Engineering manual No. 13

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Analysis of vertical load-bearing capacity of a single pile

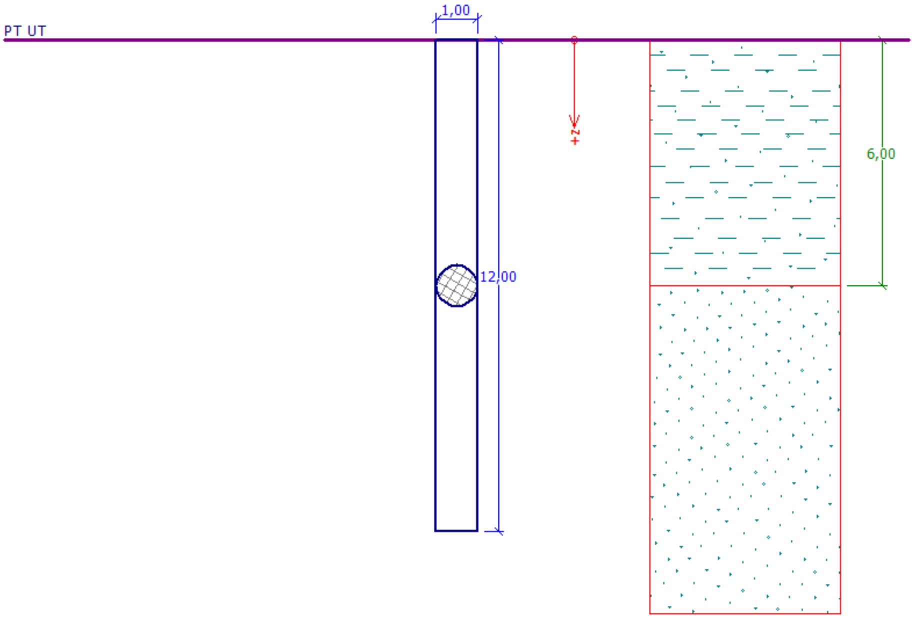
Program: Pile

File: Demo_manual_13.gpi

The objective of this engineering manual is to explain how to use the GEO 5 – PILES program for the analysis of vertical load-bearing capacity of a single pile in a specified practical problem.

Problem specification

A general specification of the problem was given in the previous chapter (*12. Pile foundations – Introduction*). All analyses of the vertical load-bearing capacity of a single pile shall be carried out in compliance with EN 1997-1 (Design approach 2). The resultant of the loading components $N_1, M_{y,1}, H_{x,1}$ acts at the pile head.



Problem specification schema – single pile

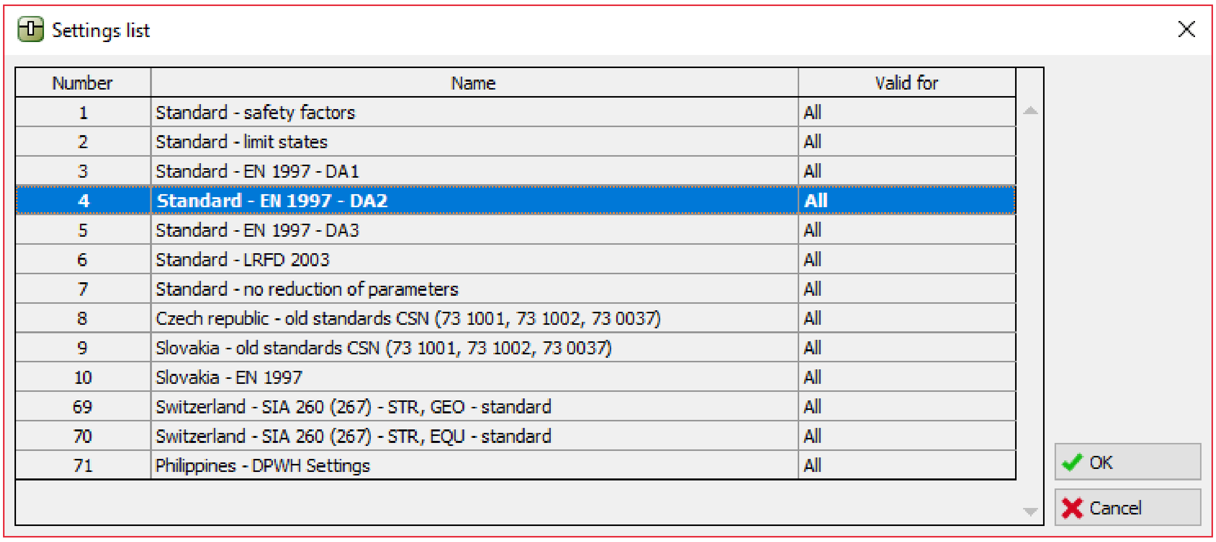
Solution

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

In this analysis we will assess a single pile using various analytical calculation methods (NAVFAC DM 7.2, EFFECTIVE STRESS and CSN 73 1002) and focus on the ***input parameters,*** which influence the overall results.

Specification input

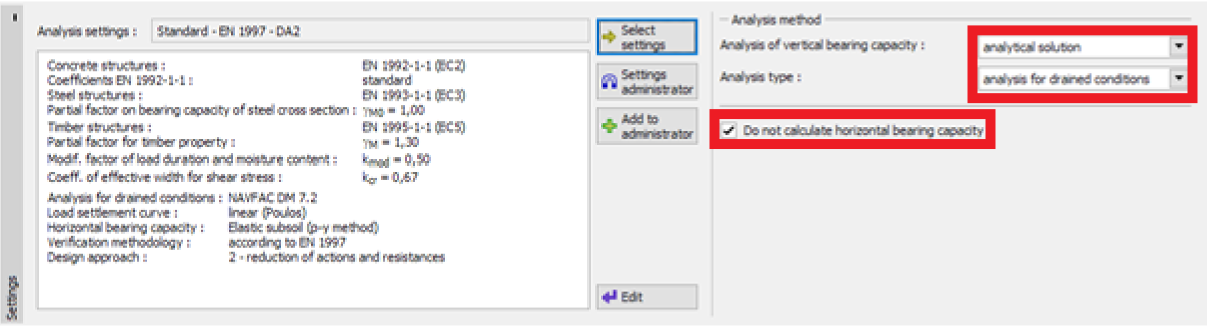
First of all, click on the “select settings” button (on the bottom of the screen) in the “Settings” frame and then select option no. 4 - “Standard – EN 1997 – DA2” analysis setting. Further, we set the method of the analysis of a vertical load-bearing capacity of a pile using *the analytical solution.* In our case we will assess the pile in ***drained conditions***.



Dialog window “Setting list”

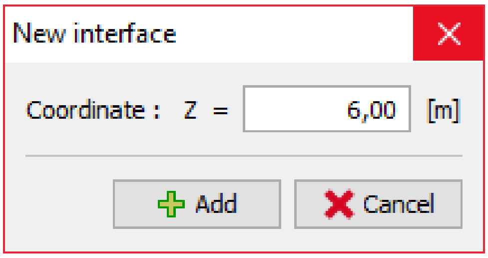
For the initial assessment of the pile, we will use the NAVFAC DM 7.2 method, which is the default one for this analysis setting (see the *figure below*).

We will not analyse horizontal bearing capacity in this task, so we check the “Do not calculate horizontal bearing capacity” option.



Frame “Settings“

Next, go to the frame “Profile”, where we’ll add a new interface at 6,0 m.



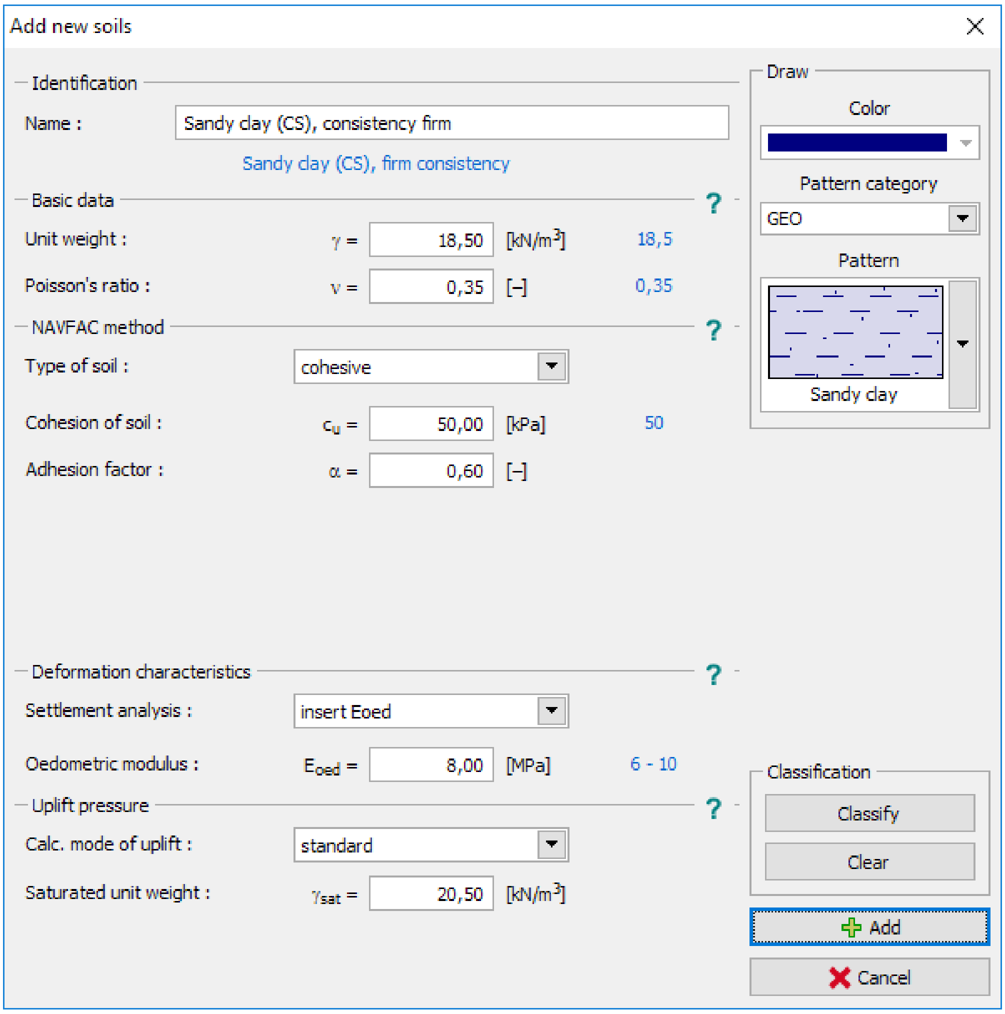
Frame "Profile" – add a new interface

Then, we will go to the frame "Soils", where we define the parameters of soils required for the analysis and assign them to the profile. The **NAVFAC DM 7.2** method requires that the soil type is defined first, i.e. whether it is a cohesive or cohesionless soil layer. All the parameters listed below influence the magnitude of skin friction R_s $[kN]$.

Soil (Soil classification)	Unit weight γ $[kN/m^3]$	Angle of internal friction φ_{ef} $[°]$	Cohesion of soil c_{ef} / c_u $[kPa]$	Adhesion factor α $[-]$	Bearing capacity coefficient β_p $[-]$
CS – Sandy clay, firm consistency	18,5	24,5	- / 50	0,60	0,30
S-F – Sand with trace of fines, medium dense soil	17,5	29,5	0 / -	-	0,45

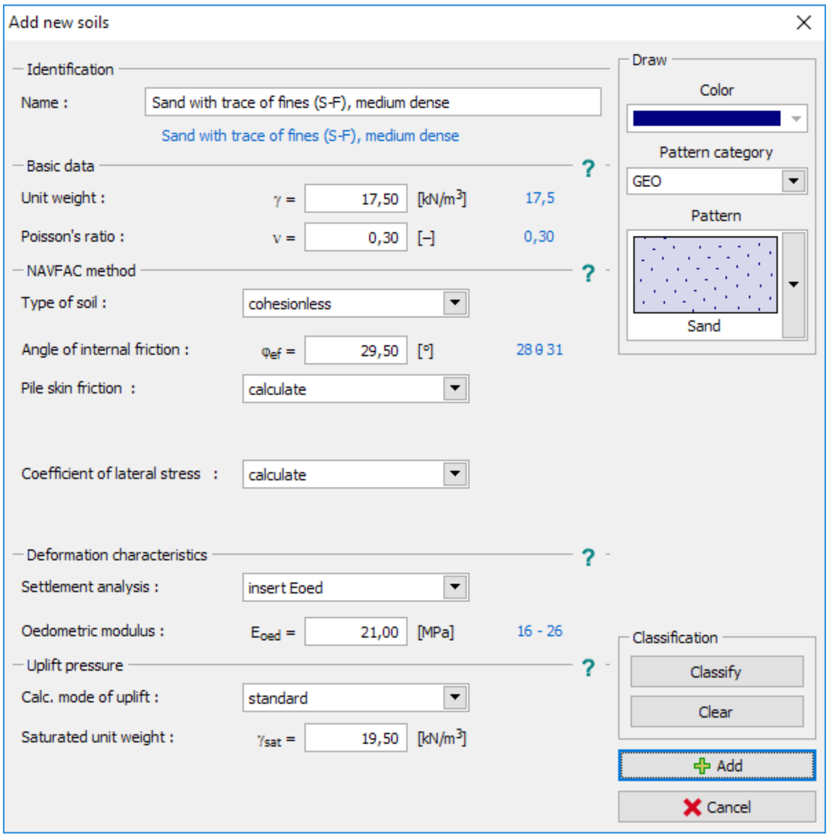
Table with the soil parameters – Vertical bearing capacity (analytical solution)

For the 1st layer, which is considered as an ***undrained cohesive soil*** (class F4, firm consistency), we must in addition specify the total soil cohesion (undrained shear strength) c_u $[kPa]$ and the so-called adhesion factor α $[-]$. This factor is determined relative to the soil consistency, pile material and total soil cohesion (for more details visit the program help – F1).



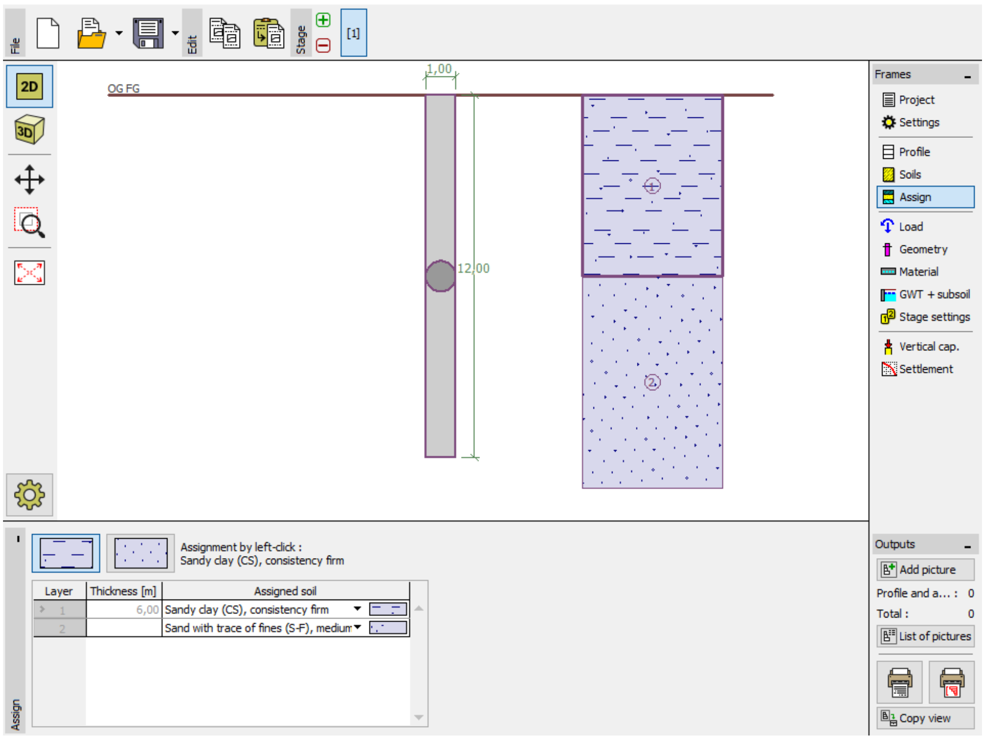
Dialog window "Add new soils" – soil CS

For the 2nd layer, which is considered a ***cohesionless soil*** (class S3, medium dense), we must in addition specify the angle of skin friction $\delta\,[°]$, which depends on the pile material. Furthermore, we must define the coefficient of lateral stress $K\,[-]$, which is affected by the type of loading (tension – pressure) and by the pile installation technology (for more details visit the program help – F1). To simplify the problem, we will select the option "calculate" for both variants.



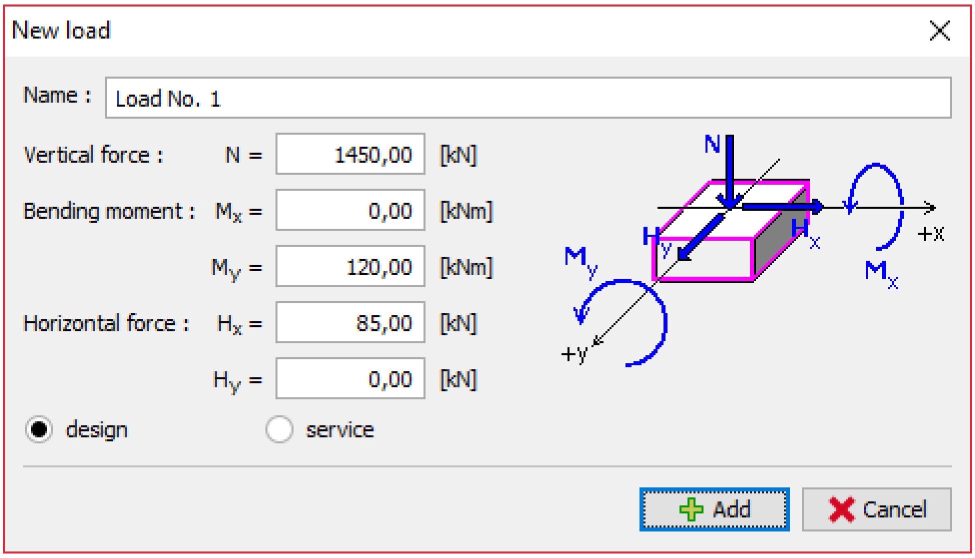
Dialog window "Add new soils" – soil S-F

Then, assign the soils to the profile in the frame "Assign".



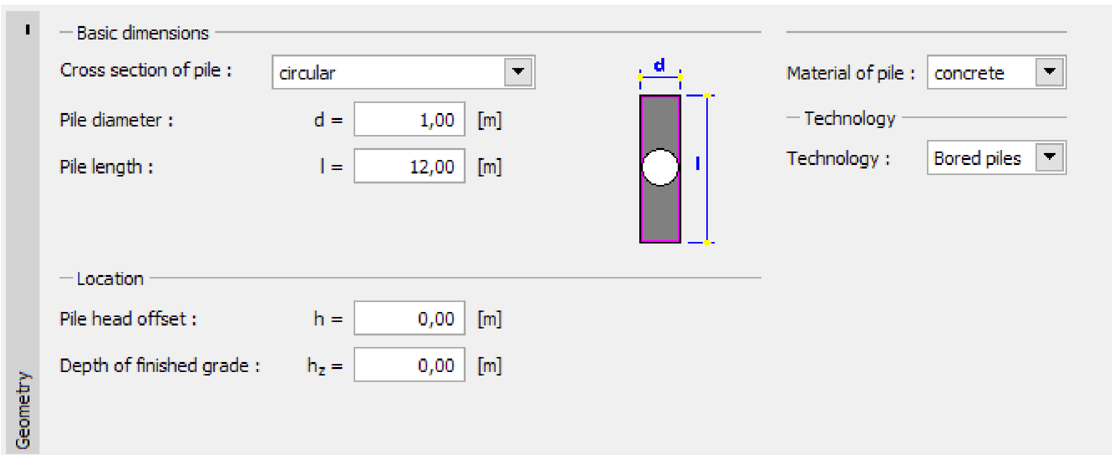
Frame "Assign" – assigning soils to profile

Next, we will define the load acting on the pile in the frame "Load". The design (calculation) loading is considered in the calculation of the vertical load-bearing capacity of the pile, while the service load is considered in the calculation of settlement. Therefore, we will add a new design load as shown in the figure below.



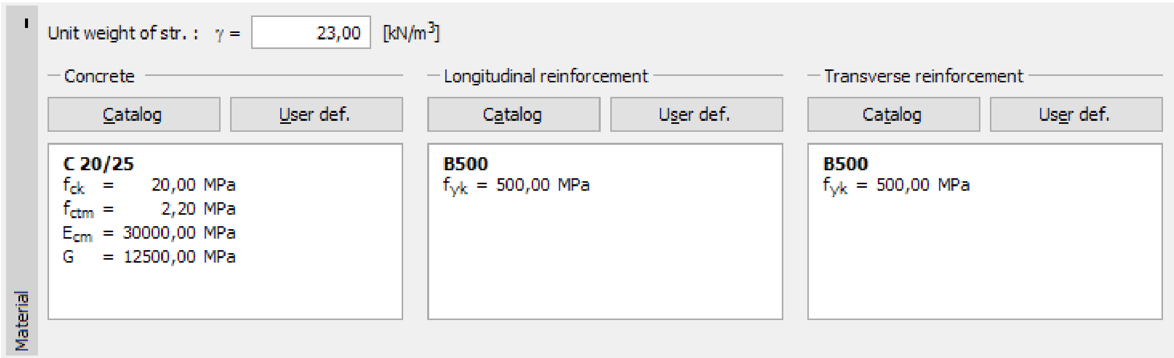
Dialogue window "New load"

In the "Geometry" frame we will specify the circular cross-section of the pile and further determine its basic dimensions, i.e. its diameter and length. Then, we will define the type of the pile installation technology.



"Geometry" frame

In the "Material" frame, we will specify the material characteristics of the pile – the unit weight of the structure $\gamma = 23.0\ kN/m^3$.



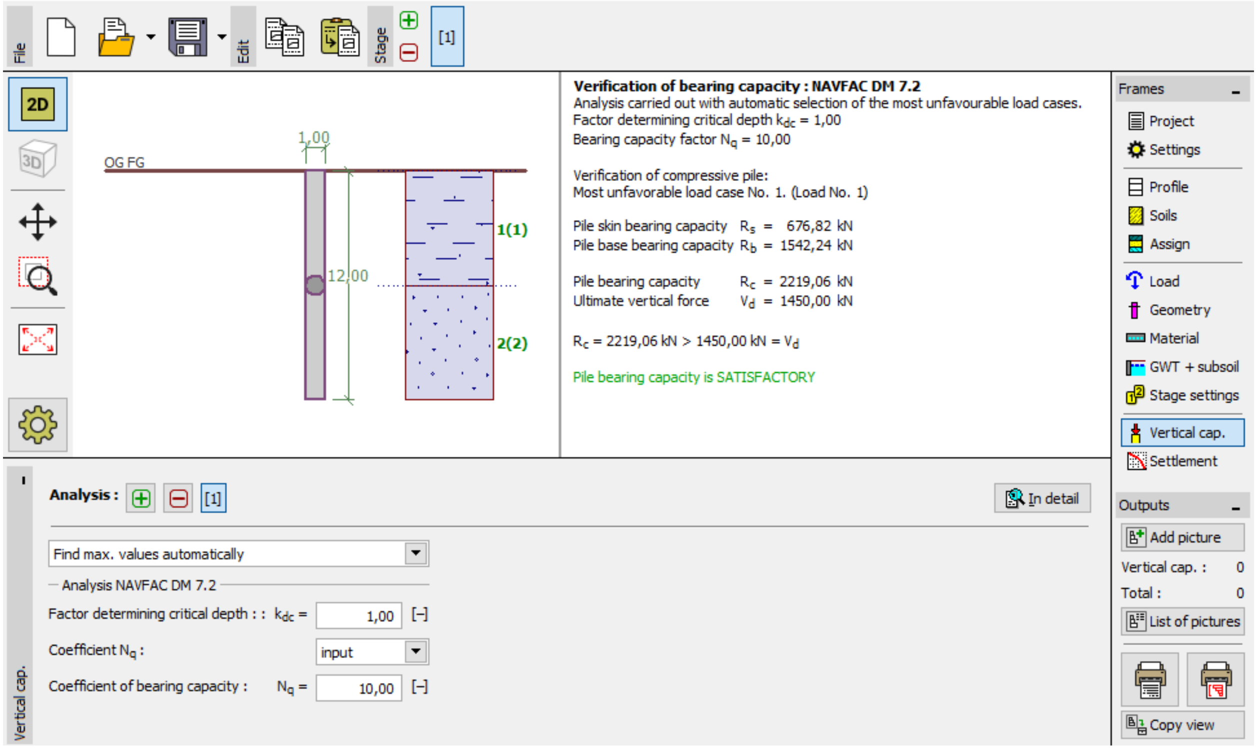
"Material" frame

We will not change anything in the "GWT + subsoil" frame. In the "Stage settings" frame we will leave the permanent design situation set and then continue to the assessment of the pile using the "Vertical capacity" frame.

Analysis of vertical load-bearing capacity of a single pile – NAVFAC DM 7.2 analysis method

In the "Vertical capacity" frame, we must firstly specify the calculation parameters affecting the magnitude of the pile base bearing capacity R_b $[kN]$. First, we will define the critical depth k_{dc} $[-]$ analysis coefficient, which is derived from the so-called critical depth depending on the soil density (for more details visit the program help – F1). We will consider this coefficient as $k_{dc} = 1{,}0$.

Another important parameter is the coefficient of bearing capacity N_q $[-]$, which is determined by the soil internal friction angle φ_{ef} $[°]$ relative to the pile installation technology (for more details visit the program help – F1). In this case we will consider $N_q = 10.0$.



"Vertical capacity" frame – assessment according to NAVFAC DM 7.2"

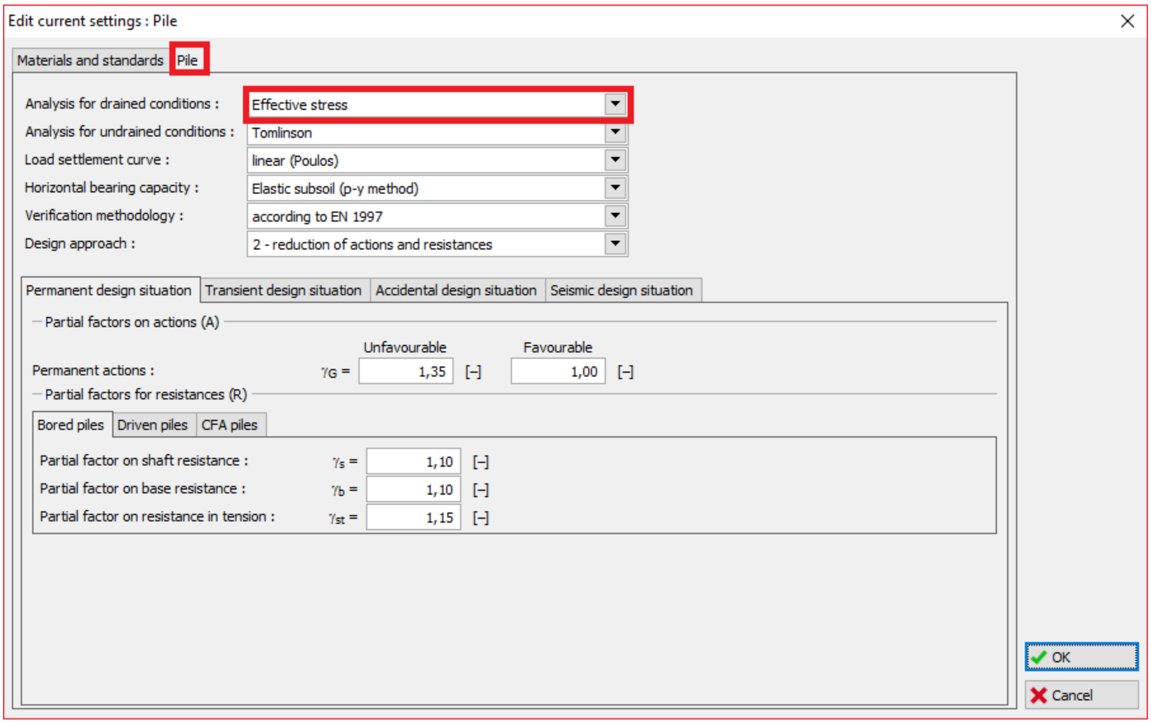
The design vertical bearing capacity of a centrally loaded pile R_c $[kN]$ consists of the sum of the skin friction R_s and the resistance on pile base R_b. To meet the condition for reliability, its value must be higher than the magnitude of the design load V_d $[kN]$ acting on the pile head.

– **NAVFAC DM 7.2**: $R_c = 2219.06\ kN > V_d = 1450.0\ kN$ SATISFACTORY

Analysis of vertical load-bearing capacity of a single pile – EFFECTIVE STRESS analysis method

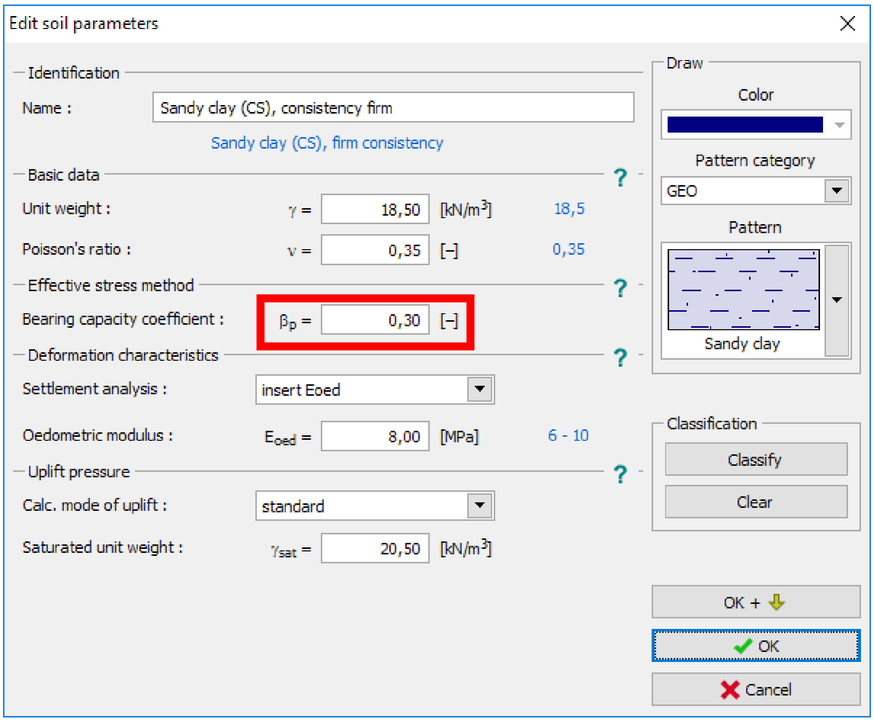
Now we will get back to the input settings and carry out the analysis of the vertical bearing capacity of a single pile using other analysis methods (Effective stress and CSN 73 1002).

In the "Settings" frame, click on the "Edit" button. Then, in the "Pile" tab, select the "Effective stress" option. The other parameters will remain unchanged.

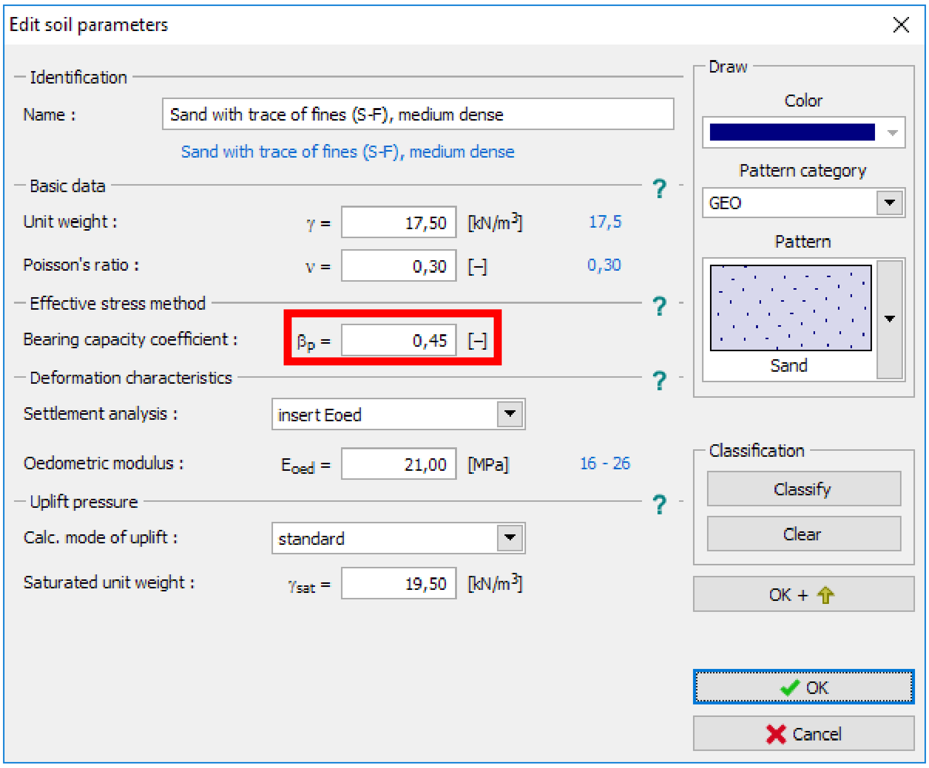


Dialog window "Edit current settings"

Then, we will proceed to the "Soils" frame. This analysis method requires that we additionally define the coefficient of pile bearing capacity β_p $[-]$ which affects the magnitude of skin friction R_s $[kN]$. This parameter is determined by the soil internal friction angle φ_{ef} $[°]$ and the soil type (for more details visit the program help – F1).



Dialog window "Edit soil parameters" – soil CS



Dialog window "Edit soil parameters" – soil S-F

The other frames remain unchanged. Now we will get back to the "Vertical capacity" frame. For the **Effective Stress** method, we must first specify the value of the coefficient of bearing capacity N_p $[-]$, which significantly affects the pile base bearing capacity R_b $[kN]$. This parameter is determined by the soil internal friction angle φ_{ef} $[°]$ and the soil type (for more details visit the program help – F1).

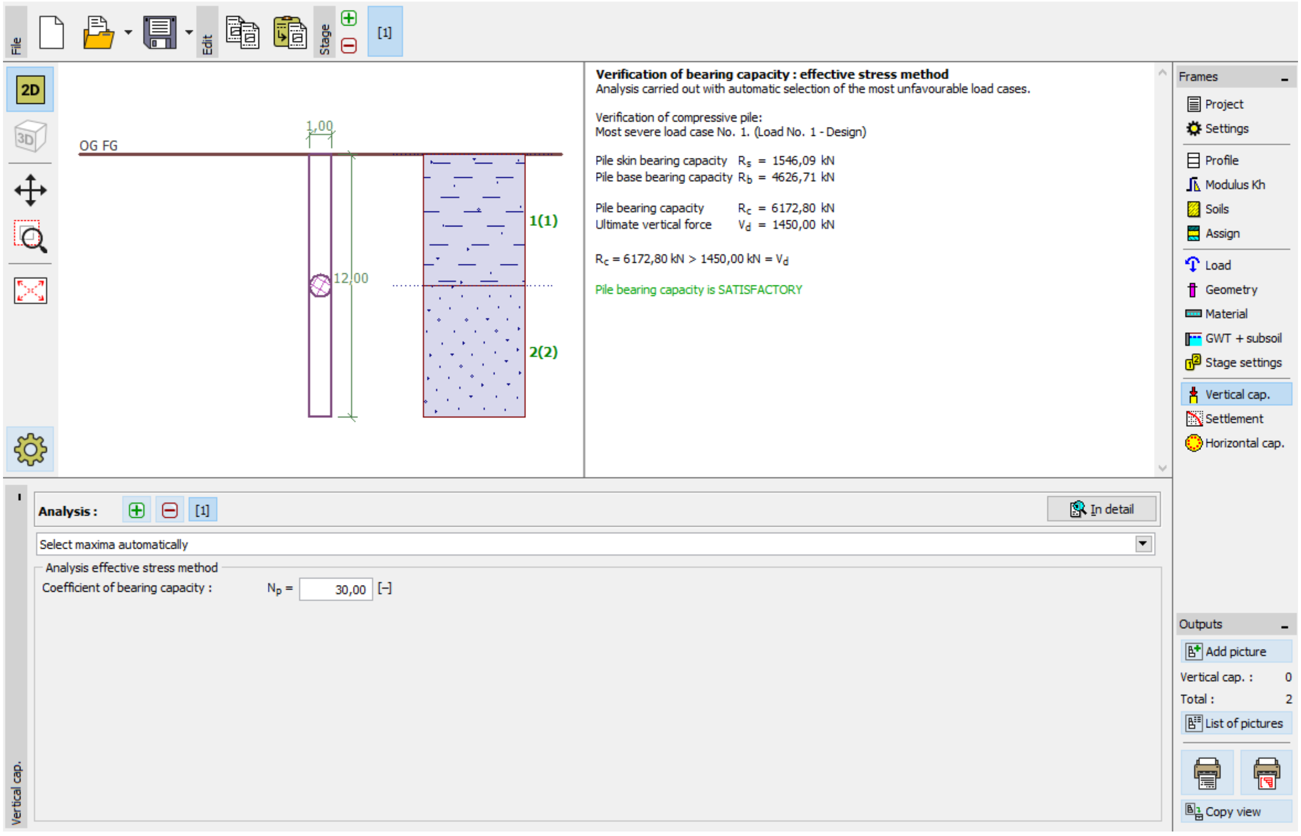
The significant influence of this parameter on the result is demonstrated by the following table:

– for $N_p = 10$ (pile base in *clayey* soil): $R_b = 1542.24\ kN$,

– for $N_p = 30$ (pile base in *sandy* soil): $R_b = 4626.71\ kN$,

– for $N_p = 60$ (pile base in *gravelly* soil): $R_b = 9253.42\ kN$.

In our problem, we consider the coefficient of bearing capacity $N_p = 30$ (the pile base in *sandy* soil). The guidance values of N_p can be found in the program help – for more details visit F1.

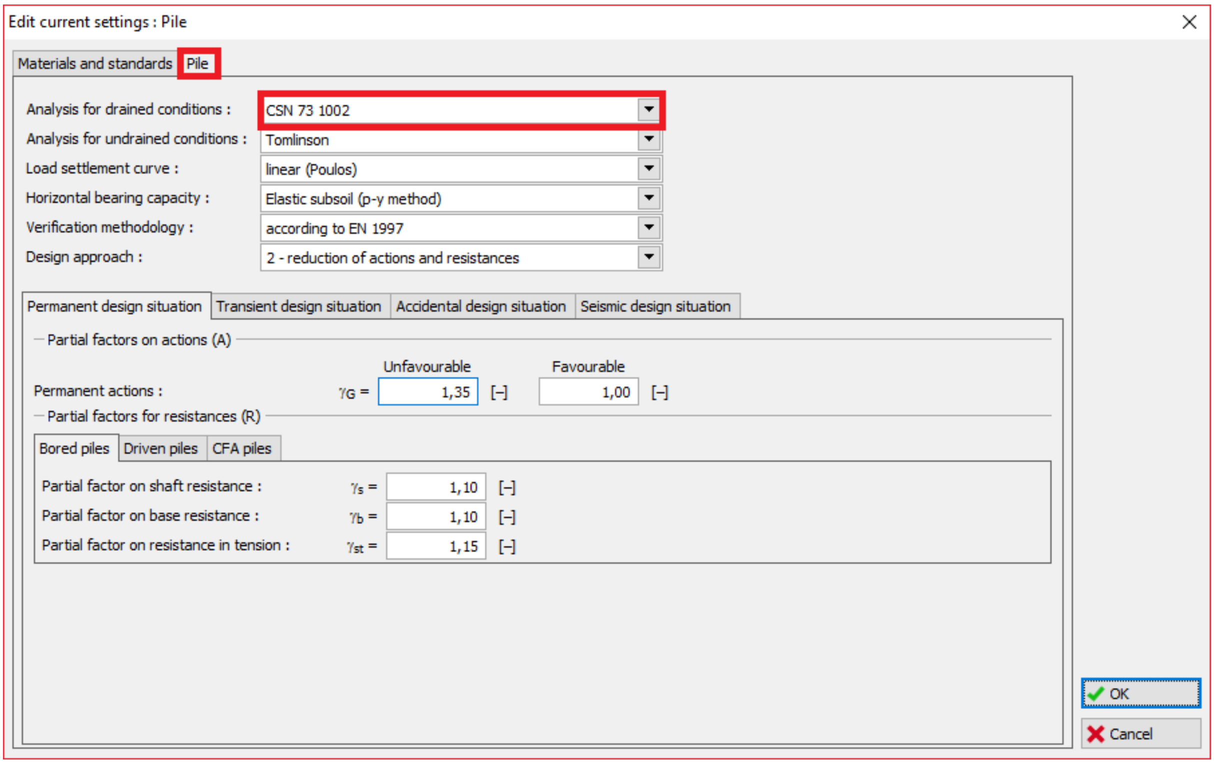


"Vertical capacity frame – assessment according to the Effective Stress method"

– **EFFECTIVE STRESS**: $R_c = 6172.8\ kN > V_d = 1450.0\ kN$ SATISFACTORY

Analysis of vertical load-bearing capacity of a single pile – CSN 73 1002 analysis method

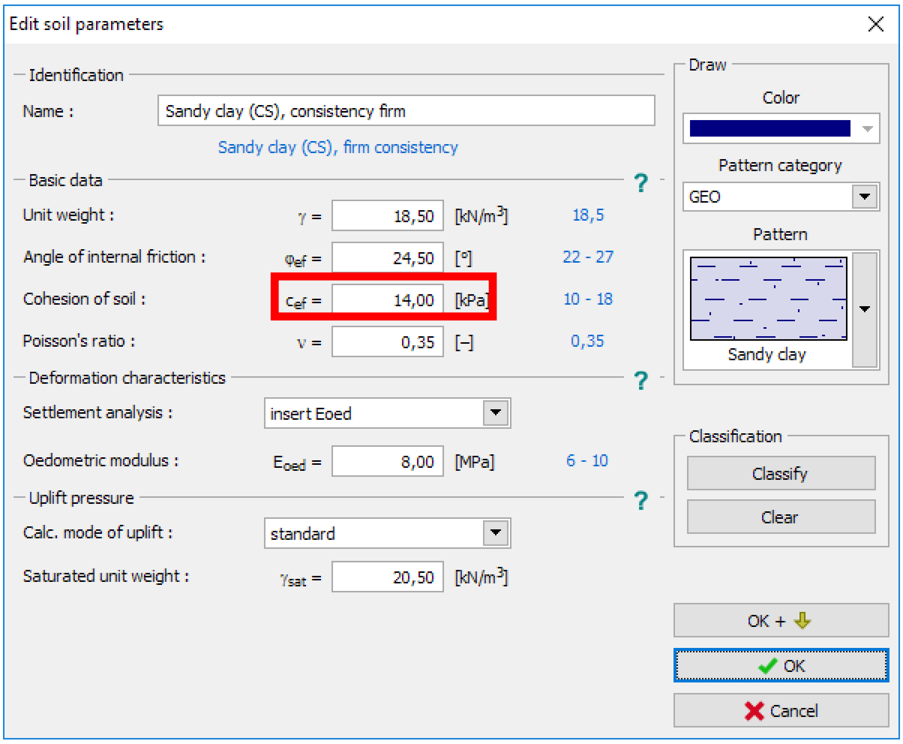
Now we will get back to the "Settings" frame, where we will change the analysis method for drained conditions by clicking the "Edit" button and changing the analysis method to "*CSN 73 1002*". All the other input parameters will remain unchanged.



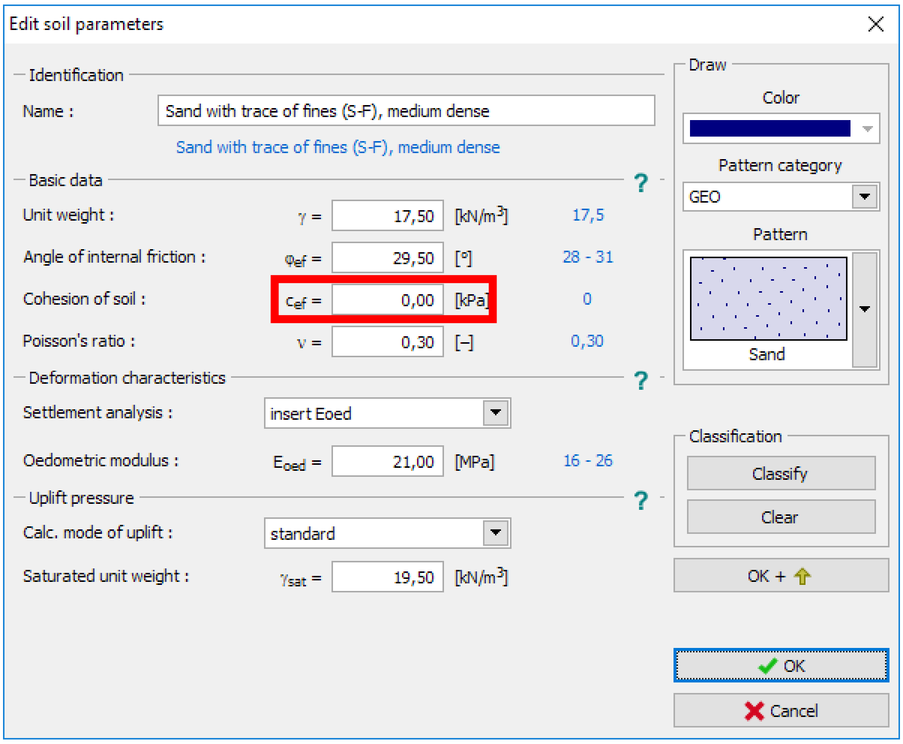
Dialogue window "Edit current settings"

Note: The analysis procedure is presented in the publication "Pile foundations – Comments on CSN 73 1002" (Chapter 3: Designing, part B – General solution according to group 1 of the limit states theory, page 15). All program procedures are based on the relationships contained in this text, with the exception of calculation coefficients, which depend on the assessment methodology adopted (for more details visit the program help - F1).

Now we will go back to the frame "Soils", where it is necessary to define effective soil parameters for each soil.

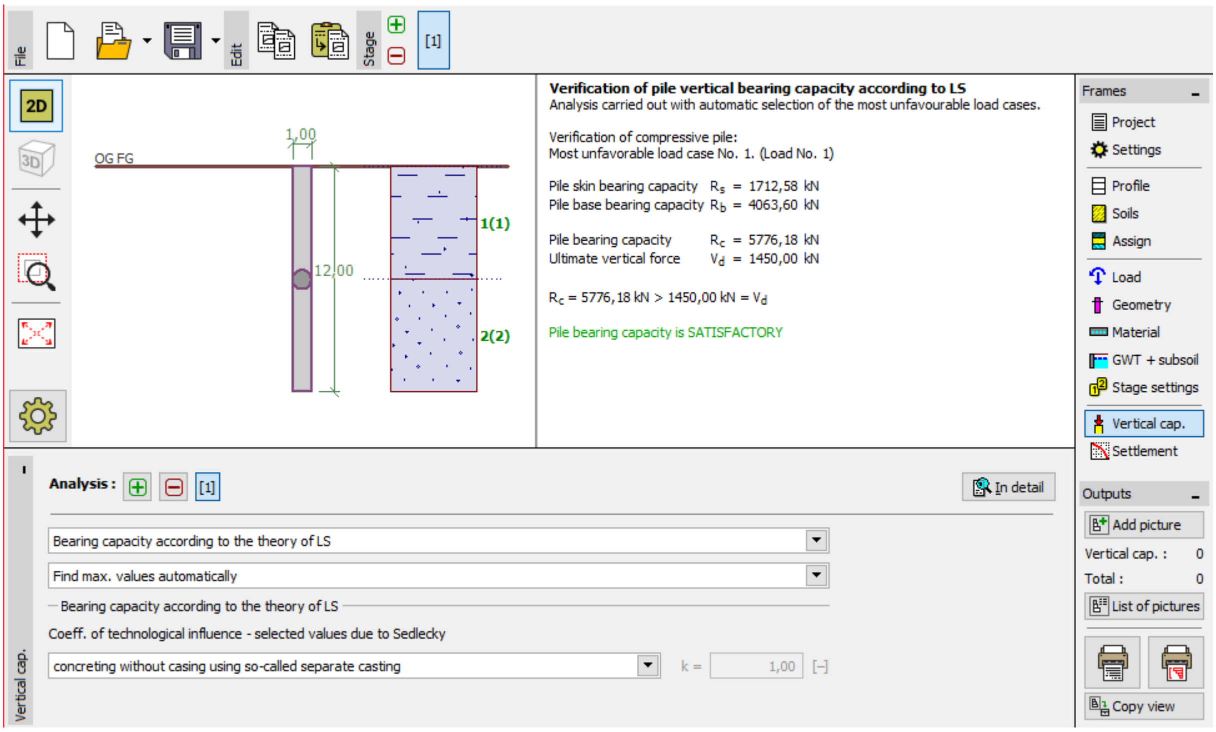


Dialog window "Edit soil parameters" – soil CS



Dialog window "Edit soil parameters" – soil S-F

Subsequently, we will re-assess the pile in the "Vertical capacity" frame. We will leave the coefficient of technological influence equal to 1.0 (the analysis of vertical load-bearing capacity of a pile without the reduction due to installation technology).



"Vertical capacity – assessment according to CSN 73 1002" frame

– **CSN 73 1002**: $R_c = 5776.18\ kN > V_d = 1450.0\ kN$ SATISFACTORY

Vertical load-bearing capacity of a single pile analysis results

The values of the total vertical bearing capacity R_c of a pile differ depending on the analysis methods used and the input parameters assumed by these methods:

NAVFAC DM 7.2: adhesion factor α $[-]$,

pile skin friction angle δ $[°]$,

coefficient of lateral soil stress K $[-]$,

critical depth analysis coefficient k_{dc} $[-]$,

coefficient of bearing capacity N_q $[-]$.

EFFECTIVE STRESS: coefficient of pile bearing capacity β_p $[-]$, coefficient of bearing capacity N_p $[-]$.

CSN 73 1002: soil cohesion c_{ef} $[kPa]$,

soil internal friction angle φ_{ef} $[°]$.

The results of the analysis of the vertical bearing capacity of a single pile in drained conditions relative to the analysis method used are presented in the following table:

EN 1997-1, DA2 (drained conditions) Analysis method	Pile skin bearing capacity R_s $[kN]$	Pile base bearing capacity R_b $[kN]$	Vertical bearing capacity R_c $[kN]$
NAVFAC DM 7.2	676.82	1542.24	2219.06
EFECTIVE STRESS	1546.09	4626.71	6172.80
CSN 73 1002	1712.58	4063.60	5776.18

Summary of results – Vertical bearing capacity of a pile in drained conditions

The total vertical bearing capacity of a centrally loaded single pile R_c is higher than the value of the design load V_d acting on it. The fundamental reliability condition for the ultimate limit state is met; the pile design is therefore satisfactory.

Conclusion

It follows from the analysis results that the total vertical bearing capacity of a pile differs in each calculation. This fact is caused both by the different input parameters and by the chosen analysis method.

The assessment of piles mostly depends on the chosen analysis method and the input parameters describing the soil. Designers should always use calculation procedures for which they have the required soil parameters available, for example values resulting from the results of geological surveys or values that reflect local practices.

It is certainly improper to assess a pile using all analysis methods contained in the program and choose the best or the worst results.

For the Czech and Slovak Republic, the GEO 5 software authors recommend calculating the vertical load-bearing capacity of a single pile using the following two methods:

- An analysis taking into consideration the value of the allowable settlement $s_{\lim} = 25\ mm$ (the procedure according to ***Masopust***, which is based on the solution of regression curves equations).

- An analysis according to ***CSN 73 1002***. The pile analysis procedure remains identical with that contained in CSN, but the loading and calculation coefficients reducing the soil parameters or the pile resistance are specified according to EN 1997-1. This analysis therefore fully complies with EN 1997-1.