Analysis of the vertical load bearing capacity and settlement of a pile group

Program: Pile Group

Soubor: Demo_manual_17.gsp

The objective of this engineering manual is to explain how to utilize the GEO 5 – PILE GROUP program.

Introduction

All analyses in the Pile Group program can be divided into two groups:

– Spring Method,

– Analytical solutions.

The Spring Method calculates the deformation of the entire pile foundation and determines the internal forces along the lengths of the individual piles. The loading is defined as a general active combination of $N, M_x, M_y, M_z, H_x, H_y$. An important result of a spring method analysis is the rotation and the displacement of the rigid pile cap and the dimensioning of the reinforcement cage for individual piles. The Spring Method is further explained in the following chapter *18. Analysis of deformation and dimensioning of a pile group*.

The analytical solution is used to analyse the vertical bearing capacity of a pile group loaded solely by a vertical normal force. This type of analysis yields the vertical bearing capacity of the pile foundation and the average settlement of the pile.

The analytical solution is further divided according to the soil type:

– for cohesive soils,

– for cohesionless soils.

The vertical bearing capacity of a pile group in **cohesive soil** is considered in undrained conditions. It is determined as the bearing capacity of an earth body in the form of a prism drawn around the pile group according to the FHWA. Only the total soil cohesion (undrained shear strength) c_u is specified for the purpose of the analysis.

The settlement of a pile group in cohesive soil (in undrained conditions) is based on the calculation of the settlement of a substitute spread foundation (the so-called *consolidation settlement of a pile group*, often abbreviated as the *2:1 method)*.

In order to assess the pile group settlement, the analysis incorporates the influence of the foundation depth and the thickness of the deformation zone according to the methodology for the calculation of the spread foundation settlement. When doing a pile group settlement analysis in Czechia or Slovakia, it is possible to use the procedure according to *CSN 73 1001 – Ground under spread foundations* .

The assessment of a pile group in **cohesionless soil** is based on procedures identical to those used for the analysis of a single pile in cohesionless soil (as described in chapter *13. Analysis of the vertical load-bearing capacity of a single pile*). The only addition to the process is the usage of the so-called *efficiency of a pile group*, which reduces the total vertical bearing capacity of the pile foundation.

The loading curve of a pile group in cohesionless soil is constructed the same way as the curve for a single pile (shown in chapter *14. Analysis of single pile settlement*) according to prof. H. G. Poulos, with the exception of the total settlement of the pile group. The total settlement is increased by the so-called group settlement factor g_f, which allows for the group effect of individual piles. The magnitude of this parameter depends on the geometrical arrangement of the pile group.

Problem specification

The general specification of the problem was described in the previous chapter (*12. Pile foundations – Introduction*). Carry out all the calculations for the vertical bearing capacity of a pile group in accordance with EN 1997-1 (DA 2) based on problem *13. Analysis of the vertical load-bearing capacity of a single pile.* The resultant of the total loading, which consists of N, M_y, H_x, acts at the upper base of the pile cap, right at its centre.
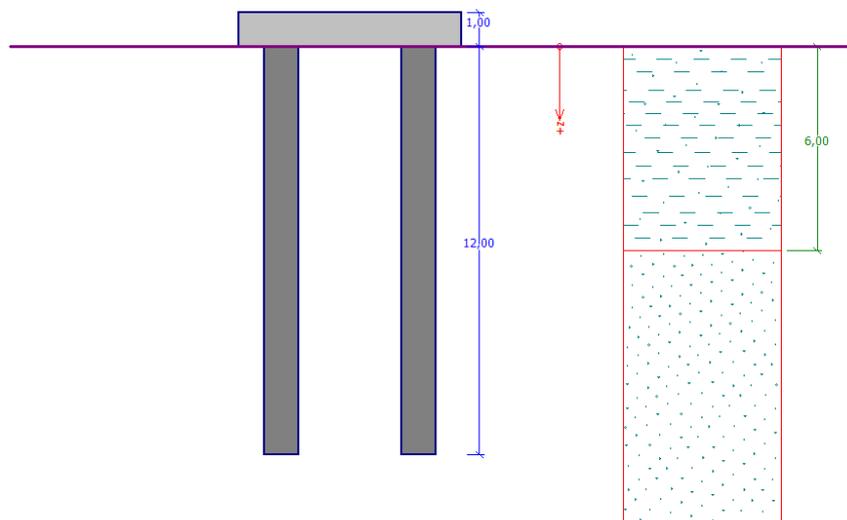

Problem specification schema – pile group

Solution

We will use the GEO 5 – PILE GROUP program to analyse this problem. To simplify the problem and quicken the input of the general problem parameters (the design, soil, assigning and the profile) we will import data from problem no. *13. Analysis of the vertical load-bearing capacity of a single pile*.

In this analysis, we will assess the pile group using the same analytical methods that we previously used when analysing a single pile (NAVFAC DM 7.2, EFFECTIVE STRESS and CSN 73 1002). We will focus on other input parameters that affect the overall results.

Specification procedure

In the "Settings" frame we will click on the "Select settings" button and then choose the "Standard – EN 1997 – DA2" calculation setting. We will keep the analysis type option on *"analytical solution"*. In our particular case we will consider the type of soil to be **cohesionless** because we will assess the piles in *drained conditions*.
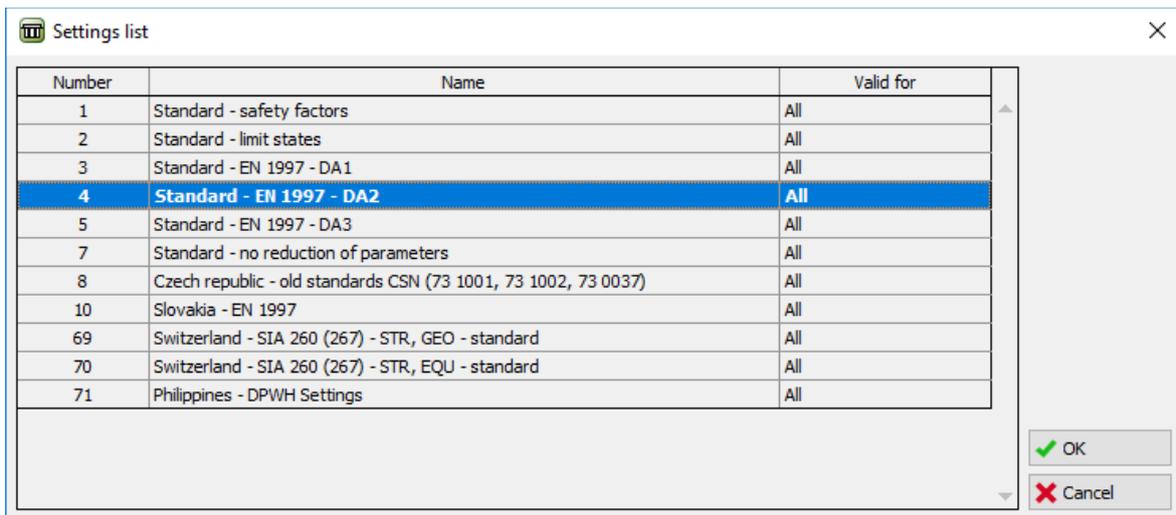

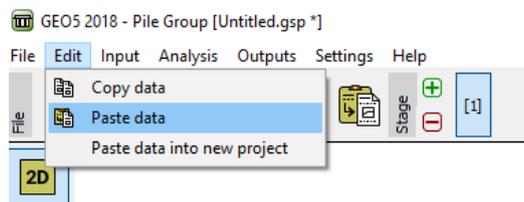*Dialogue window "Setting list"*
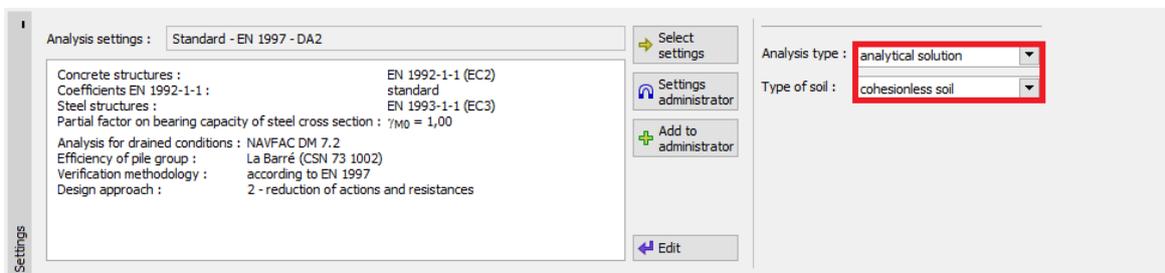
Frame "Settings"

We will import the data to avoid inputting everything again. In order to import the data into the Pile group program, we first have to open the file from manual no. 13 - *Analysis of vertical bearing*

capacity of a single pile in the GEO5 – Pile program. In the upper toolbar, we will click on the "Edit" button and then select the "Copy data" option.
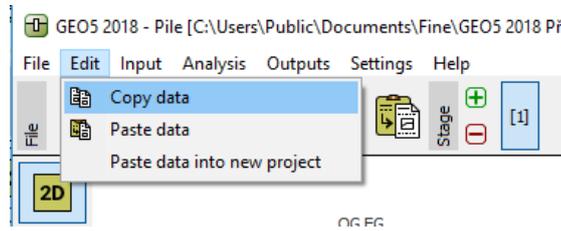

Program "Pile"

Subsequently, in the GEO 5 – Pile Group program, we will again click on the "Edit" button in the upper toolbar and choose the "Paste data" option. Through this step, the data required for the analysis will be transferred and a significant part of the work with inserting input data will be done.


Program "Pile Group"

In the dialog window that appears, we will choose to paste all data except for "Settings", "Load - LC" and "GWT + subsoil".
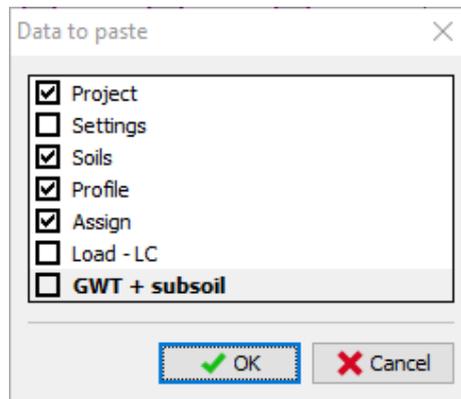

Dialogue window "Data to paste"

Now we will move to the "Structure" frame. Here we can specify the ground plan dimensions of the base slab (the pile cap), the number of piles in the group, their diameter and the spacing of their centres (between piles in direction x, or y). We will set the width of the pile cap as 6.50 m and input the number of piles as 2 in both x and y directions.
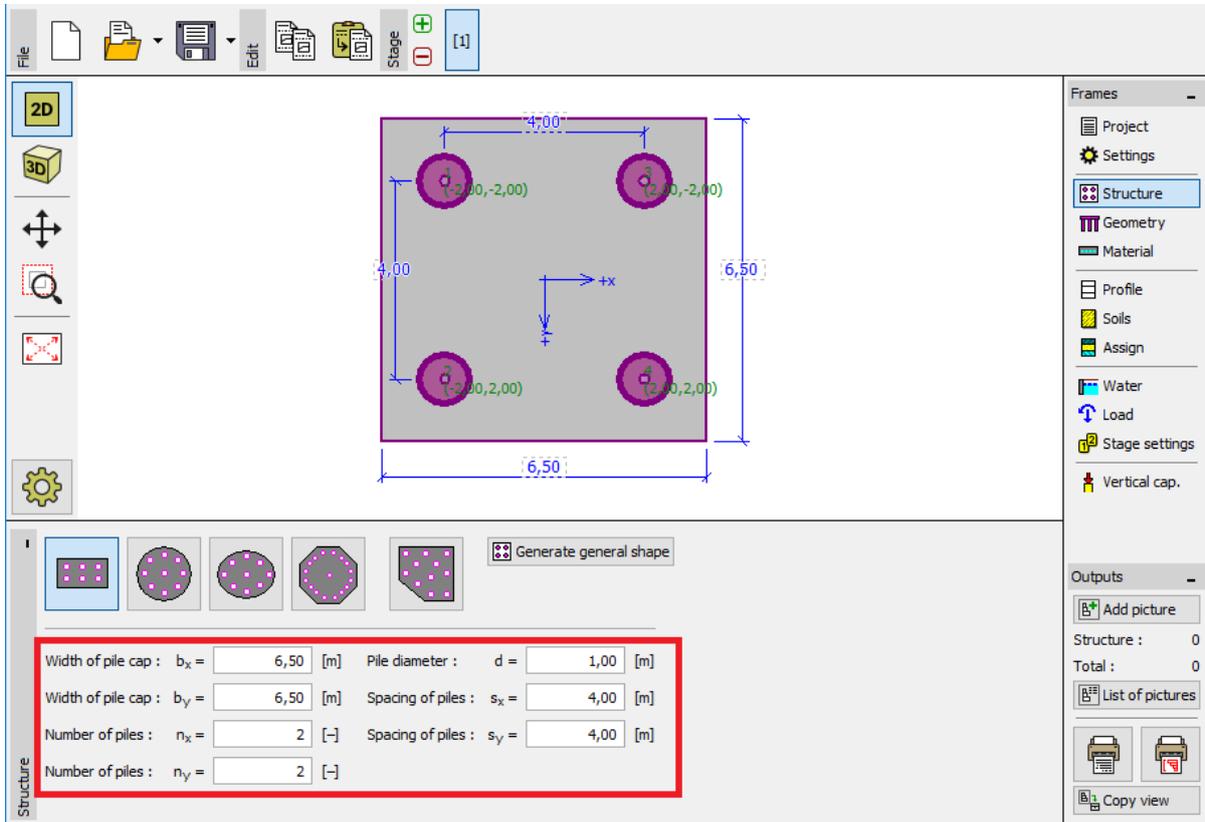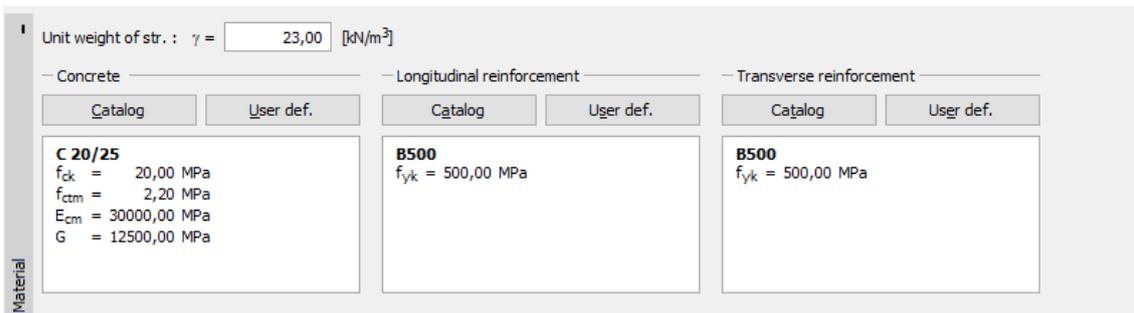

Frame "Structure"

Then, in the "Geometry" frame, we will define the depth from the ground surface, the pile head offset, the pile cap thickness and the lengths of all piles in the group. All the individual piles in the group have equal diameters and lengths.
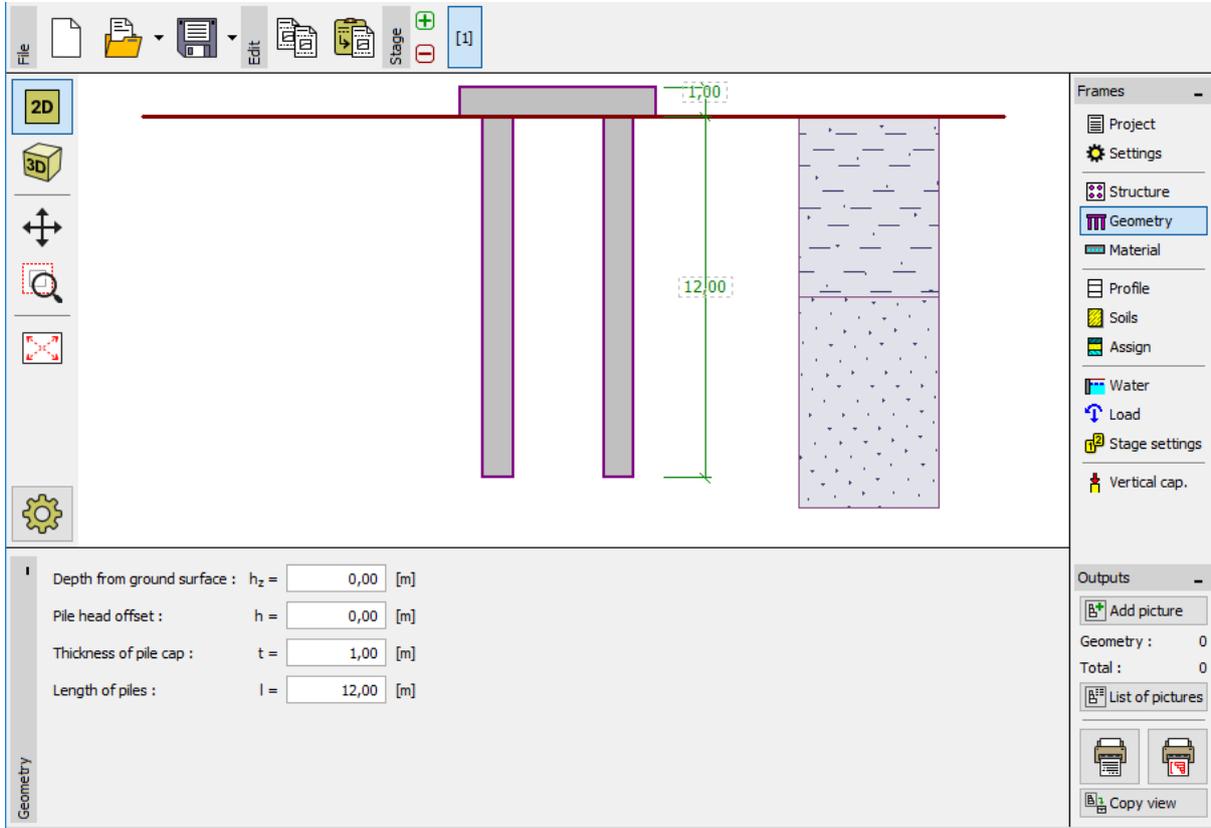
Frame "Geometry"

In the "Material" frame we will specify the unit weight of the structure $\gamma = 23.0 \; kN/m^3$.

Frame "Material"

After that, we will define the loading. The vertical bearing capacity of a pile group is analysed using design loads; the service load is used in a settlement analysis. Click on the button "Add" and add one new design load and one new service load as shown in the figures below.

New load				✕
Name :	Load No. 1			
Vertical force :	N =	5680,00	[kN]	
Bending moment :	Mx =	0,00	[kNm]	
	My =	480,00	[kNm]	
Horizontal force :	Hx =	310,00	[kN]	
	Hy =	0,00	[kN]	
Torsional moment :	Mz =	0,00	[kNm]	

◉ design   ○ service

➕ Add   ✕ Cancel

Dialogue window "New load" – Design (calculation) load

New load				✕
Name :	Load No. 2			
Vertical force :	N =	4000,00	[kN]	
Bending moment :	Mx =	0,00	[kNm]	
	My =	320,00	[kNm]	
Horizontal force :	Hx =	240,00	[kN]	
	Hy =	0,00	[kN]	
Torsional moment :	Mz =	0,00	[kNm]	

○ design   ◉ service

➕ Add   ✕ Cancel

Dialogue window "New load" – service (imposed) load

We will carry out the pile group assessment in the "Vertical capacity" frame. To meet the condition of reliability, the value of R_g must be bigger than the magnitude of the acting design load V_d (for more details visit the program help – F1). Using the **NAVFAC DM 7.2** analysis method and pile group efficiency *La Barré* (CSN 73 1002) according to the initial analysis settings, the results of the vertical bearing capacity of the pile group are as follows:

- **La Barré** (CSN 73 1002): $\eta_g = 0.84$.

$$R_g = 7491.90 \, kN > V_d = 6991.86 \, kN \qquad \text{SATISFACTORY}$$

Frame "Vertical cap."

Note: The calculated vertical bearing capacity of a pile group in cohesionless soil must be reduced because individual piles statically affect each other. The assessment in the program contains several methods of determining the pile group efficiency η_g. This dimensionless figure (usually within the range from 0.5 to 1.0) reduces the total vertical bearing capacity of the pile group R_g with respect to:

- the number of piles in the group n_x, n_y;

- the spacing of piles in the group on centres s_x, s_y;

- the diameter of piles in the group d.

The pile group efficiency η_g depends solely on the set geometry of the pile group, not on the analysis method.

We can check how the vertical bearing capacity changes when we use other methods of determination of pile group efficiency η_g. First, we will go back to the "Settings" frame. There, we will click on the "Edit" button in the bottom centre part of the screen and select the remaining possibilities „UFC 3-220-01A", and „Seiler-Keeney" step by step in the "Pile group" tab.
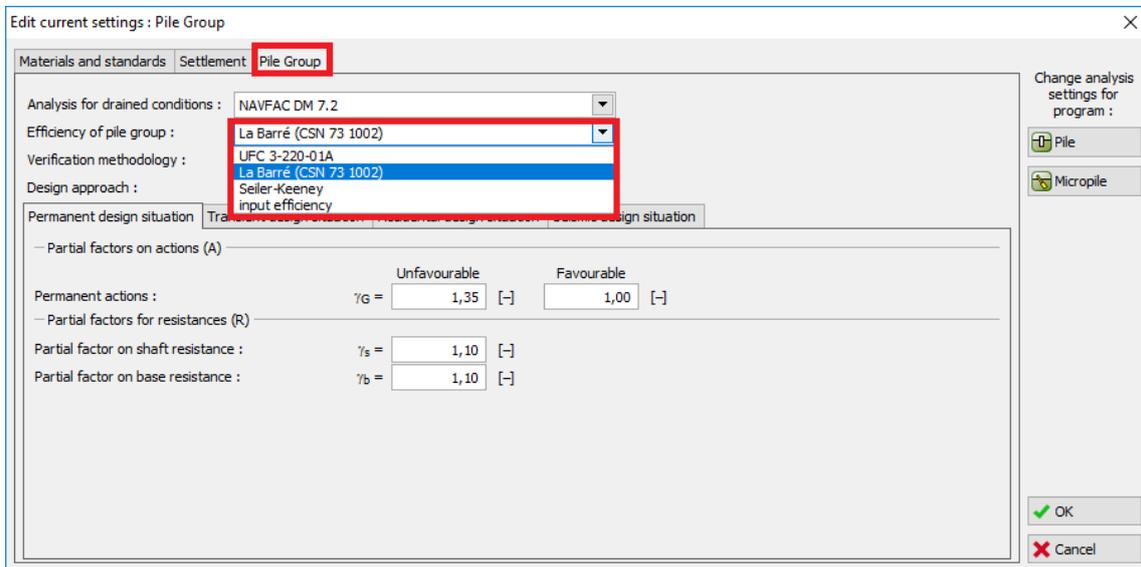
Dialogue window "Edit current settings"

Using other analysis methods, the calculation in the program is analogous to the problem solution from manual no. *13. Analysis of vertical bearing capacity of a single pile*. In the case of the effective stress method, we will set the coefficient of bearing capacity N_p to 30.

The results of the analysis of the vertical bearing capacity of a pile group in cohesionless soil (i.e. in drained conditions) relative to the method used and the pile group efficiency η_g are presented in the following table:

− **La Barré** (CSN 73 1002): $\eta_g = 0.84$,

− **UFC 3-220-01A**: $\eta_g = 0.80$,

− **Seiler-Keeney**: $\eta_g = 0.99$.

EN 1997-1, DA2 (cohesionless soil) Analysis method	Efficiency of pile group $\eta_g \; [-]$	Bearing capacity of single pile $R_c \; [kN]$	Bearing capacity of pile group $R_g \; [kN]$
NAVFAC DM 7.2	0.84	2219.06	7491.90
	0.80		7100.98
	0.99		8829.18
EFECTIVE STRESS	0.84	6172.80	20 840.41
	0.80		19 572.96
	0.99		24 560.34
CSN 73 1002	0.84	5776.18	19 501.36
	0.80		18 483.79
	0.99		22 982.28

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

Conclusion (vertical capacity of a pile group)

The calculated vertical bearing capacity of a pile group R_g in cohesionless soil must be reduced (using the so-called pile group efficiency η_g) because individual piles statically affect each other. In general, individual piles in a group affect each other more when the spacing on centres is decreased.

The designer should always carefully consider, whether to use the calculation in drained or undrained conditions for an analytical solution of vertical bearing capacity of a pile group. The two calculation types are significantly different.

Analysis of pile group settlement

The analysis of a pile group settlement is completely identical with that applied to a single pile, the only difference is that the calculated settlement is in addition multiplied by the group settlement factor g_f.

Note: The magnitude of the group settlement factor g_f depends on the geometrical arrangement of the pile group, i.e. the diameter of piles in the group and the width of the pile cap.

We analyse the settlement of a pile group according to the Poulos theory. We will use values of modulus E_s from manual no. 14 *Analysis of single pile settlement* (17 MPa for the 1st layer, 24 MPa for the 2nd layer). The maximum settlement is considered as 50 mm.
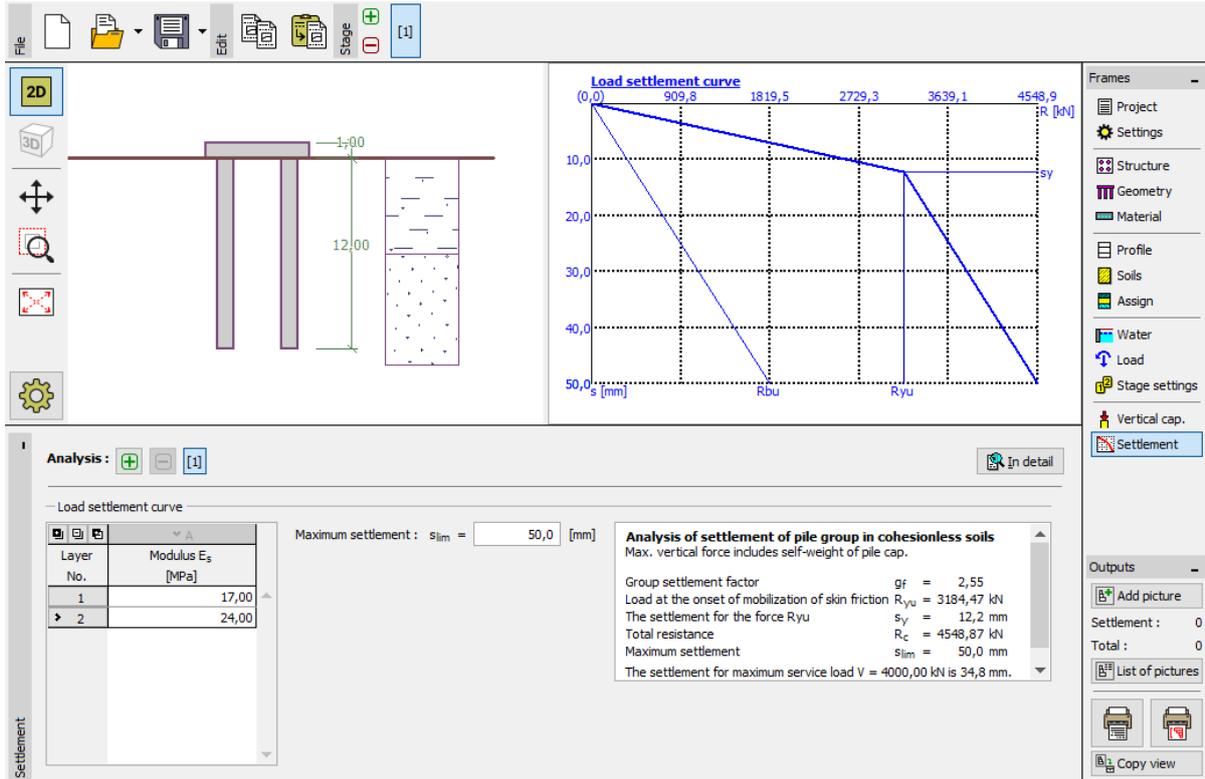
Frame "Settlement" – NAVFAC DM 7.2 method

The analysis results are presented in the following table:

Analysis method of vertical bearing capacity of pile group	Load at the onset of mobilization of skin friction R_{yu} $[kN]$	Settlement of pile group $s\,[mm]$ using force $V = 4000\,kN$
NAVFAC DM 7.2	3184.47	34.8
EFECTIVE STRESS	7274.43	15.3
CSN 73 1002	8057.77	15.3

Summary of results – Settlement of pile group according to Poulos

Conclusion (pile group settlement):

It follows from the analysis results that the vertical bearing capacity of a pile group is different as far as the total settlement is concerned. The analysis of the pile group settlement in cohesionless soil (drained conditions) is based on the linear settlement theory, which needs the values of skin friction R_s and the resistance on pile base R_b as input.

In contrast, the settlement of a pile group in cohesive soil (undrained conditions) is based on the calculation for a substitute spread foundation. This calculation method is often titled the *consolidation settlement of a pile group* or commonly abbreviated as *the 2:1 method.* For this pile group settlement assessment, the effect of the depth from ground surface and the depth of the deformation zone in

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accordance with the methodology for assessing the settlement of spread foundations is introduced into the calculation.

The two calculation methods significantly vary and provide completely different results. The GEO5 developers recommend the vertical bearing capacity and settlement of a pile group to be calculated according to local customs.