Analysis of deformation and pile group dimensioning

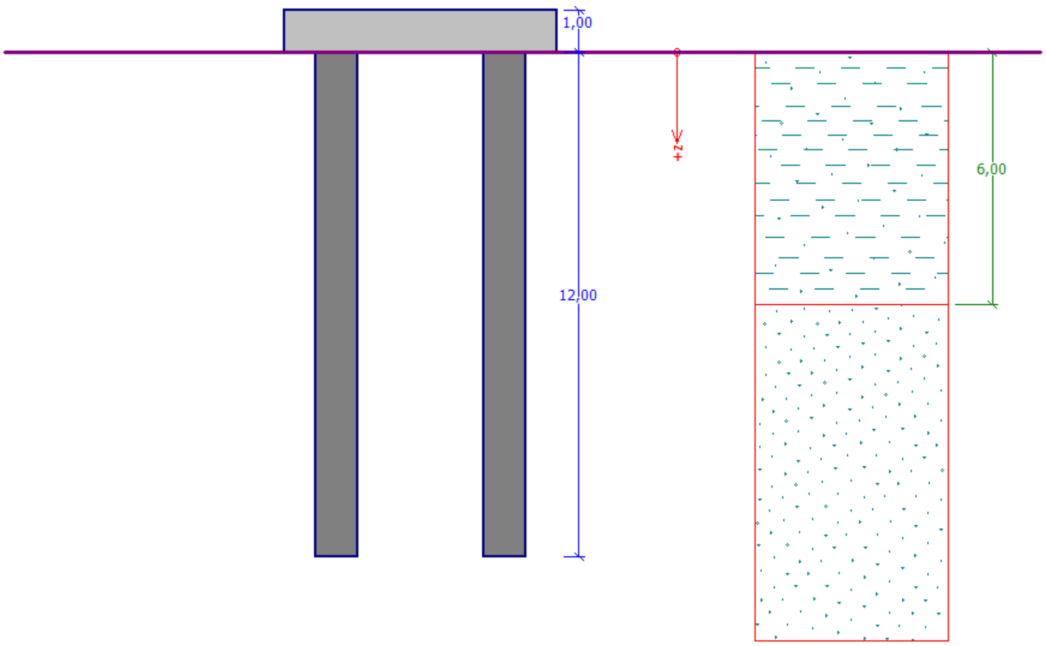
Program: Pile Group

Soubor: Demo_manual_18.gsp

The objective of this chapter is to explain the usage of the GEO 5 – PILE GROUP program to analyze the angular rotation and displacement of a stiff pile cap and to determine the internal forces acting along the lengths of individual piles and the pile cross-sections dimensioning.

Problem specification

A general specification of the problem was described in the previous chapter (*12. Pile foundations – Introduction*). All analyses of the vertical load-bearing capacity of a pile group shall be carried out on the basis of the previous problem *17. Analysis of vertical bearing capacity and settlement of a pile group.* The resultant of the total load comprising N, M_y, H_x acts at the upper base of the pile cap, right at its centre. The dimensioning of piles in the group shall be carried out in accordance with the EN 1992-1-1 (EC 2) standard, using standard values of partial coefficients.



Problem specification schema – pile group

Solution

To solve this problem, we will use the GEO 5 – PILE GROUP program. To simplify the problem and quicken the settings of the general parameters of the problem **we will base our solution on the example from the previous engineering manual** no. *17. Analysis of vertical load-bearing capacity of pile group*.

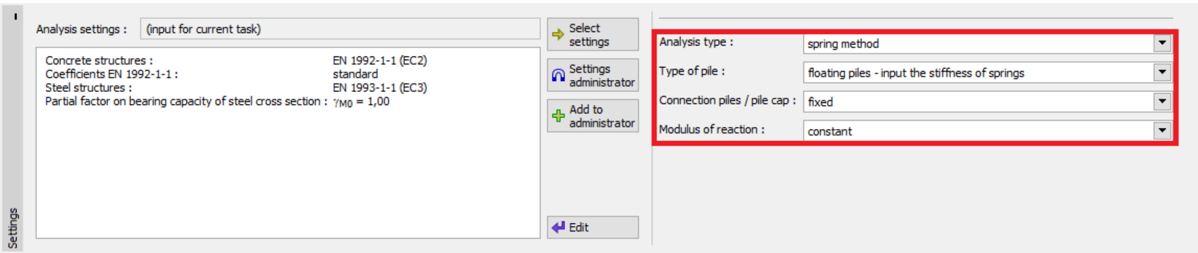
We will analyze the pile group using the so-called *Spring Method*, which models individual piles as beams on an elastic bed. Each pile is internally divided into ten sections, for which the values of horizontal and vertical springs are computed. The base slab (pile cap) is considered to be infinitely stiff. The solution itself is carried out using the deformation variant of the Finite Element Method.

Specification procedure

Firstly, we will open the file from manual no. 17 in the "Pile Group" program. Then, in the "Settings" frame, change the analysis type to the "Spring method" option. We will consider the connection of piles to the base slab to be ***stiff, i.e., fixed***. It is assumed for this boundary condition that the bending moment will be transferred in the pile heads.

For the pile bearing at the base, we will select the "floating piles – compute the stiffness of springs from the soil parameters" option.

Note: The program offers several boundary conditions options for the pile bearing in the vertical direction. For end-bearing piles, or piles keyed into bedrock, the vertical stiffness of springs is not specified – the pile base is modeled as a joint or a sliding joint. For floating piles, it is necessary to define the sizes of vertical springs, both on the skin and then on the pile base. The program makes specifying the size of the springs possible, but it is usually appropriate to select the "compute the size of springs" option. In this case, the program computes the springs using the deformational properties of soils for the typical load set (for more details, visit the program help – F1).



"Analysis settings" frame – spring method

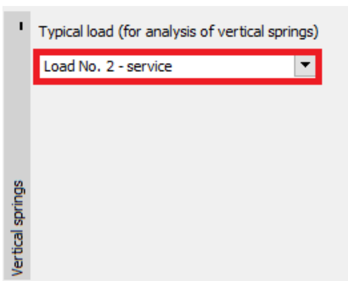
The horizontal modulus of the subsoil reaction characterizes the pile behavior in the lateral direction. In this analysis, we will consider the modulus k_h (including the parameters affecting its magnitude) to be identical with that used in the single pile solution (see *manual no. 16. Analysis of horizontal bearing capacity of a single pile).* In the first part of this chapter we will carry out the analysis using the **constant** modulus of subsoil reaction and then, in the second part, we will compare the differences between the results when other methods are used (linear – according to Bowles, according to CSN 73 1004 and according to Vesic).

When we change the method of determining the modulus of subsoil reaction, it is also necessary to edit the soil parameters in the "Soils" frame. The values of these parameters are the same as in manual no. 16. For clarity, they are also shown in the table below.

Modulus of subsoil reaction k_h $[MN/m^3]$	Angle of dispersion β $[-]$	Coefficient k $[MN/m^3]$	Modulus of elasticity E $[MPa]$	Modulus of horizontal compressibility n_h $[MN/m^3]$
CONSTANT	10 – CS	---	---	---
	15 – S-F			
LINEAR (Bowles)	10 – CS	60 – CS	---	---
	15 – S-F	150 – S-F		
CSN 73 1004	Cohesive soil – CS, firm consistency			---
	Cohesionless soil – S-F, medium dense			4,5
VESIC	---	---	5,0 – CS	---
			15,5 – S-F	

Summary table of soil parameters for determining the subsoil modulus Kh

In the "Vertical springs" frame, we will select the so-called typical load, which is used to calculate the stiffness of vertical springs. In our case, we will choose the "Load No. 2 – Service" option.



"Vertical springs" frame – typical load

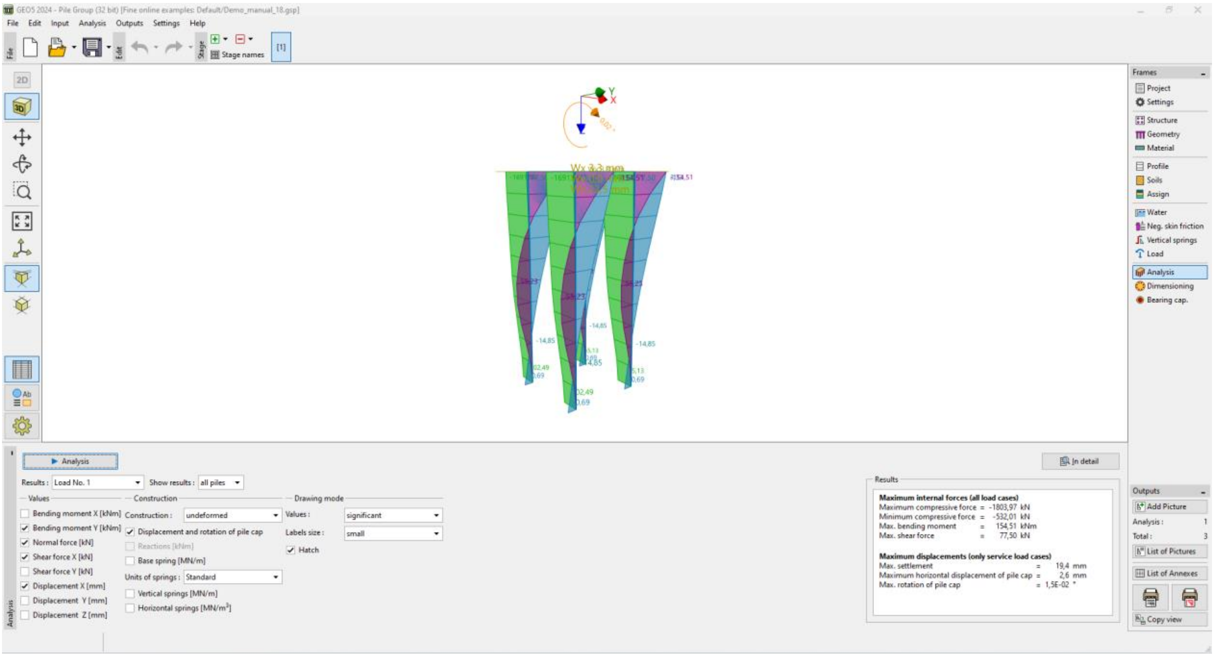
Note: In the case of the Typical load option, the service (characteristic) load that best characterizes the structure behavior should be applied (for more details, visit the program help – F1). The procedure for the computation of the vertical springs is as follows:

a) The calculated load is distributed among individual piles.
b) The size of the vertical springs on the pile skin and at the base is determined for individual piles, depending on the load and soil parameters.

The effect of the load on the calculated stiffness is significant – for example, the stiffness of the spring at the base is always zero for a tensioned pile. For that reason, it may be advantageous in some cases to carry out the calculation several times for various typical loads.

Analysis: Spring Method

In the "Analysis" frame, we will carry out the assessment of the pile group for the initial settings (the **constant** modulus of subsoil horizontal reaction) and will display the results including the internal force curves.



"Analysis" frame – Spring Method (constant modulus of subsoil reaction)

Note: The stiffness of piles in the group is automatically modified according to their locations. Piles on edge and inside the group have the sizes of the horizontal stiffness and shear stiffness of springs reduced in comparison with a single pile. Springs on pile bases are not reduced (for more details, visit the program help – F1).

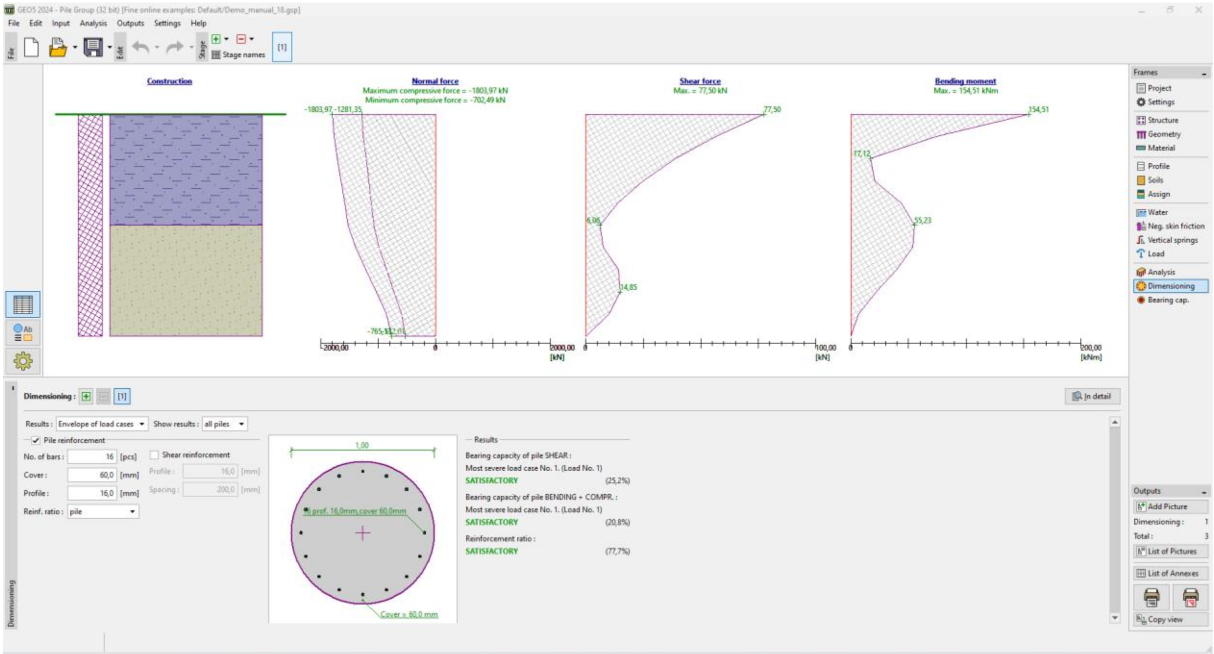
The results of the analysis for the initial settings (for maximum deformation) are as follows:

- Maximum settlement: $19.4\ mm$;
- Max. horizontal displacement of the pile cap: $2.6\ mm$;
- Maximum rotation of pile cap: $1.5 \cdot 10^{-2}\ °$.

Dimensioning

Now we will move on to the "Dimensioning" frame and, similarly to chapter *16. Analysis of horizontal bearing capacity of the single pile*, we will propose and assess the main structural reinforcement of the piles. We will consider an identical reinforcement ratio for all piles in the group – **16 pcs Ø 16 mm** and the minimum concrete cover of **60 mm,** according to the exposure grade XC1.

The reinforcement ratio for a generally loaded pile group is, in this case, considered to be in accordance with CSN EN 1536:1999 (identically with that in *chapter 16*). In the program, this option is set as “pile” *(*for more details, visit the program help – F1).



“Dimensioning“ frame – results for all piles in the group from the envelope of loading cases

The results show us the utilization of a cross-section of all piles in the group in terms of bending and the condition for the minimum reinforcement ratio for the overall envelope of load cases:

– RC pile bearing capacity (shear): 25.2% SATISFACTORY

– RC pile bearing capacity (flexure): 20.8% SATISFACTORY

– Reinforcement ratio: 77.7% SATISFACTORY

Analysis results

The procedure for other analyses in the program is analogous to the procedure applied in the previous problems. We will always change the method of the calculation of the modulus of subsoil reaction in the "Settings" frame, edit the soil parameters as needed, and then carry out the assessment of the pile group in the "Analysis" and "Dimensioning" frames. The results are recorded in the following summary tables.

Modulus of subsoil reaction k_h $[MN/m^3]$	Compressive force (maximum, minimum) $[kN]$	Maximum bending moment $[kNm]$	Maximum shear force $[kN]$
CONSTANT	-1803,97	154,51	77.50
	-532,01		
LINEAR (Bowles)	-1822,08	190,74	77.50
	-526,06		
according to CSN 73 1004	-1815,70	177,97	77.50
	-528,18		
according to VESIC	-1827,92	202,41	77.50
	-524,15		

Summary of results (internal forces) – Verification of a pile group (spring method)

Modulus of subsoil reaction k_h $[MN/m^3]$	Maximum settlement $[mm]$	Max. horizontal displacement $[mm]$	Max. rotation of pile cap $[°]$	RC pile bearing capacity $[\%]$
CONSTANT	19,4	2,6	$1{,}5 \cdot 10^{-2}$	20,8
LINEAR (Bowles)	19,8	3,5	$2 \cdot 10^{-2}$	22,1
according to CSN 73 1004	19,6	3,3	$1{,}8 \cdot 10^{-2}$	21,6
according to VESIC	19,9	4,7	$2{,}2 \cdot 10^{-2}$	22,6

Summary of results – displacements and dimensioning of a pile group

Conclusion

The values of the maximum settlement of the pile group, settlement displacements, and the base slab rotation are within the allowable limits.

It follows from the analysis results that the observed values of internal forces along the length of individual piles and the maximum deformations at pile heads in the group are slightly different, but the influence of the method selected for the calculation of the modulus of subsoil reaction k_h is not too significant.

The proposed pile reinforcement cage is satisfactory. The main condition for the reinforcement ratio of piles is also met.