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Comparison of calculation methods for sheet piling

Wiesława Kosmala-Kot[1], Jacek Selejdak[2]

ABSTRACT:
Basic methods for calculating sheet piling were presented in the paper. The Blum's graphical and analytical-graphical methods were characterized for a sheet pile that is single anchored at the top and freely supported at the bottom. Methods for determining the sheet pile length, sinkage into the soil and the selection of the sheet pile profile were shown. The method for determining the reaction value on the sheet pile support was also presented. The calculated design parameters for both methods were compared in a table. On the basis of the above calculations, it was determined that the two calculation methods lead to similar cross-sections of sheet piling.

KEYWORDS:
sheet pile; calculation method; sheet piling profile

1. Introduction

Sheet pile walls are structures consisting of longitudinal elements recessed in the ground. They can be made of materials such as steel [1, 2], reinforced concrete, wood or plastics and are used in various areas of construction. The individual wall components, called sheet piles, are plunged into the ground one next to the other by means of vibration hammers, hydraulic presses, impact hammers and pile drivers. Sheet pile walls work as vertical slabs, loaded mainly with horizontal forces such as earth and water pressure, and sometimes also with vertical force. Due to the method of construction, there are temporary walls, driven into the ground for the duration of the work. The permanent walls remain in the ground after the work is completed. Sheet piling has various functions, including [3-5]:

- it supports walls of an excavation or land fault,
- it reduces or eliminates water flow to the excavation and protects against such phenomena such as suffosion or quicksand,
- it increases the tightness of the foundation base in water dam structures,
- it strengthens levees in hydrotechnical construction,
- in the case of direct foundations on watered land, it can separate the building foundations and protect them from the washing out of the finest soil particles.

The aim of the paper is to verify the methods used to calculate the parameters of sheet piling. Then, using the two most popular methods, the parameters for the selected sheet piling are calculated. Based on the results obtained, the study determines the possibility of applying these methods in practice.

[1] Czestochowa University of Technology, Faculty of Civil Engineering, ul. Akademicka 3, 42-218 Częstochowa, e-mail: w.kosmala-kot@pcz.pl, orcid id: 0000-0002-3451-8233
[2] Czestochowa University of Technology, Faculty of Civil Engineering, ul. Akademicka 3, 42-218 Częstochowa, e-mail: jacek.selejdak@pcz.pl, orcid id: 0000-0001-9854-5962

2. Analysis of the calculation methods for sheet piling

While designing sheet piling, the limit states methods are most commonly used. They consist of the [6, 7]:
- calculation of the active and passive earth pressure and the water pressure,
- determination of the wall penetration depth for the assumed static diagram,
- calculation of bending moments and forces in the supporting members by graphic or analytical methods,
- dimensioning of sheet piling member and anchors.

The design of sheet piling can be carried out with the use of precise methods taking into account the adopted model of the ground substrate, using MES modelling and appropriate computer programs [8, 9]. It is also possible to use analytical methods known from general mechanics solutions depending on the adopted static diagram or approximate graphic and analytical methods such as Blum's method [10, 11]. In these methods, the starting point for the calculations is to determine the resultant graph of active and passive earth pressure as the basic load of the wall structure (this graph is used to load a wall with a given static diagram).

The penetration depth of a sheet piling has a significant effect on the results of static calculations. Walls inserted deeper into the ground are bent in smaller moments, and the reactions at the support points are also smaller.

The following solutions are used in practice:
- sheet piling not supported, restrained in the ground: in this case, its stability is ensured by a sufficiently large depth of penetration below the bottom of the excavation,
- the walls are tightly supported, one or more times at the top, whereas the bottom is simply supported or fixed.

Of these solutions, two methods are the most popular: analytical and graphic-analytical Blum method.

2.1. Calculation of a single anchored sheet piling using the graphic-analytical Blum method

The procedure in the graphic-analytical Blum method is as follows [6]:
1. A diagram of the wall loads is made with the following assumptions:
   - the ground is horizontal and the wall is vertical,
   - there is no friction between the wall and the ground.
2. The active and passive earth pressures are determined from formulae (1) and (2):

$$e_a(z) = qK_a + \gamma z K_a - 2c\sqrt{K_a} \tag{1}$$

$$e_p(z) = qK_p + \gamma z K_p + 2c\sqrt{K_p} \tag{2}$$

   where:
   z – depth below ground,
   γ – the volumetric weight of the ground,
   c – soil cohesion,
   $K_a = tg^2(45° - \frac{\emptyset}{2})$,
   $K_p = tg^2(45° + \frac{\emptyset}{2})$,
   $\emptyset$ - internal friction angle.
3. The surface of the resultant diagram is divided into strips and the load per individual strips is replaced by horizontal concentrated forces. Water pressure is taken into account in the case of a difference in water levels on either side of the wall, and the distribution of this pressure is assumed depending on whether there is a water flow under the wall.

4. A funicular polygon and force polygon are plotted.
5. The closing line: in the case of a wall simply supported in the ground, from the point of intersection of the first radius of a funicular polygon with the level of the support, the closing line is plotted tangentially to the funicular polygon in its lower part.

The contact point determines the required wall recess t, which for safety reasons is increased by 20% according to formula (3):

$$t = u + 1.2\,x \tag{3}$$

where: x - distance from the zero position of the resultant diagram to the bottom of the strip where the point of contact of the closing line with the funicular polygon occurs. The location of the zero point „u" is determined from the chart of the net pressures. The pattern of the closing line allows the anchoring reaction to be determined from the force polygon in accordance with the equilibrium of the horizontal forces.

The value of the maximum bending moment is calculated from formula (4):

$$M_{max} = m_{max}\,H\ [\mathrm{kN\,m}] \tag{4}$$

where: m_{max} – maximum deflection of points of the funicular polygon in relation to the closing line of the polygon measured horizontally in the direction of the separated forces H – the value of the so-called polar force (height of the force polygon).

2.2. Calculation of single anchored sheet piling using the analytical method

In the analytical method, the active and passive pressure graphs are drawn up in the same way as in the graphic-analytical method (points 1 and 2). From the diagram of resultant active and passive pressure, the place of zeroing of interactions and their pattern are determined, and the resultant values of active and passive pressures are determined as concentrated forces together with their geometric position. By determining the conditions of equilibrium as for any system of forces, the required depth of wall penetration is obtained from the condition of equilibrium of moments of forces in relation to the level of support (tie rod or spreader beam). The determination of this geometric quantity allows the calculation of the resultant passive pressure and the reaction in the support. The reaction in the support is obtained from the condition of equilibrium of force projection on the horizontal axis (this condition can be checked by the equilibrium of moments in relation to the end of the wall). The maximum bending moment for the wall is calculated for the ordinate obtained from the zeroing of the shear forces. Based on the internal forces, it is possible to select a suitable wall profile from the bending condition. It is also possible to determine the effect of the method used to anchor the wall in the upper part of the wall on the forces in the support. The calculated depth of wall penetration is increased by 20% for safety reasons; this also results from the mobilization of the passive pressure limit only in the upper part of the wall and not in the entire length of the penetration below the bottom of the excavation.

3. Assumptions for calculations

Using the analytical and graphic-analytical Blum methods, calculation of a sheet piling with a single-anchored upper part and a simply supported bottom securing a 5-metre deep excavation was performed. The excavation ground is horizontal and loaded with q = 20 kPa. The ground and water conditions in the excavation area are shown in Figures 1 and 2. In accordance with standard recommendations, 50% of cohesion for the cohesive ground was assumed for calculations. This results in taking into account the deterioration of ground conditions, dynamic interactions that may cause thixotropic phenomena.

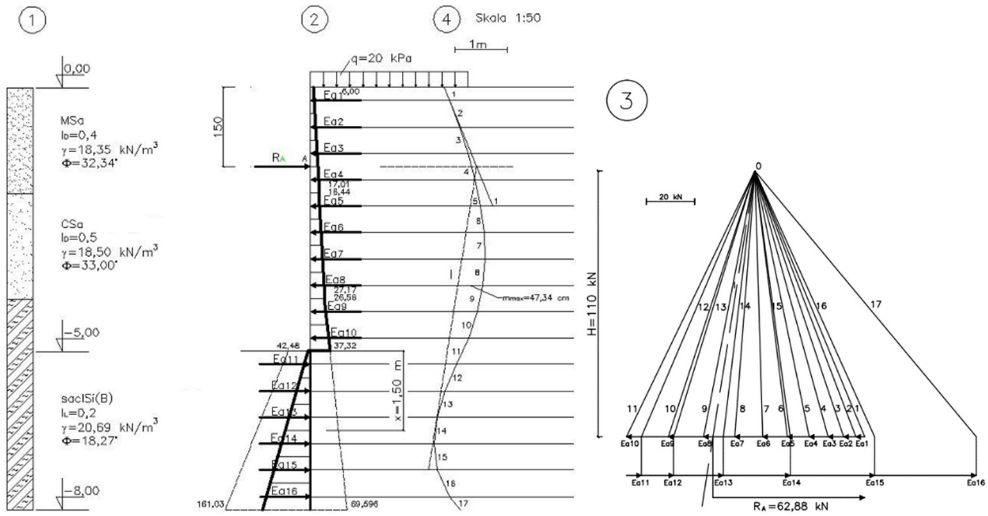

Fig. 1. Graphic-analytical calculations of the sheet piling (medium sand, coarse sand, dusty clay): 1 – geological cross-section, 2 – pressure chart, 3 – real force polygon, 4 – graph of moments of forces

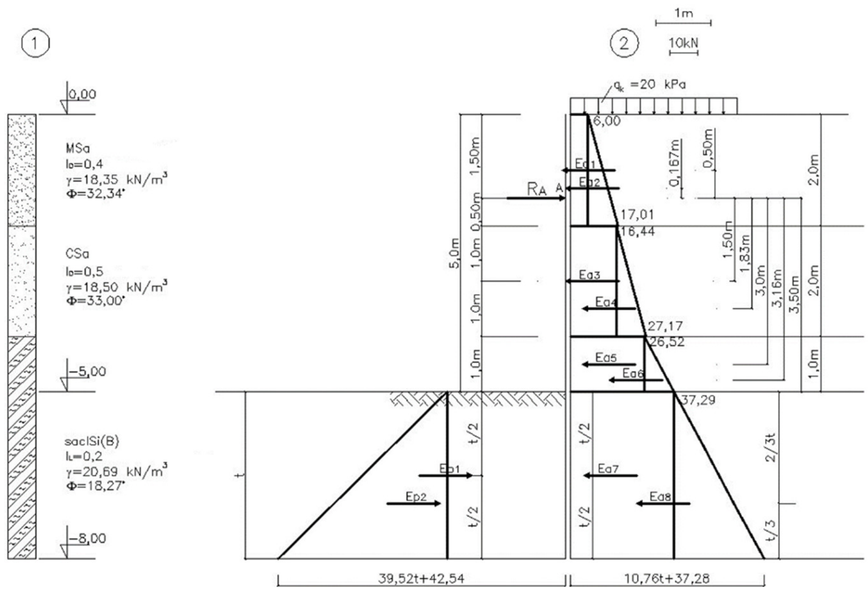

Fig. 2. Graph of active and passive earth pressure for the analytical method

4. Calculation methodology

The solution of the sheet piling using Blum's graphical and analytical method is presented in Figure 1, whereas Figure 2 presents the diagram of active and passive pressure for the analytical solution.

Using the graphic-analytical solution (Fig. 1), the maximum bending moment of the wall M_{max} = 52.074 kNm and its penetration in the ground t = 1.80 m were determined based on the values of the moments of forces read from the graph, whereas the value of the support reaction R_A = 62.88 kN was determined from the force polygon.

In Figure 2, using the equilibrium of moments and forces, the required penetration of the wall t = 1.54 m, supporting reaction R_A = 67.09 kN and the maximum wall bending moment M_{max} = 62.34 kNm are calculated.

The results obtained from the analytical and graphic-analytical Blum methods used to design the excavation are presented in Table 1.

Table 1
List of parameters obtained in the calculation of sheet piling

COMPARISON OF CALCULATION METHODS		
Parameters determined for sheet piling	Graphic-analytical method	Analytical method
Maximum bending moment M_{max}	52.074 kNm	62.34 kNm
Strength index W_x	221.59 cm^3	265.28 cm^3
Assumed wall profile	LARSSEN I	
Wall penetration t	1.80 m	1.54 m
Value of the support reaction R_A	62.88 kN	67.09 kN

Based on the obtained ranges of parameters (Table 1), it was demonstrated that the same sheet piling cross-section and anchorage type can be used to secure the excavation.

5. Conclusion

The analysis of both calculation methods revealed that the results obtained for design parameters differ slightly. The maximum bending moment of the wall obtained from the two methods differs by 10.266 kNm (18%). The values of strength indices calculated based on these values allowed for an unambiguous selection of the same sheet piling cross-section i.e. LARSSEN I steel sheet piles. Based on the values of the support reactions, the same type of anchorage can be used in the form of the same type of ground anchor. Small differences in determining design parameters may have been caused by lower accuracy of the graphic-analytical method. This inaccuracy results from the plotting of the force polygon and the funicular polygon which affect the final results. However, this does not affect the choice of the type of sheet piling or anchorage because the results are within the range of applicability of the wall cross-section chosen based on the type of anchorage.

Therefore, based on the calculations presented in the study, it was demonstrated that both the analytical and the graphic-analytical methods can be successfully applied in practice.

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Porównanie metod obliczeniowych ścianek szczelnych

STRESZCZENIE:
Przedstawiono podstawowe metody obliczania ścianek szczelnych. Scharakteryzowano metody graficzno-analityczną i analityczną Bluma dla ścianki szczelnej górą jednokrotnie zakotwionej, zaś dołem swobodnie podpartej. Pokazano sposób określania długości ścianki, potrzebnego zagłębienia w gruncie oraz doboru profilu ścianki. Ponadto zaprezentowano również metodę wyznaczenia wartości reakcji na podporze ścianki. Wyliczone parametry projektowe dla obu metod zestawiono w tabeli. Na podstawie przeprowadzonych obliczeń stwierdzono, że zastosowane dwie metody obliczeniowe prowadzą do otrzymania zbliżonych przekrojów ścianek szczelnych.

SŁOWA KLUCZOWE:
ścianka szczelna; metody obliczeniowe; profile ścianek szczelnych