STEEL SHEET PILES IN FLOOD PROTECTION STRUCTURES CASE HISTORIES AND RECENT PROJECTS IN POLAND

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Abstract. The flood of the century in Poland along the Vistula and Odra river in 1997, and the following flood in 2001 clearly showed that the state of flood protection systems required urgent modernization to fit present needs. An extensive analysis of the situation pointed out the weakest links. Steel sheet piling is a technology that can be utilized to achieve the objectives of modernization and improvements of dykes and flood walls. The paper focuses on modernization and reconstruction of the Wroclaw Floodway System, currently the largest European flood protection project under construction. Further recent flood protection references utilizing steel sheet piles in reinforcing dikes are Lipki-Oława, Sartowice, modernization of Radunia Channel and Płonie Channel.

Keywords: dyke reinforcement, steel sheet piles, flood protection, watertightness

1. Introduction

Steel sheet piles have been utilised for more than 100 years, proving that it is a reliable and cost-effective solution. Typical application fields are harbour construction and temporary cofferdams.

However, steel sheet piles have also been widely used in river control structures and flood defense.

Steel sheet piling has traditionally been used for the reinforcing and protection of river banks, lock and sluice construction, and flood protection. Ease of use, speed of execution, long service life and the ability to be driven in the water make sheet piles the obvious choice for permanent and temporary structures. The design of the shape of the profiles provides the maximum strength and durability at the lowest possible weight, and takes into account driveability. Depending on type of structure, applicable surcharge loads, soil and water conditions, standard hot rolled Z-type or U-type sections, as well as combined walls executed with box piles or the HZ/AZ system can be installed.

2. Dyke structures and flood protection systems

Sheet pile walls can be used in a variety of ways for flood-defence systems or for bank protection. For new embankments they can ensure watertightness, support, and stabilization. They are also used to strengthen existing embankments. When space is an issue, e.g. in ports or built-up areas, sheet pile walls can form freestanding floodwalls.

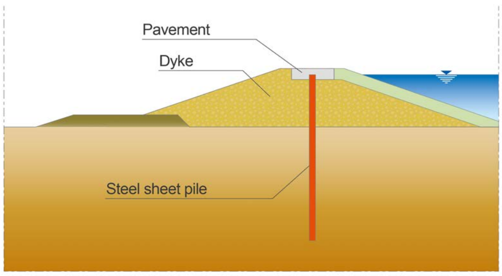

Fig 1 Stabilization of an existing dyke with steel sheet piles

In flood embankments, sheet pile walls can serve as a cutoff. The requisite watertightness of sheet pile cutoffs is often obtained through natural deposition of soil in the interlocks. If necessary, seepage through a sheet pile cutoff can be reduced by introducing highly effective sealing systems into the interlocks. A sheet pile cutoff not only reduces leakage, but also improves the overall stability of an embankment: sheet piles intersecting slip circles stabilize both the inner shoulder and the crest; the outer shoulder is stabilized by the lowering of the seepage line. With a sheet pile wall, seepage can be controlled: making the interlocks watertight reduces leakage, while natural flow can be recreated by making weep holes (see EAU 2012, E.51). In the latter case the embankment is protected from drying out. A sheet pile wall cannot be burrowed through by animals or penetrated by tree roots. This eliminates the risk of backward erosion outside the wall due to preferential flow pathways (piping).

An embankment with sheet piles can be made watertight, but it can also be modified to hold back a larger design flood without requiring greater landtake.

This is a simple matter of designing the sheet pile wall to project the requisite height above the crest. This saves on the embankment footprint that would be necessary for a conventional embankment of the same height. Because of their bending strength, cantilevered sheet pile walls have no difficulty transferring high-water pressures into the body of the embankment below. And just as when they stop at the crest, cantilevered sheet pile walls also stabilize the inner shoulder, together with the crest, and lower the seepage line in the outer shoulder.

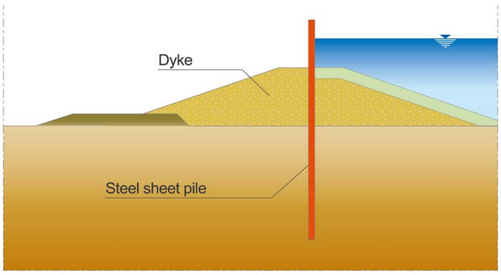

Fig 2 Extension of the flood protection system height

In addition to purely static stabilization, a sheet pile wall can also - indirectly - produce beneficial effects on the overall stability of an embankment:

- lowering the seepage line enhances the stability of the outer shoulder which can consequently be steeper or optimized in other ways,
- lengthening the seepage line enhances safety with respect to the risk of hydraulic failure,
- in the event of a leak through the impervious layer, a central sheet pile wall prevents the migration of fines, thereby preventing backward erosion in the landward shoulder. In addition, the wall significantly reduces the risk of piping caused by burrowing animals.

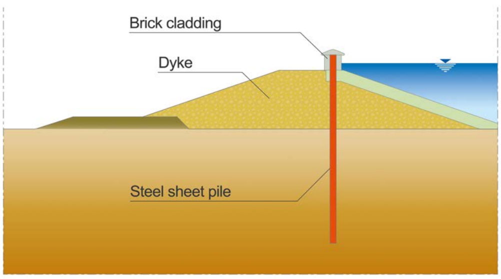

Fig 3 Extension of the flood protection system height with a brick wall cladding

3. Wroclaw Flood Protection System

The Wroclaw Floodway System in Poland is one of the largest European flood protection projects currently under work. Steel sheet piles manufactured in Luxembourg and Poland are playing a crucial role in the rehabilitation of the flood protection.

Wroclaw is quite an exceptional European city in many aspects. The fourth largest city in Poland has grown along River Odra which has its source in the mountains of Czech Republic. The challenge for a town planner is to cope with 12 islands and its 117 bridges. The residents of the city have a long history of fighting against floods caused by river. The construction of flood embankments dates back to the middle of the 19th century, which were upgraded with each major flood.

The existing Wroclaw Floodway System was built around 1923. It provided a high level of protection for decades until the night of the 11th of July 1997. The largest flood wave ever recorded flooded the whole city except the historic Old Town which was saved through thousands of volunteers that erected temporary barriers with sand bags. This flood left huge damages which were estimated to several billions US$.

A consortium of highly experienced international design engineering firms has been awarded a contract to rehabilitate the existing system of river channels and flood defences, taking into account the devastating flood as well as constraints from navigation. The river Odra is still an important navigation route. To be noted that around 4 millions of cubic meters of material will be moved during this project. Additionally, one critical issue are the bridge foundations and its structure that have to be protected during the whole project.

The civil works started in 2012 and will last until 2015. Four Polish main contractors working on this project have used more than 14,000 tonnes of steel sheet piles. The project is funded by the Polish Government, the World Bank and the European Union Cohesion Fund.

Fig 4 Wroclaw, Weir Nr. 1

The reconstruction of Weir Wroclaw no.1 is one of the major projects of the retrofit of the flood protection system in Wroclaw. The weir is located in the middle of the town, on the Odra River. It was built between 1921 and 1924, and later rehabilitated from stone & piling to a concrete structure for the purpose of increasing the level of the dam by 0.96 m. It has 3 spans: left with 6.5 m and 3 valves, middle with 22.4 m constant - without valves, right with 11.0 m and 4 valves.

The River Odra has a catchment area of over 20,000 km^2 at Wroclaw and has been an important route of transportation for a long time. Although frequency of shipping has decreased recently, the river remains heavily regulated for navigation purposes with five gated weirs, ship locks, and two navigation canals along the flood channel.

Steel sheet piling was selected for the execution of all the works below ground water level and in the river. The investment consists in reconstructing part of the weir: the demolition of the existing weir's middle span and construction of a new flap weir with spans of 2 x 20 m directly below the existing one. To enable a safe working environment during the construction period, a cofferdam built with steel sheet piles was installed downstream, around the existing bottom concrete reinforcement, and connected to the wall surrounding the right abutment. The sheet pile wall parallel to the axis of the weir is also used as a permanent formwork for the concrete structure. After completion of the works the downstream sheet pile wall will be cut off at river bed elevation, at the basin entrance point, and will serve as an anti-erosion protection. Model analysis showed the need of improving the conditions of hydraulic inflow into the weir, which will be achieved with the reconstruction of the retaining structures.

The scope of the projects encompasses also the construction of two fish passes to maintain morphological continuity of the river. A sheet piling cofferdam for this structure has been connected to the weir cofferdam. Its route is parallel to left hand waterfront edge. The sheet pile wall was anchored with drilled anchors every 1.0 m. After completion the sheets will be cut off at the top of fish pass walls.

The GU 16N sections, in S 390 GP, between 10 and 15 m long, were driven down into an impervious layer (clay or silt) in order to minimize the flow of water into the pits. The sheet piles were driven with a vibratory hammer mounted on a crane.

As a result of these civil engineering works the hydraulic capacity of the Odra River at this location will increase by almost 80 %. Works on job site started in 2012 and will be finished by the end of 2014.

4. Radunia Channel, Gdansk

The Radunia is a 100 km long small river in Kashubia (north Poland), and runs from Lake Stezyckim into the Motława river near Gdańsk. One part of its water is conveyed into the city via the 13.5 km long Radunia Channel. This medieval outstanding work of engineering was built between 1338-1356 by Teutonic Knights by creating a lock and a new artificial channel along the river. The channel starts in Pruszcz Gdański, flows through a few urbanized districts of Gdańsk, and into the Motława river in the city centre, in "Old Town". It was erected for defense and agricultural needs of Gdańsk, as well as a supply of drinking water to residents of the city. This quite unique structure was destroyed during World War II.

The city of Gdańsk is situated in a bay and is surrounded by a moreinic plateau. The slope of the plateau is characterized by high hydraulic gradients (reaching above 10 %) and lack of natural retention capabilities. Hence a large non-regular water runoff, which fills quickly the whole channel in heavy rain periods. Due to the increasing density of the urbanized areas, natural retention on the mountain side decreased constantly. As a result, the rain water runs more quickly into channel, and increases the danger of flooding the areas on the right bank of the channel. A very significant incident took place on the 9th of July 2001, when as a consequence of heavy rainfall that hit the Gdansk (90 l/m^2 of rain in 2 hours versus an average of 75 l/m^2 for whole month of July), the embankments of the Radunia Channel broke in several locations and caused a devastating flooding, resulting in large damages in several neighbourhoods of the city.

Fig 5 Radunia Channel

The main cause of the disaster was the poor state of the embankments. The analysis of its condition after the flood confirmed that the earth structure was highly perforated, and enabled large water seepage through the structure. The solution was to repair the water leakages inside the embankments, and its devastating effect on its stability. The authorities decided to take steps to reconstruct, improve and seal the core of the embankments on a total length of 7.5 km within the limits of the city of Gdańsk and over 2 km within neighbouring Pruszcz Gdańsk. The main objectives were to widen the channel, to reinforce the banks, to repair bridge abutments, and to raise and widen the top of the embankment. The expected result is a higher flow rate capacity in case of heavy rain in order to prevent flooding.

Both banks of the channel are identical, except for some minor differences in geometry. The most suitable and reliable solution for such a rehabilitation was to build the core of the structure with a sheet pile wall. Besides its retaining function, the main advantages highlighted by the design engineer were the speed of execution and the resistance of the wall to erosion by water, roots and even rodents. The choice of the section depends on the retaining height, AZ 17 in grade S 390 GP and GU 8S in grade S 355 GP, in lengths ranging from 7.0 to 13.0 m were selected. The GU 8S profile was specifically developed in close cooperation with the design engineer and the general contractor for this project, and was an excellent compromise between durability (flange thicknesses of 8.0 mm), mass per square meter, and driving efficiency (some obstacles, like pieces of old structure were expected in the ground).

Table 1 Section properties of steel sheet piles installed

Section	Width single pile	Thickness flange	Thickness web	Section modulus
	mm	mm	mm	cm^3/m
AZ 17	630	8.5	8.5	1 665
GU 8S	600	8.0	7.5	820

The sheet piles were driven in glacial sandy and loamy soils using vibratory hammers mounted on a fixed leader.

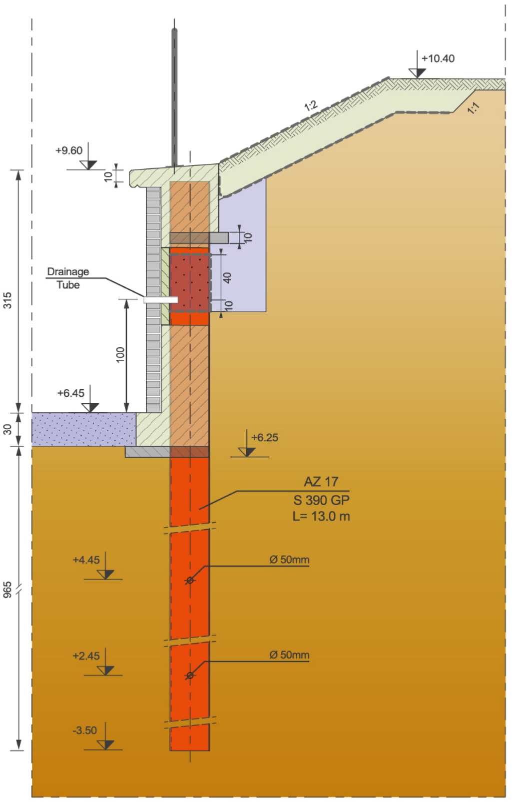

Fig 6 Typical cross-section of a rehabilitated berm of the Radunia Channel (Gdansk)

Another big challenge was logistics: there was no free space for storing the piles along the site (urbanized areas), so that the material had to be delivered just-in-time according to a detailed planning schedule; on average, two full trucks a day.

To restore the historical architectural aspect of the channel, the front face of the sheet pile wall is covered with stones or bricks fixed on a concrete sandwich layer (see typical sketch).

The delivery of 12,500 tonnes of sheet piles programmed for the first phase of 7.5 km started in September 2011 and finished in December 2012. Deliveries for the second phase of 2 km were completed in November and December 2013.

5. Recent flood protection projects in Poland

In the Sartowice - Nowe Valley, around 10.6 km of embankments were modernized along the Vistula River. The reinforcement and sealing of the dyke consisted in installing 4 m to 14 m long sheet piles.

Fig 7 Sartowice - Nowe

Lipki – Olawa: more than 1,400 hectares of urban and agricultural areas around the town of Olawa were protected by rehabilitating 4 km of existing embankments along the Odra River. Almost 12,000 m^2 of 4 m long GU 16-400 sections were installed over 3 km of the structure. The elevation of the crown of the dyke was increased in order to cope with higher flood levels.

The existing Kotowice – Siedlce dyke is located on the left bank of the Odra River, up to 1 km distance from the river. This modernization in 2012 – 2013 consisted in installing almost 1,300 tonnes of 4 m long GU 14N sheet piles over a total length of 3 km.

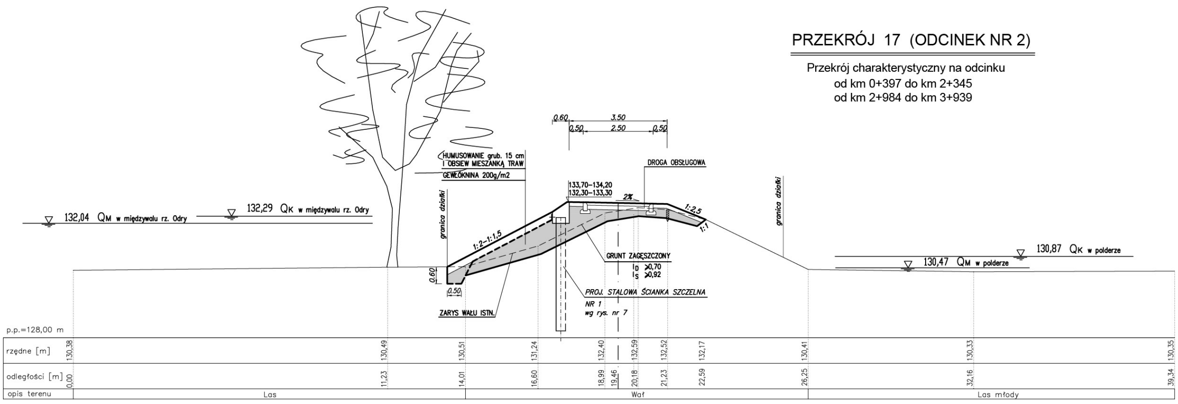

Fig 8 Lipki – Olawa. Typcial cross-section

Fig 9 Świnna Poreba

Located on the east bank of Odra River, Gryfino has been protected against flood by upgrading existing embankments, erecting new ones and building the flood protection walls. Their core consists of sheet pile wall, driven with excavator-mounted vibratory hammer, with a capping beam and concrete walls on the top.

Fig 10 Gryfino

The reconstruction of the City Channel of Odra River in Wrocław is part of greater project mentioned before. Sheet piles were installed to protect the right bank and embankment separating the City Channel and the Old Odra. Sheets were driven from water with a vibratory hammer.

Fig 11 Wrocław – City Channel

Fig 12 Opatowice

In Klokowa, the erosion of the embankment along a rail track disrupted the rail traffic. A fast track solution consisted in driving steel sheet piles along the track with a vibratory hammer to stabilize the slope, then backfilling behind the new sheet piling retaining wall before repairing the tracks.

Fig 13 Klokowa

6. Conclusions

1. Recent history has demonstrated that floods are unpredictable and can lead to devastating consequences even for populations living in areas that are theoretically protected from floods. Failures of dykes and similar protection systems are mainly due to a lack of maintenance or internal erosion of the older structures, or sometimes the consequence of unexpected higher flood actions due to changes in the neighbouring landscape (urbanization).
2. An impressive number of kilometers of dykes and embankments have been upgraded or repaired in Poland during the last years. Most of these projects rely on the use of steel sheet pile.
3. Steel sheet piles are a cost-effective and technically proven solution for the construction of new flood protection systems and the rehabilitation of existing systems, including dykes and river embankments.
4. The large production range of steel sheet piles allows matching the most suitable solution to the specific requirements of each and every flood protection project.
5. The choice of a sheet pile should take into consideration theoretical design aspects, but also driveability, durability, watertightness, impact on the environment, as well as and aesthetical aspects of the landscape.

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