Verification of a Micropile Foundation

Program: Pile Group
File: Demo_manual_en_36.gsp

The objective of this engineering manual is to explain the application of the GEO5 – Pile Group program for verification of micropile foundation.

Assignment:

Analyse a micropile foundation under a tower crane according to *EN 1997 – DA2*. In Figure 1, a scheme of the micropile foundation is shown. The coordinates and the inclination of individual micropiles are shown in Table 1. The micropiles are made of steel (S355) and the TK 108 x 20 profile is used. The overall length of the micropiles is 7.0 m and they are divided into three parts. The bottom part is the root with diameter of 0.3 m and the length of 3.0 m. The next part is the free length of the micropile with length 3.0 m and the last part is connection micropile with a pile cap of length 1.0 m. The geological profile of this task is shown in Table 2. The ground water is not considered. To calculate the vertical springs along the root of a micropile, the "Shear modulus of reaction $k_v = 45.00\ MN/m^3$ ", which will be constant along the root of micropile, and the stiffness of "Spring on the base $k_p = 5.00\ MN/m$" will be used. The "average limit skin friction" for the verification of the root of the micropiles was determined by a geological survey to be $q_{sav} = 350.00\ kPa$.
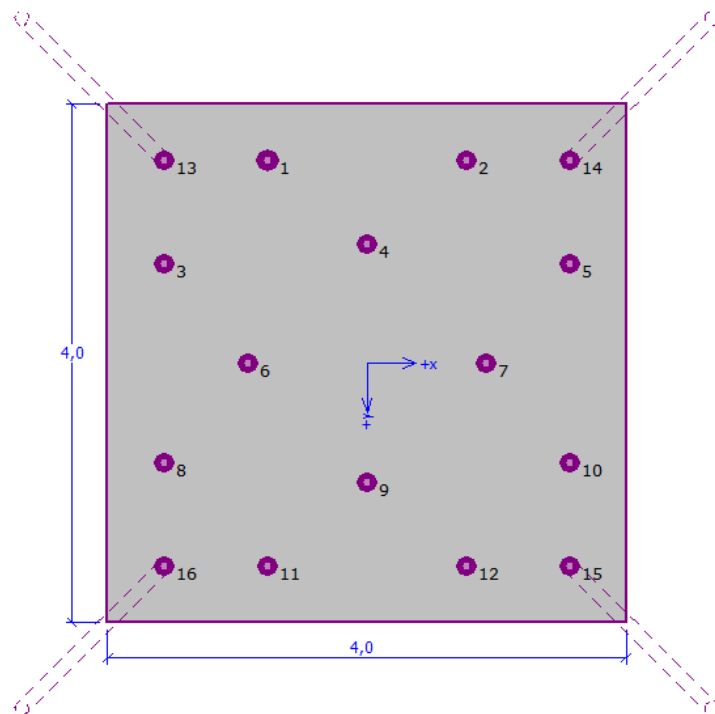

Figure 1 Scheme of the micropile foundation

Micropile No.	X	Y	Inclination
	[m]	[m]	[°]
1	-0.77	-1.57	0.00

2	0.77	-1.57	0.00
3	-1.57	-0.77	0.00
4	0.00	-0.92	0.00
5	1.57	-0.77	0.00
6	-0.92	0.00	0.00
7	0.92	0.00	0.00
8	-1.57	0.77	0.00
9	0.00	0.92	0.00
10	1.57	0.77	0.00
11	-0.77	1.57	0.00
12	0.77	1.57	0.00
13	-1.57	-1.57	15.00
14	1.57	-1.57	15.00
15	1.57	1.57	15.00
16	-1.57	1.57	15.00

Table 1 Coordinates and inclination of the micropiles

Soil	Profile [m]	γ [kN/m³]	ϕ_{ef} [°]	c_{ef} [kPa]	ν [-]	E_{def} [MPa]	k [MN/m³]	β [°]
Soil 1 (CL, CI)	0.00 – 1.90	21.00	19.00	30.00	0.40	10.00	150.00	9.50
Soil 2 (ML, MI)	1.90 – 3.10	20.00	21.00	12.00	0.40	4.00	200.00	10.50
Soil 3 (G-F)	3.10 – 4.90	19.00	35.50	0.00	0.25	95.00	250.00	12.75
Soil 4 (GP)	4.90 – 6.50	20.00	38.50	0.00	0.20	210.00	320.00	19.25
Soil 5 (CH, CV, CE)	> 6.50	20.50	15.00	5.00	0.42	3.00	60.00	7.50

Table 2 Soil properties – characteristic effective values

The service load used to calculate the rotation and settlement of the pile cap is shown in Table 3. The design load is shown in Table 4. The loads are considered in the middle of the top side of the pile cap. The design load from self-weight of the pile cap with dimensions 4.0 m x 4.0 m x 1.2 m is calculated automatically.

Load	N [kN]	M_x [kNm]	M_y [kNm]	H_x [kN]	H_y [kN]
Value	609.00	2111.00	2111.00	47.00	47.00

Table 3 Service load

| Load	N [kN]	M_x [kNm]	M_y [kNm]	H_x [kN]	H_y [kN]
Value	822.00	2850.00	2850.00	63.00	63.00

Table 4 Design load

Solution:

To solve this problem, we will use the *GEO5 – Pile* Group program. We will analyse the effect of the load on each micropile in the group and then we will assess the most loaded micropile. In the text below we will describe the solution to this task step by step.

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

In the "Settings" frame we will click on the "Setting list" button and then choose the "Standard – EN 1997 – DA2" calculation settings.
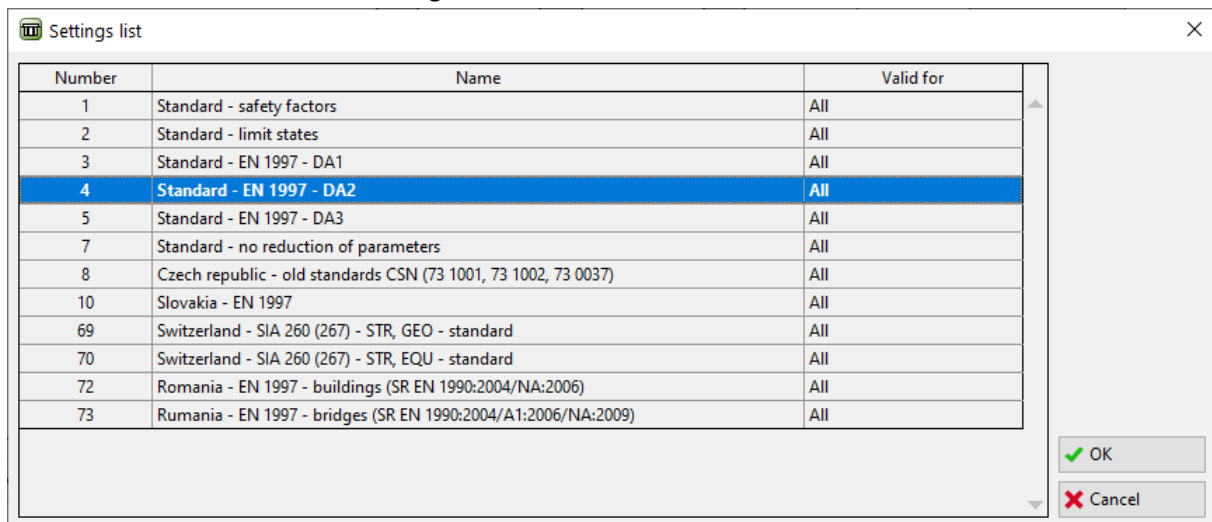

"Settings list" dialog window

The next step is changing the analysis type to "Spring method – micropiles". We will consider the connection of the micropiles to the pile cap to be "fixed". The last step in this frame is setting the "Modulus of subsoil reaction", which will describe the behavior of the micropiles in the horizontal direction. In this case, the "Linear" modulus of subsoil reaction is considered (it will be calculated according to the Bowles's method). For more information visit HELP (F1 key).
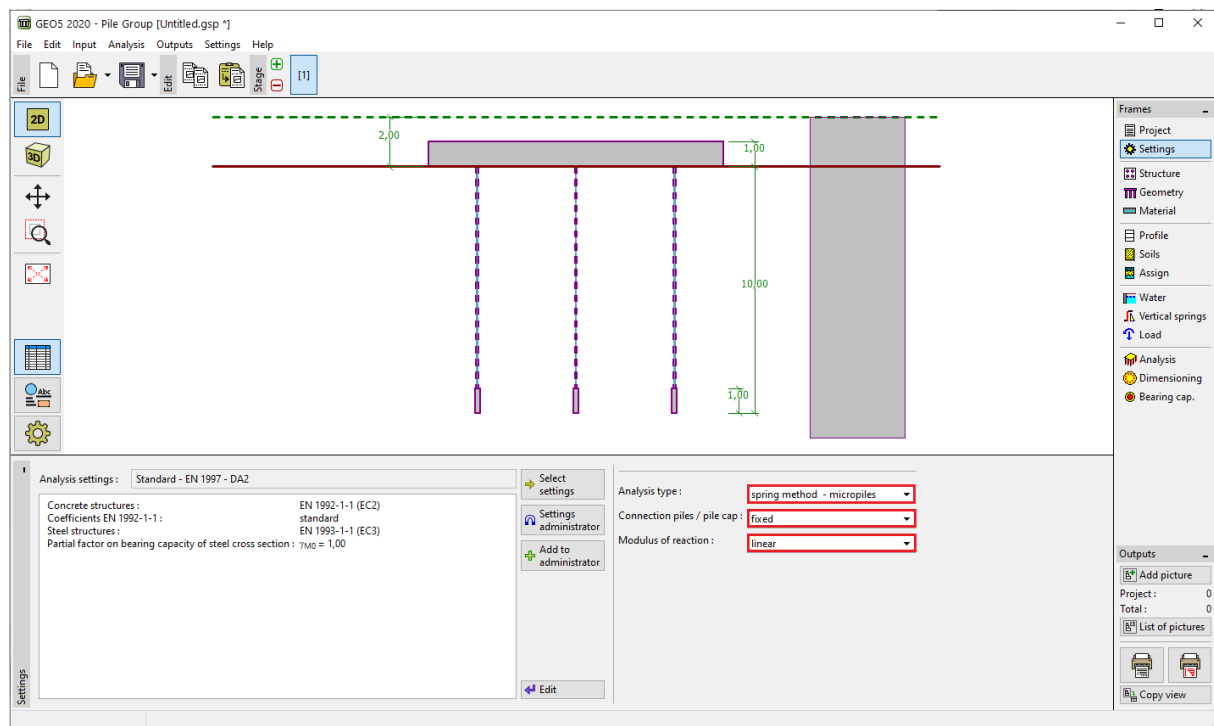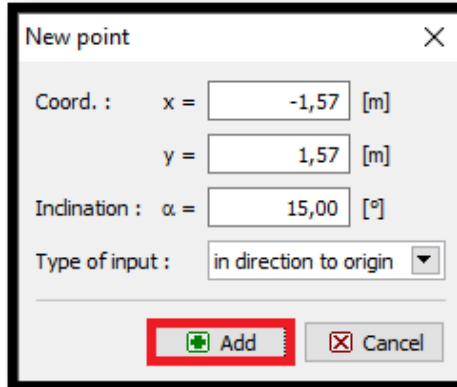
"Settings" frame

In the **"Structure" frame** we will choose the "general shape" option for the top view of the pile cap. The "cap overlap" with value „$o = 0.38\ m$" will be set. Now, we can add each micropile according to Table 1 by clicking on "Add" button.
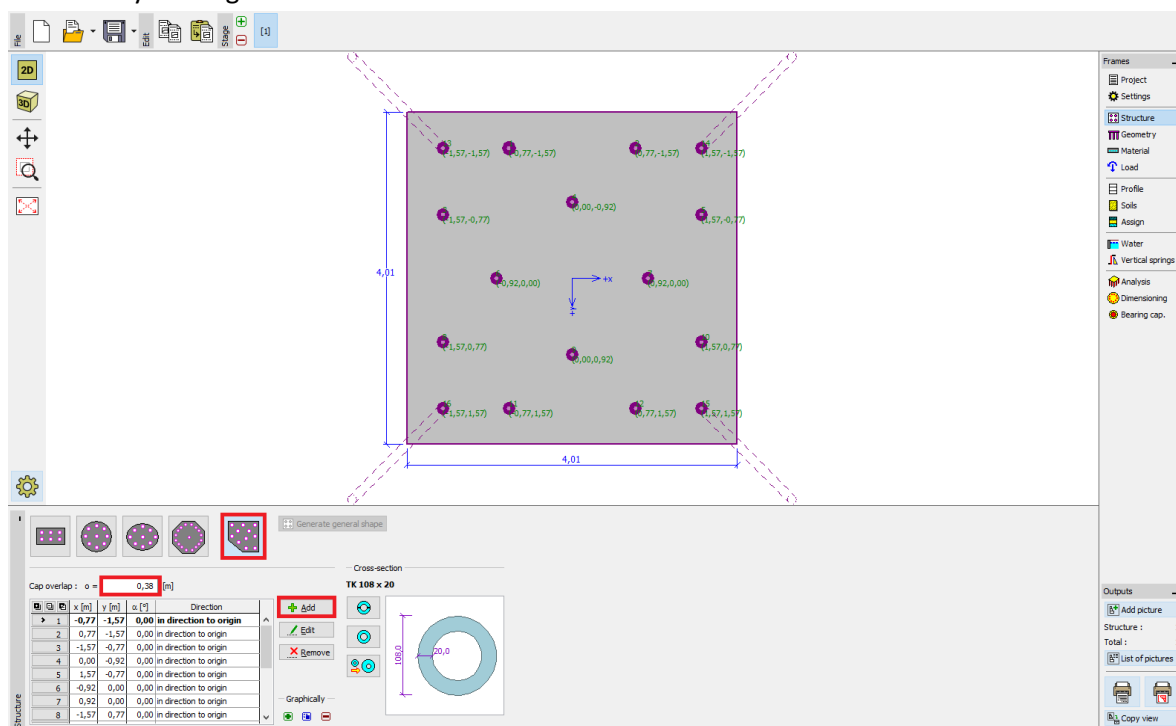
"Structure" frame

Note: The cap overlap "o " is the distance from the outer edge of the micropile to the edge of pile cap.

After clicking on the "add" button, the dialog window "New point" will appear. In this window we will input coordinates x and y and the inclination of the micropile. The coordinates and the inclination of each micropile are shown in Table 1. A new micropile will be added by clicking on the "add" button.

"New point" dialog window (micropile no. 16)

The profile of the micropile will be defined in the "Catalogue of profiles". In the section "Profile class" we will choose the "Seamless tube circular cross-section" and then in the section "Profile" the profile TK 108x20 will be chosen.
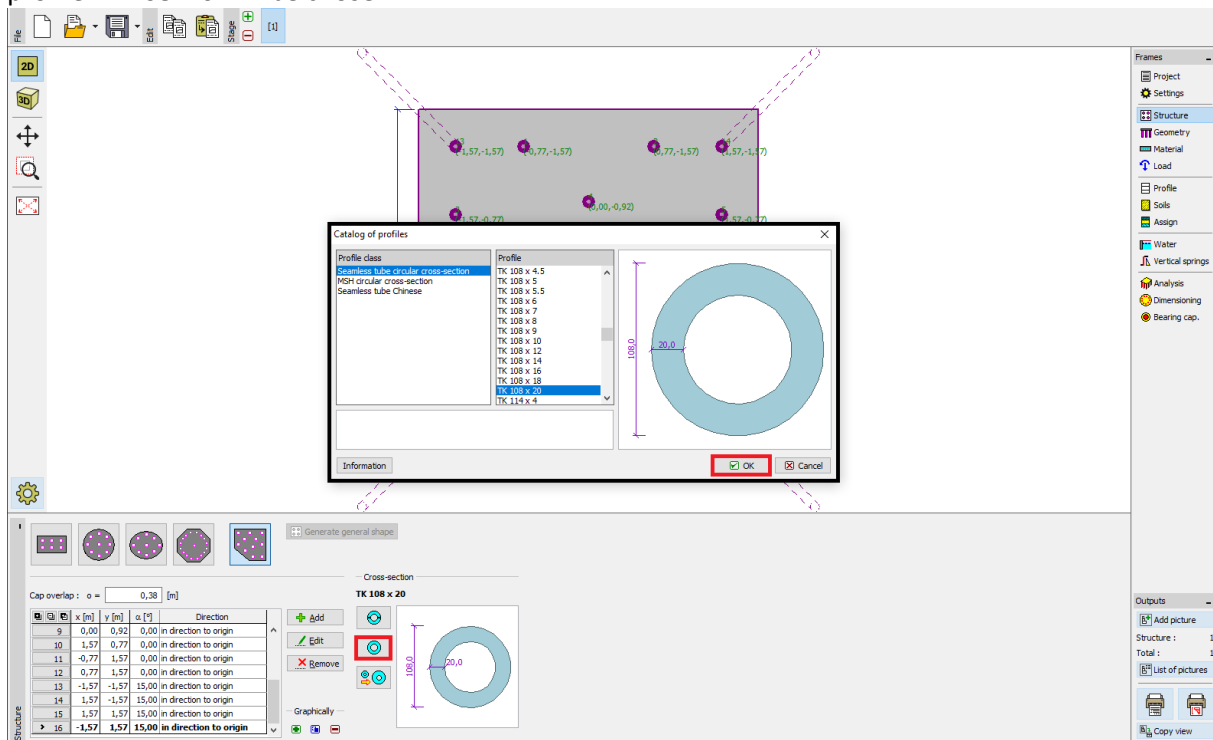
"Catalogue of profiles" dialog window

In the "Geometry" frame will be defined "Depth from ground surface $= 0.00 \ m$", „Thickness of pile cap $t = 1.20 \ m$ ", „Length of micropiles $l = 6.00 \ m$ ", „Diameter of root $d_r = 0.30 \ m$ ", „Root length $l_r = 3.00 \ m$ " and finally it is possible to define the "Resistance of the foundation soil" but it won't be considered in this case. Therefore "Resistance of foundation soil $R = 0.00 \ kPa$ ".
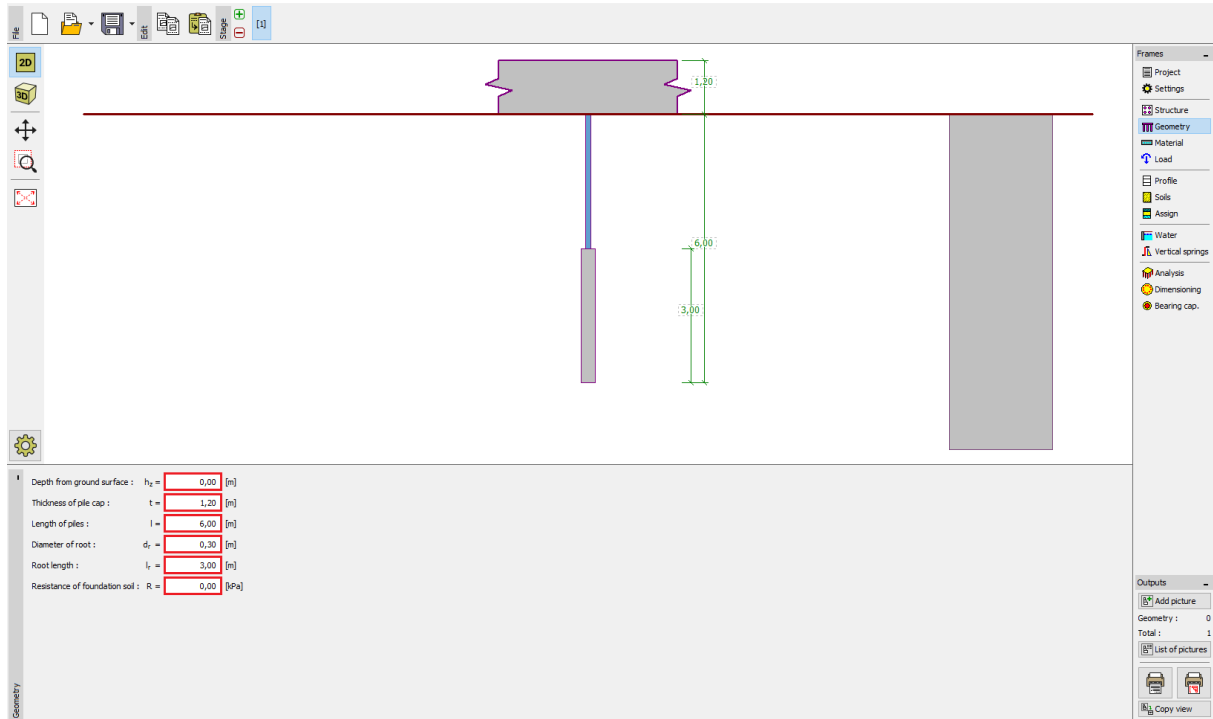

"Geometry" frame

Note: The resistance of the foundation soil is very important and has a big influence on the results of the analysis. The magnitude of the resistance of the foundation subsoil depends on the type of the subsoil, the process of building the structure (new structure, reconstruction) and the history of loading. The force $N_R = A \cdot \ R$ is subtracted from the entered load in all cases.

In the "Material" frame the material properties of the structure are defined. For a pile cap, the defined unit weight ($\gamma = 23.00 \ kN/m^3$) and concrete class C20/25 (for dimensioning) are set and for the micropiles the structural steel class *EN 10210 − 1: S355* is set. The material classes for concrete and structural steel are available by clicking on the "Catalog" button.
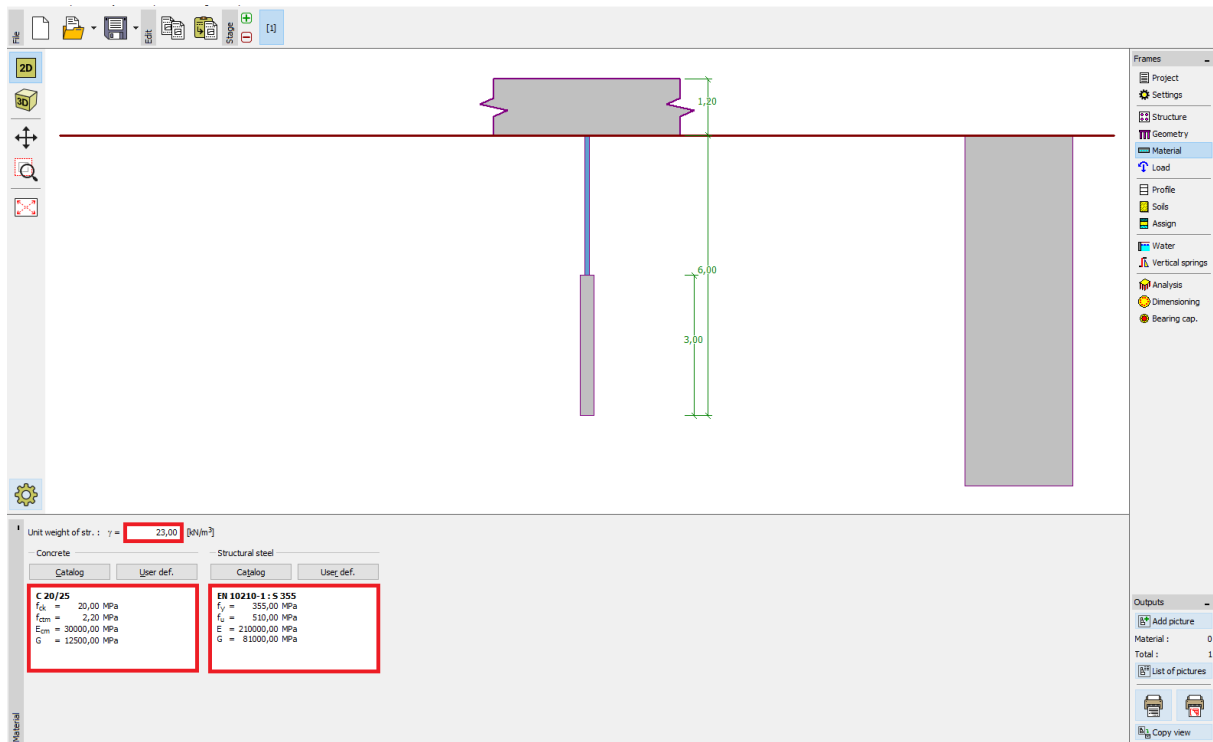
"Material" frame

In the **"Load" frame** the loads will be added. The values of the service load are shown in Table 3 and the values of the design load are shown in Table 4.
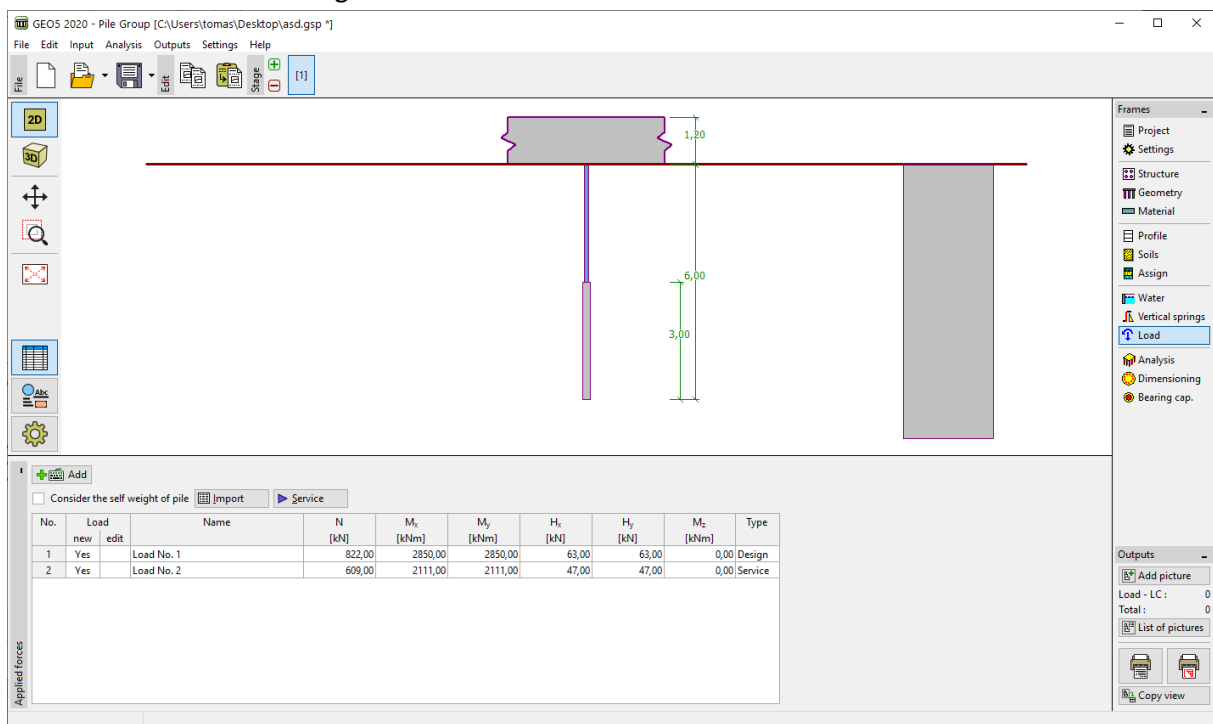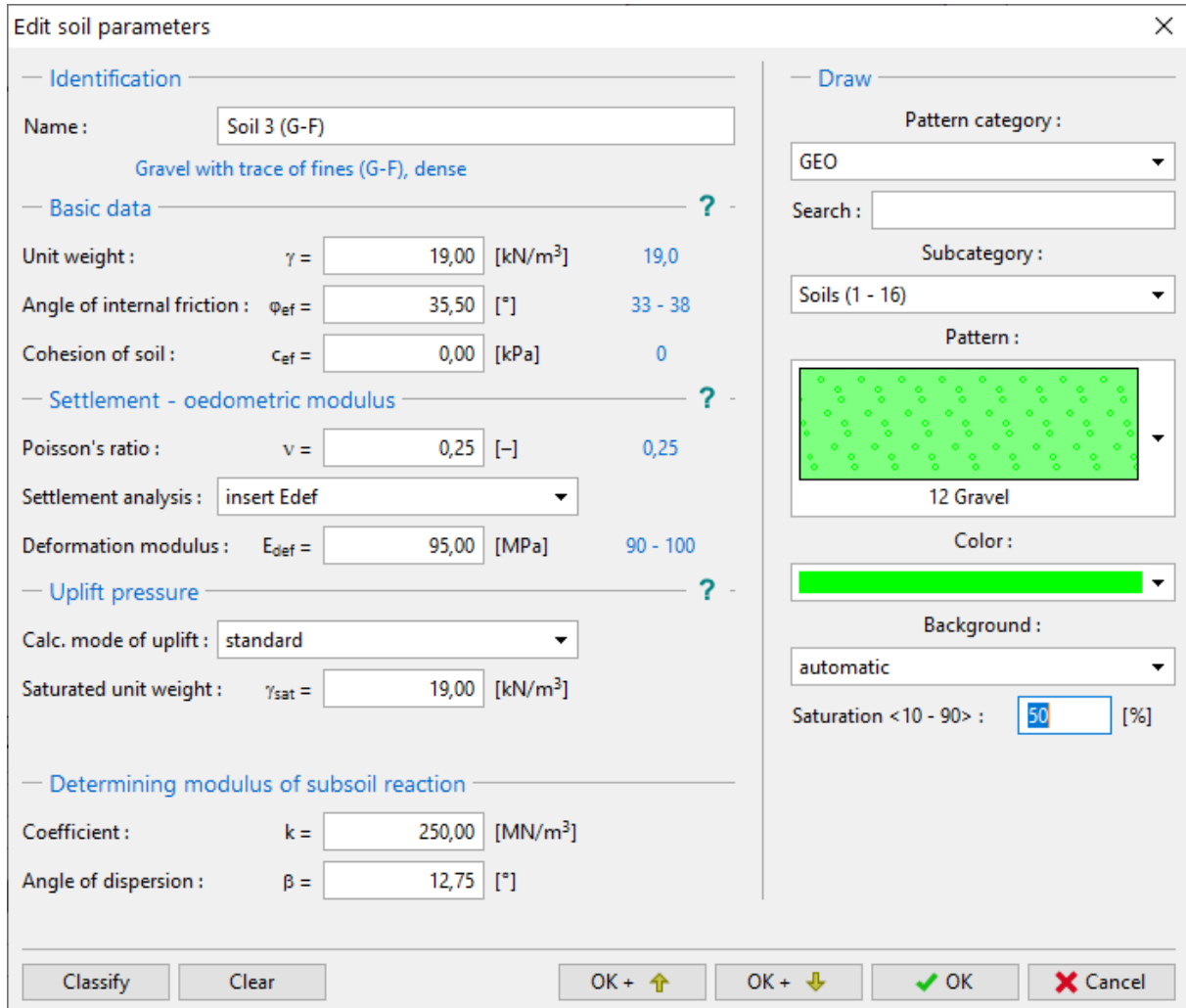

"Load" frame

The geological profile is defined in the "Profile", "Soils" and "Assign" frames. In the "Profile" frame, you will set the range of layers of the geological profile. In the "Soils" frame, you will define the

soils and the last step is done in the "Assign" frame, where the soils are assigned to various layers of the geological profile. The geological profile with properties of each soil is shown in Table 2.

In the dialog window "Add new soils" it is necessary to input values for the "Determining modulus of subsoil reaction". The representative range of values of "Coefficient k" and the formula for determining the "angle of dispersion β" are shown in HELP (F1 key), in the topic of *"Linear Modulus of Subsoil Reaction".*
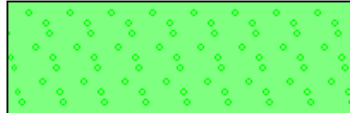
"Add new soils" dialog window
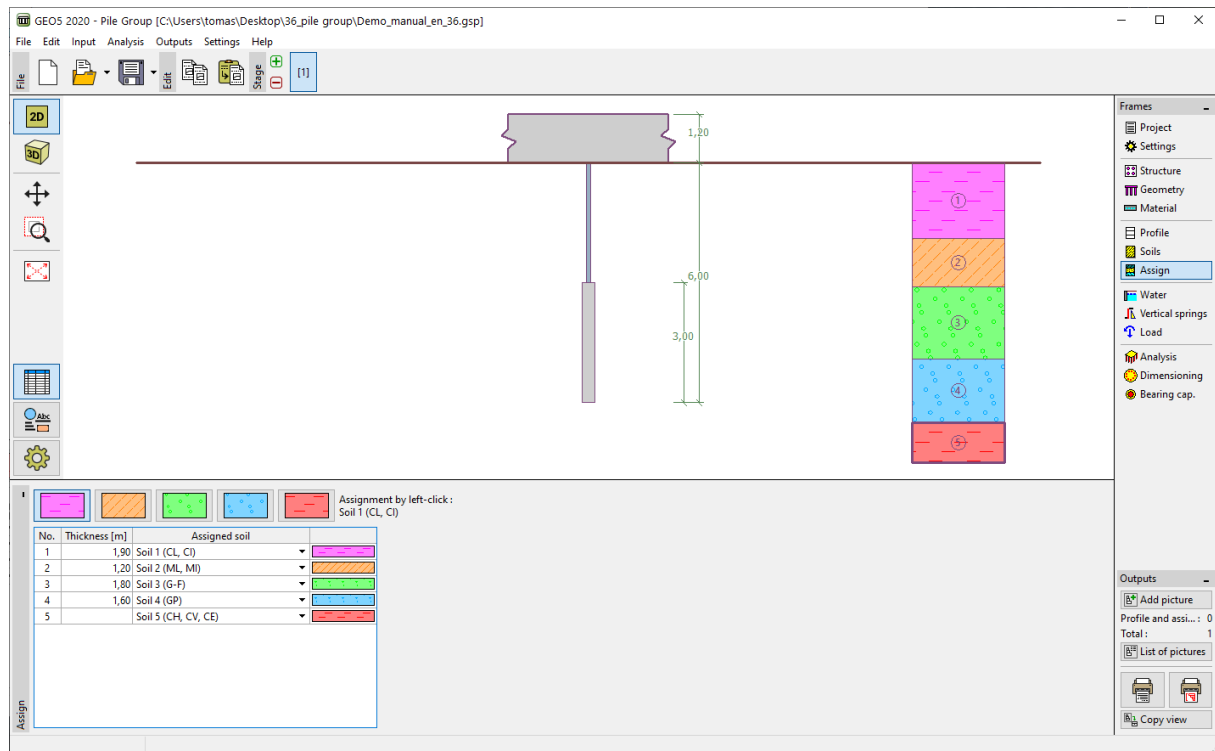
"Assign" frame

**In the "Vertical springs" frame** the behavior of a micropile in the vertical direction is defined. The load from a micropile is transmitted to the soil through the base and the skin of the root.
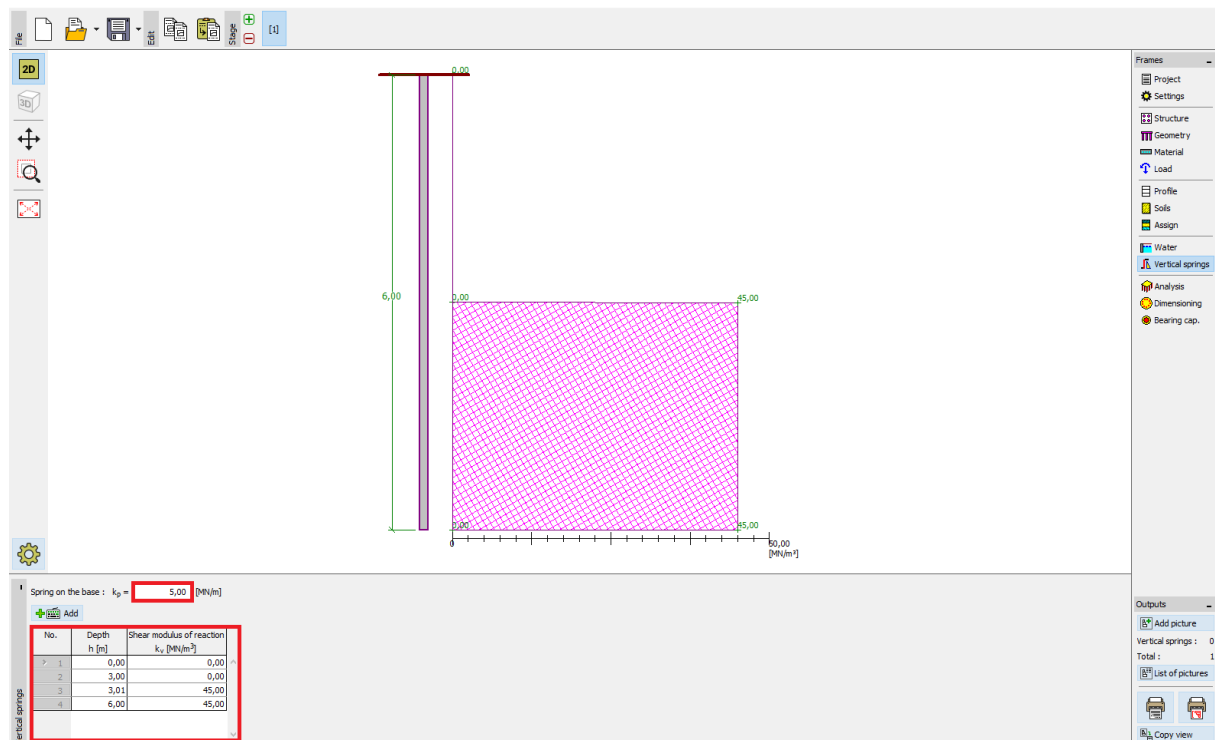
"Vertical springs" frame

In the "Analysis" frame, the calculation of the task is done. The results (internal forces, displacements, etc.) are displayed for one or for all micropiles. On the right side of the window, the

results for maximum internal forces (from all load cases) and results for maximum displacements (only from service load cases) of the whole structure are shown. In the figure below you can see the results for micropile no. 16.
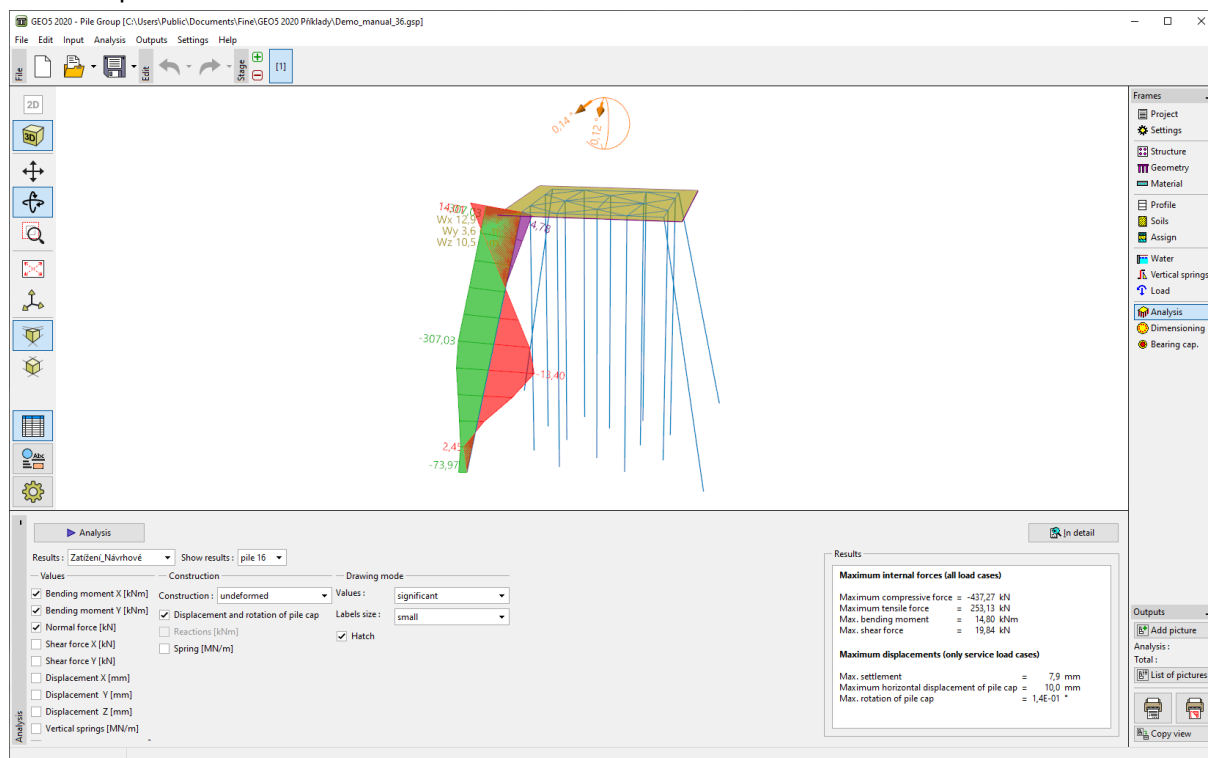

"Analysis" frame

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

- *Maximum settlement*   7.9 mm

- *Maximum horizontal displacement of a pile cap*   10 mm

- *Maximum rotation of a pile cap* $1.4E - 01°$

In the "Dimensioning" frame the internal forces from the selected load case or the envelope of load cases are shown. The results can also be shown for any pile. The total internal forces are equal to the resultant forces calculated from the X and Y components. The following figure shows the internal forces from the envelope of load cases for all micropiles.
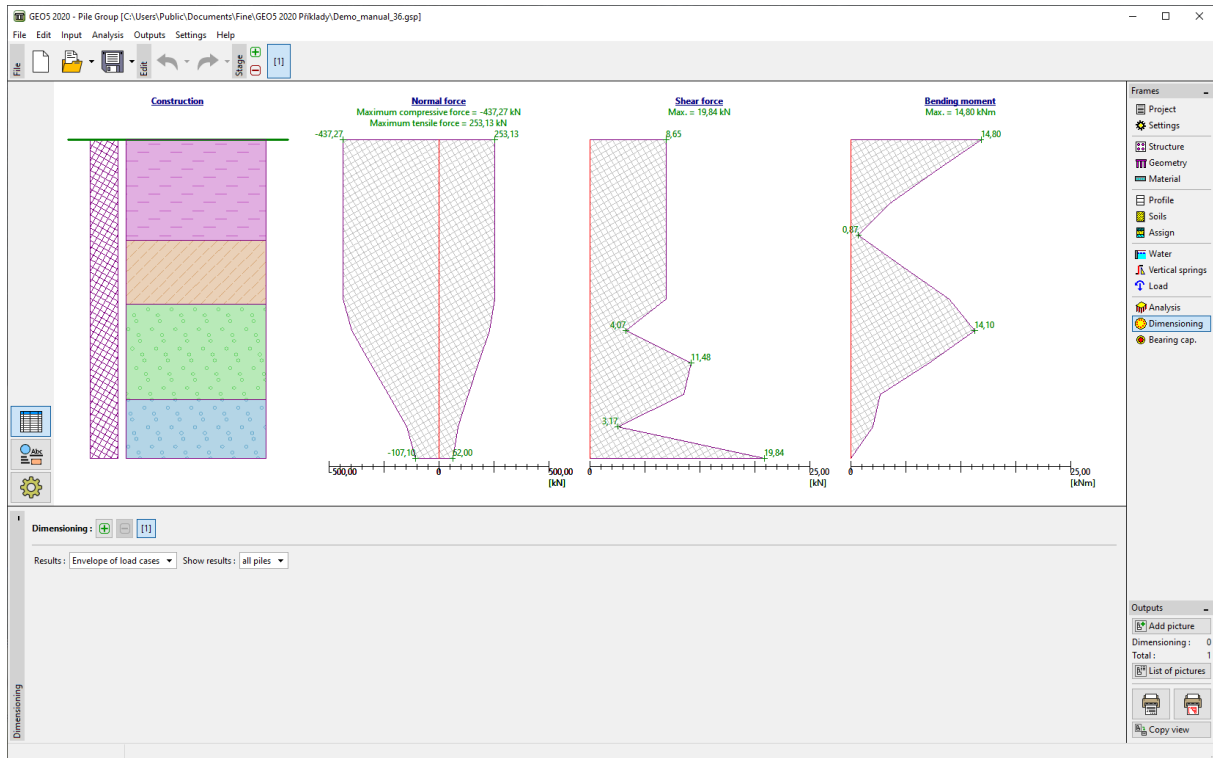
"Dimensioning" frame

To analyse the micropile cross-section and its root, it is necessary to open the *GEO5 – Micropile* program by the clicking on the "Bearing capacity" frame. All results and data are automatically imported to this program.

The verification of the steel cross-section of a micropile is in the "Section verification" frame. The results for the most loaded micropile are automatically calculated. Corrosion is not considered in this case because our micropile foundation is not a permanent structure. Boundary conditions are considered as: **hinge – fixed**.
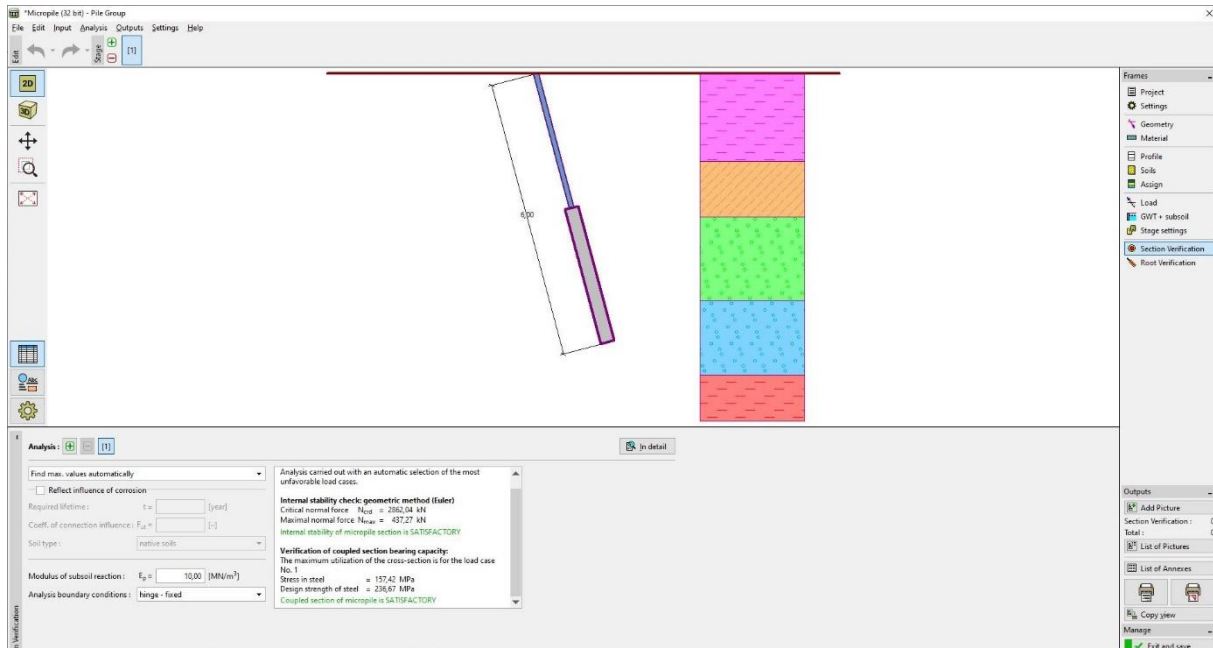
Internal stability check:

$$N_{crd} = 2862.04 \ kN \quad \geq \quad N_{max} = 437.27 \ kN$$

The internal stability of the micropile section is SATISFACTORY

Verification of the coupled section bearing capacity:

$$f_{y,d} = 236.67 \ MPa \quad \geq \quad \sigma_s = 157.42 \ MPa$$

The coupled section of the micropile is SATISFACTORY

"Section verification" frame

The verification of the root bearing capacity of the micropile is done in the frame "Root Verification". The verification is done according to Lizzi theory and average skin friction is set as **$q_{sav} = 350$ kPa**.

Note: The method of analysis for the verification of root bearing capacity can be changed in the "Settings" frame by editing the settings for "Micropile".

Verification of a compressive micropile:

$R_s = 791.68\ kN$ - Shaft resistance

$R_d = 527.79\ kN \quad \geq \quad N_{max} = 437.27\ kN$ - Bearing capacity of the micropile root

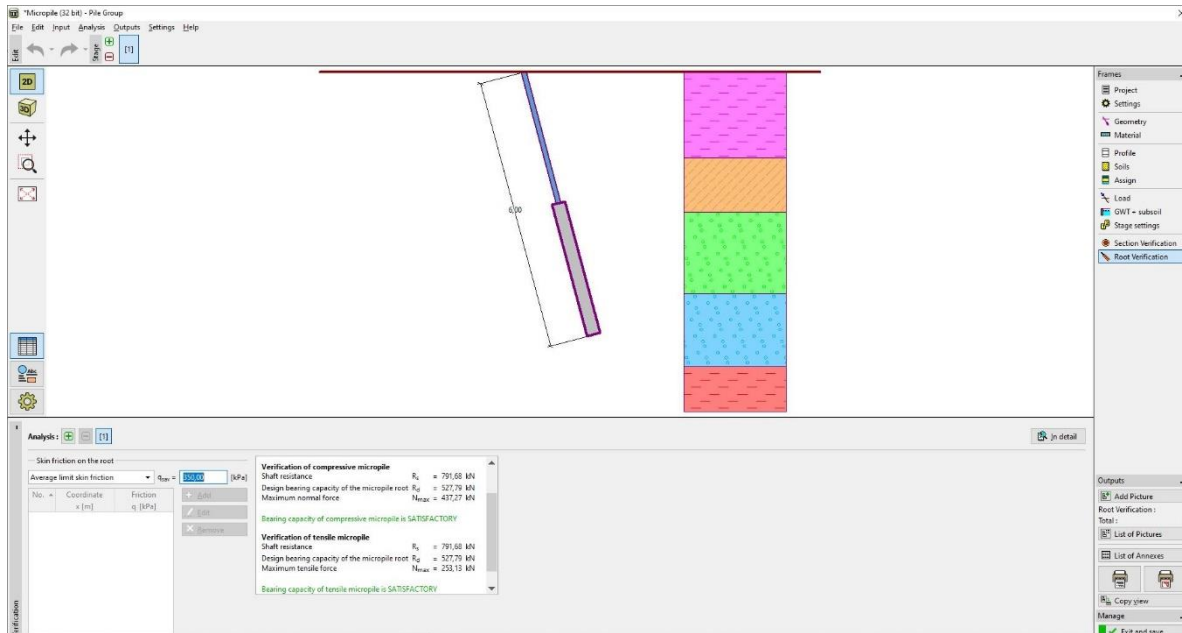**The bearing capacity of the compressive micropile is SATISFACTORY**

Verification of tensile micropile:

$R_s = 791.68\ kN$ - Shaft resistance

$R_d = 527.79\ kN \quad \geq \quad N_{max} = 253.13\ kN$ - Bearing capacity of the micropile root

The bearing capacity of the tensile micropile is SATISFACTORY

"Root Verification" frame

The last step is saving the results by clicking the "Exit and save" button as shown in the previous figure.

Conclusion:

The values for maximum settlement, maximum horizontal displacements and rotation of pile cap are within the allowable limits.

The design of a micropile TK 108/20 made of structural steel *EN 10210-1: S355* and its root are satisfactory according to *EN 1997 – DA2*.