

L'uso dell'acciaio nelle applicazioni geotecniche
Quadro normativo di riferimento
Esempi di calcolo secondo le NTC 2008



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1. Installation of steel sheet piles
2. Watertightness
3. Applications



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Installation of steel sheet piles



Installation of steel sheet piles

Equipment:

- diesel hammer
- impact hammer (hydraulic, free fall)
- vibrohammer
- hydraulic press

Accessories:

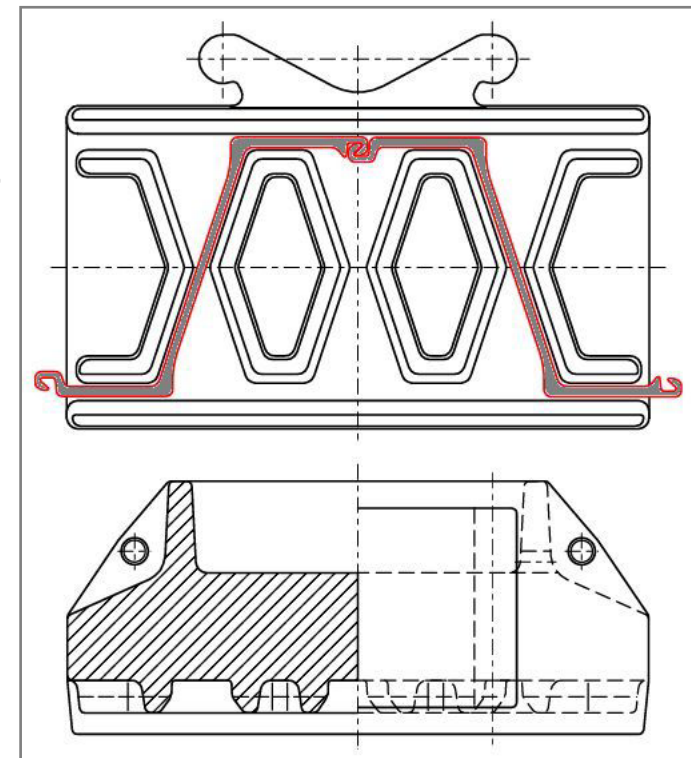
- leader, template, driving cap
- driving assistance:
 - water-jetting
 - pre-drilling
 - blasting





Installation: impact hammer

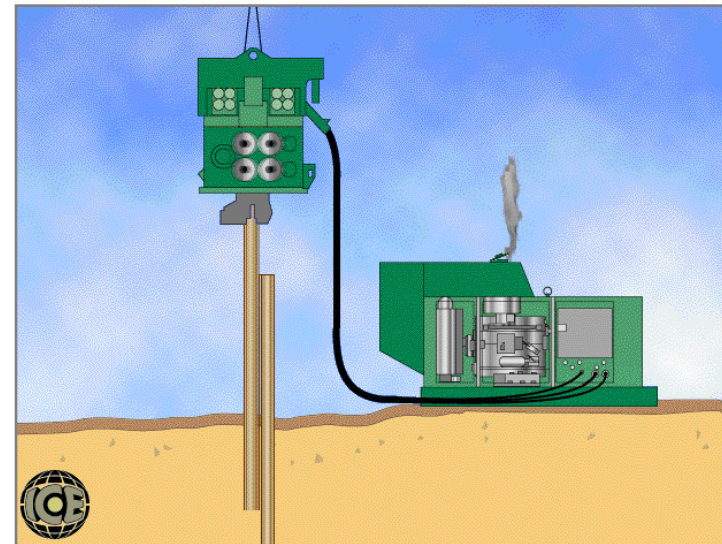
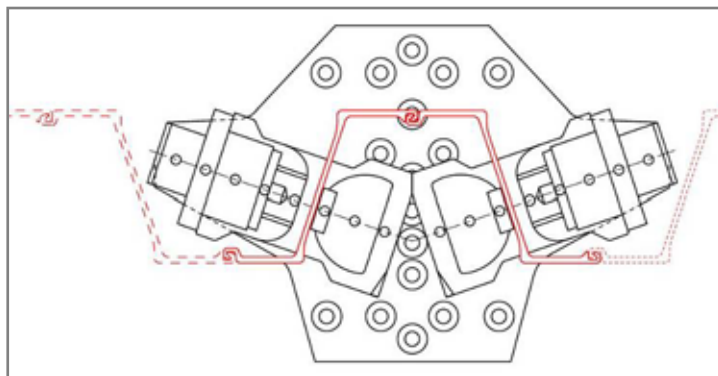
- drive in **pairs** (stiffness)
- avoid eccentricity
- distribute impact energy uniformly over ssp
- **driving cap** with diesel hammer
- large plate with hydraulic hammer



Driving cap for diesel hammer



Installation: vibrohammer

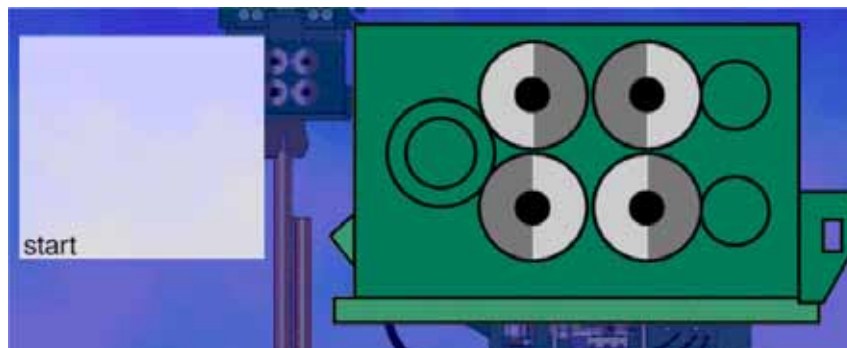


- drive in **pairs** (stiffness)
- avoid eccentricity
⇒ use **2 clamps**
- guide the ssp in adequately (leader, template,...)
- mainly used in **granular soils / soft cohesive soils**

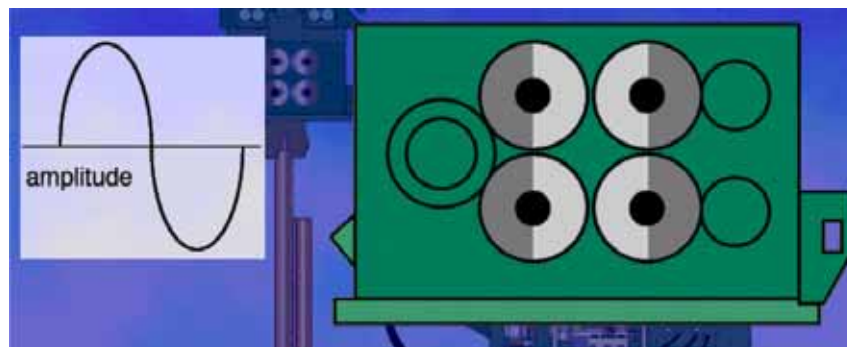
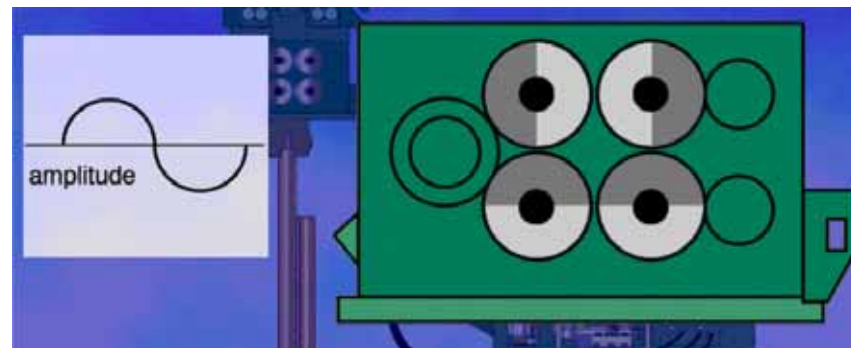


Installation: Resonance-free vibrohammer

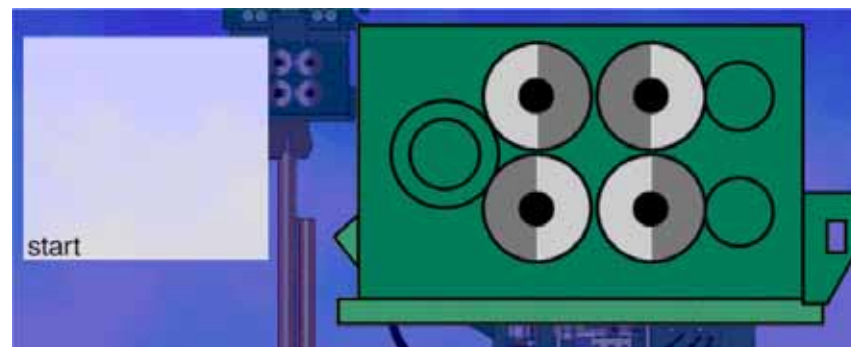
Weights in opposed position
→ no amplitude during start up phase
→ no vibrations during start up phase



Weights turned once working frequency is reached → amplitude and vibrations applied to sheet pile

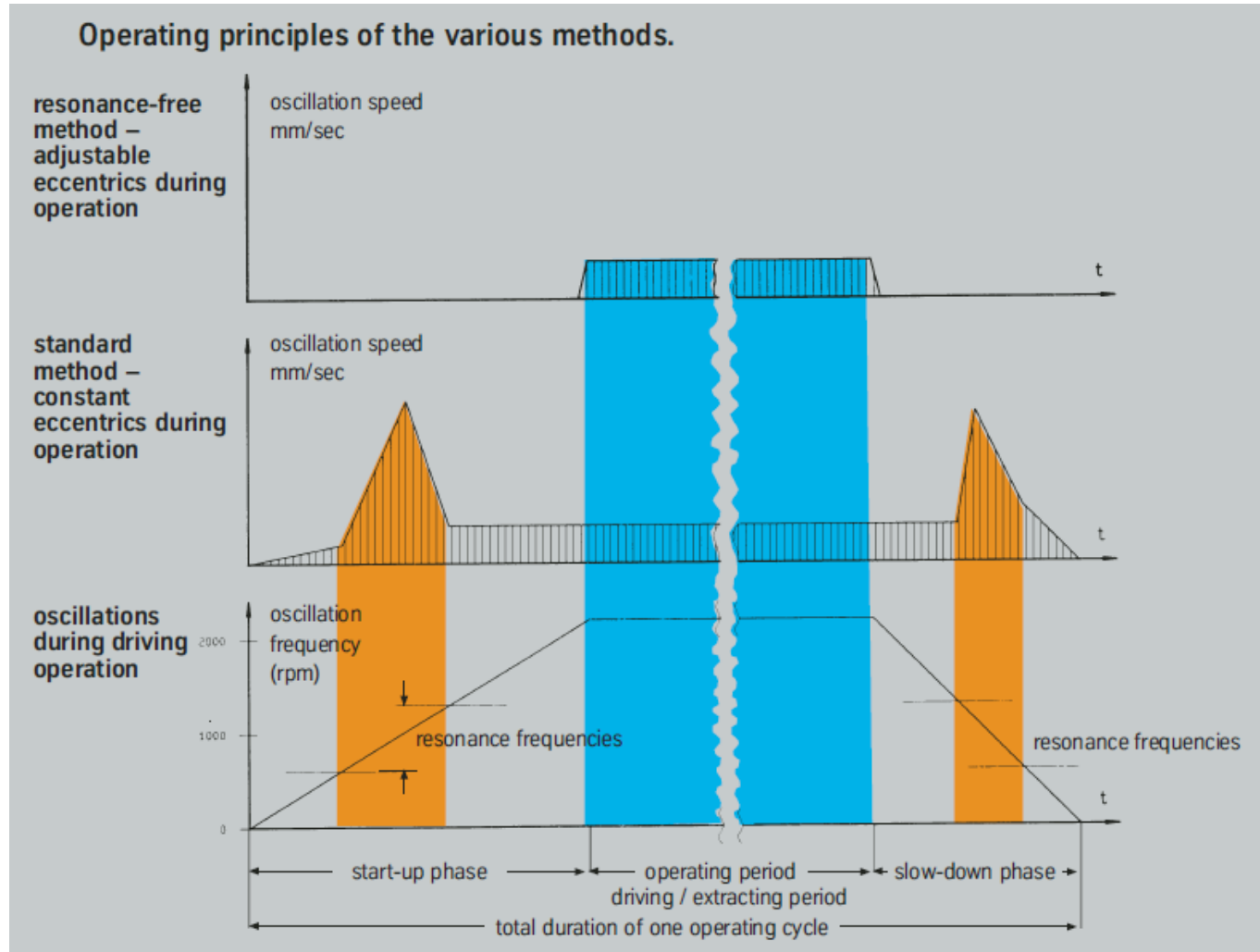


Weights giving maximum amplitude



Weights in opposed position
→ no amplitude during stop phase
→ no vibrations during stop phase

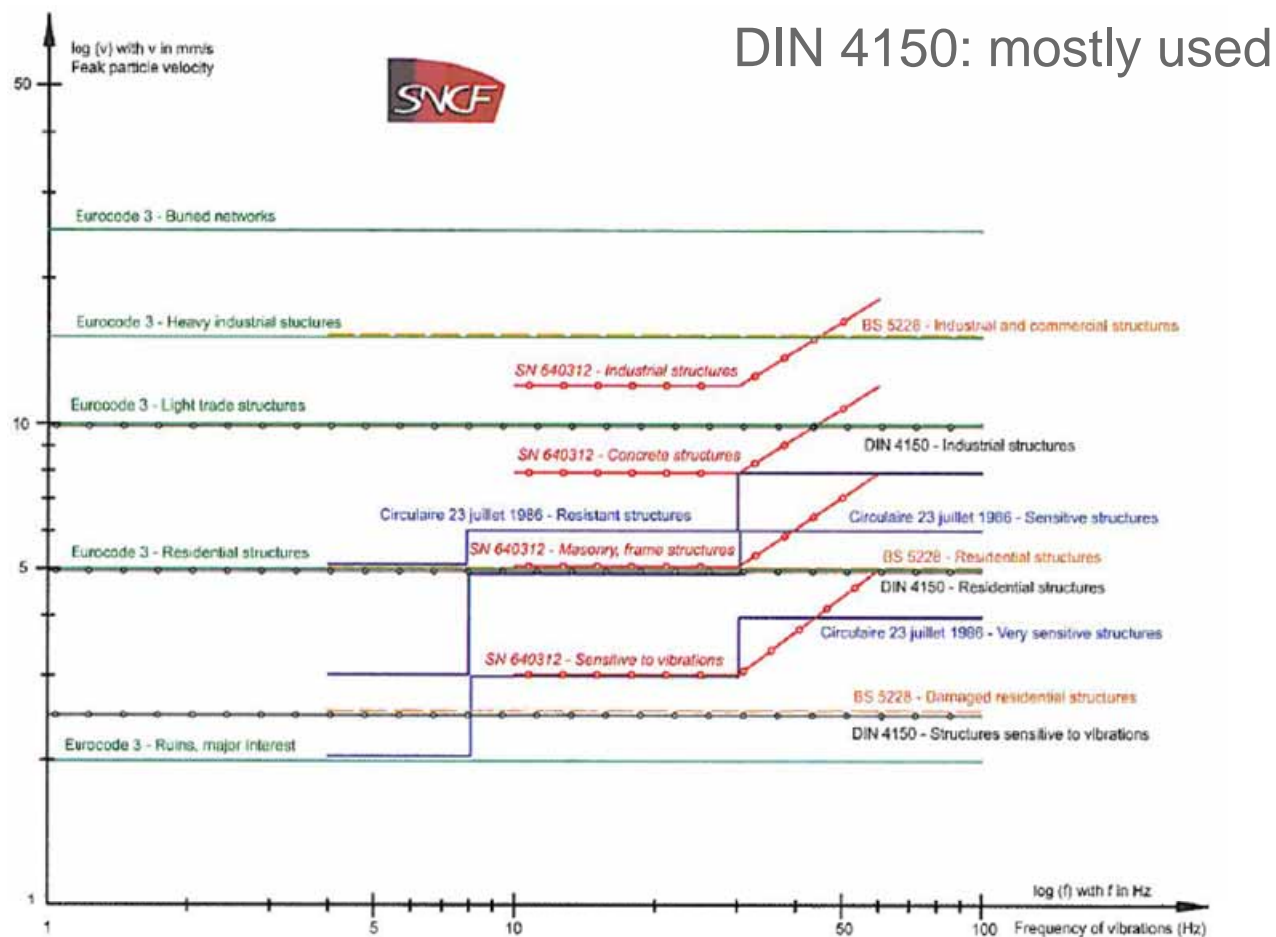
Installation: Resonance-free vibrohammer





Installation: Peak particle velocity limitations avoiding damage to buildings

- Differentiate continuous and non continuous vibrations





Installation: hydraulic press

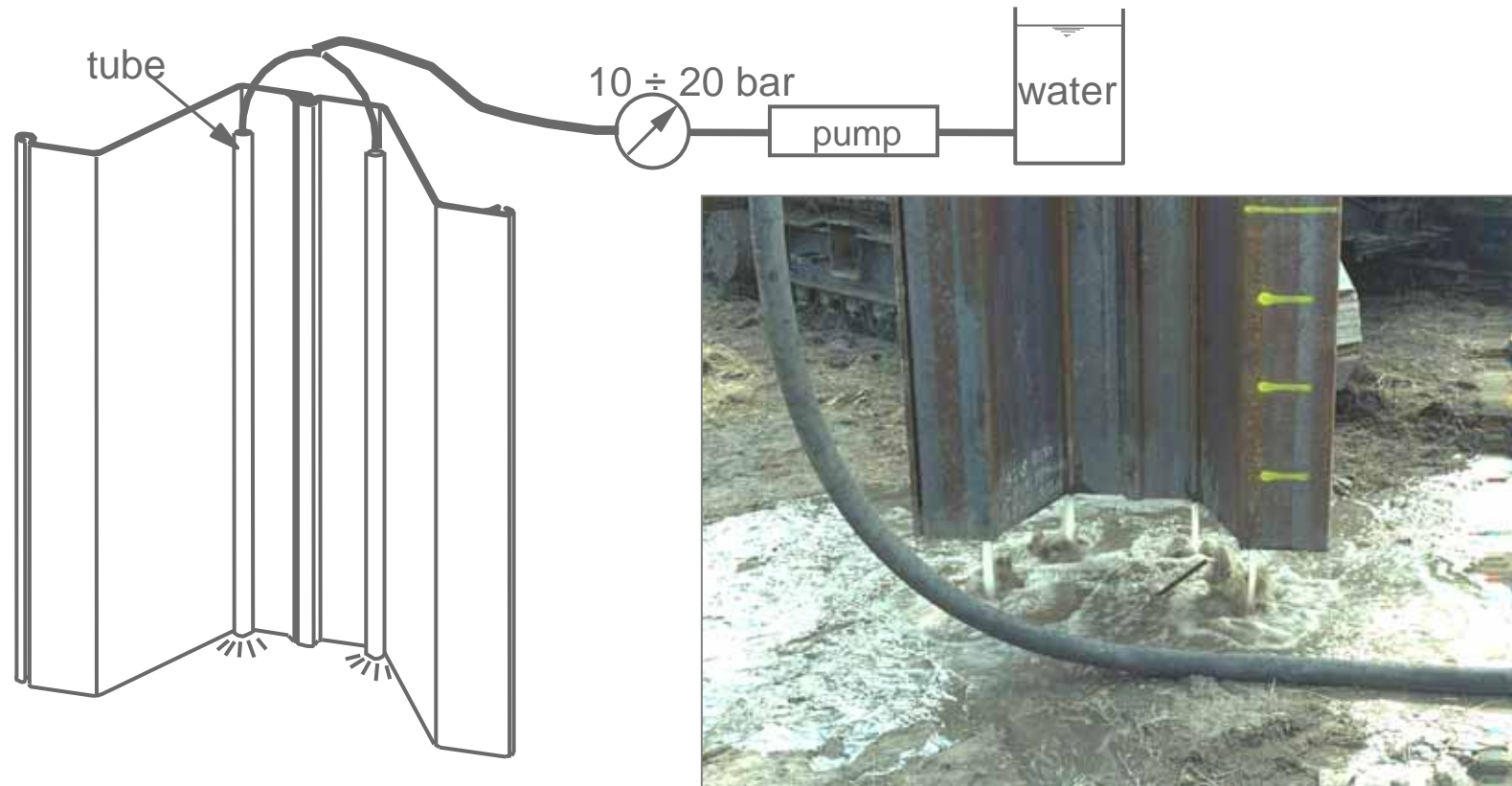


- drives single / double piles
- 'crawls' over the driven sheets
- soft soils, water-jetting & pre-drilling capability

- drives 4 single piles
- soft soils, predrilling capability

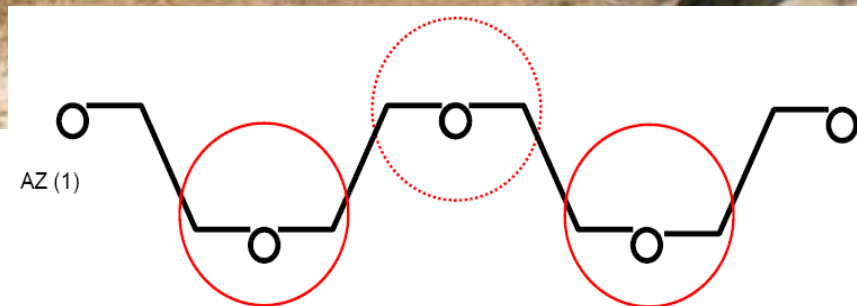


Driving assistance: water-jetting



- reduces resistance at toe of the sheet pile
- water lubricates the surface of the sheet (friction ↓)

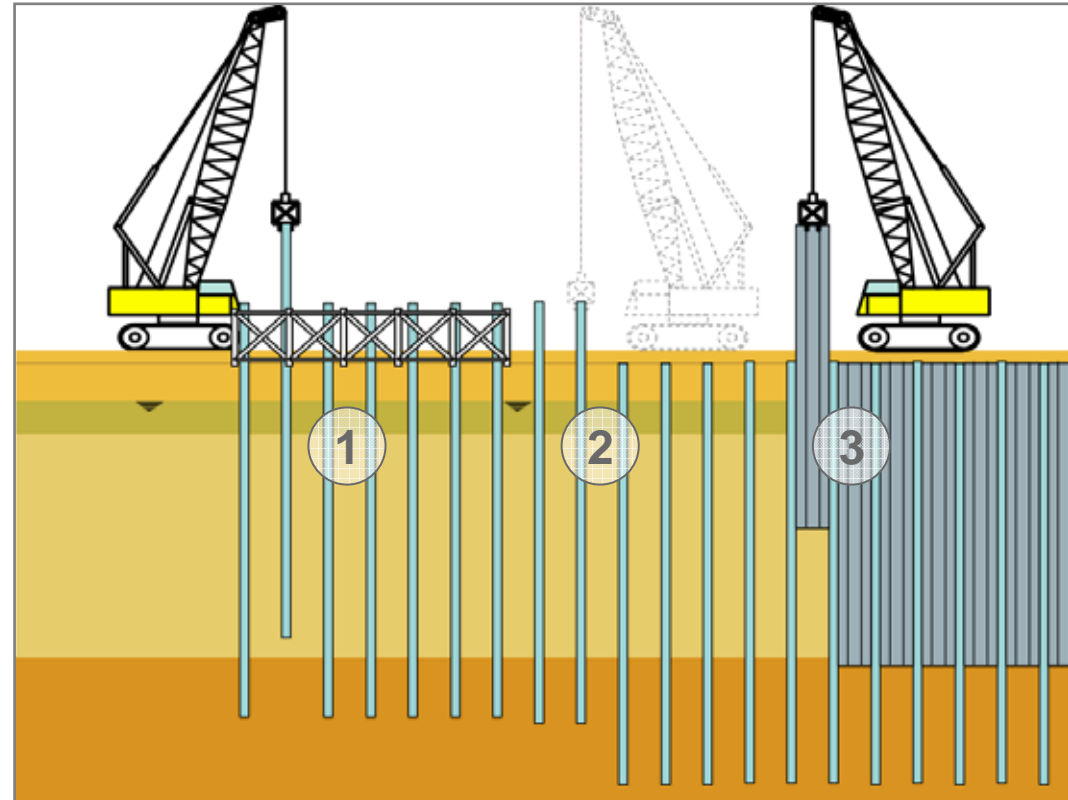
Pre-drilling





Installation of combined walls HZ/AZ

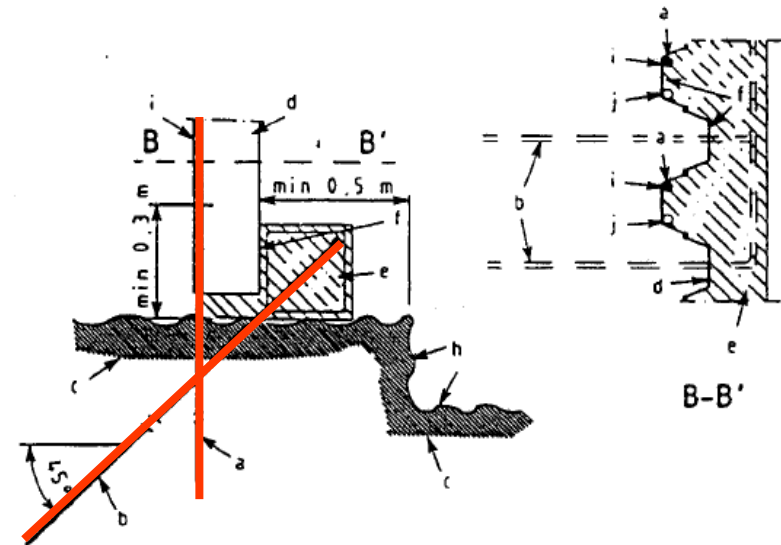
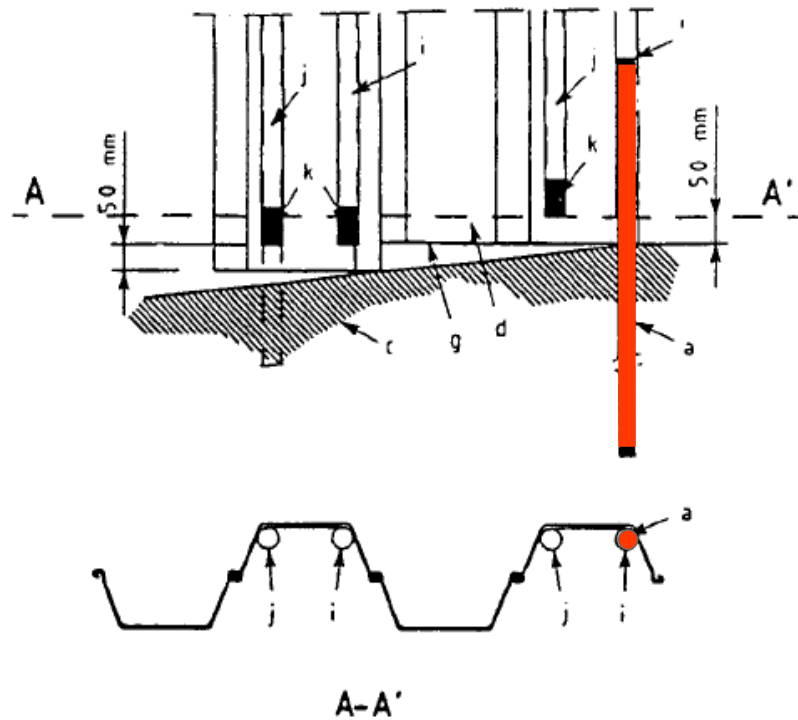
Driving Sequence



AZ infill sheets installed after driving of king piles HZ

Very hard soils: alternative solutions

Rock dowels



Very hard soils: alternative solutions

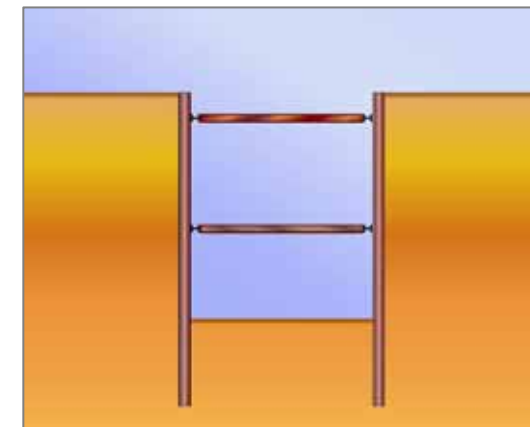
Circular cells



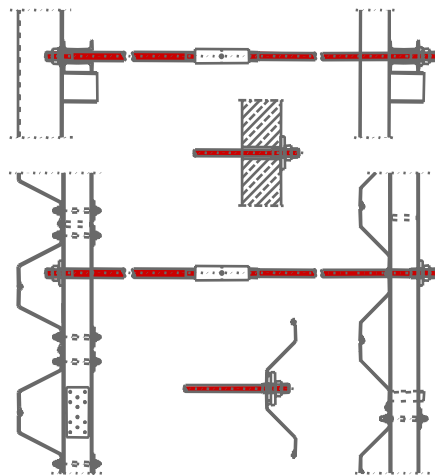


Anchors / struts

- excavation with more than 4-5 m height: anchors / struts most probably required
- prefer systems easy to install (driving tolerances)
- avoid / limit introduction of bending stresses due to settlements (hinged systems)

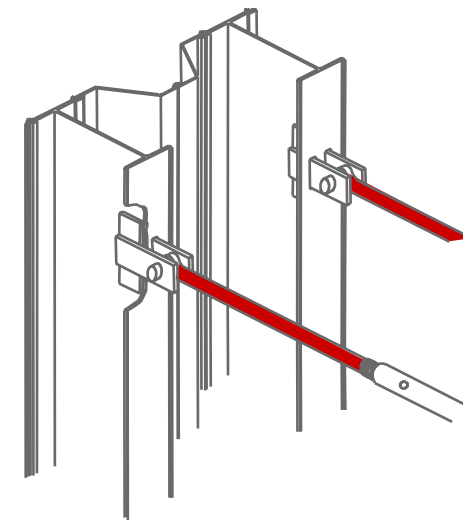
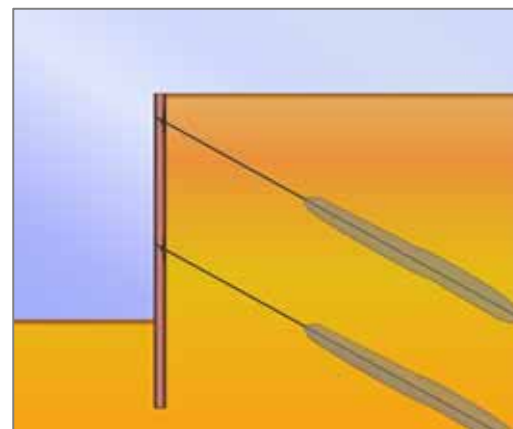


struts



tierods

tension piles /
grouted anchors



Anchors



Raked steel piles working in tension

Tie-rods / walers



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Watertightness



Impervious steel sheet pile walls

For higher watertight wall requirements:

- bituminous filler **Beltan** ($p \leq 1$ bar)
- environmental friendly **Arcoseal**,
mix of wax and mineral oil
- waterswelling filler **Roxan**[®]
($p \leq 2$ bar), applied with special template
- **weld** the interlocks

Applications:

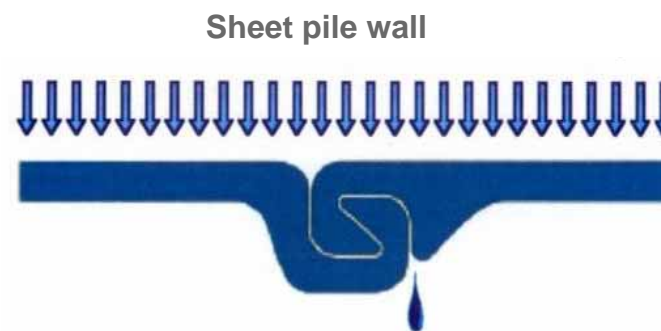
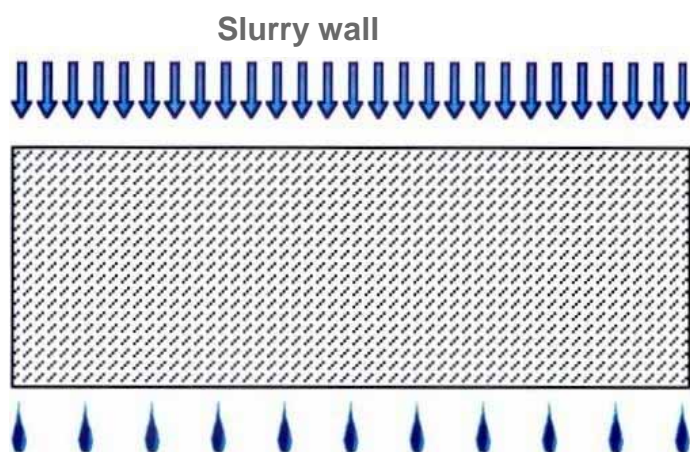
- cofferdam (high water pressure)
- cut-off wall in contaminated sites
- underground car parks





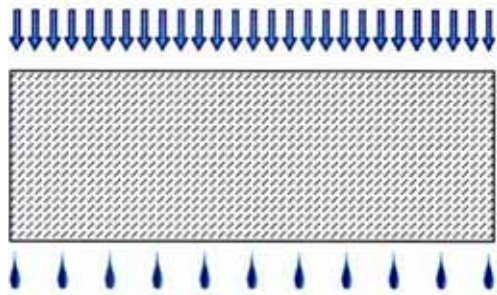
Watertightness of a sheet pile wall

- Research Project in collaboration Delft Geotechnics (Deltares):
 - Development of a coherent theoretical model for the hydraulic permeability of a sheet pile wall (\neq Darcy's law)
 - Development of a testing device to determine the permeability of the interlock in situ and in laboratory
- Method included in a standard (EN 12063)





Discharge relation of sheet piles and porous media



$$\frac{K}{d} = \frac{\rho}{b}$$



- K** : permeability coefficient of the porous media [m/s]
- d** : thickness of the porous media wall [m]
- ρ** : inverse joint resistance of the sheet pile [m/s]
- b** : width of the sheet pile [m]



Current ArcelorMittal sealing systems for sheet piles

- Inverse Joint Resistance values determined following in-situ tests in collaboration with Geodelft (Deltares)

Interlock sealing system	Inverse joint resistance ρ (m/s)
Welding	0 → Underground car parks
Roxan	3×10^{-10} → Cut-off walls in contaminated sites
Beltan et Arcoseal	6×10^{-8} → Cofferdam (high water pressure)
Without sealing system	$>10^{-7}$



ρ (ms) ↓, watertightness level ↑

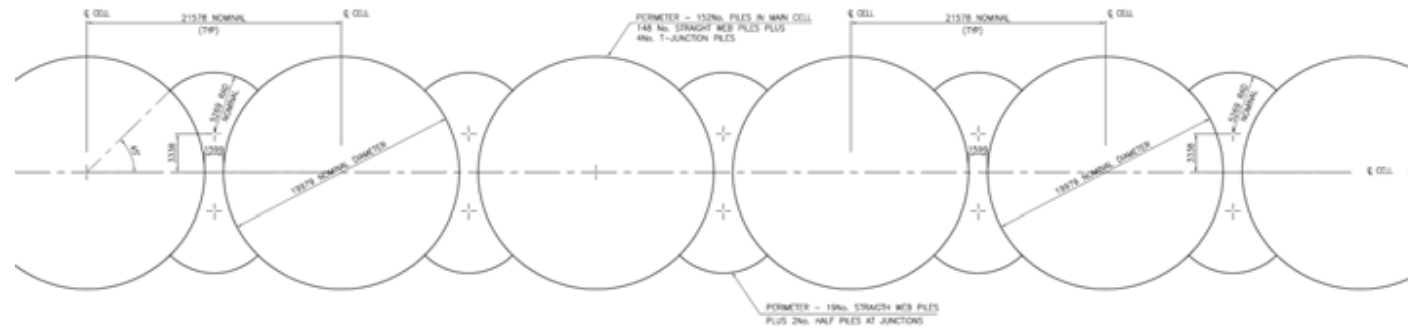


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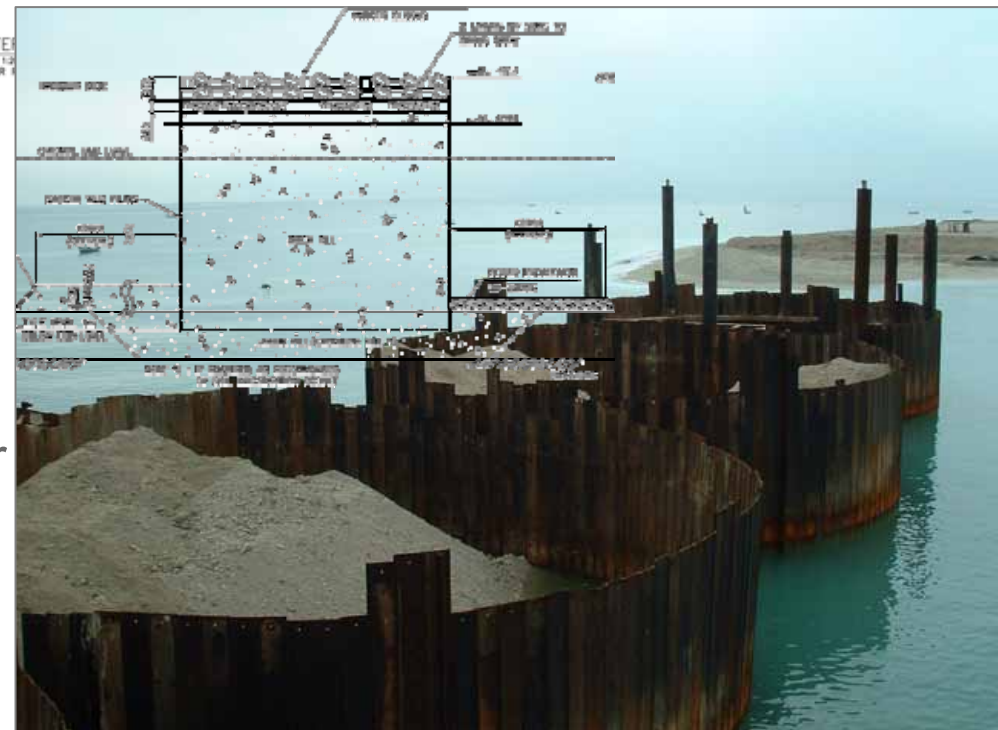
Applications



Applications



- Temporary cofferdams
- River embankments & Flood protection
- Land reclamation & Port and Harbour construction
- Cut-off walls & Waste Disposal
- Road works & Underground Car Parks
- Foundations





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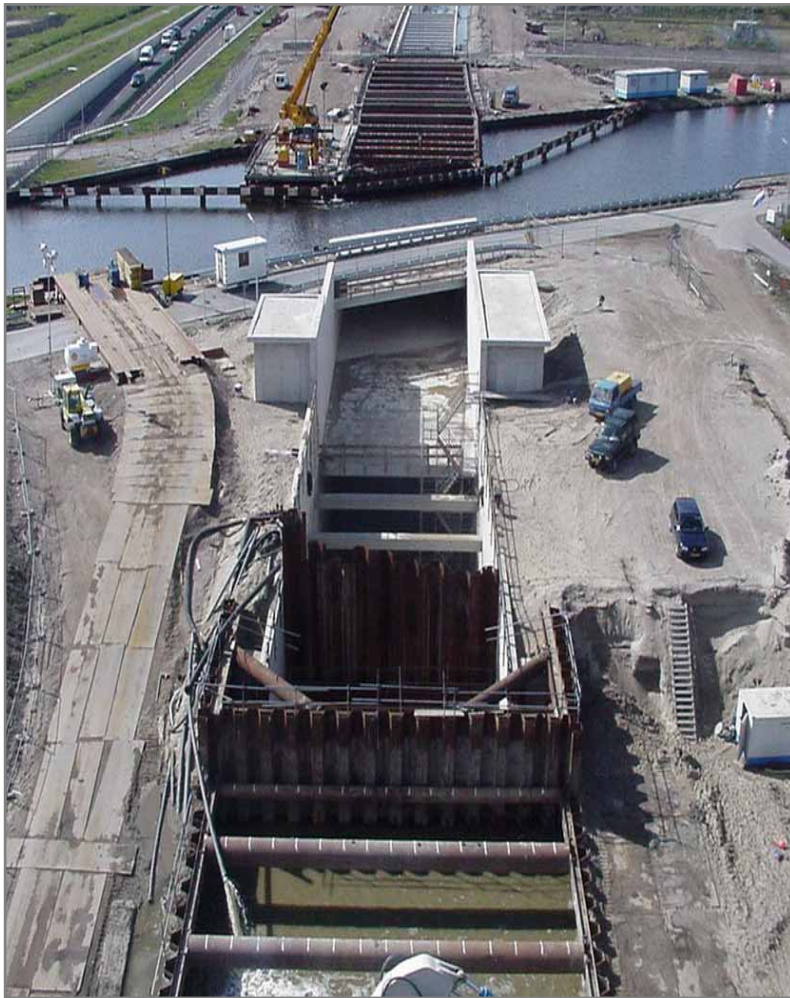
Temporary cofferdams

Impervious cofferdam / retaining wall



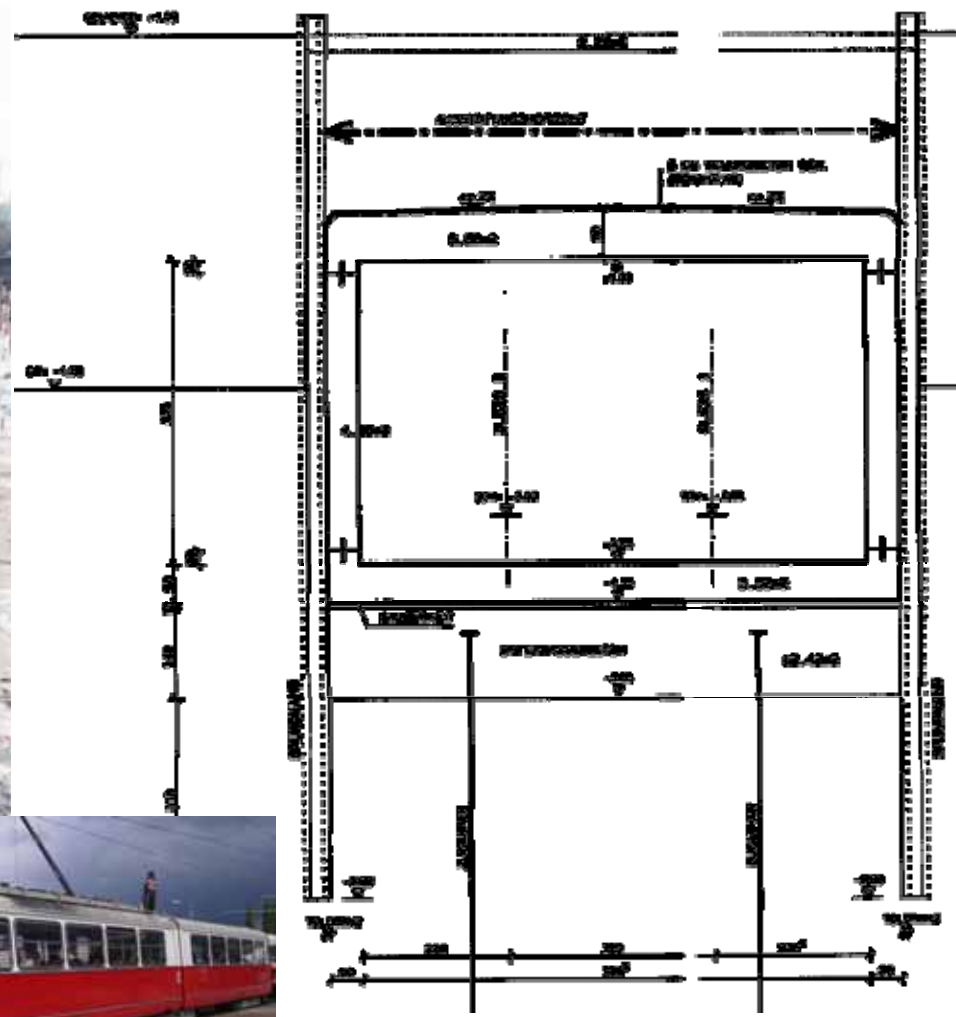
Spandau Lock, Berlin, Germany

HSL-High Speed Line, The Netherlands



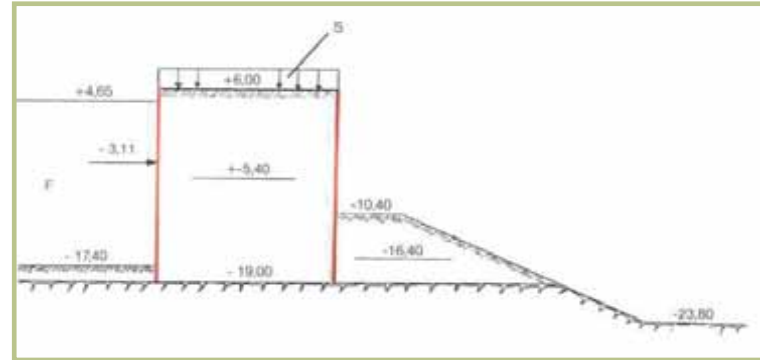


Vienna Metro Extension





Seo-Hae Grand Bridge (Korea)





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River embankments and Flood protection

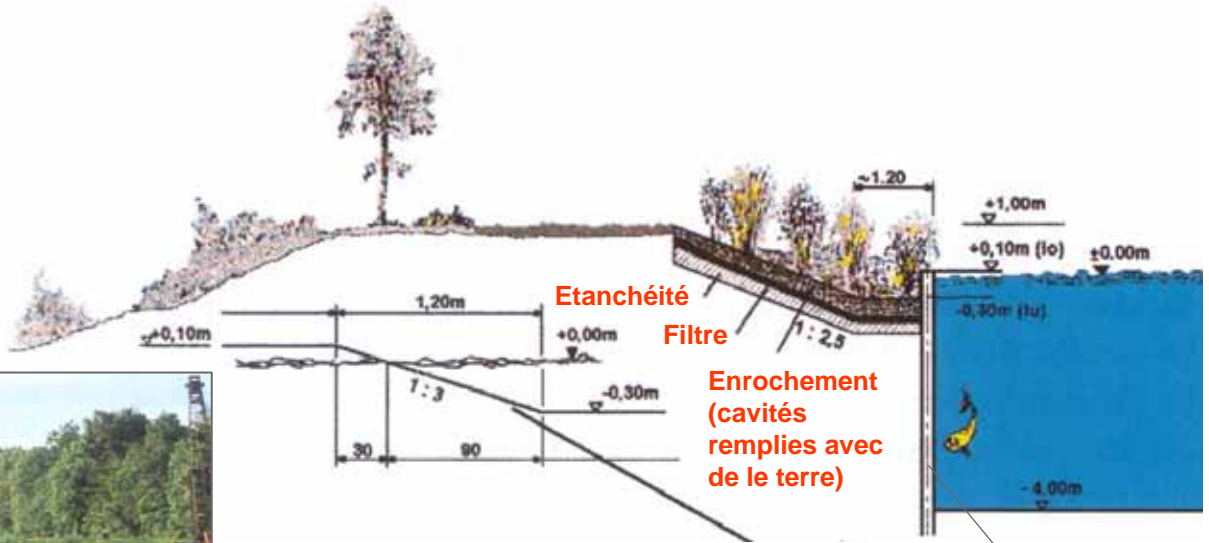
Canals & Rivers



Embankments and canal protection

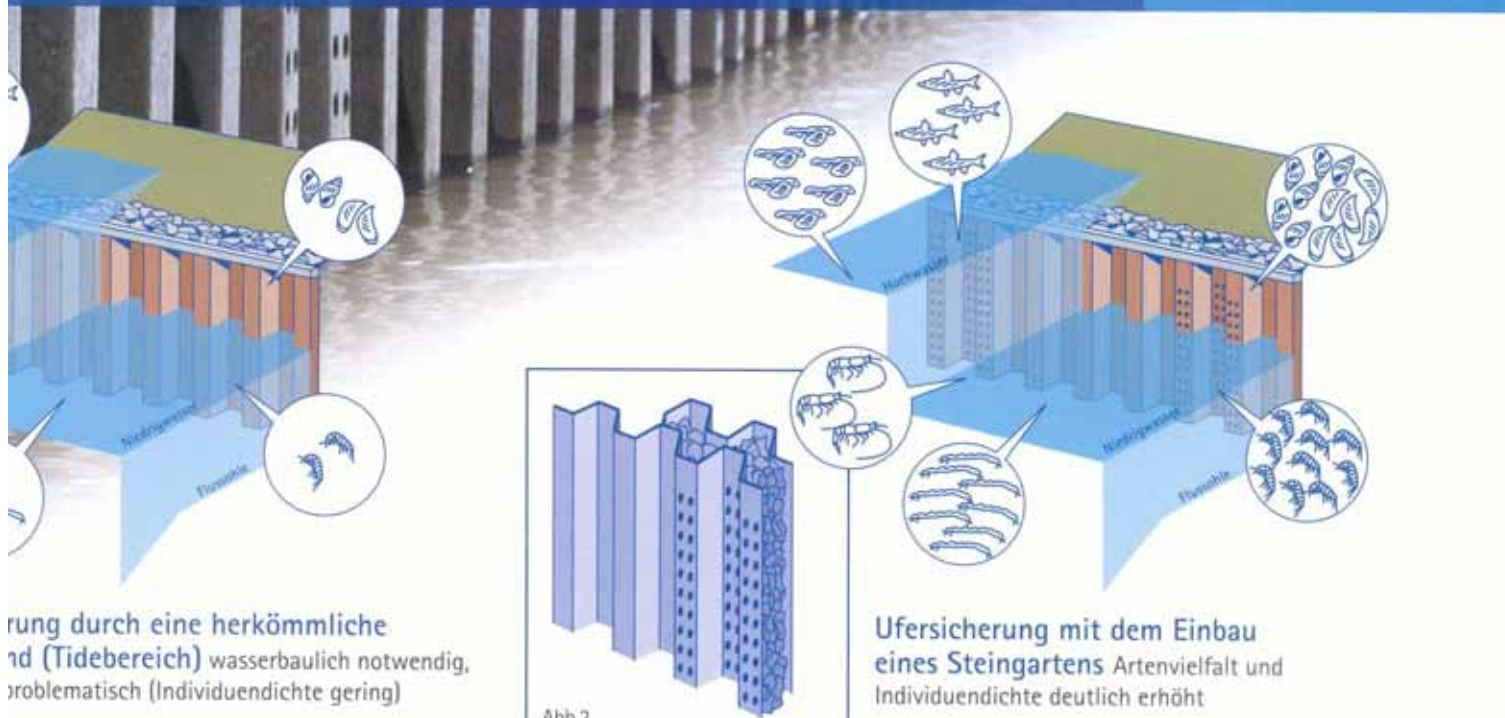


Mittellandkanal (D)





Stonegarden, Bremen (D)





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Flood protection walls

St Pierre de Gaubert, France

1400 t AZ 36 sheet piles to protect the city from the floods





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Land reclamation &
Port and Harbour construction

Jurong Island, Singapore



Land reclamation



Marina Pez Vela | Quepos | Costa Rica (2008)

Breakwater

Circular cells, $\phi = 12.2 / 18.6 \text{ m}$, $L = 540 \text{ m}$

AS 500-11.0 & 12.0

A690, I.S. = 3500 / 5500 kN/m

$l = 7.0 \sim 15.0 \text{ m}$

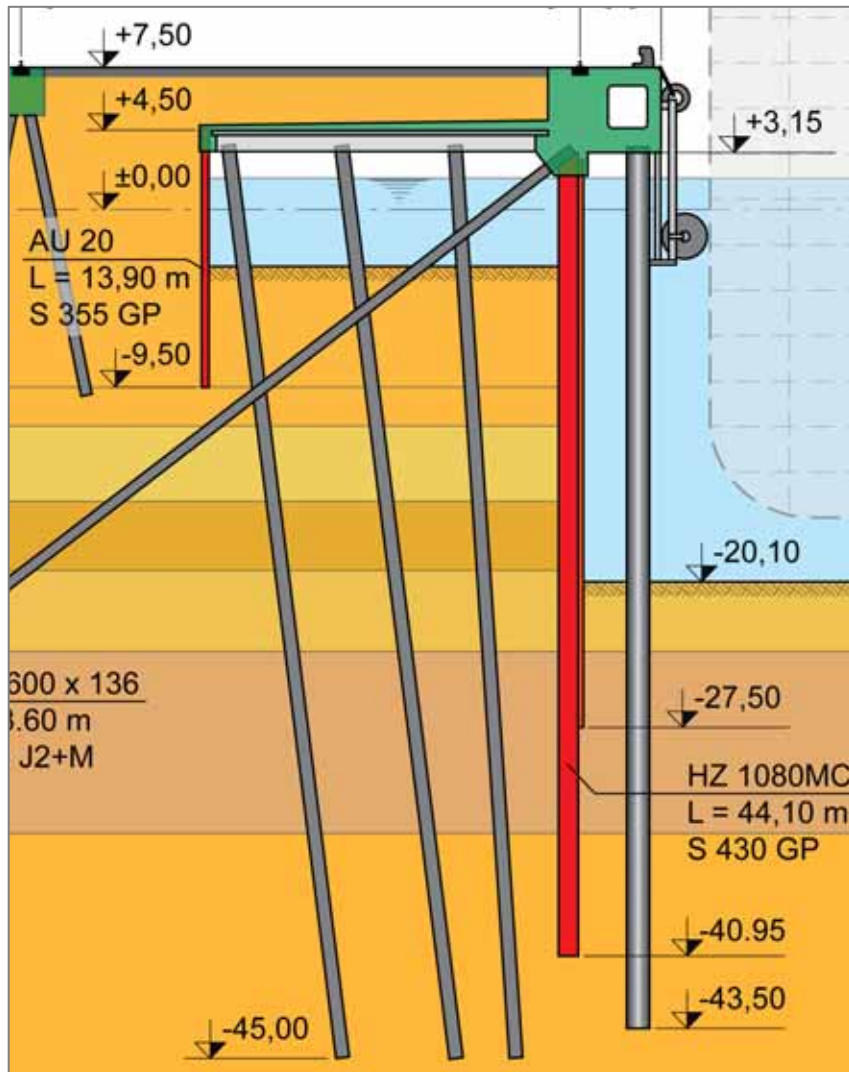
3'440 t





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JadeWeserPort, Wilhelmshaven, D (2008-2009)



1.725 km long quay wall
HZ/AZ & new **HZM/AZ** system
≥ **40 000 t**, length up to **44.0 m**

S 430 GP / S 355 GP

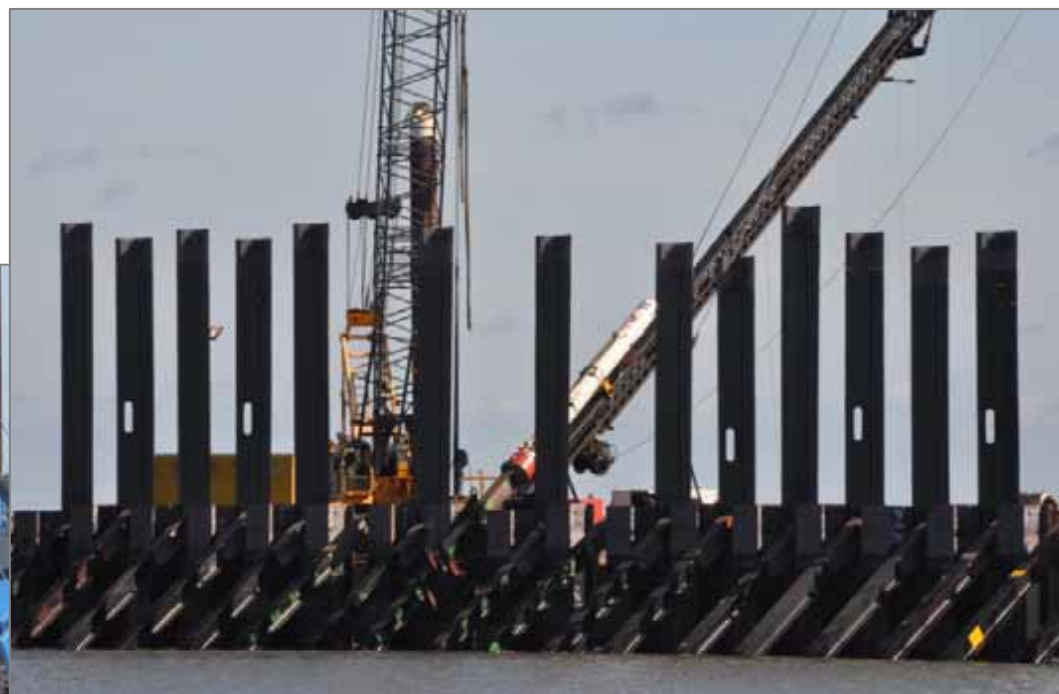
HZM: 17,200 t, HZ: 10,600 t, AZ:
9,000 t HTM: 7,000 t



JadeWeserPort, Wilhelmshaven, D (2008-2009)



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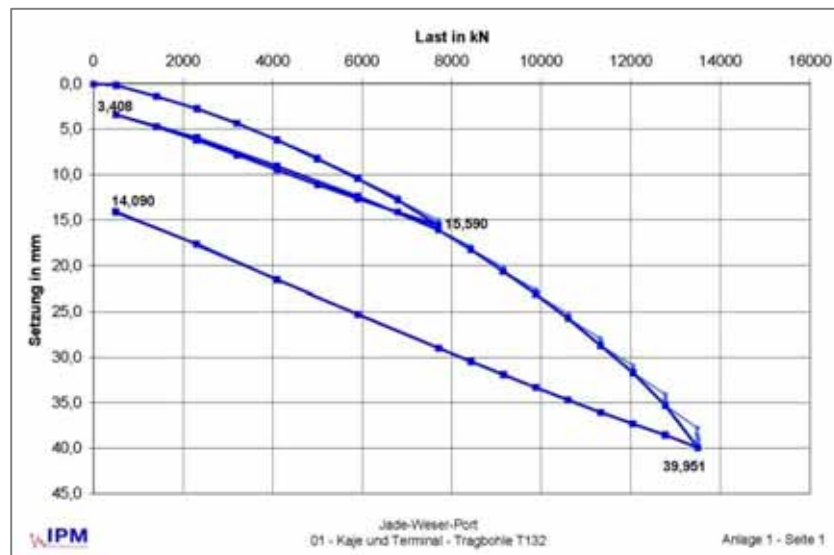




Load bearing tests for HZ-M king piles



Load bearing test: compression





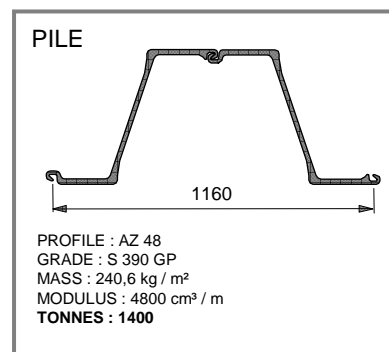
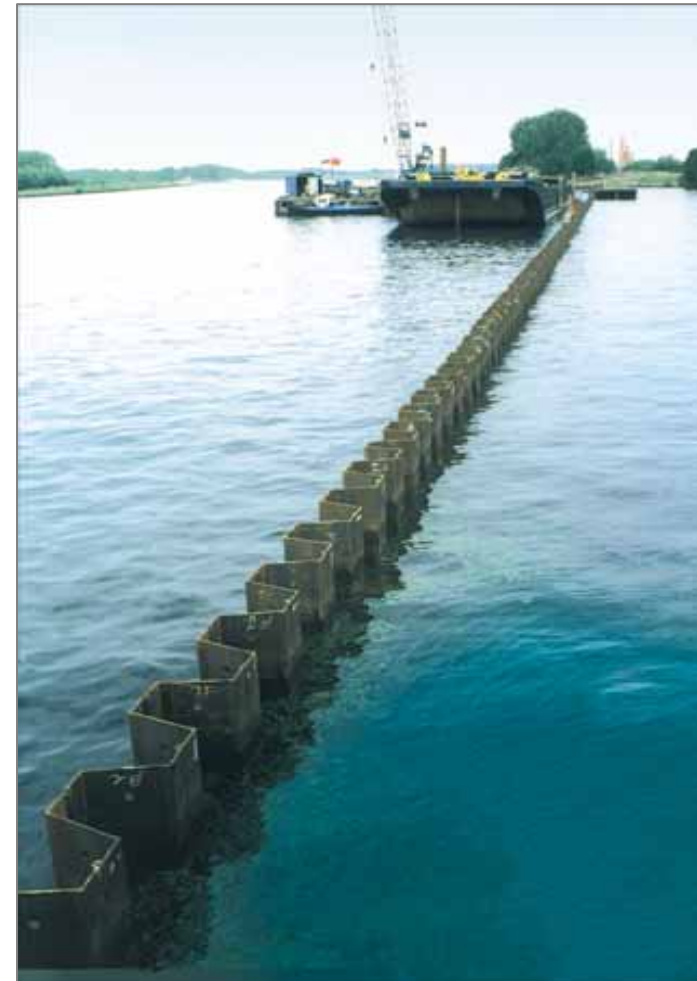
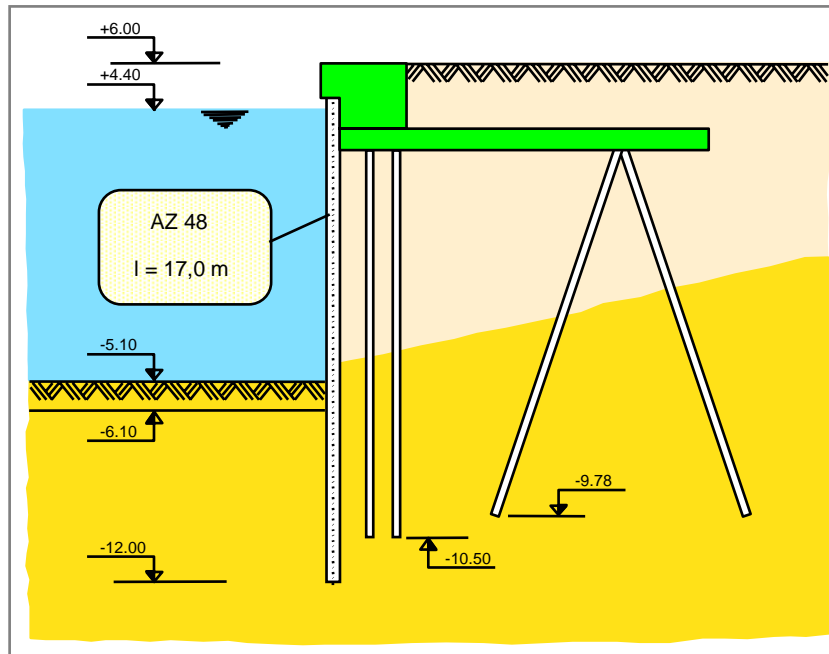
Tension tests for HTM anchor piles



Profil HTM 600/136	nachzuweisende Tragfähigkeit [kN]	nachgewiesene Tragfähigkeit [kN]
S 127	3.302	3.750
S 212	3.302	3.500
S 260	3.179	3.750
S 344	3.149	3.750
S 380	3.438	3.750
S 428	3.661	3.905

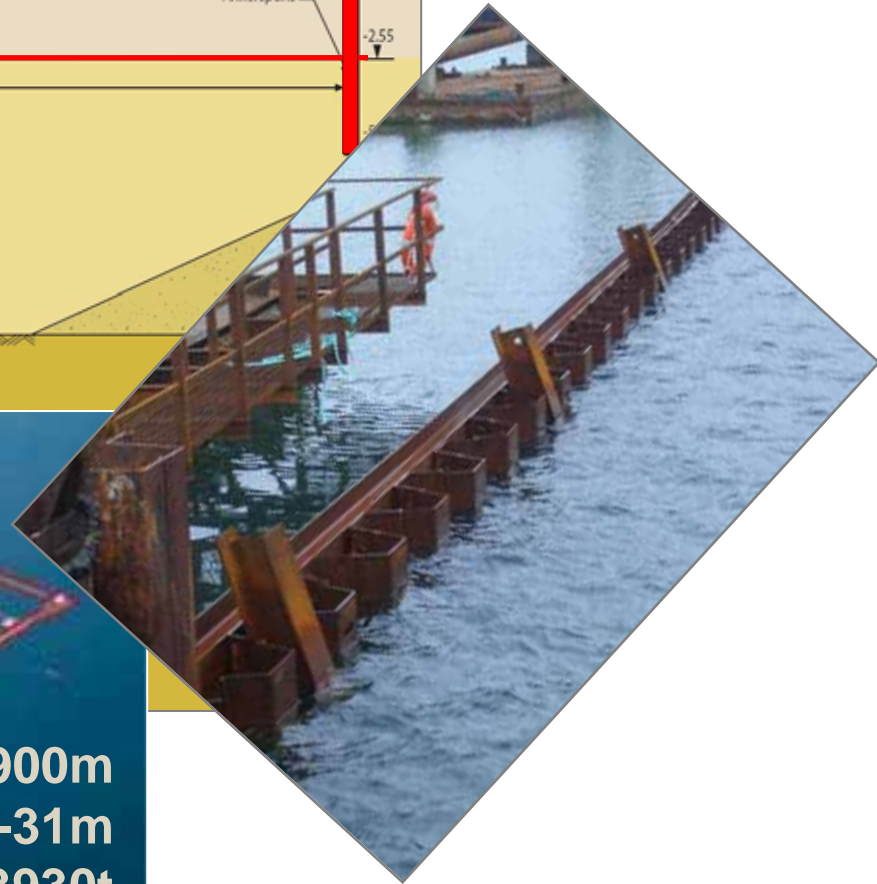
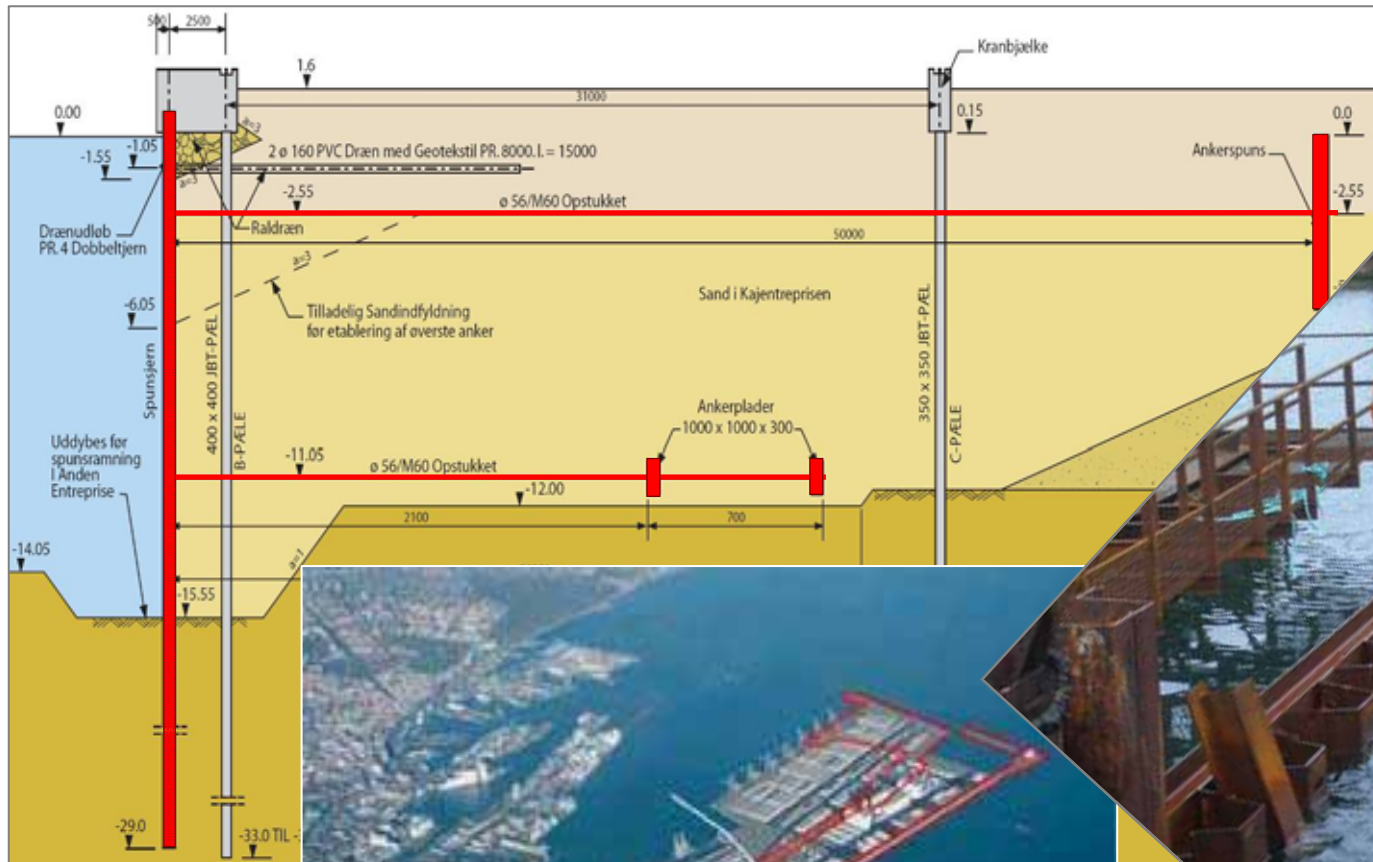


Quaywall Hellegat | Zeekanaal | B





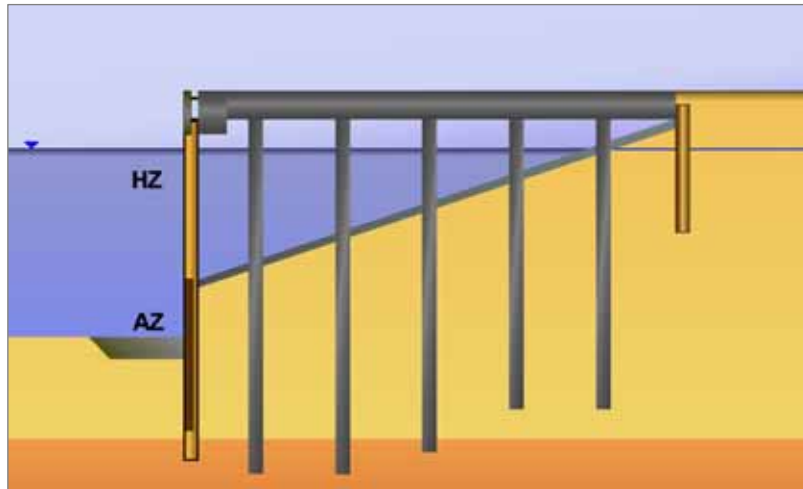
Port of Aarhus | Denmark (2005)



Wall: 900m
PU32: 20-31m
S430GP, 3930t
PU22: 5.5 m, 690t

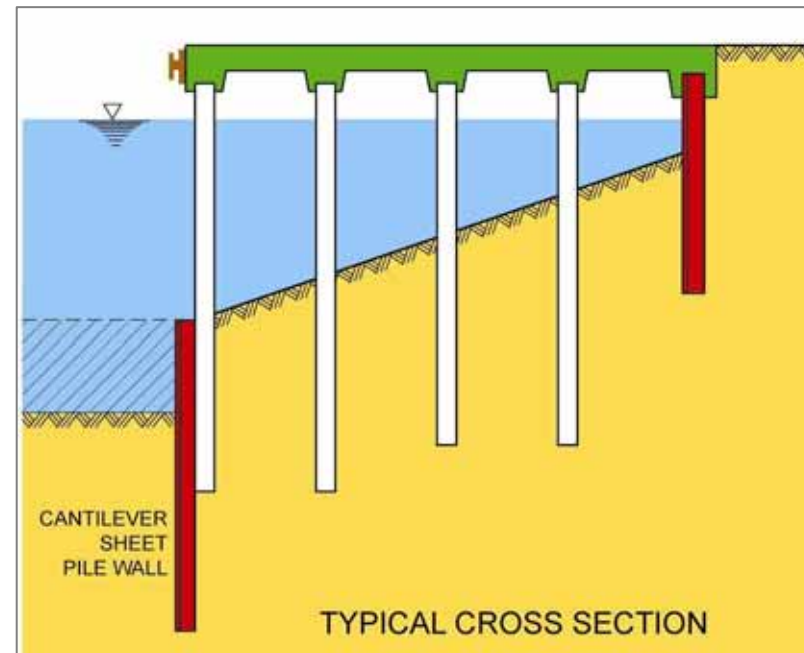
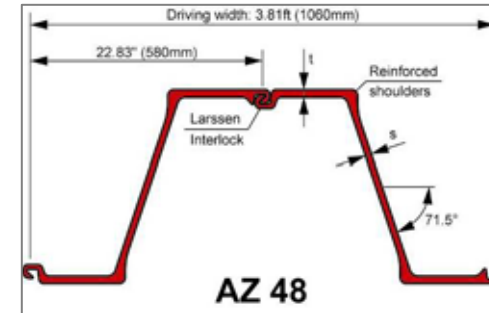


Maersk Terminal | Port Elizabeth | NJ | USA (2002) ArcelorMittal



HZ 575 B & C-12/AZ18: 1220 mt
HZ: $\pm 24.4\text{m}$
AZ: $\pm 7.6\text{m}$

Terminal 5 | Port of Seattle | USA





Prostneset | Tromsøe | Norway (2009)

Quay wall with circular cells

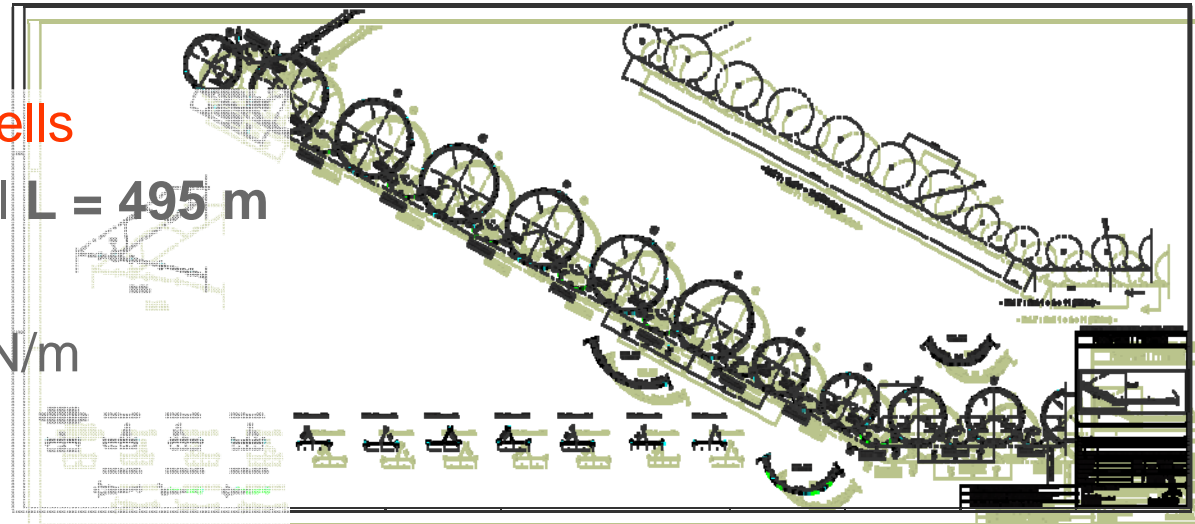
$\phi = 14.0 \text{ m} / 19.2 \text{ m}$, total **L = 495 m**

AS 500-12.0

S 355 GP, I.S. = 5000 kN/m

l = 8.6 m ~ 15.0 m

3 100 t





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Cut off walls & Waste Disposal

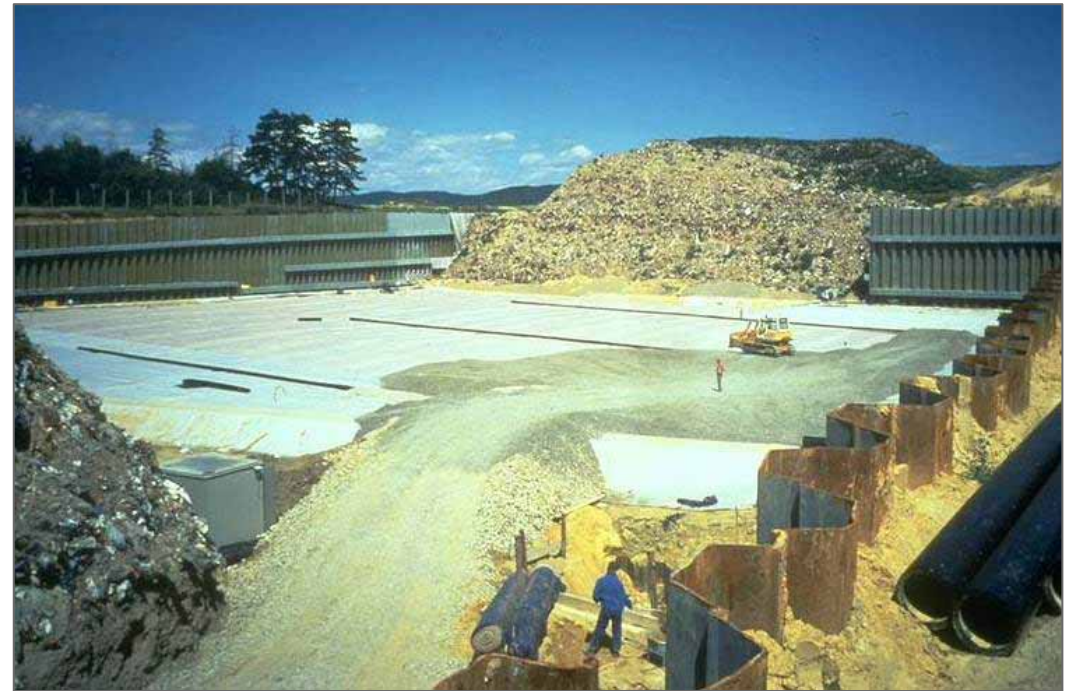
Kralingen (NL)



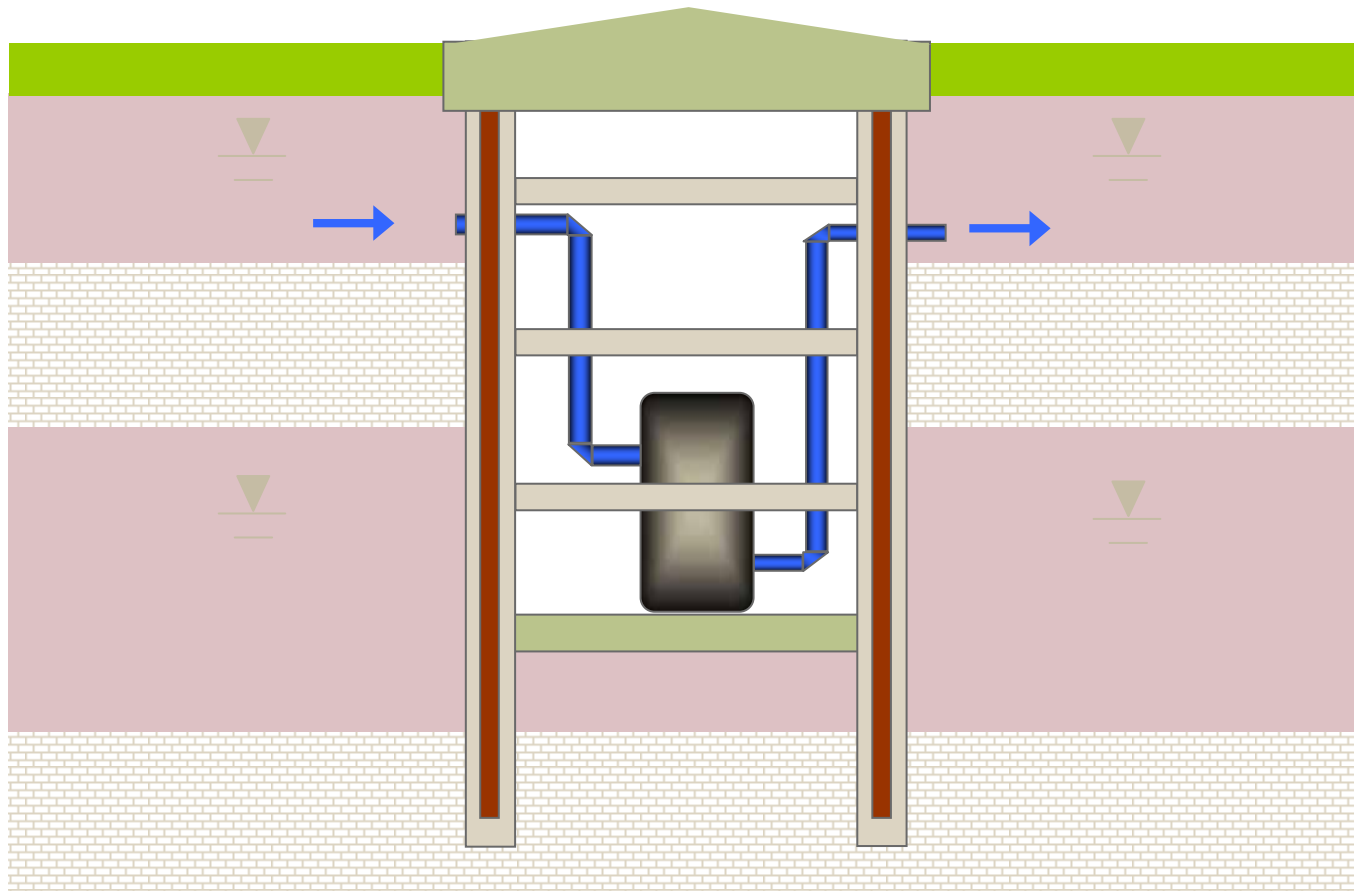
Porto Marghera



Waste disposal



Funnel and gate



Funnel and gate



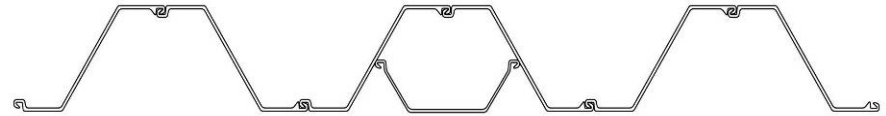


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Road works & Underground Car Parks

Road works: Underpasses & Tunnels

Vicenza (It)



Frisange (L)

Warsaw: Load bearing test



Congonhas Airport (Brazil)



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AU 14, S430GP



Woerden (NL)



Siemens, La Haye (NL)



Markthal Rotterdam (NL)



Underground car park



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Netherlands



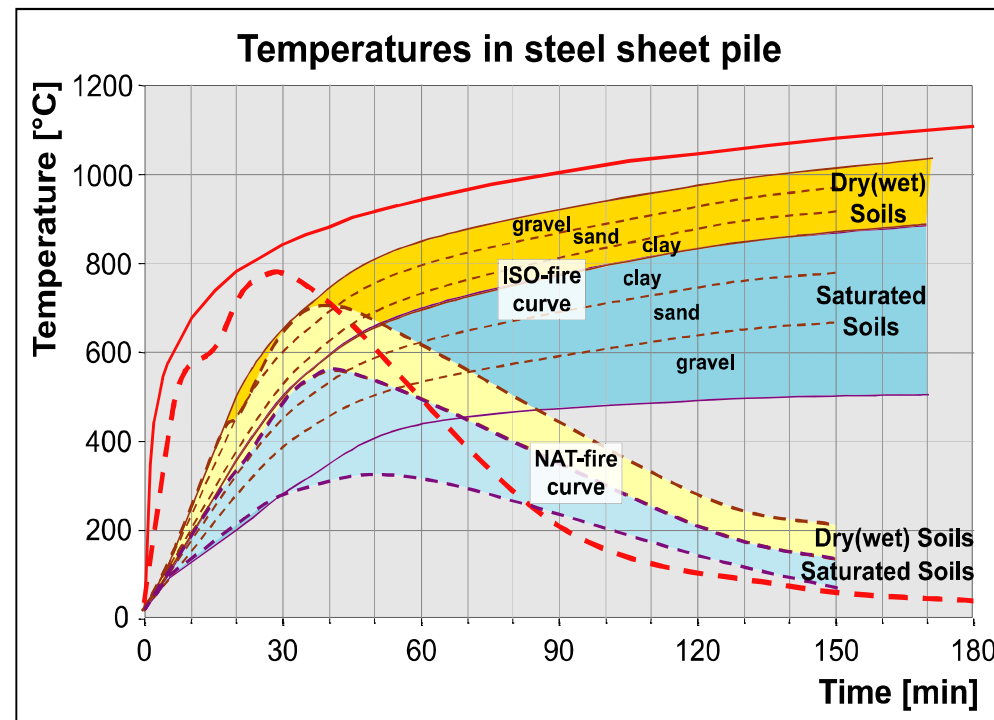
UK



Belgium



Fire resistance: design for UGCP



Behaviour of ssp in a 'natural' fire / ISO fire developed in collaboration with University of Liege, Belgium (\Rightarrow software **Safir**).



Bottom slab-sheet pile connection



Studs



Sealed Floor



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Foundations

Steel sheet piles for bridge foundations

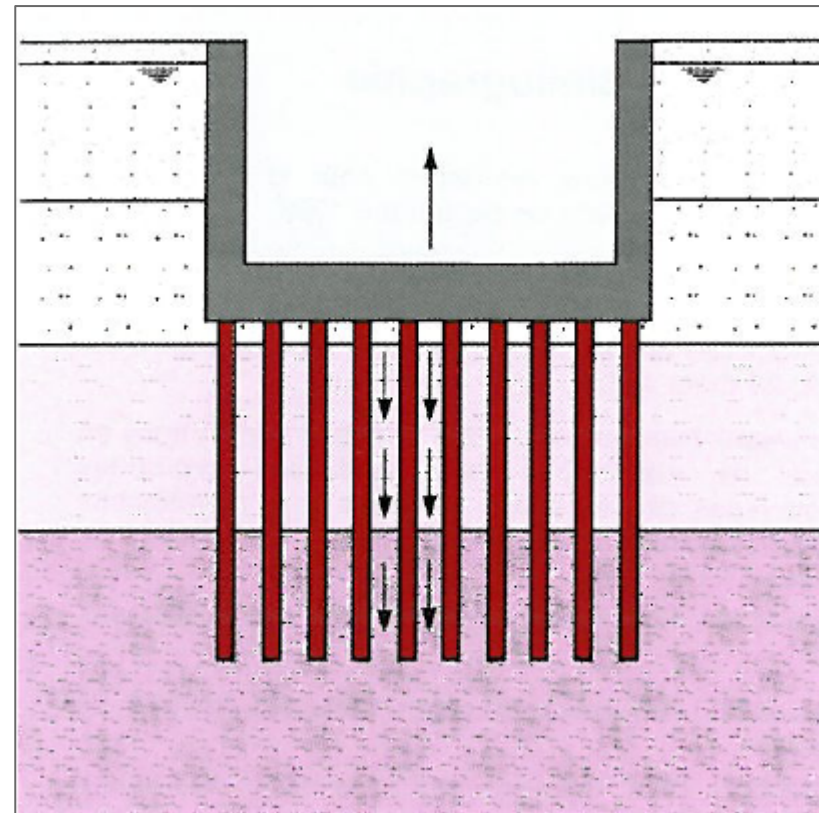
Saalach-Kraftwerk Rott (Ö)





HP Pile Foundations

Waste water treatment plant
Lübeck (D)

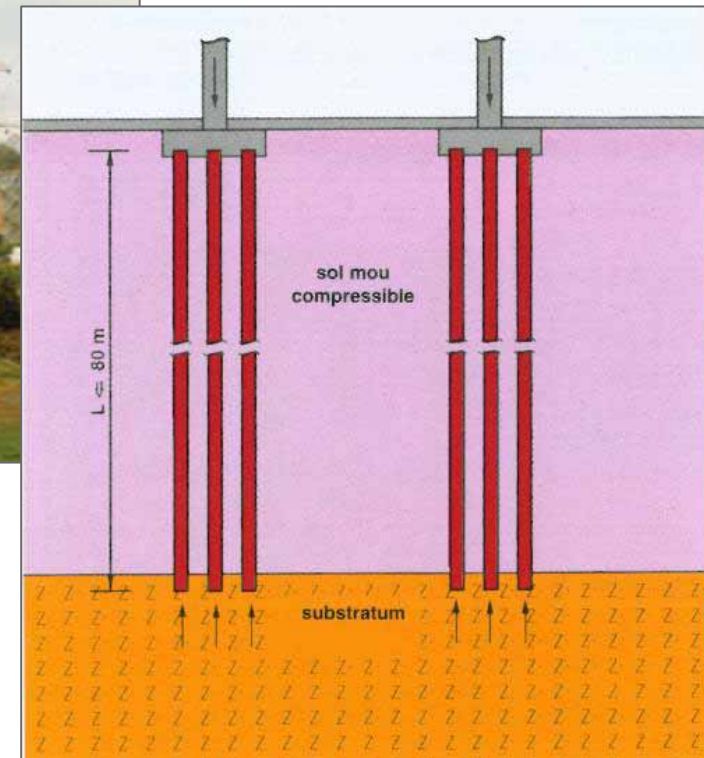




HP Pile Foundations



A29 highway
Viaduct of Merville (F)



HP bearing pile applications

Injected piles for bridge pier foundations Viaduct at José (B)



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HP bearing pile for bridge foundations



Injected piles for bridge pier foundations
Viaduct at José (B)





Assessment of pile capacity by design

The assessment of pile capacity by design can be performed based on geotechnical tests:

- Impact probe (light, heavy, SPT)
- Pressiometre (PMT) cf french fascicule 62
- Cone penetration test (CPT)
- Dynamic penetrometre
- Laboratory tests



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1. Standards
2. Literature
3. Environmental Product Declaration
4. Conclusions



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Standards



European standards

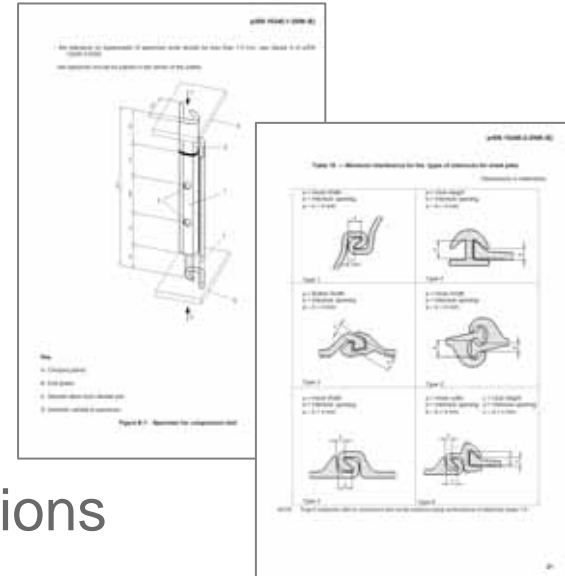
Design:

- **Eurocode 3** - Design of steel structures – **Part 5: Piling.**
 - Final version in Feb. 2007, release in 2008.
New design concept for steel structures: semi-probabilistic approach. Steel sheet piles and bearing piles.
- **EN1997:** Geotechnical design (Part 1 & 2)
 - Design methods, assumptions, testing methods and geotechnical investigations are handled in this standard.
Release in 2008.

European standards

Product: sheet piles

- **EN 10248:** Hot rolled steel sheet piling
 - Part 1: Technical delivery conditions.
 - Part 2: Tolerances on shape and dimensions



Contains sheet pile characteristics (properties of steels, chemical composition) and tolerances (length, mass, ...).



Steel grades of HRSSP

EN 10248		ASTM		
	f_{yk} [MPa]		f_{yk} [ksi]	f_{yk} [MPa]
S 240 GP	240			
S 270 GP	270	A 328	39	270
S 320 GP	320			
S 355 GP	355	A 572 Gr. 50	50	345
S 390 GP	390	A 572 Gr. 55	55	380
S 430 GP	430	A 572 Gr. 60	60	415
<i>S 460 AP*</i>	<i>460</i>	<i>A 572 Gr. 65</i>	<i>65</i>	<i>450</i>

- ASTM **A 690**: high strength steel for use in **marine environments**
- **Decreto Ministeriale**

European standards

Product: HP piles

- **EN 10025:** Hot rolled products of structural steels
 - Part 1: General technical delivery conditions
 - Part 2: Technical delivery conditions for non-alloy structural steels
 - Part 4: Technical delivery conditions for thermomechanical rolled weldable fine grain steel
- **EN 10034:** Structural steel I and H sections – Tolerances on shape and dimensions



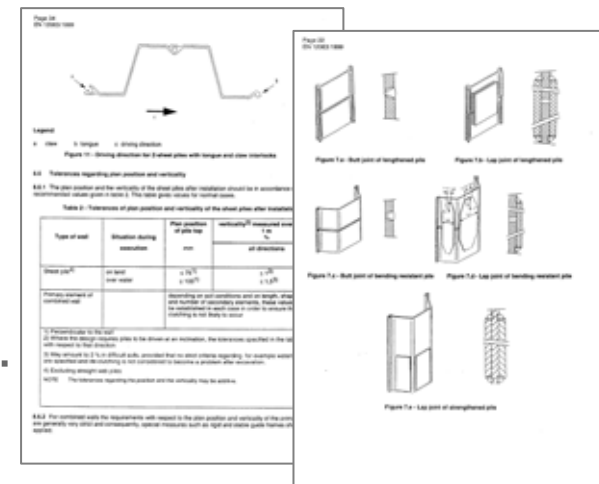
Steel grades of HP Piles

EN 10025			HISTAR	
	f_{yk} [MPa] $t \leq 16$ mm	f_{yk} [MPa] $t > 16$ mm $t \leq 40$ mm		f_{yk} [MPa]
S 235	235	225		
S 355	355	345	HI 355	355
S 460	460	440	HI 460	460
			HI 500	500

- **HISTAR** can be supplied for almost all sections
- **HI 500** only on request

Execution of Special geotechnical Works:

- **EN 12063: Sheet-pile walls.**
 - Covers fabrication, welding, installation tolerances, special solutions, handling & storage, .
- **EN 12699: Displacement piles**



Coatings:

- **EN ISO 12944:**
 - Guidance on coatings and their applications, etc



European standards

Other standards:

- **EN 10204:** Metallic products – Types of inspection documents
 - Describes the different inspections at the mill that can be agreed. Different types, different costs.
Generally: inspection certificate 2.2 or 3.1
- **EN 287:** Approval testing of welders
- **EN 288:** Specification and approval of welding procedures for metallic materials
 - Welding of steel, quality control of welding, etc
- etc...



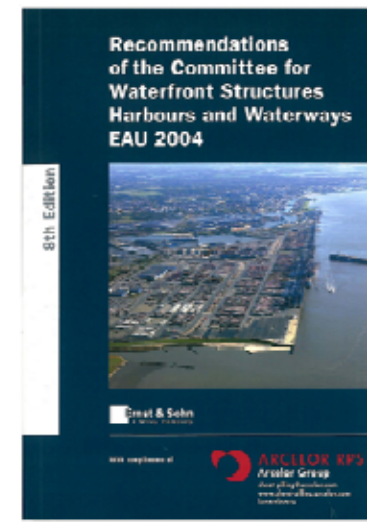
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Literature



Reference books / publications

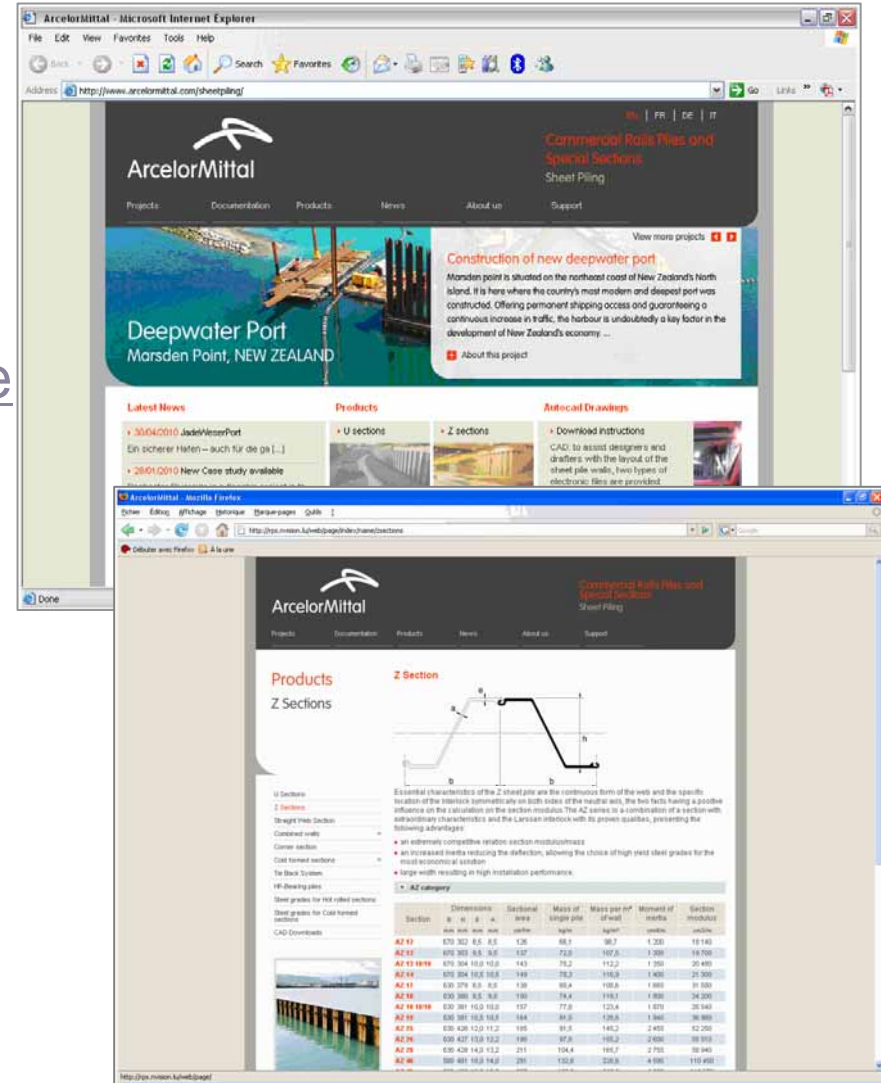
- **EAU 1990 / 1996 / 2004:** Recommendations of the Committee for Waterfront Structures Harbours and Waterways.
Available in D, E
- **EAB 2004:** Empfehlungen des Arbeitskreises Baugruben.
Available in DE & GB
- **CUR166:** Damwandconstructies.
Only in Dutch



Websites



- Lots of information (up-to-date): www.arcelormittal.com/palancole
- AutoCad files, software (Prosheets, Durability,...) & main catalogues and brochures available for download





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Available literature from ArcelorMittal

- Most relevant are:
 - **General catalogue** & HZM/AZ catalogue
 - **Installation** of steel sheet piles
 - **Piling Handbook**
 - **AS 500 straight web steel sheet piles**
 - **Special Finishing Brochure**
- Case studies:
 - **Harbour construction** (2007)
 - rail & motorways,
 - underground car parks (2008)
 - etc...





AS 500 brochure



- unique & comprehensive **design and installation manual** dedicated to straight web steel sheet piles AS500
- no such equivalent document, up-to-date available worldwide
- handles design aspects based on EuroCodes
- describes **installation procedure**
- contains 3 design examples



Free software / design support

- ‘**Prosheet**’: design of cantilever walls / one anchor level
- ‘**Durability**’: verification of steel stresses for standard HRSSP, based on design results and loss of steel (tables in EN1993-5)
- ‘**HZ / AZ Stresses**’: verification of steel stresses in the HZ/AZ system, may help choosing a combination

Free download from AMCRPS’ website.

No guarantee is given that they work correctly.

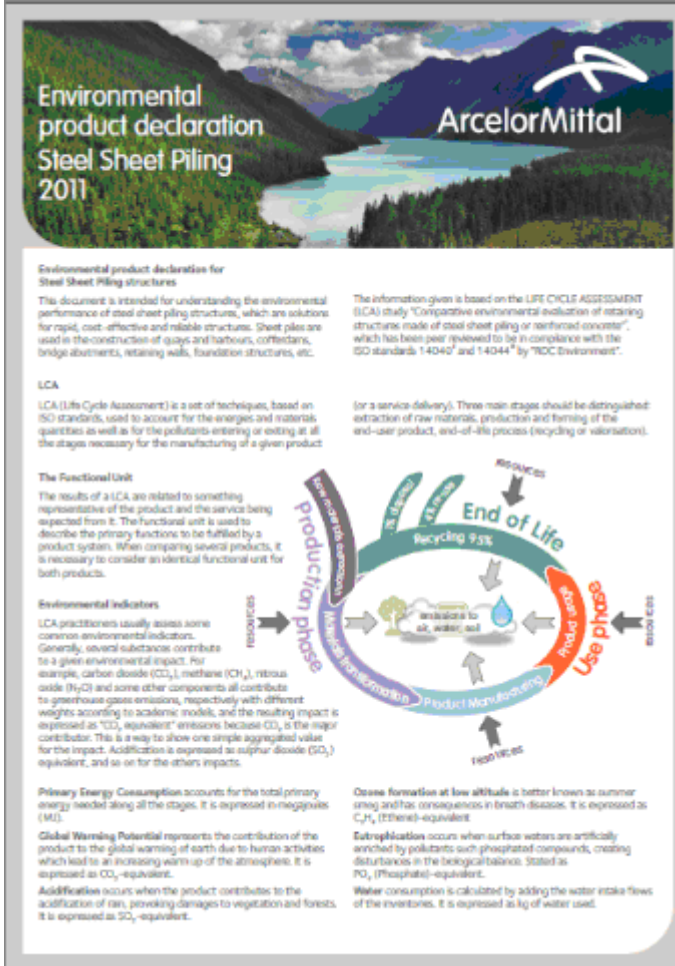


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Environmental Product Declaration (EPD)

Environmental Product Declaration for steel sheet piling

- **environmental impact:** major criterion for material selection by authorities
- reliable and understandable data have to be provided for the complete sheet piling solution: sheet piles, wailing, anchors, installation, transport
- **LCA** (Life Cycle Assessment) allows to compare the environmental performances of products / structures of ISO 14040 & 14044
- Deliverables:
 - certified LCA report ✓
 - Environmental Product Declaration ✓



Environmental product declaration Steel Sheet Piling 2011

The information given is based on the LIFE CYCLE ASSESSMENT (LCA) study "Comparative environmental evaluation of retaining structures made of steel sheet piling or reinforced concrete" which has been peer reviewed to be in compliance with the ISO standards 14040¹ and 14044² by "DCC Environment".

LCA
LCA (Life Cycle Assessment) is a set of techniques, based on ISO standards, used to account for the energies and materials quantities as well as for the pollutants entering or exiting at all the stages necessary for the manufacturing of a given product (or a service-delivery). Three main stages should be distinguished: extraction of raw materials, production and forming of the end-user product, and end-of-life process (recycling or valorisation).

The Functional Unit
The results of a LCA are related to something representative of the product and the service being expected from it. The functional unit is used to describe the primary functions to be fulfilled by a product system. When comparing several products, it is necessary to consider an identical functional unit for both products.

Environmental indicators
LCA practitioners usually assess some common environmental indicators. Generally, several substances contribute to a given environmental impact. For example, carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O) and some other components all contribute to greenhouse gases emissions, respectively with different weights according to academic models, and the resulting impact is expressed as "CO₂-equivalent" emissions because CO₂ is the major contributor. This is a way to show one simple aggregated value for the impact. Acidification is expressed as sulphur dioxide (SO₂) equivalent, and so on for the others impacts.

Primary Energy Consumption accounts for the total primary energy needed along all the stages. It is expressed in megajoules (MJ).

Global Warming Potential represents the contribution of the product to the global warming of earth due to human activities which lead to an increasing warm up of the atmosphere. It is expressed as CO₂-equivalent.

Acidification occurs when the product contributes to the acidification of rain, provoking damages to vegetation and forests. It is expressed as SO₂-equivalent.

Ozone formation at low altitude is better known as summer smog and has consequences in breath diseases. It is expressed as C₂H₄ (Ethene)-equivalent.

Eutrophication occurs when surface waters are artificially enriched by pollutants such phosphated compounds, creating disturbances in the biological balance. Stated as PO₄ (Phosphate)-equivalent.

Water consumption is calculated by adding the water intake flows of the inventories. It is expressed as kg of water used.

Product Lifecycle Diagram: A circular diagram showing the stages: Production phase (Raw materials extraction, Production, Transport), Product Manufacturing, Use phase (Product use), End of Life (Recycling 95%), and back to Production phase. Arrows indicate the flow of resources and emissions.

¹ per tonne of steel produced
² RC = 64.0% (recycled), RC = 69.0% (rebat). For example: GWP with LC_{steel} = 1.013 kg (section), LC_{steel} = 1.212 kg (sheet)
³ RR = 0% without recycling | RR = 0% with recycling



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Conclusions



Summary

Solutions for **temporary** and **permanent** structures:

- prefabricated product with high **quality control**
- fast execution
- design life of 50 years (and above)
- rehabilitation / dismantlement is possible
- steel sheet piles are a **recycled product** & easy to recycle
- **technical & commercial support** from ArcelorMittal:
 - preliminary designs
 - shop-drawings, special piles, fabrication, coatings
 - driving recommendations (method, equipment)
 - technical assistance at job-site (if required)

For technical questions please write to
cecile.prum@arcelormittal.com

or phone to +352 53 13 29 71

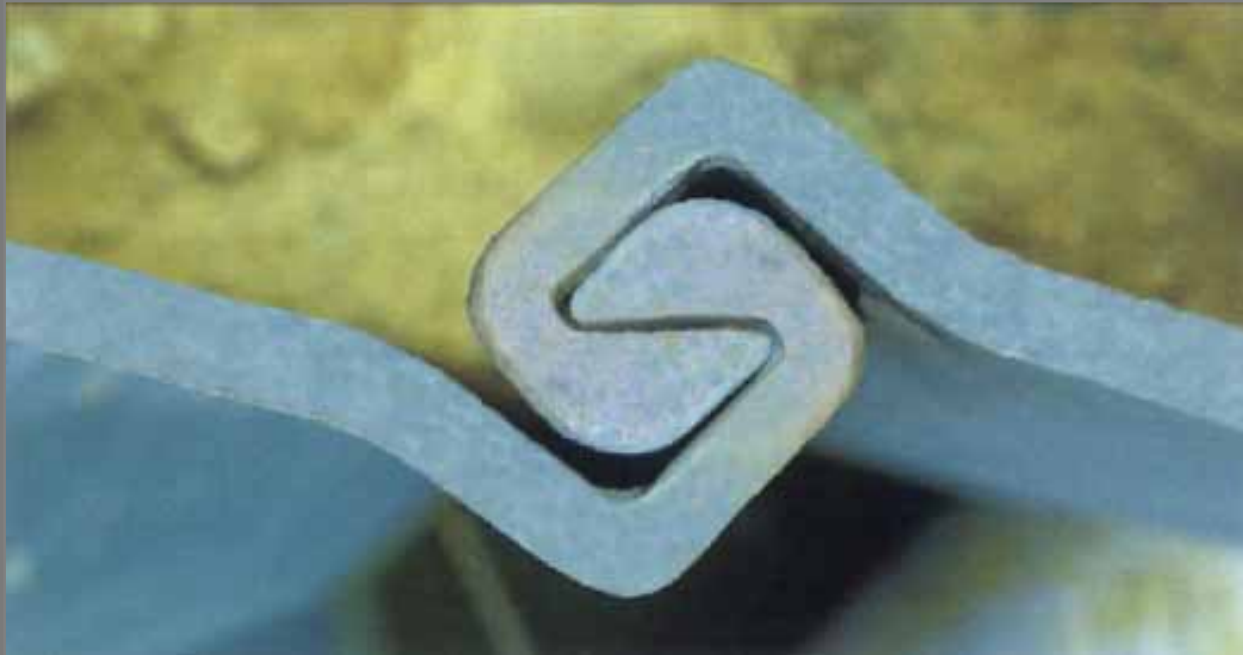
For commercial questions please write to
giancarlo.scianatico@arcelormittal.com

or phone to 347 67 61 447



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Thank you for your attention ...



... and let us stay connected!