The choice of a metal sheet piling for the construction of the foundation pit

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Abstract. Sheet piles are often used for fencing deep excavations. This is due, among other things, to the fact that when they are pressed, there is no negative impact on the surrounding buildings. In the course of the study, a technical and economic comparison of the domestic sheet pile L4 and its foreign analogue VL603K was carried out. The relevance of the study is confirmed by the fact that during the construction of underground parts of buildings and structures, great attention is paid to engineering measures to prevent the ingress of groundwater into the pits, as well as to strengthen the walls of the excavations from the possibility of collapse in unstable and water-bearing soils. It is also taken into account that the choice of the foundation pit construction depends on its depth, the level of groundwater and the structural scheme of the underground part of the structure, it is also necessary to carry out a static calculation to determine the thickness of the fence and its immersion depth. The analysis of sheet piles also revealed their disadvantages and advantages.

1. Introduction

At a great depth of the excavation, one of the most commonly used methods for fencing excavations is a metal sheet wall. (Kir'janov, Korachevskaja [1]). A widespread type of metal sheet pile is the "Larsen" type sheet pile. The length of the Larsen sheet pile varies from 5 to 22 meters. The immersion of the sheet piling by the indentation method does not have a negative impact on the surrounding buildings. In various conditions it is possible to use the Russian Larsen sheet pile and its foreign analogues. Such piles perceive the lateral pressure of groundwater and soil, at the same time being an anti-filtration curtain, which is well shown in the work of Melnikov [2]

Currently, the sheet pile is made of steel of ordinary quality St3sp, St3kp or alloy steel, due to which the elements function well under friction conditions, and also the strength of the elements subjected to shock loads increases. Alloy steel has anti-corrosion properties, heat resistance and resistance to various deterioration factors. The Larsen sheet pile has a trough or z-shaped profile.

During the process of deepening, sheet piles are connected to each other in a checkerboard pattern, with each subsequent sheet pile being rotated 180 ° relative to the previous one. The connection of the individual sheet piles takes place with the help of Larsen locks, which allow a certain rotation. The sheet piles joints are small, so the foundation pit construction is almost watertight. If it is necessary to install sheet pile fences in difficult hydrogeological conditions, it is possible to use sealants to enhance the water tightness of the sheet pile wall. A special sealant fills the space of the lock joint, expanding
in volume upon contact with water and providing protection against its penetration. If it is necessary to reuse sheet piles, this mixture can be removed from the joint (Mitin [3]).

2. Methodology
The limited choice among Russian-made sheet pile models makes us pay attention to their European analogue (see table 1). There is a European analogue of the Larsen sheet pile of the VL grade, which, in comparison with the Russian-made sheet pile of the L4, L5, L5-UM grades, has a lower mass and greater strength characteristics with a smaller wall thickness (Nosenko [4]). Including its advantage is a wide variety of standard sizes (see table 1).

Table 1. Sheet piling brands used in the construction.

| Brand     | Producing country                                      | Market distribution |
|-----------|--------------------------------------------------------|---------------------|
| L4        | Russia - Russian Mining and Metallurgical Company,      | low                 |
|           | Ukraine - Dnepropetrovsk Iron and Steel Combine         |                     |
| L 5       | Russia - Russian Mining and Metallurgical Company,      | low                 |
|           | Ukraine - Dnepropetrovsk Iron and Steel Combine         |                     |
| L 5-UM    | Russia - Nizhniy Tagil Metallurgical Combine (EVRAZ).   | high enough         |
| VL-606    | Czech Republic - EVRAZ                                 | average             |
| VL-605    | Czech Republic - EVRAZ                                 | average             |
| Omega type| -                                                      | average             |
| AS, AU, AZ, PU | Belgium - «ARCELOR»                                  | -                   |
| GU        | Poland - «ARCELOR»;                                   | -                   |
| LARSENUNION, | Germany - «Thyssen Krupp»                          | -                   |
| HOESCH    |                                                        |                     |

The low weight of the European sheet pile nicely affects the costs in the process of its immersion, and the number of reuse cycles reaches 20 times, while for the Russian sheet pile - up to 5 times (Nosenko [5]).

During the research, a technical and economic comparison was made between the Russian-made sheet pile L4 produced by the Nizhniy Tagil Metallurgical Combine at a cost of 699 euro/t, and its foreign analogue VL603K by EVRAZ VITKOVICE STEEL (Czech Republic) at a cost of 880 euro/t (Hussieny [6]).

When carrying out analytical calculations, two main schemes are distinguished: a free wall (J.K. Jacobi), an abutting wall (Bloom-Lomeyer scheme).

There is a calculation of the free sheet pile wall is made.

The main characteristics of the engineering-geological elements of the construction site, obtained from the data of engineering-geological conditions, are given in table 2. The scheme of the foundation pit and the soil column are shown in figure 1.

A foundation pit with a depth of 4 m in which the height of the ground water above the level of the bottom of the pit is 3 m. Above the bottom of the pit, there is fine sand and clay loam.

The setting of the depth of immersion of the sheet pile is performed by comparing the following values: the standard depth and the depth that ensures the stability of the pit wall (Kopotilova [7]).

The calculation includes the following steps:
1. Calculation of the coefficients of active and passive soil pressures.
2. Determination of the soil pressure on the sheet pile wall.
3. Calculation of the passive (holding) pressure is determined.
### Table 2. Engineering-geological conditions.

| Soil Layer | Thickness, m | Density of soil particles, g / m³ | Soil moisture, % | Specific weight of soil, kN/m³ | Specific adhesion, kPa | Internal friction angle, degrees | Deformation modulus, MPa |
|------------|--------------|----------------------------------|-------------------|-------------------------------|------------------------|-------------------------------|-------------------------|
| Fine sand  | 4            | 2.65                             | 0.2               | 18.5                          | -                      | 32                           | 22                      |
| Clay loam  | 6            | 2.68                             | 0.219             | 0.56                          | 41.8                   | 0.72                         | 0.82                    |

**Figure 1.** The foundation pit scheme and soil column.

Then it is necessary to plot the pressure diagrams on the sheet pile wall. The calculation is based on the assumptions that at the moment of loss of stability, the wall will rotate around the attachment point under the action of the forces of active soil pressure.

### 3. Results and discussion.

The calculation results are presented in Table 3.

The minimum depth of the sheet pile (counting from the bottom of the pit) is determined from the equation:

\[
M_a = m_o M_n
\]

where \(M_a\) is the moment of all active (overturning) forces; \(M_n\) is moment of passive (holding) forces; \(m_o\) is the coefficient of working conditions, \(m_o = 0.8\). At the same time, at the bottom of the excavation there is a soil uplift and a massive pressure reaction.

The depth of the sheet piling was the depth of the sheet piling was \(h = 4.93\) m, the total immersion depth of the sheet pile was the depth of the sheet piling was \(h' = 1.2 \times 4.93 = 5.91\) m. The position of the dangerous section in the sheet pile wall is at a depth \(z = 2.33\) m.

Determination of the moment of resistance of 1 m of sheet pile wall for a sheet pile of Russian-made production is made according to the formula:

\[
W_x [cm^3/m] = \frac{M_{max} \times 10^6}{R_y \times 1000}
\]

The moment of resistance \(M_{max}\) are taken in kN, \(R_y\) is steel resistance in N/mm².
Table 3. The calculation results.

| Pressure Component | Calculation formula | Pressure value, kPa |
|--------------------|---------------------|---------------------|
| Active pressure    |                     |                     |
| At ground level    | \( p_1 = g \cdot \lambda_{a1} \) | 3.3 |
| At the level of the groundwater surface, taking into account the characteristics of the soil of layer I in a dry state | \( p_2 = [g + \gamma_{11}(H_k - h_w)]\lambda_{a1} \) | 8.83 |
| At the level of the groundwater surface, taking into account the characteristics of the soil of layer I in a water-saturated state | \( p_3 = [g + \gamma_{11}(H_k - h_w)]\lambda_{b1} \) | 9.41 |
| At the level of the bottom of the foundation pit, taking into account the characteristics of the soil of layer I | \( p_4 = [g + \gamma_{11}(H_k - h_w) + \gamma_{11}h_w]\lambda_{a2} \) | 19.20 |
| At the level of the bottom of the foundation pit, taking into account the characteristics of the soil of layer II | \( p_{5r} = [g + \gamma_{11}(H_k - h_w) + \gamma_{11}h_w]\lambda_{a2} \) | 11.65 |
| At a depth \( h \) below the bottom of the foundation pit | \( p_6 = p_{5r} + (\gamma_{12} \cdot h \cdot \lambda_{a2}) \) | 11.65+11.4* \( h \) |

Passive pressure

| At the bottom of the foundation pit | \( p_7 = C_{12} \cdot (\lambda_{n2} - 1) / \tan \varphi_{12} \) | 39.76 |
| At a depth \( h \) below the bottom of the foundation pit | \( p_8 = p_7 + \gamma_{12} \cdot h \cdot \lambda_{n2} \) | 39.76+35.2\( h \) |
| Determination of water pressure on a sheet pile wall at a depth \( h_{II} \) | \( p_{w1} = \gamma_w \cdot h_w \) | 29.43 |
| | \( p_{w2} = p_{w1} + \gamma_w \cdot h_{II} \) | 29.43+4.91\( h \) |

The explanations of the formulas are presented in table 4.

Table 4. Designation.

| Designation | Decoding |
|-------------|----------|
| \( \gamma_{11}, \gamma_{12} \) | Soil weight |
| \( H_k \) | Pit depth |
| \( h_w \) | The difference in water levels inside and outside the fence |
| \( \lambda_{a1}, \lambda_{b1}, \lambda_{a2} \) | Active pressure coefficient |
| \( \gamma_{11} \) | Wet weight |
| \( \lambda_{n2} \) | Passive pressure coefficient |
| \( C_{12} \) | Specific soil adhesion |
| \( \gamma_w \) | Specific gravity of water |
| \( h \) | Depth below the bottom of the pit |

Determination of the moment of resistance of 1 m of sheet pile wall for the foreign product is based on the following formula:

\[
W_x [cm^3/m] = \frac{M \cdot 10^6}{d_t \cdot n_3 \cdot 10^3} \tag{3}
\]

where \( d_t \) is conditional yield stress of steel, \( n_3 \) is safety coefficient, 0.95.
The maximum moment $M_{\text{max}} = 248.25$ kN was taken. For different options of sheet piles, the calculation results are summarized in table 5. For sheet pile L4 the value for $R_y$ is 235 N / mm$^2$, for sheet pile Vl-603K value for $R_y$ is 340 N / mm$^2$.

Table 5. Compared types of Larsen sheet piles.

| Brand   | Distance between the centers of the locks (B), mm | Profile height (H), mm | Wall thickness (S), mm | Elastic moment of resistance, cm$^3$/m | Weight of 1 m$^2$ of the fence, kg | Cost of 1 m$^2$ of fencing, euro |
|---------|--------------------------------------------------|------------------------|------------------------|---------------------------------------|----------------------------------|-------------------------------|
| L4      | 400                                              | 359                    | 9.5                    | 2200                                  | 185                              | 130                           |
| Vl-603K | 600                                              | 320                    | 9                      | 1138                                  | 102.5                            | 90                            |

The sheet pile section schemes is shown in figure 2 and figure 3.

Figure 2. Sectional scheme of sheet pile L4.

Figure 3. Sectional scheme of sheet pile Vl-603K.

As a result of the calculation the best option would be a sheet pile of grade L4, steel grade C255 with a moment of resistance $W_x = 2200$ cm$^3$/m (according to the calculation 1369.15 cm$^3$/m) which costs 699 euro/t.

As a result of the calculation of a foreign-made metal sheet pile, the most optimal sheet pile would be a VL603K sheet pile with a moment of resistance $W_x = 1138$ cm$^3$/m (according to the calculation 996.13 cm$^3$/m) which costs 880 euro/t (Tanga et al [8], [9]).

In percentage terms, the cost of the domestic sheet pile is 40% higher, and the weight is 80% higher. Thus, for the considered version of the foundation pit construction, the foreign sheet pile VL603K manufactured by EVRAZ VITKOVICE STEEL (Czech Republic) is more profitable from an
economic point of view than the Russian-made sheet pile L4 manufactured by Nizhniy Tagil Metallurgical Plant.

4. Conclusion
The choice of foundation pit construction system depends on its depth, the level of groundwater and the structural scheme of the underground part of the structure; it is also necessary to perform static calculation to determine the thickness of the foundation pit construction and its depth.

On the performed analytical calculations, sheet pile L4 produced by the Russian Mining and Metallurgical Company and its foreign analogue VI-603K produced by EVRAZ VITKOVICE STEEL (Czech Republic) turned out to be the most suitable in terms of their technical characteristics.

Comparison of the Larsen sheet piling of Russian-made and foreign production reveals the advantage of the last. As a result of the analysis, we see that the width of the sheet pile of European brands is 200 mm larger than that of the standard L4, the width of which is 405 mm, as a result of which the width of the wall is obtained more in the same time. It is also possible to adjust the length of the sheet pile, not being limited to the generally offered 6 or 12 meters. The European sheet pile Larsen produced by EVRAZ is manufactured in lengths from 1 to 24 m, as agreed, a shorter length, according to the project requirements. This allows avoiding welding, joining of elements and, as a consequence of strength, turnover and the likelihood of emergencies (Mahadi [10]).

A wide variety of standard sizes, steel grades of European sheet piling in an economically gives great variability in decision-making when designing a foundation pit construction and reduces its cost. The advantages of the alternative are also large widths and less weight due to the thickness of the walls. Also, the weight of 1m² of the VL603K fence is much less, which also affects its cost.

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