Foxta v3

PART H: GROUPIE+ MODULE

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H.1. GENERAL PRESENTATION

H.1.1. Introduction

The Groupie+ module is used to calculate a foundation on a group of piles, rectangular piles or micro-piles. This is a hybrid programme which takes advantage of the power of the matrix formulations derived from finite elements for the study of soil-structure interaction problems. The calculation process is fully automated to facilitate modelling and minimise calculation time. However, the "classic" version based on manual calculation has been retained.

In any case, the three-dimensional problem is split into two parts: the piles and the surrounding soil. The piles, which can be spatially oriented, are modelled as elastic beams characterised by their axial and bending rigidity, discretised in finite elements. The piles/soil interaction is modelled by non-linear "p-y" and "t-z" type transfer laws. Finally, the loading of the footing is defined by a six-component global forces and moments vector.

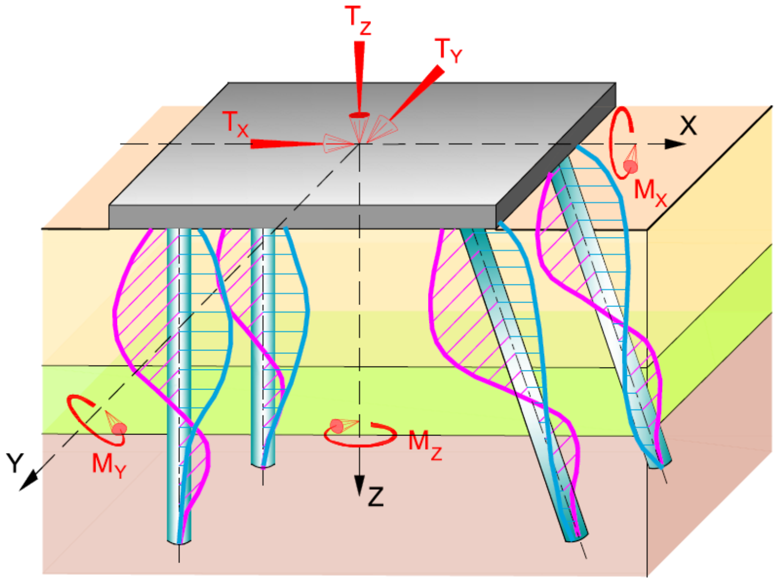


Figure H 1: Foundation on group of piles

H.1.2. Calculation methods

Two calculation methods are available:

- Manual management of the calculation process (Manual Groupie mode): Each pile is to be characterised by an equivalent pile head stiffness matrix previously defined using the Taspie+ and Piecoef+ modules. The problem can thus be reduced to the equilibrium of the footing subjected to the external global forces and moments and to the reactions at the top of the piles. The iterations to be carried out, in particular in the event of soil plastification, have to be managed manually by the user for each load case and each pile.
- Automatic calculation management (Automatic Groupie+ and Advanced Automatic Groupie+ modes): the piles are discretised into beam elements characterised by axial rigidity and a product of inertia in each direction. The user-defined multilayer soil, with elastoplastic behaviour, offers the possibility of introduce dips in both directions. The problem is to resolve the overall equilibrium of the group of piles. The calculation process is both independent and automatic.

H.2. THEORETICAL ASPECTS

H.2.1. Notations and conventions

H.2.1.1. Definition of the connecting footing – global system of coordinates

The global system of coordinates $(O,\vec{X},\vec{Y},\vec{Z})$ is a direct orthonormal system of coordinates whose axis $(O,\vec{Z})$ is vertical descending. The external global forces and moments applied to the footing and that of the resultant displacements are expressed at point O according to the conventions of mechanics. The forces and displacements are positive if oriented in the same direction as the axes of the global system of coordinates. The moments and rotations are positive if their associated vectors are positive as defined by the corkscrew rule (see Figure H 2:).

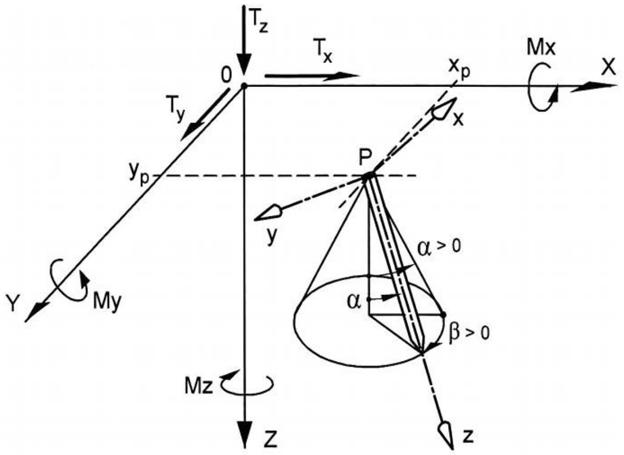


Figure H 2: Conventions and systems of coordinates

H.2.1.2. Definition of piles – local systems of coordinates

"n_p" is the total number of piles. Each pile "i" is defined by the coordinates of its head (X_P, Y_P, Z_P) and by two angles α and β specifying its orientation in the global system of coordinates (see Figure H 2:). The local system of coordinates, noted $(P,\vec{x},\vec{y},\vec{z})$, is such that the axis $(P,\vec{y})$ always remains orthogonal to axis $(O,\vec{Z})$. The global forces and moments at the top of each pile (calculation result) is expressed in its local system of coordinates, while adopting the particular sign conventions presented in Figure H 3:.

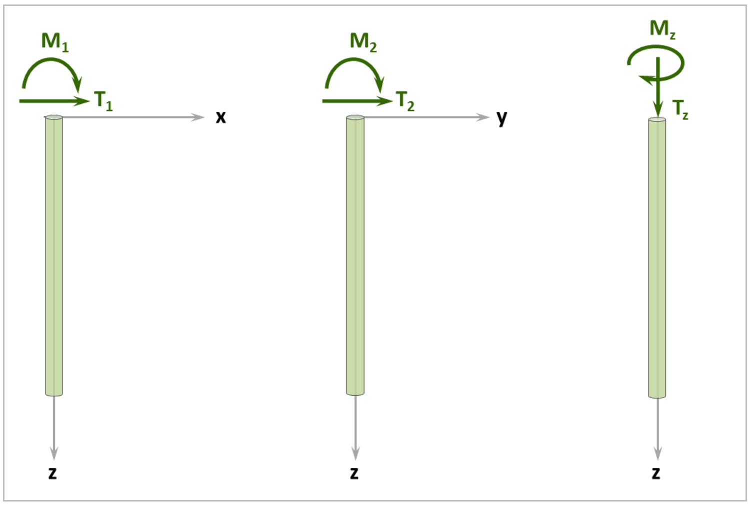


Figure H 3: Forces at pile head

A pile is characterised by different geometrical and mechanical parameters. Its layout and spatial orientation are defined by the following elements:

X_P : X-axis of pile head in the global system of coordinates;

Y_P : Y-axis of pile head in the global system of coordinates;

Z_P : elevation of the pile head;

L : length of the pile;

α : angle between the direction of the pile and the vertical $\alpha \in [0°,90°[$;

β : angle defined by rotation of the pile around the vertical axis $\beta \in [0°,360°[$.

The mechanical characteristics of a pile are:

EI_x : product of inertia of the pile in direction x ;

EI_y : product of inertia of the pile in direction y ;

ES : pile axial rigidity;

Γ : equivalent torsional stiffness at pile head.

Link with the footing:

Binding : type of binding between pile and footing (articulated or clamped).

If the piles are not free at the base, additional lateral translation and rotational stiffnesses may be defined to simulate the base binding of each pile.

H.2.1.3. Definition of soil layers

The foundation soil consists of one or more layers of different geometrical and mechanical characteristics. The geometrical parameters introduce stresses on the piles mesh. These then force the creation of imposed nodes at the points of intersection between the piles and the layer interfaces. Each soil layer is characterised by the following parameters:

$Elev_{base}$: elevation of the base at axis $(O, \vec{Z})$;

α_Y : angle between the base and axis $(O, \vec{Y})$ with $\alpha_Y \in]-90°,90°[$;

α_X : angle between the base and axis $(O, \vec{X})$ with $\alpha_X \in]-90°,90°[$.

The other characteristics are used to define pile-soil reaction laws taking account of the dimensions of the piles (reaction width, perimeter, cross-section).

H.2.2. Representation by equation

H.2.2.1. Modelling the behaviour of a pile "i"

Each pile is compared to a beam with linear elastic behaviour. The beams are considered to have homogeneous cross-section, which enables bending behaviour to be dissociated from that in traction/compression.

The combined bending behaviour of the beam representative of a pile "i" can be described using the following system of equations:

$$\begin{cases} ES^i \dfrac{d^2u_z^i(z)}{dz^2} = q_z^i(z) - r_z^i(z) \\ EI_x^i \dfrac{d^4u_x^i(z)}{dz^4} = q_x^i(z) - r_x^i(z) \\ EI_y^i \dfrac{d^4u_y^i(z)}{dz^4} = q_y^i(z) - r_y^i(z) \end{cases} \quad (1)$$

With:

- $u_k^i(z)$: displacement of pile "i" in direction "k" (k = x, y or z);
- EI_k^i: product of inertia of pile "i" in direction "k" (k = x, y);
- ES^i: axial rigidity of pile "i";
- $q_k^i(z)$: component "k" of the external linear load density on pile "i" other than the soil reaction (k = x, y or z);
- $r_k^i(z)$: component "k" of soil reaction on pile "i" (k = x, y or z).

This system of equations can be modelled numerically by discretising the pile into finite beam elements. To do this, we use "classic" elements with 2 nodes and 5 degrees of freedom per node: one axial displacement, two transverse displacements and two rotations. At any point, the rotation of the beam coincides with the derivative of the transverse displacement field (Bernoulli approximation). In the context of this discretisation, the equilibrium of the pile is represented by an equivalent matrix system of size $5(p_i+1) \times 5(p_i+1)$ where p_i designates the total number of elements of pile "i":

$$\mathbf{K}_p^i.\mathbf{u}^i = \mathbf{F}_{ext}^i - \mathbf{R}_s^i \quad (2)$$

With:

- $\mathbf{K}_p^i$: rigidity matrix of pile "i" constituted by an assembly of elementary rigidity matrices;
- $\mathbf{F}_{ext}^i$: load vector relative to the transverse loads on pile "i" other than soil reaction;
- $\mathbf{R}_s^i$: load vector related to the soil reaction on pile "i";
- $\mathbf{u}^i$: equivalent displacement vector of pile "i" constituted by displacements (u_x, u_y, u_z) and rotations (θ_x, θ_y) at each node.

H.2.2.2. Modelling of piles/soil interaction

The interaction between the piles and the surrounding soil can be described by:

- A frontal reaction with two components (decoupled), along x and y;
- An axial reaction (friction) along z;
- A base reaction, usually limited to its axial component along z.

The modelling of each of these components is based on the principles of the "p-y" (frontal components) and "t-z" (axial components) models. These models consist in comparing the frontal and axial responses of the surrounding soil to those of a distribution of juxtaposed elastoplastic springs (see following figure).

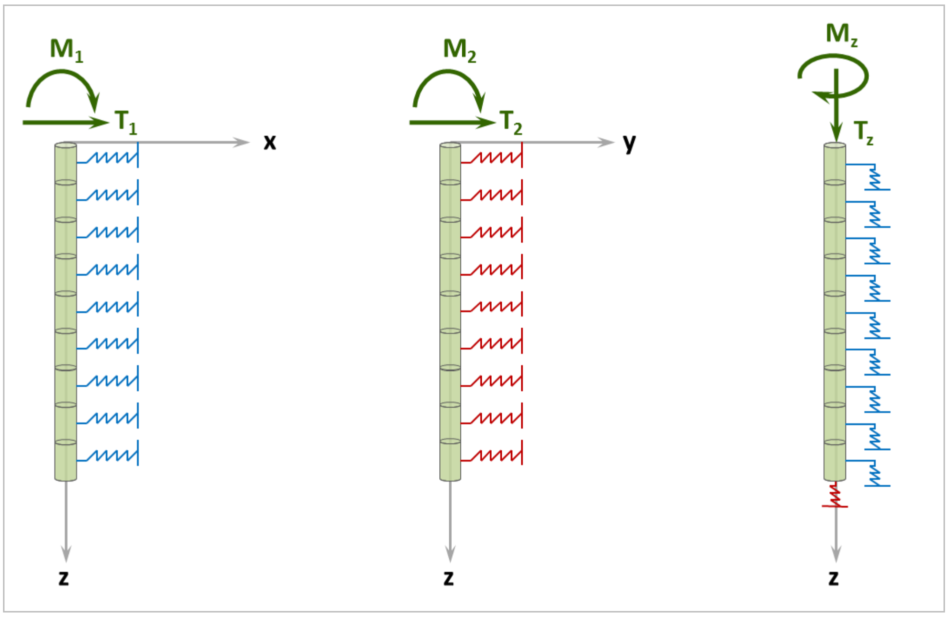


Figure H 4: Soil/pile interaction modelling principle

Each of these spring distributions is characterised by a mobilisation law with three plateaux linking soil reaction (for a given component) to relative pile displacement (along a given axis), as shown in the following figure. The relative nature of the displacement shown on the X-axis in particular makes it possible to deal with cases of interference (transverse effects of type "g(z)" or negative friction) developing in one or more soil layers.

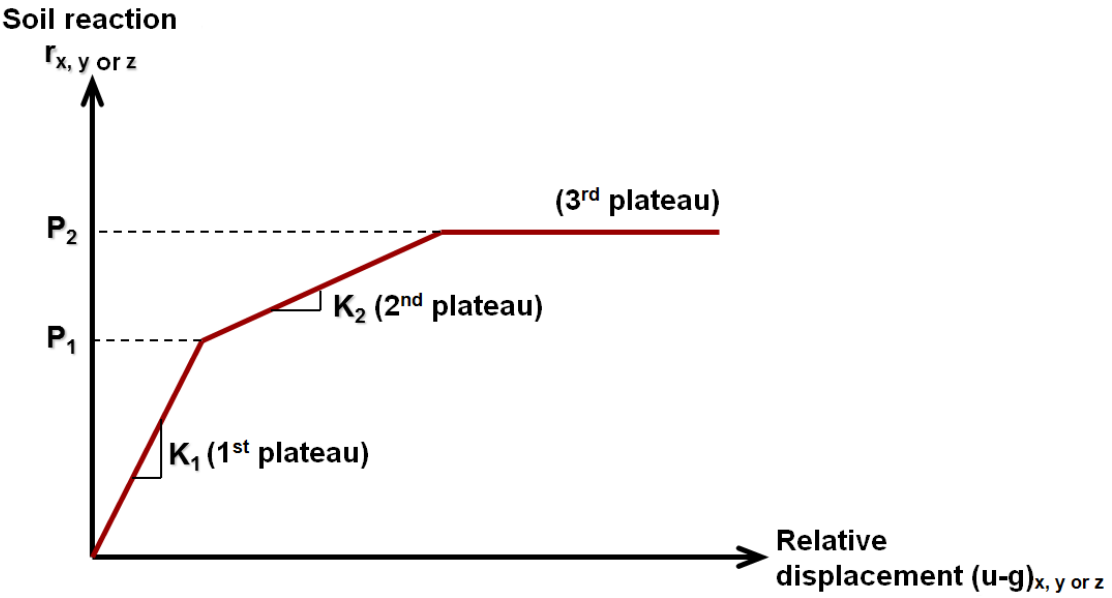


Figure H 5: General form of the soil reaction mobilisation law

According to the notations in the above figure, the soil transverse reaction r(z) is expressed thus:

$$r = \alpha[u - g] + \beta$$

With:

- For the 1st plateau: $\alpha = K_1$ & $\beta = 0$;
- For the 2nd plateau: $\alpha = K_2$ & $\beta = P_1.\left(1 - \frac{K_2}{K_1}\right)$;
- For the 3rd plateau: $\alpha = 0$ & $\beta = P_2$;

In the context of the finite elements discretisation chosen for pile "i", this relation can be written in the form of the following matrix:

$$\mathbf{R}_s^i = \mathbf{K}_s^i.(\mathbf{u}^i - \mathbf{g}^i) + \mathbf{c}_s^i \qquad (3)$$

Where:

- $\mathbf{K}_s^i$: matrix of soil rigidity in contact with pile "i", corresponding to the elastic part of the mobilisation curve in each element;
- $\mathbf{c}_s^i$: equivalent load vector corresponding to the "plastic" part of the soil reaction in contact with pile "i";
- $\mathbf{g}^i$: equivalent displacement vector corresponding to free displacement of the soil in contact with pile "i".

Combining the previous equations leads to the global formulation of the system representing the response of pile "i" interacting with the surrounding soil:

$$(\mathbf{K}_p^i + \mathbf{K}_s^i)\mathbf{u}^i = \mathbf{F}_{ext}^i + \mathbf{K}_s^i.\mathbf{g}^i - \mathbf{c}_s^i \qquad (4)$$

Soil plastification is managed using an iterative process during which $\mathbf{K}_s^i$ and $\mathbf{c}_s^i$ change until a compatible solution is obtained, at all points on the pile and in each direction, with the soil reaction mobilisation law.

H.2.2.3. Modelling footing/piles interaction

Interaction between the footing and the piles is described using a "clamped" or "articulated" type contact condition. In the first case, we consider equality between the displacements and rotations of the footing and those of the pile head. In the second, only equality of displacements is considered.

In both cases, the static equilibrium of the footing can be written in the form:

$$\mathbf{K}_{foot}.\mathbf{u}_{pile}^{top} = \mathbf{T}_{ext} - \mathbf{T}_{pile}^{top} \qquad (5)$$

With:

- $\mathbf{K}_{foot}$: footing rigidity matrix;
- $\mathbf{T}_{ext}$: vector representing the external loading global forces and moments applied to the footing (problem data);
- $\mathbf{u}_{pile}^{top}$: vector representing displacements and rotations at the piles heads. This vector is directly linked to the displacement vectors $\mathbf{u}^i$ for each pile;
- $\mathbf{T}_{pile}^{top}$: vector representing the forces and moments at the piles heads. It is directly linked to the external loading vectors $\mathbf{F}_{ext}^i$ for each pile.

H.2.3. Implementation

Model implementation is based on the creation and resolution of the global system of equations governing the equilibrium of the '"footing + piles" system interacting with the soil. Thus, in the same matrix system, the Groupie+ calculation engine assembles the footing equilibrium equation (5) with those representing the local equilibriums of each pile (4). The elements of this system can be supplemented by additional support conditions introduced at any point on the pile in the form of a elastic point support. As the calculation is non-linear, resolution is iterative.

Resolution of the final system gives the displacements, rotations and reactions at all points on each pile, in particular at the head. Once the reactions are known, the internal forces (T_x T_y T_z M_x M_y) are then calculated by integration using the following general formula:

$$T_k(z)=\int_0^z [q_k(t)-r_k(t)]dt+T_k(0) \qquad \text{k = x, y or z}$$

$$M_k(z)=\int_0^z T_k(t)dt+M_k(0) \qquad \text{k = x or y}$$

The model can also be used to define an equivalent tangent stiffness system at the centre of the footing, which can then be used as an input parameter for the "structure" model. The system of head stiffnesses comprises a 6x6 symmetric stiffness "matrix" and a "constant" term according to the following general formula:

$$\begin{bmatrix} T_X \\ M_Y \\ T_Y \\ M_X \\ T_Z \\ M_Z \end{bmatrix} = \begin{bmatrix} k_{u_X,u_X} & k_{u_X,\theta_Y} & k_{u_X,u_Y} & k_{u_X,\theta_X} & k_{u_X,u_Z} & k_{u_X,\theta_Z} \\ . & k_{\theta_Y,\theta_Y} & k_{\theta_Y,u_Y} & k_{\theta_Y,\theta_X} & k_{\theta_Y,u_Z} & k_{\theta_Y,\theta_Z} \\ . & . & k_{u_Y,u_Y} & k_{u_Y,\theta_X} & k_{u_Y,u_Z} & k_{u_Y,\theta_Z} \\ . & . & . & k_{\theta_X,\theta_X} & k_{\theta_X,u_Z} & k_{\theta_X,\theta_Z} \\ . & . & . & . & k_{u_Z,u_Z} & k_{u_Z,\theta_Z} \\ . & . & . & . & . & k_{\theta_Z,\theta_Z} \end{bmatrix} . \begin{bmatrix} u_X \\ \theta_Y \\ u_Y \\ \theta_X \\ u_Z \\ \theta_Z \end{bmatrix} + \begin{bmatrix} T_{0X} \\ M_{0Y} \\ T_{0Y} \\ M_{0X} \\ T_{0Z} \\ M_{0Z} \end{bmatrix}$$

H.2.4. Validity limits

The previous formulation is valid in the case of piles with a homogeneous cross-section authorising decoupling between the axial and bending behaviour. The validity of the system considered also assumes that the piles are slender enough to ignore the influence of deformation caused by shear forces.

The validity of the general model also assumes prior adaptation of the pile/soil interaction laws to take account of certain special cases, such as that of a foundation situated close to a bank or pile zones close to the surface. The group effect between piles (pile/soil/pile interaction) is also such as to require a prior degradation of the slope parameters and/or plastic plateaux characterising the soil reaction mobilisation law.

As an example, the following figure recalls the principle of the adaptations recommended in standard NF P94-262 in the case of a group effect affecting the transverse behaviour of the piles. Values ρ_1 and ρ_2 are a function of the diameter to spacing ratio.

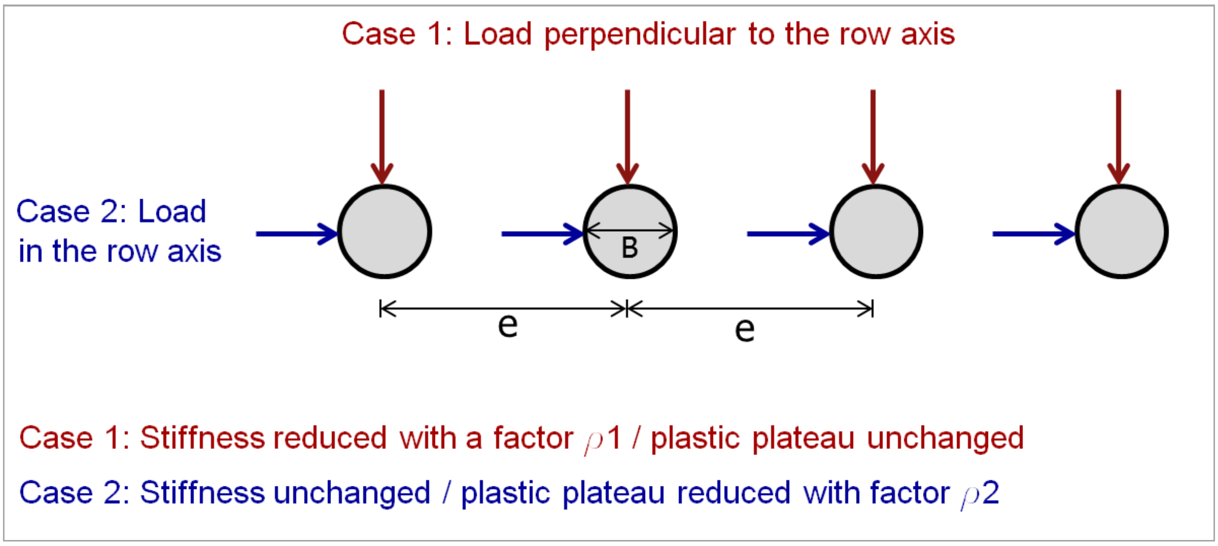


Figure H 6: Processing of group effects with respect to transverse behaviour of piles

H.2.5. Implementation in "manual" mode

The manual mode consists in characterising the response of each pile by an equivalent head stiffness matrix resulting from a prior calculation made using the Taspie+ and Piecoef+ modules (see figure below).

The mathematical formulation of the system is then adapted, replacing equation (4) by that represented by the head stiffness matrices taken from Taspie+ and Piecoef+.

$$\begin{pmatrix} T_1 \\ M_1 \end{pmatrix} = \begin{pmatrix} \rho_1 & -\rho_2 \\ -\rho_2 & \rho_3 \end{pmatrix} \cdot \begin{pmatrix} u_1 \\ \theta_1 \end{pmatrix} \qquad \begin{pmatrix} T_2 \\ M_2 \end{pmatrix} = \begin{pmatrix} \rho_4 & -\rho_5 \\ -\rho_5 & \rho_6 \end{pmatrix} \cdot \begin{pmatrix} u_2 \\ \theta_2 \end{pmatrix} \qquad \begin{pmatrix} T_z \\ M_z \end{pmatrix} = \begin{pmatrix} \mu & 0 \\ 0 & \Gamma \end{pmatrix} \cdot \begin{pmatrix} u_z \\ \theta_z \end{pmatrix}$$

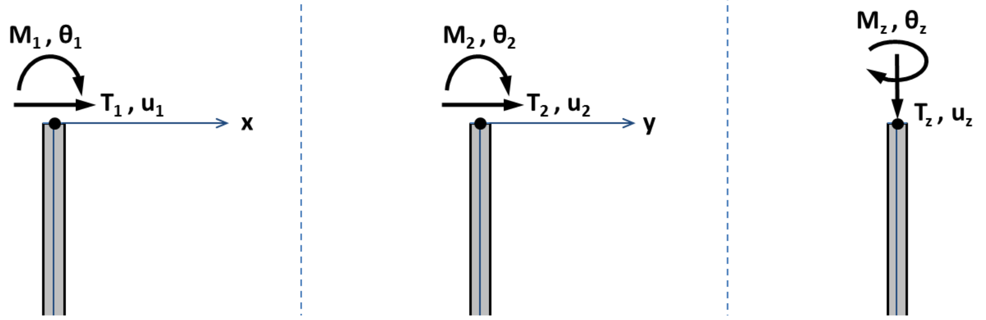


Figure H 7: Equivalent stiffness matrices at pile head (Piecoef+, Taspie+)

H.2.6. Definition of "p-y" and "t-z" laws from pressuremeter tests

H.2.6.1. "p-y" frontal reaction mobilisation law

As defined in standard NF P94-262, the frontal reaction mobilisation law can be defined according to the general shape of the following figure.

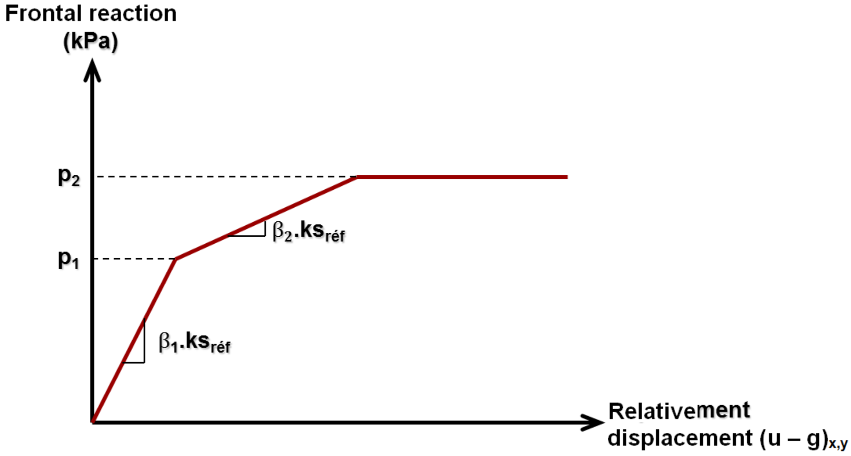


Figure H 8: General shape of the soil frontal reaction mobilisation law

Where $ks_{ref,}$ is a reference reaction coefficient (stress per unit length), expressed as a function of the pressuremeter modulus E_M, the rheological coefficient α, the (equivalent) diameter of pile B and a reference diameter B_0 considered to be equal to 0.6 m:

$$ks_{ref} = \frac{1}{B}.\frac{18.E_M}{\left(4.\left(2,65.\frac{B}{B_0}\right)^{\alpha}.\frac{B_0}{B}+3.\alpha\right)} \quad \text{si} \quad B \geq B_0$$

$$ks_{ref} = \frac{1}{B}.\frac{18.E_M}{\left(4.(2,65)^{\alpha}+3.\alpha\right)} \quad \text{si} \quad B \leq B_0$$

The values of β_i and p_i, which vary according to the type of loads, are summarised in the following table:

Type of load	**β₁**	**β₂**	**p1**	**p2**
Case in which permanent loads predominate at the head	1	0	p_f*	p_f*
Case in which loads caused by lateral earth pressure predominate		1/2		p_l*
Case in which short-duration loadings at the head predominate	2	0		p_f*
Case in which very short accidental loadings at the head predominate		1		p_l*

Table H 1: *Parameters of the frontal reaction mobilisation law*

Where p_f* and p_l* respectively designate the soil net creep pressure and the net limit pressure resulting from the pressuremeter test. It should be noted that for the case in which p1 = p2, we have $\beta_2 = 0$ and therefore have a two-plateau mobilisation curve (elastoplastic law).

H.2.6.2. Shaft friction and base resistance

As defined in standard NF P94-262, the shaft friction and base resistance mobilisation laws can be defined according to the general shape of the following figure.

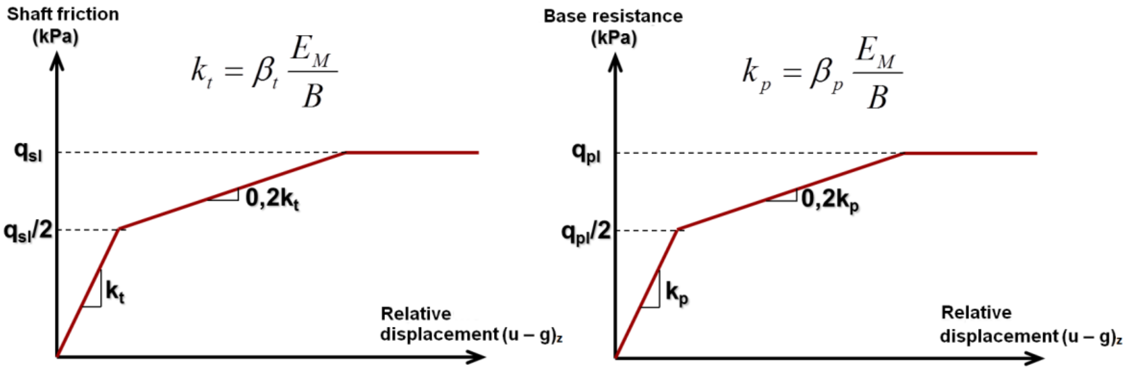


Figure H 9: General shape of the soil axial reaction mobilisation law

Where q_{sl} and q_{pl} are the limit shaft friction and the limit base resistance respectively, E_M the pressuremeter modulus and B the equivalent pile diameter. The values of β_t and β_p are given in the following table for the case of a bored pile. In the absence of specific experimental data, we can use the same values for driven piles.

Type of soil	β_t	β_p
Fine soils	2.0	11
Granular soils	0.8	4.8

Table H 2: *Parameters of axial reaction mobilisation laws*

H.3. USER'S MANUAL

This chapter is devoted to presenting the interface of the Groupie+ module. It describes the following elements in detail:

- The input parameters necessary for the calculation;
- The results generated by the calculation.

To build a model, the Groupie+ module offers three possibilities, referred to by modes: Manual Groupie, Automatic Groupie+ or Automatic Advanced Groupie+. The choice of any given mode determines the content of the active tabs and also influences their number:

- Manual Groupie : 4 tabs;
- Automatic Groupie+ : 5 tabs;
- Automatic Advanced Groupie+: 3 tabs + an additional tab per created family.

The presentation of the results also varies according to the selected mode.

To select a mode, simply click the corresponding button. This choice is to be defined in the first tab activated by default.

ManualGroupie: this mode is used in conjunction with Taspie+ and Piecoef+. Each pile is modelled by its equivalent stiffnesses matrix at pile head. Groupie resolves the equilibrium of the footing, assumed to be infinitely rigid, subjected to external global forces and moments and to pile reactions. If the plastic soil deformation occurs, the iterative calculation is managed manually by the three modules alternately.

Automatic Groupie+ (default mode selected): this is an autonomous mode that does not interact with the other modules. It is dedicated to the case of a group of piles with a uniform circular cross-section. The piles may have different geometrical/mechanical characteristics and any spatial distribution. The soil medium is defined overall as multiple layers independently of the foundation and can accept the input of layer dips in both directions.

Automatic Advanced Groupie+: this mode works primarily in families. It was originally designed to allow the calculation of rectangular piles. Unlike the previous mode, a cross-section with variable sections can be assigned and soil/pile transverse interaction laws specific to each direction can be defined.

In this manual, the Groupie+ module inputs and outputs are presented per mode and then per tab.

This chapter does not detail the actual user interface and its operations (buttons, menus, etc.). These aspects are covered in part C of the FoXta v3 user's manual.

H.3.1. Manual Groupie Mode

H.3.1.1. “Settings/Piles” tab

Select the Manual Groupie mode by clicking the button.

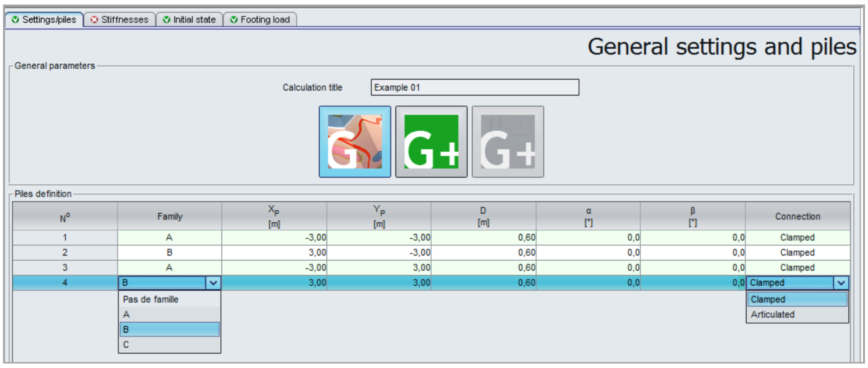


Figure H 10: “Settings/Piles” tab in Manual Groupie

This table comprises two frames:

- General parameters;
- Piles definition.

H.3.1.1.1. “General parameters” frame

It contains the following data:

- Calculation title;
- Manual Groupie mode: selected.

H.3.1.1.2. "Piles definition” frame

This frame is used to define the distribution and orientation of the piles, as well as their connection to the footing.

It is possible to allocate a family to a set of piles, enabling the forces obtained on all the piles of a given family to be grouped. To allocate a family to a pile, simply select a letter from the “Family” drop-down list. If you do not wish to manage families, simply leave the default " no family " () value.

To add a pile, click the "Add line" button then define its characteristics. The following data are then to be input:

Designation	**Unit**	**Default value**	**Display condition**	**Mandatory value**	**Local checks**
Pile family	-	No family	Always	Yes	-
X_P: X-axis of pile head – global system of coordinates	m	0	Always	Yes	-
Y_P: Y-axis of pile head – global system of coordinates	m	0	Always	Yes	-
D: diameter of pile cross-section (*)	m	0	Always	Yes	> 0
α: angle of inclination of pile to axis (OZ)	°	0	Always	Yes	-
β: orientation of pile around axis (OZ)	°	0	Always	Yes	-
Connection: connection at pile head: clamped or articulated (ball and socket joint)	-	Clamped	Always	Yes	-

Table H 3: *“Settings/Piles” tab – “Piles definition” frame*

(*) Unlike the other parameters, the diameter input in Manual Groupie is not a calculation parameter. Its value simply allows configuration of the graphic representation of the foundation.

Two help diagrams are available which give a schematic representation of the global coordinates system of the foundation (OXYZ).

- Perspective view:

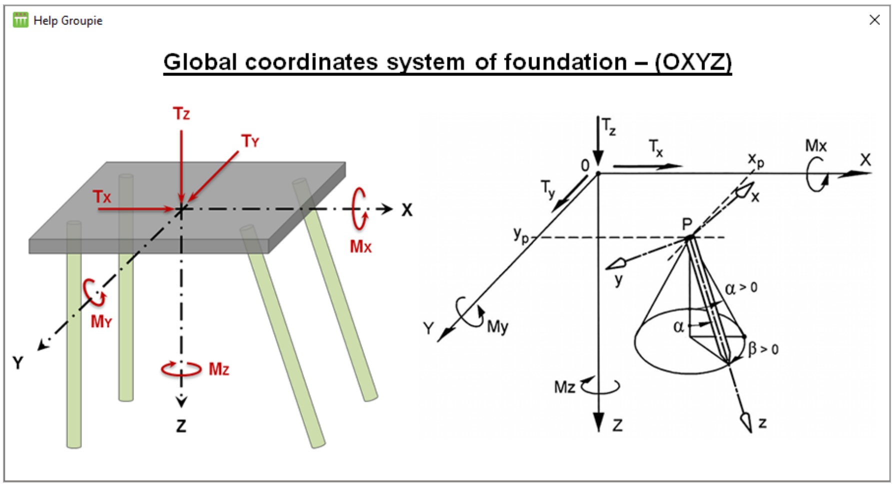


Figure H 11: Help diagram: Global coordinates system of foundation – perspective view

- Top view:

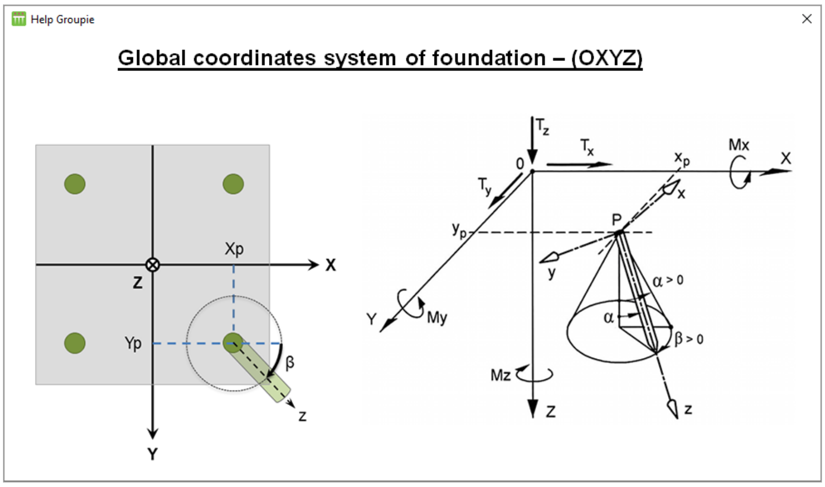


Figure H 12: Help diagram: Global coordinates system of foundation – top view

H.3.1.2. "Stiffnesses" tab

In this tab, the equivalent stiffnesses at the pile head are input. These stiffnesses can be easily evaluated by the Taspie+ and Piecoef+ modules.

The "Stiffnesses" tab comprises a single frame with an import wizard.

H.3.1.2.1. "Equivalent stiffnesses at pile head" frame

This frame is used to define the equivalent stiffnesses at the piles heads. They are expressed in the local coordinates system (Pxyz) of each pile. The parameters required are shown in the following table.

Designation	Unit	Default value	Display condition	Mandatory value	Local checks
μ: equivalent axial stiffness	kN/m	0	Always	Yes	> 0
ρ_1: translation stiffness along (Px)	kN/m	0	Always	Yes	≥ 0
ρ_2: "combined" translation/rotation stiffness in plane (Pxz)	kN	0	Always	Yes	≥ 0
ρ_3: rotation stiffness in plane (Pxz)	kN.m/rad	0	Always	Yes	≥ 0
ρ_4: translation stiffness along (Py)	kN/m	0	Always	Yes	≥ 0
ρ_5: "combined" translation/rotation stiffness in plane (Pyz)	kN	0	Always	Yes	≥ 0
ρ_6: rotation stiffness in plane (Pyz)	kN.m/rad	0	Always	Yes	≥ 0
Γ: equivalent torsional stiffness	kN.m/rad	1.0	Always	Yes	≥ 0

Table H 4: *"Stiffnesses" tab – "Equivalent stiffnesses at pile head" frame*

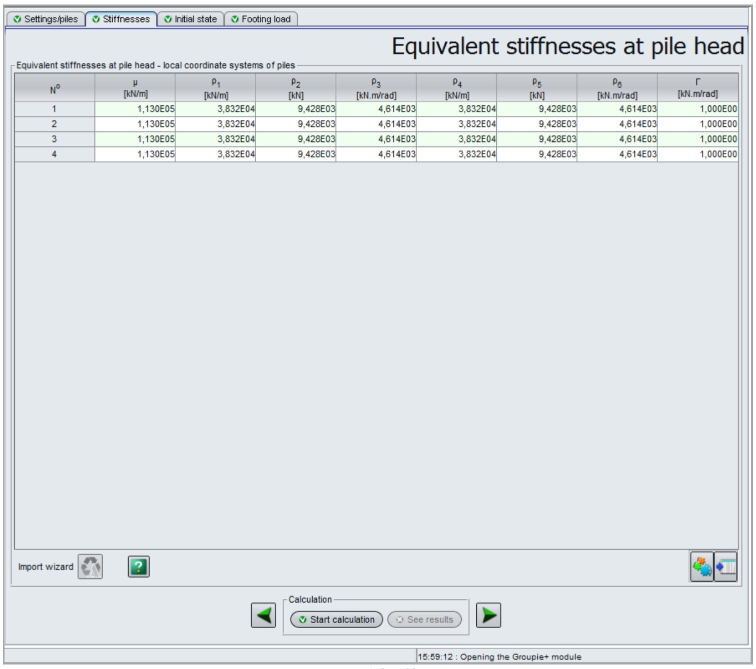


Figure H 13: "Stiffnesses" tab

H.3.1.2.2. Wizard for importing piles into Groupie

This wizard is used to import the calculated stiffnesses from the Taspie+ and Piecoef+ modules. To use it, simply select a line in the "Stiffnesses" table and click the  button. Once started, the import wizard comprises two sub-tabs.

"Import from Taspie+" sub-tab

This wizard is used to import the axial stiffness μ along direction z.

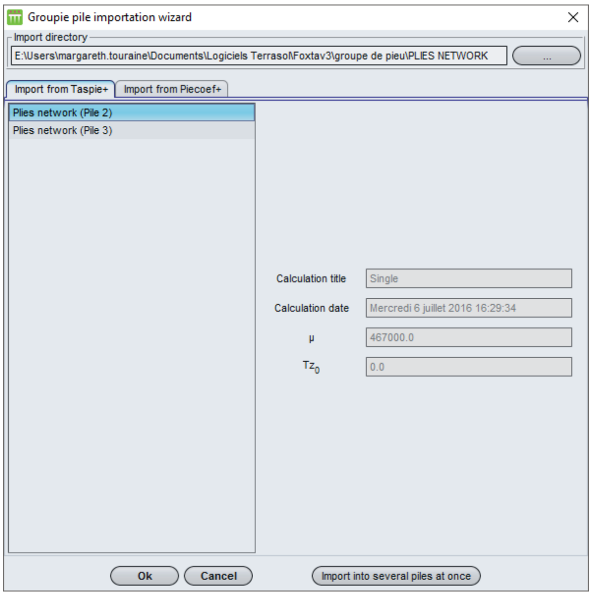


Figure H 14: Import from Taspie+ wizard

Procedure:

- Select a pile;
- To import the values for all piles, click the Import into several piles at once button. With the mouse, select the various piles which appear, as in the following window. Click the OK button.
  Otherwise, the value will only be imported for the line selected.

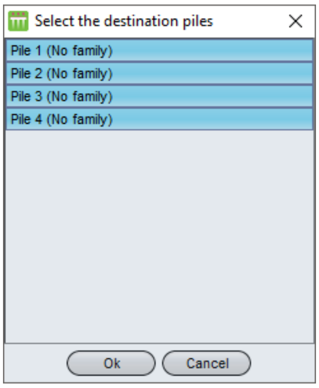


Figure H 15: Import from Taspie+ wizard – Selection of piles

Nota:

- The value of μ imported corresponds to the secant stiffness at SLS in quasi-permanent combination.
- The imported value of T_{z0} is always equal to 0. This is because stiffness μ is defined as being the secant stiffness and not the tangent stiffness (see diagram below).

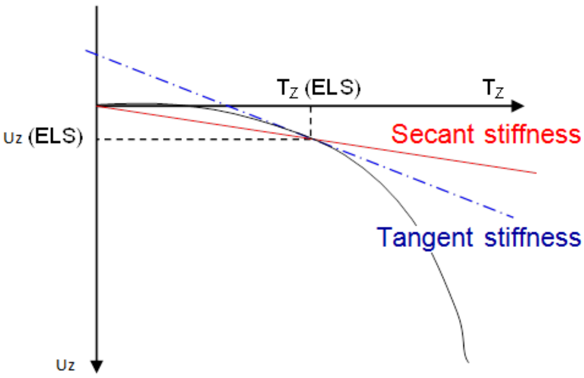


Figure H 16: Secant stiffness / Tangent stiffness

"Import from Piecoef+" wizard

Proceed in the same way as for import from Taspie+.

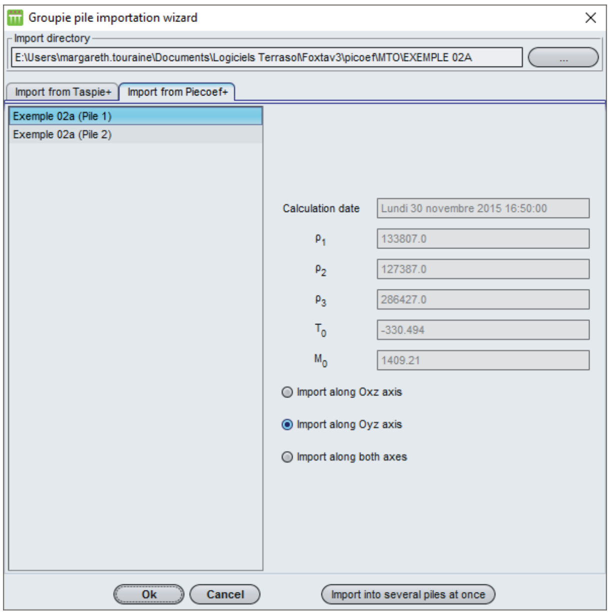


Figure H 17: Piecoef+ import wizard

NB: Importing from Piecoef+ allows ρ1, ρ2, ρ3, T_0 and M_0 to be imported in direction x, y or in both directions at the same time.

H.3.1.3. "Initial state" tab

For the values introduced in the previous tab to make sense, each stiffness value must be assigned a reference (origin value). Apart from the axial and torsional stiffnesses, which are defined as secant, the other stiffnesses tend more to be tangent and their initial state must be characterised.

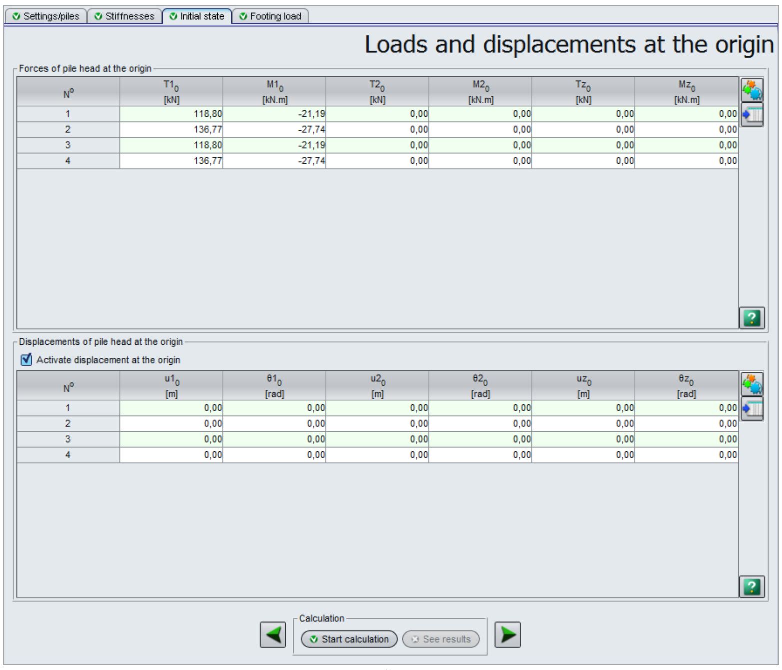


Figure H 18: "Initial state" tab

The initial state can be expressed by forces (default option) or by displacements at the origin. If the "Stiffnesses" tab was defined via the import wizard, the forces at the origin associated with the lateral stiffness matrices are filled out automatically.

H.3.1.3.1. "Forces of pile head at the origin" frame

The elements to be defined are presented in the following table. They are expressed in the pile local coordinates system (Pxyz)

Designation	Unit	Default value	Display condition	Mandatory value	Local checks
$T1_0$: side force at origin defined along (Px)	kN	0	Always	Yes	-
$M1_0$: bending moment at origin defined around (-Py)	kN.m	0	Always	Yes	-
$T2_0$: side force at origin defined along (Py)	kN	0	Always	Yes	-
$M2_0$: bending moment at origin defined around (Px)	kN.m	0	Always	Yes	-
Tz_0: axial force at origin defined along (Pz)	kN	0	Always	Yes	-
Mz_0: torsional moment at origin defined around (Pz)	kN.m	0	Always	Yes	-

Table H 5: *"Initial state" tab – "Forces of pile head at origin" frame*

H.3.1.3.2. "Displacements of pile head at the origin" frame

The table of values is only visible if the "Activate displacement at the origin" box is ticked. The parameters to be defined are listed in the following table:

Designation	Unit	Default value	Display condition	Mandatory value	Local checks
$u1_0$: horizontal displacement at origin defined along (Px)	m	0	Always	Yes	-
$\theta1_0$: rotation at origin defined around (-Py)	rad	0	Always	Yes	-
$u2_0$: horizontal displacement at origin defined along (Py)	m	0	Always	Yes	-
$\theta2_0$: rotation at origin defined around (Px)	rad	0	Always	Yes	-
uz_0: vertical displacement at origin defined along (Pz)	m	0	Always	Yes	-
θz_0: rotation at origin defined around (Pz)	rad	0	Always	Yes	-

Table H 6: *"Initial state" tab – "Displacement of pile head at the origin" frame*

H.3.1.4. "Footing load" tab

This tab is used to define one or more load cases expressed at point O at the centre of the global coordinates system, characterised by the project's reference elevation. A load case is defined by six components of global forces and moments (3 forces and 3 torques). The resultant displacement global forces and moments give the 3 translations and 3 rotations of the footing at the centre of the coordinates system.

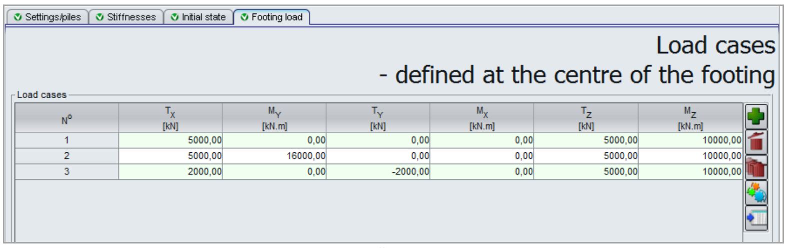


Figure H 19: "Footing load" tab

The only frame available, "Load case", is used to fill out the reduction elements of the global forces and moments expressed at point O. Details of the input are given in the following table.

Designation	Unit	Default value	Display condition	Mandatory value	Local checks
T_X: horizontal force along (OX)	kN	0	Always	Yes	-
M_Y: moment around (OY)	kN.m				
T_Y: horizontal force along (OY)	kN				
M_X: moment around (OX)	kN.m				
T_Z: vertical force along (OZ)	kN				
M_Z: moment around (OZ)	kN.m				

Table H 7: *"Footing load" tab – "Load cases" frame*

H.3.1.5. Calculation

The calculation can be started from any tab, provided that the project has been correctly filled out, that is when all the tabs are marked with a green tick (for example: Settings/piles).

A tab is marked with a red cross (for example: Settings/piles) if incorrectly filled out (data missing or not conforming to the expected values).

To start the calculation, click the Start calculation button.

In this mode (Manual Groupie), the calculation is virtually instantaneous, because the iterations are managed manually. The calculation time is slightly influenced by the number of piles or load cases.

H.3.1.6. Results

Manual Groupie only proposes numerical results presented as "Formatted results" and "Result tables".

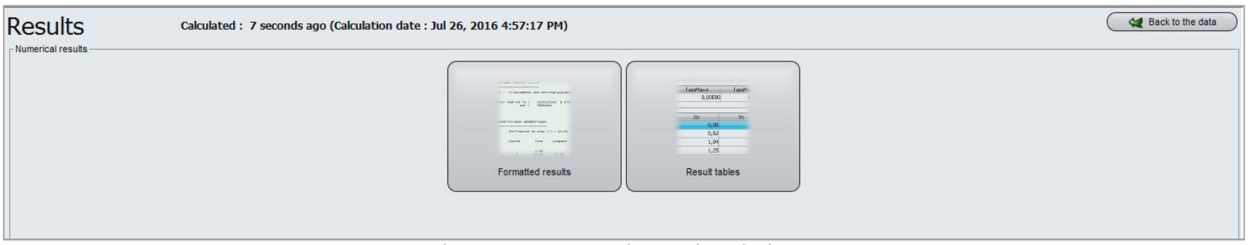
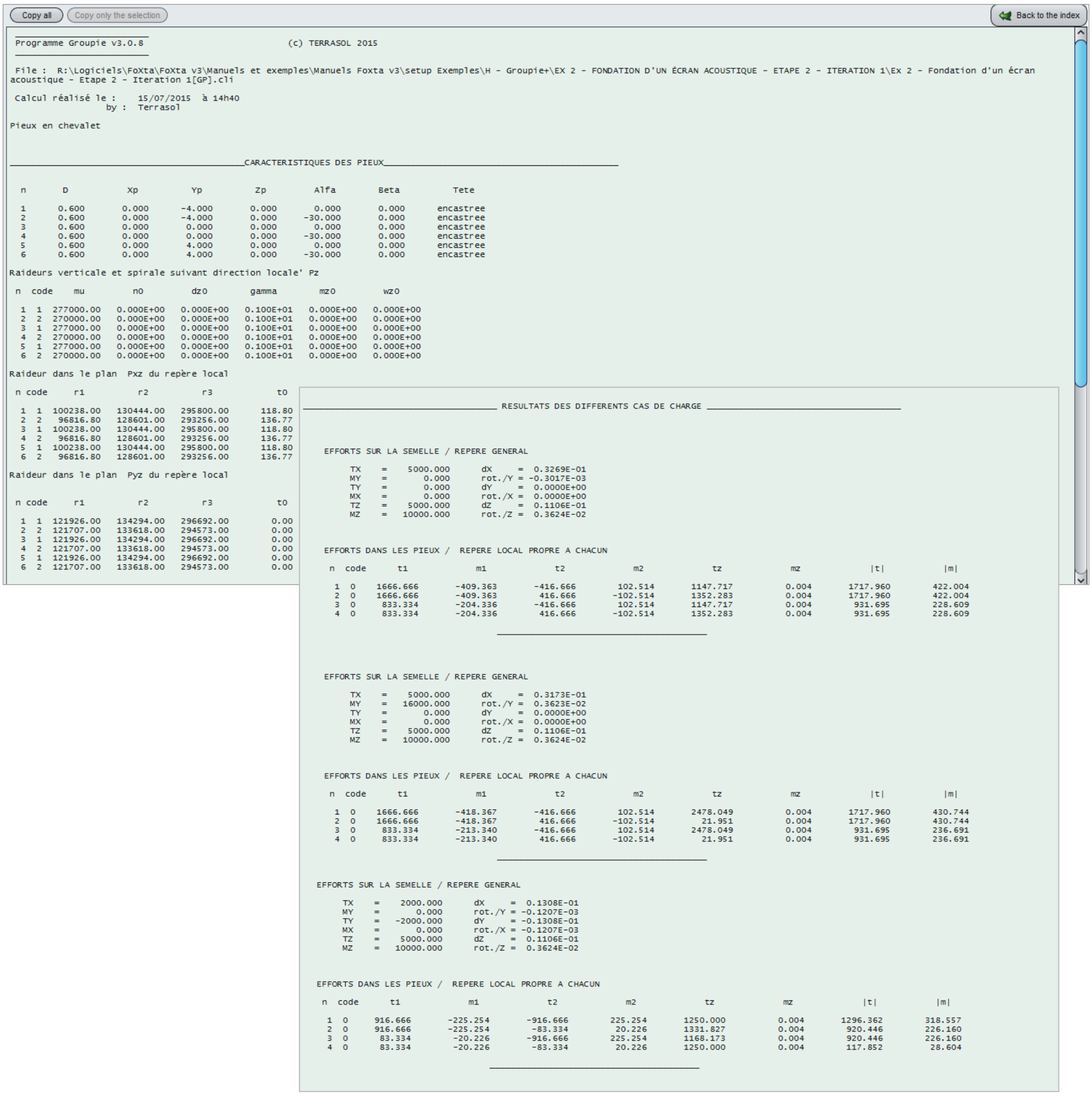


Figure H 20: Groupie results window

H.3.1.6.1. Numerical results: Formatted results

This type of result is only accessible for calculations in Manual Groupie mode.



```
Copy all   Copy only the selection                                  Back to the index

 Programme Groupie v3.0.8                         (c) TERRASOL 2015

 File :  R:\Logiciels\FoXta\FoXta v3\Manuels et exemples\Manuels Foxta v3\setup Exemples\H - Groupie+\EX 2 - FONDATION D'UN ÉCRAN ACOUSTIQUE - ETAPE 2 - ITERATION 1\Ex 2 - Fondation d'un écran
acoustique - Etape 2 - Iteration 1[GP].cli

 Calcul réalisé le :    15/07/2015  à 14h40
                by :    Terrasol

Pieux en chevalet

__________________________________CARACTERISTIQUES DES PIEUX__________________________________

  n       D          Xp          Yp          Zp         Alfa        Beta        Tete

  1     0.600      0.000      -4.000       0.000       0.000       0.000      encastree
  2     0.600      0.000      -4.000       0.000     -30.000       0.000      encastree
  3     0.600      0.000       0.000       0.000       0.000       0.000      encastree
  4     0.600      0.000       0.000       0.000     -30.000       0.000      encastree
  5     0.600      0.000       4.000       0.000       0.000       0.000      encastree
  6     0.600      0.000       4.000       0.000     -30.000       0.000      encastree
Raideurs verticale et spirale suivant direction locale' Pz

 n  code    mu          n0          dz0         gamma        mz0         wz0

  1  1  277000.00   0.000E+00   0.000E+00   0.100E+01   0.000E+00   0.000E+00
  2  2  270000.00   0.000E+00   0.000E+00   0.100E+01   0.000E+00   0.000E+00
  3  1  277000.00   0.000E+00   0.000E+00   0.100E+01   0.000E+00   0.000E+00
  4  2  270000.00   0.000E+00   0.000E+00   0.100E+01   0.000E+00   0.000E+00
  5  1  277000.00   0.000E+00   0.000E+00   0.100E+01   0.000E+00   0.000E+00
  6  2  270000.00   0.000E+00   0.000E+00   0.100E+01   0.000E+00   0.000E+00
Raideur dans le plan  Pxz du repère local

 n code     r1          r2          r3              t0

  1  1  100238.00   130444.00   295800.00       118.80
  2  2   96816.80   128601.00   293256.00       136.77
  3  1  100238.00   130444.00   295800.00       118.80
  4  2   96816.80   128601.00   293256.00       136.77
  5  1  100238.00   130444.00   295800.00       118.80
  6  2   96816.80   128601.00   293256.00       136.77
Raideur dans le plan  Pyz du repère local

 n code     r1          r2          r3              t0

  1  1  121926.00   134294.00   296692.00         0.00
  2  2  121707.00   133618.00   294573.00         0.00
  3  1  121926.00   134294.00   296692.00         0.00
  4  2  121707.00   133618.00   294573.00         0.00
  5  1  121926.00   134294.00   296692.00         0.00
  6  2  121707.00   133618.00   294573.00         0.00
```

```
_______________________ RESULTATS DES DIFFERENTS CAS DE CHARGE _______________________

   EFFORTS SUR LA SEMELLE / REPERE GENERAL

       TX    =    5000.000      dX     =  0.3269E-01
       MY    =       0.000      rot./Y = -0.3017E-03
       TY    =       0.000      dY     =  0.0000E+00
       MX    =       0.000      rot./X =  0.0000E+00
       TZ    =    5000.000      dZ     =  0.1106E-01
       MZ    =   10000.000      rot./Z =  0.3624E-02

   EFFORTS DANS LES PIEUX /  REPERE LOCAL PROPRE A CHACUN

  n  code     t1          m1          t2          m2          tz          mz          |t|         |m|

  1  0    1666.666    -409.363    -416.666     102.514    1147.717      0.004    1717.960     422.004
  2  0    1666.666    -409.363     416.666    -102.514    1352.283      0.004    1717.960     422.004
  3  0     833.334    -204.336    -416.666     102.514    1147.717      0.004     931.695     228.609
  4  0     833.334    -204.336     416.666    -102.514    1352.283      0.004     931.695     228.609
                         ______________________________

   EFFORTS SUR LA SEMELLE / REPERE GENERAL

       TX    =    5000.000      dX     =  0.3173E-01
       MY    =   16000.000      rot./Y =  0.3623E-02
       TY    =       0.000      dY     =  0.0000E+00
       MX    =       0.000      rot./X =  0.0000E+00
       TZ    =    5000.000      dZ     =  0.1106E-01
       MZ    =   10000.000      rot./Z =  0.3624E-02

   EFFORTS DANS LES PIEUX /  REPERE LOCAL PROPRE A CHACUN

  n  code     t1          m1          t2          m2          tz          mz          |t|         |m|

  1  0    1666.666    -418.367    -416.666     102.514    2478.049      0.004    1717.960     430.744
  2  0    1666.666    -418.367     416.666    -102.514      21.951      0.004    1717.960     430.744
  3  0     833.334    -213.340    -416.666     102.514    2478.049      0.004     931.695     236.691
  4  0     833.334    -213.340     416.666    -102.514      21.951      0.004     931.695     236.691
                         ______________________________

  EFFORTS SUR LA SEMELLE / REPERE GENERAL

      TX    =    2000.000      dX     =  0.1308E-01
      MY    =       0.000      rot./Y = -0.1207E-03
      TY    =   -2000.000      dY     = -0.1308E-01
      MX    =       0.000      rot./X = -0.1207E-03
      TZ    =    5000.000      dZ     =  0.1106E-01
      MZ    =   10000.000      rot./Z =  0.3624E-02

  EFFORTS DANS LES PIEUX /  REPERE LOCAL PROPRE A CHACUN

 n  code     t1          m1          t2          m2          tz          mz          |t|         |m|

 1  0     916.666    -225.254    -916.666     225.254    1250.000      0.004    1296.362     318.557
 2  0     916.666    -225.254     -83.334      20.226    1331.827      0.004     920.446     226.160
 3  0      83.334     -20.226    -916.666     225.254    1168.173      0.004     920.446     226.160
 4  0      83.334     -20.226     -83.334      20.226    1250.000      0.004     117.852      28.604
                        ______________________________
```

Figure H 21: Manual Groupie Formatted results

The formatted results contain:

- A recapitulation of the pile characteristics
  - Definition of piles (distribution, orientation and type of anchor);
  - Vertical and spiral stiffnesses along the local direction (Pz);
  - Stiffnesses in the (Pxz) plane of local coordinates system;
  - Stiffnesses in the (Pyz) plane of local coordinates system.
- The results of the different load cases:

- Forces on footing and displacements at centre of footing / general coordinates system;
- Forces at pile heads / coordinates system specific to each one.

H.3.1.6.2. Numerical results: Results tables

This table contains the forces at the pile heads obtained following the Manual Groupie calculation. These values already appear in the Formatted results, although they cannot be exported in table format. This table is created for this purpose.

Exporter Retour

Numéro du cas de ch.	Numéro du pieu	T1	M1	T2	M2	Tz	Mz
1	1	404,14	-17,52	-0,00	0,00	289,60	-0,00
1	2	371,23	17,52	0,00	0,00	-548,73	-0,00
1	3	404,14	-17,52	-0,00	0,00	289,60	-0,00
1	4	371,23	17,52	0,00	0,00	-548,73	-0,00
1	5	404,14	-17,52	-0,00	0,00	289,60	-0,00
1	6	371,23	17,52	0,00	0,00	-548,73	-0,00

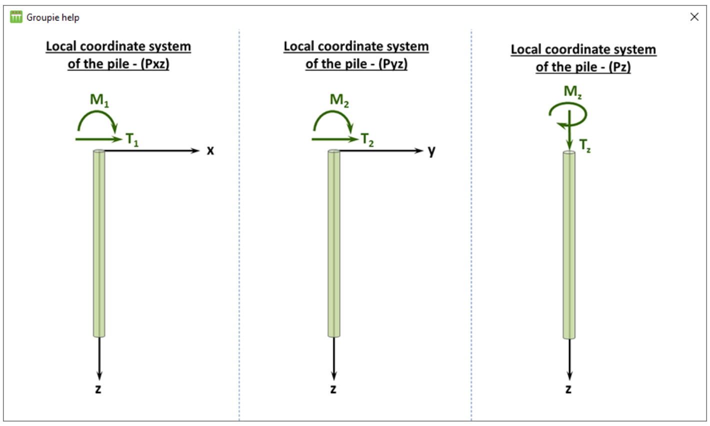
Figure H 22: Groupie Results table

Details of the results table are given below:

Designation	Unit	Display condition
T1: side force at pile head – direction x	kN	Always
M1: bending moment at pile head – direction x	kN.m	
T2: side force at pile head – direction y	kN	
M2: bending moment at pile head – direction y	kN.m	
Tz: axial force at pile head – direction z	kN	
Mz: torsional moment at pile head – around z	kN.m	

Table H 8: *Details of Groupie numerical results*

These forces at pile head are expressed in the local coordinates system of each pile. The additional results (displacements and internal loadings in the piles) can be evaluated during post-processing, after convergence of the Manual Groupie calculation, by inputting the forces at pile heads in the Taspie+ and Piecoef+ modules.



Pile local coordinates system

Figure H 23: Pile local coordinates system help diagram along Pxz, Pyz and Pz

H.3.2. Automatic Groupie+ Mode

H.3.2.1. "Parameters" tab

Select Automatic Groupie+ mode by clicking the  button.

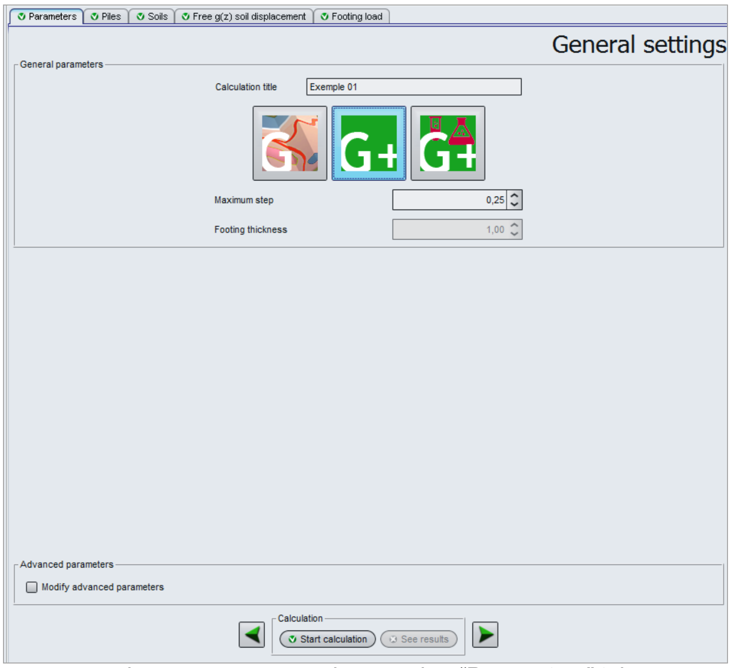


Figure H 24: Automatic Groupie+ "Parameters" tab

This tab comprises two frames:

- General parameters;
- Advanced parameters (masked by default).

H.3.2.1.1. "General parameters" frame

In this frame, Automatic Groupie+ requests the following information:

- Calculation title;
- Automatic Groupie+ Mode: selected;
- Maximum step (pitch) (m): maximum length of pile subdivisions (value of 0.5 m by default);
- Footing thickness (m): perfectly rigid footing.

H.3.2.1.2. "Advanced parameters" frame

If the "Modify advanced parameters" box is activated, the following fields appear:

- Number of increments of the global forces and moments;
- Relative tolerance used for the convergence check;
- Maximum number of iterations;
- Use the azimuth: if this option is activated, the soil layer dips are defined using an azimuth angle and a dip angle instead of the angles projected along the (OY) and (OX) axes. This option is exclusive to this mode;
- Use an optimised algorithm: ultra-fast resolution by comparison with the default situation.

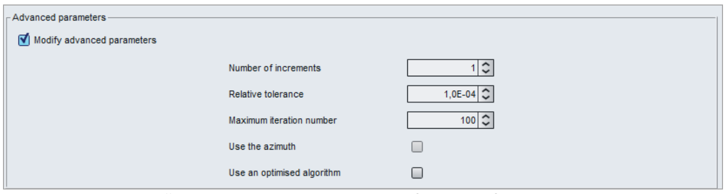


Figure H 25: "Advanced parameters" frame of Automatic Groupie+

H.3.2.2. "Piles" tab

This tab is used to input parameters defining the piles.

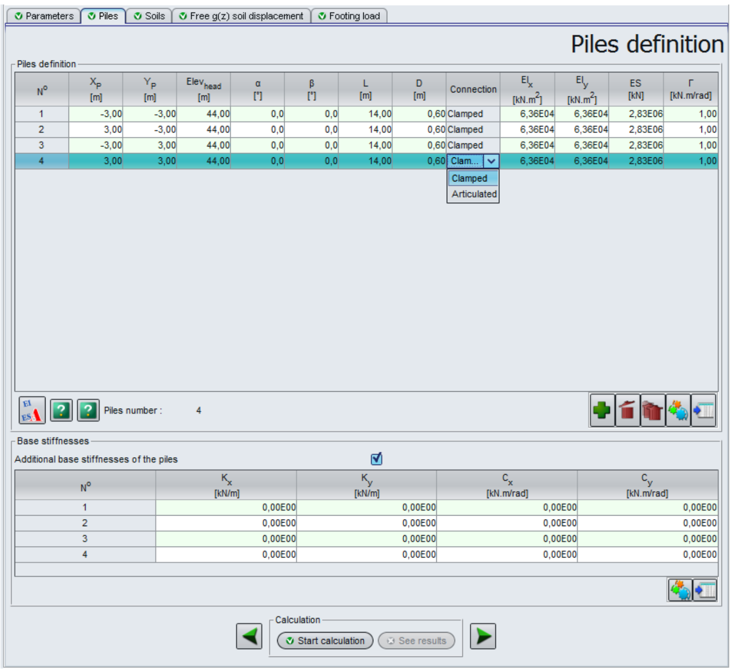


Figure H 26: "Piles" tab of Automatic Groupie+

The geometrical parameters must be input (as for Manual Groupie), but also the mechanical characteristics of the piles.

It should be remembered that in this mode, each pile is characterised by a uniform cross-section along its entire length, which is also why the piles and soils domains are defined independently.

This tab contains two frames:

- Piles definition;
- Base stiffnesses (masked by default).

H.3.2.2.1. "Piles definition" frame

The pile orientation conventions are comparable to those used in the Manual Groupie mode.

It should be recalled that the "Piles" tab remains marked by a red cross until the following "Soils" tab is completely filled out. FoXta checks that the pile bases are not out of the soil.

It should be noted that if a pile head has an elevation strictly lower than the reference elevation, it is connected perfectly rigidly to the footing. The opposite case is not possible.

The pile characteristics detailed in the following table must be defined.

Designation	Unit	Default value	Display condition	Mandatory value	Local checks
X_P: X-axis of pile head – global coordinates system	M	0.00	Always	Yes	-
Y_P: Y-axis of pile head – global coordinates system					
$Elev_{head}$: elevation of pile head read on the ascending vertical axis					
α: angle of inclination of pile in relation to axis (OZ)	°	0.00	Always	Yes	-
β: orientation around axis (OZ)					
L: pile length	M	0.00	Always	Yes	> 0 and ≤ soil depth
D: diameter of pile section (*)	M	0.00	Always	Yes	> 0
Connection: articulated or clamped	-	Clamped	Groupie+	Yes	-
EI_x: product of inertia of pile in direction x – local coordinates system	kN.m²	0.00	Always	Yes	≥ 0
EI_y: product of inertia of pile in direction y – local coordinates system	kN.m²				
ES: axial rigidity of pile – local coordinates system	kN				
Γ: equivalent torsional stiffness at pile head - local coordinates system	kN.m/ rad				

Table H 9: *"Piles" tab – "Piles definition" frame*

(*) Contrary to the Manual Groupie mode, the pile diameter is a decisive parameter for calculating the foundation.

H.3.2.2.2. "Base stiffnesses" frame

This frame is used to add the lateral stiffnesses at the pile bases. These stiffnesses are defined in the local coordinates system associated with each pile. If the "Additional base stiffnesses of the piles" box is ticked, Groupie+ asks for the following data to be input:

Designation	Unit	Default value	Display condition	Mandatory value	Local checks
K_x: Point restoring stiffness for lateral translation in direction x	kN/m	0	Always	Yes	≥ 0
K_y: Point restoring stiffness for lateral translation in direction y	kN/m	0	Always	Yes	≥ 0
C_x: Point restoring stiffness for rotation in direction x	kN.m/rad	0	Always	Yes	≥ 0
C_y: Point restoring stiffness for rotation in direction direction y	kN.m/rad	0	Always	Yes	≥ 0

Table H 10: *"Piles" tab – "Base stiffnesses" frame*

H.3.2.3. "Soils" tab

This tab is used to define the soil model for a calculation in Automatic Groupie+ mode. It consists of a permanent "Soil definition" frame and a "Laws" frame displayed in certain conditions.

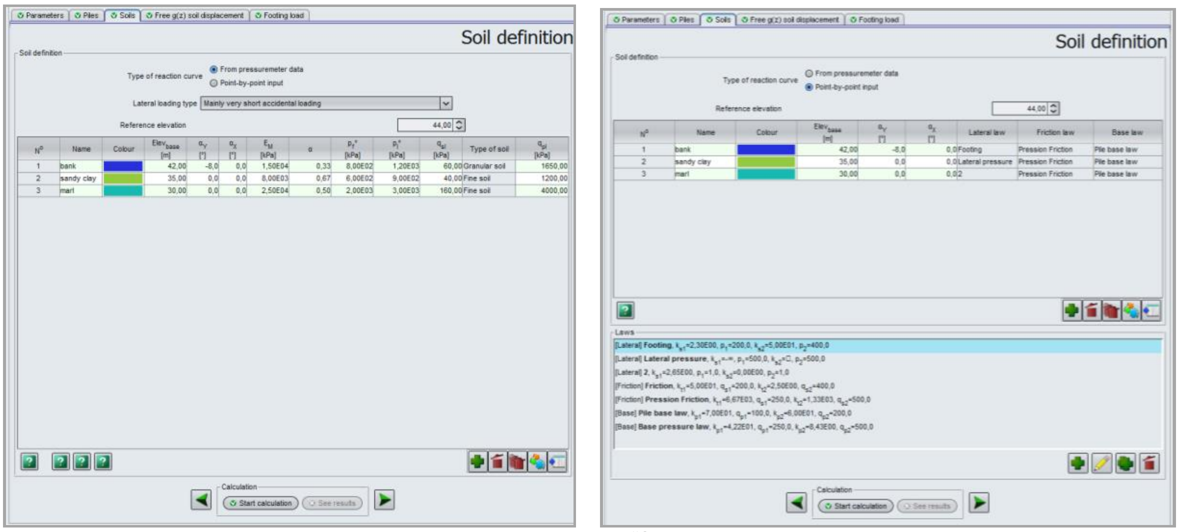


Figure H 27: "Soils" tab

H.3.2.3.1. "Soil definition" frame

The first option is to choose the type of "p-y" and "t-z" transfer curves. The transfer laws can be defined in two ways:

- "From pressuremeter data"
- "Point-by-point input"

The theoretical framework of these laws (general shape, definition of parameters) is presented in the technical guide available at the beginning of this manual.

If the choice was made to define the reaction curves "From pressuremeter data", the predominant "Lateral loading type" must be specified. There are four possible choices:

- Mainly permanent loading at pile head;
- Mainly lateral earth pressure loadings;
- Mainly short loading at pile head;
- Mainly very short accidental loading.

The second important parameter is the project reference elevation (in metres).

The following table describes the soil parameters to be input. Some columns use laws described in the "Laws" frame presented later.

Designation	Unit	Default value	Display condition	Mandatory value	Local checks
Elev$_{base}$: elevation of base read on ascending vertical axis	m	0	Always	Yes	The elevations do not overlap and are strictly descending
α_Y: dip of layer base around (OY) – global coordinates system	°	0	Always	Yes	-
α_X: dip of layer base around (OX) – global coordinates system	°	0	Always	Yes	-

Designation	Unit	Default value	Display condition	Mandatory value	Local checks
E_M: pressuremeter modulus	kPa	0		Yes	≥ 0
α: Ménard's rheological coefficient	-	0		Yes	0 < α ≤ 1
p_f*: net creep pressure	kPa	0	From pressuremeter data	Yes	≥ 0
p_l*: net limit pressure	kPa	0		Yes	≥ p_f
q_{sl}: limit shaft friction	kPa	0		Yes	≥ 0
Soil type: fine or granular	-	Fine soil		Yes	-
q_{pl}: base resistance pressure	kPa	0		Yes	≥ 0
Lateral law: lateral reaction law – local coordinates system	-	-		Yes	-
Friction law: shaft friction law - local coordinates system	-	-	Manual input point by point	Yes	-
Base law: base force law – local coordinates system	-	-		Yes	-

Table H 11: *"Soils" tab – "Soil definition" frame*

H.3.2.3.2. "Laws" frame

This frame only appears if "Point by point input" is selected as the type of reaction curve.

To add a law:

- click the button;

To edit a law:

- double-click the corresponding line

Or

- select it and click the "Edit" button.

To copy a law:

- select the required law;
- click the button: the law is copied, with only the names of the laws being numbered so that they can be differentiated from each other.

There are two options for defining a law.

Manual data

The law parameters (slopes and plateaux) are defined explicitly. This concerns the three types of law: lateral reaction, shaft friction and base resistance.

"Lateral" type law:

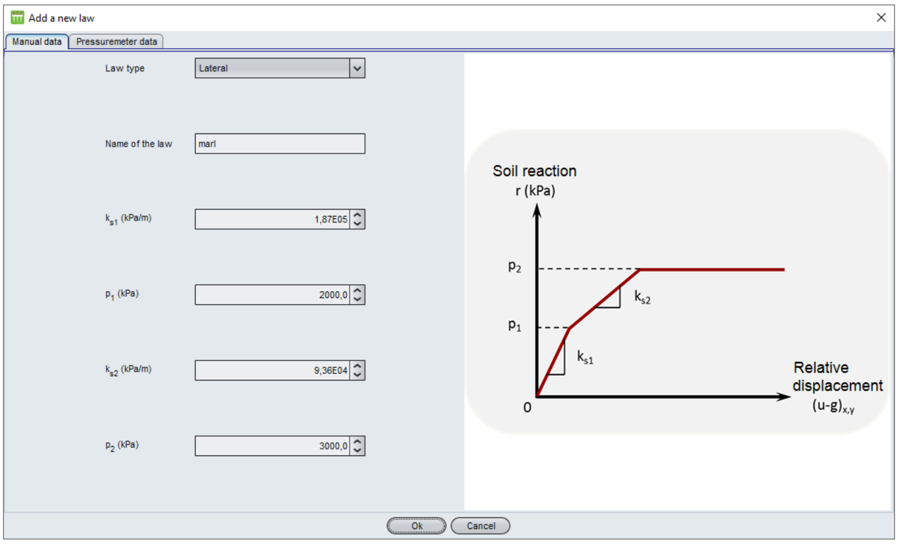


Figure H 28: Manual data – "Lateral" type law

"Friction" type law:

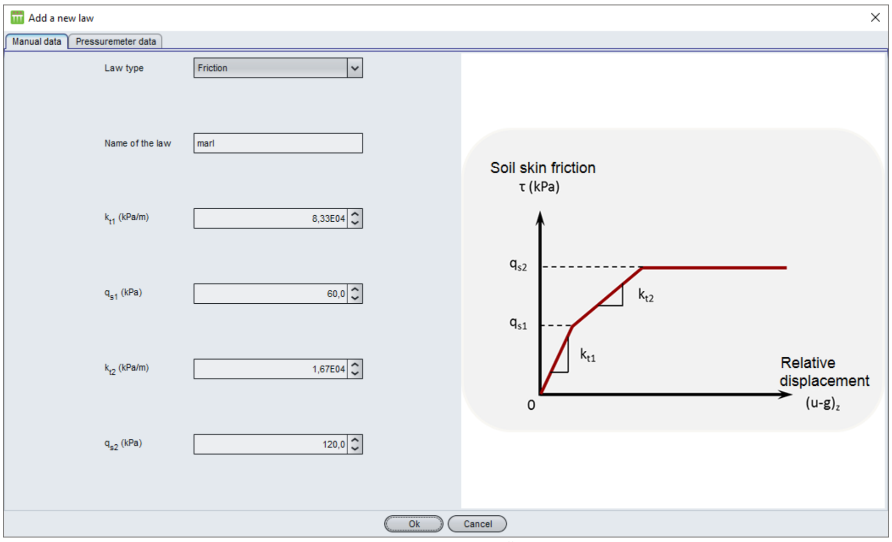


Figure H 29: Manual data – "Friction" type law

"Base" type law:

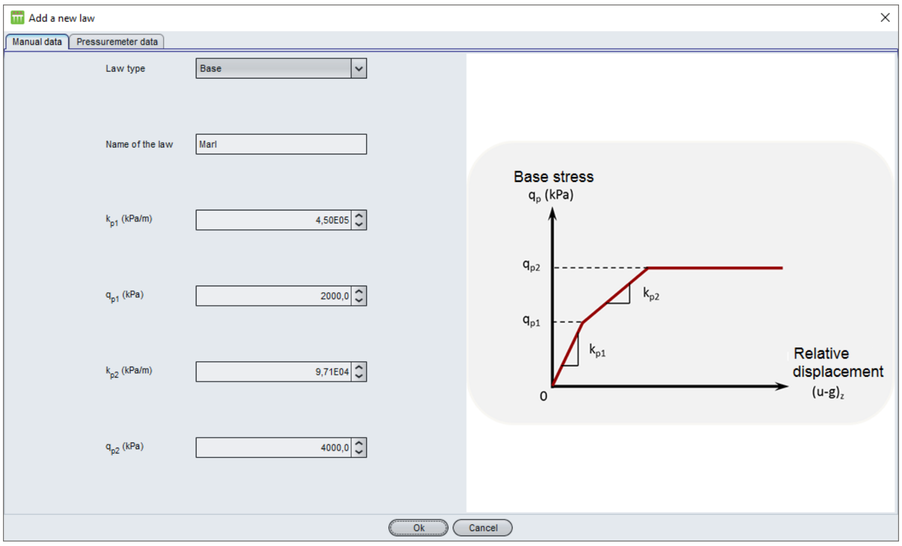


Figure H 30: Manual data – "Base" type law

The following table describes the various parameters of the laws defined by "Manual data":

Designation	Unit	Default value	Display condition	Mandatory value	Local checks
Name of law	-	-	Always	Yes	Specific name never blank
k_{s1}: reaction coefficient at 1st plateau	kPa/m	0	"Lateral" type law	Yes	-
p_1: plastification pressure at 1st plateau	kPa				
k_{s2}: reaction coefficient at 2nd plateau	kPa/m				
p_2: plastification pressure at 2nd plateau	kPa				
k_{t1}: 1st slope of friction mobilisation curve	kPa/m	0	"Friction" type law	Yes	-
q_{s1}: 1st plateau of friction mobilisation curve	kPa				
k_{t2}: 2nd slope of friction mobilisation curve	kPa/m				
q_{s2}: 2nd plateau of friction mobilisation curve	kPa				
k_{p1}: 1st slope of base resistance mobilisation curve	kPa/m	0	"Base" type law	Yes	-
q_{p1}: 1st plateau of base resistance mobilisation curve	kPa				
k_{P2}: 2nd slope of base resistance mobilisation curve	kPa/m				
q_{p2}: 2nd plateau of base resistance mobilisation curve	kPa				

Table H 12: *"Soils" tab – Laws definition: Manual data*

Pressuremeter data

The parameters of laws (slopes and plateaux) are defined indirectly on the basis of pressuremeter data. The three types of laws are possible.
"Lateral" type law (4 different types of loading):

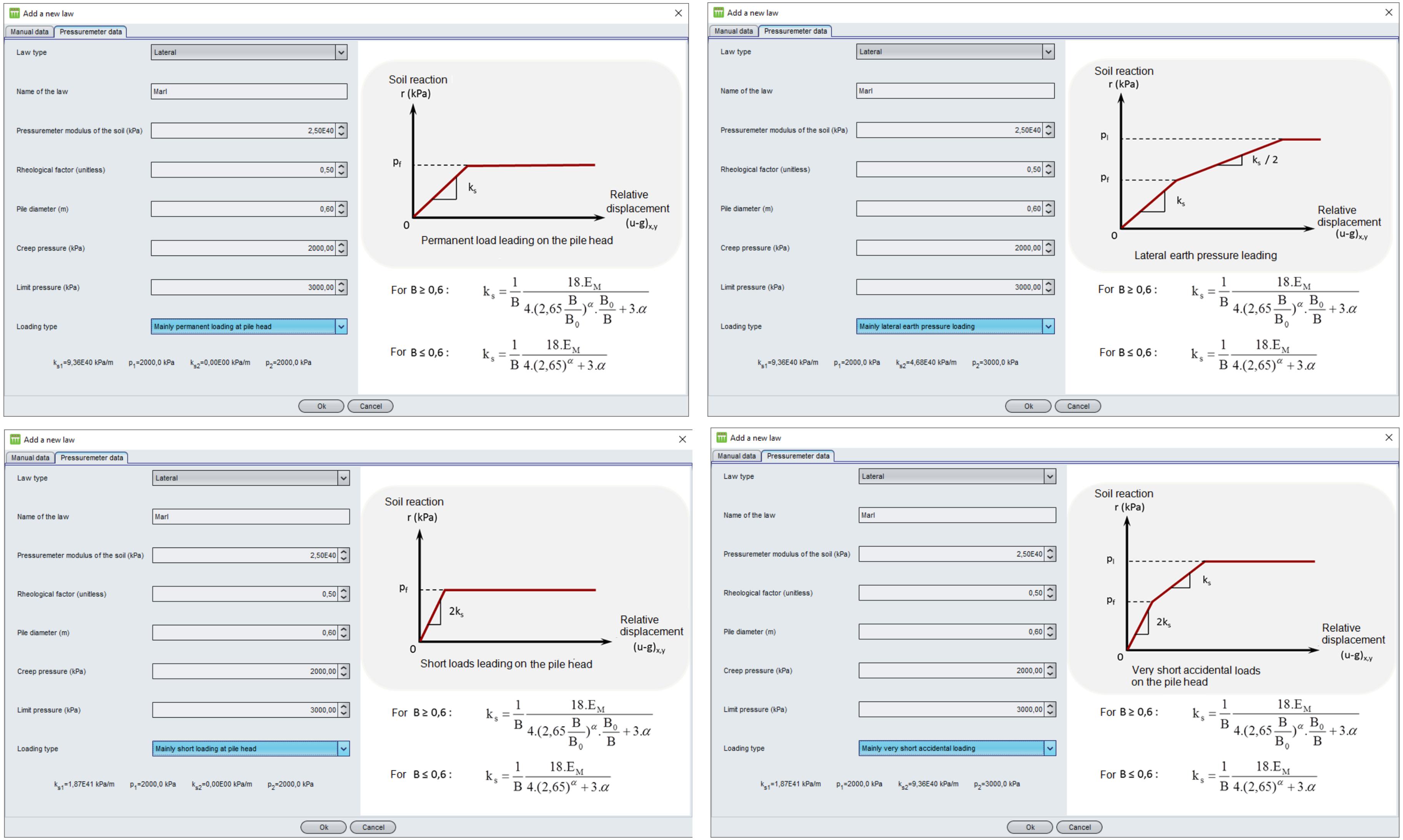


Figure H 31: Pressuremeter data – "Lateral" type law

"Friction" type law (two different soil types):

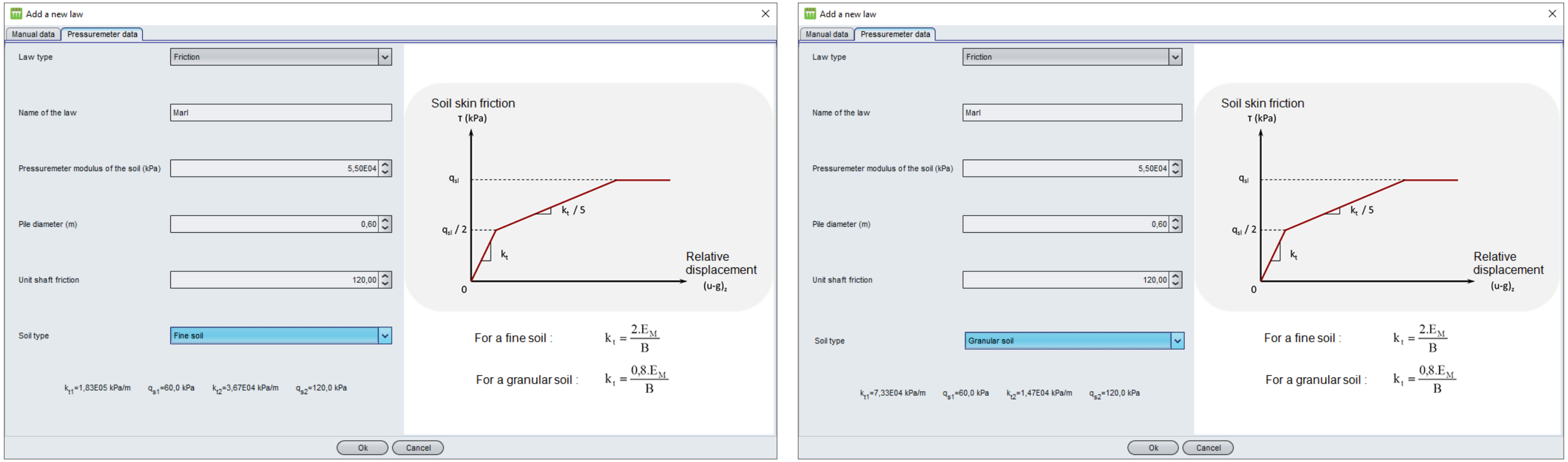


Figure H 32: Pressuremeter data – "Friction" type law

"Base" type law (two different soil types):

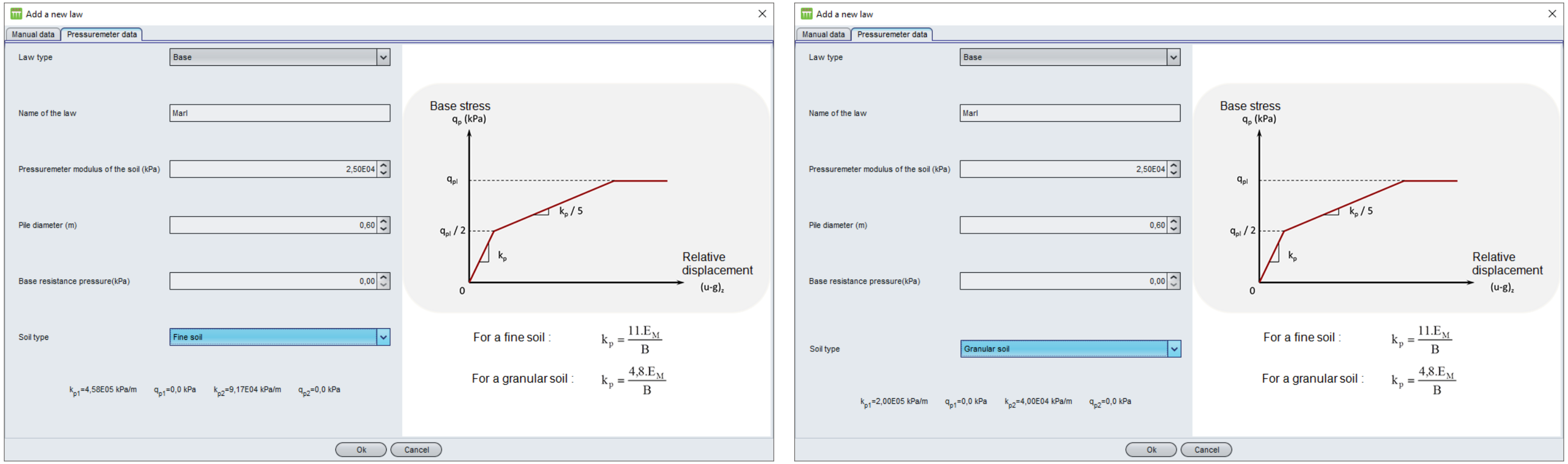


Figure H 33: Pressuremeter data – "Base" type law

The following table describes the various law parameters based on "Pressuremeter" data:

Designation	Unit	Default value	Display condition	Mandatory value	Local checks
Name of law	-	-	Always	Yes	Specific name never blank
Pressuremeter modulus	kPa	0	Always	Yes	-
Pile diameter	m	0	Always	Yes	> 0
Ménard's rheological coefficient	-	0	"Lateral" type law"	Yes	$0 < \alpha \leq 1$
Net creep pressure	kPa	0	"Lateral" type law	Yes	> 0
Net limit pressure	kPa	0	"Lateral" type law	Yes	> 0
Loading types(1)	-	Mainly permanent at pile head	"Lateral" type law	Yes	-
Limit shaft friction	kPa	0	"Friction" type law	Yes	-
Base resistance pressure	kPa	0	"Base" type law	Yes	-
Soil type (2)	-	Fine soil	"Friction" or "Base" type law	Yes	-

Table H 13: *"Soils" tab – Laws definition: Pressuremeter data*

Observations:

1. For "Lateral" type laws

   The "Loading type" field offers a choice between four values:

   - mainly permanent loading at pile head;
   - mainly lateral earth pressure loading;
   - mainly short loading at pile head;
   - mainly very short accidental loading.

   Depending on the type of loading chosen, the programme calculates and displays the values of k_{s1}, p_1, k_{s2} and p_2 at the bottom of the tab. The meaning of these parameters is mentioned on the diagram displayed in the right-hand part of the wizard.

2. For the "Friction" and "Base" type laws

   The "Soil type" field offers a choice of two values:

   - fine soil;
   - granular soil.

   Depending on the soil type chosen, the programme calculates and displays the following at the bottom of each tab:

   - the values of k_{t1}, q_{s1}, k_{t2} and q_{s2} at the bottom of the "Friction" law tab;
   - the values of k_{p1}, q_{p1}, k_{p2} and q_{p2} at the bottom of the "Base" law tab.

   The meaning of these parameters is given in the diagram presented in the right-hand part of the wizard.

Four help diagrams are available.

- Diagrams accessible whatever the type of reaction curve:
  - Layer dip: conventions to be adopted for definition of a soil layer with a non-horizontal base.

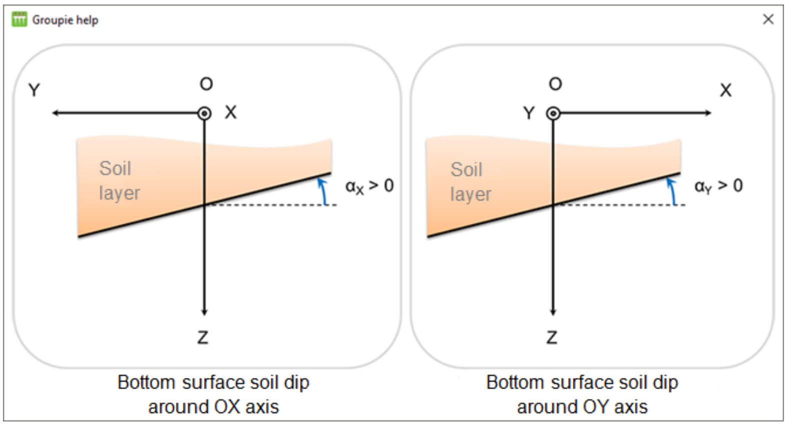


Figure H 34: Help diagram for soil layer dip

- Diagrams only accessible if the "From pressuremeter data" option was chosen. They show the shape of the transfer law as a function of mainly lateral loadings (lateral reaction law) or of the soil type (friction law and base resistance).
  - Lateral law

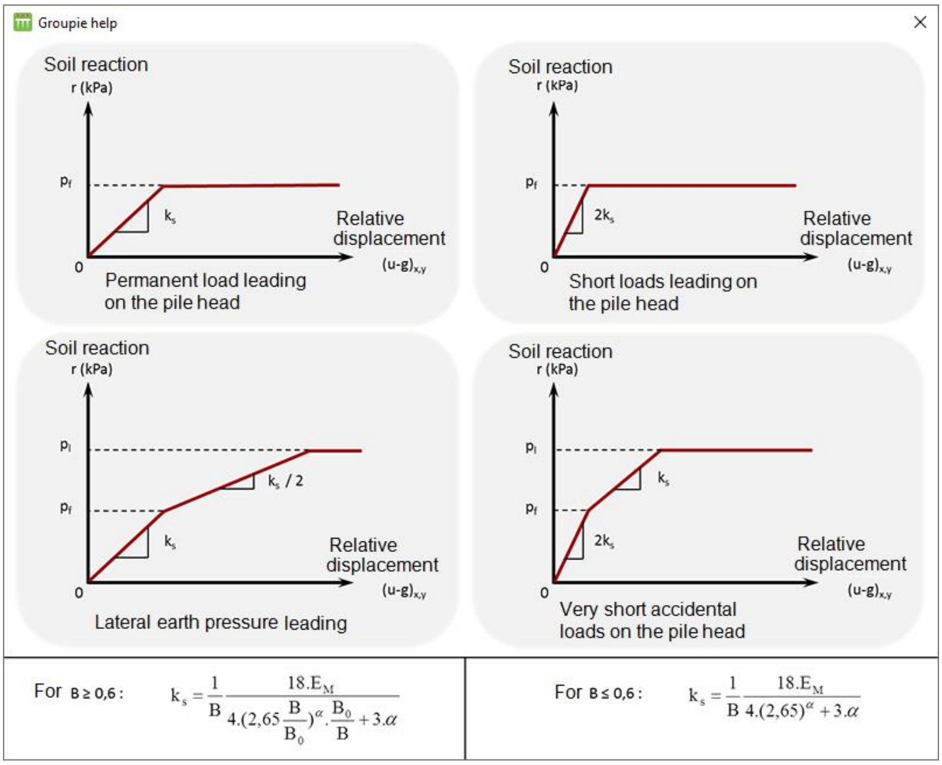


Figure H 35: Help diagram for the lateral law

- Friction law

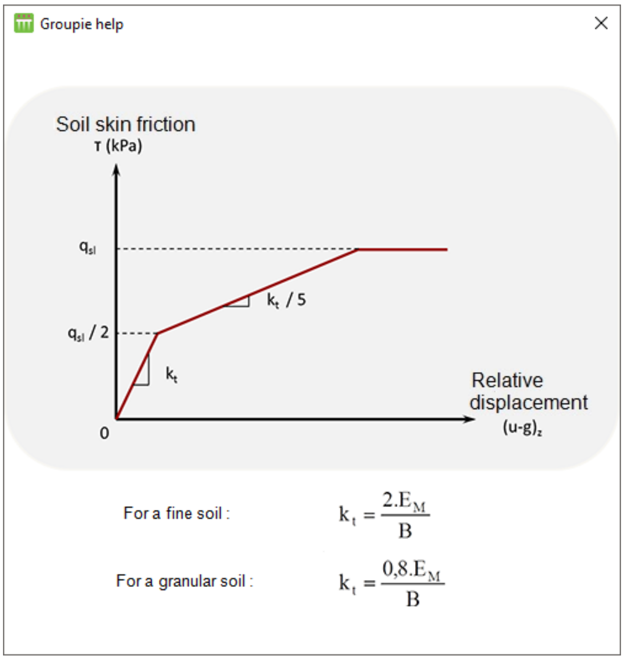


Figure H 36: Help diagram for the friction law

- Base law

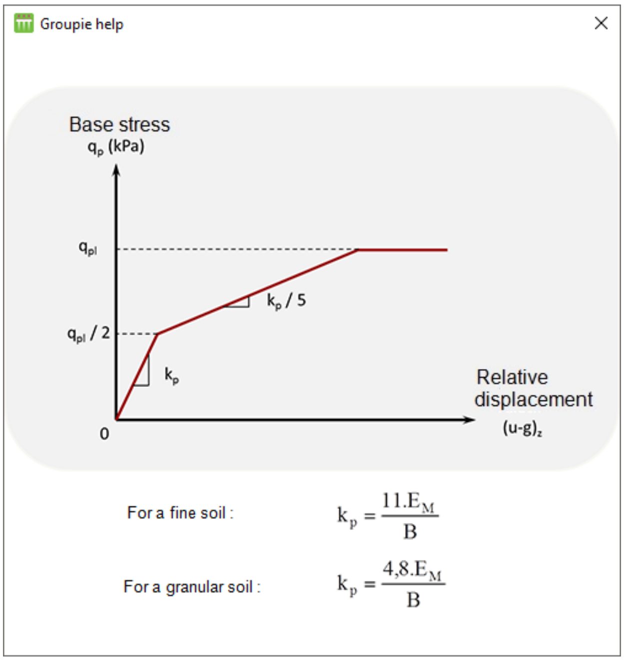


Figure H 37: Help diagram for the base law

H.3.2.4. "Free g(z) soil displacement" tab

This (optional) function can be used to define a global soil displacement in the three spatial directions. It can be used to simulate:

- A free lateral displacement g(z) of the soil: this is a horizontal displacement field defined in the global coordinates system by components along X or Y, the amplitude of which depends only on the elevation (thus implicitly on Z).

  This displacement is generally developed within a layer that is compressible under the effect of a bank created following installation of piles as schematically shown in the following figure (cross-section orthogonal to X).

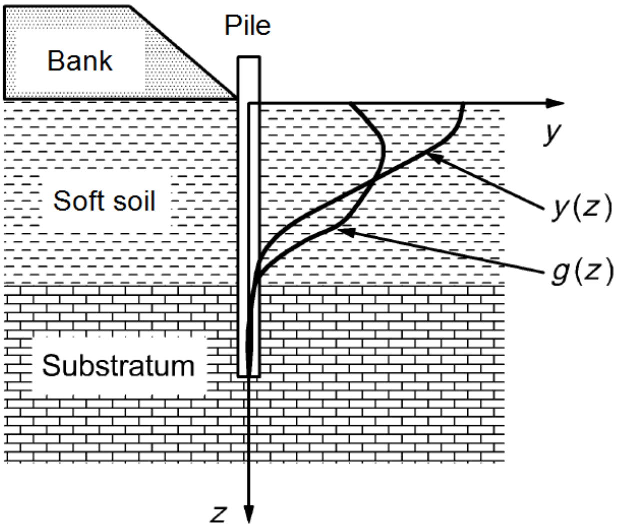
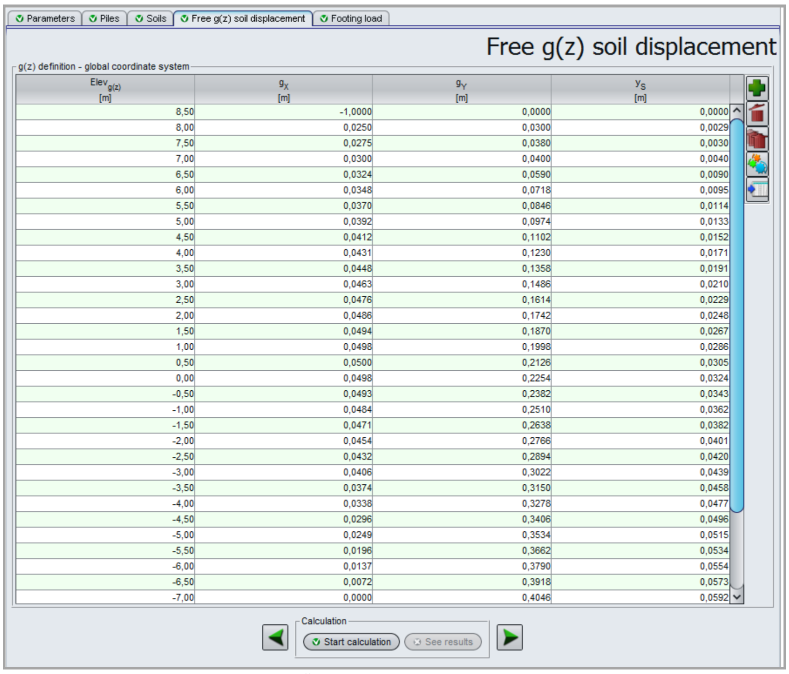


Figure H 38: Lateral g(z) soil displacement

- Imposed $y_S(z)$ soil settlement: this is a vertical displacement field defined in the global coordinates system by a component along Z. Its amplitude depends only on the elevation.

  The applied displacement represents an imposed soil settlement around the piles, which leads to the creation of negative friction on a part of their shafts.

In practice, the global displacement is defined by the following table. The values must be listed in descending order of elevation. At least two rows with different elevations must be filled out.



$Elev_{g(z)}$ [m]	g_X [m]	g_Y [m]	y_S [m]
8,50	-1,0000	0,0000	0,0000
8,00	0,0250	0,0300	0,0029
7,50	0,0275	0,0380	0,0030
7,00	0,0300	0,0400	0,0040
6,50	0,0324	0,0590	0,0090
6,00	0,0348	0,0718	0,0095
5,50	0,0370	0,0846	0,0114
5,00	0,0392	0,0974	0,0133
4,50	0,0412	0,1102	0,0152
4,00	0,0431	0,1230	0,0171
3,50	0,0448	0,1358	0,0191
3,00	0,0463	0,1486	0,0210
2,50	0,0476	0,1614	0,0229
2,00	0,0486	0,1742	0,0248
1,50	0,0494	0,1870	0,0267
1,00	0,0498	0,1998	0,0286
0,50	0,0500	0,2126	0,0305
0,00	0,0498	0,2254	0,0324
-0,50	0,0493	0,2382	0,0343
-1,00	0,0484	0,2510	0,0362
-1,50	0,0471	0,2638	0,0382
-2,00	0,0454	0,2766	0,0401
-2,50	0,0432	0,2894	0,0420
-3,00	0,0406	0,3022	0,0439
-3,50	0,0374	0,3150	0,0458
-4,00	0,0338	0,3278	0,0477
-4,50	0,0296	0,3406	0,0496
-5,00	0,0249	0,3534	0,0515
-5,50	0,0196	0,3662	0,0534
-6,00	0,0137	0,3790	0,0554
-6,50	0,0072	0,3918	0,0573
-7,00	0,0000	0,4046	0,0592

Figure H 39: "Free g(z) soil displacement" tab

This tab comprises a single "g(z) definition" frame, which can be filled out with the import wizard described later.

H.3.2.4.1. "g(z) definition" frame

The following table describes the properties to be input in this tab:

Designation	**Unit**	**Default value**	**Display condition**	**Mandatory value**	**Local checks**

Designation	Unit	Default value	Display condition	Mandatory value	Local checks
Elev$_{g(z)}$: elevation of definition point	m	0	Always	Yes	-
g$_X$: lateral soil displacement – direction X	m	0	Always	Yes	-
g$_Y$: lateral soil displacement – direction Y	m	0	Always	Yes	-
y$_S$: imposed soil displacement – direction Z	m	0	Always	Yes	-

Table H 14: *"Free g(z) soil displacement" tab – "g(z) definition" frame*

H.3.2.4.2. Import wizard

It is also possible to import data from an outside file (Excel for example) using the import wizard. This is accessible in several FoXta modules.

Select the data to be imported and copy them to clipboard.

- Click the  "Table modification wizard".

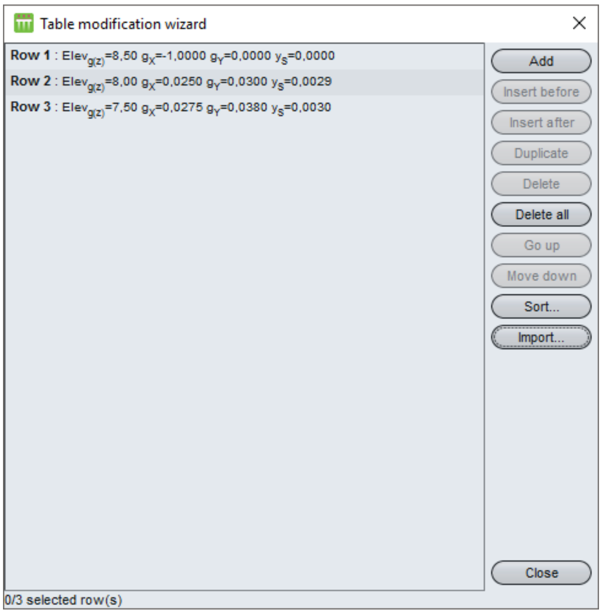
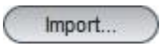


Figure H 40: Table modification wizard

If the "g(z) definition" frame already contained rows, they will be automatically displayed in the wizard.

- Click the  button.

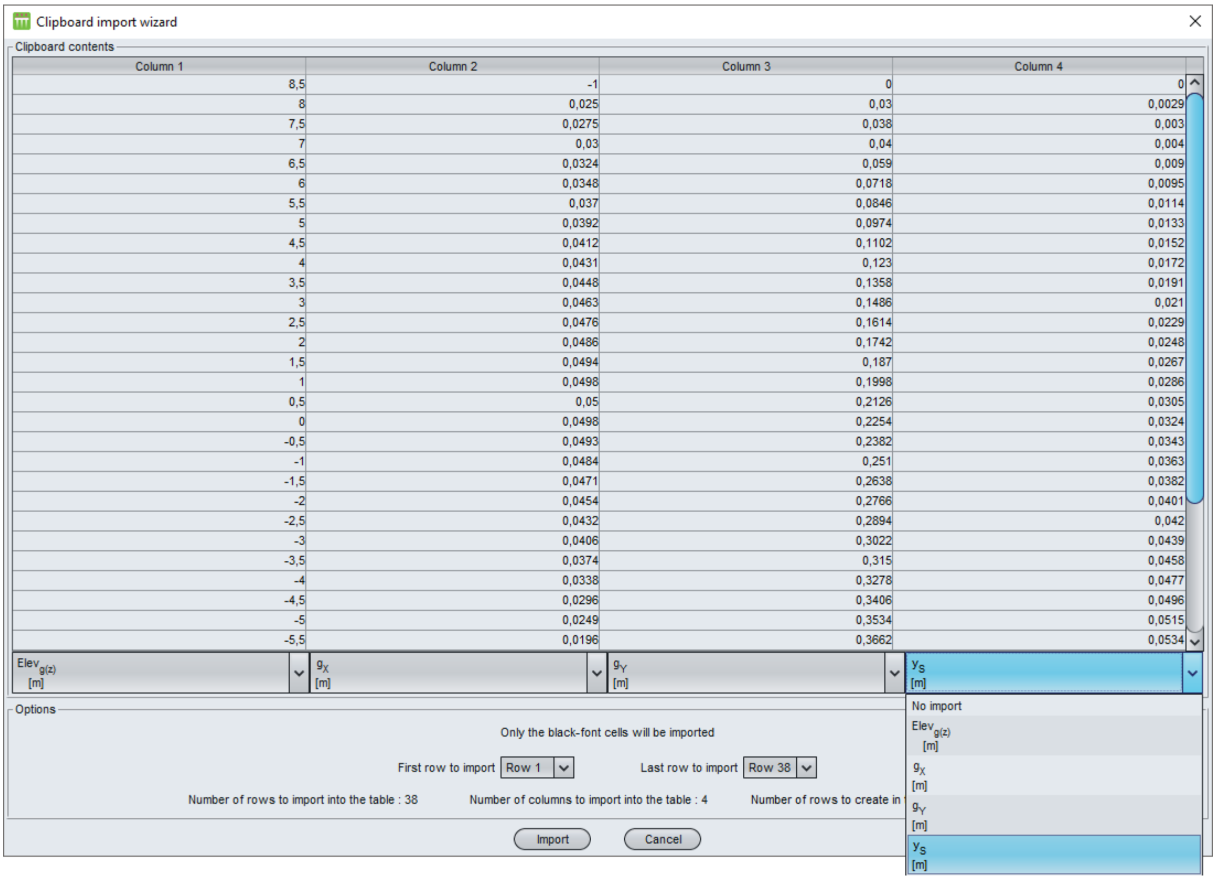


Figure H 41: Clipboard import wizard

<u>"Clipboard contents" frame</u>

The import wizard automatically displays in black the data to be imported into the four columns available, corresponding to the four columns of the "Free g(z) soil displacement" tab. The shaded data will be ignored.

At the bottom of each column, a drop-down list is used to establish the correspondence between the displayed data from the file to be imported and the columns of the "Free g(z) soil displacement" tab.

<u>"Options" frame</u>

Using drop-down lists, the rows to be imported are specified: the first and the last.

Groupie+ then indicates the following information (cannot be modified):

- the number of rows to be imported into the table;
- the number of columns to be imported into the table;
- the number of rows to be created in the table.

Click the Import... button. The imported values are now available in the project.

H.3.2.5. "Footing load" tab

This tab is used to define the load cases applied to the footing. This tab is comparable to that of the Manual Groupie mode described in paragraph H.3.1.4.

H.3.2.6. Calculation

The calculation can be started from any tab provided that the project has been correctly filled out, in other words, when all the tabs are marked with a green tick (for example: Settings/piles).

A tab is marked with a red cross (for example: Settings/piles) as long as it is not correctly filled out (data missing or not in conformity with expected values).

To start the calculation, click the Start calculation button.

The Automatic Groupie+ mode can be used to manage models for which the piles mesh has a size of several thousand elements. However, the maximum memory that can be allocated to the programme under Microsoft Windows® may be a limiting factor. It is therefore recommended that the maximum mesh size does not exceed 2500 elements.

The general calculation process involves the following steps:

1. Read data;
2. Construct mesh;
3. Run equation;
4. Study each load case:
    - Initialisation
    - Iterations
    - Calculation of displacements, reactions and loadings
5. Generate output files;
6. End of programme.

The user is informed of the progress of the various calculation steps in the following window.

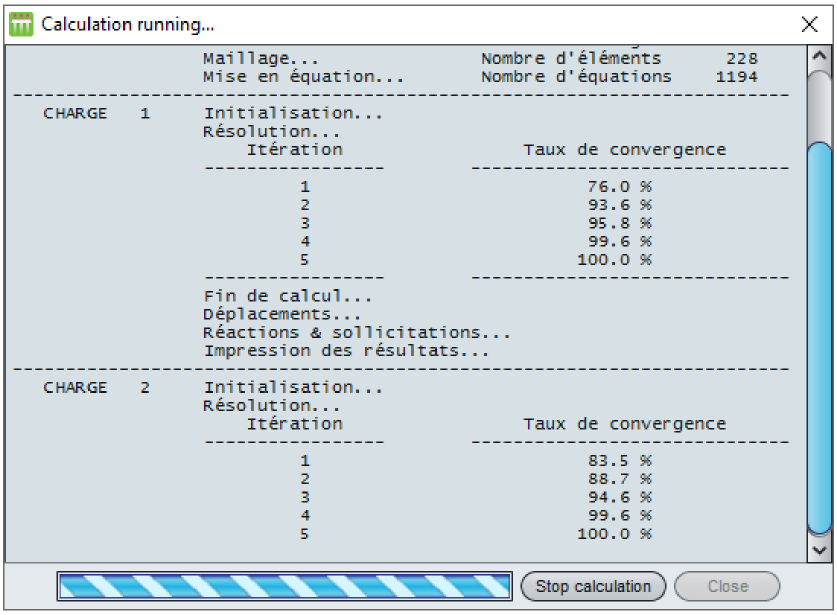


Figure H 42: "Calculation running" window

To display the calculation results, click the Close button as necessary and then the See results button.

H.3.2.7. Results

The Automatic Groupie+ mode gives numerical and graphical results. The available results are presented in the following paragraphs.

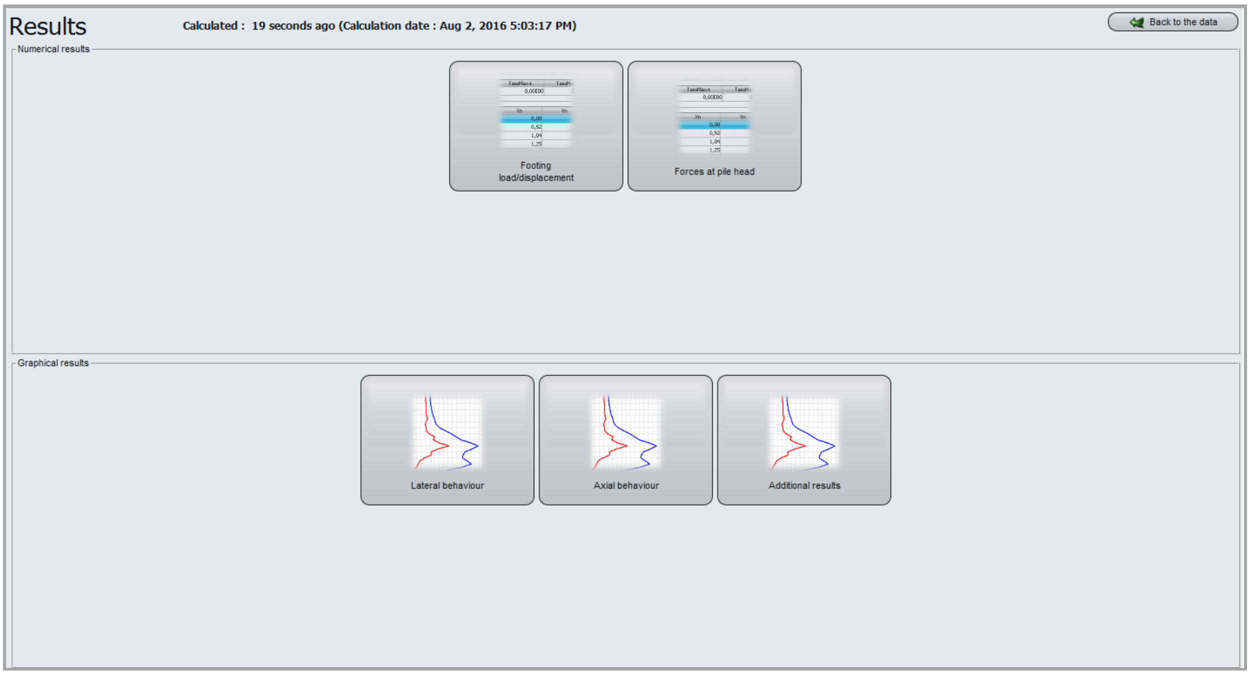


Figure H 43: Window of Automatic Groupie+ results

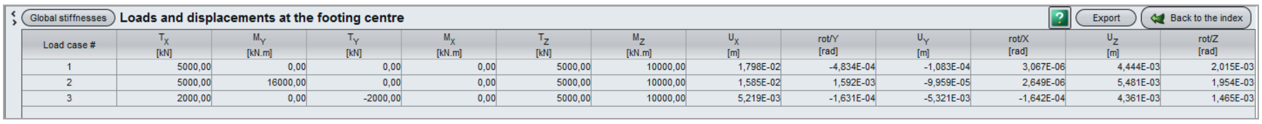
H.3.2.7.1. Numerical results

<u>Numerical results: Results tables</u>

This window contains the footing displacements produced by each load case. It also gives access to the overall stiffnesses of the footing.

<u>Footing loads and displacements</u>

This is an exportable table which, for each load case, gives the resultant displacement global forces and moments.


Global stiffnesses | Loads and displacements at the footing centre | Export | Back to the index

Load case #	T_X [kN]	M_Y [kN.m]	T_Y [kN]	M_X [kN.m]	T_Z [kN]	M_Z [kN.m]	U_X [m]	rot/Y [rad]	U_Y [m]	rot/X [rad]	U_Z [m]	rot/Z [rad]
1	5000,00	0,00	0,00	0,00	5000,00	10000,00	1,798E-02	-4,834E-04	-1,083E-04	3,067E-06	4,444E-03	2,015E-03
2	5000,00	16000,00	0,00	0,00	5000,00	10000,00	1,585E-02	1,592E-03	-9,959E-05	2,649E-06	5,481E-03	1,954E-03
3	2000,00	0,00	-2000,00	0,00	5000,00	10000,00	5,219E-03	-1,631E-04	-5,321E-03	-1,642E-04	4,361E-03	1,465E-03

Figure H 44: : Numerical results - "Loads and displacements at the footing centre"

Details of the various elements of the previous table are given below (the whole is expressed at centre O of the footing).

Designation (*)	**Unit**	**Display condition**
$\mathbf{T_X}$: horizontal force along (OX)	kN	Always
$\mathbf{M_Y}$: moment around (OY)	kN.m	
$\mathbf{T_Y}$: horizontal force along (OY)	kN	
$\mathbf{M_X}$: moment around (OX)	kN.m	
$\mathbf{T_Z}$: vertical force along (OZ)	kN	
$\mathbf{M_Z}$: moment around (OZ)	kN.m	
$\mathbf{U_X}$: translation in direction X	m	Always
rot/Y: rotation around axis (OY)	rad	

U_Y: translation in direction Y	m	
rot/X: rotation around axis (OX)	rad	
U_Z: translation in direction Z	m	
rot/Z: rotation around axis (OZ)	rad	

Table H 15: *Numerical results – "Footing load/displacement"*

<u>Global stiffnesses of footing</u>

Clicking the Global stiffnesses button gives the global stiffness matrices for the foundation expressed at the centre of the footing. Choose the relevant load case from the drop-down list.

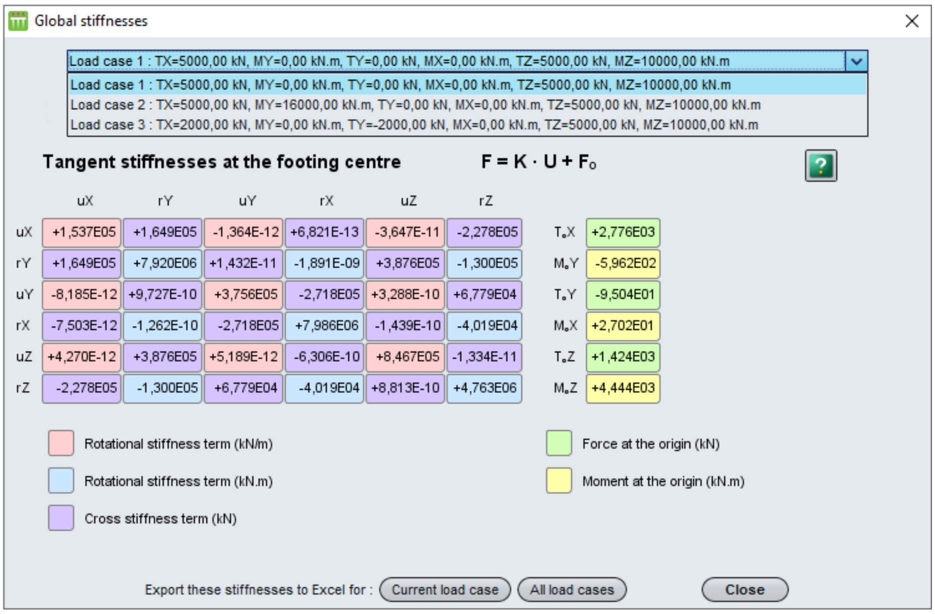


Figure H 45: Global stiffnesses of foundation

It is possible to export the following stiffnesses to an EXCEL spreadsheet:

- a single load case by clicking the Current load case button

Or

- all load cases by clicking the All load cases button

A help diagram explains the various symbols:

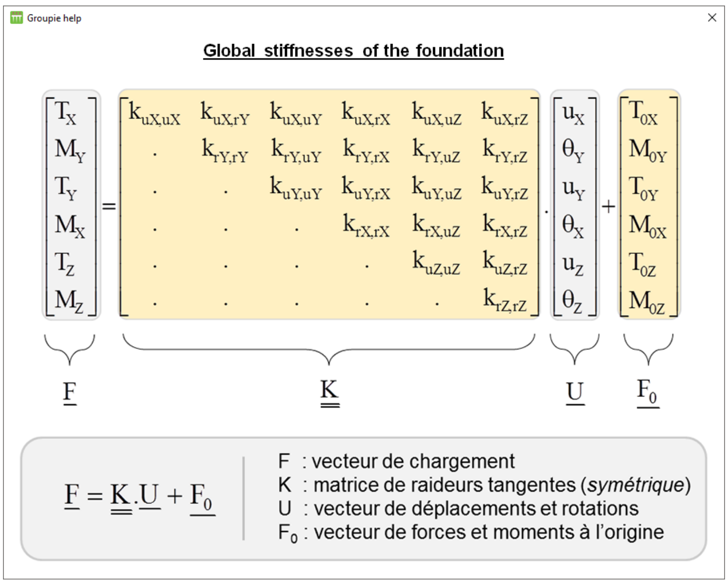


Figure H 46: Help diagram for foundation global stiffnesses

Numerical results: Forces at pile heads

This table is comparable to that available in the Manual Groupie mode (see chapter H.3.1.6.2).

Forces at pile heads

Load case #	Pile #	T_1 [kN]	M_1 [kN.m]	T_2 [kN]	M_2 [kN.m]	T_z [kN]	M_z [kN.m]
1	1	1369,960	-1128,090	-648,097	417,442	925,903	0,002
1	2	1500,510	-1271,070	648,097	-429,129	1570,200	0,002
1	3	1039,650	-702,127	-648,097	417,442	930,393	0,002
1	4	1089,880	-760,940	648,097	-429,129	1573,500	0,002
2	1	1388,390	-1198,520	-629,966	404,645	2237,460	0,002
2	2	1518,340	-1341,150	629,966	-416,624	258,546	0,002
2	3	1020,250	-767,995	-629,966	404,645	2239,560	0,002
2	4	1073,010	-830,185	629,966	-416,624	264,428	0,002
3	1	903,537	-606,943	-910,613	612,436	1253,690	0,001
3	2	941,903	-652,763	-89,387	51,415	1467,600	0,001
3	3	76,196	-41,438	-910,613	612,436	1022,090	0,001
3	4	78,364	-44,175	-89,387	51,415	1256,620	0,001

Figure H 47: Numerical results - "Forces at pile heads"

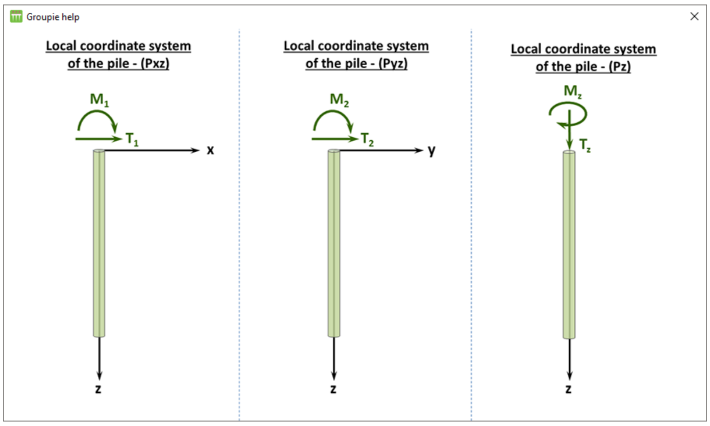


Figure H 48: Help diagram for forces at pile heads

H.3.2.7.2. Graphical results

For each load case, these curves present the deformations and loads in each pile. The results of several load cases and/or piles can be superposed. Navigating through these results is described below:

- From the menu at top-left, select the load case to be displayed;
- At the bottom-left, select the pile to be displayed;
- At the bottom of each graphic, the minimum and maximum bounds of each physical quantity are given for the selected elements.

Several load cases or several piles can be selected by holding the Ctrl or Shift key on the keyboard.

The results obtained are expressed in the pile local coordinates system. There are various choices for exporting graphical results.

Graphical results: Lateral behaviour

This window gives the deformation and loading curves for the piles in the local (oxz) and (oyz) planes.

- Pile deflection and lateral soil displacement (m): - u1, gz1: in direction x
  - u2, gz2: in direction y
- Bending moment (kN.m): - M1: in direction x
  - M2: in direction y

- Shear force (kN): - T1: in direction x
  - T2: in direction y

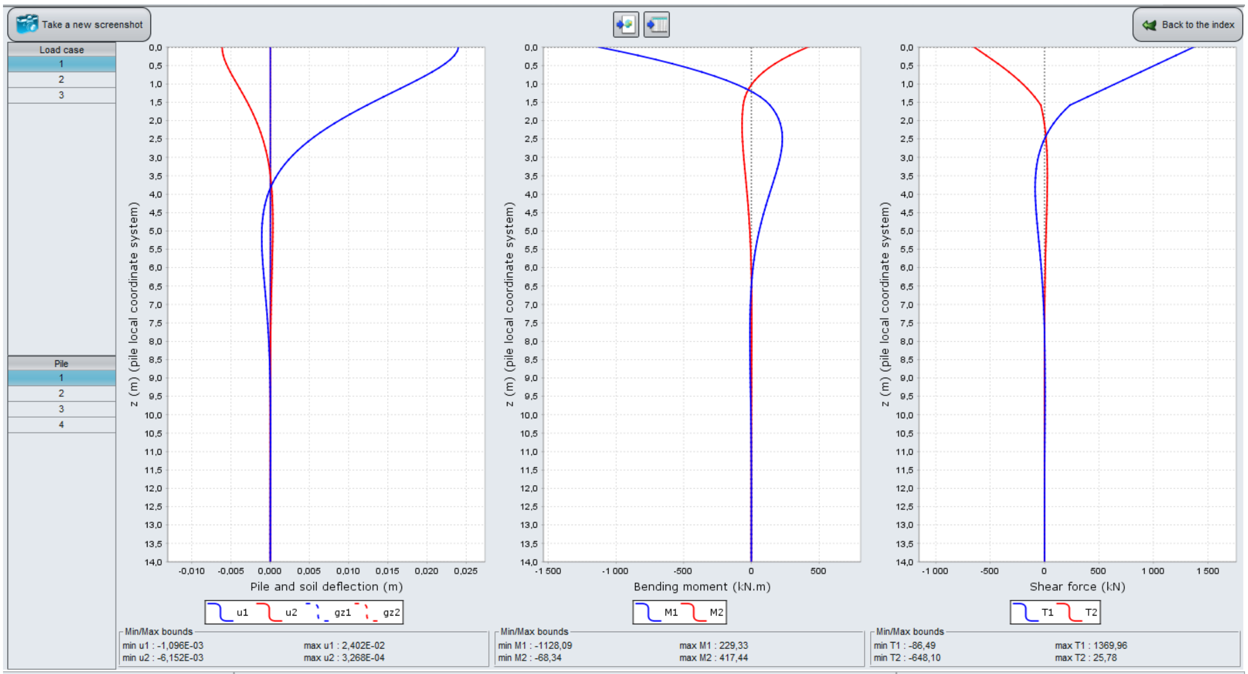


Figure H 49: Graphical results – "Lateral behaviour" curves

Graphical results: Axial behaviour

This window gives the piles deformation and loading curves in the axial direction (oz).

- uz, ys : pile and soil settlement (m);
- fmob, qs : mobilised and limit shaft friction (kPa);
- Nz : axial force (kN).

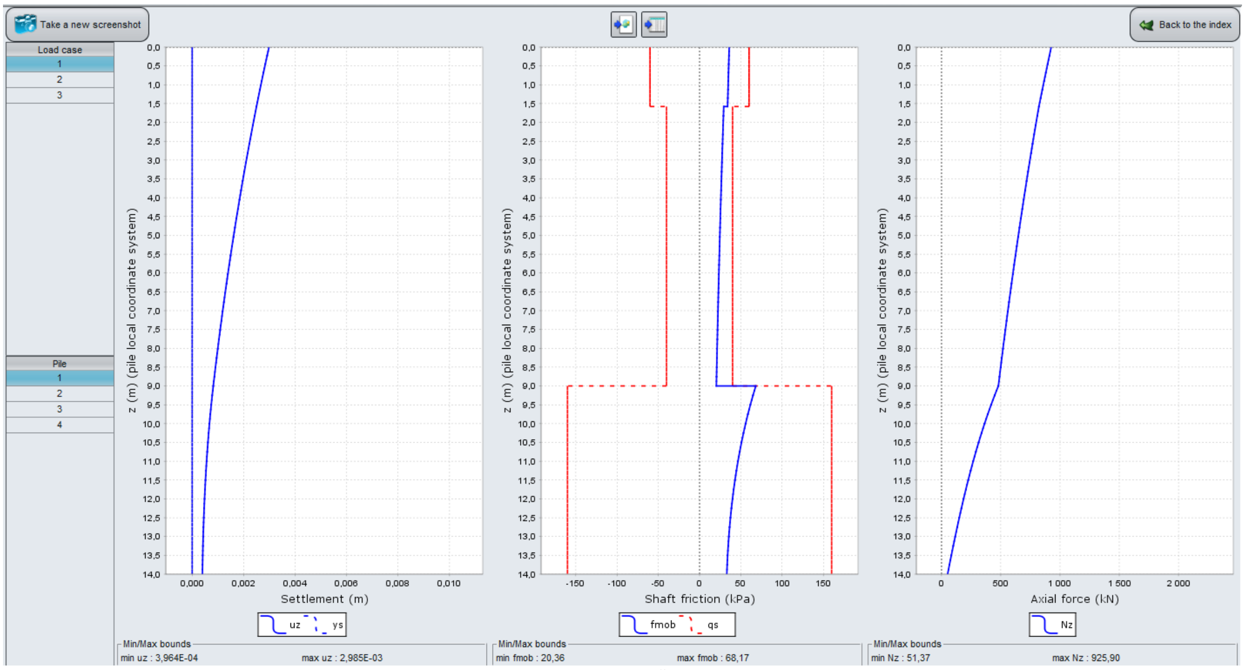


Figure H 50: Graphical results – "Axial behaviour" curves

Graphical results: Additional results

This window gives access to the following results:

- Tcomb: combined axial force (kN);
- Mcomb: combined bending moment (kN.m);
- Ratios: ratios in directions x, y and z (%) which, at a given level, represent the mobilisation ratio:
  - of lateral soil reaction with respect to the plastification pressure (ratio x and ratio y);
  - of mobilised shaft friction with respect to limit friction (ratio z).

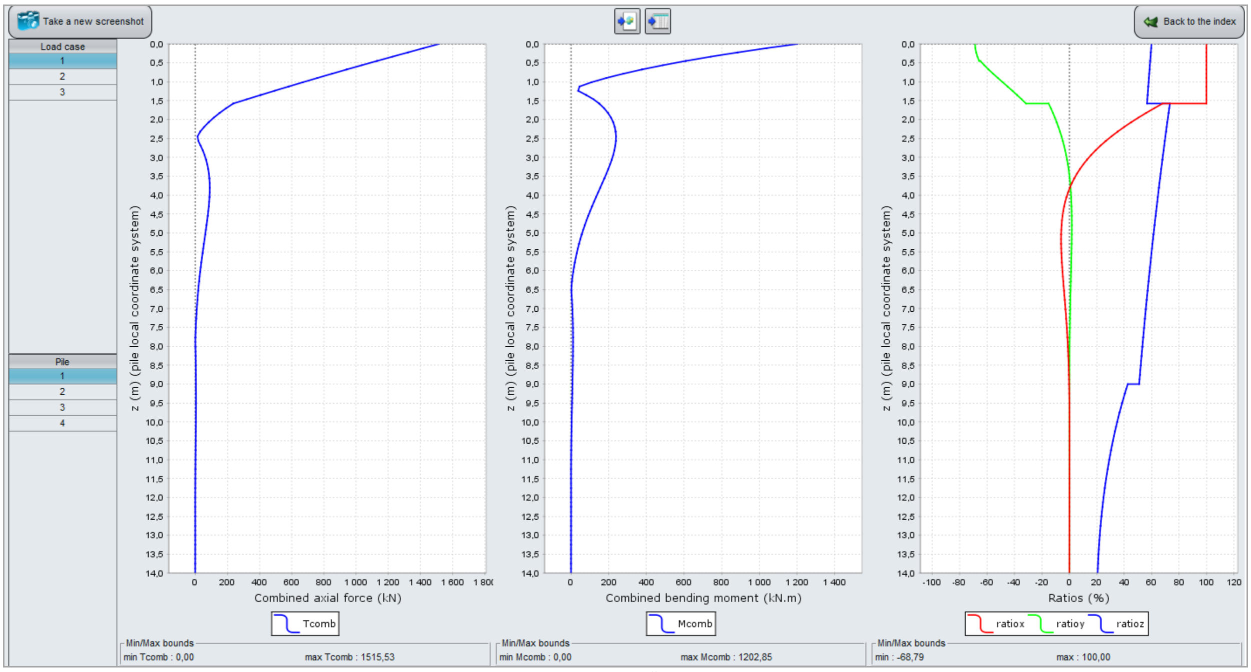


Figure H 51: Graphical results – "Additional results" curves

H.3.3. Advanced Automatic Groupie+ Mode

H.3.3.1. "Parameters" tab

Select the Advanced Automatic Groupie+ mode by clicking the button. The buttons for the other modules are then shaded.

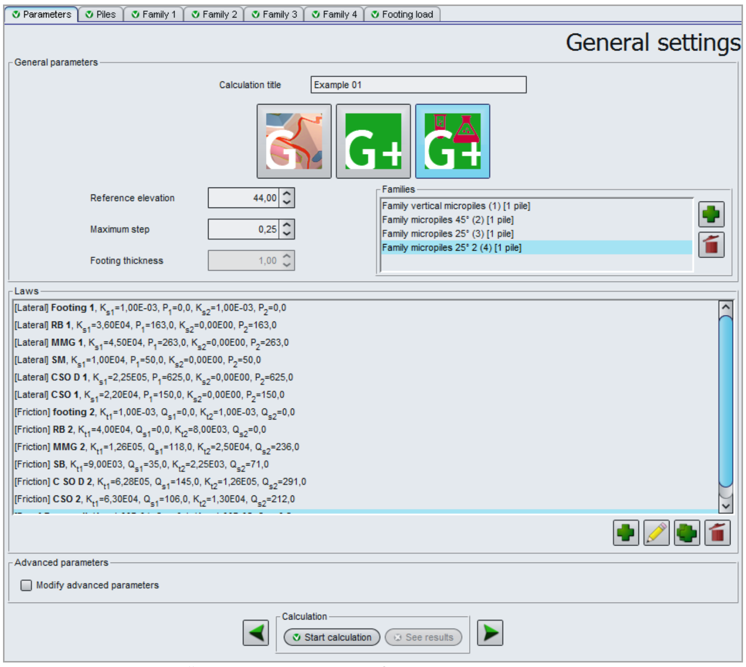


Figure H 52: "Parameters" tab of Advanced Automatic Groupie+

This tab comprises three frames:

- General parameters;
- Laws;
- Advanced parameters (masked by default).

H.3.3.1.1. "General parameters" frame

In this frame, Advanced Automatic Groupie+ asks for the following information:

- Calculation title;
- Advanced Automatic Groupie+ mode: selected;
- Maximum step (m): maximum thickness of the layers subdivisions (value of 0.5 m by default);
- Footing thickness (m): perfectly rigid footing.

This same frame contains a "Families" zone. This is used to indicate the pile family or families, which will enable the piles of the same category to be grouped together. Each time a family is created, Advanced Automatic Groupie+ adds an extra tab. This latter will contain the characteristics common to the piles of the family in question.

At least one family must be defined, which will then be assigned to one or more piles.

Click the button to create a family. When creating an extra family, the programme proposes using an existing family as the basis. In this case, the new family is created as a copy of the existing family.

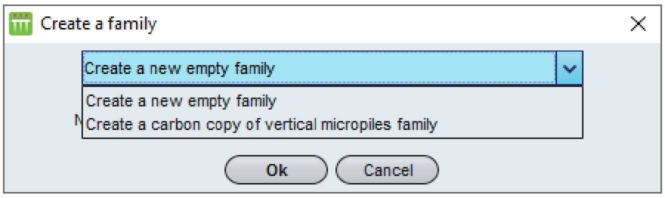


Figure H 53: Creating a family

When the family is created and piles assigned to it, the programme states the number of piles assigned between parentheses, just after its name.
When the user double-clicks a family, Advanced Automatic Groupie+ automatically switches to the corresponding tab.

H.3.3.1.2. “Laws” frame

This frame comprises the pile-soil interaction laws to which the user can refer when defining the “Soils/Piles” frame in the “Family X” tab.

To add a law:

- Click the button.

To edit a law:

- Double-click the corresponding row;

Or

- Select the law and click the "Edit" button .

To copy a law:

- Select the relevant law;
- Click the button: the law is copied identically but the names are numbered so that they can be differentiated from each other. It should be noted that the list of laws is ordered in three blocks that are identifiable by a prefix [type of law] before the name of the law. The laws in each block retain the order in which they were created.

Whatever its type, a law is defined by two slope parameters and two characteristic points. All the laws are explicitly defined by manual data. Particular attention must be paid to the law parameters, especially their units.

“Lateral” type law:

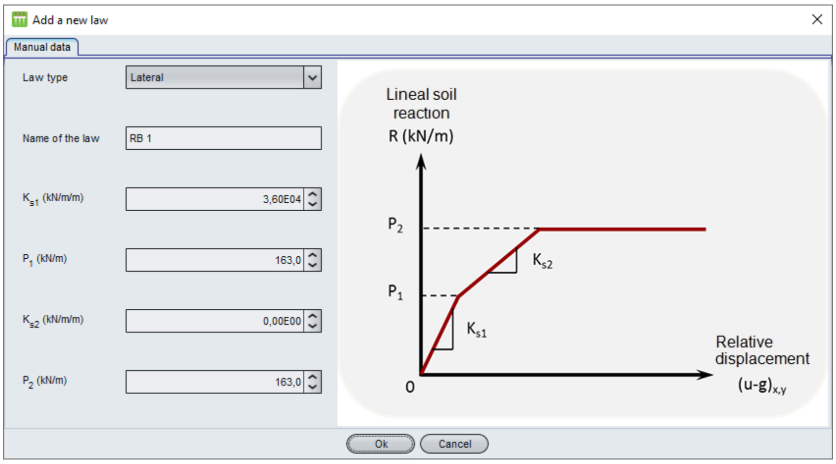


Figure H 54: “Lateral” type law

"Friction" type law:

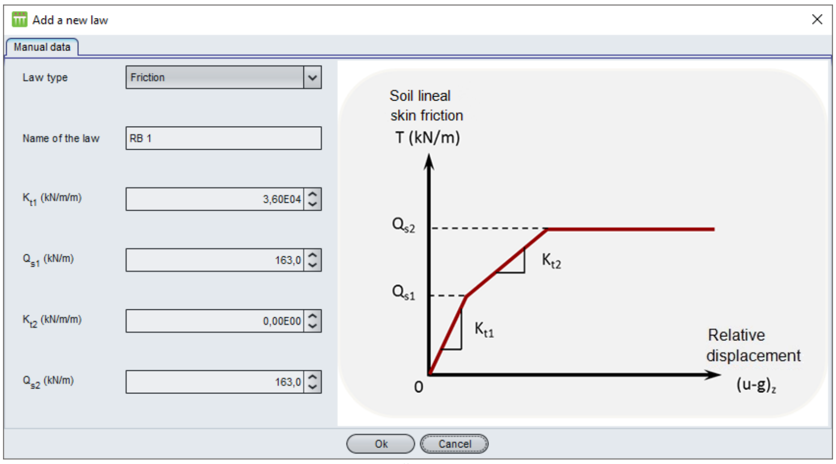


Figure H 55: "Friction" type law

"Base" type law:

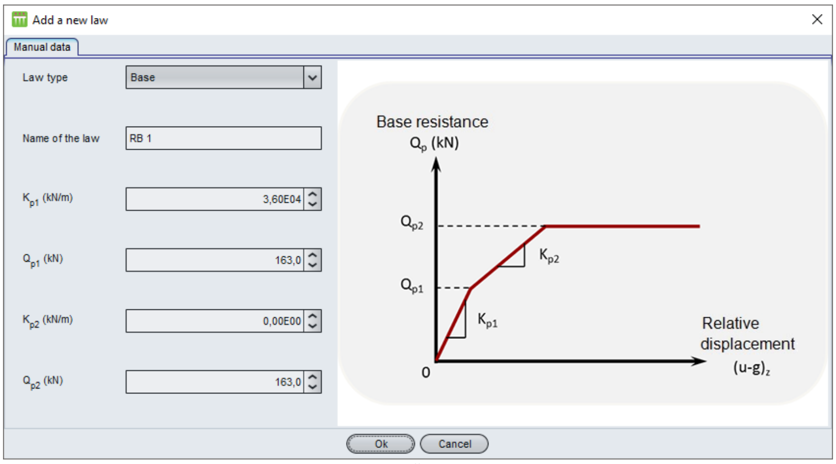


Figure H 56: "Base" type law

Clicking the 

button validates the law and adds it to the block corresponding to its type.

The following data must be input:

Designation	Unit	Default value	Display condition	Mandatory value	Local checks
Type of law	-	Lateral	Always	Yes	-
Name of law	-	-			
K_{s1}: soil reaction modulus at 1st plateau	kN/m/m	0	"Lateral" type law	Yes	-
P_1: soil reaction at 1st plateau	kN/m				
K_{s2}: soil reaction modulus at 2nd plateau	kN/m/m				
P_2: soil reaction at 2nd plateau	kN/m				
K_{t1}: 1st slope of friction mobilisation curve	kN/m/m	0	"Friction" type law	Yes	-
Q_{s1}: 1st plateau of friction mobilisation curve	kN/m				
K_{t2}: 2nd slope of friction mobilisation curve	kN/m/m				

Designation	Unit	Default value	Display condition	Mandatory value	Local checks
Q_{s2}: 2nd plateau of friction mobilisation curve	kN/m				
K_{p1}: 1st slope of base resistance mobilisation curve	kN/m	0	"Base" type law	Yes	-
Q_{p1}: 1st plateau of base resistance mobilisation curve	kN				
K_{p2}: 2nd slope of base resistance mobilisation curve	kN/m				
Q_{p2}: 2nd plateau of base resistance mobilisation curve	kN				

Table H 16: *"Parameters" tab – Laws: Manual data*

H.3.3.1.3. "Advanced parameters" frame

Except for the use of azimuth, which does not apply in this mode, the content of this frame is comparable to that presented for the Automatic Groupie+ mode.

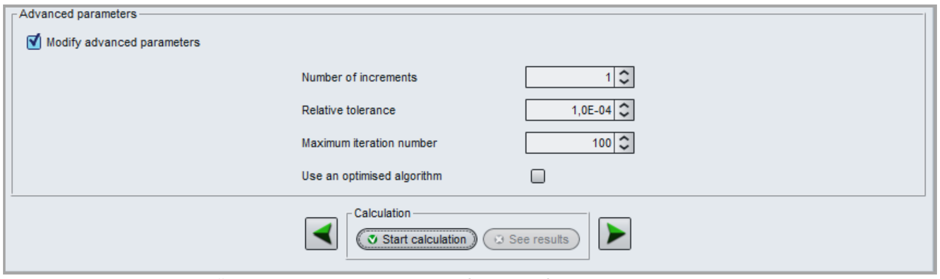


Figure H 57: "Advanced parameters" frame of Advanced Automatic Groupie+

H.3.3.2. "Piles" tab

This tab is used to create piles. The X and Y coordinates of their heads can be input and they can be assigned to the families previously defined in the project. The initially shaded pile then takes on the colour corresponding to the family of which it is a member.

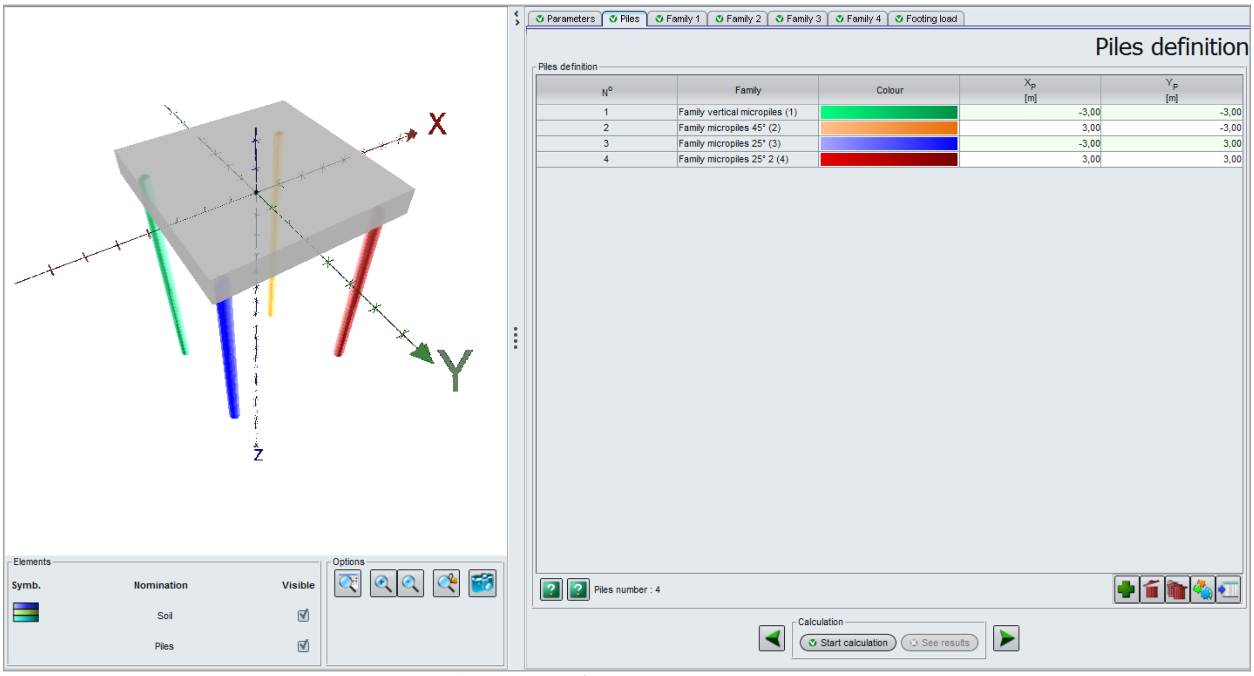


Figure H 58: "Piles" tab of Advanced Automatic Groupie+

This tab only contains a single frame, the parameters of which are described below.

Designation	Unit	Default value	Display condition	Mandatory value	Local checks
Pile family	-	No family	Always	Yes	-
XX_P: X-axis of pile head – global coordinates system	m	0.00	Always	Yes	-
Y_P: Y-axis of pile head – global coordinates system					

Table H 17: *"Piles" tab – "Piles definition" frame*

H.3.3.3. "Family" tabs

There are as many "Family" tabs as there are families created in the "Parameters" tab (see paragraph H.3.3.1). When a family is created, the programme automatically allocates it a number and asks for a name to be filled in. The family number is used to name the tab. Its full name appears at the top of an active tab.

The piles belonging to a given family have the following parameters in common:

- Orientation;
- Section and length;
- Mechanical characteristics;
- Footing binding type;
- Geotechnical model: elevations and transfer curves, point stiffnesses, g(z).

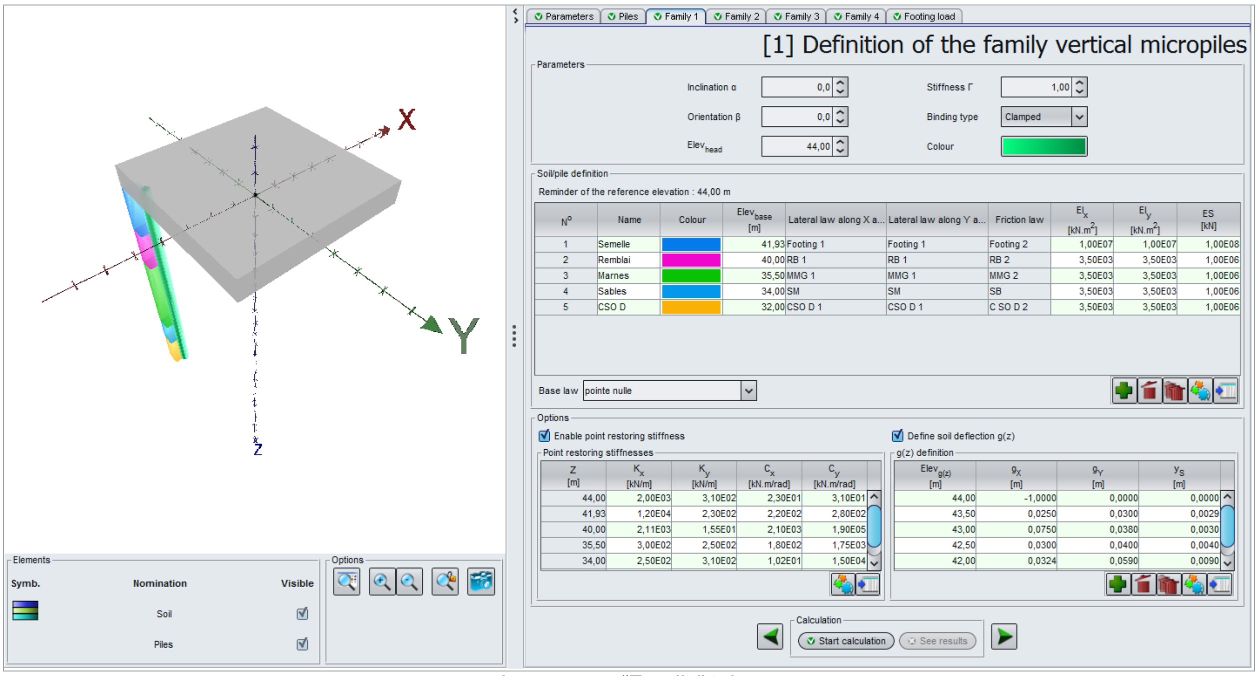


Figure H 59: "Family" tab

The "Family" tab comprises three frames, the last one of which is optional.

- Parameters;
- Soil/pile definition;
- Options.

H.3.3.3.1. "Parameters" frame

This frame completes the definition of the pile distribution. The parameters to be filled out are described in the following table.

Designation	Unit	Default value	Display condition	Mandatory value	Local checks
α: inclination of piles of this family with respect to axis (OZ) – global coordinates system	°	0	Always	Yes	-
β: orientation of piles of this family around axis (OZ) – global coordinates system	°				

Designation	Unit	Default value	Display condition	Mandatory value	Local checks
Elev$_{head}$: elevation of head of piles of this family on ascending vertical axis	m				
Γ: equivalent torsional stiffness at pile head – local coordinates system	kN.m/rad	1	Always	Yes	≥ 0
Binding type: clamped or articulated (ball-joint)	-	Clamped	Always	Yes	-

Table H 18: *"Family" tab – "Parameters" frame*

The "Colour" field is used to display all the piles of a given family with a single colour, with the aim of making it easier to differentiate between the various families in the graphical part.

H.3.3.3.2. "Soil/Pile definition" frame

The layer interfaces should not exceed the reference elevation recalled in each "Family" tab. Furthermore, they are considered to be horizontal at each family. This hypothesis was adopted to remain consistent with the notion of family which consists in retaining a single geotechnical model for all the piles in a given family.

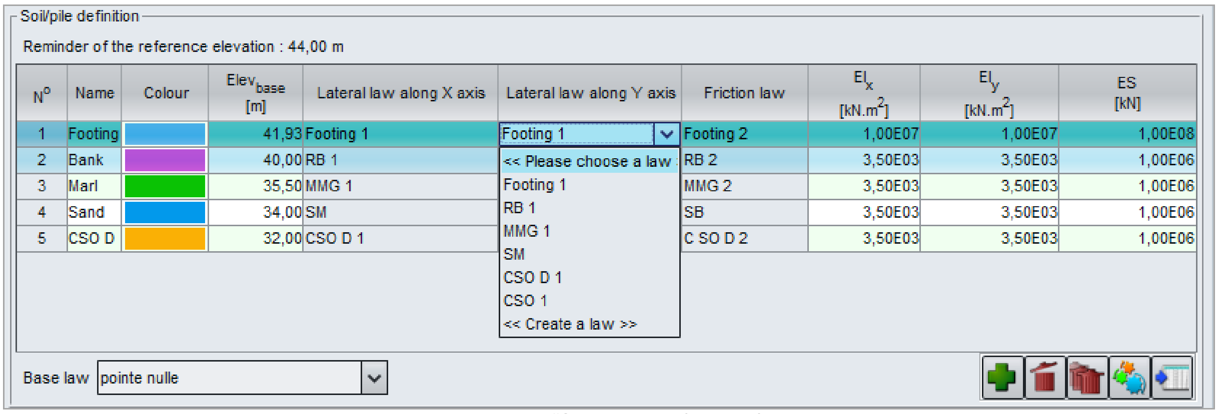


Figure H 60: *"Soil/Pile" definition frame*

The soil characteristics table then needs to be filled out: three columns use the laws defined in the "Parameters" tab. However, it is also possible to create them directly from the drop-down list by clicking the "Create a law" option. In this case, the laws created will be added to the "Laws" frame in the "Parameters" tab in accordance with the classification previously presented.

Designation	Unit	Default value	Display condition	Mandatory value	Local checks
Elev$_{base}$: elevation of bottom of layer read on ascending vertical axis	m	0	Always	Yes	-
Lateral law x: lateral reaction law in direction x – local coordinates system	-	-	Always	Yes	Not blank
Lateral law y: lateral reaction law in direction y – local coordinates system	-	-	Always	Yes	Not blank

Designation	**Unit**	**Default value**	**Display condition**	**Mandatory value**	**Local checks**
Friction law: shaft friction mobilisation law – local coordinates system	-	-	Always	Yes	Not blank
EI_x: product of inertia of pile section in direction x – local coordinates system	kN.m²	0	Always	Yes	≥ 0
EI_y: product of inertia of pile section in direction y – local coordinates system	kN.m²	0	Always	Yes	≥ 0
ES: axial rigidity of pile section – local coordinates system	kN	0	Always	Yes	≥ 0

Table H 19: *"Family" tab – "Soil/Pile definition" frame*

The last element to be defined in this frame is the **Base law** which must be chosen from the drop-down list.

H.3.3.3.3. "Options" frame

This frame comprises two optional tables.

Point restoring stiffnesses

If the "Activate point restoring stiffnesses" box is ticked, the point stiffnesses (translation and rotation) at the layer interfaces can be defined. It should be noted that these stiffnesses are expressed in the local coordinates system of each pile.

The data to be filled out are detailed in the following table.

Designation	**Unit**	**Default value**	**Display condition**	**Mandatory value**	**Local checks**
Z: elevation	m	Function of "Soil/Pile definition" frame	Always	Yes	Not modifiable
k_x: point restoring stiffness in lateral translation in direction x	kN/m	0	Always	Yes	≥ 0
k_y: point restoring stiffness in lateral translation in direction y	kN/m				
C_x: point restoring stiffness in rotation direction x	kN.m/rad				
C_y: point restoring stiffness in rotation direction y	kN.m/rad				

Table H 20: *"Family" tab – "Options" frame – Point restoring stiffnesses*

Free g(z) displacement

If the "Define g(z) soil displacement" box is ticked, a g(z) displacement applied to the piles of the family in question can be defined. The components of g(z) are expressed in the global coordinates system. The definition method is comparable to that used for the Automatic Groupie+ mode (see chapter H.3.2.4).

The data to be input are detailed in the following table:

<table>
<tr><th>Designation</th><th>Unit</th><th>Default value</th><th>Display condition</th><th>Mandatory value</th><th>Local checks</th></tr>
<tr><td>Elev$_{g(z)}$</td><td rowspan="4">m</td><td rowspan="4">0</td><td rowspan="4">Always</td><td rowspan="4">Yes</td><td rowspan="4">-</td></tr>
<tr><td>$\mathbf{g_X}$: lateral soil displacement – direction X</td></tr>
<tr><td>$\mathbf{g_Y}$: lateral soil displacement – direction Y</td></tr>
<tr><td>$\mathbf{y_S}$: imposed soil settlement – direction Z</td></tr>
</table>

Table H 21: *"Family" tab – "Options" frame – "Define g(z)"*

H.3.3.4. "Footing loading" tab

This tab is used to define the load cases to which the anchor footing is subjected. This tab is comparable to that of the Manual Groupie mode described in paragraph H.3.1.4.

H.3.3.5. Calculation

The calculation approach is exactly the same as in Automatic Groupie+ mode (chapter H.3.2.6).

H.3.3.6. Results

The results of Advanced Automatic Groupie+ are comparable to those presented in Automatic Groupie+ mode (chapter H.3.2.7).

Figure H 61: Window of Advanced Automatic Groupie+ results

H.3.3.6.1. Numerical results

Same as for Automatic Groupie+ mode (see chapter H.3.2.7.1).

H.3.3.6.2. Graphical results

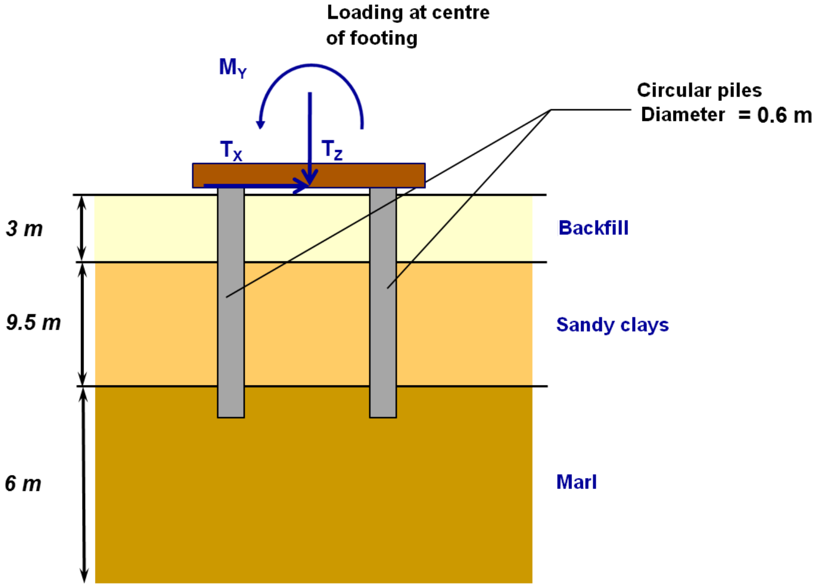
Same as for Automatic Groupie+ mode (see chapter H.3.2.7.2).

Advanced Automatic Groupie+ also enables the list of piles to be filtered by family. It is possible to select a pile family from the drop-down list initialised by default at "All families".

NB: It should be noted that the friction along the piles, given in the "Axial behaviour" window, is expressed in kN/m instead of kPa. This is the only difference between the results of the Automatic modes.

H.4. EXAMPLES

H.4.1. Example 1: Footing on circular piles



H.4.1.1. Data input

When the application opens, FoXta proposes:

- Creating a new project;
- Opening an existing project;
- Automatically opening the last project used.

In the case of this example:

- Choose to create a new project by selecting the [New project] radio-button;
- Click the [OK] button.

H.4.1.1.1. New project wizard

"File" frame

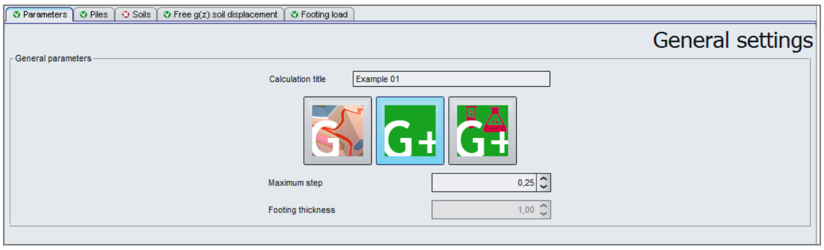
- Fill out the project path by clicking the [...] button;
- Give the file a name and save it.

"Project" frame

- Give the project a title;
- Enter a project number;
- Add a commentary if required;
- Leave the "Use database" box unticked (we will not use the database for this example) and click the [Next] button.

H.4.1.1.2. New project wizard: choice of modules

In the "Choose modules" window, select the Groupie+ module then click the [Create] button.



The Groupie+ window appears. Fill out the various data tabs.

H.4.1.1.3. "Parameters" tab

This tab contains two separate frames:

<u>"General parameters" frame</u>

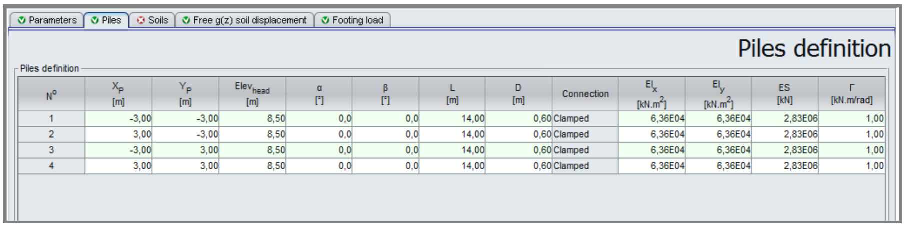
- Title of Groupie+ calculation: for this example, we will simply use "Example 01";
- Automatic Groupie+ Mode: selected;
- Maximum step (m): 0.25;
- Footing thickness (m): perfectly rigid footing.

<u>"Advanced parameters" frame</u>

- Modify the advanced parameters: unticked.

H.4.1.1.4. "Piles" tab

This tab is used to define the pile characteristics. We first of all consider them to be clamped in the connection footing.



<u>"Piles definition" frame</u>

- Create 4 piles by clicking the button.

The data to be input are as follows:

Pile N°	**X_P** (m)	**Y_P** (m)	**$Elev_{head}$** (m)	**α** (°)	**β** (°)	**L** (m)	**D** (m)	**Connection**	**EI_x** (kN.m²)	**EI_y** (kN.m²)	**ES** (kN)	**Γ** (kN.m/rad)
1	-3.00	-3.00	8.50	0	0	14.0	0.6	Clamped	6.36E04	6.36E04	2.83E06	1.00
2	3.00	-3.00	8.50	0	0	14.0	0.6	Clamped	6.36E04	6.36E04	2.83E06	1.00
3	-3.00	3.00	8.50	0	0	14.0	0.6	Clamped	6.36E04	6.36E04	2.83E06	1.00
4	3.00	3.00	8.50	0	0	14.0	0.6	Clamped	6.36E04	6.36E04	2.83E06	1.00

<u>"Base stiffnesses" frame</u>

- Specific stiffnesses at pile bases: unticked

Note: the "Piles" tab remains marked by a red cross until the following "Soils" tab has been completely filled out. FoXta checks that the piles are not out of the ground.

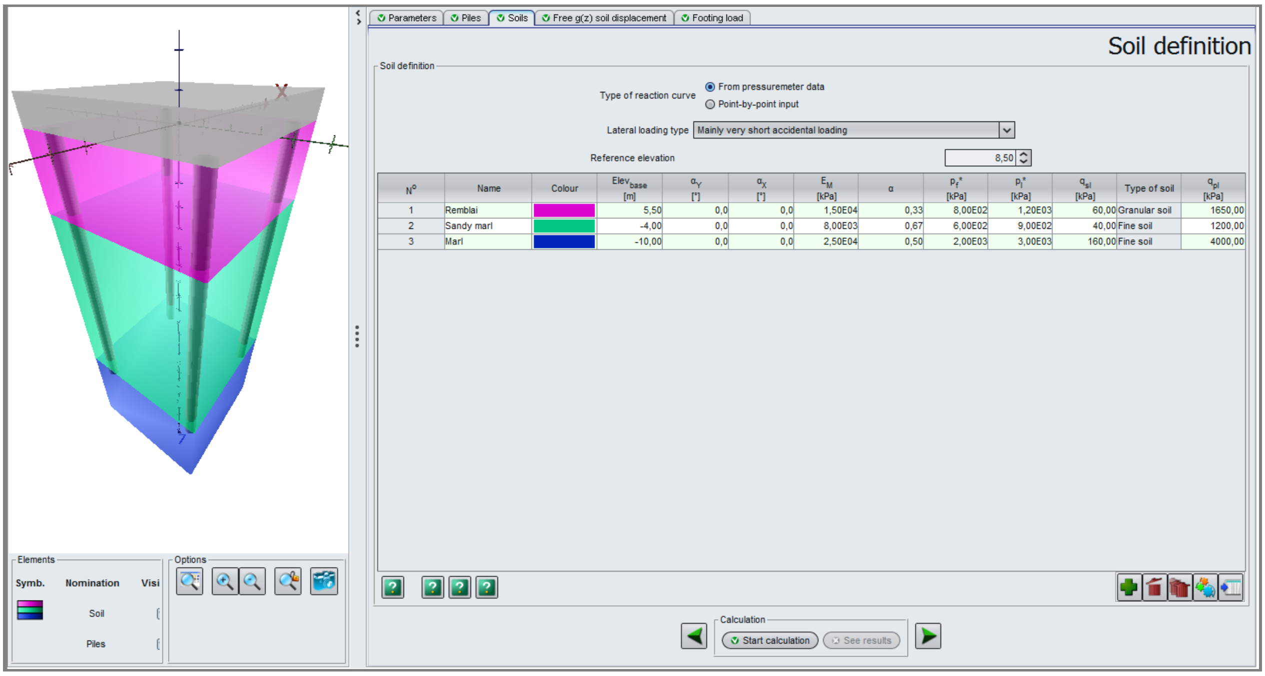
H.4.1.1.5. "Soils" tab

The third tab is used to define the soil characteristics.
In this example, the reaction laws are defined on the basis of pressuremeter data. The lateral loadings at pile head are accidental.

- Type of reaction curve: "From pressuremeter data";
- Lateral loading type: "Mainly very short accidental loading";
- Reference elevation: 8.50 m.

The data characterising the soil layers are listed below:

Name	Elevation $_{base}$ (m)	θ_Y (°)	θ_X (°)	E_M (kPa)	α (-)	p_f^* (kPa)	p_l^* (kPa)	q_{sl} (kPa)	Soil type	q_{pl} (kPa)
Bank	5.5	0	0	1.5E04	0.33	8.0E02	1.2E03	60	granular	1650
Sandy marl	-4.0	0	0	8.0E03	0.67	6.0E02	9.0E02	40	fine	1200
Marl	-10.0	0	0	2.5E04	0.50	2.0E03	3.0E03	160	fine	4000



The "Piles" and "Soils" tabs are now marked by a green tick indicating that the data input in them are coherent.

H.4.1.1.6. "Free g(z) soil displacement" tab

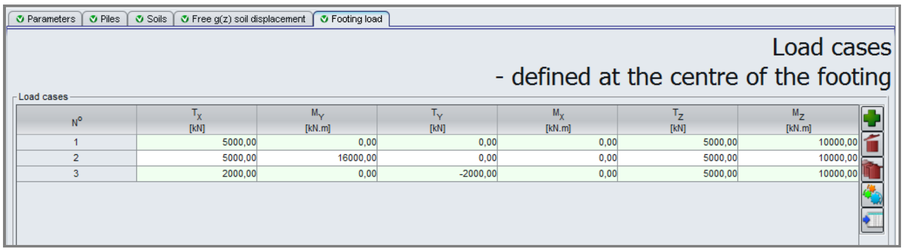
This tab is not used in this example.

H.4.1.1.7. "Footing loading" tab

The load cases are expressed at the centre of the footing, at point O.

Three different load cases are studied.

Load case N°	T_X (kN)	M_Y (kN.m)	T_Y (kN)	M_X (kN.m)	T_Z (kN)	M_Z (kN.m)
1	5000	0	0	0	5000	10000
2	5000	16000	0	0	5000	10000
3	2000	0	-2000	0	5000	10000



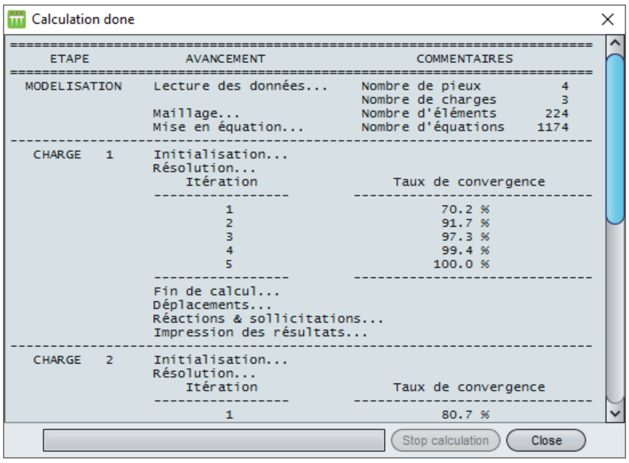
H.4.1.2. Calculation and results

H.4.1.2.1. Calculation

Until all mandatory tabs have been filled out, the button used to start the calculation is marked by a red cross: Start calculation.

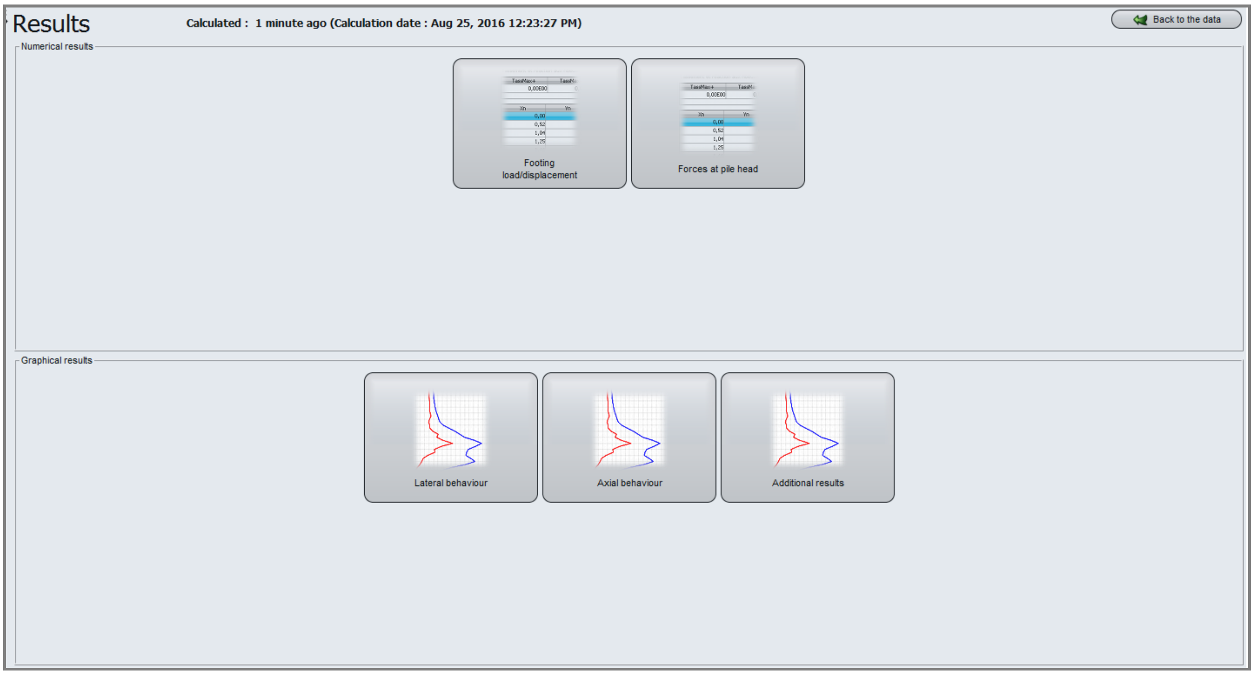
Once all the data have been correctly input, the Start calculation button (accessible from all the tabs) becomes active.

Clicking this button will start the calculation and display the calculation progress window.



At the end of calculation, click the Close button.

To access the results, click the See results button.



H.4.1.2.2. Results

<u>Numerical results</u>

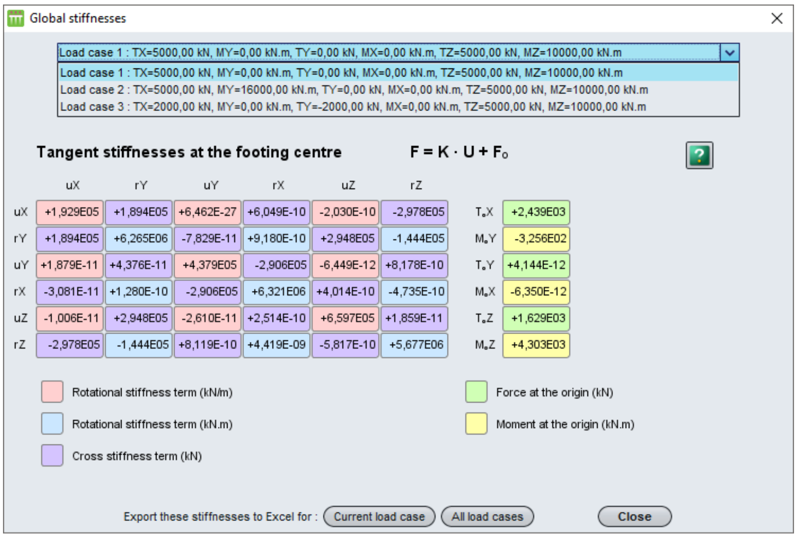
<u>Results tables</u>:

Loads and displacements at the footing centre: for each load case, this table gives the displacement global forces and moments at point O.

Loads and displacements at the footing centre

Load case #	T_X [kN]	M_Y [kN.m]	T_Y [kN]	M_X [kN.m]	T_Z [kN]	M_Z [kN.m]	U_X [m]	rot/Y [rad]	U_Y [m]	rot/X [rad]	U_Z [m]	rot/Z [rad]
1	5000,00	0,00	0,00	0,00	5000,00	10000,00	1,682E-02	-6,680E-04	-1,334E-17	2,834E-19	5,408E-03	1,869E-03
2	5000,00	16000,00	0,00	0,00	5000,00	10000,00	1,325E-02	2,848E-03	-1,137E-17	9,278E-19	9,341E-03	1,774E-03
3	2000,00	0,00	-2000,00	0,00	5000,00	10000,00	5,120E-03	-2,355E-04	-5,120E-03	-2,355E-04	5,322E-03	1,401E-03

The global stiffnesses are accessible by clicking the Global stiffnesses button; simply choose the relevant load case from the drop-down list.



	uX	rY	uY	rX	uZ	rZ		
uX	+1,929E05	+1,894E05	+6,462E-27	+6,049E-10	-2,030E-10	-2,978E05	T_oX	+2,439E03
rY	+1,894E05	+6,265E06	-7,829E-11	+9,180E-10	+2,948E05	-1,444E05	M_oY	-3,256E02
uY	+1,879E-11	+4,376E-11	+4,379E05	-2,906E05	-6,449E-12	+8,178E-10	T_oY	+4,144E-12
rX	-3,081E-11	+1,280E-10	-2,906E05	+6,321E06	+4,014E-10	-4,735E-10	M_oX	-6,350E-12
uZ	-1,006E-11	+2,948E05	-2,610E-11	+2,514E-10	+6,597E05	+1,859E-11	T_oZ	+1,629E03
rZ	-2,978E05	-1,444E05	+8,119E-10	+4,419E-09	-5,817E-10	+5,677E06	M_oZ	+4,303E03

Groupie help

Global stiffnesses of the foundation

$$\underbrace{\begin{bmatrix} T_X \\ M_Y \\ T_Y \\ M_X \\ T_Z \\ M_Z \end{bmatrix}}_{\underline{F}} = \underbrace{\begin{bmatrix} k_{uX,uX} & k_{uX,rY} & k_{uX,uY} & k_{uX,rX} & k_{uX,uZ} & k_{uX,rZ} \\ . & k_{rY,rY} & k_{rY,uY} & k_{rY,rX} & k_{rY,uZ} & k_{rY,rZ} \\ . & . & k_{uY,uY} & k_{uY,rX} & k_{uY,uZ} & k_{uY,rZ} \\ . & . & . & k_{rX,rX} & k_{rX,uZ} & k_{rX,rZ} \\ . & . & . & . & k_{uZ,uZ} & k_{uZ,rZ} \\ . & . & . & . & . & k_{rZ,rZ} \end{bmatrix}}_{\underline{\underline{K}}} . \underbrace{\begin{bmatrix} u_X \\ \theta_Y \\ u_Y \\ \theta_X \\ u_Z \\ \theta_Z \end{bmatrix}}_{\underline{U}} + \underbrace{\begin{bmatrix} T_{0X} \\ M_{0Y} \\ T_{0Y} \\ M_{0X} \\ T_{0Z} \\ M_{0Z} \end{bmatrix}}_{\underline{F_0}}$$

$$\underline{F} = \underline{\underline{K}}.\underline{U} + \underline{F_0}$$

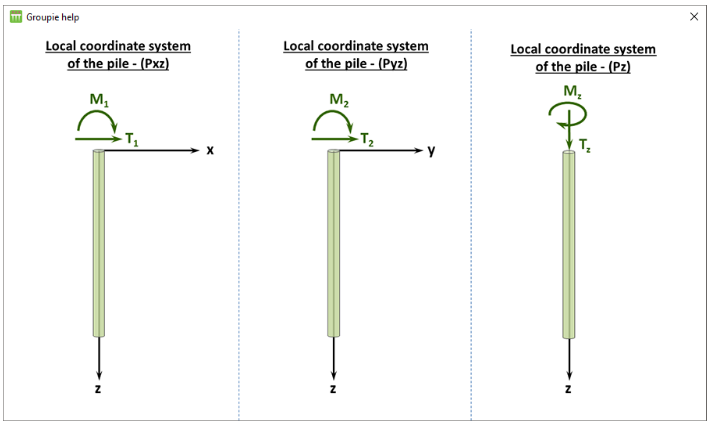
F : Loads vector
K : Tangential stiffness matrix (symmetrical)
U : Displacement and rotation vector
F_0 : Initial internal efforts

<u>Forces at piles heads</u>:

This table presents the forces transmitted at the piles heads. The conventions used are recalled in the following figure.

Forces at pile heads

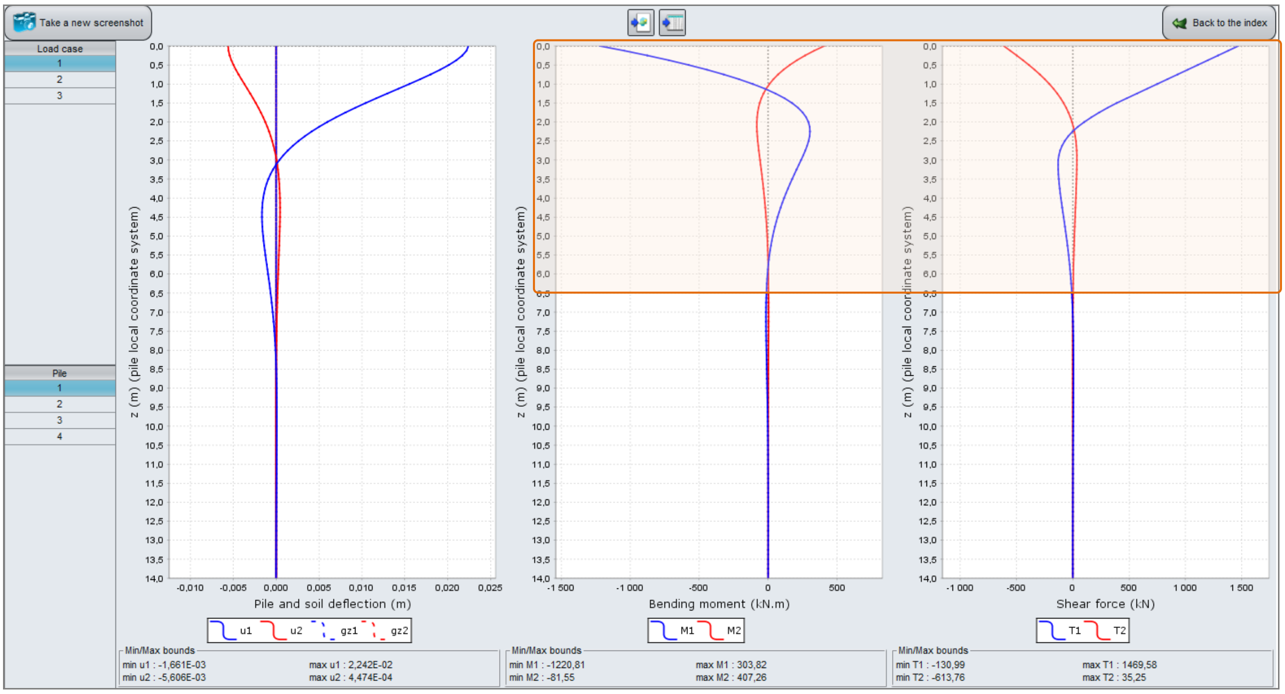
Load case #	Pile #	T_1 [kN]	M_1 [kN.m]	T_2 [kN]	M_2 [kN.m]	T_z [kN]	M_z [kN.m]
1	1	1469,580	-1220,810	-613,757	407,263	928,896	0,002
1	2	1469,580	-1220,810	613,757	-407,263	1571,100	0,002
1	3	1030,420	-705,815	-613,757	407,263	928,896	0,002
1	4	1030,420	-705,815	613,757	-407,263	1571,100	0,002
2	1	1500,610	-1342,580	-582,724	386,671	2221,980	0,002
2	2	1500,610	-1342,580	582,724	-386,671	278,020	0,002
2	3	999,391	-825,542	-582,724	386,671	2221,980	0,002
2	4	999,391	-825,542	582,724	-386,671	278,020	0,002
3	1	916,666	-631,222	-916,666	631,222	1251,820	0,001
3	2	916,666	-631,222	-83,334	44,070	1473,280	0,001
3	3	83,334	-44,070	-916,666	631,222	1023,080	0,001
3	4	83,334	-44,070	-83,334	44,070	1251,820	0,001



<u>Graphical results</u>

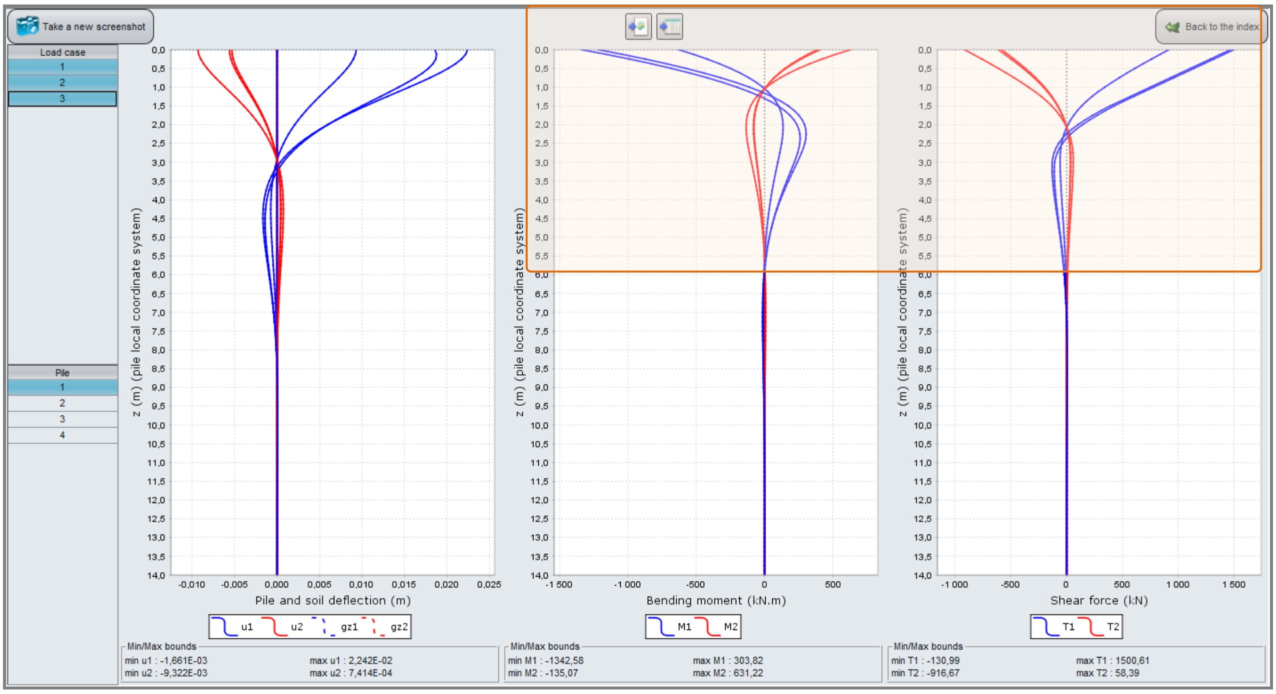
<u>Lateral behaviour:</u>

Load case N°1 – Pile N°1



The shape of the lateral displacement of the pile is compatible with the fact that it is clamped in the anchor footing. As the piles are vertical, the rotations at their heads are equal to the rotations of the footing.

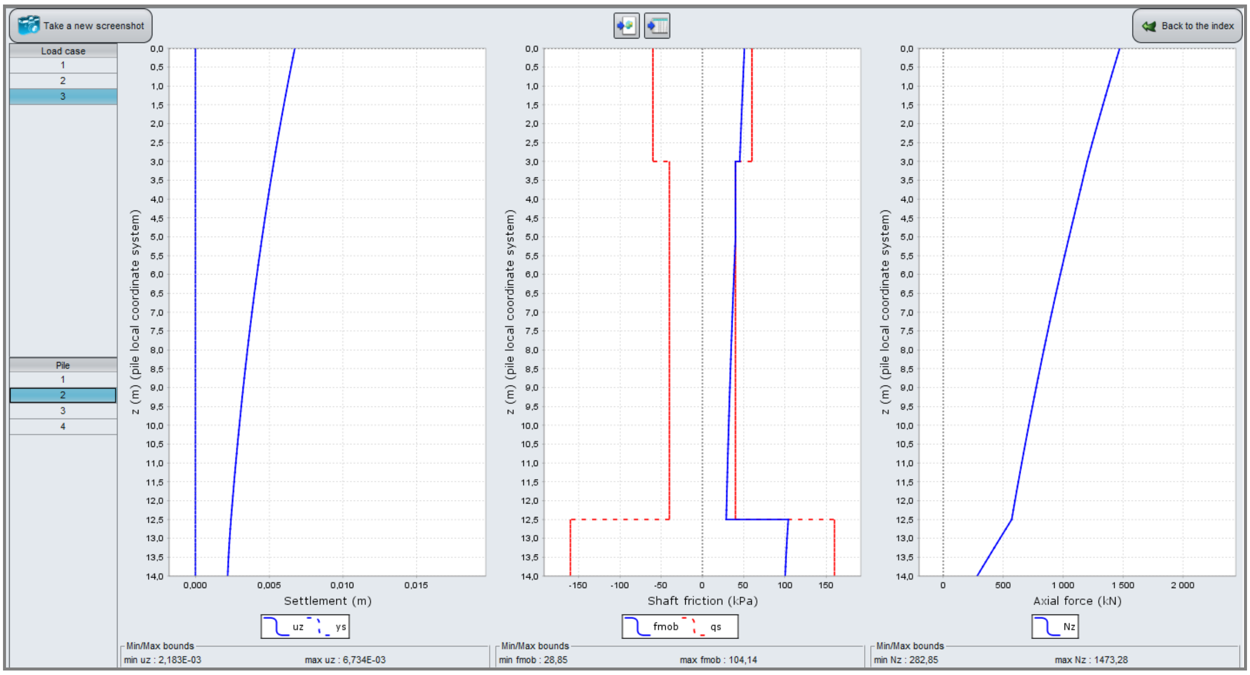
All load cases – Pile N°1



Pile N°1 is the most heavily loaded laterally. Moreover, given the clamping of the piles in the footing, the moment and shear force are maximum at the head. They are then attenuated over the first 6 metres of the pile, finally reaching very low values.

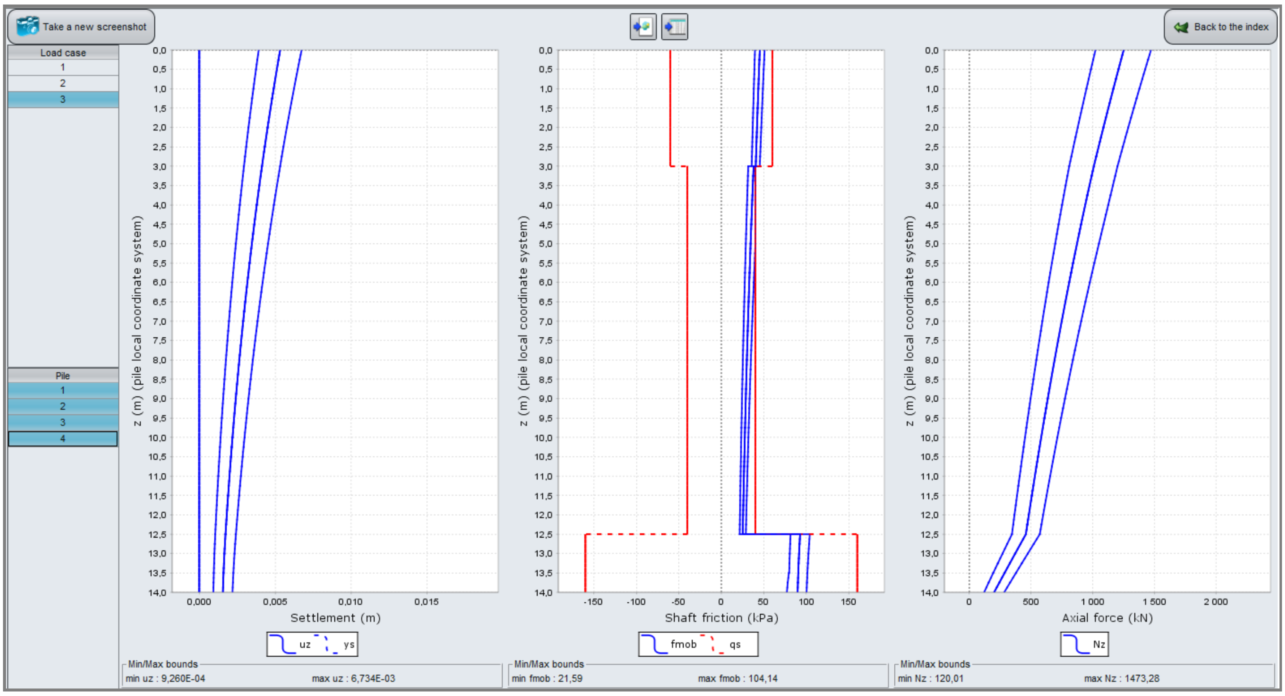
<u>Axial behaviour</u>:

Load case N°3 – Pile N°2



Pile N°2 is subjected to an axial load at the head of 1473 kN. The mobilised friction, which is positive over the length of the shaft, has a resultant value of 1190 kN. The rest of the load (283 kN) is taken up at the base.

Load case N°3 – All piles



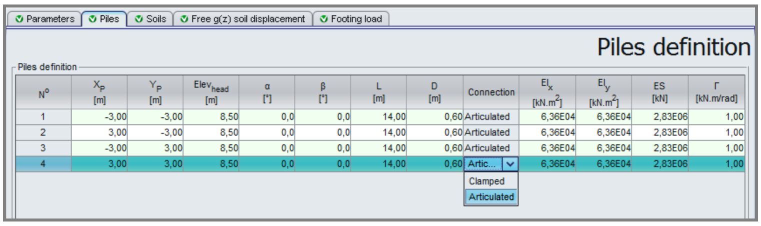
For this load case, all the piles work in compression (pile N°2 is the most heavily loaded).

H.4.1.3. Articulated piles variant

In this part we will study the differences obtained by using articulated piles instead of clamped piles.

H.4.1.3.1. Modification of data

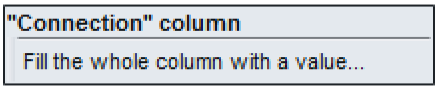
The only modification to make is setting the piles as “articulated at the top” using the drop-down list in the “Connection” column of the “Piles” tab.



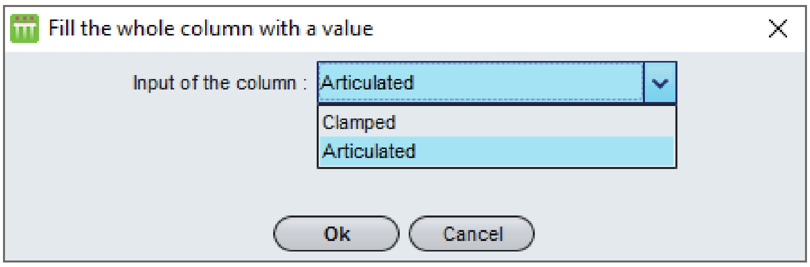
N°	X_P [m]	Y_P [m]	$Elev_{head}$ [m]	α [°]	β [°]	L [m]	D [m]	Connection	EI_x [kN.m²]	EI_y [kN.m²]	ES [kN]	Γ [kN.m/rad]
1	-3,00	-3,00	8,50	0,0	0,0	14,00	0,60	Articulated	6,36E04	6,36E04	2,83E06	1,00
2	3,00	-3,00	8,50	0,0	0,0	14,00	0,60	Articulated	6,36E04	6,36E04	2,83E06	1,00
3	-3,00	3,00	8,50	0,0	0,0	14,00	0,60	Articulated	6,36E04	6,36E04	2,83E06	1,00
4	3,00	3,00	8,50	0,0	0,0	14,00	0,60	Artic...	6,36E04	6,36E04	2,83E06	1,00

Tip: to give the same value to all the boxes in a column:

- Right-click the header of the “Connection” column, then click the “Fill the whole column with a value...” option



- Here choose “Articulated” and click the  button.



H.4.1.3.2. Calculation and results

Restart the calculation by again clicking the Start calculation button and then See results to access the results.

Results tables:

Loads and displacements at the footing centre:

Global stiffnesses | **Loads and displacements at the footing centre** | Export | Back to the index

Load case #	T_X [kN]	M_Y [kN.m]	T_Y [kN]	M_X [kN.m]	T_Z [kN]	M_Z [kN.m]	U_X [m]	rot/Y [rad]	U_Y [m]	rot/X [rad]	U_Z [m]	rot/Z [rad]
1	5000,00	0,00	0,00	0,00	5000,00	10000,00	8,587E-02	-1,909E-19	3,469E-18	-1,909E-19	5,310E-03	6,360E-03
2	5000,00	16000,00	0,00	0,00	5000,00	10000,00	8,587E-02	5,643E-03	3,469E-18	-1,084E-18	1,669E-02	6,360E-03
3	2000,00	0,00	-2000,00	0,00	5000,00	10000,00	1,657E-02	-1,909E-19	-1,657E-02	-1,909E-19	5,310E-03	5,012E-03

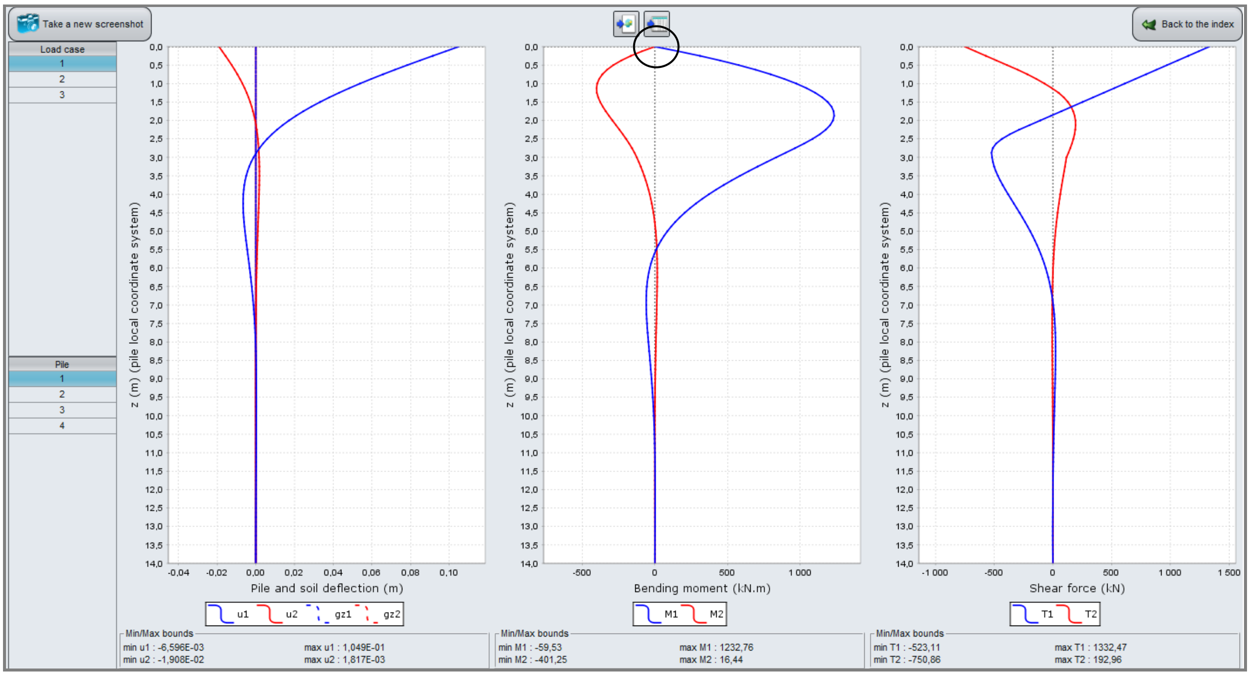
Forces at pile heads:

Forces at pile heads | Export | Back to the index

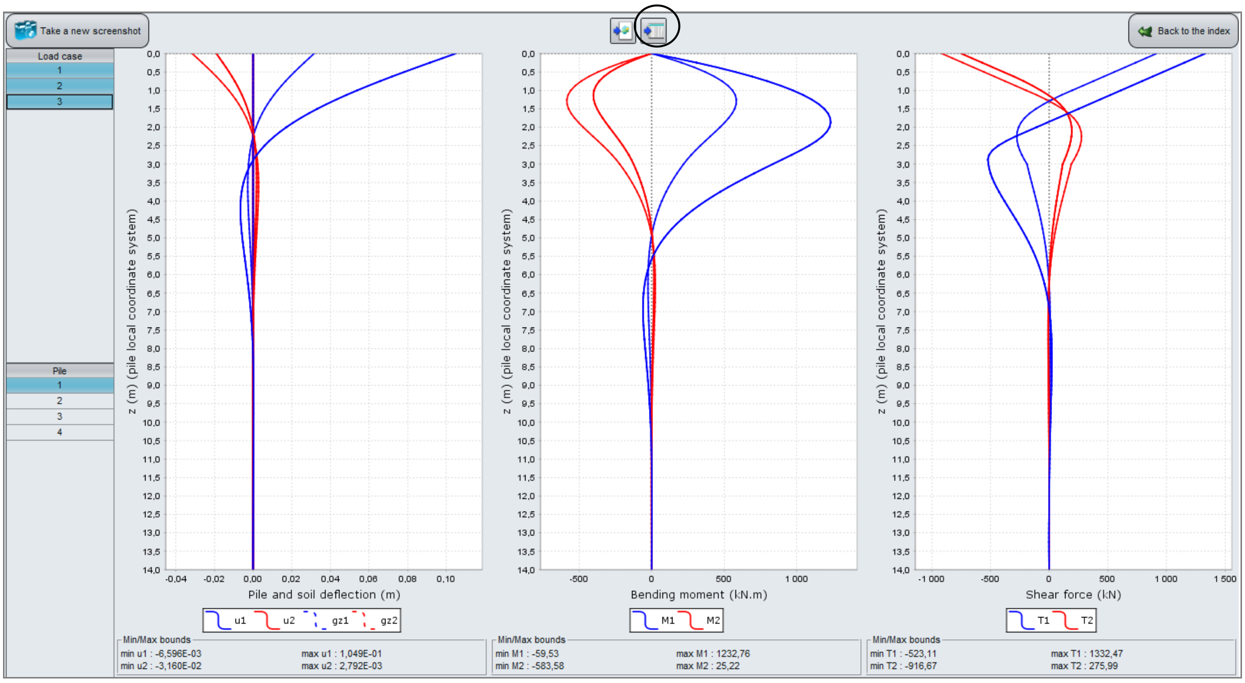
Load case #	Pile #	T_1 [kN]	M_1 [kN.m]	T_2 [kN]	M_2 [kN.m]	T_z [kN]	M_z [kN.m]
1	1	1332,470	0,000	-750,864	0,000	1250,000	0,000
1	2	1332,470	0,000	750,864	0,000	1250,000	0,000
1	3	1167,530	0,000	-750,864	0,000	1250,000	0,000
1	4	1167,530	0,000	750,864	0,000	1250,000	0,000
2	1	1332,470	0,000	-750,864	0,000	2583,330	0,000
2	2	1332,470	0,000	750,864	0,000	-83,333	0,000
2	3	1167,530	0,000	-750,864	0,000	2583,330	0,000
2	4	1167,530	0,000	750,864	0,000	-83,333	0,000
3	1	916,667	0,000	-916,667	0,000	1250,000	0,000
3	2	916,667	0,000	-83,333	0,000	1250,000	0,000
3	3	83,333	0,000	-916,667	0,000	1250,000	0,000
3	4	83,333	0,000	-83,333	0,000	1250,000	0,000

As the piles are articulated at the anchor footing, no moment is transmitted to their heads (M1 = 0 kN and M2 = 0 kN).

Lateral behaviour:
Load case N°1 – Pile N°1



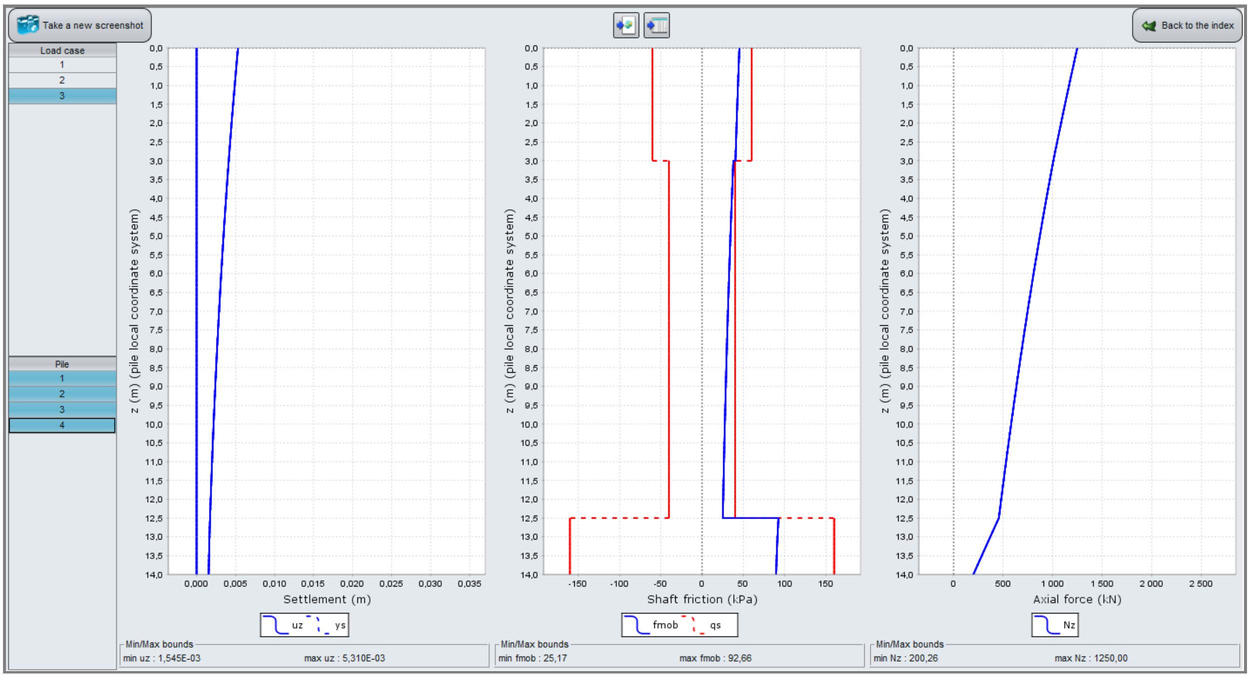
All load cases - Pile N°1



The pile heads are free to rotate, which explains the shape of their lateral displacements. The moments, which are nil at the head, reach their maximum at a depth of 1.5 to 2m with respect to the base of the footing. The shear forces tend to be the highest at the heads.

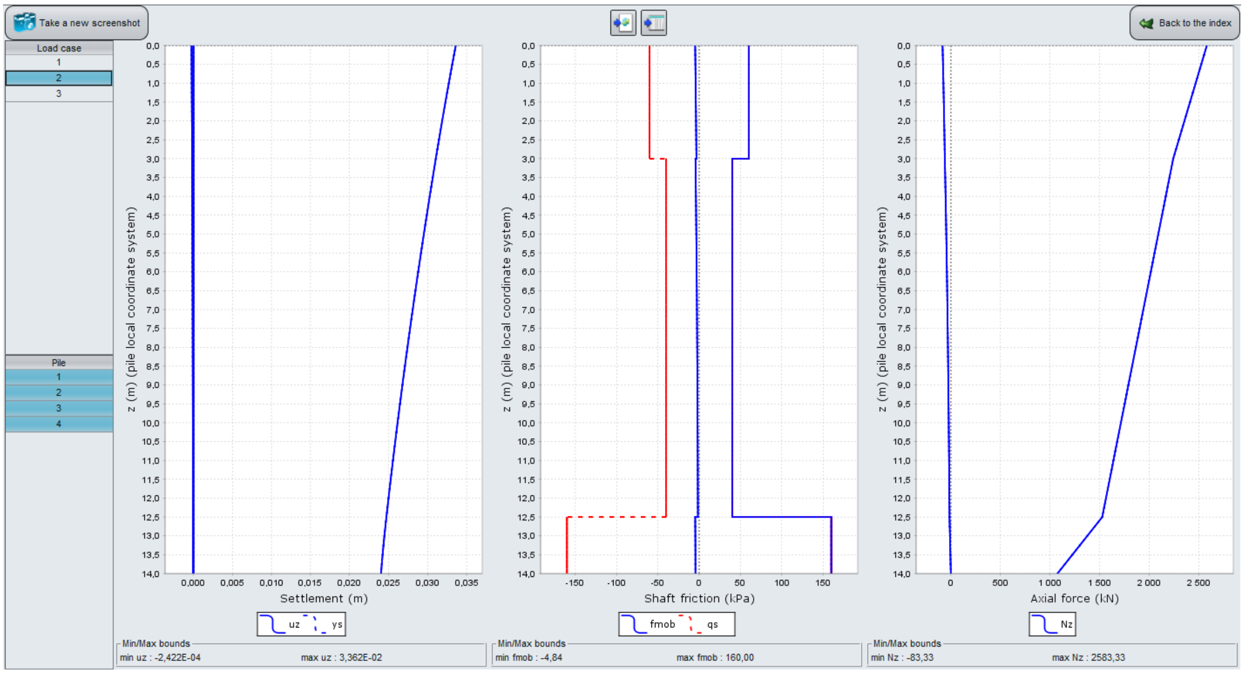
<u>Axial behaviour</u>:

Load case N°3 – All piles



For this load case, the four piles are evenly loaded (1250 kN = 5000 kN / piles). The same remark applies to the 1st load case.

Load case N°2 – All piles



For this load case, the two piles N°2 and 4 work in traction and thus develop negative friction on their shafts. The base resistance related to these piles is nil.

Comparison of results: Clamped piles / Articulated piles.

Lateral behaviour:

All load cases – All piles

	Deflection (m)				Bending moment (kN.m)				Shear force (kN)			
	Clamped		Articulated		Clamped		Articulated		Clamped		Articulated	
	u1	u2	u1	u2	M1	M2	M1	M2	T1	T2	T1	T2
Min. bound	-1.661E-03	-9.322E-03	-6.596E-03	-3.160E-02	-1342.58	-407.26	-59.53	-583.58	-130.99	-916.67	-523.11	-916.67
Max. bound	2.242E-02	5.606E-03	1.049E-01	1.908E-02	303.82	631.22	1232.76	401.25	1500.61	613.76	1332.47	750.86

Axial behaviour :

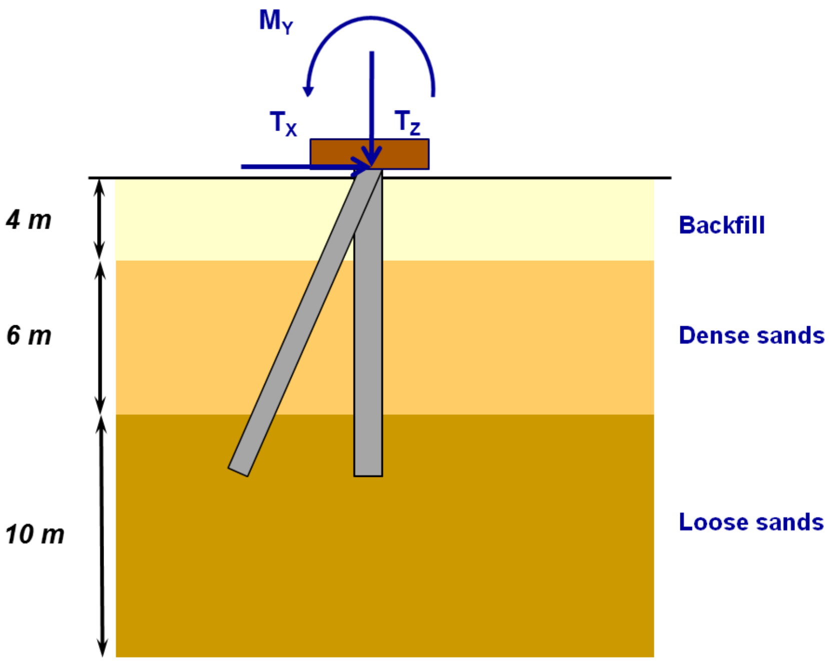
All load cases – All piles

	uz: Settlement (m)		fmob: Shaft friction (kPa)		Nz: Axial force (kN)	
	Clamped	Articulated	Clamped	Articulated	Clamped	Articulated
Min. bound	1.427E-04	-2.422E-04	4.31	-4.84	18.50	-83.33
Max. bound	1.789E-02	3.362E-02	160.00	160.00	2221.98	2583.33

Under the same load cases, the pile (and footing) displacement are amplified when the piles are articulated. The overall behaviour of the foundation then becomes more flexible. By comparison with the solution with piles clamped in the connection footing, the case of articulated piles shows larger axial forces combined with lower shear forces and bending moments.

H.4.2. Example 2: Foundation of a noise-abatement structure

This example deals with the design of a group of piles representing the foundation of a noise-abatement structure. The foundation comprises 6 piles, 3 of which are vertical and 3 inclined.



The first step is to produce the project in Automatic Groupie+ mode. As a comparison, the second step presents the approach to be followed to carry out the same calculation in Manual Groupie using the Taspie+ and Piecoef+ modules.

H.4.2.1. Step 1: Automatic Groupie+ mode

H.4.2.1.1. Data input

The approach to create a new project is comparable to that presented in example 01 (see chapter H.4.1.1).

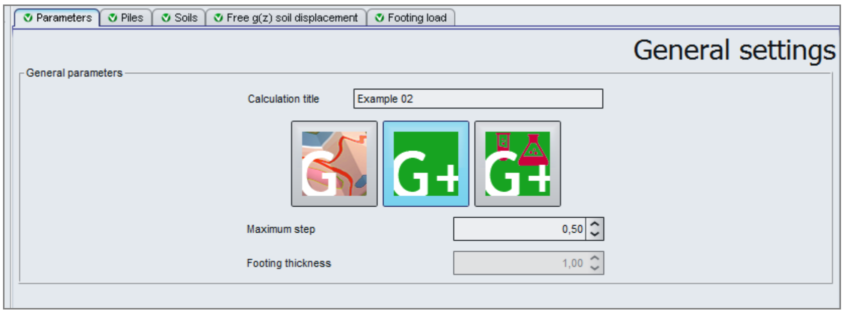
<u>"Parameters" tab</u>

<u>"General parameters" frame</u>

- Calculation title: simply enter "Easel piles";
- Automatic Groupie+: selected;
- Maximum step: 0.50 m.

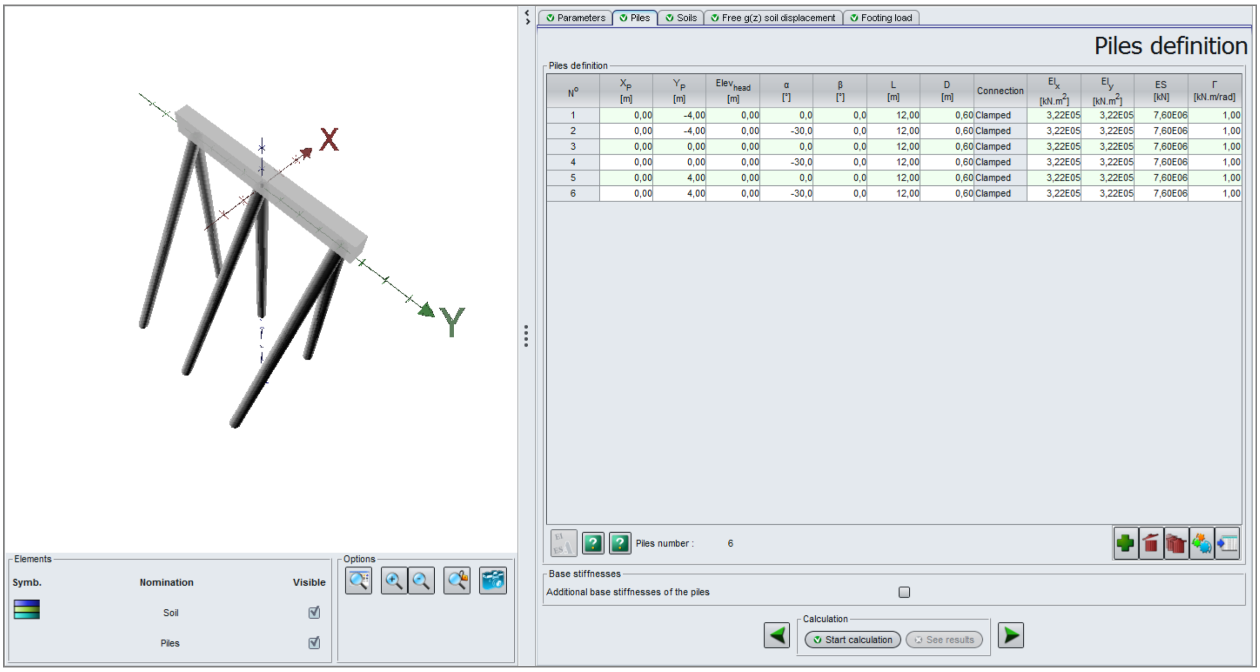
<u>"Advanced parameters" frame</u>

- Modify advanced parameters: unticked.



"Piles" tab

This tab is used to define the characteristics of the piles.



"Piles definition" frame

- Create 6 piles with the button.

The data to be input are as follows:

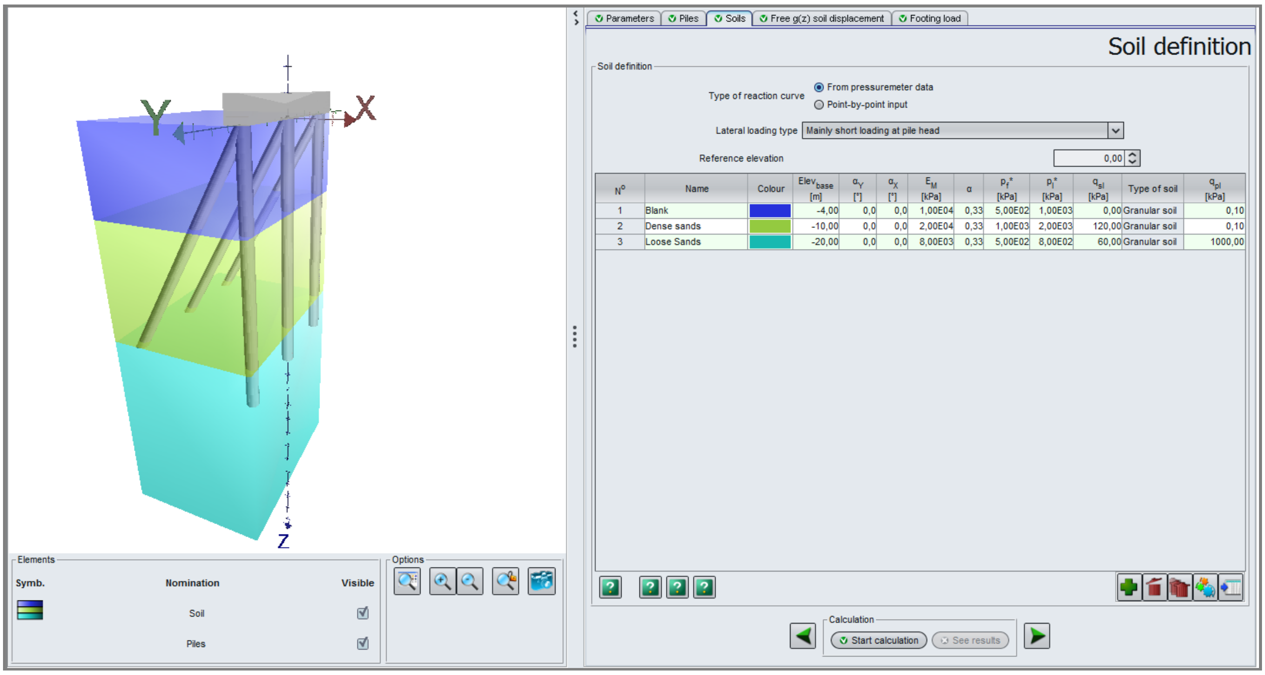
N° of piles	X_P (m)	Y_P (m)	Elev. head	α (°)	B (°)	L (m)	D (m)	Connection	EI_x (kN.m²)	EI_y (kN.m²)	ES (kN)	Γ (kN.m/rad)
1	0.0	-4.0	0.0	0	0	12.0	0.6	Clamped	3.22E05	3.22E05	7.60E06	1.00
2	0.0	-4.0	0.0	-30	0	12.0	0.6	Clamped	3.22E05	3.22E05	7.60E06	1.00
3	0.0	0.0	0.0	0	0	12.0	0.6	Clamped	3.22E05	3.22E05	7.60E06	1.00
4	0.0	0.0	0.0	-30	0	12.0	0.6	Clamped	3.22E05	3.22E05	7.60E06	1.00
5	0.0	4.0	0.0	0	0	12.0	0.6	Clamped	3.22E05	3.22E05	7.60E06	1.00
6	0.0	4.0	0.0	-30	0	12.0	0.6	Clamped	3.22E05	3.22E05	7.60E06	1.00

"Base stiffnesses" frame

- Additional base stiffnesses of the piles: unticked

"Soils" tab

The third tab is used to define the characteristics of the soils.



The interaction of the piles with the soil will be modelled by reaction laws based on pressuremeter parameters. They are appropriate for short duration lateral loads.

- Type of reaction curve: "From pressuremeter data";
- Lateral loading type: "Mainly short loading at pile head";
- Reference elevation (m): 0.00.

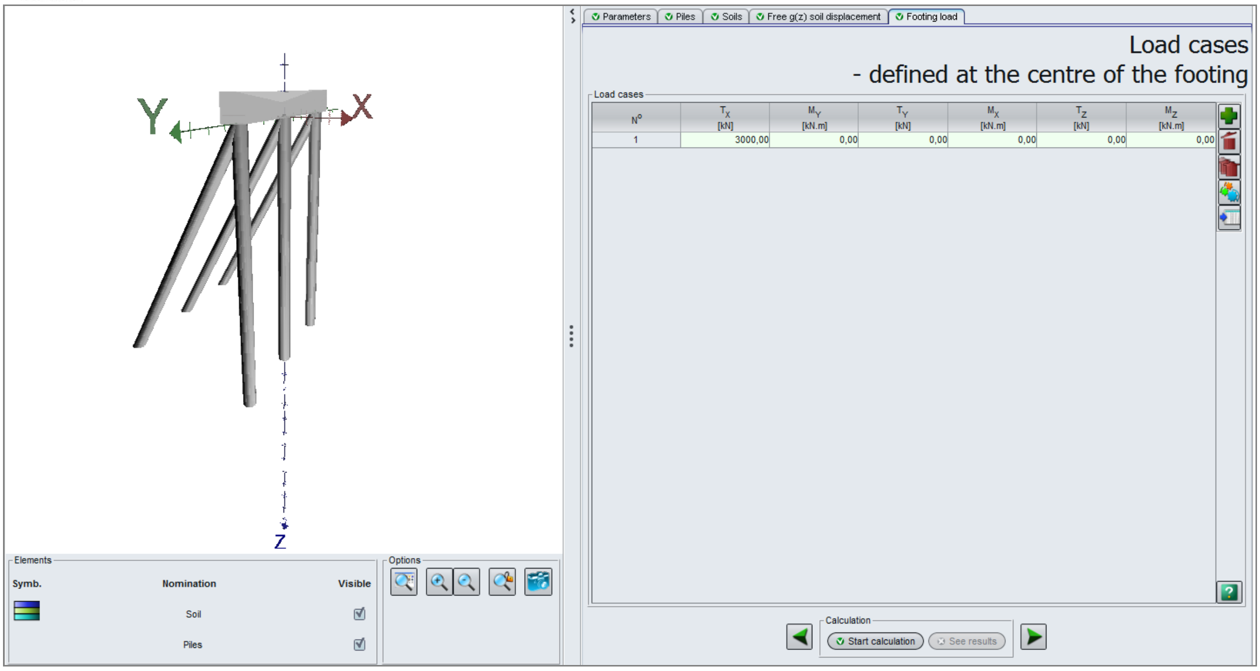
Name	$Elev_{base}$ (m)	α_Y (°)	α_X (°)	E_M (kPa)	α (-)	p_f* (kPa)	p_l* (kPa)	q_{sl} (kPa)	Soil type	q_{pl} (kPa)
Backfill	-4	0	0	1.0E04	0.33	5.0E02	1.0E03	0.001	granular	0.1
Dense sands	-10	0	0	2.0E04	0.33	1.0E03	2.0E03	120	granular	0.1
Loose sands	-20	0	0	8.0E03	0.33	5.0E02	8.0E02	60	granular	1000

"Free g(z) soil displacement"

This tab is not used in this example.

"Footing load" tab

A single load case is to be defined. It is expressed at the centre of the footing (point O) and corresponds to a horizontal force T_X of 3000 kN. Only the T_X box is to be filled out, with the values in the other boxes kept at 0.



H.4.2.1.2. Calculation and results

Carry out the calculation according to the procedure presented in example 1 (chapter H.4.1.2.1).

<u>Numerical results</u>

<u>Loads and displacements at the footing centre</u>:

This table gives the components of the footing displacement field expressed at point O. Given the data of the problem (geometrical symmetries and loading), this field is entirely defined in the OXZ plan. The components which are not part of this plane are null.

Global stiffnesses | **Loads and displacements at the footing centre** | Export | Back to the index

Load case #	T_X [kN]	M_Y [kN.m]	T_Y [kN]	M_X [kN.m]	T_Z [kN]	M_Z [kN.m]	U_X [m]	rot/Y [rad]	U_Y [m]	rot/X [rad]	U_Z [m]	rot/Z [rad]
1	3000,00	0,00	0,00	0,00	0,00	0,00	6,389E-03	-2,835E-03	-6,450E-20	-2,566E-19	1,176E-03	4,337E-19

The global stiffness of the foundation is accessible by clicking the Global stiffnesses button.

<u>Forces at pile heads</u>:

The piles are loaded in their local planes Pxz ($T_2 = M_2 = M_z = 0$). The vertical piles are subjected to compression in ($T_z > 0$) while the inclined piles are subjected to tensile work ($T_z < 0$). The piles which are part of each family of piles (vertical or inclined) are loaded in exactly the same way.

Forces at pile heads | Export | Back to the index

Load case #	Pile #	T_1 [kN]	M_1 [kN.m]	T_2 [kN]	M_2 [kN.m]	T_z [kN]	M_z [kN.m]
1	1	390,934	-16,547	-0,000	-0,000	325,444	0,000
1	2	364,744	16,547	0,000	-0,000	-586,375	0,000
1	3	390,934	-16,547	-0,000	-0,000	325,444	0,000
1	4	364,744	16,547	-0,000	0,000	-586,375	0,000
1	5	390,934	-16,547	0,000	-0,000	325,444	0,000
1	6	364,744	16,547	-0,000	0,000	-586,375	0,000

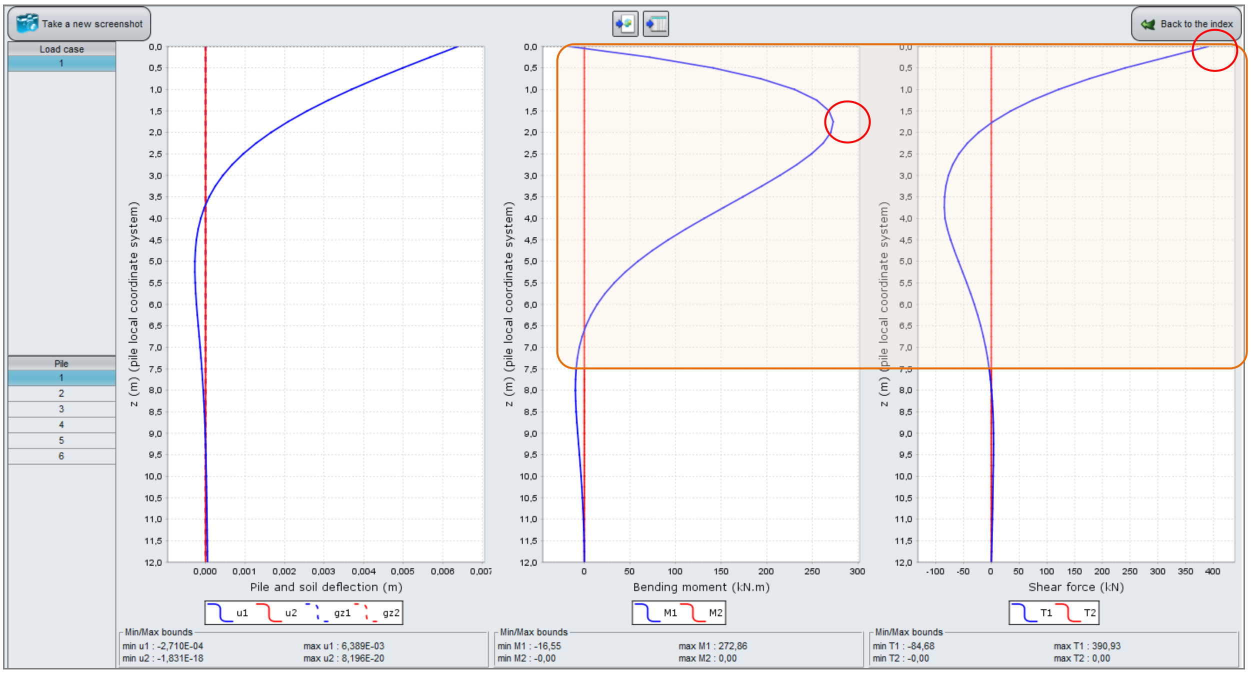
<u>Graphical results</u>

In this part of the results, it is possible to access the deformation and internal loading diagrams along the shafts.

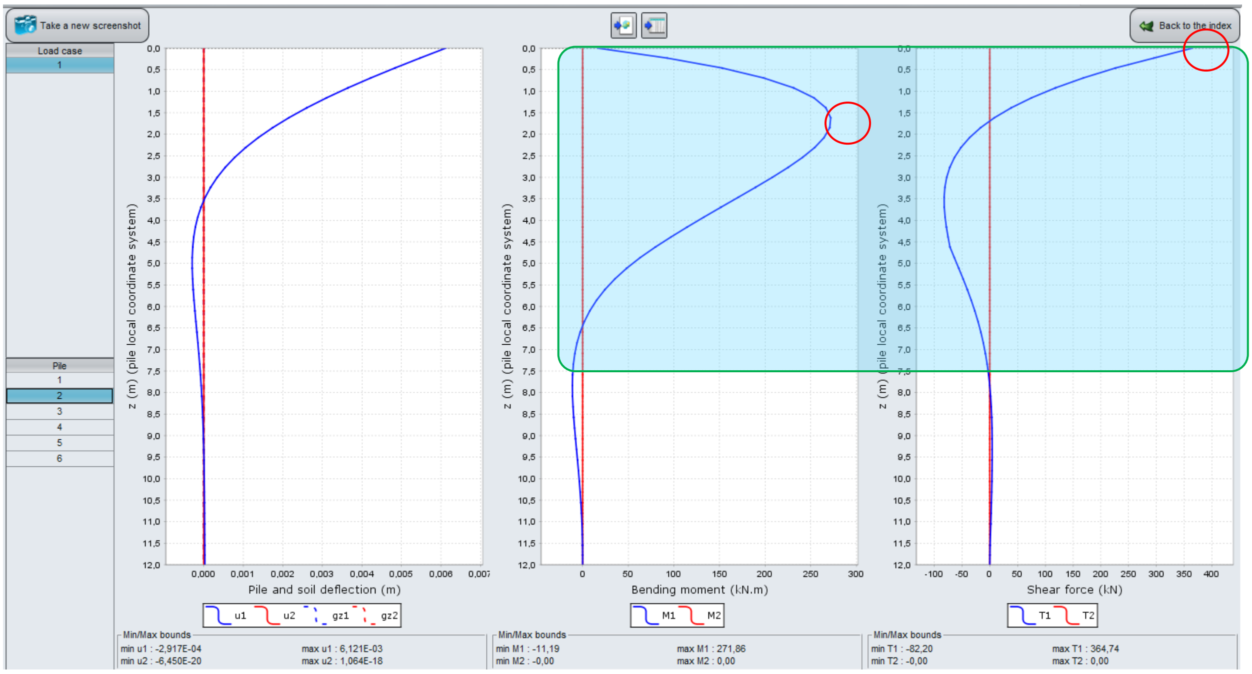
Lateral behaviour:

The shear force is maximal at pile head. However, the bending moment reaches its maximum at the sections with a curvilinear X-axis close to 2 m. These loadings are attenuated at depth to reach very low values in the sections situated at more than 7 m from the pile heads.

Pile N°1 vertical



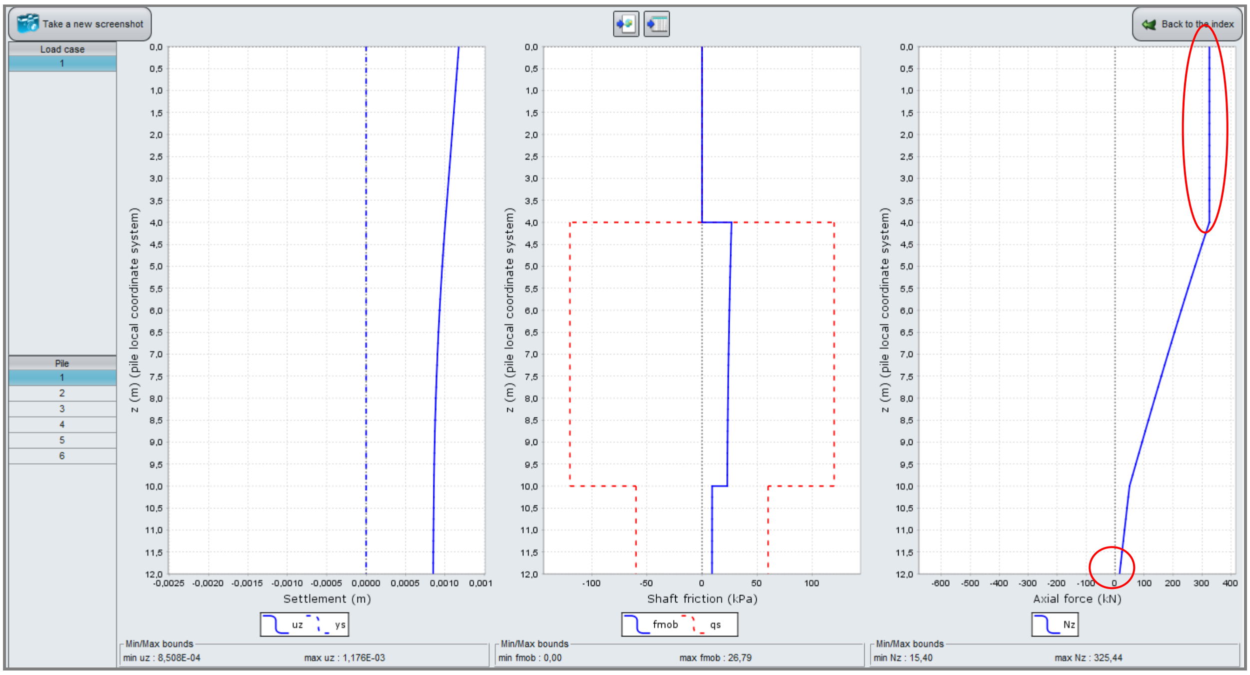
Pile N°2 inclined



<u>Axial behaviour</u>:

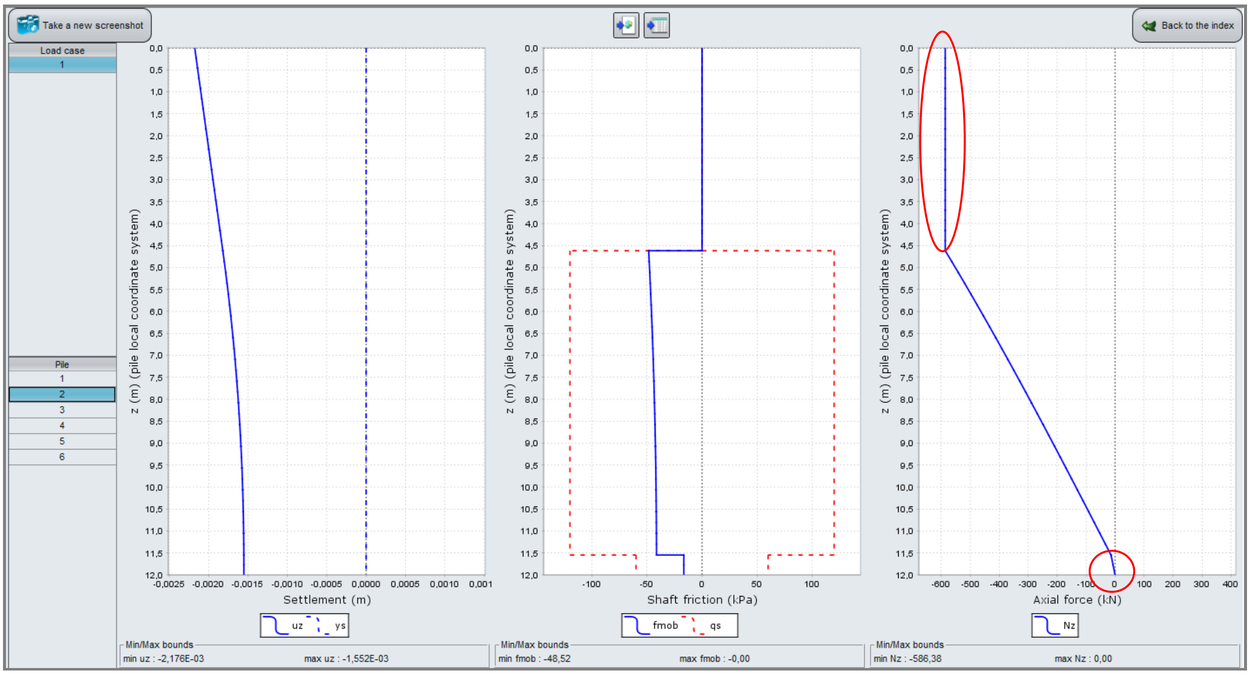
Pile N°1 vertical

The vertical piles work in compression. They are subjected to a pile head force of 325 kN, the contribution of the base is 15 kN. As friction is ignored in the backfill, the axial force remains constant in this first layer.



Pile N°2 inclined

The inclined piles are tensile loaded. The pile head force is -586 kN and is fully balanced by friction at the pile/soil interface (base force is nil).

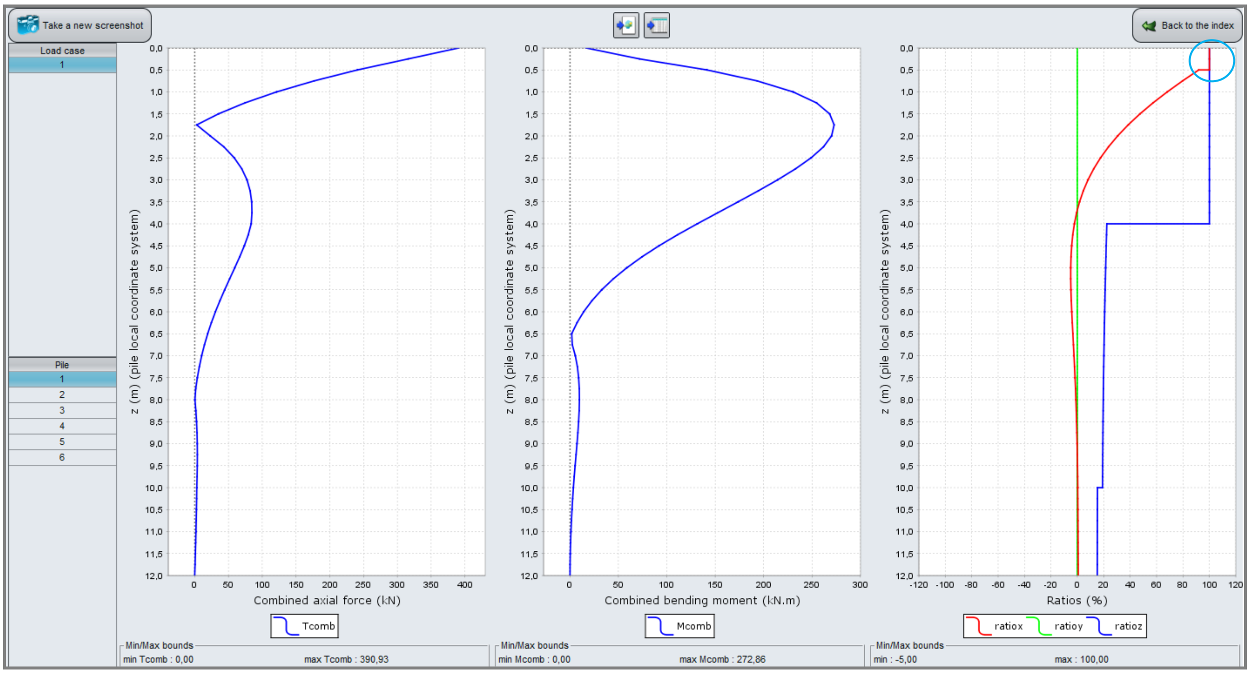


Additional results:

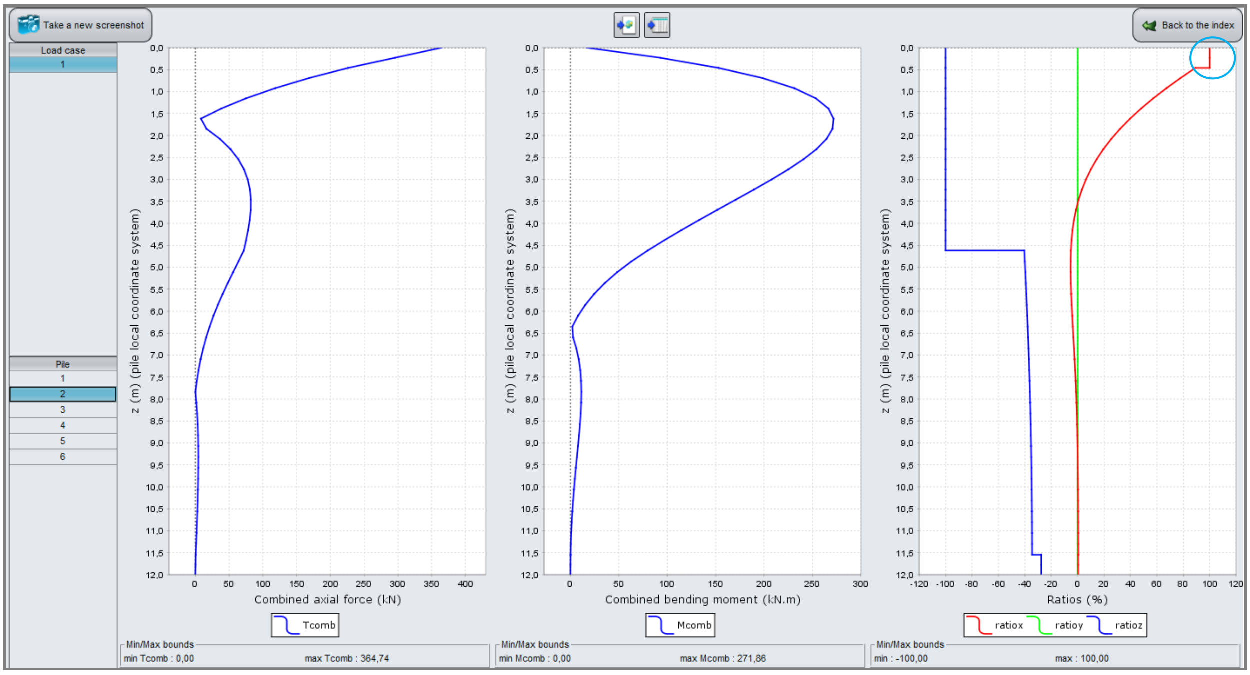
These diagrams give the combined lateral loads, as well as the mobilisation ratios of the lateral reactions and shaft friction. These curves show that:

- The soil is plastified laterally in direction x-x over a length of 0.5 m;
- Beyond the layer of backfill in which friction was ignored, shaft friction mobilisation remains elastic because the corresponding ratios remain below 50%.

Pile N°1 vertical



Pile N°2 inclined



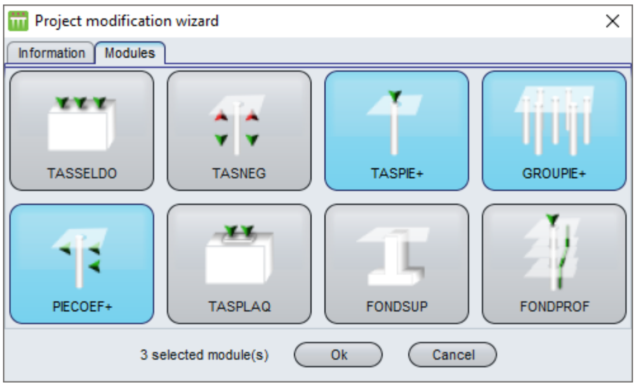
H.4.2.2. Step 2: Manual Groupie mode

Using the Manual Groupie mode means that the equivalent axial and lateral stiffnesses at the pile heads have to be determined with Taspie+ and Piecoef+. These stiffnesses will be used as the basis for calculating the distribution of forces at the pile heads using Manual Groupie.

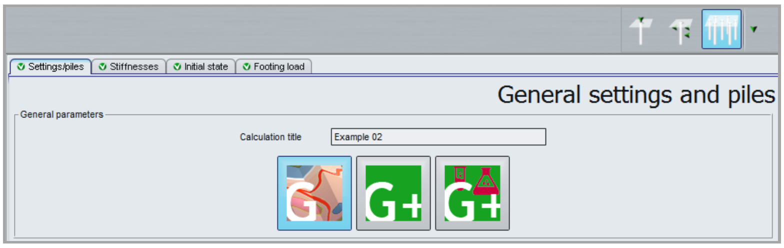
By alternating between the three modules, the values of displacements of the footing and consequently the values of the forces at the pile heads, will stabilise. When they virtually cease to vary, we can consider that the calculation has converged.

Below is the procedure for this calculation:

- Save the project under a different name, "Easel piles – Manual mode" for example.
- Add the Taspie+ and Piecoef+ modules to the project:
  - Project menu, "Modify project data and modules";
  - "Modules" tab: select Taspie+ and Piecoef+, in addition to Groupie+.



- Click the  button.
- From the Groupie+ module window, select Manual Groupie mode.



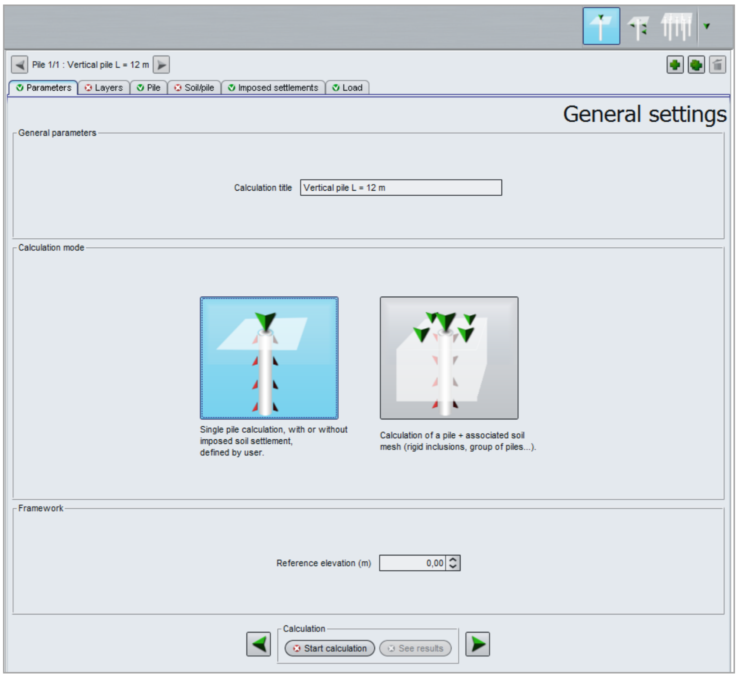
- Switch to the Taspie+ module by clicking .

In this module, we will build a vertical pile model and an inclined pile model.

H.4.2.2.1. Calculation of axial stiffness of a vertical pile (Taspie+)

<u>"Parameters" tab</u>

This tab concerns the general calculation parameters.



<u>"General parameters" frame</u>

- Give the calculation title: "Vertical pile L = 12 m" for example.

<u>"Calculation mode" frame</u>

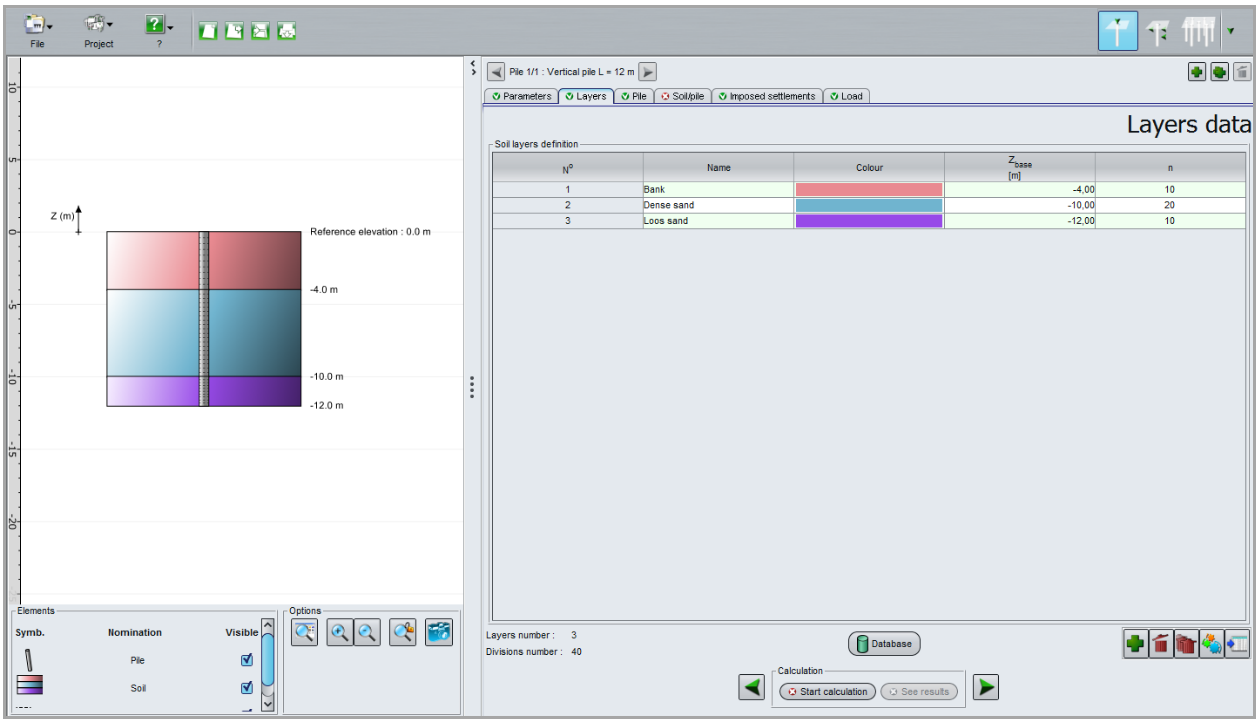
- Select "Single pile calculation".

<u>"Framework" frame</u>

- Reference elevation (m): 0.00.

<u>"Layers" tab</u>

This tab concerns the definition of soil layers.



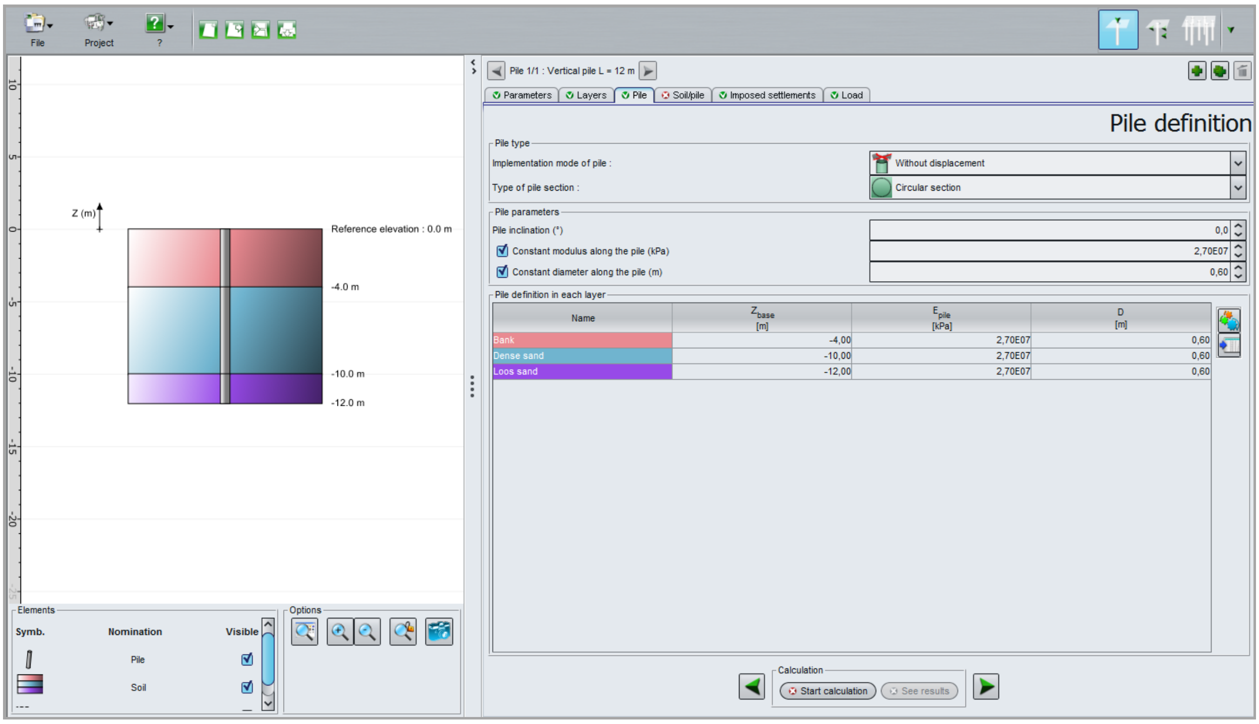
Click the  button to create each layer.

Elements to be input for the various soil layers:

Name	Z_{base} (m)	n
Bank	-4.00	10
Dense sand	-10.00	20
Loose sand	-12.00	10

<u>**"Pile" tab**</u>

This tab concerns the piles parameters.



<u>"Pile type" frame</u>

- Implementation mode of pile: Without displacement;
- Type of pile section: Circular section.

<u>"Pile parameters" frame</u>

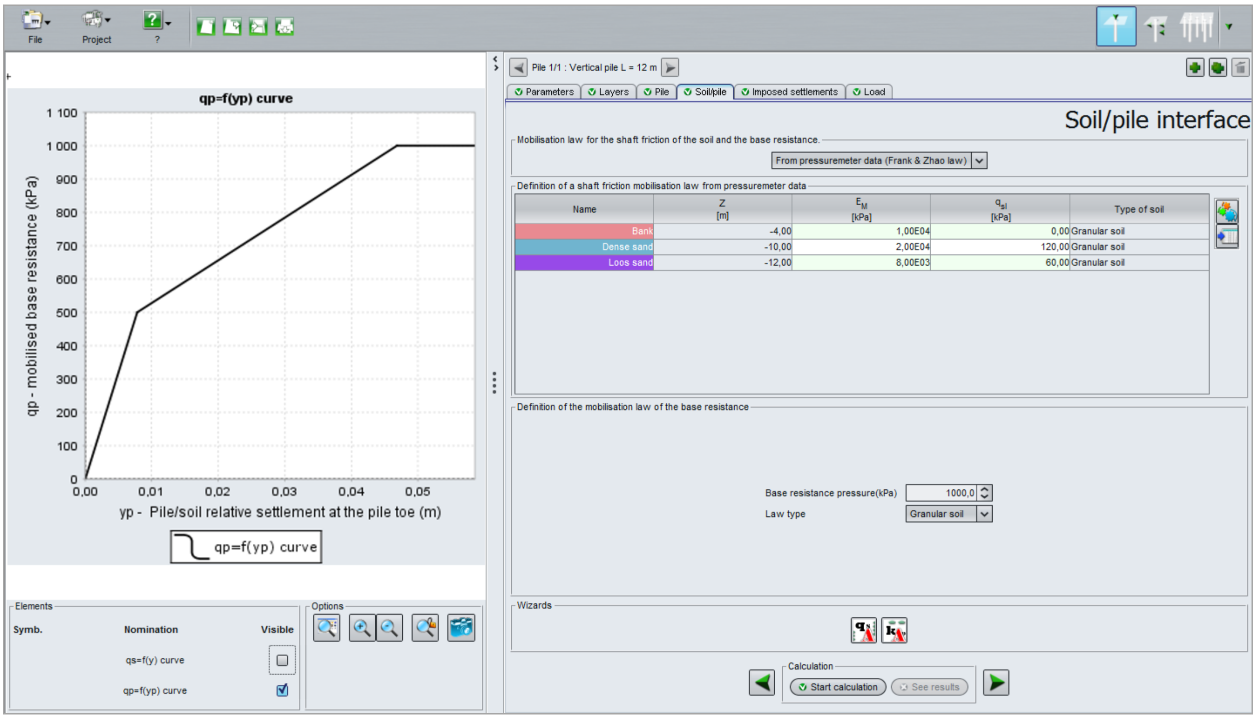
- Pile inclination (°) : 0.0;
- Constant modulus along the pile (kPa): Ticked: 2.70E07;
- Constant diameter along the pile (m): Ticked: 0.60.

<u>"Pile definition in each layer" frame</u>

As the characteristics are constant along the pile, the data were taken automatically.

<u>**"Soil/Pile" tab**</u>

This tab concerns the friction mobilisation laws and the base resistance.



<u>"Mobilisation law for the shaft friction of the soil and the base resistance" frame</u>

- Choose from the drop-down list: "From pressuremeter data (Frank & Zhao law)".

<u>"Definition of a shaft friction mobilisation law from pressuremeter data"</u>

The parameters to be input are given below:

Nom	Z_{base} (m)	E_M (kPa)	q_{sl} (kPa)	Type of soil
Bank	-4.00	1.00E04	0.001	Granular soil
Dense sand	-10.00	2.00E04	120.00	Granular soil
Loose sand	-12.00	8.00E03	60.00	Granular soil

<u>"Definition of the mobilisation law of the base resistance" frame</u>

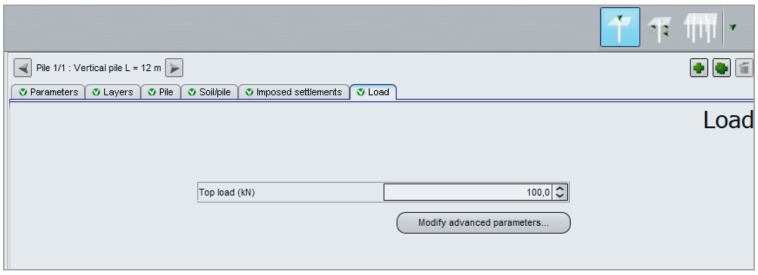
- Base resistance pressure (kPa): 1000.0;
- Law type: Granular soil.

<u>"Imposed settlements" tab</u>

This tab does not need to be filled out for this example.

<u>"Load" tab</u>

Input a pile head load of 100 kN. For this initial calculation, this value is not of any great importance.



Calculation and results

Once the mandatory data have been input, the calculation can be started.

The equivalent axial stiffness, used for the Manual Groupie calculation, is given at the end of the "Formatted results" file. For this initial calculation, we take 2.44E05 kN/m which corresponds to the equivalent stiffness under a load equal to 70% of the creep load of a vertical pile.

```
RAIDEUR EQUIVALENTE

======================================================================================================
                                                          Charge      Déplacement      Raideur

 --- Sous une charge égale à 70% de la charge de fluage   874.81      0.00359          0.244E+06
 --- Sous la charge définie par l'utilisateur             100.00      0.00036          0.277E+06
======================================================================================================
```

In order to create the inclined pile model, go back to the data by clicking the 

button.

H.4.2.2.2. Calculation of axial stiffness of an inclined pile (Taspie+)

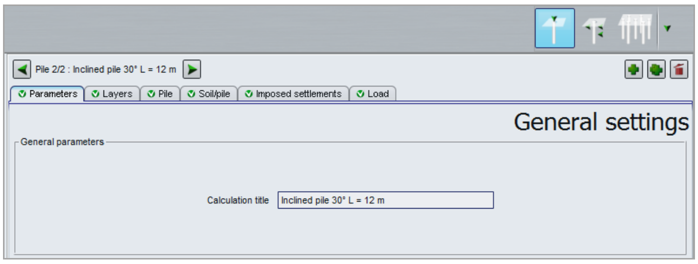
We will duplicate the existing pile and make a few modifications specific to the inclination of the pile.

To do this, click the "Duplicate the current pile"  button.

The tabs to be modified are listed below.

"Parameters" tab

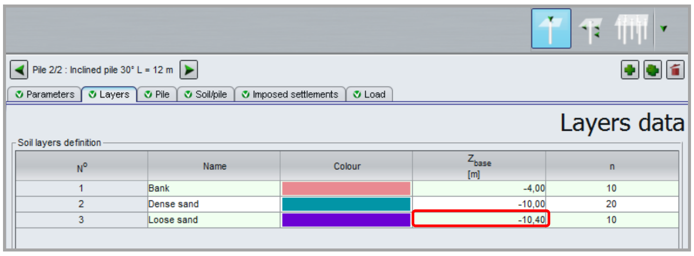
- Change the calculation title. For example: "Inclined pile 30° L = 12 m".



"Layers" tab

Given that we are modelling an inclined pile, the elevation of the base of the last layer is to be modified.

- Elevation of "loose sand" layer: -10.40 m (to obtain a pile length of 12 m).

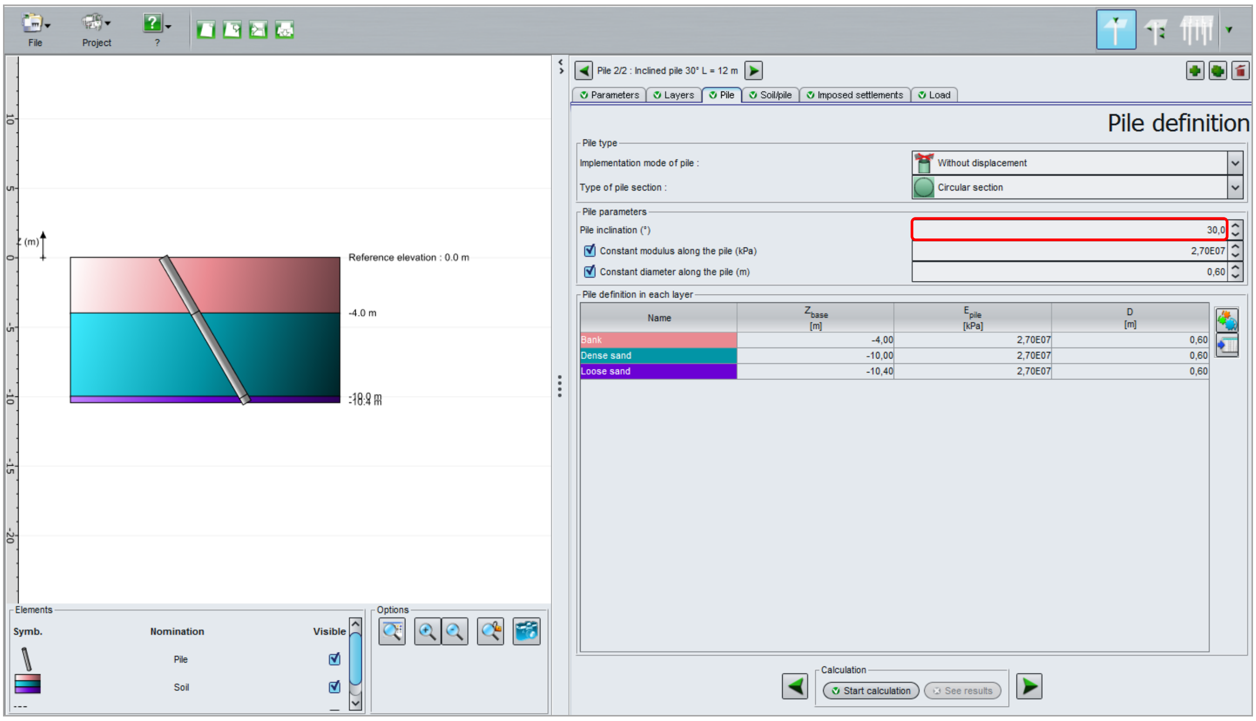


"Pile" tab

The only data to be modified is the pile inclination:

"Pile parameters" frame

- Pile inclination: 30°



Calculations and results

The axial stiffness μ necessary for the Manual Groupie calculation is given at the end of the "Formatted results" file. For this initial calculation, we take 2.48E05 kN/m which corresponds to the equivalent stiffness under a load equal to 70% of the creep load of an inclined pile.

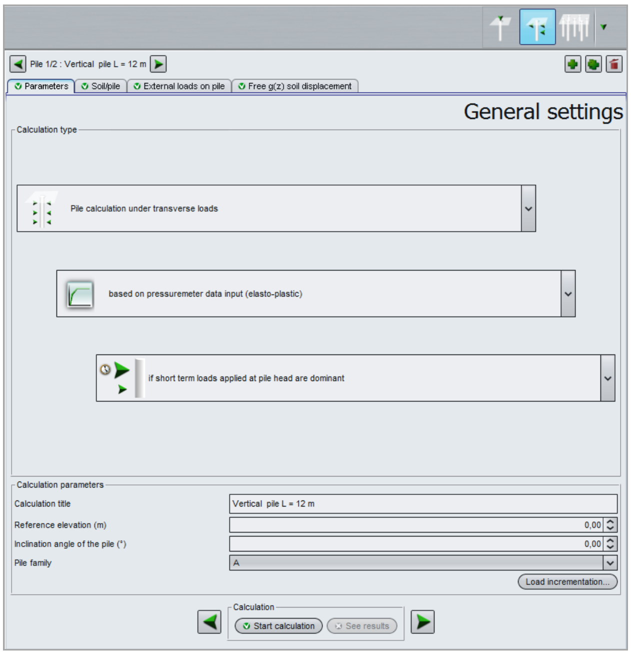
```
RAIDEUR EQUIVALENTE

==========================================================================================
                                                           Charge      Déplacement     Raideur

  --- Sous une charge égale à 70% de la charge de fluage    892.45       0.00360      0.248E+06
  --- Sous la charge définie par l'utilisateur              100.00       0.00036      0.279E+06

==========================================================================================
```

H.4.2.2.3. Calculation of lateral stiffnesses of a vertical pile (Piecoef+)

Switch to the Piecoef+ module by clicking the corresponding icon 

at the top-right of the window.

"Parameters" tab


Pile 1/2 : Vertical pile L = 12 m
Parameters
Soil/pile
External loads on pile
Free g(z) soil displacement
General settings
Calculation type
Pile calculation under transverse loads
based on pressuremeter data input (elasto-plastic)
if short term loads applied at pile head are dominant
Calculation parameters
Calculation title
Vertical pile L = 12 m
Reference elevation (m)
0,00
Inclination angle of the pile (°)
0,00
Pile family
A
Load incrementation...
Calculation
Start calculation
See results

<u>"Calculation type" frame</u>

Select:

- "Pile calculation under transverse loads";
- "Based on pressuremeter data input" (elasto-plastic)";
- "If short-term loads applied at pile head are dominant".

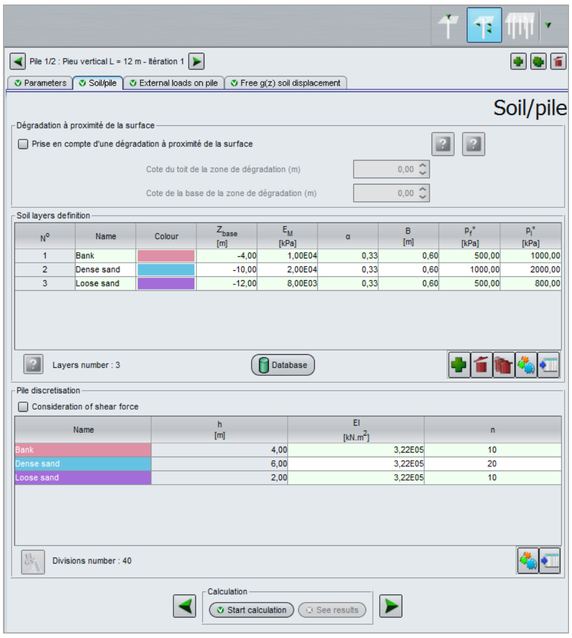
<u>"Calculation parameters" frame</u>

- Give the calculation title: for example "Vertical pile L = 12 m";
- Reference elevation (m): 0.00;
- Inclination angle of the pile (°): 0.00;
- Pile family: A.

Note: In order to differentiate between inclined piles and vertical piles, we assign them to a family, which enables them to be differentiated when building the project in Manual Groupie. Vertical piles are part of family A, inclined piles are part of family B.

<u>"Soil/Pile" tab</u>

This tab concerns soil layers definition and pile discretisation.



<u>"Soil layers definition" frame</u>

The parameters to be input are given below:

Note: in the same way as for Taspie+, the model stops at the base of the pile.

Name	Z_{base} (m)	E_M (kPa)	α	B (m)	p_f* (kPa)	p_l* (kPa)
Bank	-4.00	1.00E04	0.33	0.60	500	1000
Dense sand	-10.00	2.00E04	0.33	0.60	1000	2000
Loose sand	-12.00	8.00E03	0.33	0.60	500	800

<u>"Pile discretisation" frame</u>

Consideration of shear force: Unticked.

Enter the pile properties for each layer:

- Product of inertia of pile EI;
- Number of subdivisions of layer n.

The layer thickness h is automatically deduced from the data previously input.

Name	h (m)	E.I (kN.m^2)	n
Bank	4,00	3,22E05	10
Dense sand	6,00	3,22E05	20
Loose sand	2,00	3,22E05	10

<u>"External loads on pile" tab</u>

This tab does not need to be filled out for this calculation phase.

Note: The lateral stiffnesses are calculated first of all for an unloaded pile.

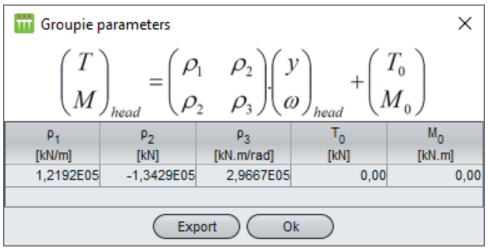
<u>"Free g(z) soil displacement" tab</u>

This tab does not need to be filled out for this example.

<u>Calculation and results</u>

Once the mandatory data have been filled out, the calculation can be started.

The lateral stiffnesses ρ used for the Manual Groupie calculation are accessible from the "Main Curves" using the Groupie parameters button. This table displays the results of the calculation for a vertical pile (family A).



ρ_1 [kN/m]	ρ_2 [kN]	ρ_3 [kN.m/rad]	T_0 [kN]	M_0 [kN.m]
1,2192E05	-1,3429E05	2,9667E05	0,00	0,00

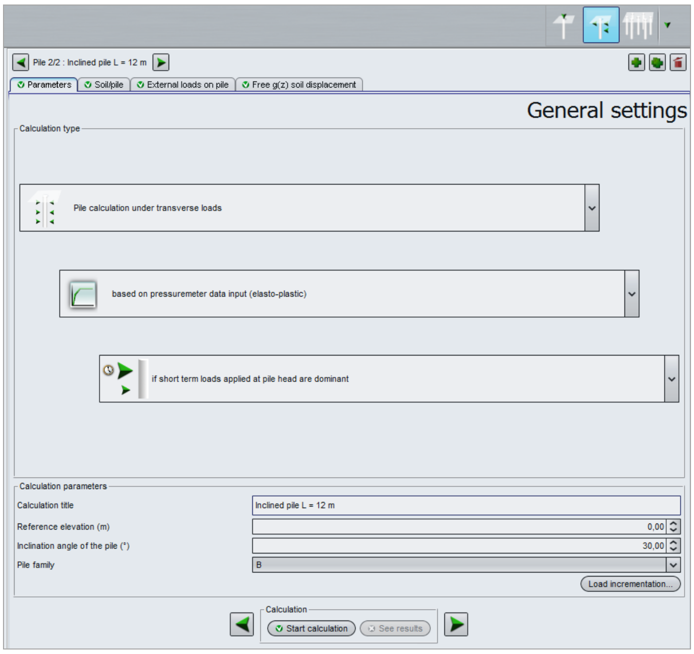
These stiffnesses will be imported into Manual Groupie with the help of the import wizard.

In order to model inclined piles, go back to the data input part by clicking the Back to the index button and then the Back to the data button.

H.4.2.2.4. Calculation of lateral stiffnesses of an inclined pile (Piecoef+)

Click the button to copy the model of pile N°1 (vertical pile) to pile N°2 (inclined pile).

"Parameters" tab



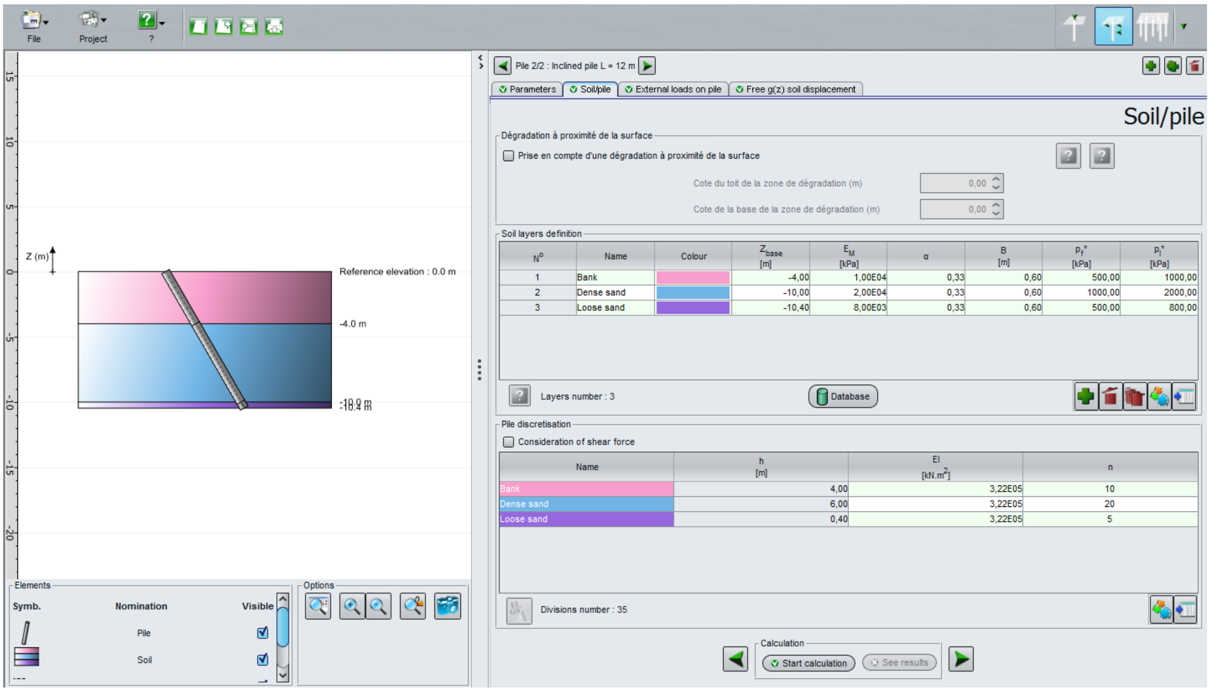
Modify the following parameters:

"Calculation parameters" frame

- Modify the calculation title: "Inclined pile L = 12 m" for example;
- Pile inclination angle (°): 30.00;
- Pile family: B.

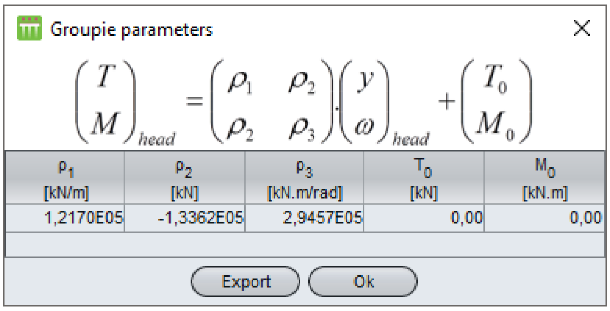
"Soil/Pile" tab

The elevation of the base of the last soil layer (loose sand) is to be modified to obtain a pile 12 m long. We take Z_{base} = -10.40 m.



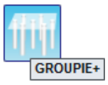
Calculation and results

The lateral stiffnesses ρ used for the Manual Groupie calculation are as follows (family B).



These stiffnesses will be imported into Manual Groupie with the help of the import wizard.

H.4.2.2.5. Distribution of forces at pile heads (Manual Groupie)

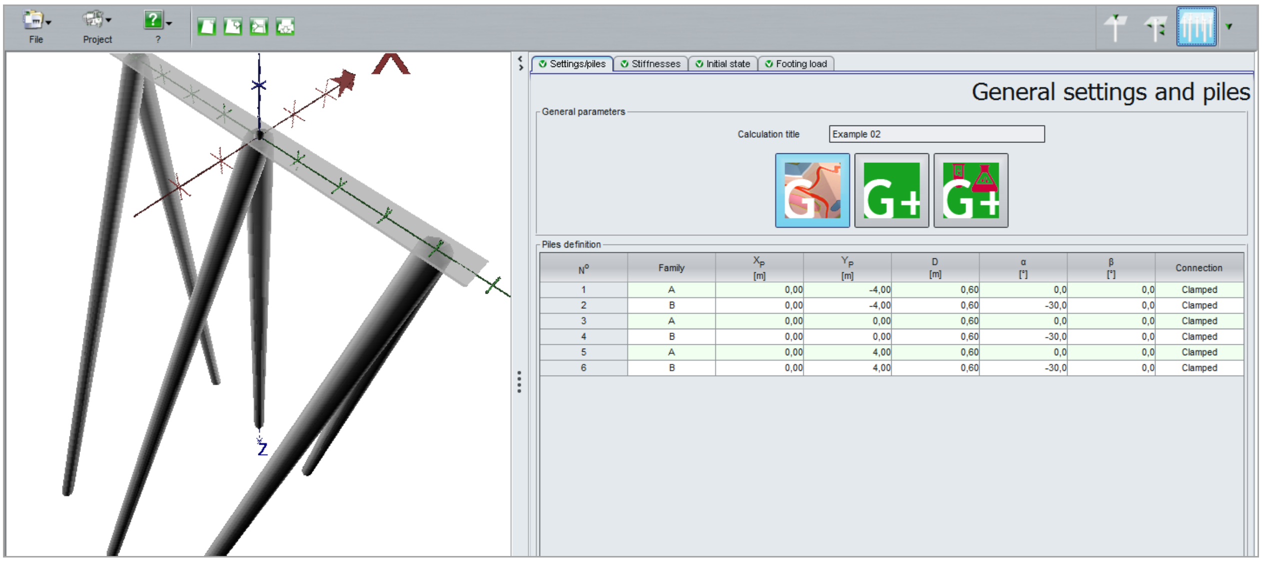
Switch to the Groupie+ module by clicking the  button.

<u>"Settings/Piles" tab</u>

This tab is used to define piles.

<u>"General parameters" frame</u>

- Give the calculation title: "Easel piles" for example;
- Select Manual Groupie.



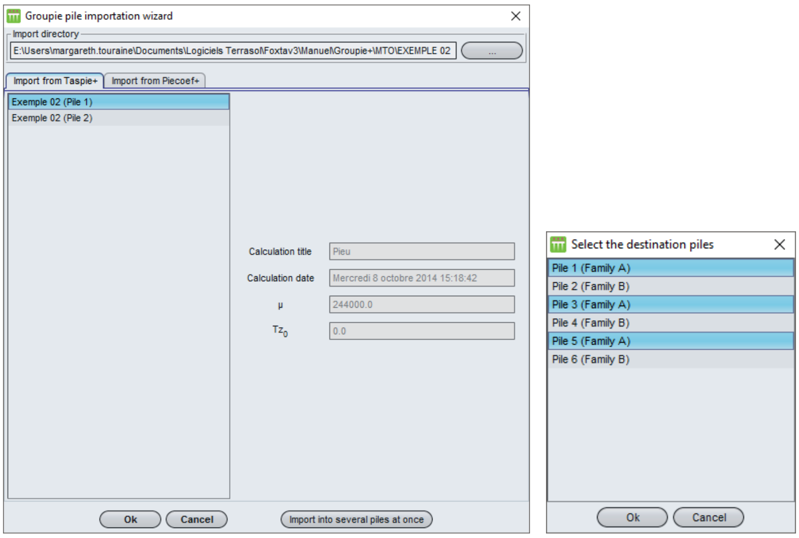
<u>"Piles definition" frame</u>

Input the following characteristics:

N°	Family	X_P (m)	Y_P (m)	D (m)	α (°)	β (°)	Connection
1	A	0.00	-4.00	0.60	0.00	0.00	Clamped
2	B	0.00	-4.00	0.60	-30.00	0.00	Clamped
3	A	0.00	0.00	0.60	0.00	0.00	Clamped
4	B	0.00	0.00	0.60	-30.00	0.00	Clamped
5	A	0.00	4.00	0.60	0.00	0.00	Clamped
6	B	0.00	4.00	0.60	-30.00	0.00	Clamped

"Stiffnesses" tab

- This tab, as well as the following one, is used to define the stiffnesses at the pile heads. Their values are imported from the Taspie+ and Piecoef+ models produced previously. The import process is as follows: Click the first row of the table and use the import wizard :

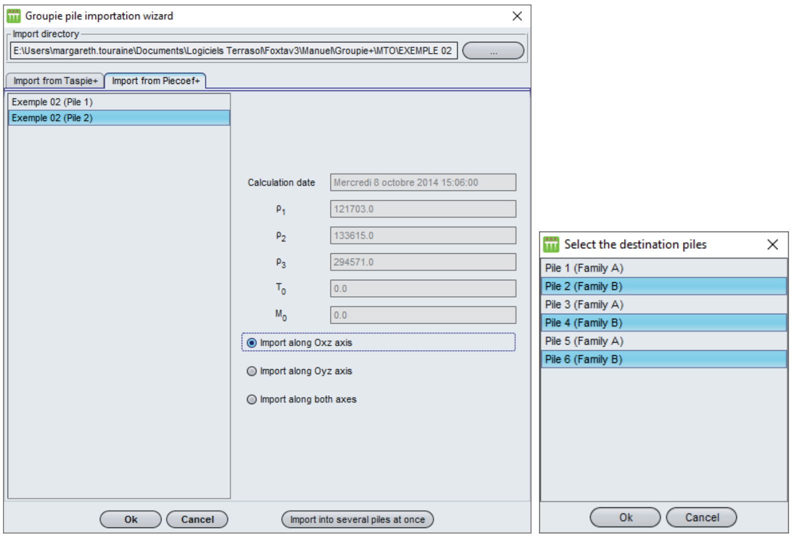


"Import from Taspie+" tab:

- Select "Example 02 (pile 1)" and import these values for the piles of family A (vertical piles) by clicking on the "Import into several piles at once" button. With the mouse, select the 3 piles of family A. Click the "OK" button in the two windows of the wizard.
- Repeat the operation with pile n°2 using the "Import into several piles at once" button and select the 3 piles of family B (inclined piles).

"Import from Piecoef+" tab:

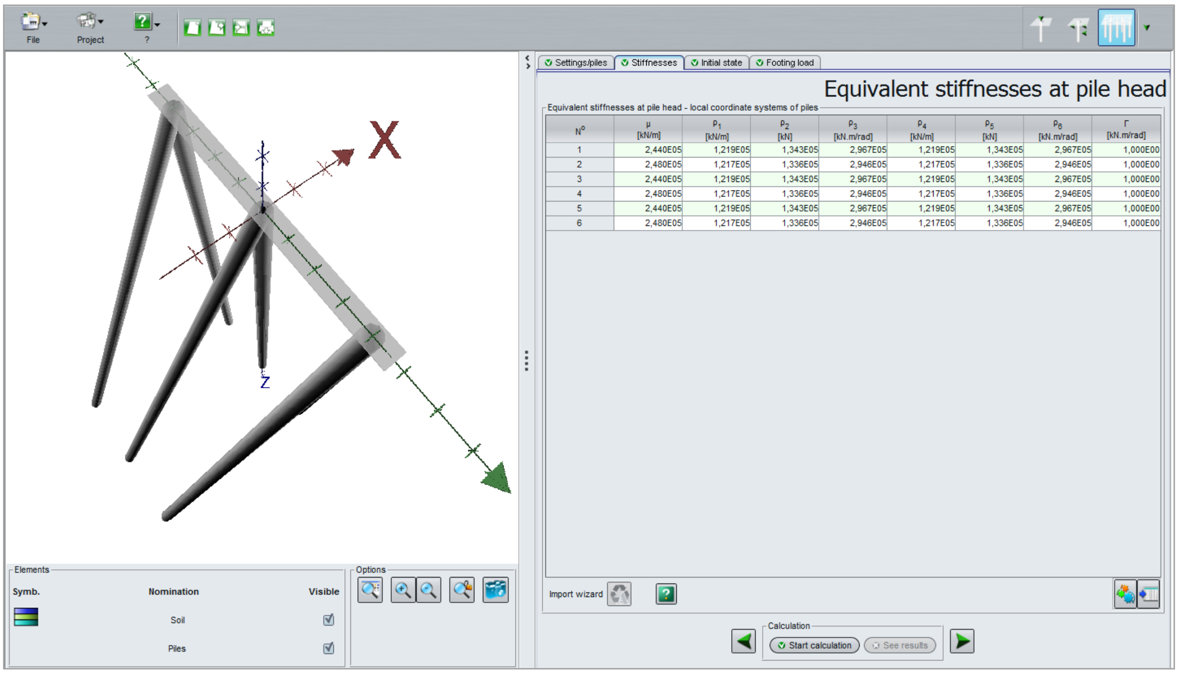
- Select "Example 02 (pile 1)", choose "Import along both axes" and import these values for All piles of family A (vertical piles) by clicking the "Import into several piles at once" button. Click the "OK" button.
- Repeat the operation with pile n°2 using the "Import into several piles at once" button and select All piles of family B (inclined piles).



- The equivalent torsional stiffness ϒ, which by default is set at 1, is not modified.

Following these operations, the following table is obtained:

N°	μ (kN/m)	ρ_1 (kN/m)	ρ_2 (kN)	ρ_3 (kN.m/rad)	ρ_4 (kN/m)	ρ_5 (kN)	ρ_6 (kN.m/rad)	Γ (kN.m/rad)
1	2.440E05	1.219E05	1.343E05	2.967E05	1.219E05	1.343E05	2.967E05	1.000E00
2	2.480E05	1.217E05	1.336E05	2.946E05	1.217E05	1.336E05	2.946E05	1.000E00
3	2.440E05	1.219E05	1.343E05	2.967E05	1.219E05	1.343E05	2.967E05	1.000E00
4	2.480E05	1.217E05	1.336E05	2.946E05	1.217E05	1.336E05	2.946E05	1.000E00
5	2.440E05	1.219E05	1.343E05	2.967E05	1.219E05	1.343E05	2.967E05	1.000E00
6	2.480E05	1.217E05	1.336E05	2.946E05	1.217E05	1.336E05	2.946E05	1.000E00

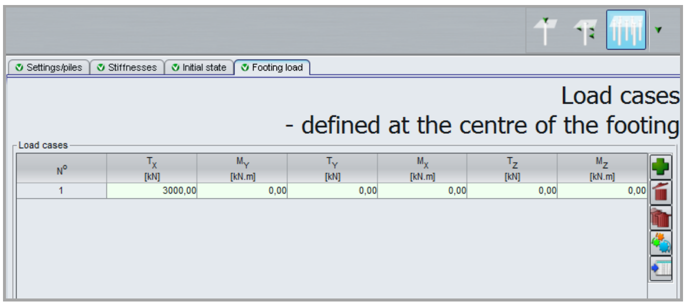


"Initial state" tab

This tab is automatically filled out when the stiffnesses are imported (operation carried out in previous tab). All the values remain nil for this initial phase.

"Footing load" tab

This is the same load case as for step 1 of the example.



Define a load case with the following values:

N°	T_X (kN)	M_Y (kN.m)	T_Y (kN)	M_X (kN.m)	T_Z (kN)	M_Z (kN.m)
1	3000	0	0	0	0	0

Calculation and results

Numerical results

Results table:

Number of load case	Number of pile	T_1 [kN]	M_1 [kN.m]	T_2 [kN]	M_2 [kN.m]	T_z [kN]	M_z [kN.m]
1	1	404,14	-17,52	-0,00	0,00	289,60	-0,00
1	2	371,23	17,52	0,00	0,00	-548,73	-0,00
1	3	404,14	-17,52	-0,00	0,00	289,60	-0,00
1	4	371,23	17,52	0,00	0,00	-548,73	-0,00
1	5	404,14	-17,52	-0,00	0,00	289,60	-0,00
1	6	371,23	17,52	0,00	0,00	-548,73	-0,00

Note the values obtained for each type of pile:

Vertical pile (family A):

- ✓ Side force at pile head in plane (Pxz): T1 = 404.14 kN
- ✓ Bending moment at pile head in plane (Pxz): M1= -17.52 kN.m
- ✓ Axial force at pile head: Tz= 289.6 kN

Inclined pile (family B):

- ✓ Side force at pile head in plane (Pxz): T1 = 371.23 kN
- ✓ Bending moment at pile head in plane (Pxz): M1= 17.52 kN.m
- ✓ Axial force at pile head: Tz= -548.73 kN

The various stiffnesses used in the Manual Groupie calculation must now be updated. To do this, we reuse the Taspie+ and Piecoef+ models, introducing the forces at the pile heads presented above. This operation, which consists in updating the stiffnesses followed by the Manual Groupie calculation, is to be repeated until there is virtually no further change in the distribution of forces. The iterative process is then said to have converged.

Save your project under a different name: "Ex2 iteration1", for example.

Go back to the Taspie+ module by clicking the corresponding icon 

and go to pile N°1.

H.4.2.2.6. Updating axial stiffness of a vertical pile (Taspie+)

"Parameters" tab

- Modify the calculation title: "Vertical pile L= 12 m – Iteration 1" for example.

"Load" tab

Input the force previously obtained for a vertical pile following the Manual Groupie calculation.

- Load at pile head: 290.0 kN

Calculation and results

Note that the stiffness obtained under the load defined by the user is 2.77E05 kN/m for the vertical pile. The stiffness has changed. The axial stiffness is greater than initially anticipated.

```
RAIDEUR EQUIVALENTE

==========================================================================================
                                                       Charge      Déplacement      Raideur

  --- Sous une charge égale à 70% de la charge de fluage     874.81       0.00359      0.244E+06
  --- Sous la charge définie par l'utilisateur              290.00       0.00105      0.277E+06

==========================================================================================
```

We will proceed in the same way for the inclined pile.

Switch to the inclined pile (Pile N°2) by clicking the button.

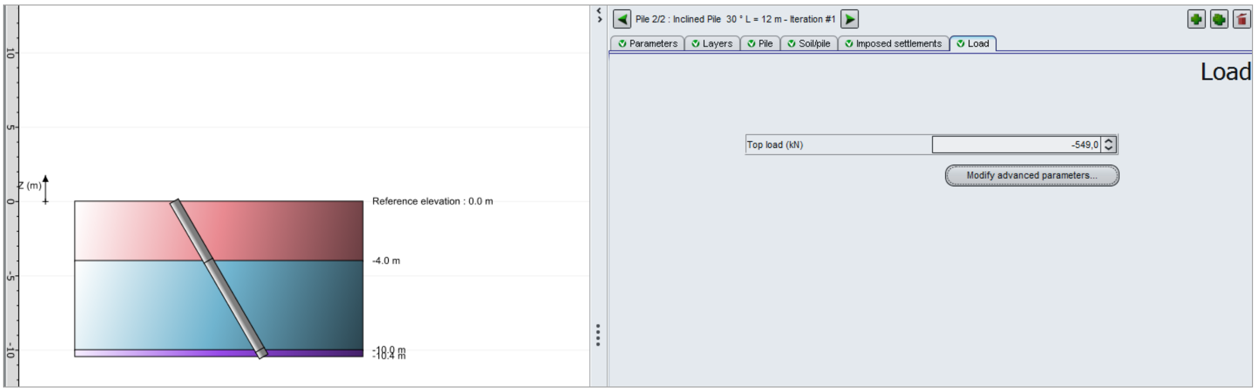
H.4.2.2.7. Updating axial stiffness of an inclined pile (Taspie+)

“Parameters” tab

- Modify the calculation title: "Inclined pile 30° L = 12 m - Iteration 1" for example.

“Load” tab

- Input the load resulting from the Manual Groupie calculation: -549.0 kN



Calculation and results

Note that the stiffness obtained under the load defined by the user is 2.70E05 kN/m for the inclined pile.

```
RAIDEUR EQUIVALENTE

==========================================================================================
                                                       Charge      Déplacement      Raideur

  --- Sous une charge égale à 70% de la charge de fluage    -793.49      -0.00298      0.266E+06
  --- Sous la charge définie par l'utilisateur             -549.00      -0.00203      0.270E+06

==========================================================================================
```

H.4.2.2.8. Update of lateral stiffnesses of a vertical pile (Piecoef+)

For the side force – bending moment pair obtained, the new equivalent pile head stiffnesses must be determined. To do this, we reuse the Piecoef+ models and define the loads at the pile heads.

Switch to the Piecoef+ module by clicking the corresponding icon .

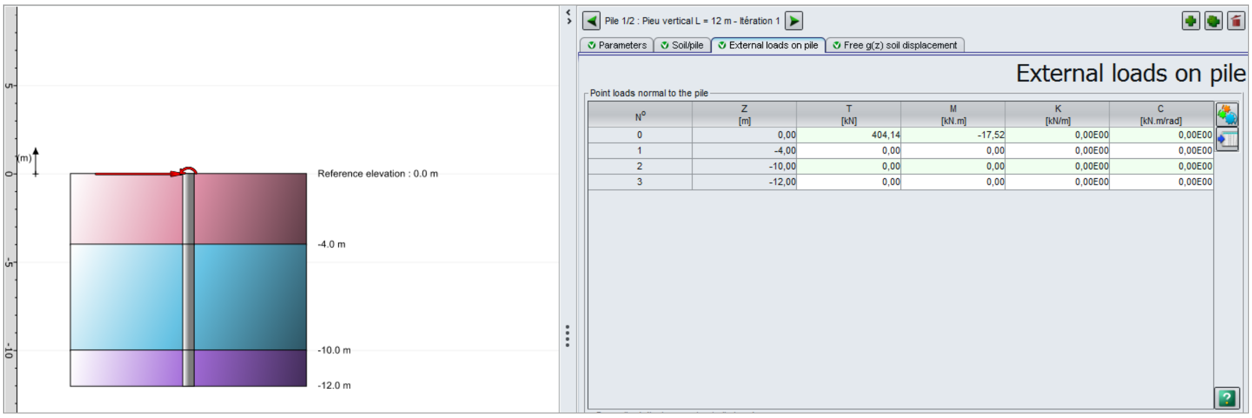
"Parameters" tab

- Modify the calculation title: "Vertical pile L = 12 m - Iteration 1" for example.

"External loads on pile" tab

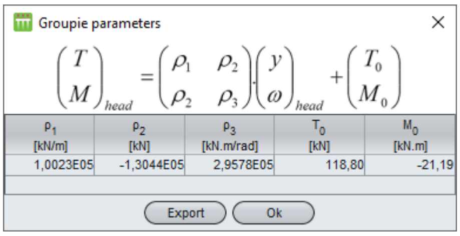
Input side force T1 and bending moment M1 at the vertical pile head.

- Point side force T: 404.14 kN
- Point bending moment M: -17.52 kN.m



N°	Z [m]	T [kN]	M [kN.m]	K [kN/m]	C [kN.m/rad]
0	0,00	404,14	-17,52	0,00E00	0,00E00
1	-4,00	0,00	0,00	0,00E00	0,00E00
2	-10,00	0,00	0,00	0,00E00	0,00E00
3	-12,00	0,00	0,00	0,00E00	0,00E00

Calculation and results



$$\begin{pmatrix} T \\ M \end{pmatrix}_{head} = \begin{pmatrix} \rho_1 & \rho_2 \\ \rho_2 & \rho_3 \end{pmatrix} \begin{pmatrix} y \\ \omega \end{pmatrix}_{head} + \begin{pmatrix} T_0 \\ M_0 \end{pmatrix}$$

ρ_1 [kN/m]	ρ_2 [kN]	ρ_3 [kN.m/rad]	T_0 [kN]	M_0 [kN.m]
1,0023E05	-1,3044E05	2,9578E05	118,80	-21,19

The stiffnesses obtained will be imported into Manual Groupie, through the import wizard.

We will proceed in the same way for the inclined pile.

H.4.2.2.9. Update of lateral stiffnesses of an inclined pile (Piecoef+)

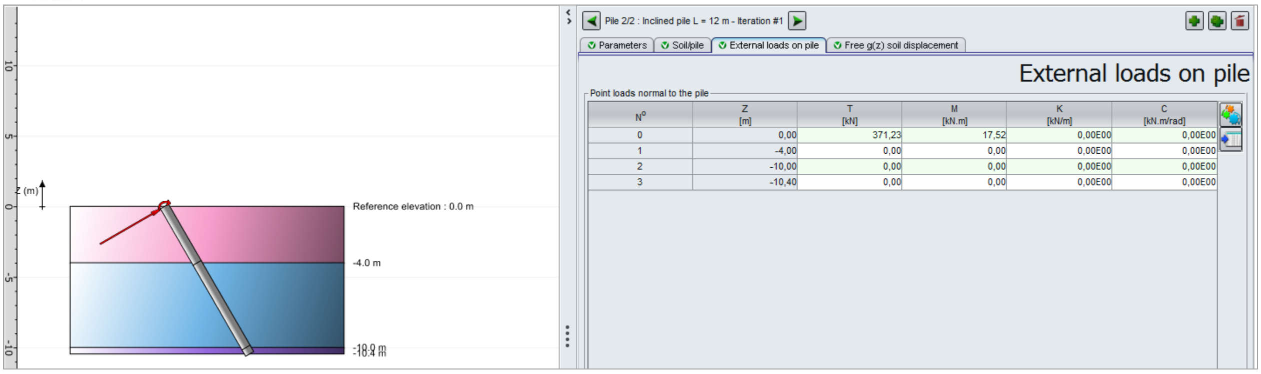
"Parameters" tab

- Modify the calculation title: "Inclined pile L = 12 m - Iteration 1" for example.

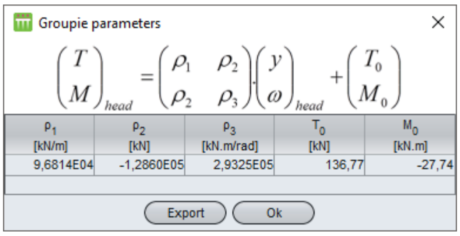
"External loads on pile" tab

Input the following forces on the head of the inclined pile:

- Point side force T: 371.23 kN
- Point bending moment M: 17.52 kN.m



Calculation and results



We will now recalculate the new distribution of forces at the pile heads following updating of the equivalent stiffnesses.

To do this, click the  button and directly access the "Stiffnesses" tab.

H.4.2.2.10. Distribution of forces – 1st iteration (Manual Groupie)

<u>"Stiffnesses" tab</u>

The stiffness resulting from the new Taspie+ and Piecoef+ calculations must be updated.

- Input the equivalent axial stiffness defined by the user for each type of pile, resulting from the Taspie+ calculations:
  - vertical pile μ : 2.77E05 kN/m
  - inclined pile μ : 2.70E05 kN/m

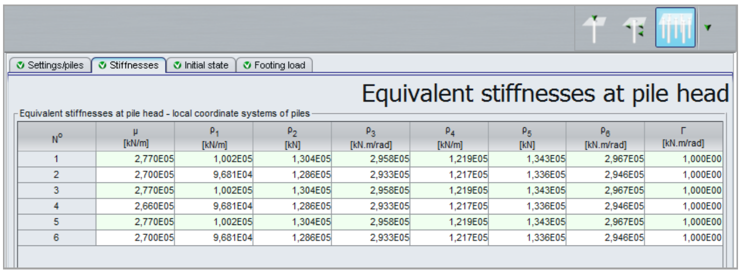
  Note: you may not use the import wizard to retrieve the stiffness values. This is because the wizard always points to the stiffnesses corresponding to 70% of the creep load.

- Import the different stiffnesses ρ_1 to ρ_6 obtained with Piecoef+:
  - select a row from the table then click on the "Import wizard" button;
  - from the "Import from Piecoef+" tab, select pile N°1;
  - tick the "Import along oxz axis" radio button;
  - click the [Import into several piles at once] button and select All piles of family A (vertical piles).
  - click the [OK] button in the two windows of the wizard.

Repeat the operation for pile N°2, using the [Import into several piles at once] button and only select the piles of family B (inclined piles).

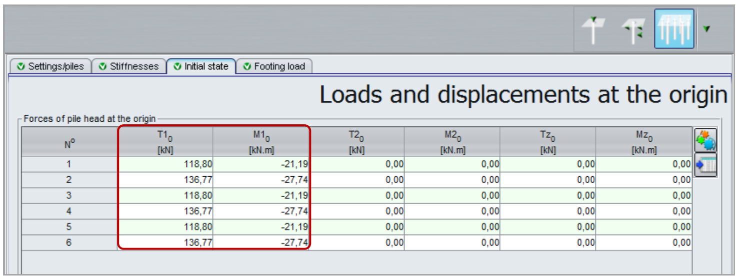
Once these operations are completed, the stiffnesses table contains the following values:

N°	μ (kN/m)	ρ1 (kN/m)	ρ2 (kN)	ρ3 (kN.m/rad)	ρ4 (kN/m)	ρ5 (kN)	ρ6 (kN.m/rad)	ϒ (kN.m/rad)
1	2.770E05	1.002E05	1.304E05	2.958E05	1.219E05	1.343E05	2.967E05	1.000E00
2	2.700E05	9.681E04	1.286E05	2.933E05	1.217E05	1.336E05	2.946E05	1.000E00
3	2.770E05	1.002E05	1.304E05	2.958E05	1.219E05	1.343E05	2.967E05	1.000E00
4	2.700E05	9.681E04	1.286E05	2.933E05	1.217E05	1.336E05	2.946E05	1.000E00
5	2.770E05	1.002E05	1.304E05	2.958E05	1.219E05	1.343E05	2.967E05	1.000E00
6	2.700E05	9.681E04	1.286E05	2.933E05	1.217E05	1.336E05	2.946E05	1.000E00



<u>"Initial state" tab</u>

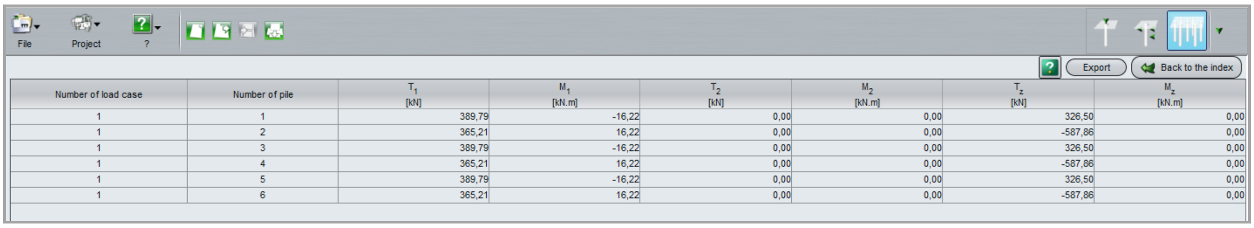
When importing stiffnesses into the oxz planes, Manual Groupie automatically fills out the loads and displacements at the origin for each pile. It should be noted that these values are no longer null, which indicates soil plastification in the lateral direction x-x. This finding can be visualised by accessing the graphical results of the Piecoef+ models.



N°	$T1_0$ [kN]	$M1_0$ [kN.m]	$T2_0$ [kN]	$M2_0$ [kN.m]	Tz_0 [kN]	Mz_0 [kN.m]
1	118,80	-21,19	0,00	0,00	0,00	0,00
2	136,77	-27,74	0,00	0,00	0,00	0,00
3	118,80	-21,19	0,00	0,00	0,00	0,00
4	136,77	-27,74	0,00	0,00	0,00	0,00
5	118,80	-21,19	0,00	0,00	0,00	0,00
6	136,77	-27,74	0,00	0,00	0,00	0,00

Calculation and results

Now restart the calculation by clicking the Start calculation button then access the results tables.



Number of load case	Number of pile	T_1 [kN]	M_1 [kN.m]	T_2 [kN]	M_2 [kN.m]	T_z [kN]	M_z [kN.m]
1	1	389,79	-16,22	0,00	0,00	326,50	0,00
1	2	365,21	16,22	0,00	0,00	-587,86	0,00
1	3	389,79	-16,22	0,00	0,00	326,50	0,00
1	4	365,21	16,22	0,00	0,00	-587,86	0,00
1	5	389,79	-16,22	0,00	0,00	326,50	0,00
1	6	365,21	16,22	0,00	0,00	-587,86	0,00

Note the values obtained for each type of pile:

Vertical pile:

- ✓ T1: 389.79 kN
- ✓ M1: -16.22 kN.m
- ✓ Tz: 326.50 kN

Inclined pile:

- ✓ T1: 365.21 kN
- ✓ M1: 16.22 kN.m
- ✓ Tz: -587.86 kN

The loads and displacements at the pile heads have changed, so a second iteration will be carried out.

Save your project under a different name: "Ex2 iteration 2" for example

Go back to the Taspie+ module by clicking the corresponding icon TASPIE+ and display pile N°1.

H.4.2.2.11. Updating the axial stiffness of a vertical pile (Taspie+)

"Parameters" tab

Change the calculation title: "Vertical pile L = 12 m - Iteration 2" for example.

"Load" tab

Input the Tz value from the Manual Groupie calculation, for a vertical pile:

- Top load: 326.5 kN

Calculation and results

We can see that the equivalent stiffness under the new load defined by the user is exactly the same as that of the first iteration: 2.77E05 kN/m.

```
RAIDEUR EQUIVALENTE

=====================================================================================================
                                                                Charge      Déplacement      Raideur

  --- Sous une charge égale à 70% de la charge de fluage        874.81        0.00359       0.244E+06
  --- Sous la charge définie par l'utilisateur                  326.50        0.00118       0.277E+06

=====================================================================================================
```

Repeat the operation for an inclined pile.

H.4.2.2.12. Updating the axial stiffness of an inclined pile (Taspie+)

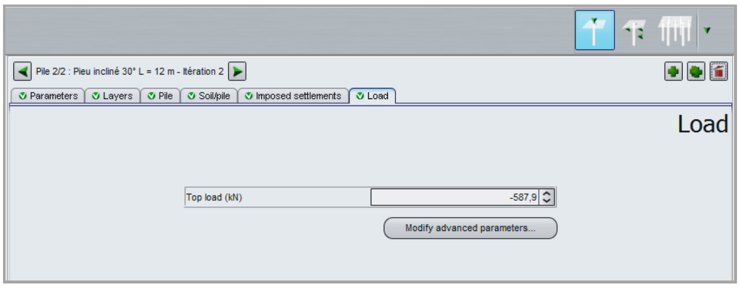
"Parameters" tab

Change the calculation title: "Inclined pile 30° L = 12 m - Iteration 2" for example.

"Load" tab

Input value Tz for an inclined pile, resulting from the Manual Groupie calculation:

- Top load: -587.9 kN



Calculation and results

We can see that the equivalent stiffness under the new load defined by the user is exactly the same as that of the first iteration: 2.70E05 kN/m.

```
RAIDEUR EQUIVALENTE

=====================================================================================================
                                                                Charge      Déplacement      Raideur

  --- Sous une charge égale à 70% de la charge de fluage       -793.49       -0.00298       0.266E+06
  --- Sous la charge définie par l'utilisateur                 -587.86       -0.00218       0.270E+06

=====================================================================================================
```

Switch to the Piecoef+ module and go to the vertical pile (Pile N°1).

H.4.2.2.13. Updating the lateral stiffnesses of a vertical pile (Piecoef+)

"Parameters" tab

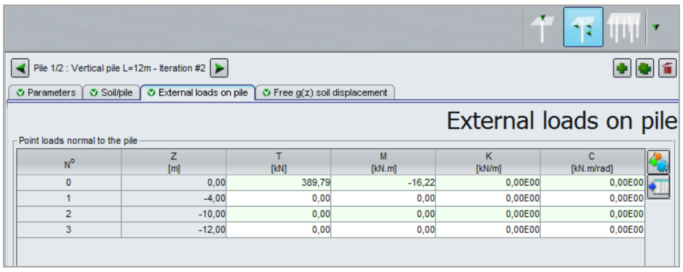
"Calculation parameters" frame

- Change the calculation title: "Vertical pile L = 12 m - Iteration 2" for example.

"External loads on pile" tab

The load is defined by:

- Point side force T: 389.79 kN
- Point bending moment M: -16.22 kN.m



Now restart the calculation. The new stiffnesses will be imported into Manual Groupie with the help of the import wizard.

Repeat the operation for the inclined pile.

H.4.2.2.14. Updating the lateral stiffnesses of an inclined pile (Piecoef+)

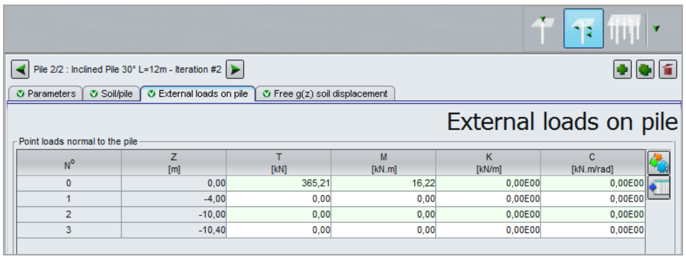
"Parameters" tab

Change the calculation title: "Inclined pile L = 12 m - Iteration 2" for example.

"External loads on pile" tab

The load is defined by:

- Side force T: 365.21 kN
- Point bending moment M: 16.22 kN.m



Calculation and results

Now restart the calculation. The new stiffnesses obtained will be imported into Manual Groupie with the help of the import wizard.

Switch to the Groupie+ module and go directly to the "Stiffnesses" tab.

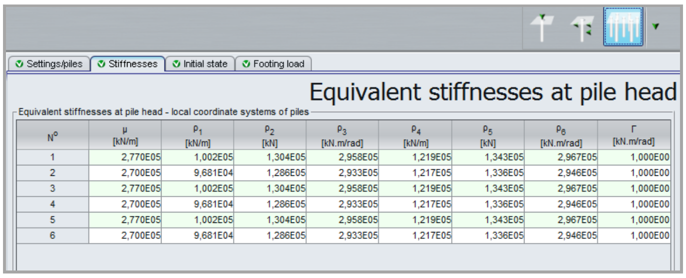
H.4.2.2.15. Distribution of forces – 2nd iteration (Manual Groupie)

"Stiffnesses" tab

Earlier on, we observed that the stiffnesses produced by the two Taspie+ calculations are identical with respect to the previous iteration. No modification needs to be considered in the first column.

The stiffnesses from the last Piecoef+ calculations must now be imported, in the same way as for the first iteration. The following values are then obtained.

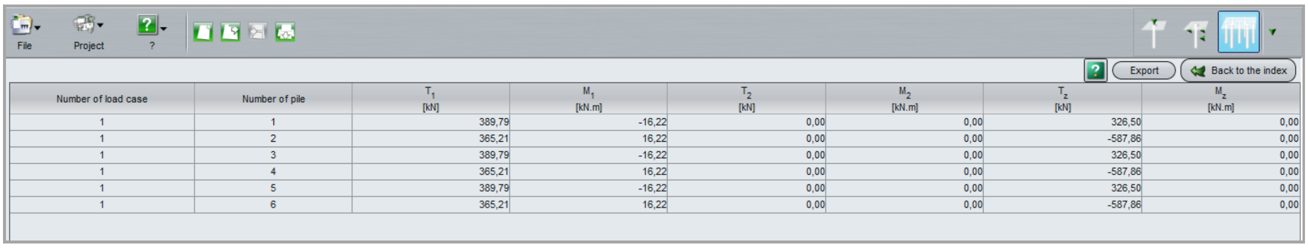
Pile N°	μ (kN/m)	ρ1 (kN/m)	ρ2 (kN)	ρ3 (kN.m/rad)	ρ4 (kN/m)	ρ5 (kN)	ρ6 (kN.m/rad)	Γ (kN.m/rad)
1	2.77E05	1.002E05	1.304E05	2.958E05	1.219E05	1.343E05	2.967E05	1.000E00
2	2.70E05	9.681E04	1.286E05	2.933E05	1.217E05	1.336E05	2.946E05	1.000E00
3	2.77E05	1.002E05	1.304E05	2.958E05	1.219E05	1.343E05	2.967E05	1.000E00
4	2.70E05	9.681E04	1.286E05	2.933E05	1.217E05	1.336E05	2.946E05	1.000E00
5	2.77E05	1.002E05	1.304E05	2.958E05	1.219E05	1.343E05	2.967E05	1.000E00
6	2.70E05	9.681E04	1.286E05	2.933E05	1.217E05	1.336E05	2.946E05	1.000E00



N°	μ [kN/m]	ρ_1 [kN/m]	ρ_2 [kN]	ρ_3 [kN.m/rad]	ρ_4 [kN/m]	ρ_5 [kN]	ρ_6 [kN.m/rad]	Γ [kN.m/rad]
1	2,770E05	1,002E05	1,304E05	2,958E05	1,219E05	1,343E05	2,967E05	1,000E00
2	2,700E05	9,681E04	1,286E05	2,933E05	1,217E05	1,336E05	2,946E05	1,000E00
3	2,770E05	1,002E05	1,304E05	2,958E05	1,219E05	1,343E05	2,967E05	1,000E00
4	2,700E05	9,681E04	1,286E05	2,933E05	1,217E05	1,336E05	2,946E05	1,000E00
5	2,770E05	1,002E05	1,304E05	2,958E05	1,219E05	1,343E05	2,967E05	1,000E00
6	2,700E05	9,681E04	1,286E05	2,933E05	1,217E05	1,336E05	2,946E05	1,000E00

Calculation and results

Now restart the calculation and access the results tables.



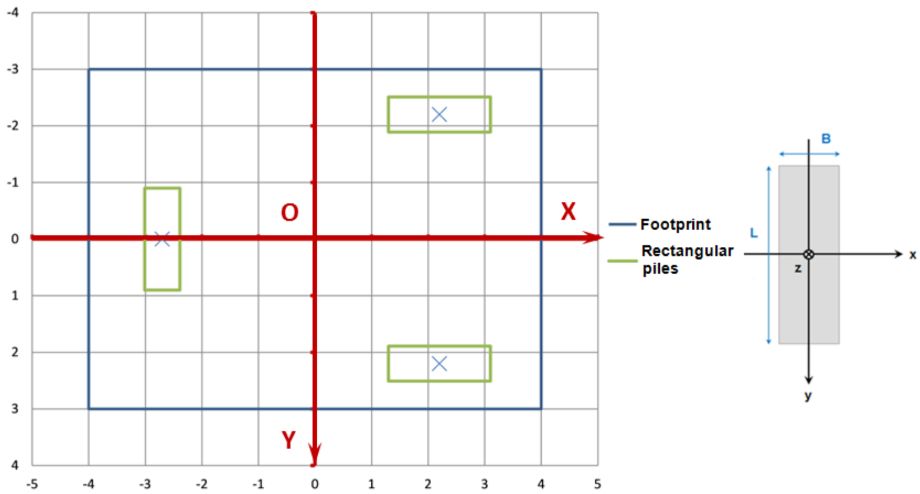
Number of load case	Number of pile	T_1 [kN]	M_1 [kN.m]	T_2 [kN]	M_2 [kN.m]	T_z [kN]	M_z [kN.m]
1	1	389,79	-16,22	0,00	0,00	326,50	0,00
1	2	365,21	16,22	0,00	0,00	-587,86	0,00
1	3	389,79	-16,22	0,00	0,00	326,50	0,00
1	4	365,21	16,22	0,00	0,00	-587,86	0,00
1	5	389,79	-16,22	0,00	0,00	326,50	0,00
1	6	365,21	16,22	0,00	0,00	-587,86	0,00

It can be seen that the forces at the pile heads are identical to those obtained with the first iteration. The Manual Groupie calculation has therefore converged.

It can also be seen that these results are very similar to those obtained with the Automatic Groupie+ calculation, considered to be the reference. The calculation results in Manual Groupie mode (step 2) deviated from the reference by an average of 3 ‰.

H.4.3. Example 3: Rectangular piles

This involves studying the behaviour of an infinitely rigid footing built on an assembly of three 1.80 m x 0.62 m rectangular piles. Given the transverse dimensions of the rectangular piles and their orientation, it is essential to switch to Advanced Automatic Groupie+ mode. Two rectangular pile families are to be considered.



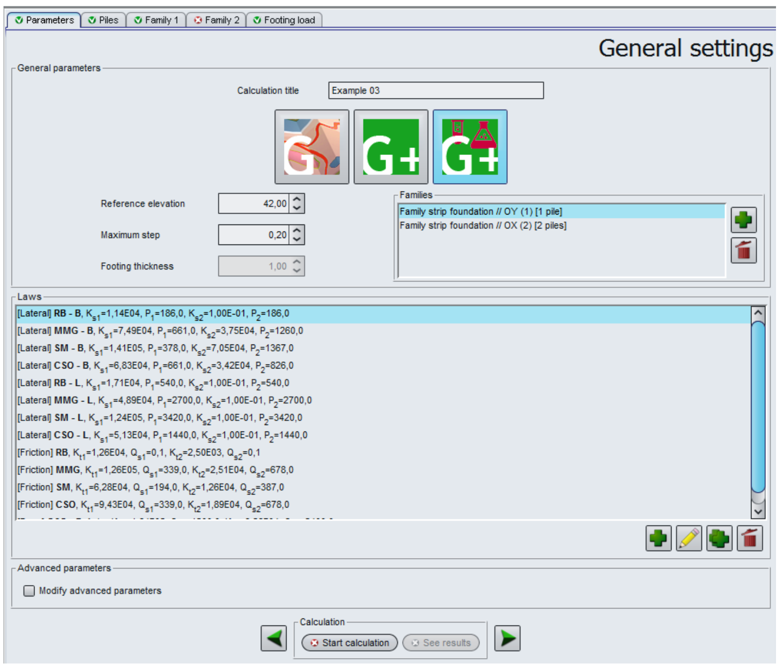
For easier understanding, below is the list of soil layers defined in this example:

- RB: Bank (backfill);
- MMG: Gypsum media and Marls (Marl);
- SM: Monceau sands (Sand);
- CSO: Saint-Ouen marly limestone (Marly Limestone).

H.4.3.1. Data input

A new project is created and the modules chosen in exactly the same way as presented in example 01 (see first two sub-parts § H.4.1.1).

H.4.3.1.1. "Parameters" tab



<u>"General parameters" frame</u>

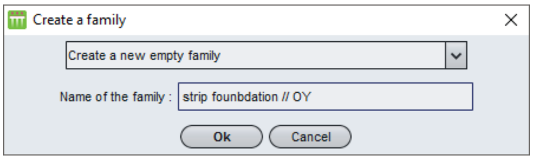
- Groupie+ calculation title: simply enter "Example 03";
- Advanced Automatic Groupie+: selected;
- Reference elevation (m): 42.00;
- Maximum step (m): 0.20;
- Footing thickness (m): perfectly rigid footing.

The advanced mode calls up the secondary "Families" frame:

Two rectangular pile families are to be created by clicking the button:

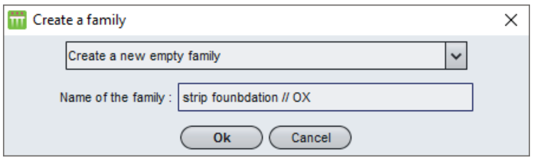
- Create a new empty family:

  Name of the family: Rectangular pile // OY and click the OK button;



- Create a new empty family:

  Name of the family: Rectangular pile // OX and click the OK button.



After creating these two families, two tabs appear, marked with a red cross Family 1 Family 2 because they have not been filled out yet.

<u>"Laws" frame</u>

The laws created here are used to allocate parameters to the soil layers. These will be defined in the "Family 1" and "Family 2" tabs.

- Click the button to add a law:

  <u>Lateral laws</u>:

  The following data are to be input:

Name of law	**K_{s1}** (kN/m/m)	**P_1** (kN/m)	**K_{s2}** (kN/m/m)	**P_2** (kN/m)
RB – B	1.14E04	186.0	1.00E-01	186.0
MMG – B	7.49E04	661.0	3.75E04	1260.0
SM – B	1.41E05	378.0	7.05E04	1367.0
CSO – B	6.83E04	661.0	3.42E04	826.0
RB – L	1.71E04	540.0	1.00E-01	540.0
MMG – L	4.89E04	2700.0	1.00E-01	2700.0
SM – L	1.24E05	3420.0	1.00E-01	3420.0
CSO – L	5.13E04	1440.0	1.00E-01	1440.0

Friction laws:

The following data are to be input:

Name of law	K_{t1} (kN/m/m)	Q_{s1} (kN/m)	K_{t2} (kN/m/m)	Q_{s2} (kN/m)
RB	1.26E04	0.1	2.50E03	0.1
MMG	1.26E05	339.0	2.51E04	678.0
SM	6.28E04	194.0	1.26E04	387.0
CSO	9.42E04	339.0	1.88E04	678.0

Base law:

The following data are to be input:

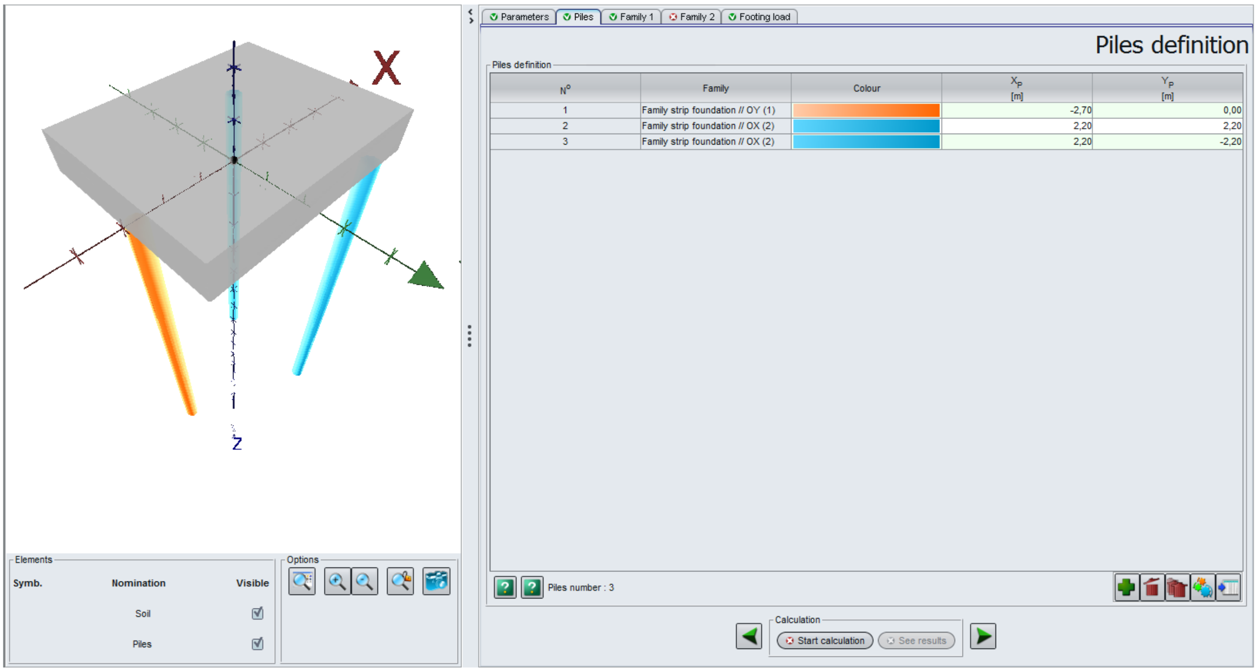
Name of law	K_{p1} (kN/m)	Q_{p1} (kN)	K_{p2} (kN/m)	Q_{p2} (kN)
CSO - Base	1.64E05	1200.0	3.28E04	2400.0

"Advanced parameters" frame

- Modify advanced parameters: unticked.

H.4.3.1.2. "Piles" tab

Three elements (rectangular piles) are created with the button.



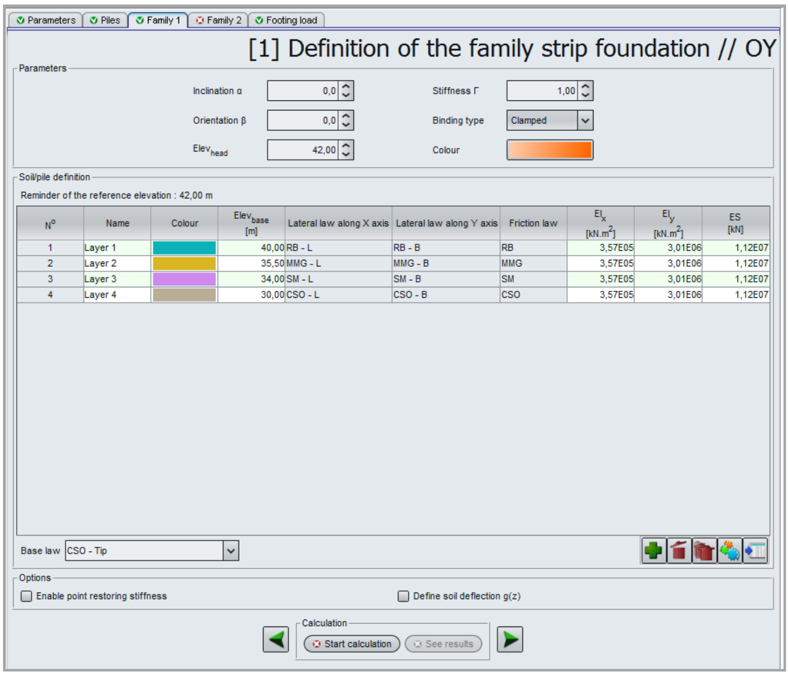
The following data are to be input:

Pile N°	**Family**	X_P	Y_P
1	Family rectangular piles // OY (1)	-2.70	0.00
2	Family rectangular piles // OX (2)	2.20	2.20
3	Family rectangular piles // OX (2)	2.20	-2.20

Note: the colours are automatically assigned to each family.

H.4.3.1.3. "Family 1" tab

This first "Family 1" tab is used to define the characteristics of the first family of rectangular piles. The name of the "Rectangular piles // OY" family input in the "Parameters" tab is given at the top of the tab.



<u>"Parameters" frame</u>

Data to be input:

- α: Inclination (°): 0.0
- β: Orientation (°): 0.0
- **Elev$_{head}$** (m): 42.00
- γ: Stiffness (kN.m/rad): 1.00
- **Binding type**: clamped
- **Colour**: automatically initialised at creation of family.

<u>"Soil/Pile definition" frame</u>

Advanced Automatic Groupie+ recalls the reference elevation: 42.0 m.

Data to be input:

Layer name	**Elev$_{base}$** (m)	**Lateral law x**	**Lateral law y**	**Friction law**	**EI$_x$** (kN.m²)	**EI$_y$** (kN.m²)	**ES** (kN)
Bank	40.0	RB - L	RB - B	RB	3.57E05	3.01E06	1.12E07
Marl	35.5	MMG - L	MMG - B	MMG	3.57E05	3.01E06	1.12E07
Sand	34.0	SM - L	SM - B	SM	3.57E05	3.01E06	1.12E07
Marly limestone	30.0	CSO - L	SM - B	CSO	3.57E05	3.01E06	1.12E07

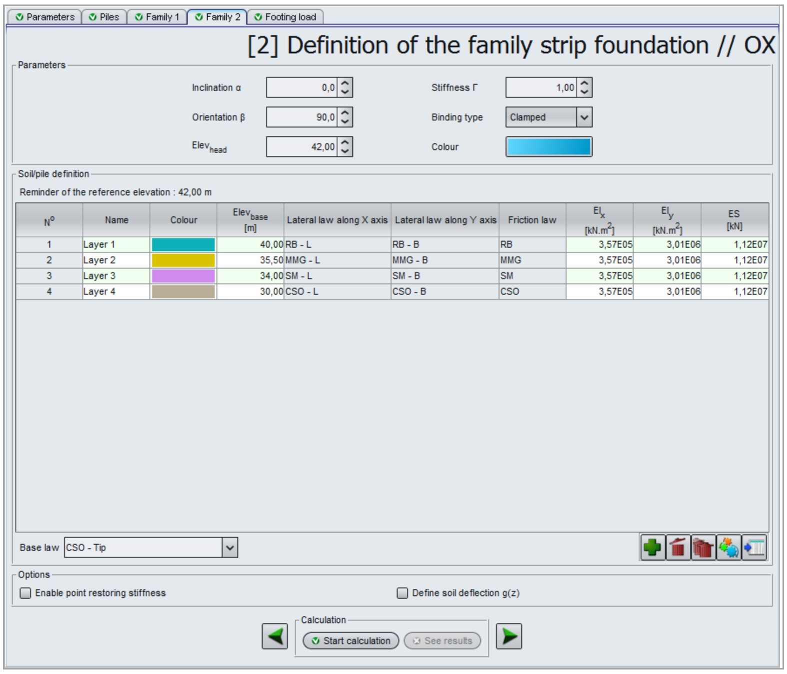
- Base law: CSO – Base

<u>"Options" frame</u>

- Enable point restoring stiffness: unticked
- Define soil deflection g(z): unticked

H.4.3.1.4. "Family 2" tab

This second "Family 2" tab is used to define the characteristics of the second family of rectangular piles. The name of the "Rectangular piles // OX" family input in the "Parameters" tab is given at the top of the tab.



<u>"Parameters" frame</u>

Data to be input:

- α: Inclination (°): 0.0
- β: Orientation (°): 90.0
- **Elev$_{head}$** (m): 42.00
- γ: Stiffness (kN.m/rad): 1.00
- **Binding type**: clamped
- **Colour**: automatically initialised at creation of the family.

<u>"Soil/pile definition" frame</u>

Advanced Automatic Groupie+ recalls the reference elevation: 42.00 m.

Data to be input:

Name of layer	**Elev$_{base}$** (m)	**Lateral law x**	**Lateral law y**	**Friction law**	**EI$_x$** (kN.m²)	**EI$_y$** (kN.m²)	**ES** (kN)
Bank	40.0	RB - L	RB - B	RB	3.57E05	3.01E06	1.12E07
Marl	35.5	MMG - L	MMG - B	MMG	3.57E05	3.01E06	1.12E07
Sand	34.0	SM - L	SM - B	SM	3.57E05	3.01E06	1.12E07
Marly limestone	30.0	CSO - L	SM - B	CSO	3.57E05	3.01E06	1.12E07

- Base law: CSO – Base

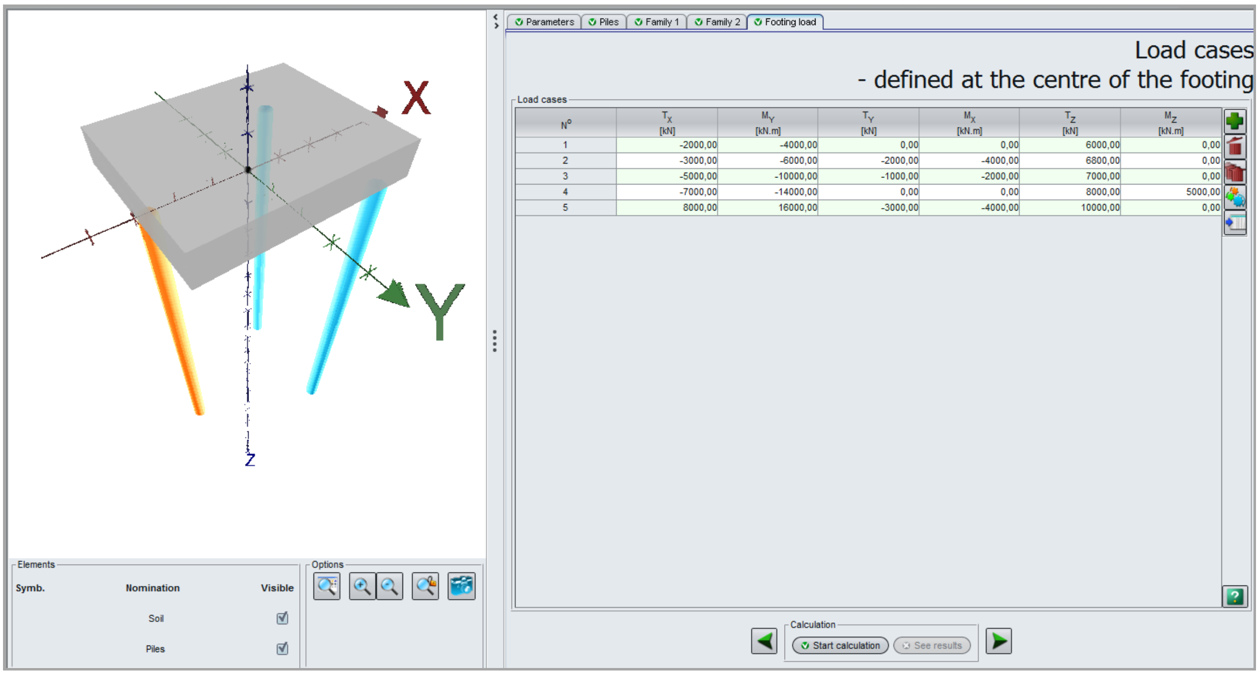
<u>"Options" frame</u>

- Enable point restoring stiffness: unticked
- Define soil deflection g(z): unticked

Note: the only difference between the two families is the orientation of the rectangular piles around the OZ axis, so it is possible to create family 2 as an exact copy of family 1 and then make the minor modification (β = 90°).

H.4.3.1.5. "Footing load" tab

The load cases input in this tab are expressed at the centre of the footing O.



"Load case" frame

Data to be input:

Load case N°	T_X (kN)	M_Y (kN.m)	T_Y (kN)	M_X (kN.m)	T_Z (kN)	M_Z (kN.m)
1	-2000	-4000	0	0	6000	0
2	-3000	-6000	-2000	-4000	6800	0
3	-5000	-10000	-1000	-2000	7000	0
4	-7000	-14000	0	0	8000	5000
5	8000	16000	-3000	-4000	10000	0

H.4.3.2. Calculation and results

H.4.3.2.1. Calculation

The calculation procedure presented in example 01 applies (see chapter H.4.1.2.1).

H.4.3.2.2. Results

Numerical results:

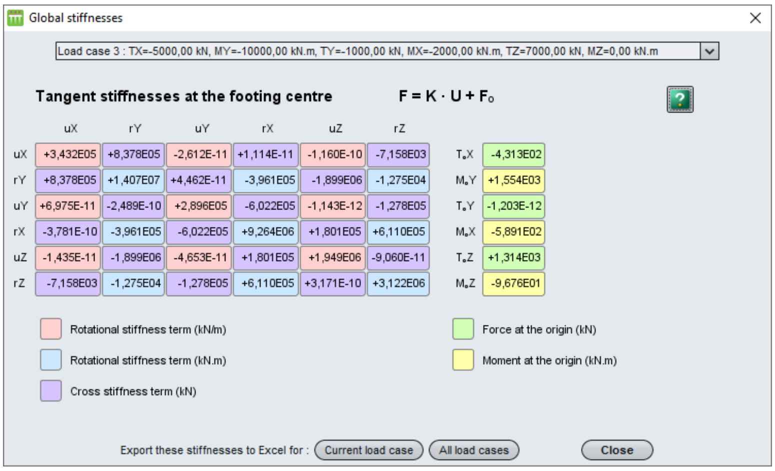
Loads and displacements at the footing centre

This table presents the displacements of the foundation, expressed at the centre of the footing, with a reminder of the associated load global forces and moments.

Global stiffnesses | **Loads and displacements at the footing centre** | Export | Back to the index

Load case #	T_X [kN]	M_Y [kN.m]	T_Y [kN]	M_X [kN.m]	T_Z [kN]	M_Z [kN.m]	U_X [m]	rot/Y [rad]	U_Y [m]	rot/X [rad]	U_Z [m]	rot/Z [rad]
1	-2000,00	-4000,00	0,00	0,00	6000,00	0,00	-6,001E-03	3,065E-04	3,085E-18	-4,202E-20	2,779E-03	6,329E-18
2	-3000,00	-6000,00	-2000,00	-4000,00	6800,00	0,00	-8,774E-03	3,634E-04	-9,171E-03	-1,055E-03	3,379E-03	-1,599E-04
3	-5000,00	-10000,00	-1000,00	-2000,00	7000,00	0,00	-1,452E-02	4,948E-04	-4,501E-03	-4,847E-04	3,445E-03	-8,959E-05
4	-7000,00	-14000,00	0,00	0,00	8000,00	5000,00	-2,189E-02	7,398E-04	6,531E-04	-7,539E-05	4,212E-03	1,836E-03
5	8000,00	16000,00	-3000,00	-4000,00	10000,00	0,00	2,349E-02	-7,233E-06	-1,428E-02	-1,832E-03	5,588E-03	-2,573E-04

To obtain the overall stiffnesses of the foundation, click the Global stiffnesses button. Use the drop-down list to change load cases.



	uX	rY	uY	rX	uZ	rZ		
uX	+3,432E05	+8,378E05	-2,612E-11	+1,114E-11	-1,160E-10	-7,158E03	T₀X	-4,313E02
rY	+8,378E05	+1,407E07	+4,462E-11	-3,961E05	-1,899E06	-1,275E04	M₀Y	+1,554E03
uY	+6,975E-11	-2,489E-10	+2,896E05	-6,022E05	-1,143E-12	-1,278E05	T₀Y	-1,203E-12
rX	-3,781E-10	-3,961E05	-6,022E05	+9,264E06	+1,801E05	+6,110E05	M₀X	-5,891E02
uZ	-1,435E-11	-1,899E06	-4,653E-11	+1,801E05	+1,949E06	-9,060E-11	T₀Z	+1,314E03
rZ	-7,158E03	-1,275E04	-1,278E05	+6,110E05	+3,171E-10	+3,122E06	M₀Z	-9,676E01

Forces at pile heads

For each load case, this table gives the forces transmitted at the head of each rectangular pile.

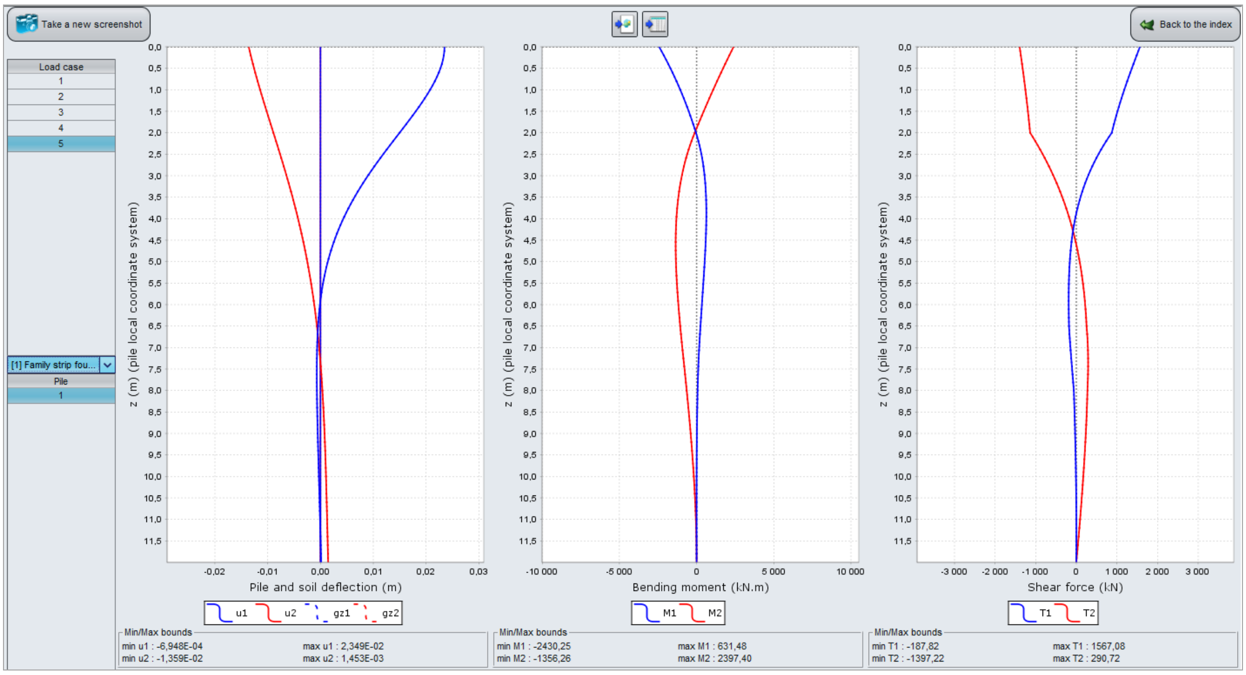
Forces at pile heads

Load case #	Pile #	T_1 [kN]	M_1 [kN.m]	T_2 [kN]	M_2 [kN.m]	T_z [kN]	M_z [kN.m]
1	1	-368,797	534,183	-0,000	0,000	2751,310	0,000
1	2	0,000	-0,000	815,601	-1873,630	1624,340	0,000
1	3	0,000	-0,000	815,601	-1873,630	1624,340	0,000
2	1	-548,010	805,157	-947,282	1741,560	3167,120	-0,000
2	2	-526,359	685,894	1171,070	-2737,840	199,773	-0,000
2	3	-526,359	685,894	1280,920	-3015,870	3433,110	-0,000
3	1	-917,971	1362,840	-473,270	896,453	3375,530	-0,000
3	2	-263,365	348,539	2013,960	-4816,630	995,521	-0,000
3	3	-263,365	348,539	2068,060	-4960,650	2628,940	-0,000
4	1	-1384,420	2056,130	-641,898	1577,660	4010,420	0,002
4	2	320,949	-507,254	3229,310	-8302,170	1866,800	0,002
4	3	320,949	-507,254	2386,270	-5692,760	2122,780	0,002
5	1	1567,080	-2430,250	-1397,220	2397,400	3739,580	-0,000
5	2	-801,389	1016,350	-3272,450	8799,350	1214,280	-0,000
5	3	-801,389	1016,350	-3160,460	8446,450	5046,140	-0,000

<u>Graphical results</u>:

<u>Lateral behaviour</u>

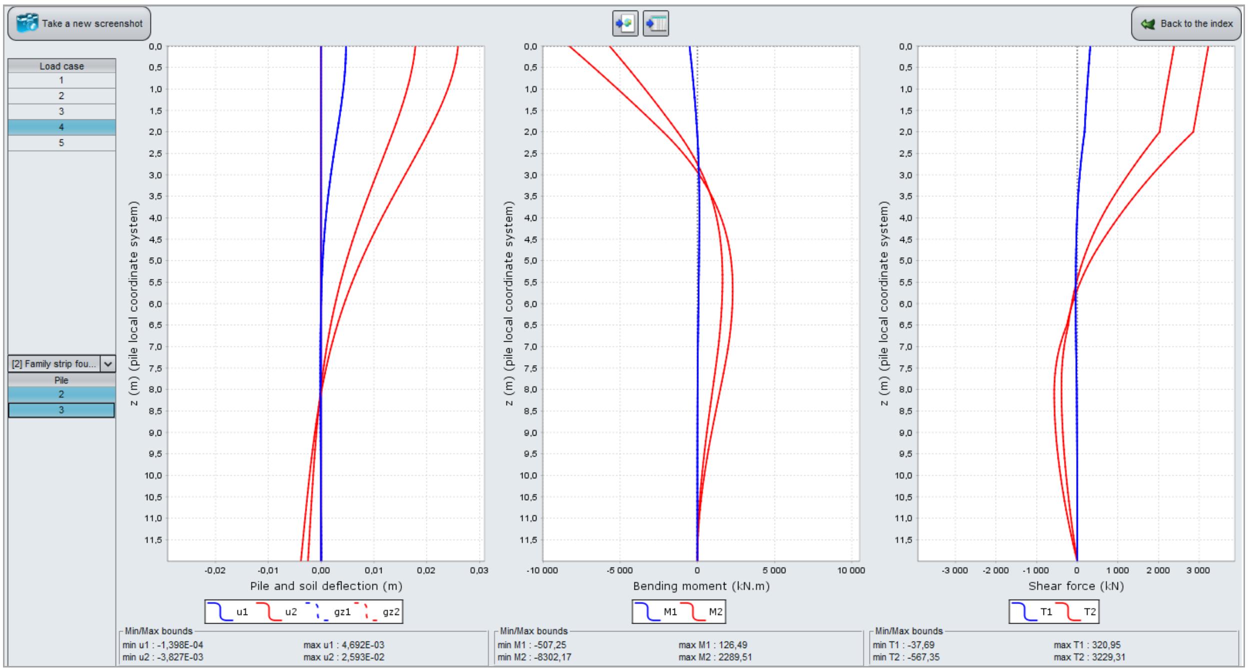
Load case N°5: Family N°1 "Rectangular piles // OY" – Rectangular pile N°1



Minimum and maximum bounds of the various physical quantities:

	Deflection (m)		Bending moment (kN.m)		Shear force (kN)	
	u1	**u2**	**M1**	**M2**	**T1**	**T2**
Min. bound	-6.948E-04	-1.359E-02	-2430.25	-1356.26	-187.82	-1397.22
Max. bound	2.349E-02	1.453E-03	631.48	2397.40	1567.08	290.72

Load case N°4: Family N°2 "Rectangular piles // OX" – Rectangular piles N° 2 and 3

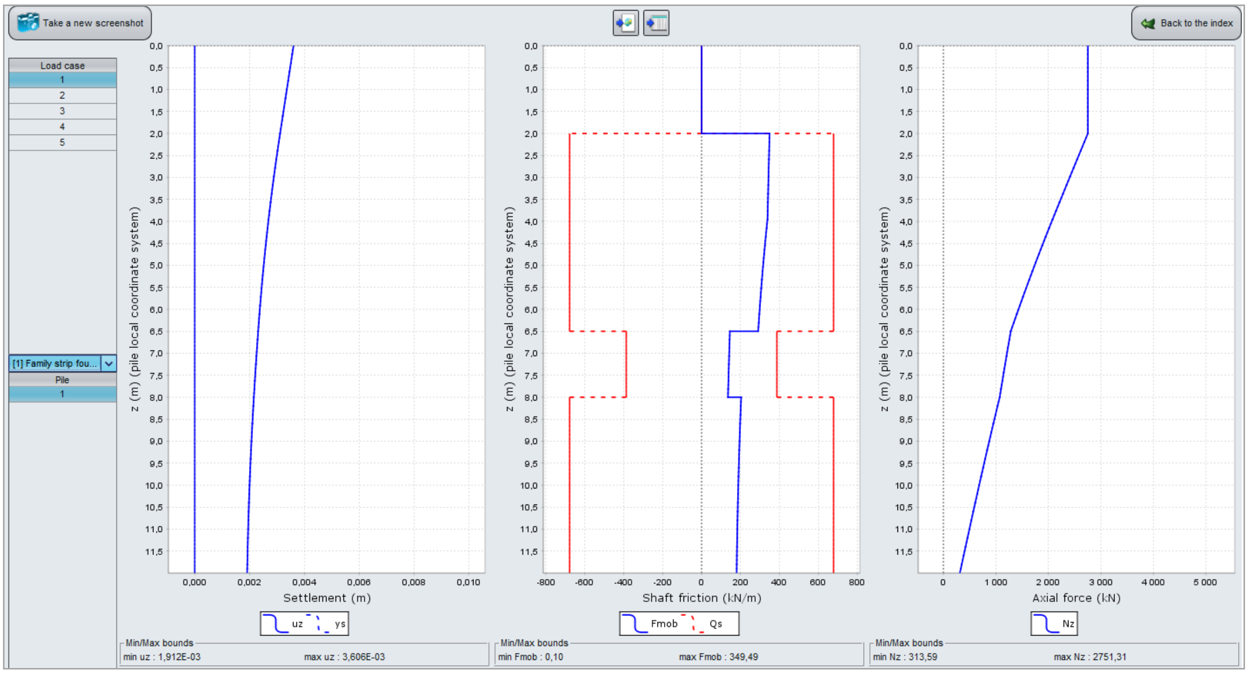


Minimum and maximum bounds of the various physical quantities:

	Deflection (m)		Bending moment (kN.m)		Shear force (kN)	
	u1	**u2**	**M1**	**M2**	**T1**	**T2**
Min. bound	-1.398E-04	-3.827E-03	-507.25	-8302.17	-37.69	-567.35
Max. bound	4.692E-03	2.593E-02	126.49	2289.51	320.95	3229.31

Axial behaviour

Load case N°1: Family N°1 "Rectangular piles // OY" – Rectangular pile N°1

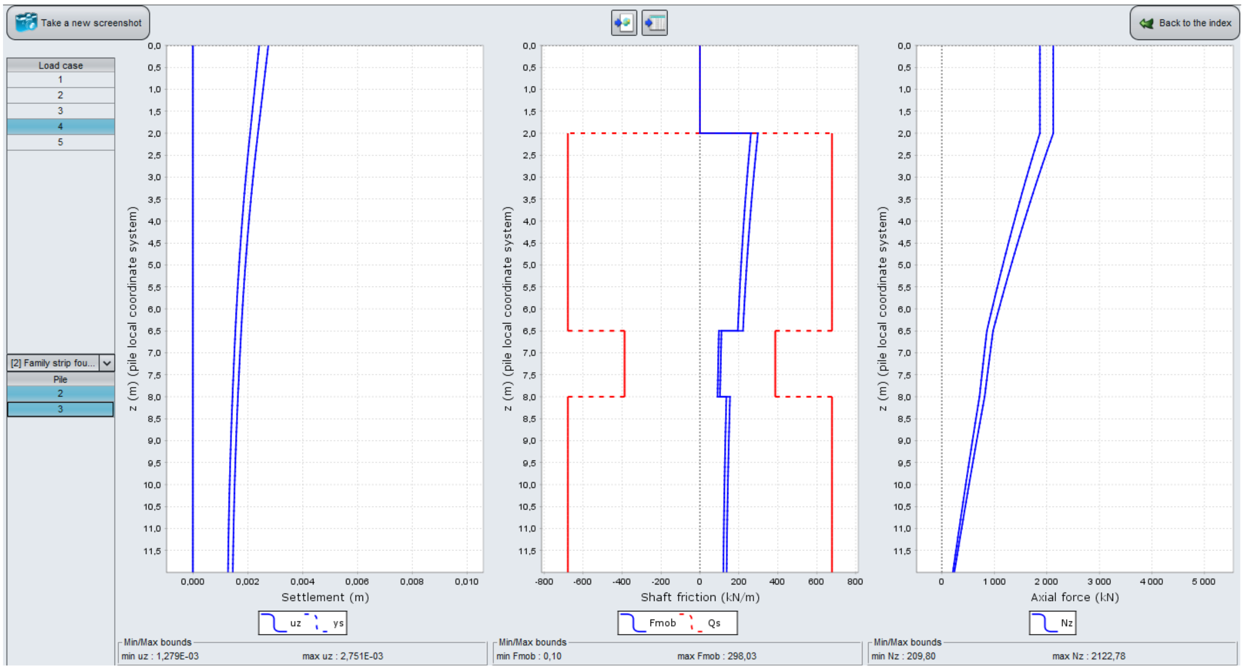


Minimum and maximum bounds of the various physical quantities:

	Settlement (m)	Shaft friction (kN/m)	Axial force (kN)
Min. bound	1.912E-03	0.10	313.59
Max. bound	3.606E-03	349.49	2751.31

Note: the mobilised friction is expressed in linear form (kN/m) which corresponds to the entire friction within the perimeter of each rectangular pile.

Load case N°4: Family N°2 "Rectangular piles // OX" – Rectangular piles N°2 and 3

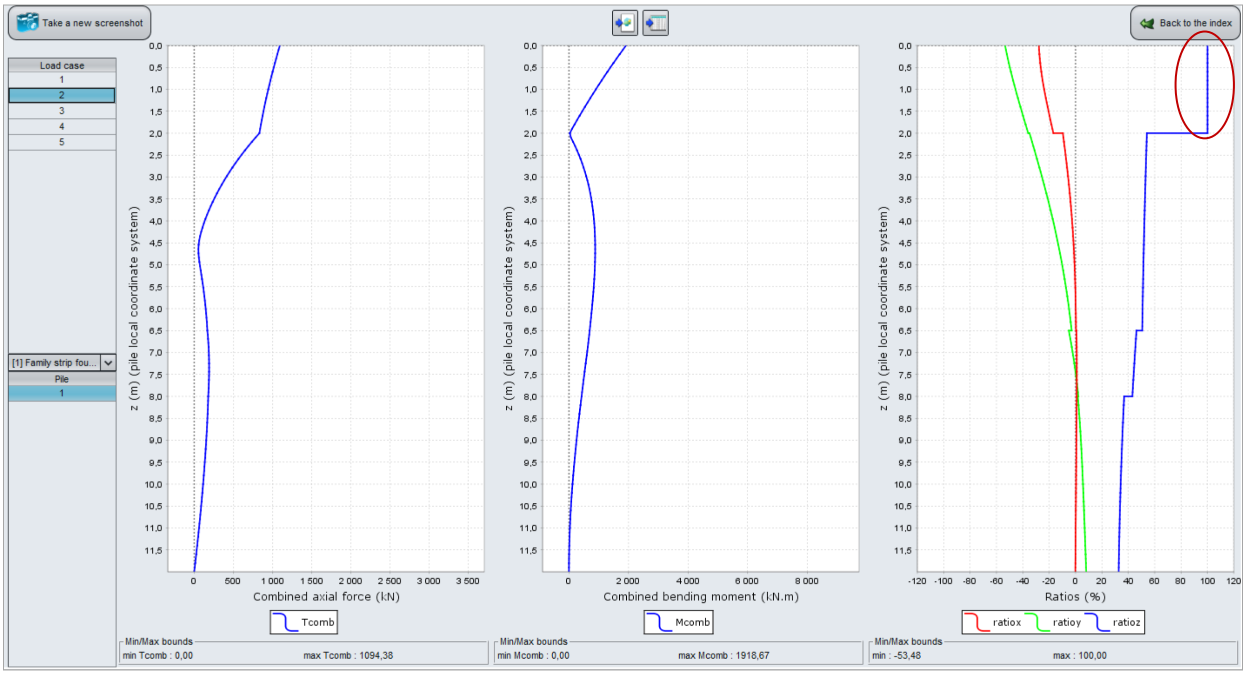


Minimum and maximum bounds of the various physical quantities:

	Settlement (m)	Shaft friction (kN/m)	Axial force (kN)
Min. bound	1.279E-03	0.10	209.80
Max. bound	2.751E-03	298.03	2122.78

Additional results

Load case N°2: Family 1 "Rectangular piles // OY" – Rectangular pile N°1

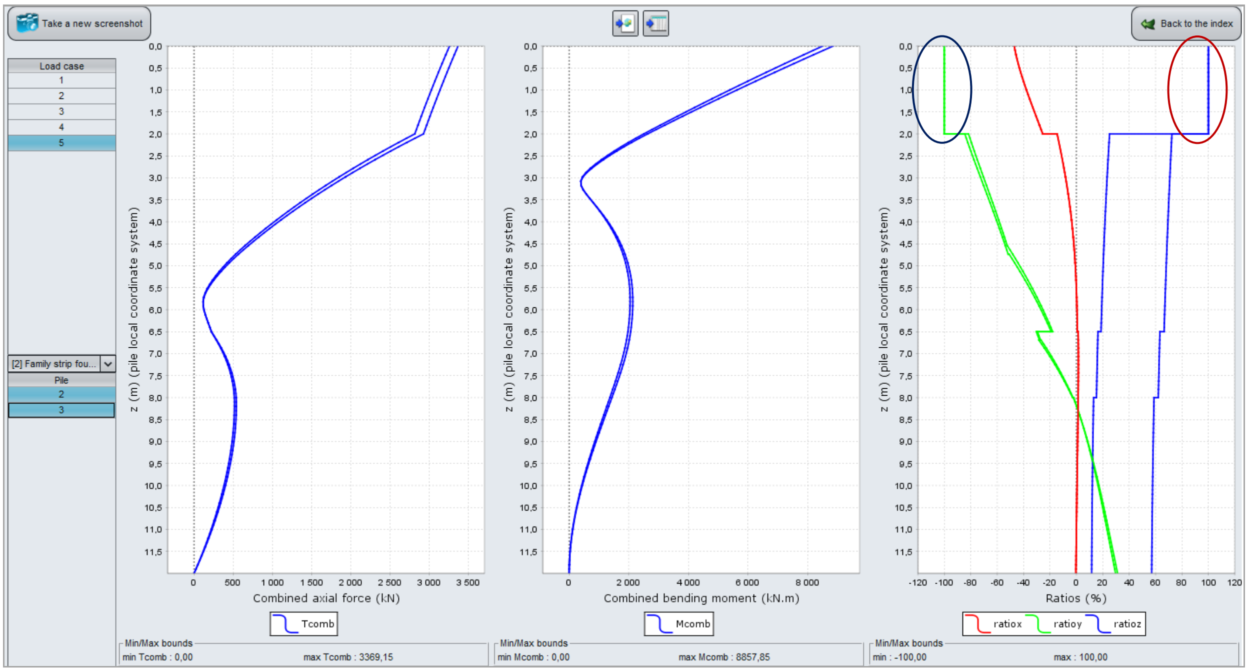


Minimum and maximum bounds of the various physical quantities:

	Combined shear force (m)	Combined bending moment (kN/m)	Ratios (%)
Min. bound	0.00	0.00	-53.48
Max. bound	1094.38	1918.67	100.00

Note: as friction is ignored in the banks, the mobilisation ratio easily reaches 100% in this layer. This explains the vertical parts at 100% on the blue curves.

Load case N°5: Family N°2 "Rectangular piles //OX" – Rectangular piles N°2 and 3



Minimum and maximum bounds of the various physical quantities:

	Combined shear force (m)	Combined bending moment (kN/m)	Ratios (%)
Min. bound	0.00	0.00	-100.00
Max. bound	3369.15	8857.85	100.00

Note: soil plastification occurs in the local direction y-y for rectangular piles of family 2 under load case N°5. This shows that the lateral reaction produced over the width of the rectangular piles (noted B) reaches its limit over the entire height of the bank layer.