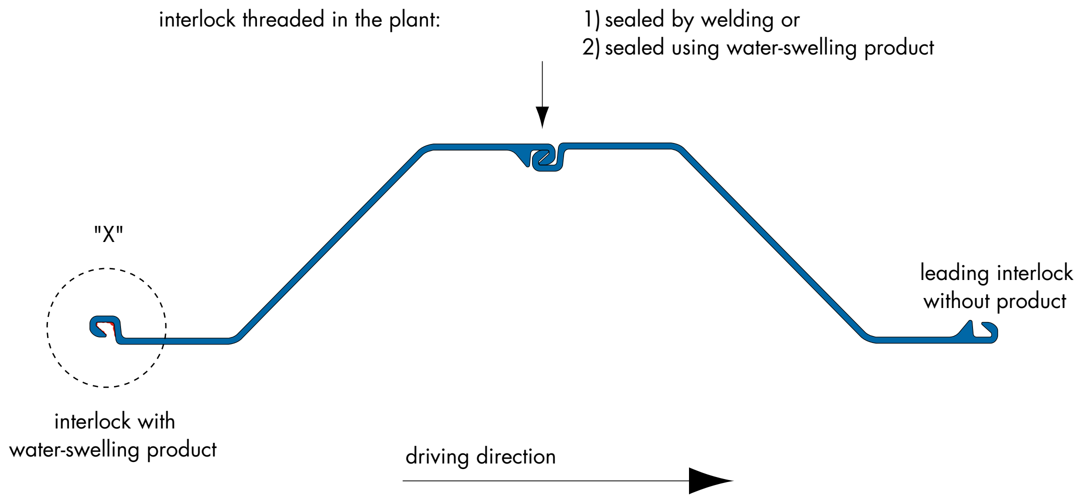


for detail "X" see Fig. 6-1

Figure 7

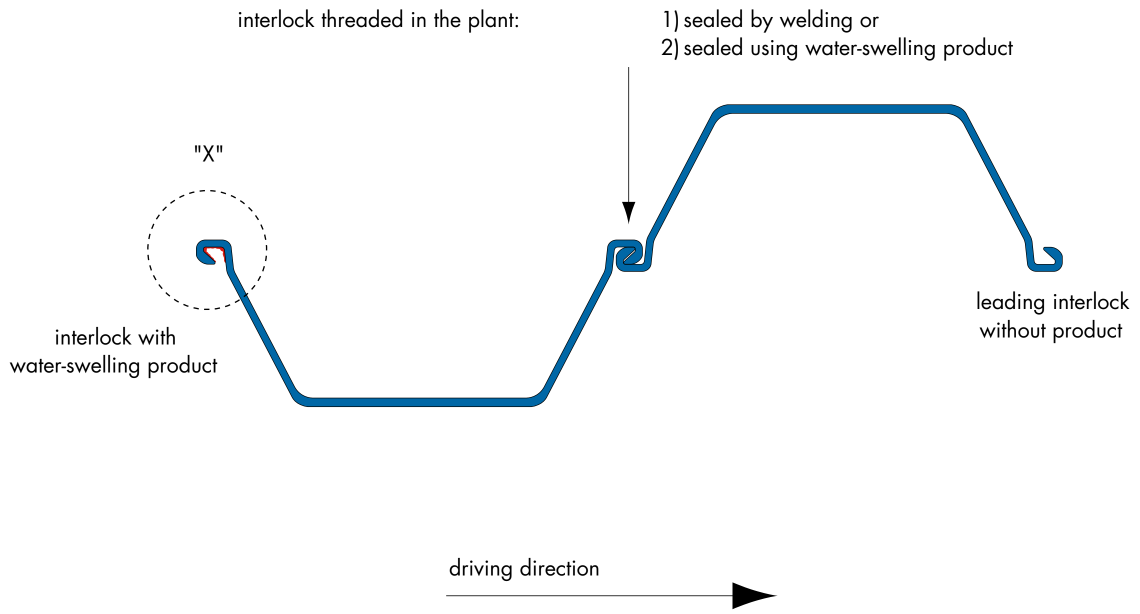
Water-swelling product: Feeding into the interlocks of threaded sheet piles

1) Sheet piles AZ



for detail "X" see Fig. 6-1

2) Sheet piles AU/PU/LS/JSP



for detail "X" see Fig. 6-1

Figure 8

Illustrated description of the feeding of a water-swelling product

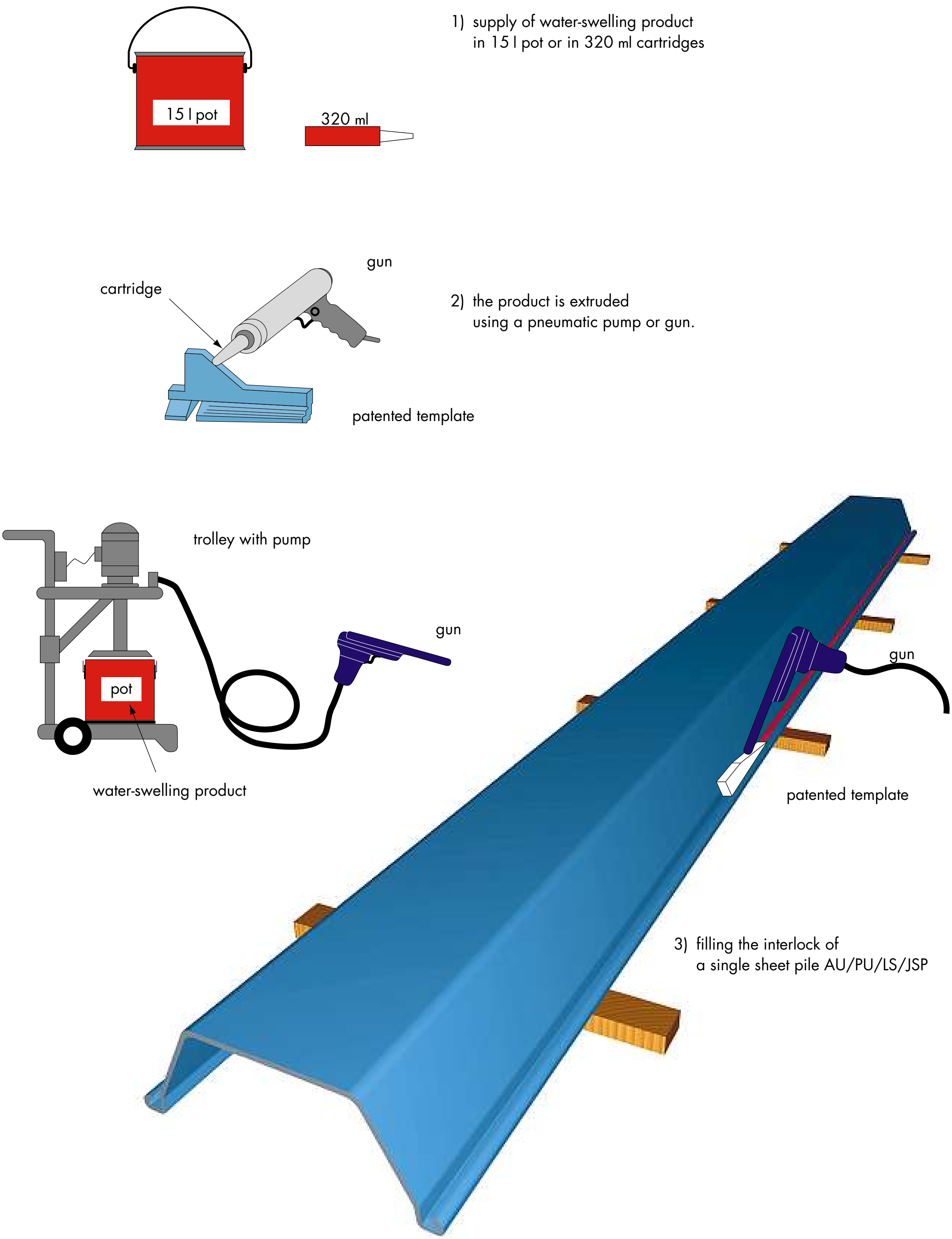


Figure 9

Transport and storage of sheet piles sealed with a water-swelling product

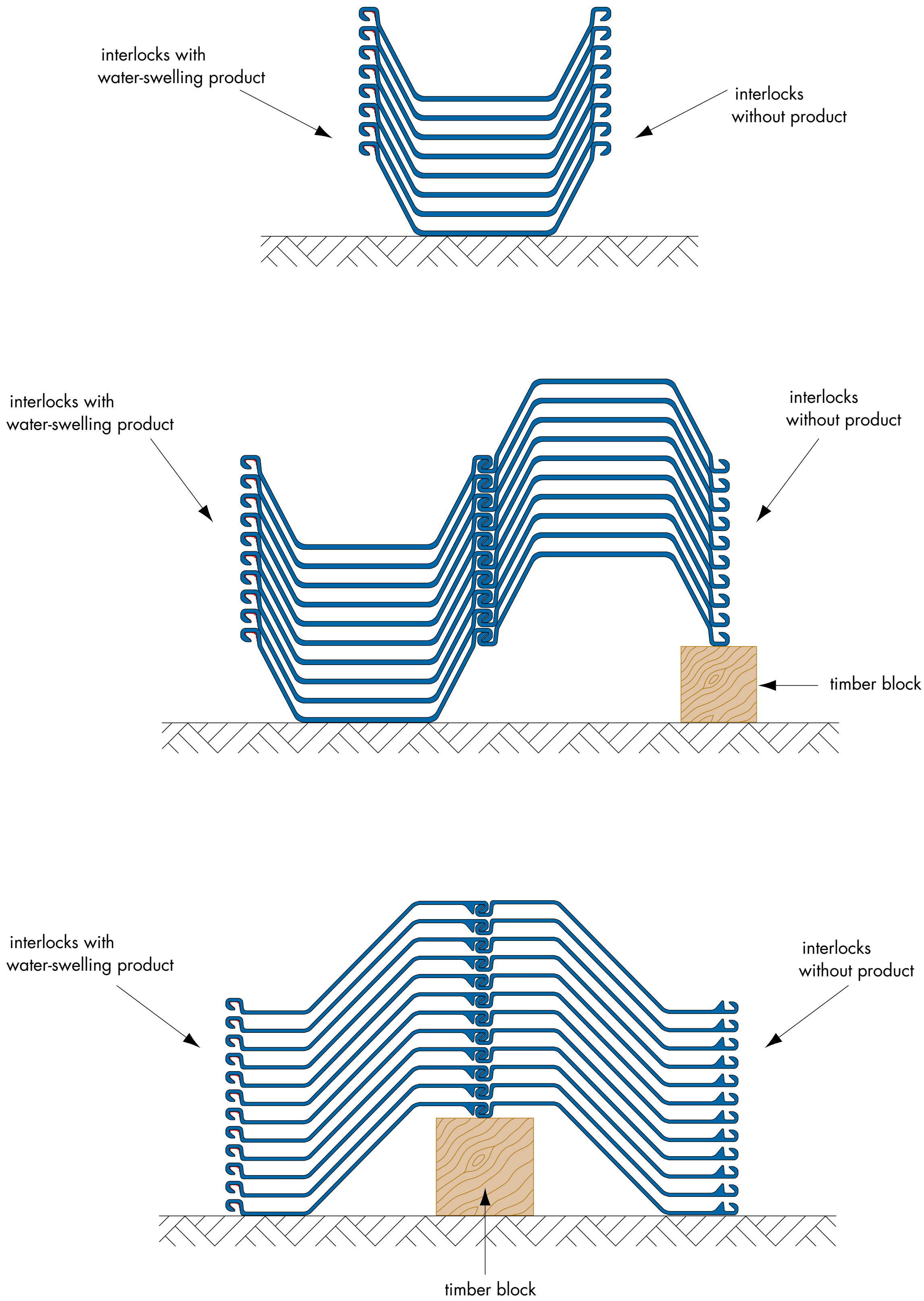


Figure 10

1.1.2.8 Transport of treated piling (Figure 10)

Piles fitted with the water-swelling product must be transported so that no treated interlock which has not been threaded to another interlock (open interlock) comes into contact with standing water (risk of expansion of the product after polymerization, loss of adhesion). Care must be taken therefore to transport the piles with the openings of the sealed free interlocks **facing downwards.**

In the case of threaded piles which are not crimped, where the intermediate interlock and an open interlock have been sealed with the water-swelling product, the interlocks which have been threaded must be locked into position to avoid the two units sliding on each other and to stop the sealing product from being damaged.

1.1.2.9 Installing the sheet piling (Figure 11)

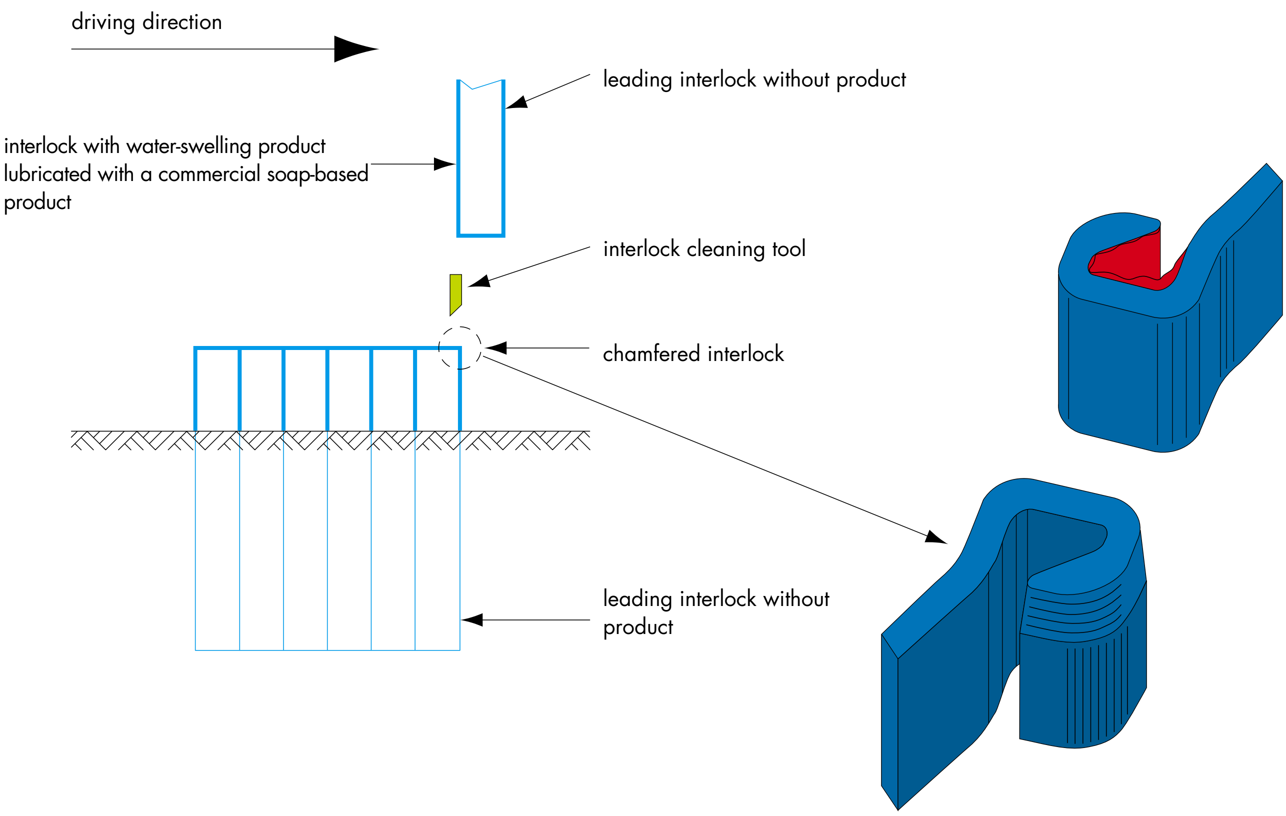
Piling which has been sealed using a water-swelling product is installed in the totally classic way, either by drop hammer, vibrator or by jacking.

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

- the leading interlock without a sealing product must first be cleaned by preceding the sealed interlock of the next pile by a cleaner, ie a cleaning tool **(Figure 12)** which fits the shape of the interlock perfectly and takes away with it the impurities which might prevent the joint from working properly. This part, which is not recovered, can be supplied by ProfilArbed. In this same context it should be noted that **driving piles which have been threaded and sealed at the factory one by one** is not possible (deterioration of product);
- when driving piles sealed with the water-swelling product, 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;
- the sealing product **must be lubricated** before driving using a commercial soapy product. This product must be spread in the sealed interlock using a paintbrush;
- 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 engine 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 joint);
- when water is present, driving of a **partially driven pile must not be suspended for more than two hours.** Expansion of the sealing product would cause it to be torn off when driving is resumed.

Installation of sheet piles sealed with a water-swelling product

1) Single sheet piles with water-swelling product



2) Threaded double sheet piles with water-swelling product

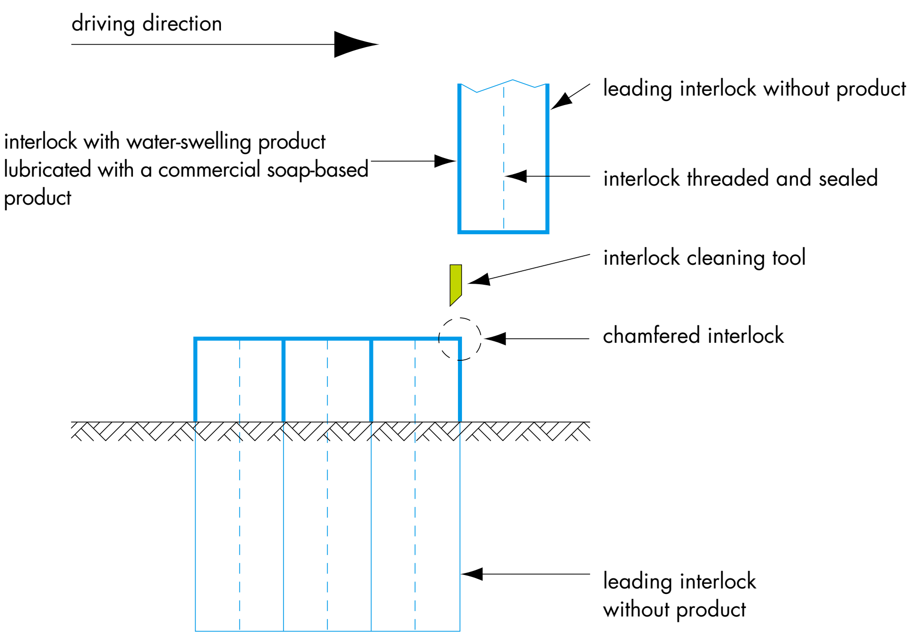


Figure 11

Cleaning tool for the interlock of sheet piles sealed with a water-swelling product

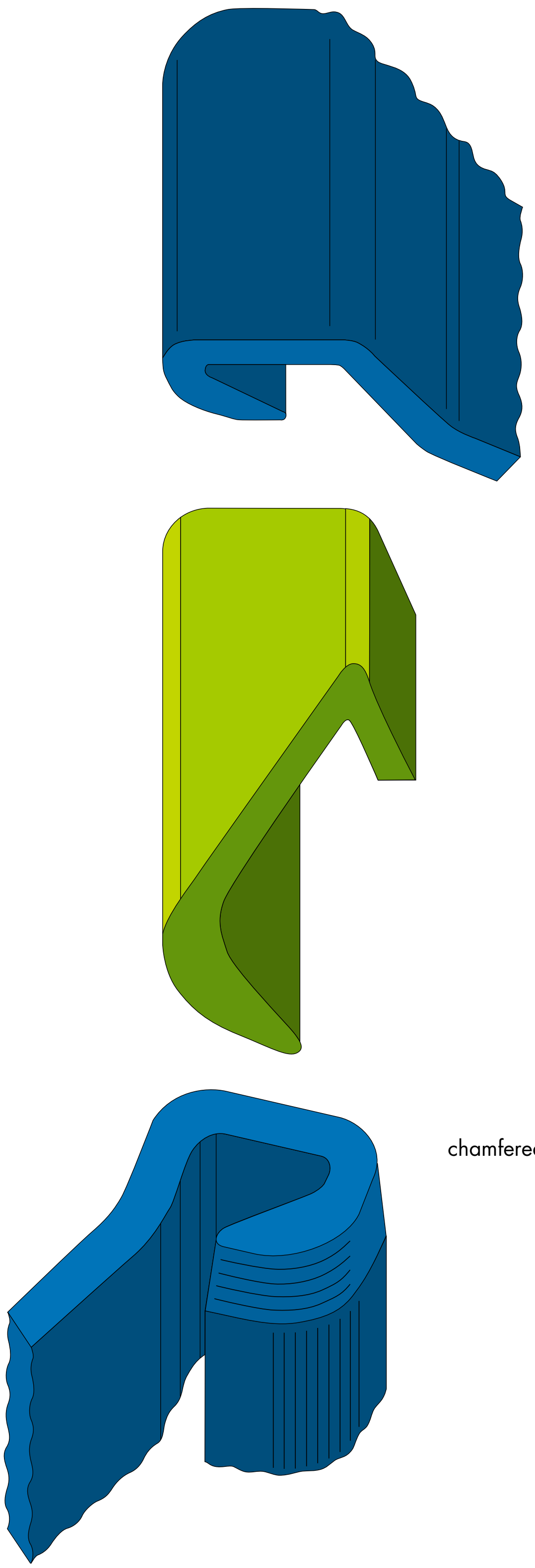


Figure 12

1.1.3 Welding

1.1.3.1 Introduction

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

As every user is always encouraged to pay particular attention to problems connected with the quality of welding, increased importance must therefore be attached to anything concerning feasibility and competitiveness of welding processes.

It should be remembered that the competitiveness of a welding process rests on several factors, for example:

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

In conditions other than those of the factory, which are known and totally under control, the criteria defined above can be influenced by various factors and particular attention must be paid to the following points:

- the possibility of access to the pile,
- atmospheric conditions on the site,
- the mechanical strength of the weld metal (see thickness of seam and penetration to be observed),
- the amount of damp in the interlocks,
- the distance between the interlocks,
- the aggressiveness of the environment acting on the welds.

For any project to seal the interlocks of sheet piling, care must be taken to choose the most suitable process for the conditions encountered. Arcelor RPS Sheet Piling is at your disposal to advise you on the choice of the best process.

1.1.3.2 Possible ways of welding the interlocks of sheet piling (see Figures 13 and 14)

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 centre interlocks (threaded at the factory) can be provided with sealing welding carried out at the factory or, possibly, on site before they are driven. This welding must be carried out **in a horizontal position;**
- interlocks locked together when driven can only be welded on site after the sheet piling has been installed and, possibly, only after excavation. This welding must be carried out **in a vertical position.**

Table 1 sets out the main conditions governing the choice of methods of welding in the various cases.

Note:
If, to achieve a perfect seal, interlocks threaded together when driven must be welded on site, a preliminary seal, carried out either in the factory or on site before driving, using a bituminous product, is recommended. This sealing prevents the interlock from becoming too damp which could cause serious problems when welding. In this case the positioning of the bituminous sealer must be as shown in Figure 18, detail A, which prevents contact between the weld and the bituminous product!!! This requirement must be mentioned in the specification.

1.1.3.3 Choice of site welding process

With knowledge of the possible ways of carrying out sealing welding on site, the choice of possible processes is limited to the following systems:

(a) Sheathed electrode welding

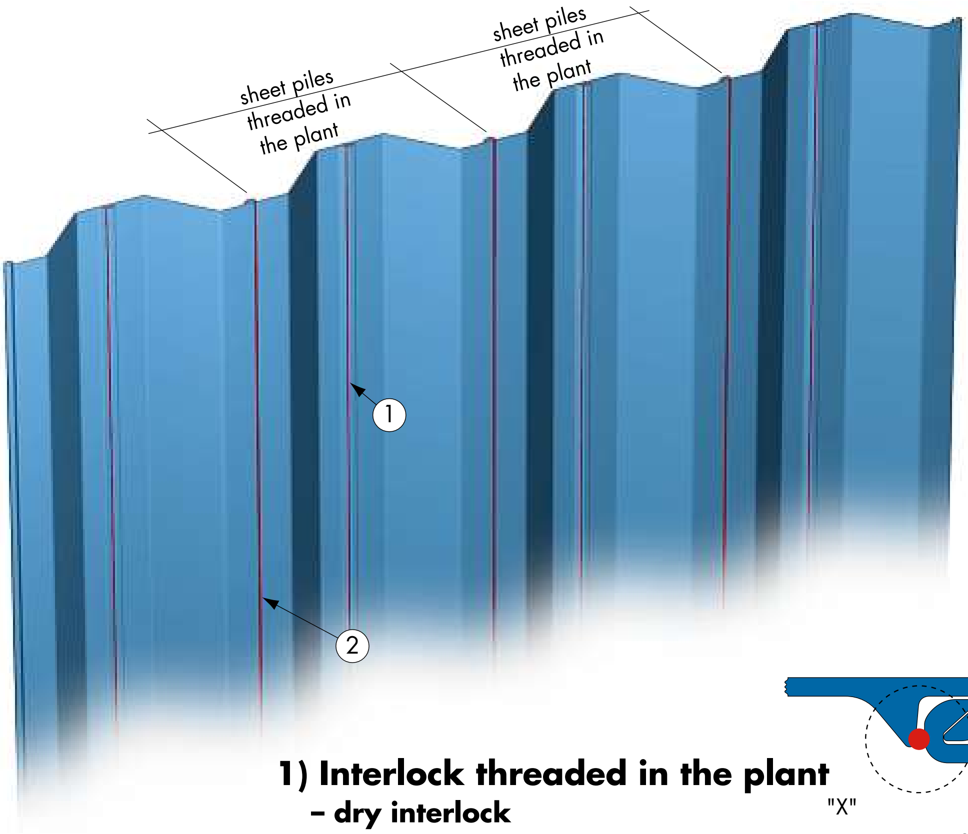
Advantages:

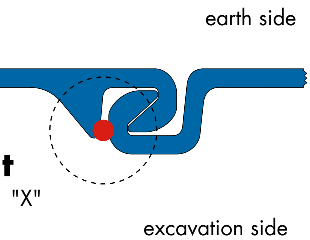
- well-known process,
- used universally,
- easy to carry out,
- good quality welding,
- influenced very little by atmospheric conditions on the site,
- craftsmen easily available (little training),
- minimum investment in machinery,
- robust, few stops.

Disadvantages:

- rather low deposition rate (**Figure 15**).

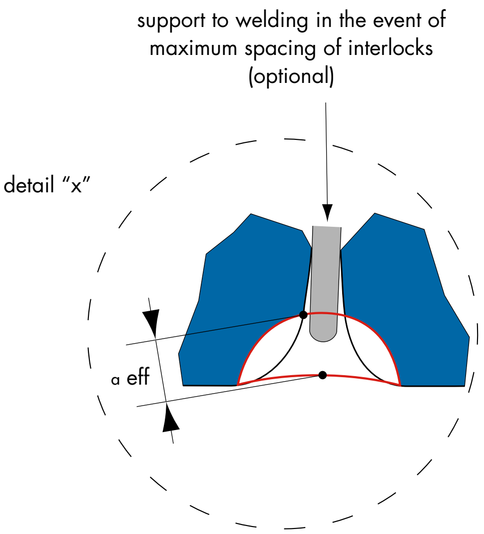
Realizing of sealing by welding
Double sheet piles AZ





1) Interlock threaded in the plant
- **dry interlock**
- **welded in a horizontal position**

2) Interlock threaded on site
- **dry or damp interlock**
- **welded in a vertical position**



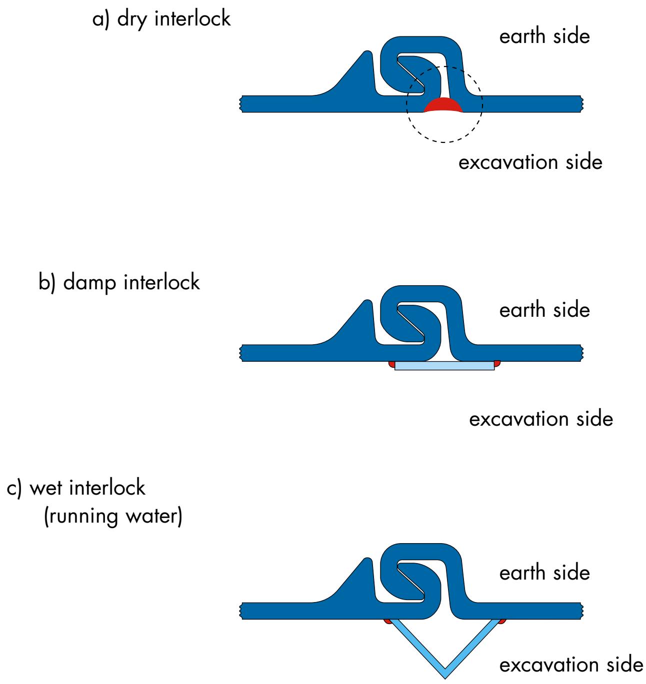
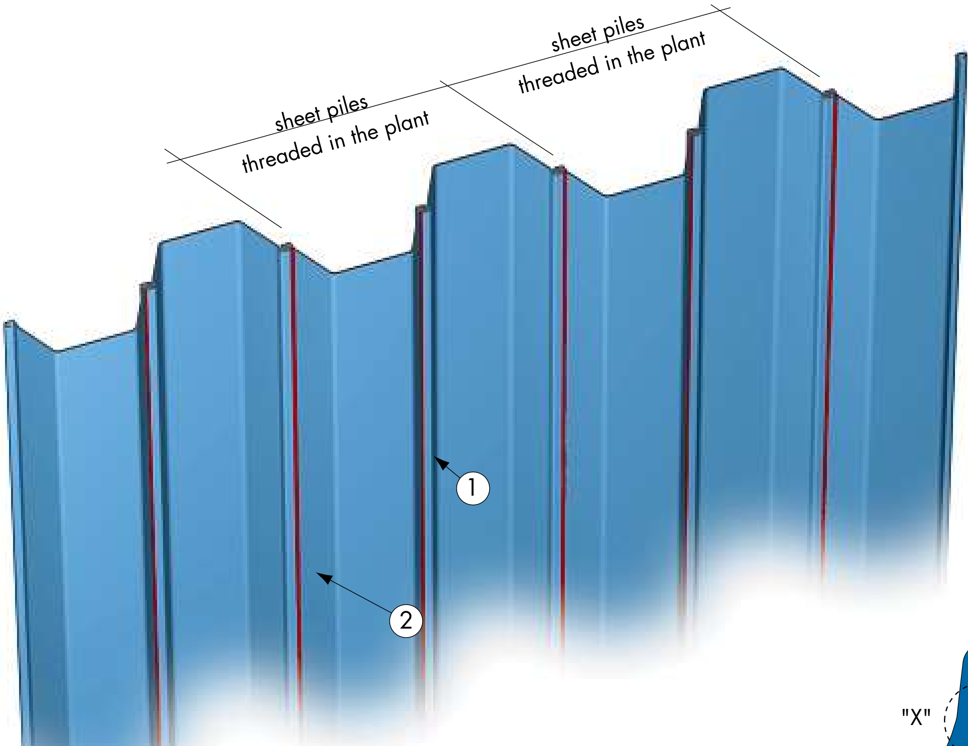
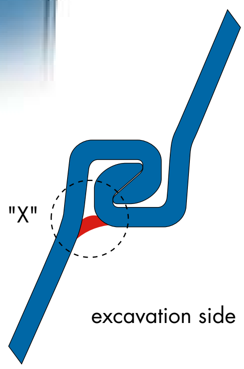


Figure 13

Realizing of sealing by welding
Double sheet piles of AU/PU/LS/JSP



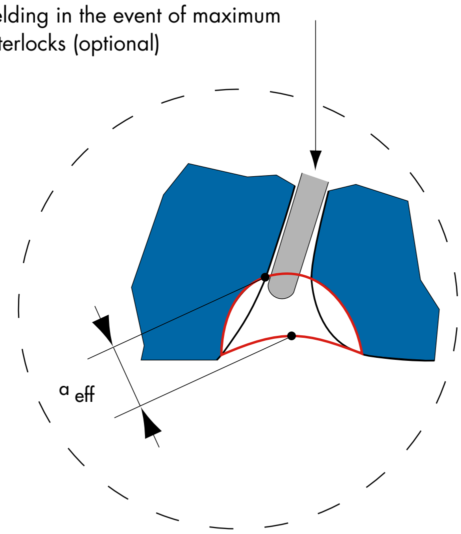


1) Interlock threaded in the plant
- **dry interlock**
- **welded in a horizontal position**

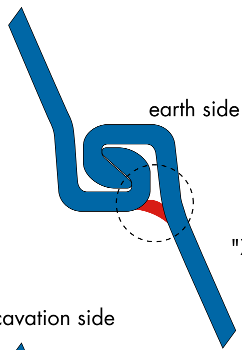
2) Interlock threaded on site
- **dry or damp interlock**
- **welded in a vertical position**

support to welding in the event of maximum spacing of interlocks (optional)

detail "X"



a) dry interlock



B) wet interlock
(running water)

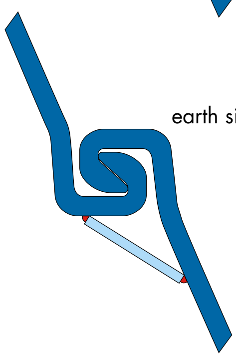


Figure 14

Possible ways of welding joints in steel piling
(Summary table)

Table 1

	Interlock		Type of welding		Welding position			Welding process (see paragraph 1.3.3)	Advantages	Disadvantages
	dry	damp	in the interlock	with sheet metal covering	vertical		horizontal			
		see note 1			direction of welding: upwards (a eff: > 6 mm)	direction of welding: downwards (a eff: 3-4 mm)				
Interlock connected at the factory with welding at the factory or on site	X						X	all	- all the advantage of horizontal welding as opposed to vertical welding	
Interlock connected on site with 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 note 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 note 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 note 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 note 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 piling joint; - the size of the spout in the covering should be selected according to the rate of flow of water across the joint (no effect on the welding on both sides).

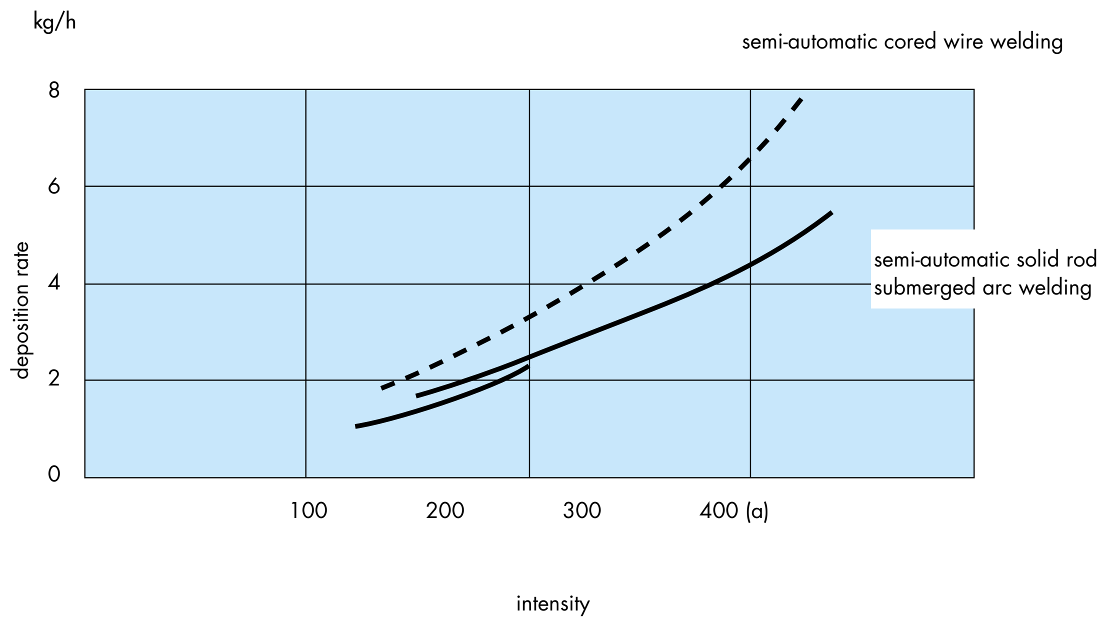


Figure 15

(b) Semi-automatic solid rod submerged arc welding

Advantages:

- easy to carry out,
- high deposition rate (**Figure 15**).

Disadvantages:

- trained craftsmen,
- higher investment in machinery,
- gas protection lacking in the event of draughts, sometimes causing irregular quality welding.

(c) Semi-automatic cored rod welding

Advantages:

- used universally,
- easy to carry out,
- high deposition rate (**Figure 15**),
- can be used without gas or specific protection in the event of draughts,
- process combining the efficiency of electrode welding with a semi-automatic process.

Disadvantages:

- higher investment in machinery,
- trained craftsmen.

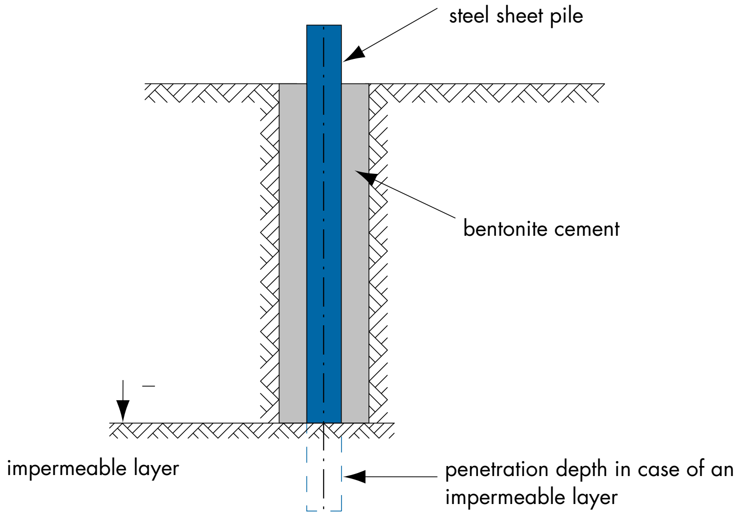
1.1.3.4 Automation of welding of sheet piling joints on site

Because of the very large number of factors affecting the carrying out 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 spacings 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.

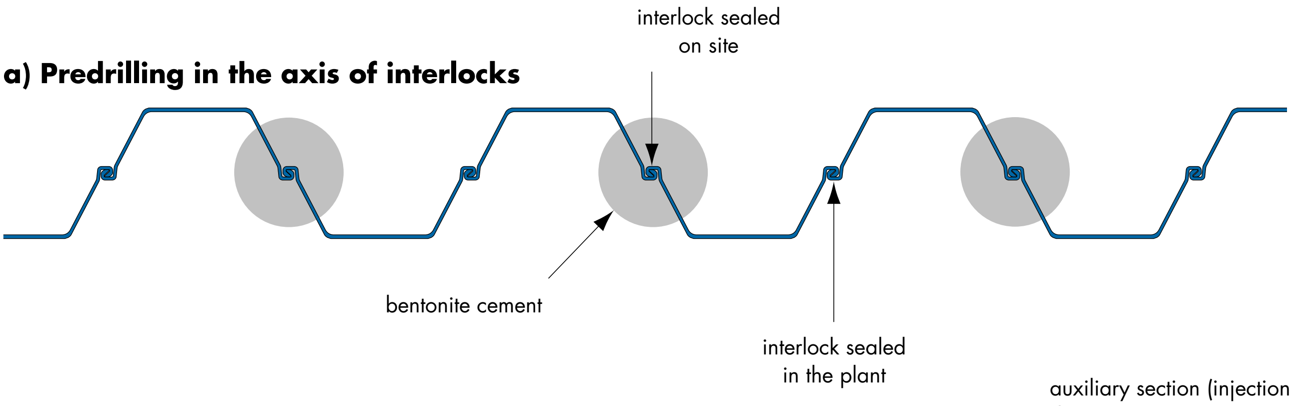
Other solution for vertical sealing of steel sheet piling walls

1) Sheet pile wall in combination with a bentonite-cement lining



2) Column of bentonite around the interlock

a) Predrilling in the axis of interlocks



b) Using an auxiliary section

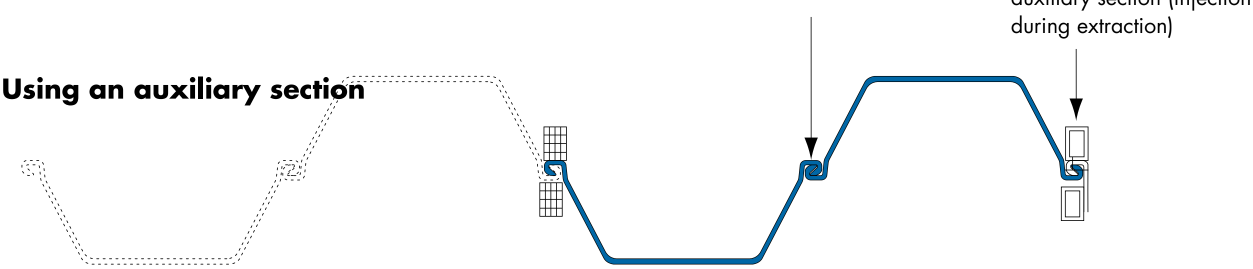


Figure 16

1.1.4 Other solutions for vertical sealing of walls of steel sheet piling

Apart from products inserted into the interlocks, other processes exist on the market to seal steel sheet pile walls.

1.1.4.1 Composite wall with bentonite cement (Figure 16/1)

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.

1.1.4.2 Vertical pre-drilling on the axis of the leading interlock to be driven after drilling (Figure 16/2a)

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. The soil extracted is replaced with a bentonite slurry. This method also assists driving and can be combined with a sealed interlock as described in para. 1.1. The production of muddy excavated material is limited.

1.1.4.3 Driving using a special auxiliary section (Figure 16/2b)

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. A slurry is injected through these tubes as the auxiliary section is withdrawn. In this way the soil near the leading interlock is injected and moved aside to allow the next pile to be driven more easily.

1.1.4.4 Driving using a special compression unit (Figure 17)

For this method of working, two specially made compression units consisting of a standard beam section with sheet metal welded to the sides for 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 cavity thus formed 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.

1.1.4.5 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.

Other solutions for vertical sealing of steel sheet piling walls
- using a special compression section

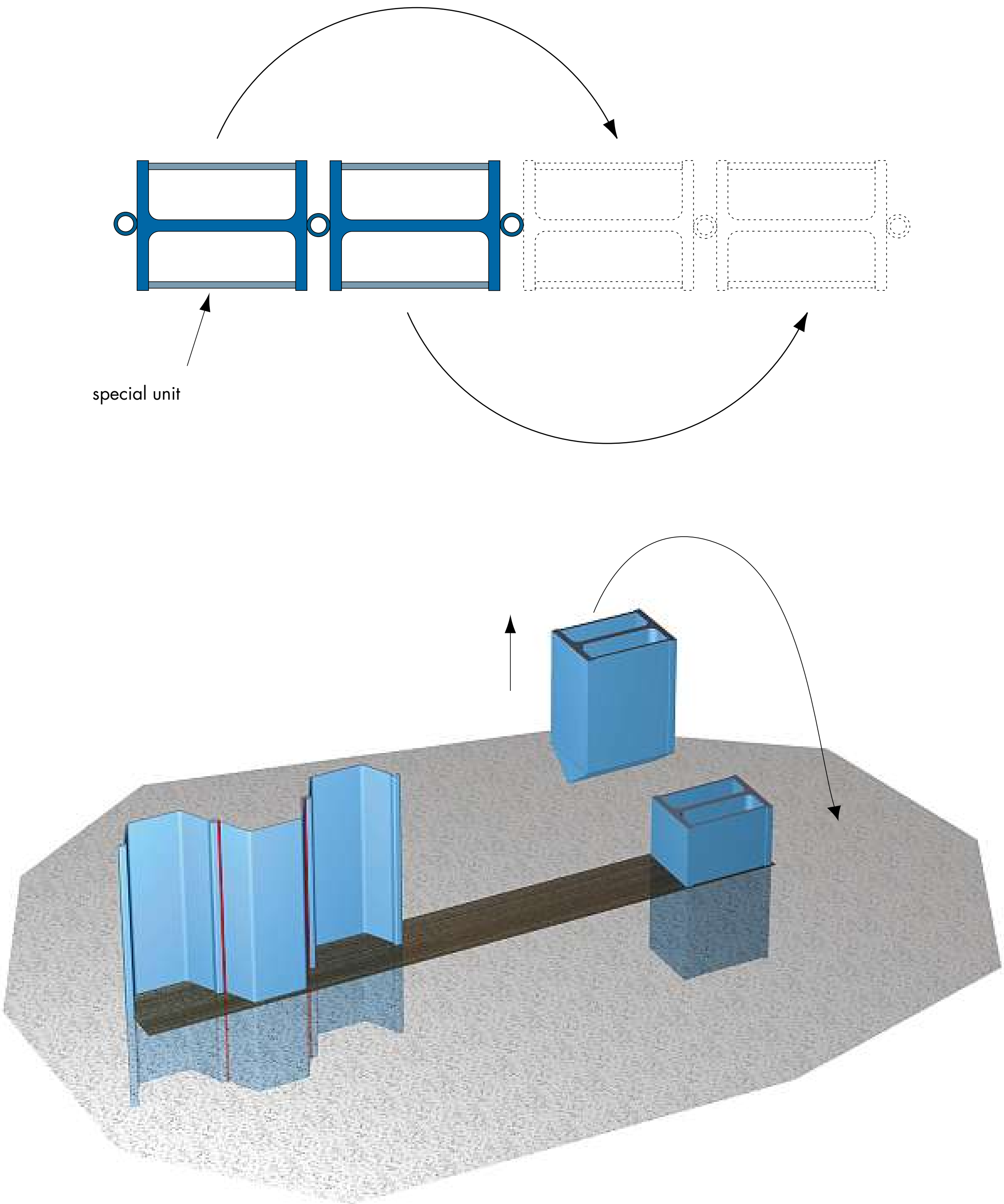


Figure 17

1.1.5 Repairing defects in the sealing of interlocks

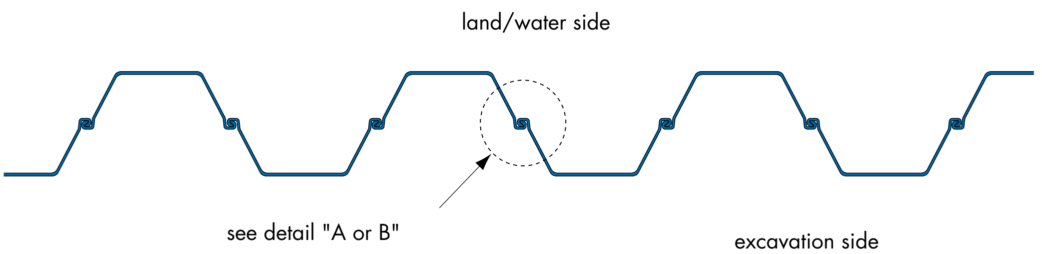
When a driving incident damages a sealed interlock there are certain processes which will allow it to be repaired.

The choice of the repair method to be used depends on the following factors:

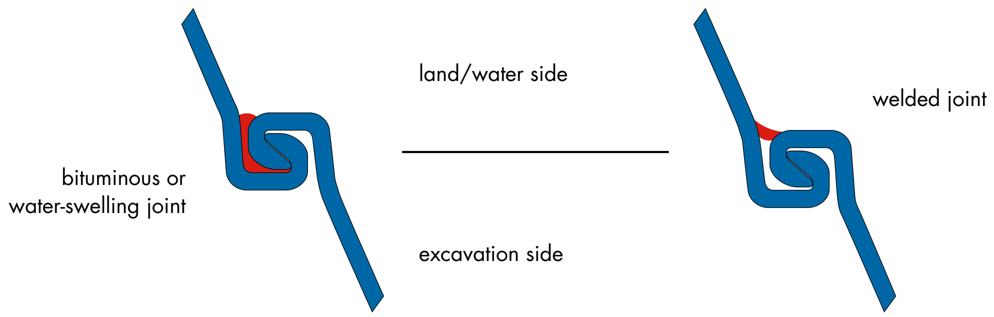
- Type of sealing product (eg: bituminous, water-swelling, welding)
- Location of the sealing joint (see **Figures 18 and 19**)
- Spacing of interlocks (see **Figure 20**)
- Level of humidity in the interlocks
- Possibility of access

The various methods are set out below and Table 2 shows the main criteria governing the choice of the proper method.

Repairing sealing defects in the interlocks
Location of the sealer (Pile U)



Detail "A"



Detail "B"

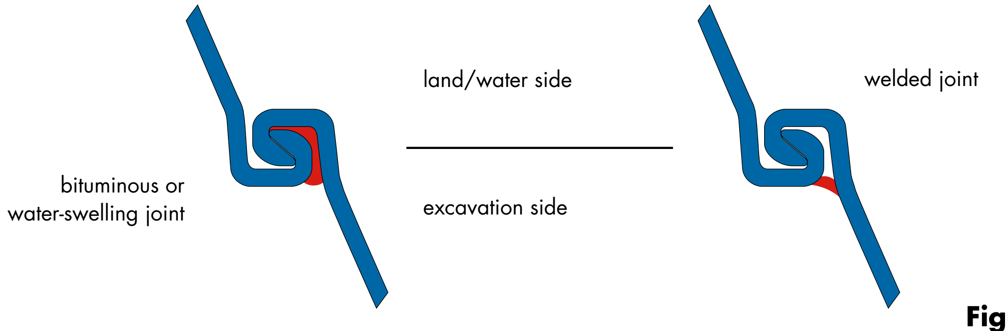
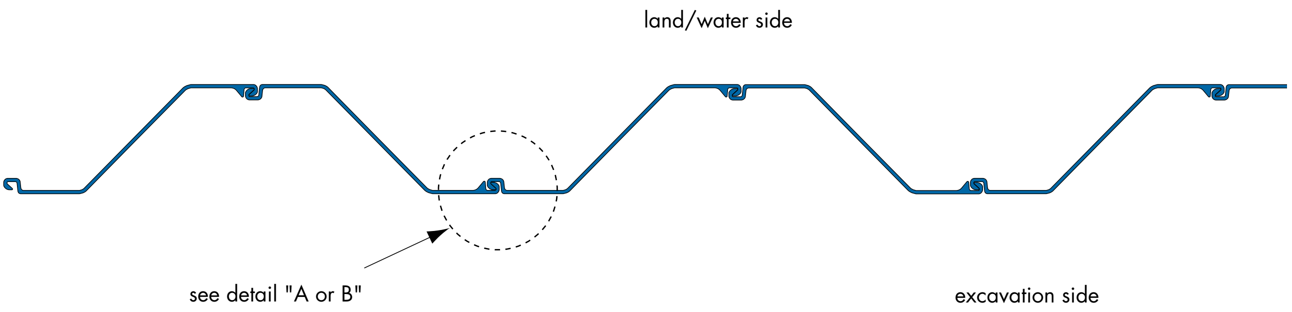
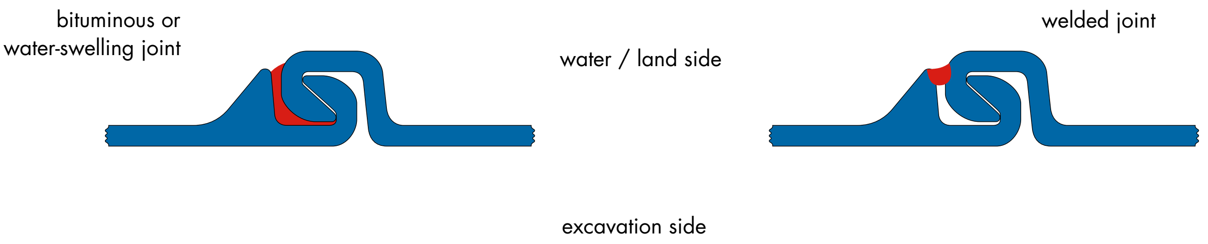


Figure 18

Repairing sealing defects in the interlocks
Location of the sealer (Pile Z)



Detail "A"



Detail "B"

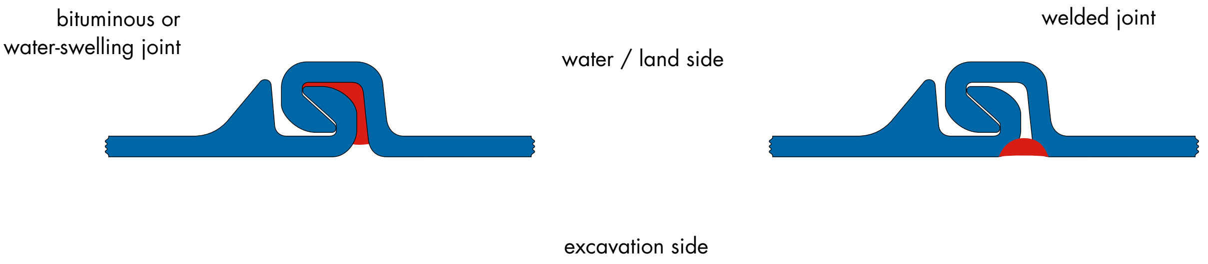


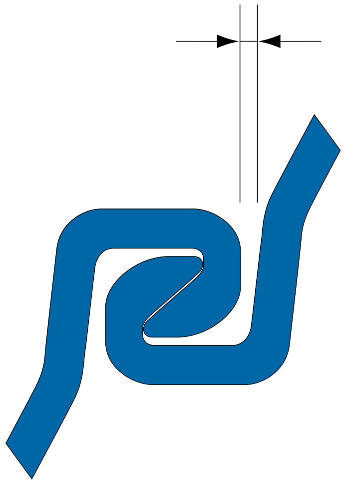
Figure 19

Repairing sealing defects in the interlocks

Spacing of interlocks (Pile U)

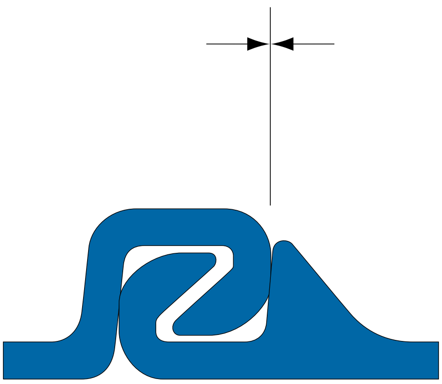
A) Without spacing

B) With spacing



Spacing of interlocks (Pile Z)

A) Without spacing



B) With spacing

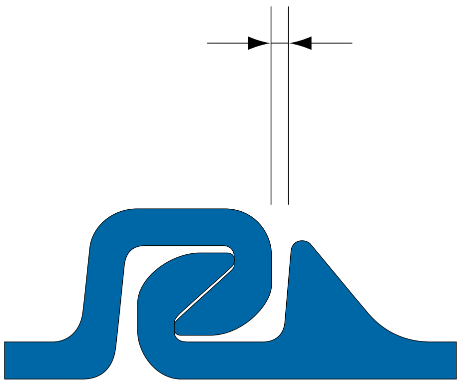
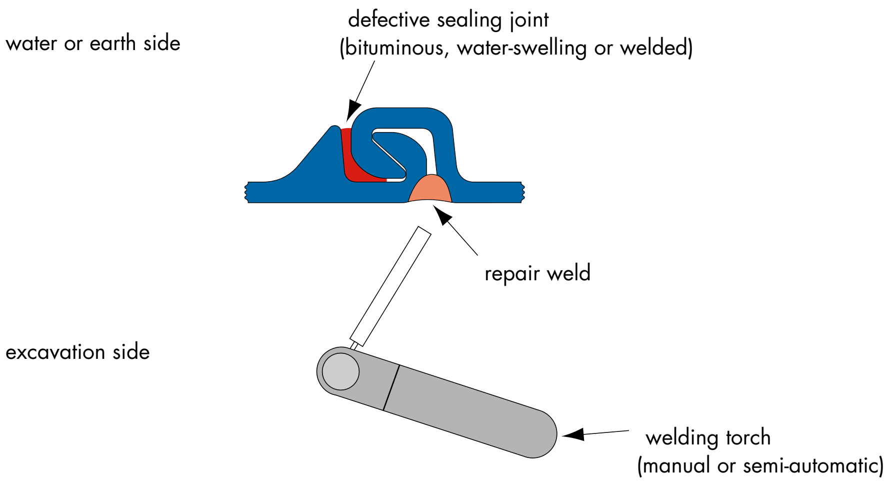


Figure 20

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

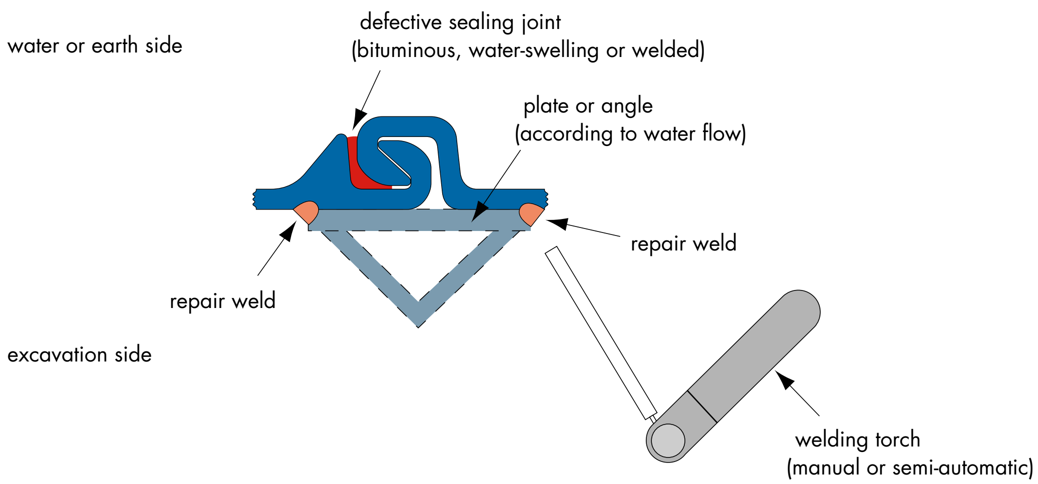
Method 1:

Sealing by applying a sealing weld along the interlock for the required height of the pile.



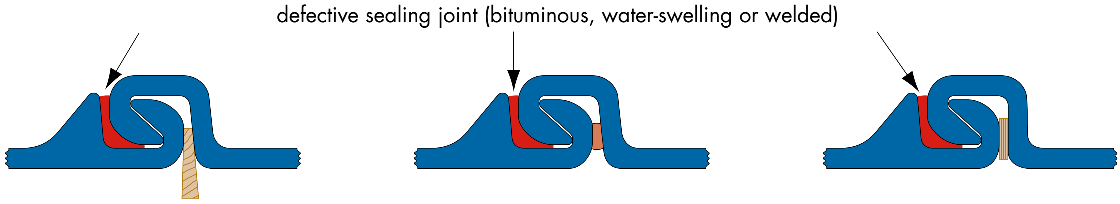
Method 2:

Sealing by welding a plate or an angle over the interlock for the required height of the pile.



Method 3:

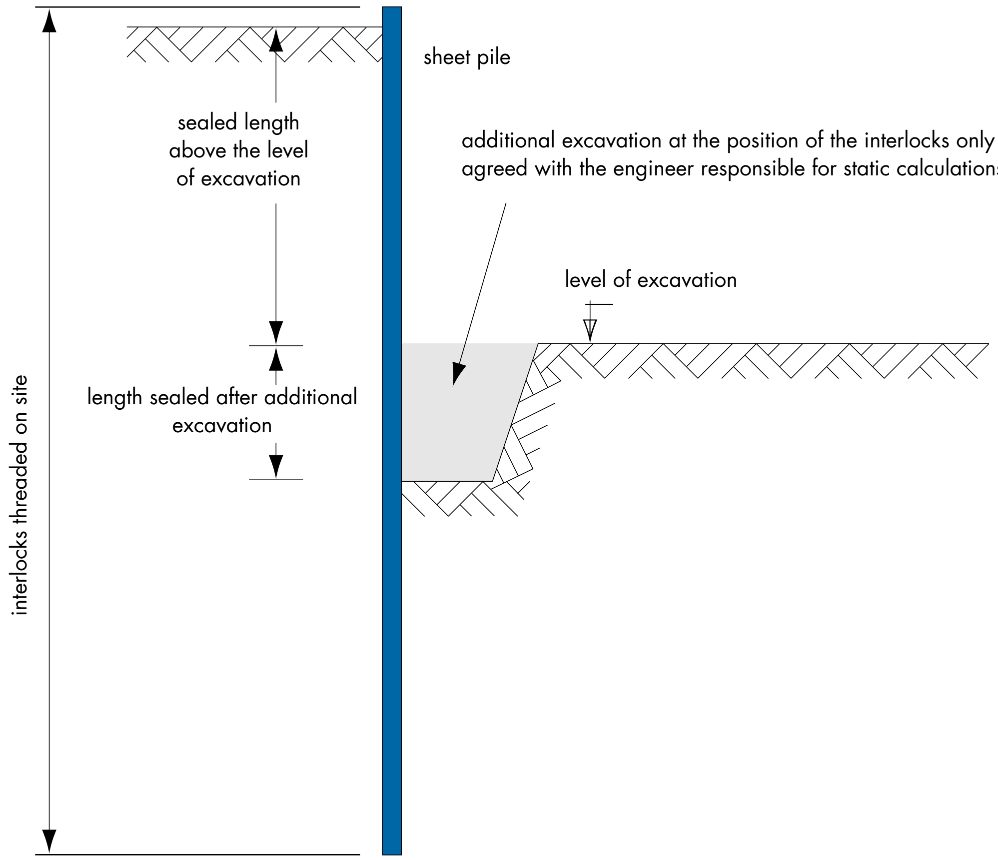
Sealing by packing the space in the interlocks with plastic sections, strips of water-swelling rubber or prelaminated timber laths for the required height of the pile.



1.1.5.2 Repairs below ground level

Method 4:

Excavation down the length of the interlock to be sealed and extension of the sealing weld or the interlock packing down to the necessary depth.



Choice of methods for repairing seals in steel sheet piling

Table 2

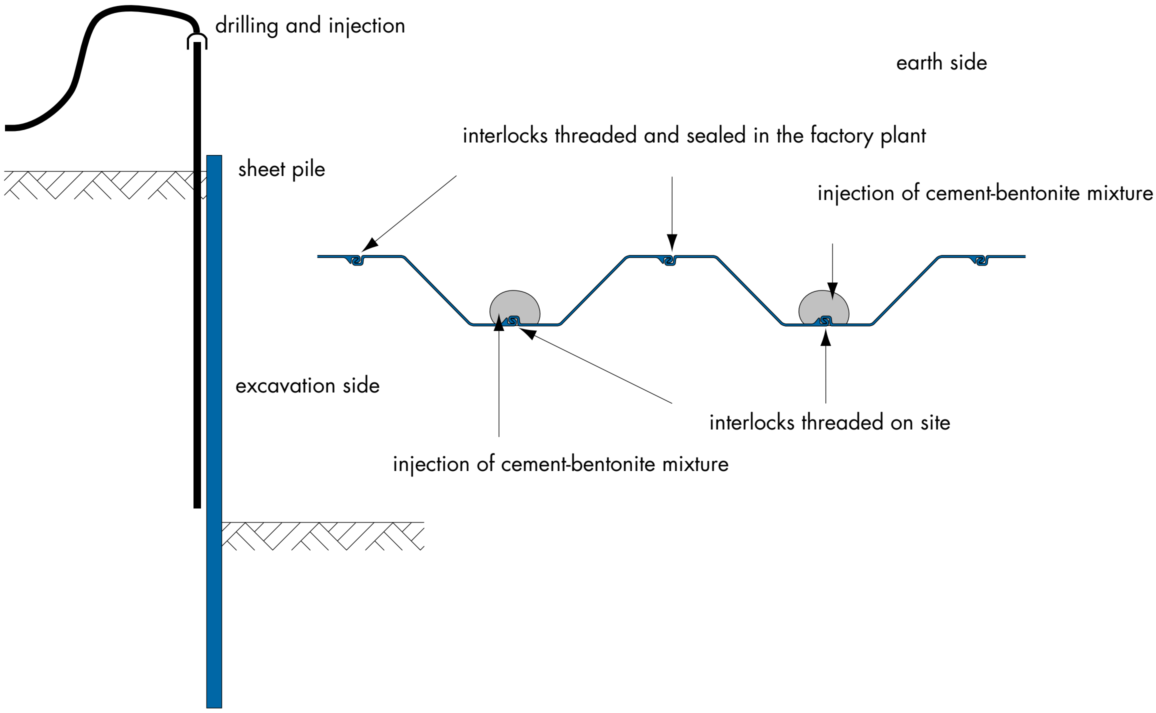
Location of sealing joint	Type of sealing joint			Spacing of interlocks (see figure 20)		Humidity in the interlocks		Possibility of access	Method to be used (see text para 1.1.5.1.)
	Bituminous joint	Water-swelling joint	Welded joint	Not spaced	Spaced	Humidity without leakage	Humidity with leakage	Excavation side only	
As detail A (Figs. 18 and 19) (joint on water side)	X	X	X	X		X		X	Method 1 or 2
	X	X	X		X	X		X	Method 1 or 2 or 3
Ex:	X	X	X		X		X	X	Method 2 or 3
As detail B (Figs. 18 and 19) (joint on excavation side)	X	X		X		X		X	Method 2
	X	X			X	X	X	X	Method 2 or 3 (intermittently)
			X	X	X	X	X	X	Method 1 (intermittently) or 2

Example: Pile AZ - Water-swelling joint - located facing water side as Figure 19 detail A - with spacing between interlocks - large water flow across the joint, see 'with leakage' - possibility of access via the cofferdam.

- Repair: as shown in the methods.

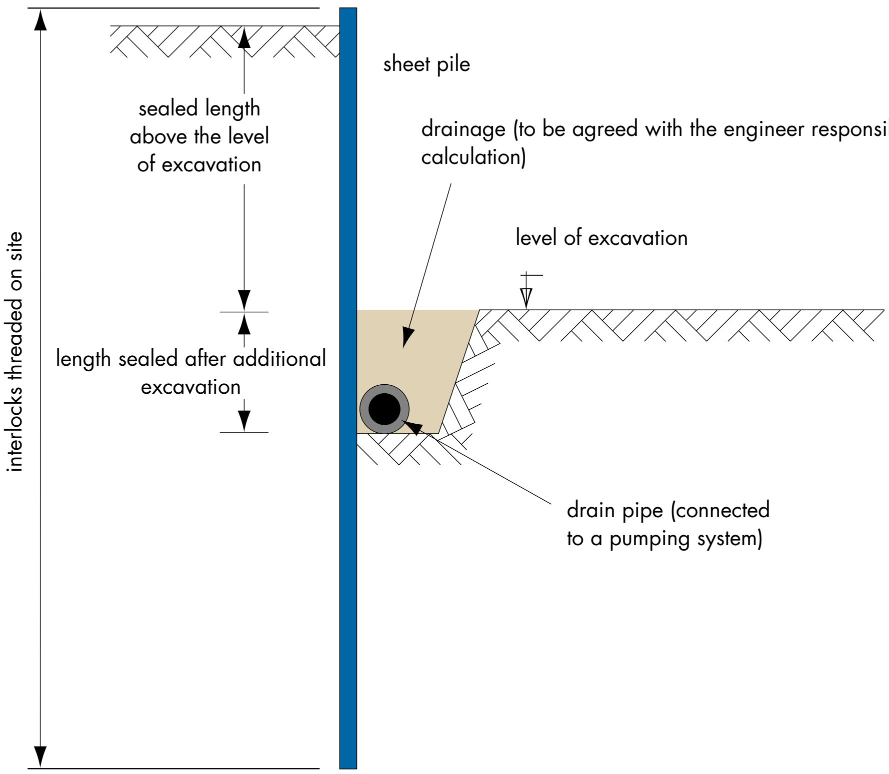
Method 5:

Injection of a product [cement (rapid hardening) or bentonite] along the interlock to be sealed.



Method 6:

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.



1.1.5.3 Repairs in water

Method 7:

In the event that it is required to create or repair a seal on the water side, the examples shown in Figs. 21a and 21b may be satisfactory.

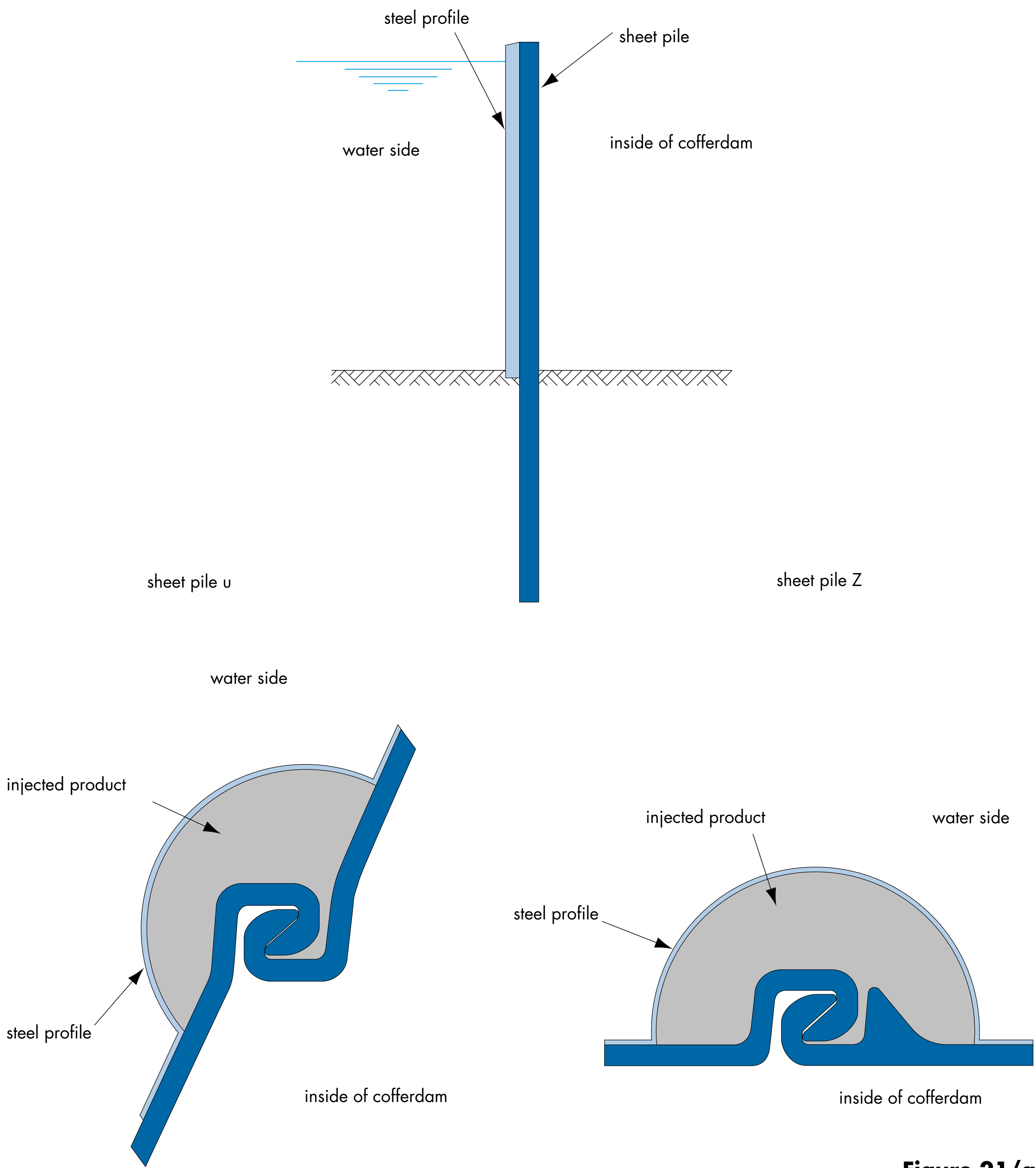
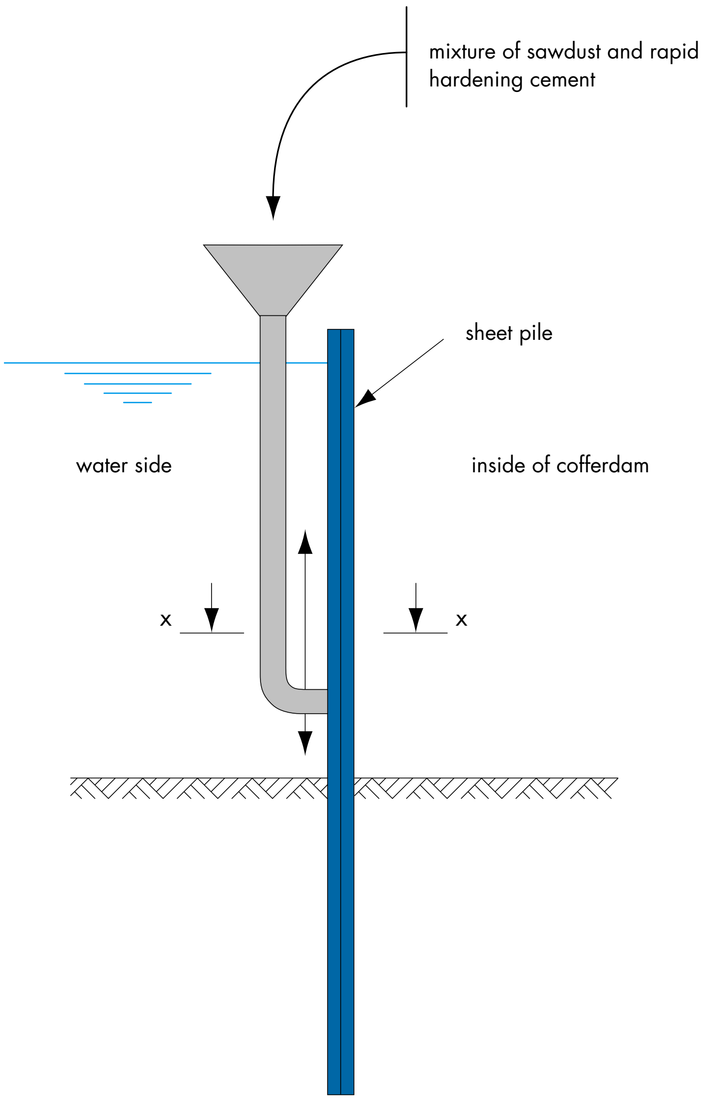


Figure 21/a

Possible methods of sealing on water side



section x-x

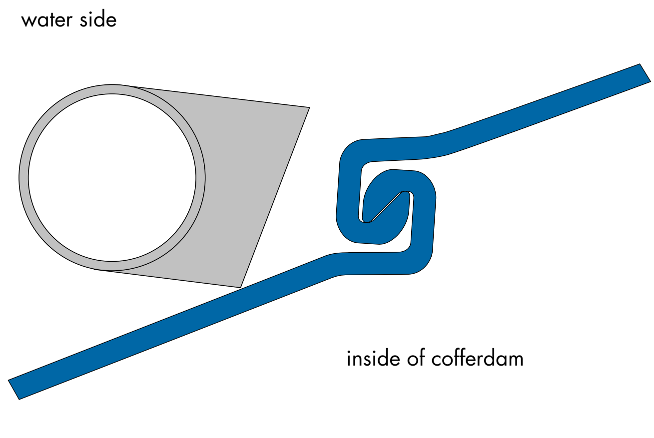


Figure 21/b

2. Horizontal sealing

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

In general, two types of sealing can be noted:

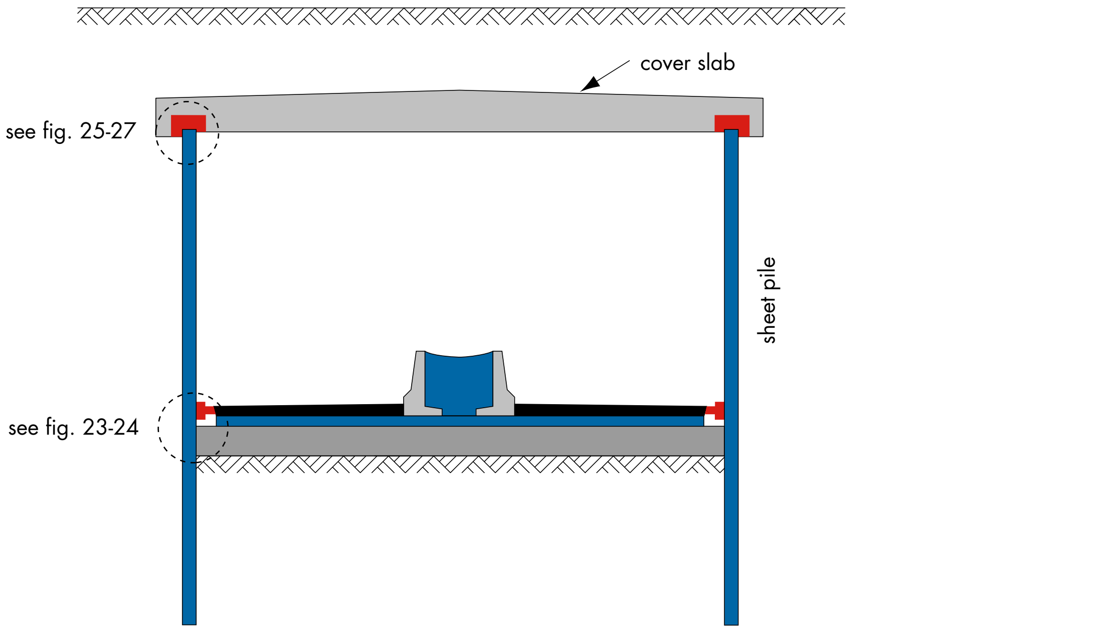
- sealing of the base slab, ie forming a water-tight seal in zones which are often under water;
- sealing the covering element.

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 23-24: examples of connection of a base slab (raft).

Figures 25-27: examples of connection of a cover slab.

1) Tunnel



2) Landfill waste containments

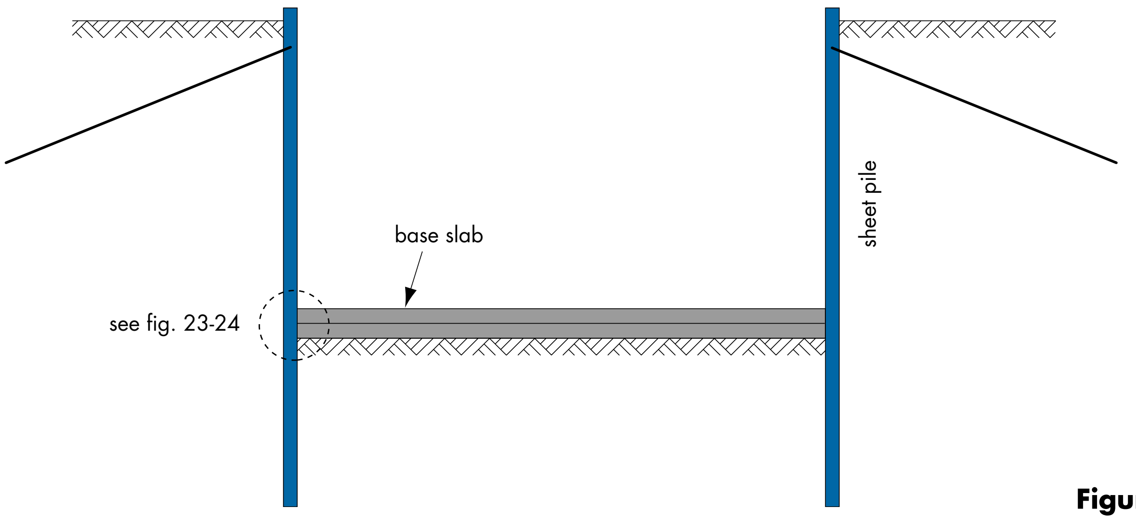
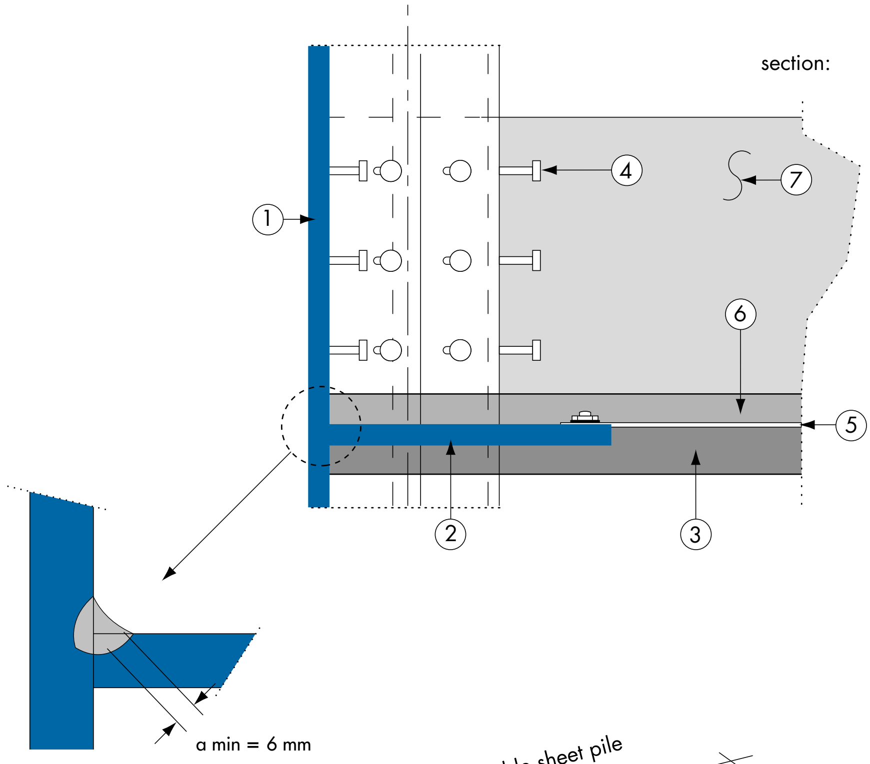


Figure 22

Horizontal sealing using a sheet metal and 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
7) concrete base slab

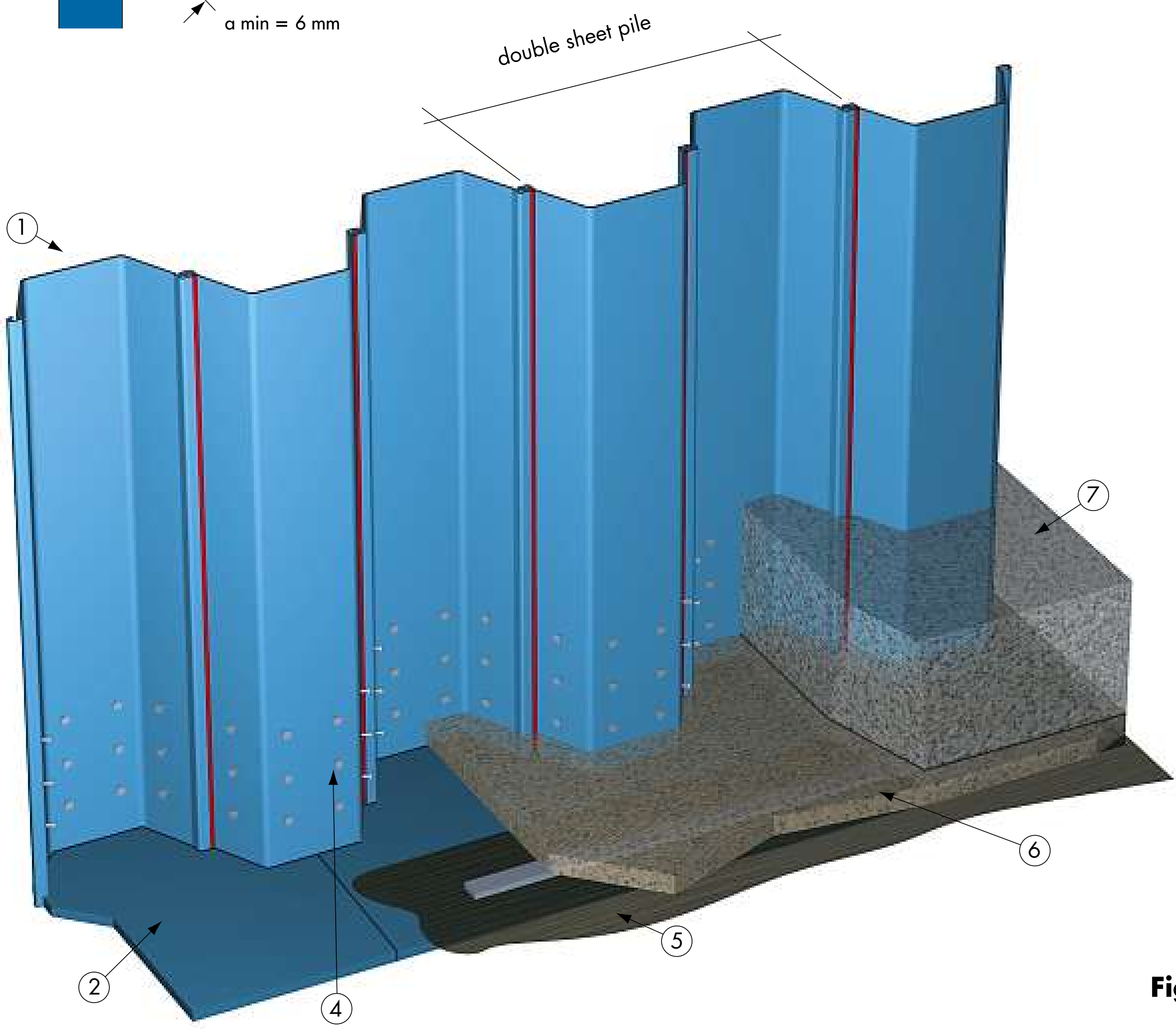
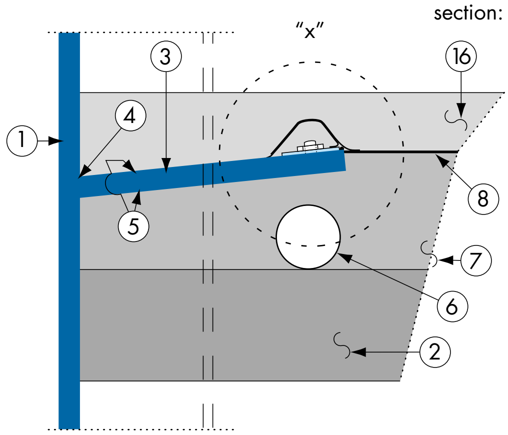
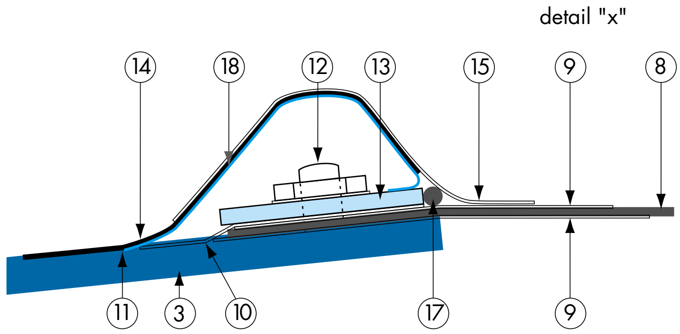


Figure 23

Horizontal sealing using a sheet metal and membrane system for high stresses and loads



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) spot 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 (mm thick/300 mm wide)



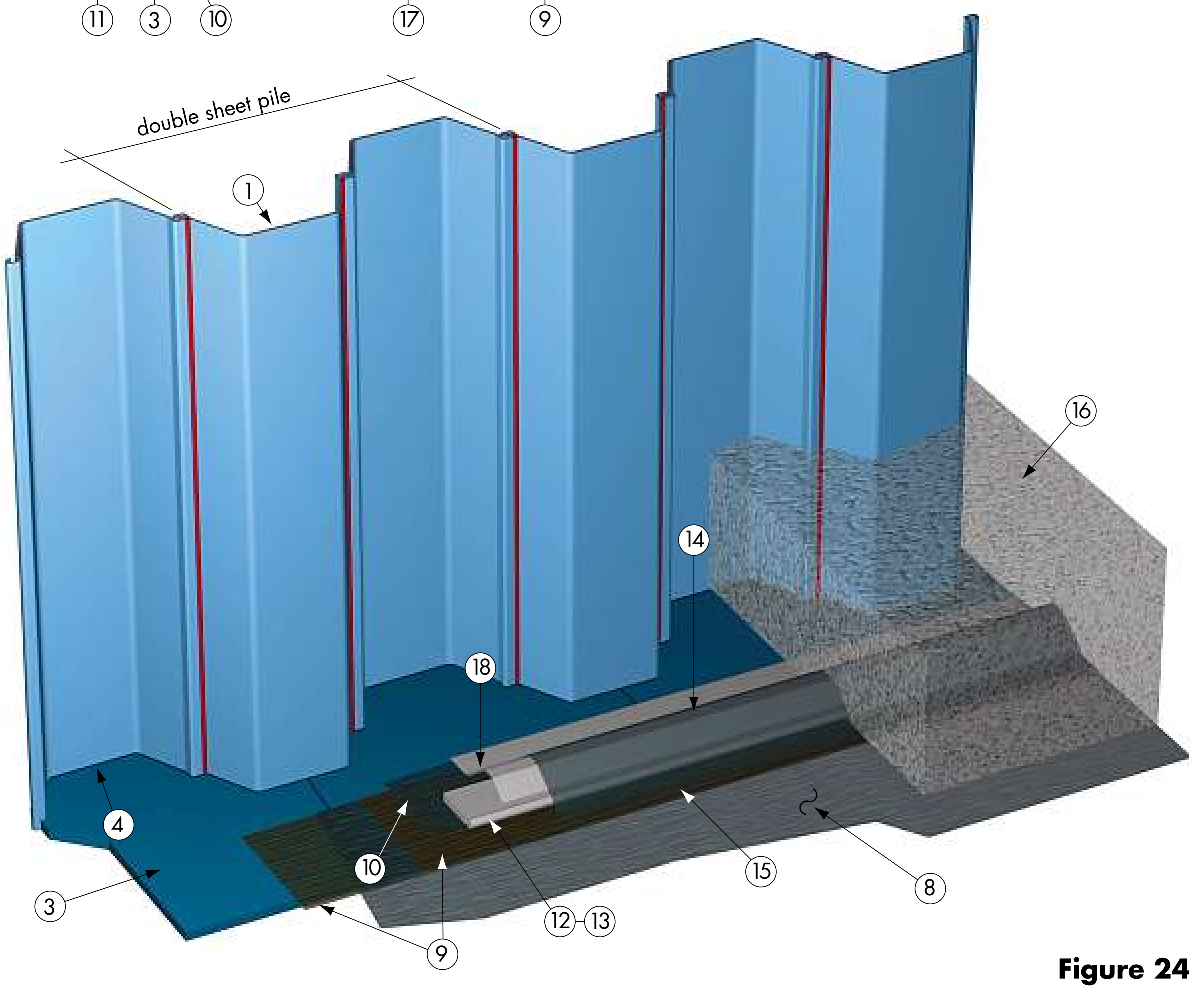
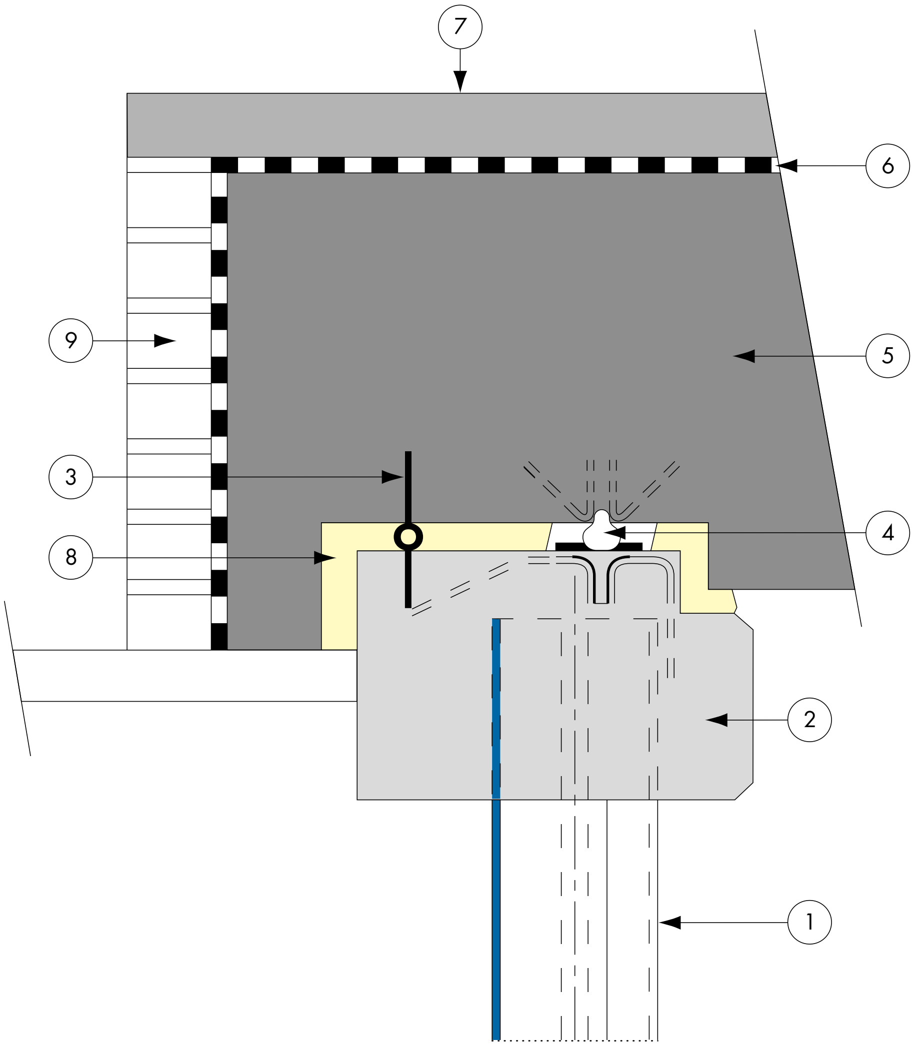


Figure 24

Horizontal sealing
Example of flexible connection between slab and steel sheet piling wall in the presence of water infiltration

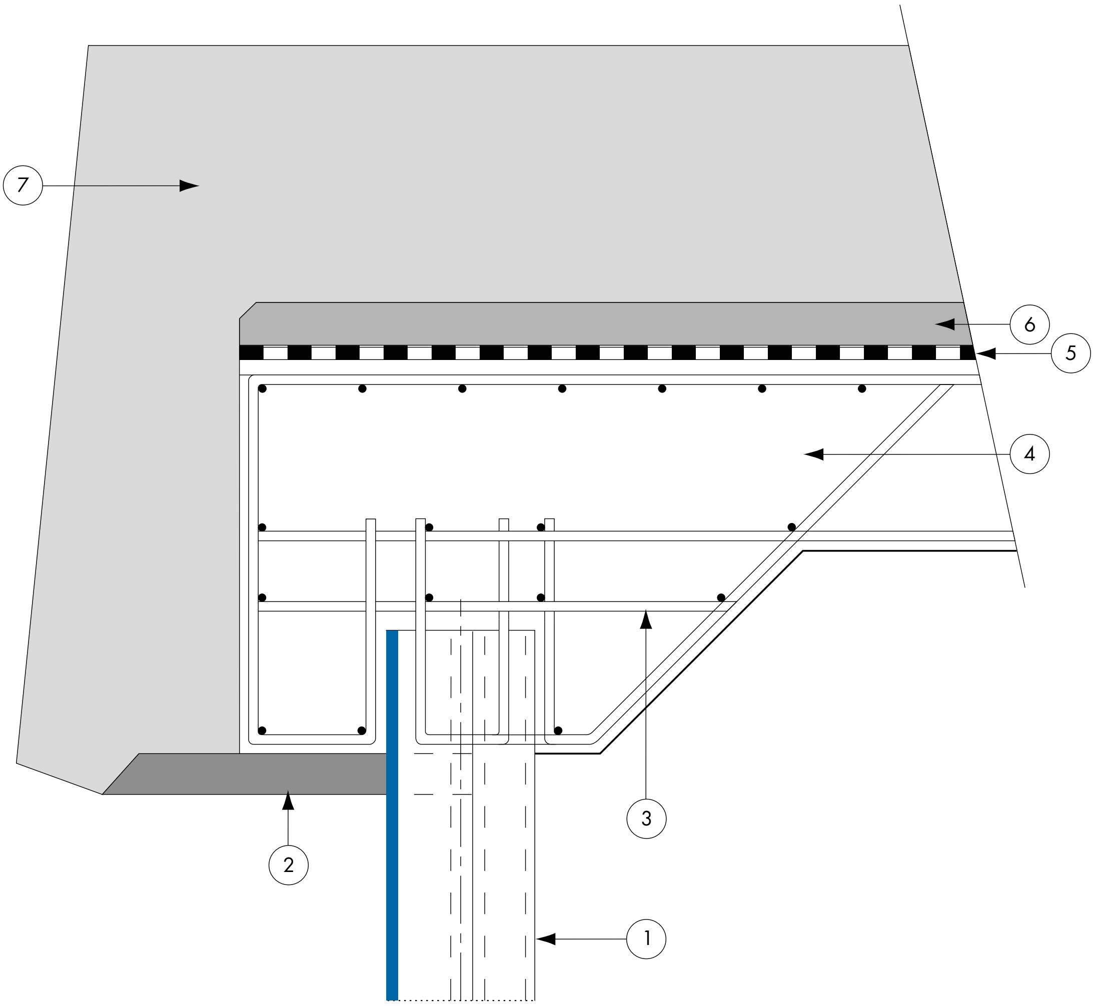


1) sheet pile
2) reinforced concrete
3) sika type joint or similar
4) support
5) reinforced concrete cover slab
6) sealing
7) concrete protection or asphalt screed
8) expanded polystyrene (formwork left in)
9) vertical protection

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

Figure 25

Horizontal sealing
Example of fixed connection between tunnel and steel sheet piling wall in the presence of water infiltration

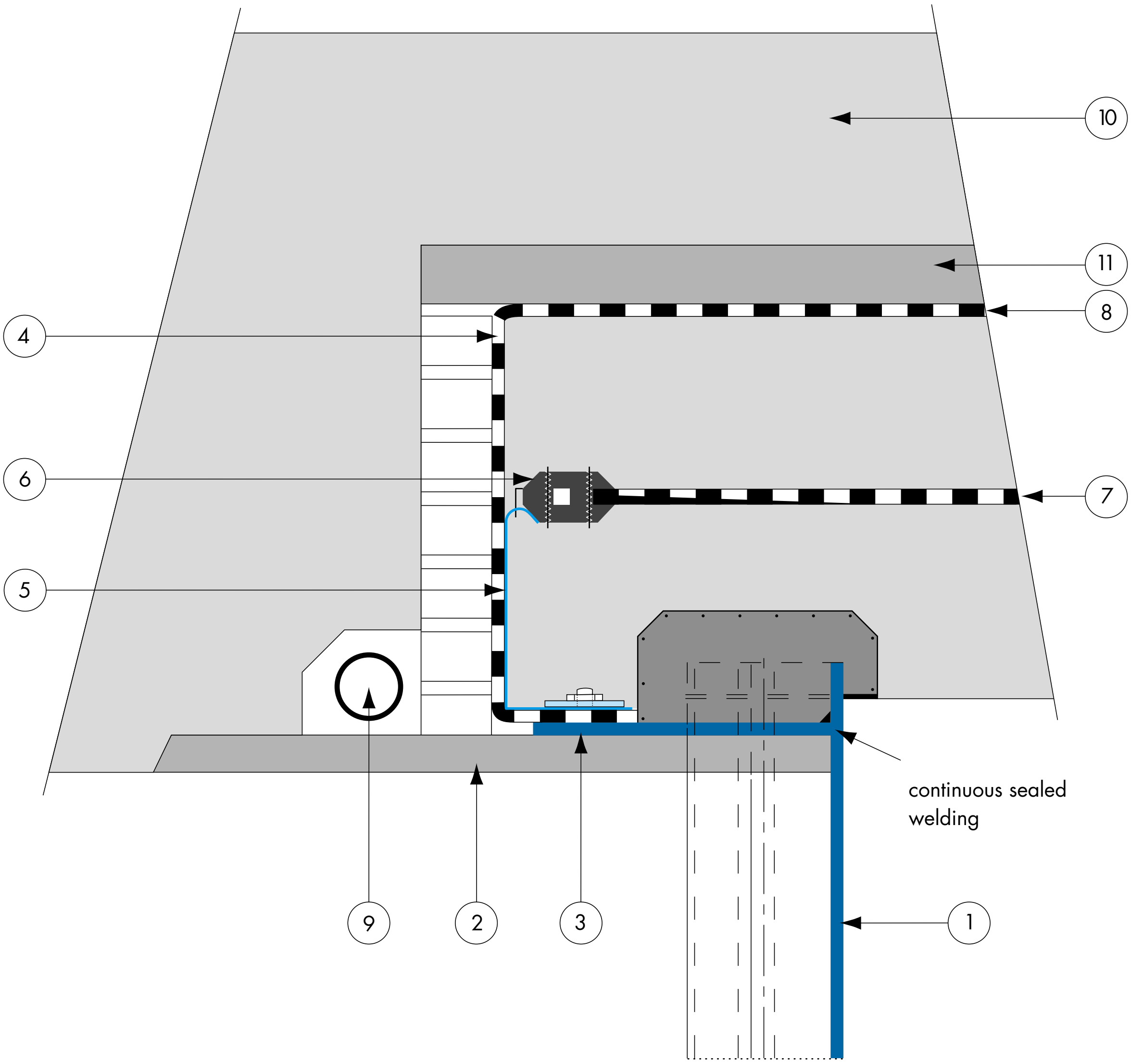


1) sheet pile
2) concrete subbase
3) reinforcement
4) reinforced concrete cover slab
5) sealing
6) concrete protection or asphalt screed
7) backfill, concrete slab

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

Figure 26

Horizontal sealing
Example of flexible connection between tunnel 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 with adhesive or
mechanical fixing with flexible strip
5) copper sheet
6) clamping plate
7) sealing
8) filter sheet
9) drainage
10) reinforced concrete cover slab
11) concrete protection or asphalt screed
respectively brickwork in the vertical section

phases of execution:
a) excavation, setting piles to level, cleaning subbase, cleaning etc...
b) preparation of the formwork for the reinforced concrete
c) formwork for the cover slab
d) installation of seal of a type as specified, concrete protection or asphalt cover screed including drainage

Figure 27

3. References

For additional background information, please refer to:

1) Steel Sheet Pile Seepage Resistance,
J.B. Sellmeijer,
Fourth International Landfill Symposium,
Cagliari, Italy, 1993

2) Joint Resistance of Steel Sheet Piles, Definition,
J.B. Sellmeijer,
August 1993 (unpublished)

3) The Hydraulic Resistance of Steel Sheet Pile Joints
J.B. Sellmeijer, J.P.A.E. Cools,
W.J. Post, J. Decker
1993 (published by ASCE)

4) EAU 1990. Recommendations of the Committee for
Waterfront Structures, Harbours and Waterways,
Berlin, 1992

The theoretical aspects connected with the sealing of steel sheet piling walls are dealt with in Part 1 of this brochure: **'Design'**

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