Chapter 3
Reuse of Steel Sheet Piles—Best Practice

François Fohl and Oliver Hechler

Abstract Steel sheet piles are used for retaining walls. Due to their modularity, they can be easily installed and extracted after their service life. After their first use, they can be either directly recycled or reused several times and then recycled. The reuse of steel sheet piles allows to avoid new production and thus CO_2-emissions for their production, reducing the environmental impacts per use. In temporary works, like construction pits, the reuse of sheet piles is common practice. Also, for certain permanent projects, there is no disadvantage in using second-hand sheet piles. This paper shows, on the basis of two case studies the best practice for reuse of sheet piles. The environmental impacts for a temporary project in Germany are discussed based on a Life Cycle Assessment for the sheet piling tonnage. Over the life cycle of the steel, 1,535 t of CO_2-eq are emitted. Reuse of the sections saved 79% of greenhouse gases. For a dyke reinforcement in the Netherlands, the project owner partly chose second-hand sheet piles to reduce the environmental impacts of the infrastructure project.

Keywords Steel · Sheet piles · Reuse · Environmental impacts

3.1 Steel Sheet Piles—a Short Introduction

Steel sheet piles are widely used in infrastructure applications. Functioning mainly as a retaining wall, they are found for example in quay walls, cofferdams, bridge abutments, underground car parks or temporary pits. Steel sheet piles are sections that are driven into the ground and are connected over interlocks (or clutches), to form a continuous wall. There is a wide variety of sections, but U- and Z-piles are the most common (see Fig. 3.1). Common widths for one sheet pile (one module) are ranging

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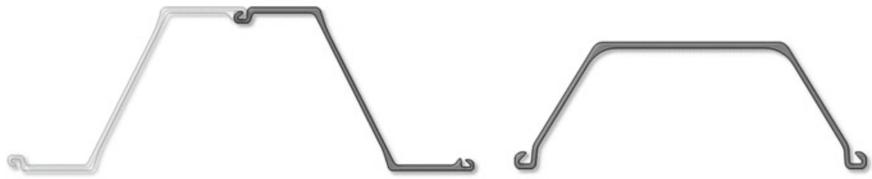

Fig. 3.1 Common types of steel sheet piles—Cross section

from 600 to 800 mm. Steel sheet piles are completely impervious, an infiltration of water through a sheet pile wall is only possible along the interlocks. Due to the tight shape of the interlocks of type ‘Larssen’, a high seepage resistance is already given for ArcelorMittal sheet piles. For applications with high requirements to watertightness, like cut-off walls for contaminated sites, several sealant systems are available. Welding of the interlocks can provide complete watertightness. The durability of steel sheet piles is well documented. Unprotected steel in the atmosphere, water or soil is subject to corrosion. However, based on the life-time requirements for the steel structure, the integrity can be assured by several methods. ‘Sacrifical steel’ to build a structural design reserve is common, but the corrosion process can also be limited by coatings, low-corrosion steel grades, cathodic protection and others. Corrosion rates for steel sheet piles for all relevant environments are well documented in Eurocode 5—Part 5 (EN 1993–5) [1]. Sheet pile structures can be easily dimensioned for 50–100 years lifetime depending on the application. Steel sheet piles are prefabricated products, hence very efficient in installation due to their modular system [2].

3.2 Steel Sheet Piles—a Product in the Sense of Circular Economy

Circular economy is a concept that aims to minimize the use of resources, energy and waste flows. Unlike the linear economy, which follows a take—make—use—throw-away approach, the circular economy is looking to extend the lifecycle of products. The 9 R framework is describing the way from a linear to a circular economy, hence closing material loops, following several key words, such as Reduce, Reuse, Refurbish, Recycle [3]. Especially for construction products, the end-of-life credentials are of high importance as they are consuming important material resources. These resources are lost unless they are maintained in use through reuse or genuine recycling. The Construction Product Regulation (CPR) [4] or initiatives from European Commission such as:

- The European Resource Efficiency Platform [5],
- Towards a circular economy: A zero waste programme for Europe [6],
- Resource efficiency opportunities in the building sector [7],

are an opportunity for steel construction methods in general, due to the inherent properties of steel and the possibility to deliver sustainable structures, with components which are demountable and reusable [8].

Steel sheet piles perform especially well in the following categories, relevant for a transition to circular economy:

- Reduce: Resource efficient design;
- Reuse: Steel sheet piles can be reused multiple times;
- Recycle: Steel can be 100% recycled.

Through optimization of sheet pile solutions, the profiles have become lighter and lighter over the past decades, while still meeting the same requirements. This is mainly due to optimized and efficient profiles and high strength steel grades. Steel sheet piles can be used and reused up to 10 times for temporary applications, thus reducing the environmental impact each time the sheets are reused. ArcelorMittal also offers rental and sale of second-hand sheet piles. In addition, steel is a permanent material. It can be 100% recycled without any loss of quality. Steel sheet piles from ArcelorMittal, that are produced in Luxembourg are out of 100% recycled steel [2]. In this paper, the focus is on the advantages on reusing sheet piles.

3.3 Reuse of Steel Sheet Piles

3.3.1 How-To

Firstly, the reuse of steel sheet piles is possible due to their modularity forming the system. The sections can be extracted after their specific service life. Contrary to temporary applications, sheet piles in permanent applications are generally not reused after their service life, but directly recycled and in consequence, reintroduced into the steel loop. However, for temporary applications, sheet piles have much shorter life cycles; normally less than 2 years. It is common practice for contractors to use sheet piles for temporary excavation pits and reuse them again in following projects. Depending on the soil, the sections can be reused up to 10 times, however a small portion ($\leq$50 cm) of the length of the section is generally cut-away after each use, due to deformations respectively damages at the head. The symmetric U-sections are well suited for reuse, as they offer high stiffness due to their compactness. The extraction of the sheet piles can be realized with vibratory hammers, which are usually also used also for the installation (see Fig. 3.2).

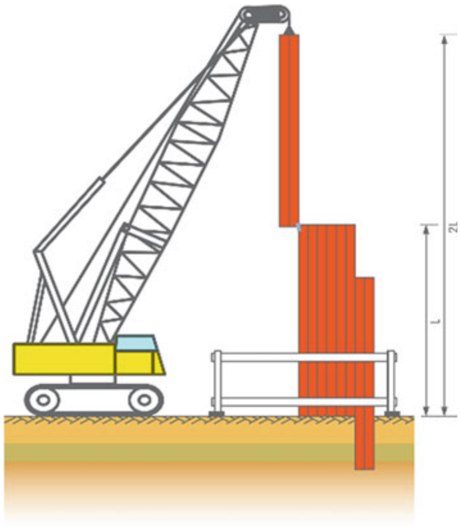

Fig. 3.2 Procedure of sheet piles installation (panel driving) [9]

3.3.2 *Global Warming Potential Over the Life Cycle of Steel Sheet Piles*

Production of steel represents over 7% of global greenhouse gas emissions [10]. One way to reduce these, is the reuse of used steel products such as sections and sheet piles. Their reuse avoids the production of new products, hence the consumption of raw materials, energy and the average emission of 1.89 tonnes of CO_2 per tonne of crude steel [11]. The environmental impacts of building materials can be documented by type III Environmental Product Declarations (EPDs), following EN 15804 [12] and ISO 14025 [13]. An EPD is a document that describes the environmental impacts of a product based on a life cycle assessment with quantitative data. It enables manufacturers to transparently communicate the environmental impacts of their products. EPDs form the basis for the ecological assessment of buildings or other construction projects. ArcelorMittal's EPDs are verified and published by independent experts, such as the *Institut Bauen und Umwelt e.V.* (IBU).

In case new sheet piles are reused several times on the same project and recycled afterwards, then the analysis of the environmental impacts is straightforward. The total quantity of new material purchased for the project can be used. However, in most cases, the sheet piles will return to a storage yard, will be cleaned and/or repaired (damaged portions or piles will be scrapped), and later reused on a different project. Based on feedback from customers from ArcelorMittal, around 25% of the sheets produced are reused several times. Hence for temporary applications, the LCA practitioner can assume that steel sheet piles pertaining to the "rental business" will be used 5 times with some small losses during the total life cycle due to damages during installation. This approach reduces the environmental impact for each use phase to around 1/5 of the overall impact. Note that generally speaking, the lifecycle of a used

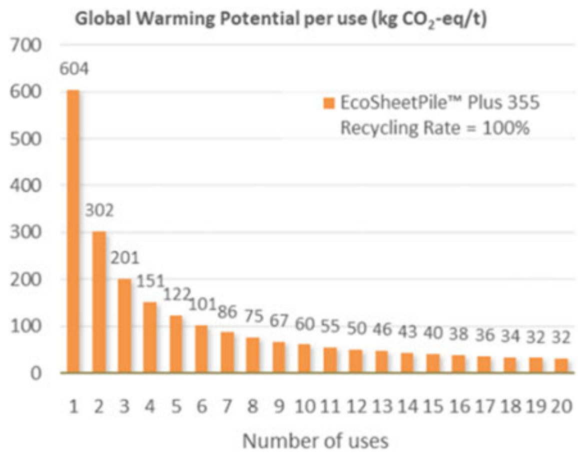

Fig. 3.3 Global Warming Potential over the entire life cycle—Influence of reuse

sheet pile is quite short (rentals can be as short as a few weeks to two or three years) and rarely above five years. Figure 3.3 shows the decreasing environmental impact of sheet piles, when used multiple times. The calculation is based on ArcelorMittal's EcoSheetPile Plus EPD and shows the Global Warming Potential (GWP) for one tonne of sheet piles considering modules A1-A3, C3, C4 and D according to EN 15804. Module A4 (transport gate to site), A5 (installation), C1 (deconstruction) and C2 (transport) are not considered.

Based on the EPD, one single use of one tonne of sheet piles emits as much as 604 kg CO_2-eq over the lifecycle. Reusing the sheet pile once, results in a GWP of 302 kg CO_2-eq for each use, whereas using them 5 times leads to a GWP of 122 kg CO_2-eq per use. When doing life cycle assessments for temporary works, the business practice of cutting of the head of the sheet pile due to damages may also be considered.

According to the EPD EcoSheetPile Plus, the production (modules A1-A3) of one tonne of sheet piles emits 370 kg CO_2-eq. Around 96% of all the relevant greenhouse gas emissions for a sheet pile structure, are emitted during the production stage of the steel. Energy emissions for installation as well as transport shouldn't be neglected but have a rather small influence on the total emissions [14].

3.3.3 End-of-Life Assumptions for Steel Sheet Piles

The calculation shown in Fig. 3.3 considers a final recycling rate of 100%. However, the basic end-of-life assumptions for the EPD EcoSheetPile Plus are the following, representing an average use of ArcelorMittal's sheet piles [15]:

- Reuse: 25%;
- Recycling: 60%;

- Landfill: 15%.

The reuse and recycling rate contribute together to the final recycling rate. The assumptions are based on a preliminary standard elaborated by CEN TC 135 WG 17 [16] and a detailed analysis of ArcelorMittal, considering the:

- Application type of the sheet pile (quay wall, bridge abutment, …);
- Sheet pile type (Heavy or light sections);
- Corrosion depending on the environment;
- Use for permanent or temporary applications;
- Possibility to extract the sheet piles;
- Design life (50 years, 100 years).

Note that the corrosion rate, which depends greatly on the environment and the service life of the sheet pile structure, has a large impact on the landfill rate.

3.4 Case Study: Reuse of Sheet Piles for Temporary Works

Today's *Schwarze Pumpe* Industrial Park is located about 120 km southeast of Berlin on the territory of the German states of Brandenburg and Saxony in Spremberg. The site was founded as the *VEB Gaskombinat Schwarze Pumpe* in 1955 with the task to utilize the nearby mined brown coal for energy supply or to refine it as briquettes for domestic heating. There were gas production plants, coking plants, combined heat and power plants and briquette factories with the necessary ancillary facilities on the site. By 1989, this had created the world's largest brown coal processing plant with 15,200 employees. By 1992, this figure had already been reduced to just 6,600 employees, together with the start of dismantling obsolete plants and the simultaneous construction of new power plants in line with current environmental protection standards. The remediation of the contaminated sites that had accumulated over decades required careful planning and preparation. Starting in 2017, over a period of several years, 430,000 tonnes of contaminated soil will be processed in total. Part of the material, which is mainly contaminated with benzene and phenols, is cleaned using soil treatment processes. The heavily contaminated areas are excavated, thermally treated and reinstalled. In order to reduce the necessary transports, a soil cleaning plant is built on site.

The main argument to use a sheet pile solution for this project, is their modularity and the possibility to reuse them on the jobsite several times. A PU 22^{-1} profile was chosen for this purpose, as it's a robust section suitable for reuse. It has a weight of 136.5 kg/m^2 and an elastic section modulus of 2,060 cm^3 per m of wall (Fig. 3.4).

The lengths of the sheet piles are optimized for the areas of application and range from 14.0 m to 23.0 m. Length reduction due to multiple uses is already included in the length determination. Figure 3.5 shows the plan view of the project.

Inside the surrounding primary pit, secondary pits are constructed. In these, the contaminated soil is excavated, decontaminated, and then placed again. Once the

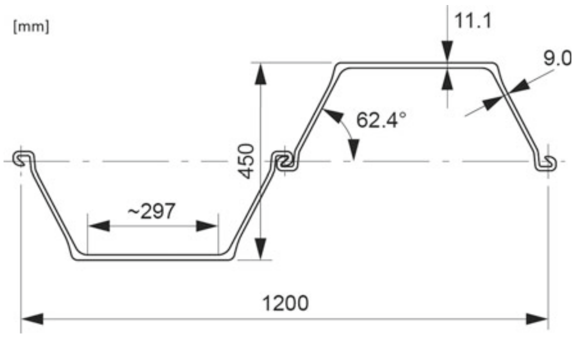

Fig. 3.4 Steel sheet pile PU 22^{-1} [17]

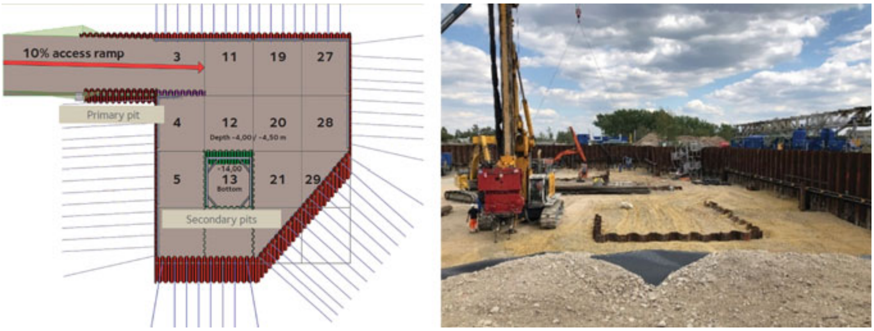

Fig. 3.5 Left: Plan view—Excavation pit; Right: Installation of sheet piles for the secondary excavation pit [18]

process is finished for one of these areas, the sheet piles are extracted. After inspection, washing, and cutting in case of deformations, the sections are used for another secondary pit. One sheet pile is used on average 5 times on the site, before it gets recycled.

The environmental impact of the sheet piles tonnage for this project is assessed with an internal Life Cycle Assessment (LCA) tool. Based on the actually delivered sheet piles, the GWP and other relevant indicators are assessed following EN 15804 and ISO 14025, on the basis of ArcelorMittal's EPD EcoSheetPiles [19]. In the analysis, modules A1-A3, A4, C3 and D are considered. Table 3.1 shows the parameters and assumptions, which are the basis for the Life Cycle Assessment.

Figure 3.6 compares the Global Warming Potential for both scenarios, the first being an approximation of the as-built condition with sheet piles that are used 5 times in total, and the second one representing the case with no reuse of the sections. In this case, the non-reuse of the sections is approximated by multiplying the required tonnage by a factor of 5. Based on the considered modules, the as-built scenario emits 1,535 t of CO_2-eq. This represents a reduction of 79% in greenhouse gases over the life cycle, due to the multiple reuse of sections.

Table 3.1 Parameters for the life cycle assessment

	Reuse of sheet piles as-built	No reuse of sheet piles
Tonnage	2,000 t	10,000 t
Length of sheet piles	18.5 m (avg. length)	
Minimum length before recycling	16.5 m (cut 0.5 m after each use)	*Not applicable*
Number of uses	5×	1×
EPD	EcoSheetPiles	
End-of-Life Assumptions	Reuse: 78.9%, Recycling: 20.9%, Landfill: 0.2% Final recycling rate: 99%	Reuse: 0%, Recycling: 99%, Landfill: 1% Final recycling rate: 99%
Transport by truck	Belval (LU)—Spremberg (DE)—793 km	

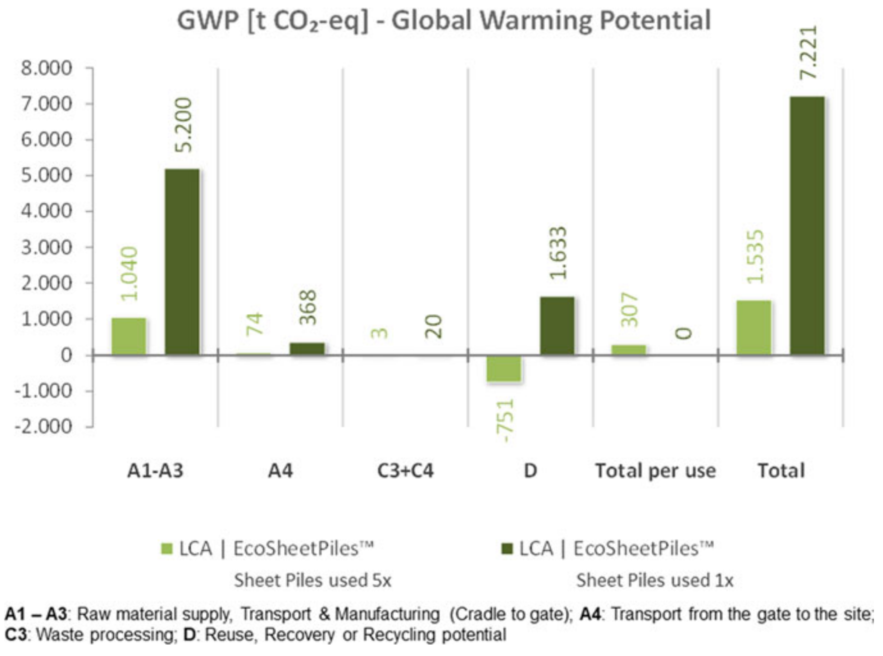

Fig. 3.6 GWP based on EPD EcoSheetPiles—Influence of reuse

3.5 Case Study: Reuse of Sheet Piles for Permanent Application

For the reinforcement of the Gorinchem-Waardenburg (GoWa) dyke in the Netherlands, steel sheet piles are used on a large scale. Many efforts are being made to reduce the environmental impact of the project by the project alliance *Graaf Reinald Alliantie*, including the use of used sheet piles, made from recycled steel.

Water regulation in the Netherlands has always been important to the survival of the country: about two-thirds of the Netherlands is vulnerable to flooding and marine submersion, while one-third of the country's surface is below sea level. The first major hydrological works to gain territory over the water date back to the thirteenth century, and today a network of more than 17,500 km of dykes protect the 6,000 km of canals that run through the country. In particular, 3,750 km of dykes form the primary flood defence, protecting the Netherlands against flooding from the North Sea, the Wadden Sea and the major rivers. Following the dramatic floods of 1953, the major 'Delta' plan was launched to improve the safety of the reclaimed land. It is estimated that the risk of flooding has been reduced to less than once every 4,000 years in Zeeland and even once every 10,000 years in the Rotterdam area. Dyke strengthening and raising work continues across the country, especially on the 1,850 km of dykes that do not yet meet the safety standards required by 2050.

For the reinforcement of the GoWa dyke, steel sheet piles are used on more than 6 km of the dyke, 23 km in total length. They are installed with the aim to protect the dyke against the risk of failure due to general stability and/or piping. In this case, sheet piling is an ideal solution to support and reinforce the dyke against these two types of failure, especially where the surrounding space is limited and does not allow the extension of the dyke footprint. In this case, the construction of a sheet pile wall can provide both reinforcement tasks (see Fig. 3.7).

For the Gorinchem-Waardenburg project, the project owner deliberately chose to install used sheet piles at locations where there is a risk of hydraulic failure by piping. In order to protect the dyke against piping, the length of the seepage path

Fig. 3.7 Dyke reinforcement with sheet piles in Wolferen-Sprok [20]

must be extended so that the phenomenon can no longer occur. A sheet pile wall can perfectly fulfil this function. In fact, in this application, a used sheet pile section can perform this function just as well as a new sheet pile. The main difference is that the total greenhouse gas emissions of the steel sheet pile production phase do not have to be included in the environmental balance of the project, as they have already been partially included in the previous temporary applications. The scope of the project, and the recent inclusion of environmental criteria in the Dutch tendering process, means that the environmental impact of the selected solutions must be reduced as much as possible. The project owner and ArcelorMittal worked together to reduce the carbon footprint of the project by applying the three important principles of the circular economy: Reduce, Reuse, Recycle. If technically possible, reuse of steel products should always be considered, even for permanent applications.

3.6 Conclusion

Steel sheet piles, especially produced from recycled steel, offer the potential to reduce the carbon footprint of a project. Due to the modularity, steel sheet piles can further be reused and may contribute significantly to a circular economy concept in foundation solutions. The projects ‘Schwarze Pumpe’ and ‘GoWa’ show perfect examples how the concept may be applied. Considering ‘Schwarze Pumpe’, the sheet piling tonnage emits in total 1,535 t of CO_2-eq, based on the assumption that the sheet piles are used 5 times on average and taking into account a shortening of the sections after each use, due to damages and deformations. The choice of the right sheet pile section is important in terms of reduction of the environmental impacts over the entire life cycle. If the sections are reused several times before recycling, robust sections should be chosen, like the PU’s with reinforced shoulders from ArcelorMittal. These sections have higher environmental impacts than AZ sections with similar mechanical properties in the production stage, however due to their stiffness they can be reused more often, hence the impact over the entire life cycle is reduced. For permanent applications, efficient AZ sections are often the right choice. Due to their efficient shape, lighter sections can assure the same mechanical properties. Furthermore, the current method from the Worldsteel Association, which allows the repartition of the environmental impacts on the number of usages (see Fig. 3.3) can be discussed. Another approach would be, that the environmental impacts are taken into account for the first use, and for consecutive usages, there is no significant impact.

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