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## ON THE BEARING CAPACITY OF LARSEN SHEET PILES UNDER STATIC COMPRESSIVE LOAD

**Abstract.** This article describes the use of steel sheet piles as a permanent structural element supporting compressive loads, as well as methods for calculating their load-bearing capacity. Sheet piles can be used as retaining walls during excavation work, supporting horizontal loads (soil pressure), creating a watertight foundation for the excavation, and later, during the subsequent operation of the structure, they can form an external wall and support compressive loads. Switching from temporary retaining walls to the use of steel sheet piles as permanent walls reduces construction and installation time and generally improves economics.

**Keywords:** Larsen sheet piles, bearing capacity, static compressive load, soil, retaining walls, foundation.



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### Introduction.

Since the early 1980s, Larsen sheet piles have been used to transfer light vertical loads to the ground. In structures such as underground parking lots, piers, bridges, and tunnels, the sheet piles not only function as a support structure under soil and water pressure but also support the weight of the building structure.

At the same time, research began to develop methods for the safe and cost-effective design of sheet piles supporting vertical loads. Tests conducted in France between 1983 and 1986 focused on correlating in-situ soil probing results using a Menard pressuremeter, a CPT penetration probe, and a PAF self-drilling pressuremeter with the results of in-situ static loads on a four-pile sheet pile wall. An extensometer attached to the sheet pile made it possible to separate the soil resistance along the side of the pile from the soil resistance under its tip. The article by M. Bustamante and L. Geneslieg, describing these tests, also proposes a method for calculating the bearing capacity of sheet pile walls under vertical load [1].

Based on research results, the French Central Laboratory of Bridges and Roads in Paris (Laboratoire Central des Ponts et Chaussées de Paris) developed the "Technical Rules for the Design and Engineering of Civil Engineering Foundations." Issue 62, Section V ("Fascicule 62 Titre V") of these rules sets forth

pile design requirements. Several sections are devoted to axial loads on sheet piles and their design using in-situ soil test results with a Ménard pressure meter and a CPT penetration probe.

Due to the limited popularity of soil property studies using a Ménard pressure meter, only the method based on CPT penetration probe results is presented below. The original notations from "Fascicule 62 Titre V" are retained in this article.

#### Materials and methods.

The objective of this study is to determine the bearing capacity of Larsen sheet piles under vertical axial loads, as well as to assess the influence of sheet pile geometry, soil physical and mechanical properties, and the interaction conditions of the sheet pile-soil system on the ultimate load.

The study was conducted using a combination of analytical, numerical, and comparative methods. A computational model of Larsen sheet piles supporting vertical axial loads was developed. In the design model, the sheet pile is considered as a steel element interacting with the surrounding soil mass through lateral friction and soil resistance beneath the bottom edge. The bearing capacity calculation was performed taking into account the combined action of the structure and the underlying soil.

#### Research results.

Determining the soil resistance under the tip of a sheet pile -  $Q_{pu}$

$$Q_{pu} = \rho_p \times A \times q_u, \quad (1)$$

where:  $\rho_p$  is the cross-sectional area reduction factor (Table 1);  $A$  is the cross-sectional area of the sheet pile and the soil between the side faces of the sheet pile (Figure 1);  $q_u$  is the calculated specific resistance of the soil under the sheet pile tip.

It should be emphasized that during sheet pile installation, the soil between the side faces (inside the "trough") is compacted [2]. This creates a so-called "soil plug," which is why Z-shaped sheet piles must be installed in double panels.

Table 1

Coefficient $\rho_p$			
Cohesive Soils		Cohesionless Soils	
$\rho_p$	$\rho_s$	$\rho_p$	$\rho_s$
0.50	1.00	0.30	0.50

The value of  $q_u$  is determined by the formula:

$$q_u = k_c \times q_{ce} \quad (2)$$

where  $k_c$  is a coefficient that depends on the soil type;  $q_{ce}$  is the average specific soil resistance to the probe tip (cone), determined by the formula:

$$q_{ce} = \frac{1}{b+3a} \times \int_{D+3a}^{D-b} q_{cc}(z) \times dz \quad (3)$$

where  $b$  is the smaller of "a" and "h";  $a$  is equal to half the width of the foundation if it is greater than 1.0 m and is taken as 0.5 m if the foundation width does not exceed 1.0 m;  $h$  is the depth of penetration of the sheet pile tip into the bearing soil layer, m;  $D$  is the depth of sheet pile driving, m;  $q_{cc}$  is the adjusted value of the soil resistivity under the probe tip (cone), determined as follows:

- calculate the average value of the soil resistivity under the probe tip (cone)  $q_{cm}$  at depth  $b+3a$  (Figure 1);
- adjust the graph by removing all values exceeding  $1.3 q_{cm}$ ;

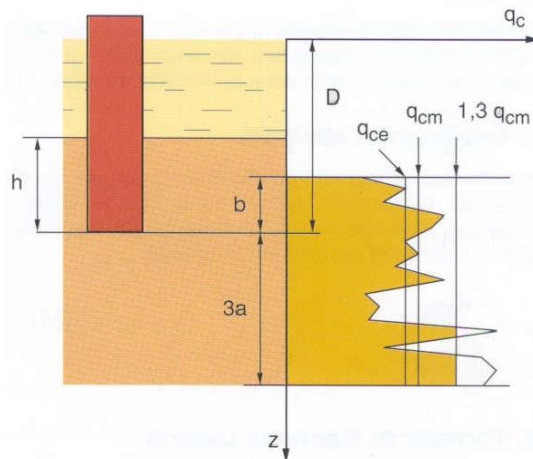


Figure 1. Graphical representation of the method for determining the average soil resistivity under the probe tip (cone)

Table 2

Coefficient $k_c$				
Soil Type	Class	Soil Condition	$q_c$ [MPa]	$k_c$
Clay, loam	A	Soft plastic	<3.0	0.55
	B	Hard plastic	3.0-6.0	
	C	Hard and semi-hard	>6.0	
Sand, gravel, pebbles	A	Loose	<5.0	0.50
	B	Medium density	8.0-15.0	
	C	Dense	>20.0	

Determining the soil resistance along the lateral surface of a sheet pile -  $Q_{su}$

$$Q_{su} = \rho_s \times P \times \int_0^h q_s(z) \times dz \quad (4)$$

where  $\rho_s$  is the coefficient reducing the cross-sectional area (Table 1);  $P$  is the perimeter of the sheet pile cross-section (Figure 1);  $q_s(z)$  is the calculated specific soil resistance along the lateral surface at depth, determined by the formula:

$$q_s(z) = \min\left(\frac{q_c(z)}{\beta}; q_{smax}\right) \quad (5)$$

where  $q_{c(z)}$  is the specific soil resistance under the tip (cone) of the CPT probe at depth  $z$  (the resistance to penetration of the CPT probe at depth  $z$ );  $\beta$  is the correction parameter (Table 3);  $q_{smax}$  is the maximum permissible value of specific soil resistance along the lateral surface (Table 3).

Table 3

$\beta$ and $q_{smax}$ values			
Soil Type	Class	$\beta$	$q_{s\ max}$ [kPa]
Clay, loam	A	-	15
	B	120	40
	C	150	80
Sand, gravel, pebbles	A	300	-
	B	300	-
	C	300	120

## Boundary State Verification to Determine Strength

$$Q_{max,ELU} = \frac{Q_u}{\gamma} \geq F_{ELU} \quad (6)$$

where  $Q_{max,ELU}$  is the ultimate design strength of sheet piles on soil;  $\gamma$  is the safety factor, equal to 1.4 for driven piles;  $F_{ELU}$  is the sum of the design loads;  $Q_u$  is the characteristic ultimate strength of sheet piles on soil, determined by the formula:

$$Q_u = Q_{pu} + Q_{su} \quad (7)$$

## Boundary State Verification to Determine Suitability for Service

$$Q_{max,ELS} = \frac{Q_C}{\gamma} \geq F_{ELS} \quad (8)$$

where:  $Q_{max,ELS}$  is the ultimate creep strength of sheet piles on soil;  $\gamma$  is the safety factor, equal to 1.4 for driven piles;  $F_{ELS}$  is the sum of the characteristic loads;  $Q_C$  is the characteristic creep strength of sheet piles on soil, determined by the formula:

$$Q_C = 0.7 \cdot Q_{pu} + 0.7 \cdot Q_{su} = 0.7 \cdot Q_u \quad (9)$$

Examples of projects in Poland. Comparison of calculations with test loads.

Several projects have been built in Poland using sheet piling as a foundation [3,4]:

- Railway viaduct in Levin Brzeski - thanks to the sheet piling and ready-made prefabricated elements, train traffic was closed for only 48 hours (Figure 2);
- Railway viaduct in Swarzedz on the Warsaw - Berlin line - in this project the bridge slab was slid onto bridge abutments made of sheet piles (Figure 3);
- road viaduct in Warsaw on the S8 road - the viaduct is built on a double row of sheet piles on both sides, the supporting walls are also made of sheet piles;
- road viaduct in Kielce on the S74 road - a roundabout was built above the S74 road. In this case, the integrated viaduct is built on a double row of sheet piles on both sides, the supporting walls are also made of sheet piles (Figure 4);
- berths of the pedestrian bridge above the entrance to the port in Novaya Sol (Figure 5).



Figure 2. Railway viaduct, Lewin Brzeski



Figure 3. Railway viaduct, Swarzędz



Figure 4. Road viaduct, Kielce



Figure 5. Pedestrian bridge piers, Nowa Sól

The most interesting project is the 17.5-meter-wide viaduct built in Rzeszów on Route 4 (Figure 6). The tender for this project also included design work. The best bid was submitted by Skanska, which adopted Aarsleff's idea to build an integrated bridge with a Larsen sheet pile foundation. The construction technology for this project is shown in Figure 8. The bridge was built in 11 months.

Integrated bridges are a very popular solution worldwide. The rigid connection between the bridge slab and the sheet pile wall increases the strength of the entire structure and makes it possible to reduce the thickness of the superstructure, eliminating the need for sliding bearings and expansion joints. This reduces the volume and cost of building materials, and shortens construction time.



Figure 6. Road viaduct, Rzeszow

Aarsleff was responsible for calculating the vertical load-bearing capacity of the sheet piles, driving them, and conducting test static loads. The calculations were performed using Fascicule 62 Titre V and CPT sounding data from the sheet pile installation site. The strength of a single 18.5 m long sheet pile was determined to be  $0.9 \cdot N_t = 430 \text{ kN}$  under a load of 320 kN.

To conduct test loads, an additional single sheet pile was driven near the main wall. After excavation, using the viaduct slab as a counterweight, test loading of the sheet pile was performed (Figure 7). The results showed that the sheet pile strength was lower than the design value but higher than the required loads. This test result was most likely due to the use of water jetting during the first few meters of sheet pile penetration [5].



Figure 7 - Test site

The success of this and other projects gives hope that the use of metal sheet piles as foundations for building structures will become more popular.

**Conclusion.** A very important factor affecting the vertical load-bearing capacity of sheet piles, which is not considered in this document, is the sheet pile driving technology. The coefficients used in calculations using the "Fascicule 62 Titre V" method were determined for sheet piles driven with diesel hammers. Piles driven with vibratory hammers have lower load-bearing capacity than those driven with pneumatic or diesel hammers. To determine this difference, static load tests were conducted in 2002 on sheet piles driven using these two methods. The greatest difference in readings reached 50% in favor of sheet piles driven with a pneumatic hammer.

In 2006, S. Borel, M. Bustamante, and F. Rocher-Lacoste published the results of these tests and compiled historical results from seven other tests of sheet piles (pipe and reinforced concrete). The authors proposed reducing the soil resistance under the pile tip and along the sheet pile sidewall, calculated according to "Fascicule 62 Titre V," by 50% and 30%, respectively. A solution that can increase the strength of vibratory driven sheet piles is to drive the last 2-3 meters to the specified depth using pneumatic or diesel hammers.

The "Fascicule 62 Titre V" document does not provide any recommendations for conducting static test loads. When conducting such tests, it is important to remember that the sheet piles being tested should not be interlocked with other sheet piles. This is done intentionally to eliminate the influence of friction in the interlocks. Therefore, it is recommended to drive individual test piles in close proximity to the building structures. A second option is to remove adjacent piles from the pile being tested during testing and re-drive them after test loads have been applied, although this method weakens the soil around the piles.

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### СТАТИКАЛЫҚ СЫҒЫМДЫ ЖҮКТЕМЕЛЕР АСТЫНДАҒЫ LARSEN ҚҰРЫЛҒЫ ҚАҒАЗДАРЫНЫҢ ТІРЕКТЕУ ҚАБІЛЕТТІЛІГІ ТУРАЛЫ

**Аңдатпа.** Бұл мақалада болат қаңылтыр қадаларды қысу жүктемелерін көтеретін тұрақты құрылымдық элемент ретінде пайдалану, сондай-ақ олардың көтеру қабілетін есептеу әдістері сипатталған. Қаңылтыр қадалар қазу жұмыстары кезінде тірек қабырғалары ретінде пайдаланылуы мүмкін, көлденең жүктемелерді (топырақ қысымын) көтере алады, қазу үшін су өткізбейтін негіз жасайды, ал кейіннен құрылымды пайдалануды жалғастыру кезінде олар сыртқы қабырға құра алады және қысу жүктемелерін көтере алады. Уақытша тірек қабырғалардан болат қаңылтыр қадаларды тұрақты қабырғалар ретінде пайдалануға көшу құрылыс және орнату уақытын қысқартады және, әдетте, шығындардың тиімділігін арттырады.

**Тірек сөздер:** Larsen қадалары, көтеру қабілеті, статикалық қысу жүктемесі, топырақ, тірек қабырғалары, іргетас.

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### О НЕСУЩЕЙ СПОСОБНОСТИ ШПИЛЬНЫХ СВАЙ LARSEN ПРИ СТАТИЧЕСКОЙ СЖИМАЮЩЕЙ НАГРУЗКЕ

**Аннотация.** В данной статье описывается использование стальных шпунтовых свай в качестве постоянного конструктивного элемента, воспринимающего сжимающие нагрузки, а также методы расчета их несущей способности. Шпунтовые сваи могут использоваться в качестве подпорных стен во время земляных работ, воспринимая горизонтальные нагрузки (давление грунта), создавая водонепроницаемый фундамент для котлована, а впоследствии, в ходе дальнейшей эксплуатации сооружения, могут образовывать наружную стену и воспринимать сжимающие нагрузки. Переход от временных подпорных стен к использованию стальных шпунтовых свай в качестве постоянных стен сокращает время строительства и монтажа и, как правило, повышает экономическую эффективность.

**Ключевые слова:** шпунтовые сваи Larsen, несущая способность, статическая сжимающая нагрузка, грунт, подпорные стены, фундамент.