

MICHAŁ GRODECKI\*

**INFLUENCE OF A SURCHARGE LINE LOAD ON  
CANTILEVER SHEET PILE WALL BEHAVIOR**

---

**WPŁYW OBCIĄŻEŃ LINIOWYCH NA PRACĘ ŚCIANKI  
SZCZELNEJ NIEKOTWIONEJ****Abstract**

The results of a parametric study of a surcharge line load influence on sheet pile wall behavior are presented in this paper. Results obtained from numerical analysis and classic engineering methods are compared.

*Keywords: excavation, sheet pile wall, FEM, line load*

**Streszczenie**

W artykule przedstawiono rezultaty studium parametrycznego wpływu obciążenia liniowego naziomu na pracę ścianki szczelnej niekotwionej stanowiącej zabezpieczenie wykopu. Porównano wyniki uzyskane za pomocą analizy numerycznej i klasycznymi metodami inżynierskimi.

*Słowa kluczowe: wykop, ścianka szczelna, MES, obciążenie liniowe*

---

\* Ph.D. Michał Grodecki, Department of Geotechnics, Faculty of Environmental Engineering, Cracow University of Technology.

## Symbols

$\phi$	– internal friction angle [deg]
$\gamma$	– soil bulk density [kN/m <sup>3</sup> ]
$c$	– cohesion [kPa]
$h$	– excavation depth [m]
$H$	– total length of wall [m]
$L$	– distance from wall to line load [m]
SF	– stability factor [–]
$q$	– soil pressure [kPa]
$Q$	– surcharge line load [kN/m]
$UX$	– horizontal displacement [m]

## 1. Introduction

The main subject of this investigation is an excavation with depth  $h$ , supported by a cantilever sheet pile wall (with total height  $H$ ), and with a line load  $Q$  on the surcharge parallel to the wall (with distance  $L$  from the wall). This is of course a simplification of a real situation, where rather strip load exist. But if the load dimension perpendicular to the wall is narrow (in comparison with excavation depth  $h$ ), such an approach could be used.

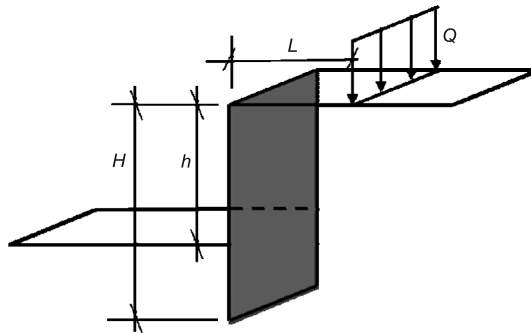


Fig. 1. Analyzed object

The main goal of this paper is to show the surcharge line load influence on sheet pile wall behavior (stability, bending moment and displacements).

Such an object can be analyzed in different ways. Three approaches can be used: ultimate soil pressure theory, elastic soil pressure theory and numerical analysis (based on elasto – plastic soil model).

### 1.1. Ultimate soil pressure caused by surcharge line load

Solution of the ultimate soil pressure caused by surcharge line load problem one can find for example in Polish code PN-83/B-03010 [3]. It shows that additional pressure caused by

surcharge line load starts acting with the value of  $q_{int}$  at depth  $L \cdot \text{tg}(\varphi)$  under the surcharge while the sum of this pressure and soil active pressure is uniform, as shown in Fig. 2.

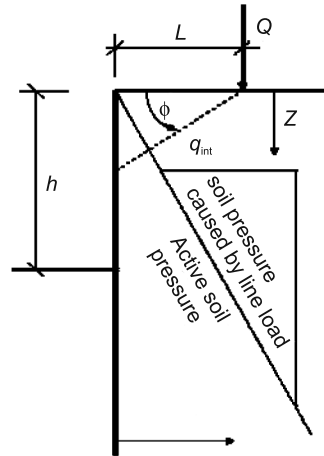


Fig. 2. Ultimate soil pressure caused by surcharge line load

Value of  $q_{int}$  can be calculated from equation:

$$q_{int} = \sqrt{2\gamma Q K_a^{1.5}} \quad (1)$$

where:

$$K_a = \text{tg}^2 \left( 45^\circ - \frac{\phi}{2} \right) \quad (2)$$

Distribution of such additional soil pressure depends on soil parameters (especially on internal friction angle). One can see that soil pressure distribution in this case is discontinuous, which raises question of whether or not it is a good representation of the real soil behavior.

## 1.2. Elastic (intermediate) soil pressure caused by surcharge line load

Solution of the elastic (intermediate) soil pressure caused by surcharge line load problem one can find in Polish code PN-83/B-03010 or in US Guidelines EM 1110-2-2504 [1].

It shows that additional pressure caused by the surcharge line load is acting on the whole wall and does not depend on soil properties. Values of this pressure at depth  $z$  under the surcharge could be calculated from equations:

$$q = \frac{1.27 \cdot Q \cdot L^2 \cdot z}{(L^2 + z^2)^2} \quad \text{for } L > 0.4 h \quad (3)$$

$$q = \frac{0.203 \cdot Q \cdot h^2 \cdot z}{(0.16h^2 + z^2)^2} \quad \text{for } L < 0.4 h \quad (4)$$

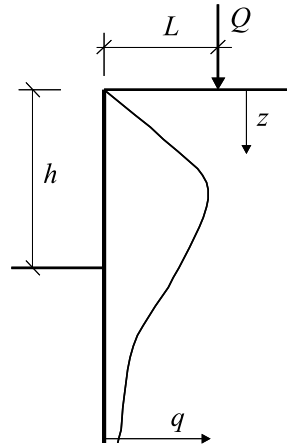


Fig. 3. Elastic (intermediate) soil pressure caused by surcharge line load

### 1.3. Numerical simulation with stage construction algorithm

Numerical simulation with a stage construction algorithm can also be used to deal with aforementioned problem. Two different stage construction schemes can be taken into account – first with line load added before inserting the wall (simulation of the excavation in the vicinity of existing load), second with line load added after inserting the wall and excavation (simulation of the influence of the added later line load on existing excavation support). In the second approach, an ultimate load analysis can be performed (line load could be increased to obtain loss of stability of the structure). In this case, special attention should be paid to distinguish between two possible failure mechanisms, loss of stability of the excavation support (which is the topic of this paper) or subsoil bearing capacity (like for direct foundation problem, which is out of the scope of this paper).

## 2. Numerical experiment

The numerical experiment was performed in order to assess the influence of the surcharge line load on sheet pile cantilever wall (acting as excavation support) behavior. Walls with a total height  $H = 6$  m supporting excavation with depth  $h = 3$  m embedded in soils with different properties were analysed. Soil properties were selected to obtain the stability factor  $SF = 1.35$  for situation without surcharge load (which is reasonable margin of stability). In the numerical analysis, the following initial assumptions were used:

- plane strain conditions,
- Coulomb – Mohr elasto – plastic model for soil, with tensile “cut-off” condition (no tension),
- elastic model for the wall,
- contact elements with no friction between the wall and soil,
- stage construction algorithm with partial unloading,
- stability analysis based on c-fi reduction algorithm (described in details in [5]),
- to prevent the construction from failure from subsoil load capacity loss (which is not the topic of this paper) a small area of soil under the line load was modeled as an elastic one.

All numerical simulations were performed with the use of the FEM system ZSoil v 12 (which is described in details in [4–6]). A full description of methodology used can be found

in [2]. Obtained results were compared with results from of simplified methods. Ultimate load in the case of use of simplified methods were identified as load for which moment of soil pressure acting on retained side of the wall (it means moment caused by active soil pressure and additional pressure produced by line load) is equal to the moment acting on dredge side (caused by passive soil pressure).

### 3. Obtained results

The ultimate load analysis shows that it is possible to calculate ultimate load  $Q_{\max}$  of the structure with the use of simplified methods, but with some limitations. The elastic pressure approach yields reasonable results (comparable with those obtained from numerical simulations) if the line load is located closer to the wall then excavation depth. For loads located a larger distance from the wall, this approach leads to underestimating the ultimate load, which is especially visible for walls embedded in soils with small cohesion. The ultimate soil pressure approach can only be used for soils with small cohesion. For soils with high values of cohesion, this approach leads to significant underestimation of the ultimate load.

Relationships between the obtained values of ultimate load and distance  $L$  for walls embedded in different soils, obtained with three described before approaches, are presented on the graphs below.

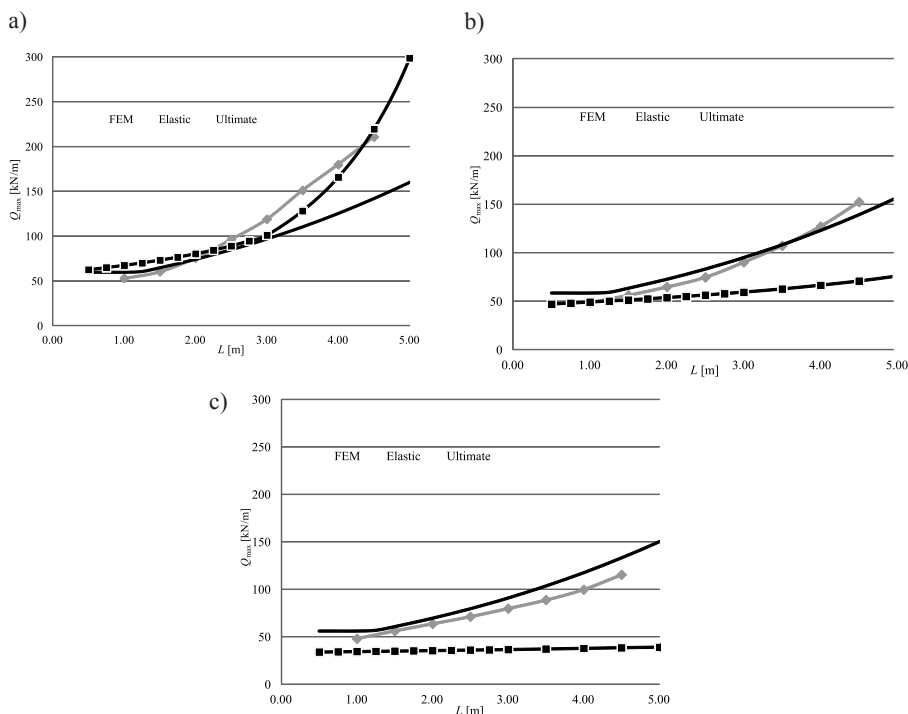


Fig. 4. Ultimate load as a function of line load location, for soils with different strength parameters: a) soil with small cohesion ( $c = 4$  kPa,  $\phi = 30^\circ$ ), b) soil with intermediate cohesion ( $c = 10$  kPa,  $\phi = 20^\circ$ ), c) soil with high cohesion ( $c = 17.5$  kPa,  $\phi = 8^\circ$ )

Plots of additional soil pressure produced by a line load are presented in graphs below. One can see that a decrease of the soil pressure on the retained side of the wall at the part of the wall under the excavation bottom is obtained in the numerical simulations. It is due to rotational movement of the wall, which reduces soil pressure to the ultimate one. Such an effect is not observed in simplified calculations methods.

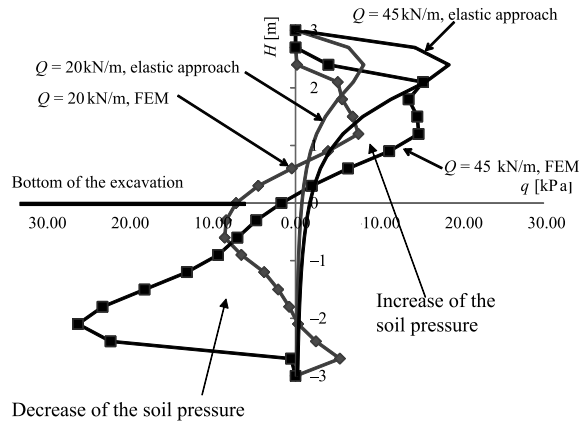


Fig. 5. Additional soil pressure produced by line load – FEM simulations results vs elastic approach

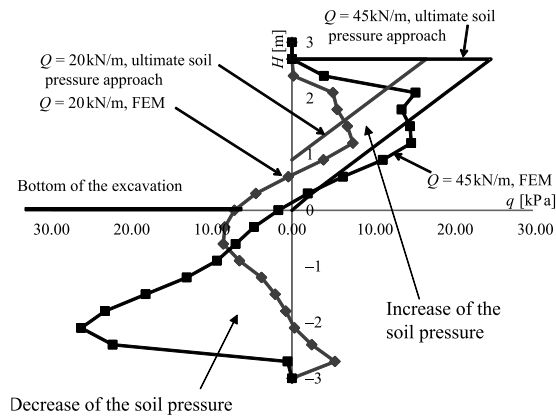
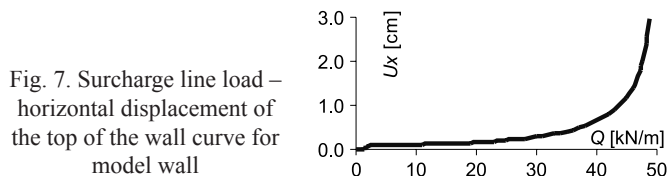


Fig. 6. Additional soil pressure produced by line load – FEM simulations results vs ultimate soil pressure approach

Discrepancies in the obtained additional soil pressure distributions show that simplified approaches could not be used in the bending analysis of the wall. It would result in obtaining an unrealistic distribution of the bending moment.

The staging scheme does not affect the stability of the wall or bending moment. Displacements obtained in the case with load added after excavation are a bit bigger than in the case with load added before wall inserting.

Load – displacements curves obtained in numerical analyses are strongly nonlinear, especially when the line load is close to the ultimate one.



#### 4. Final remarks

The analysis described above shows that simplified approaches can be used for stability analysis of the cantilever wall with some line load on the surcharge, but with some limitations. The elastic approach yields results consistent with those obtained from FEM simulations for non-cohesive soils or for cohesive soils but with limitation to  $L < h$ . The ultimate soil pressure approach can be used for the stability analysis. but only for soils with small cohesion. Both simplified approaches fail to represent bending behavior because of discrepancies in additional soil pressure distributions.

#### References

- [1] Design of *sheet* pile walls. Engineer Manual 1110-2-2504, Department of the Army, U.S. Army Corps of Engineers, Washington 1994.
- [2] Grodecki M., Truty A., Urbański A., *Modelowanie numeryczne ścian szczelnych*, Górnictwo i Geoinżynieria, Kwartalnik AGH, Rok 27, zeszyt 3-4, 2003.
- [3] PN-83/B-03010 Ściany oporowe. Obliczenia statyczne i projektowanie.
- [4] Podleś K., Truty A., Urbański A., *Analiza zagadnień geotechnicznych w systemie Z\_SOIL*, X Jubileuszowa Konferencja Naukowa „Metody Numeryczne do Projektowania i Analizy Konstrukcji Hydrotechnicznych”, Korbilów 1998, 100-108.
- [5] Truty A., Urbański A., Grodecki M., Podleś K., *Komputerowe modele zagadnień osuwiskowych oraz ich zabezpieczeń*, Zeszyty Naukowo-Techniczne Stowarzyszenia Inżynierów i Techników Komunikacji Rzeczpospolitej Polskiej w Krakowie nr 88 (zeszyt 144), 2009.
- [6] *Z\_Soil.PC, Theoretical Manual*, ZACE Services Ltd., Lozanna 2000.