Analysis of a single pile settlement

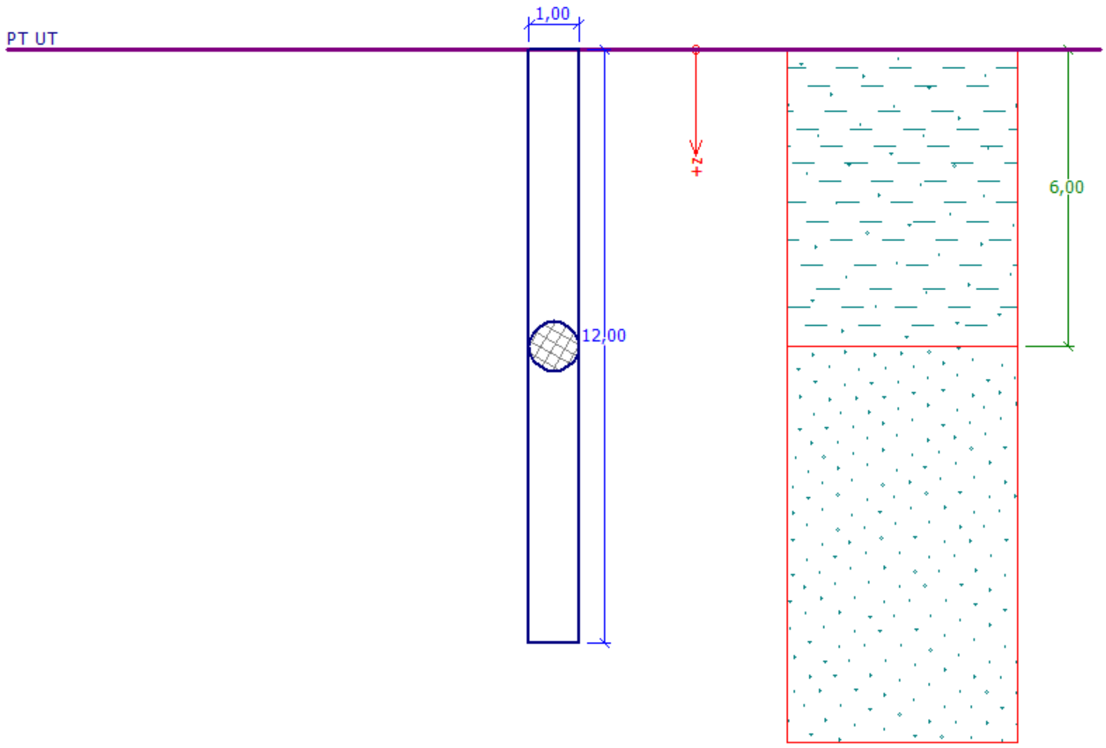
Program: Pile

File: Demo_manual_14.gpi

The objective of this engineering manual is to explain the application of the GEO 5 – PILE program for the analysis of the settlement of a single pile in a specified practical problem.

Problem specification

The general specification of the problem is described in chapter *12. Pile foundations – Introduction*. All analyses of the single pile settlement shall be carried out on the foundations of the previous problem presented in chapter *13. Analysis of vertical load-bearing capacity of a single pile*.



Problem specification chart – single pile

Solution

We will use the GEO 5 – Piles program to analyze this problem. In the text below, we will describe the solution to this problem step by step.

In this analysis, we will calculate the settlement of a single pile using the following methods:

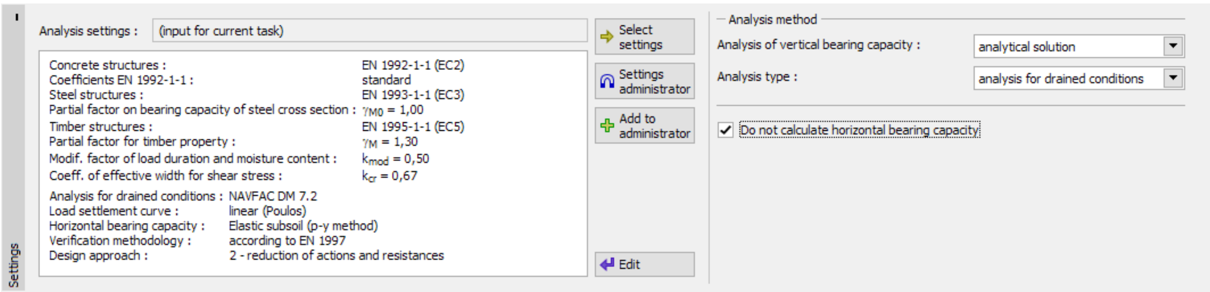
- *linear settlement theory* (according to prof. **Poulos**)
- *nonlinear settlement theory* (according to **Masopust**)

The **linear loading curve** (solution, according to Poulos) is determined from the results of the calculation of the vertical bearing capacity of the pile. The fundamental input into the calculation comprises of **the pile skin bearing capacity and pile base bearing capacity values** – R_s and R_b. These values are obtained from the previous analysis of the vertical bearing capacity of a single pile depending on the method applied (NAVFAC DM 7.2, Effective Stress, CSN 73 1002 or Tomlinson).

The **nonlinear loading curve** (solution, according to Masopust) is based on the specification using the so-called **regression coefficients.** The result is, therefore, independent of the load-bearing capacity analysis methods and can, therefore, even be used to determine the vertical bearing capacity of a single pile when the capacity corresponds to the allowable settlement (usually 25 mm).

Specification process: Linear settlement theory (POULOS)

In the "Pile" program, open up the file from manual no. 13. In the "Settings" frame, we will leave the analysis settings unchanged – we will use the "Standard – EN 1997 – DA2" setting, which is the same as in the previous problem. The analysis of bearing capacity will be done according to NAVFAC DM 7.2. We will also check the box "Do not calculate horizontal bearing capacity". The linear loading curve (Poulos) has already been specified for this analysis setting.



"Settings" frame

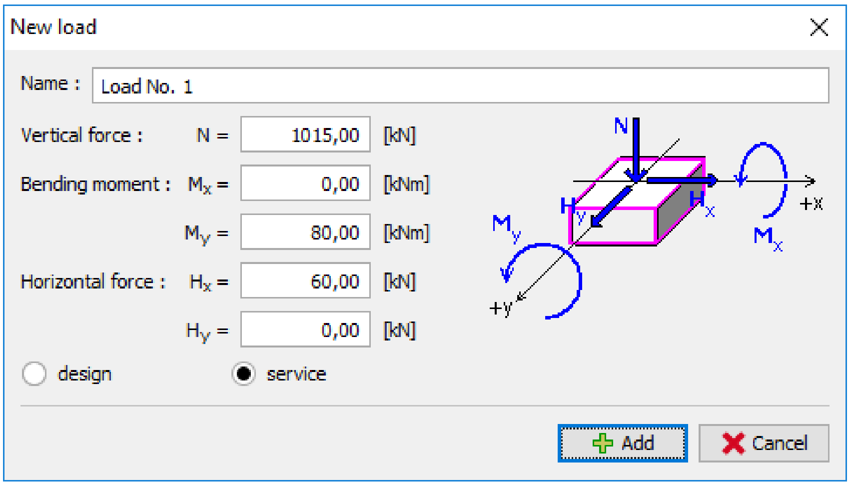
Note: The analysis of the limit loading curve is based on the theory of elasticity. The ground is characterized by the modulus of deformation E_{def} and Poisson's ratio ν.

In the next step, we will go to the "Soils" frame and check the deformational properties of soils required for the analysis of settlement, i.e., the oedometric modulus E_{oed}, or deformation modulus E_{def} and Poisson's ratio ν.

Soil (Soil classification)	Unit weight $\gamma\ [kN/m^3]$	Angle of internal friction $\varphi_{ef}\ /\ \varphi_u\ [^\circ]$	Cohesion of soil $c_{ef}\ /\ c_u\ [kPa]$	Poisson´s ratio $\nu\ [-]$	Oedometric modulus $E_{oed}\ = [MPa]$
CS – Sandy clay, firm consistency	18,5	-/0,0	-/50,0	0,35	8,0
S-F – Sand with trace of fines, medium dense soil	17,5	29,5	0,0	0,30	21,0

Soil parameters table – Settlement of a single pile

Then, in the "Load" frame, we will define the service load for the purpose of analyzing the settlement of a single pile. Click on the "Add" button and add a new load with the parameters as shown in the figure below.

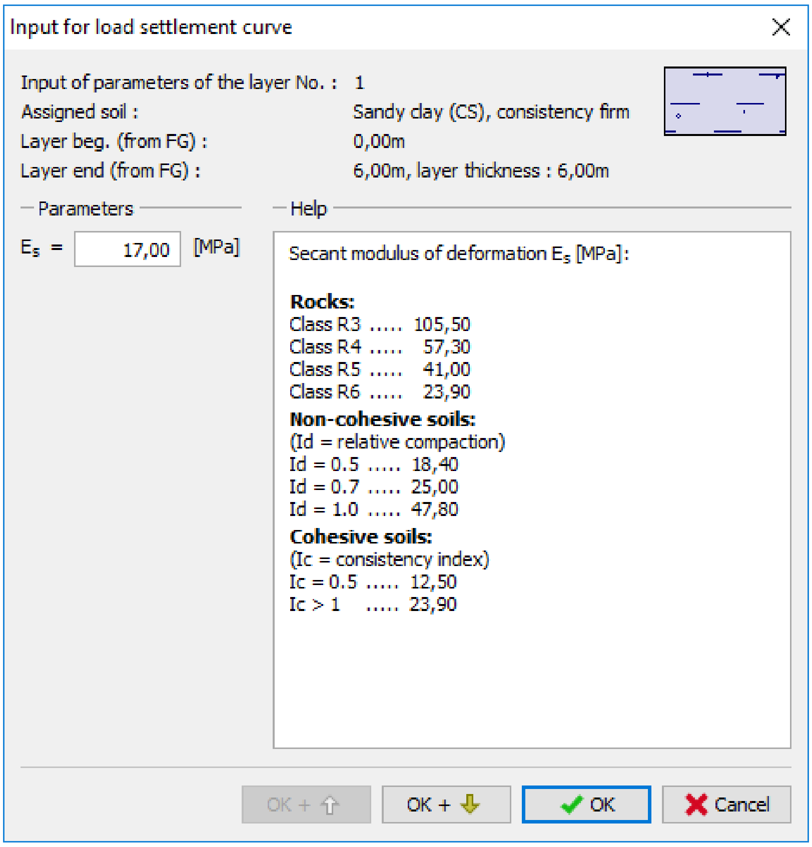


"New load" Dialog window

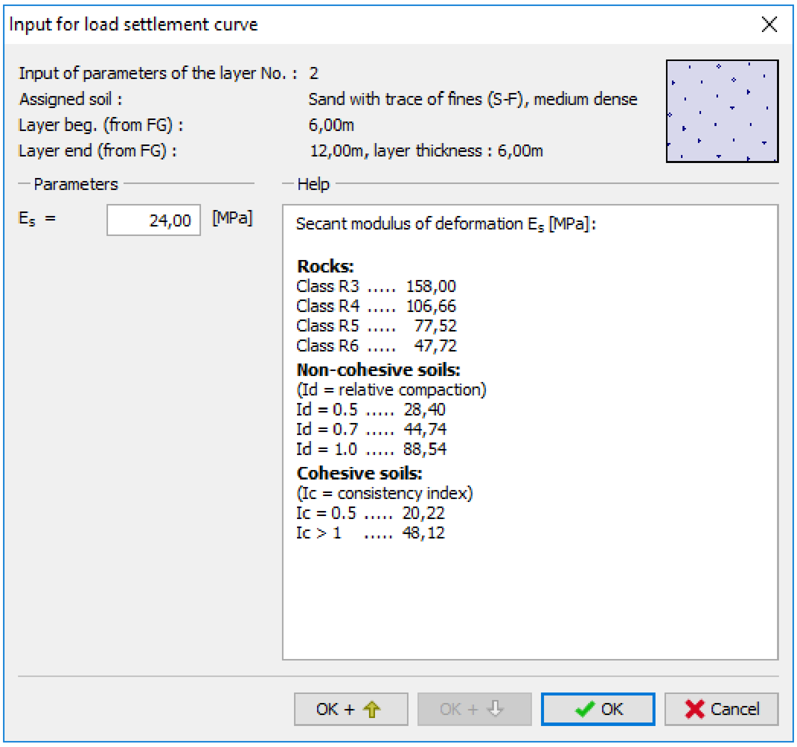
All other frames will remain unchanged. We can now continue to the settlement analysis in the "Settlement" frame.

In the "Settlement" frame, we will specify the secant modulus of deformation $E_s\ [MPa]$ for each of the soil types using the "edit E_s" button.

For the 1st layer of *cohesive soil* (class CS), we will set the value of the secant modulus of deformation to $E_s \cong 17.0\ MPa$. For the 2nd layer of *cohesionless soil* (class S-F), we will assume the secant modulus of deformation $E_s \cong 24.0\ MPa$.



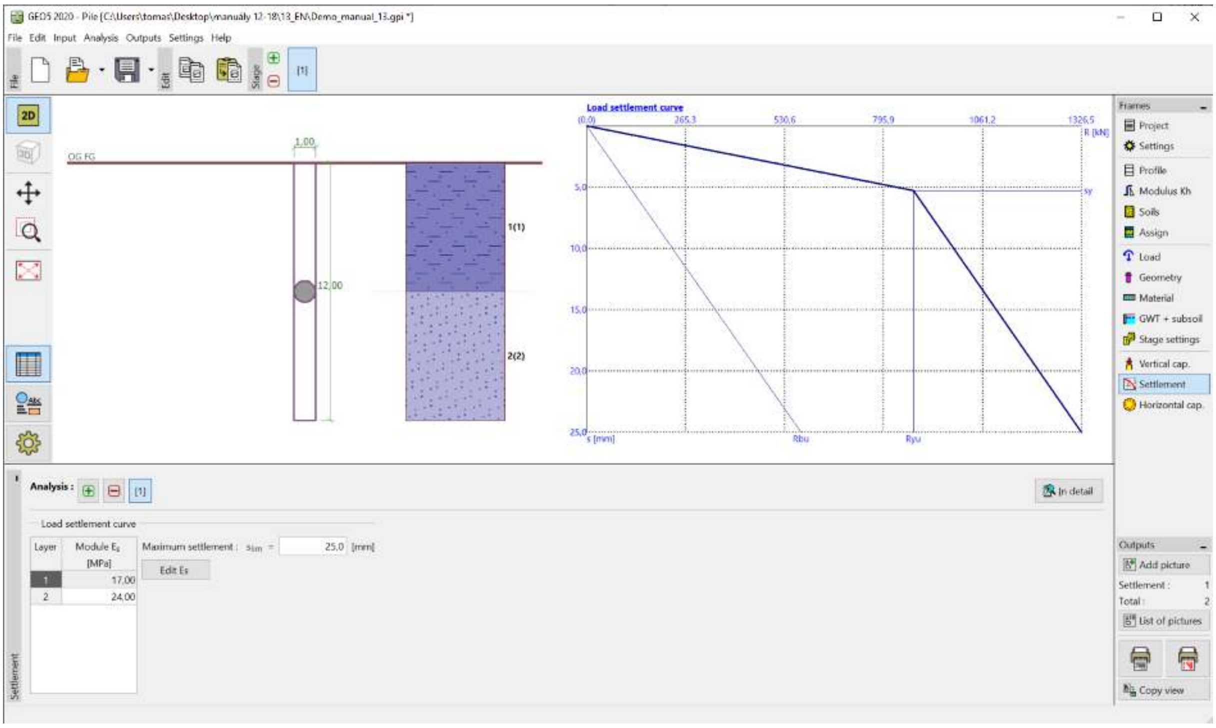
"Input for load settlement curve – secant modulus of deformation E_s " Dialog window – CS soil



"Input for load settlement curve – secant modulus of deformation E_s" Dialog window – S-F soil

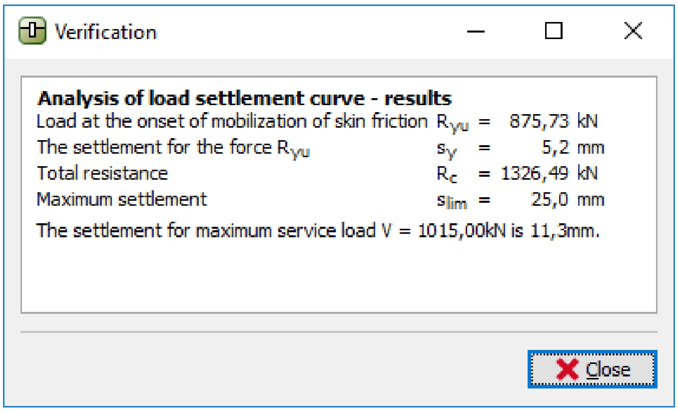
Note: The secant modulus of deformation E_s depends on the diameter of the pile and the thickness of each of the soil layers. The values of this modulus should be determined on the basis of in-situ tests. Its value for cohesionless and cohesive soils further depends on the relative density index I_d and the consistency index I_c, respectively.

Further, we will set the limit settlement, which is the maximum settlement value for which the loading curve is calculated. In this task, we will consider a maximum settlement of 25 mm.



"Settlement" frame – Linear loading curve (solution according to Poulos)

Then, we will click on the "In detail" button and in the dialog window, we can see the settlement value calculated for the maximum service load.

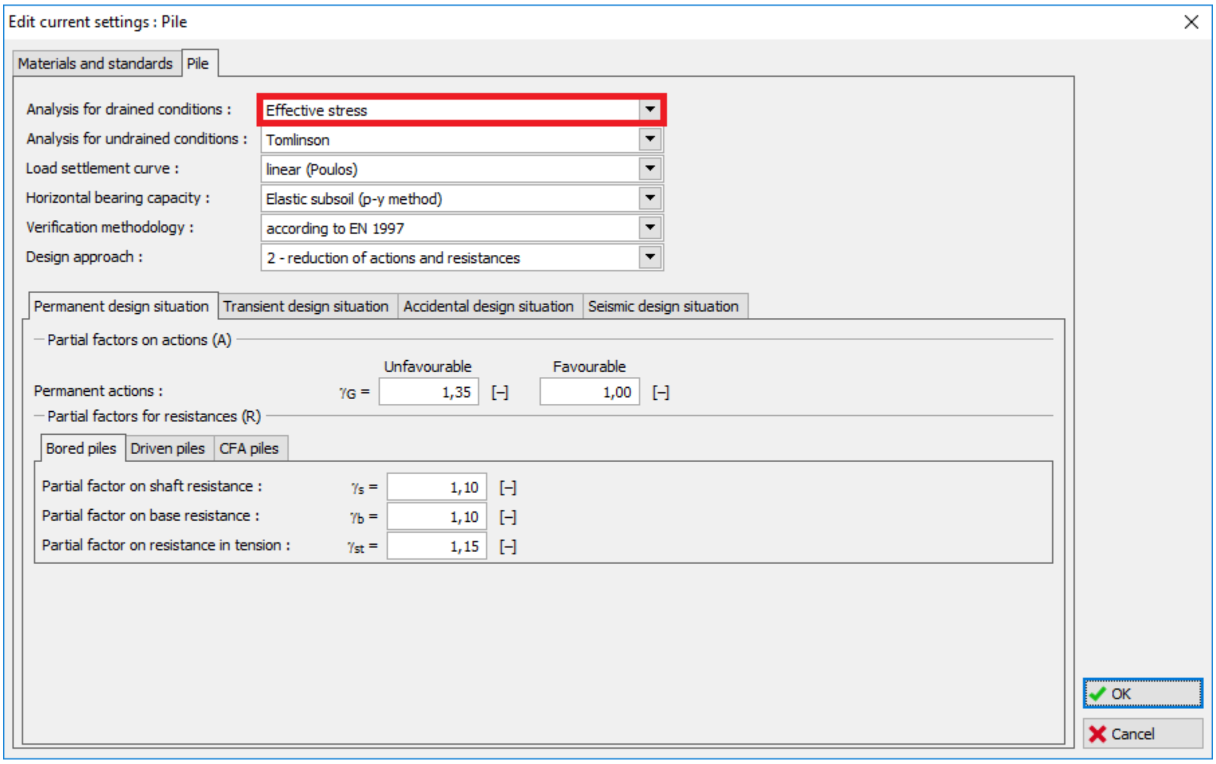


Results of settlement

For the vertical bearing capacity analysis using the ***NAVFAC DM 7.2,*** the resultant settlement of the single pile is **11,3 mm**.

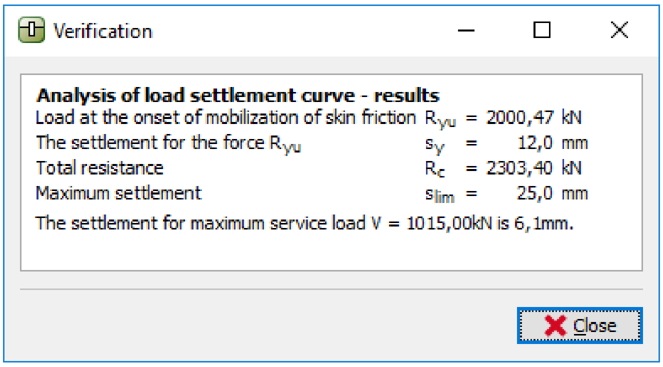
Single pile settlement analysis: Linear settlement theory (POULOS), other methods

Now we will go back to the settings of the analysis. In the "Settings" frame, click on the "Edit" button. In the "Pile" tab for the analysis for drained conditions, we will first select the option "Effective Stress" and later the option "CSN 73 1002" for the next analysis. The other input parameters will remain unchanged.



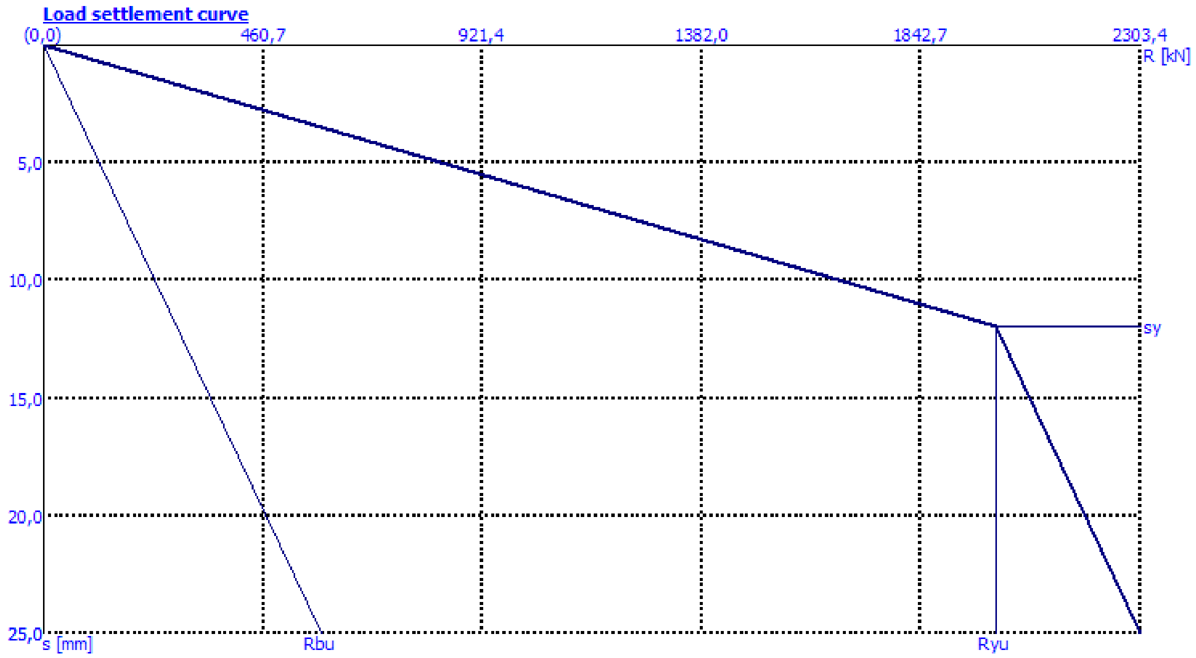
"Edit current settings"Dialog window

Subsequently, we will get back to the "Settlement" frame, where we will see the results. The magnitude of the limit settlement $s_{\lim}$, the pile type, and the secant modulus of deformation E_s remain identical with those used in the previous analysis.



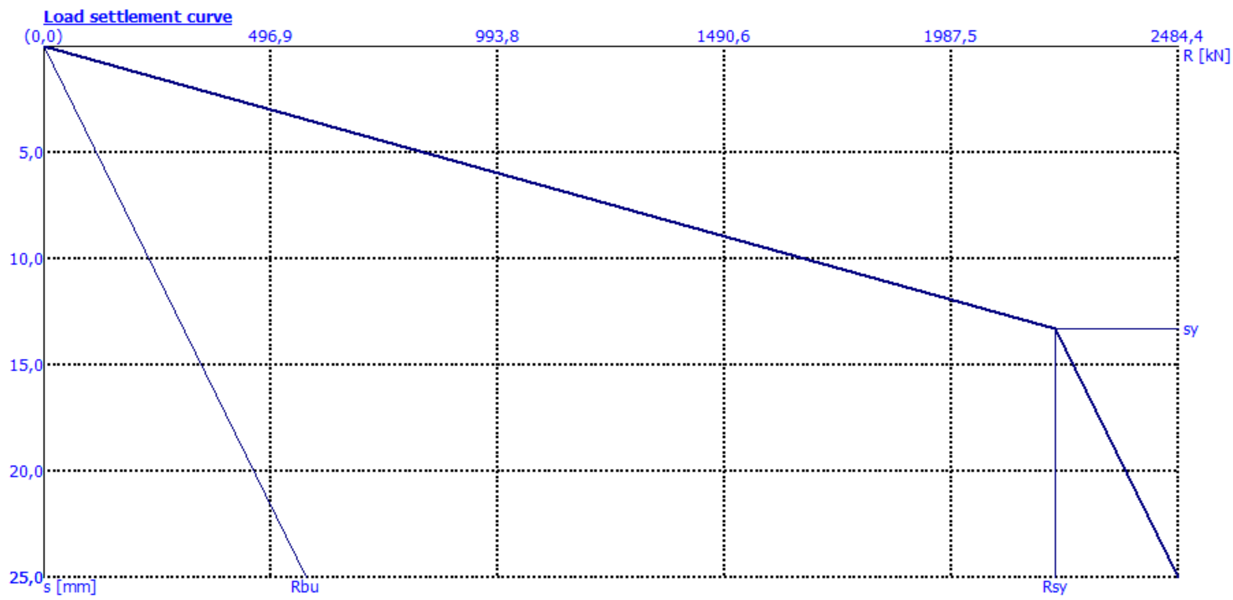
"In detail" Dialog window – effective stress method results

For the vertical bearing capacity of a single pile determined using the ***EFFECTIVE STRESS*** method, the resultant settlement is $s = 6.1\ mm$.



"Settlement" frame – Linear loading curve (according to Poulos) for the Effective Stress method

For the vertical bearing capacity of a single pile, which is determined by the ***CSN 73 1002*** method, the pile settlement is $s = 6.1\ mm$.



"Settlement" frame – Linear loading curve (according to Poulos) for the CSN 73 1002 method

The results of the single pile settlement analysis according to linear theory (***Poulos***) dependent on the vertical bearing capacity analysis method used are presented in the following table:

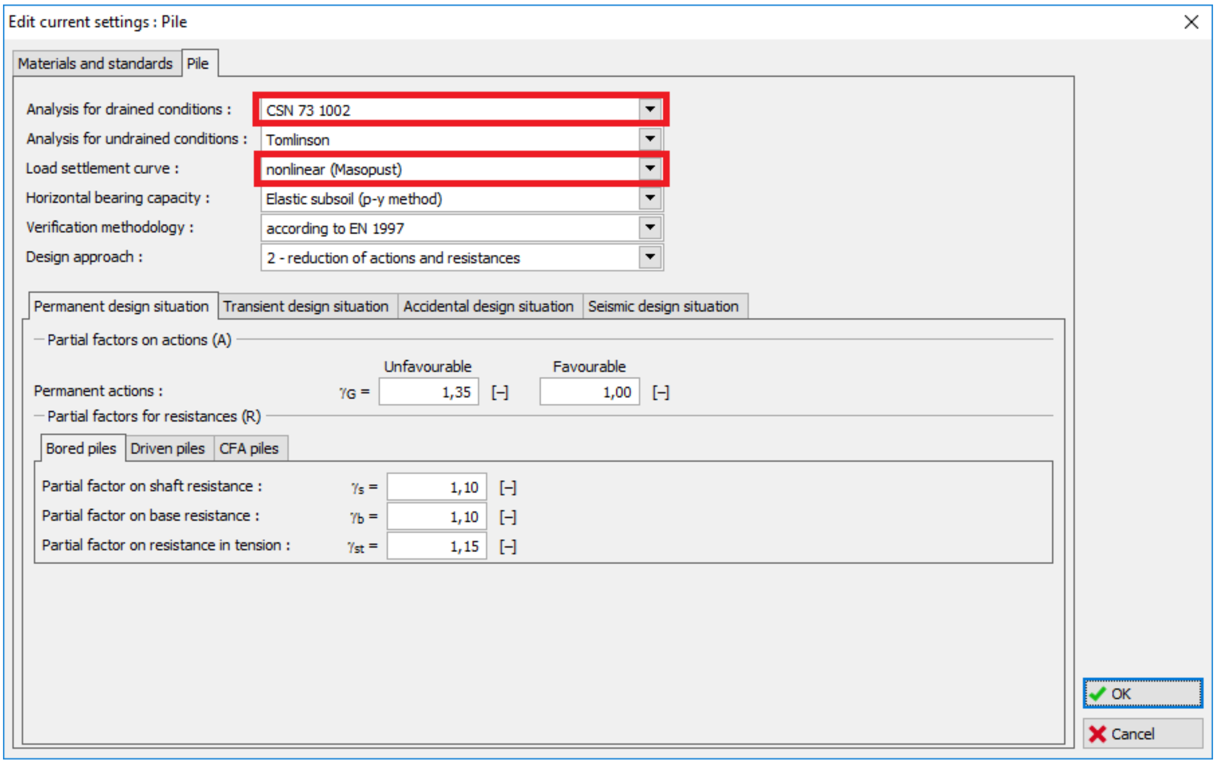
Linear loading curve Analysis method	Load at the onset of mobilization of skin friction R_{yu} $[kN]$	Total resistance R_c $[kN]$ for $s_{\lim} = 25{,}0\ mm$	Settlement of single pile s $[mm]$
NAVFAC DM 7.2	875,73	1326,49	11,3
EFECTIVE STRESS	2000,47	2303,4	6,1
CSN 73 1002	2215,89	2484,40	6,1

Summary of results – Settlement of a single pile according to Poulos

Analysis of single pile settlement: Nonlinear settlement theory (MASOPUST)

This solution is independent of the previous analyses of the vertical bearing capacity of a pile. The method is based on the solution to regression curve equations according to the results of static pile loading tests. This method is mostly used in Czechia and Slovakia. It provides reliable and conservative results for the local engineering geological conditions.

We will click on the "Edit" button in the "Settings" frame. In the "Pile" tab, we will choose the "nonlinear" option (Masopust)" for the loading curve.

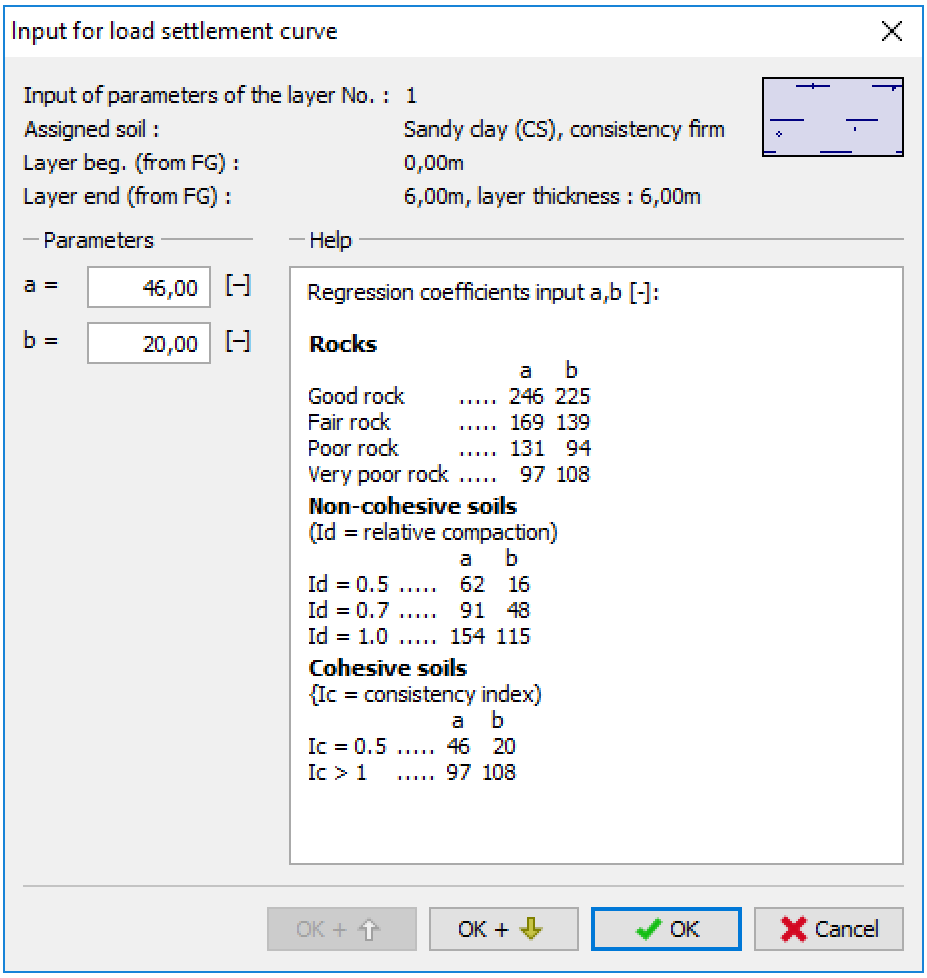


"Edit current settings" Dialog window

The other data remain unchanged. Then we will continue to the "Settlement" frame.

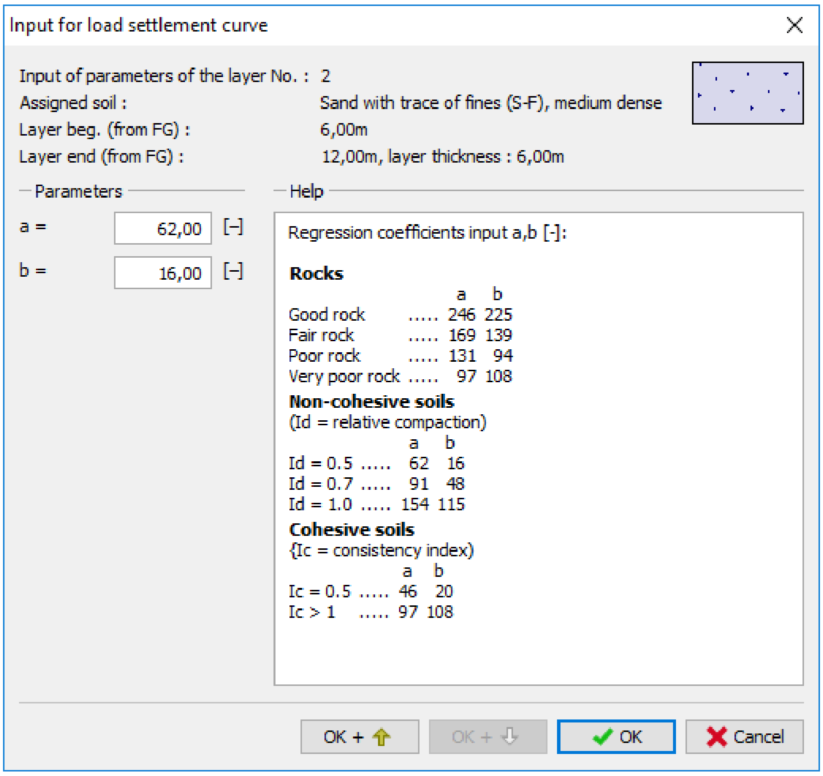
We consider the *service load* for the nonlinear limit loading curve because this is an analysis according to the limit state of serviceability. We will leave the shaft protection factor value at $m_2 = 1.0$. That means we will not reduce the resultant value of the vertical bearing capacity of the pile with respect to the installation technology. We will leave the values of the allowable (maximum) settlement $s_{\lim}$ and secant modulus of deformation E_s identical with those used in the previous analyses.

Furthermore, we will set the values of the regression coefficients using the "*Edit a, b*" and "*Edit e, f*" buttons, as shown in the figures below. While editing is being carried out, the values of regression coefficients recommended for various types of soils and rocks are displayed in the dialogue window.

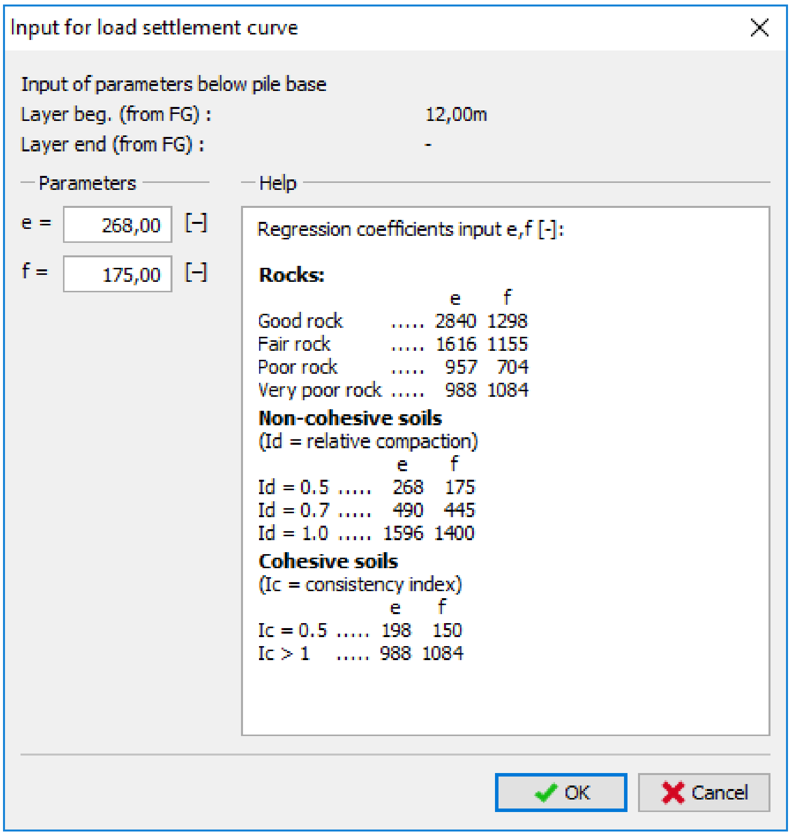


"Input for load settlement curve – regression coefficients a, b (e, f)" Dialog window – CS soil

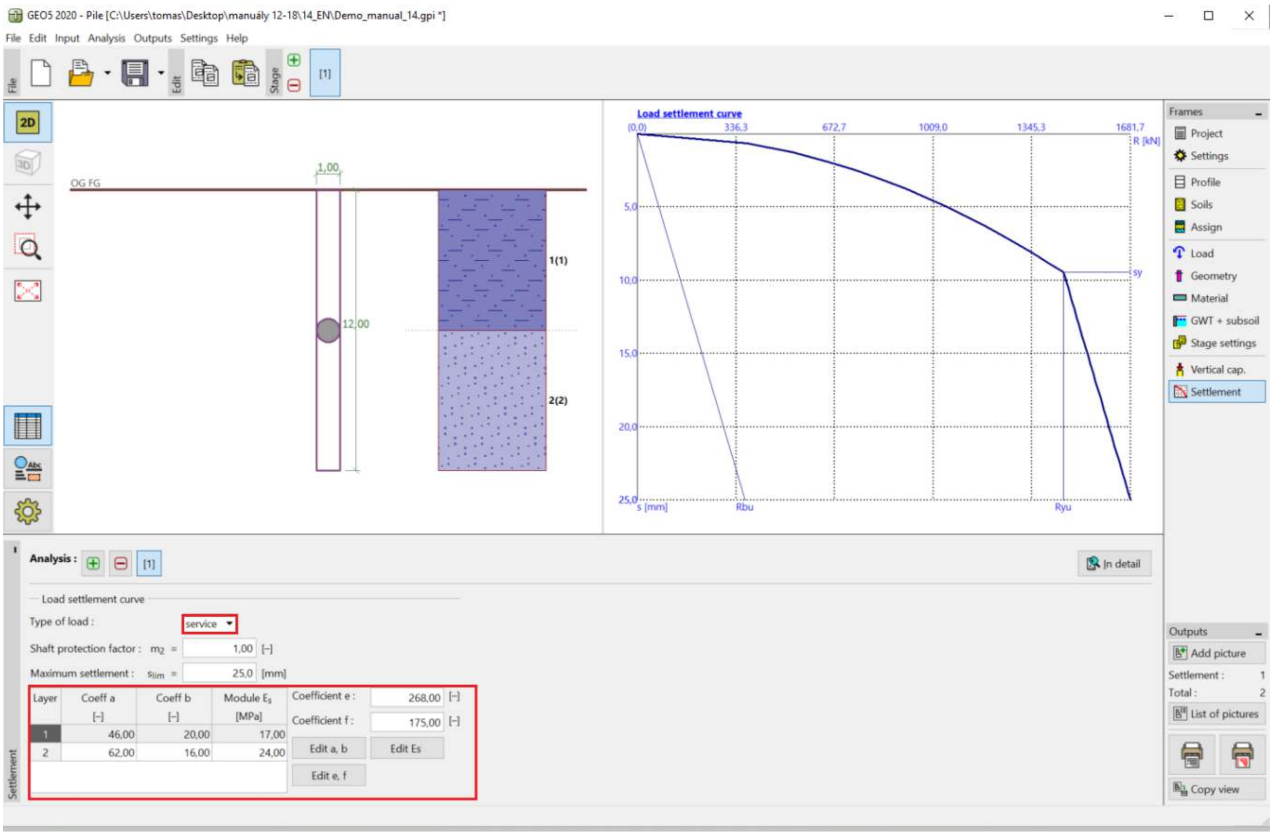
GEO5



"Input for load settlement curve – regression coefficients a, b" Dialog window – S-F soil



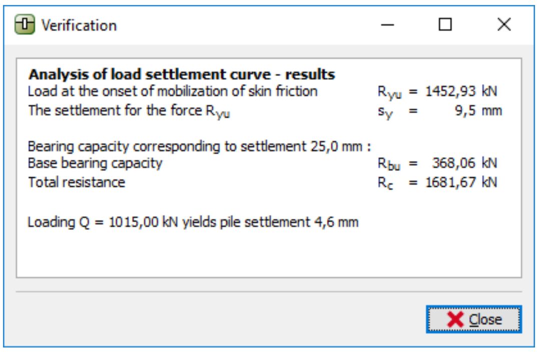
"Input for load settlement curve – regression coefficients e, f" Dialog window



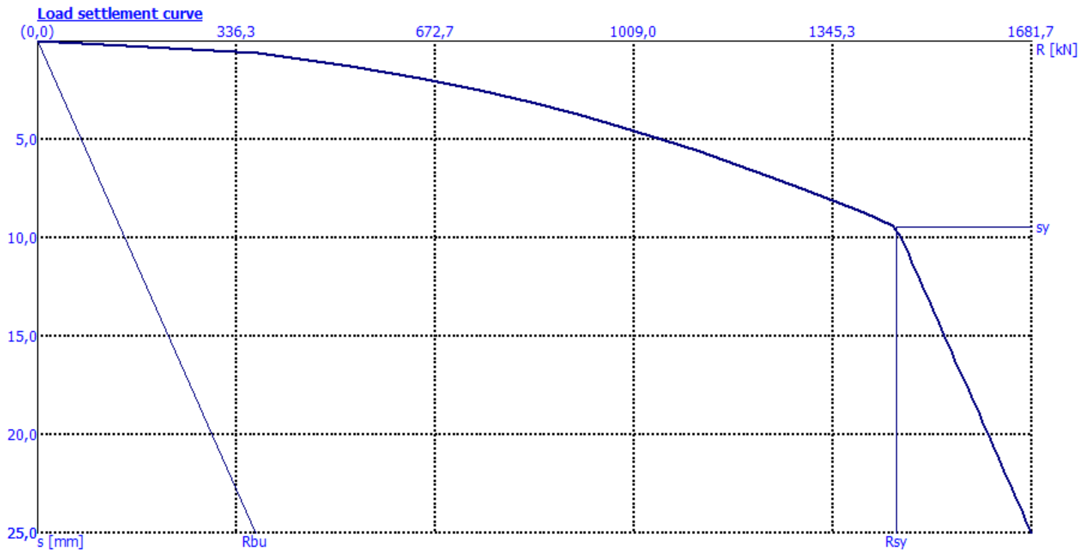
"Settlement" frame – solution according to the nonlinear settlement theory (Masopust)

Note: The specific skin friction depends on regression coefficients "a, b". The stress on the pile base (at fully mobilized skin friction) depends on regression coefficients "e, f". The values of these regression coefficients were derived from regression curve equations determined on the basis of a statistical analysis with results from about 350 static pile loading tests in Czechia and Slovakia (for more details visit the program help – F1). For cohesionless soils and cohesive soils, these values depend on the relative density index I_d and the consistence index I_c, respectively (for more details, visit the program help – F1).

The pile settlement for the specific service load is $s = 4.6\ mm$.



Results of settlement – nonlinear curve



"Settlement" frame – Nonlinear loading curve (according to Masopust)

Note: This method is also used for the pile load-bearing capacity analysis, where the program calculates the pile bearing capacity for the limit settlement on its own (usually 25 mm).

Total load-bearing capacity for $s_{\lim}$: $R_c = 1681.67\ kN > V_d = 1015.0\ kN$ SATISFACTORY

Conclusion

The program calculated the pile settlement for the specified service load to be within the range from 4,6 to 11,3 mm (depending on the method used). This settlement is smaller than the maximum allowable settlement – the pile is satisfactory from the 2nd limit state point of view.