



PART G: PIECOEF+ MODULE

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G.1. Introduction

Piecoef+ module is used to model, in a refined manner, the behaviour of a single pile submitted to transverse loads on the basis of a beam model on elastoplastic supports ("p-y" type model).

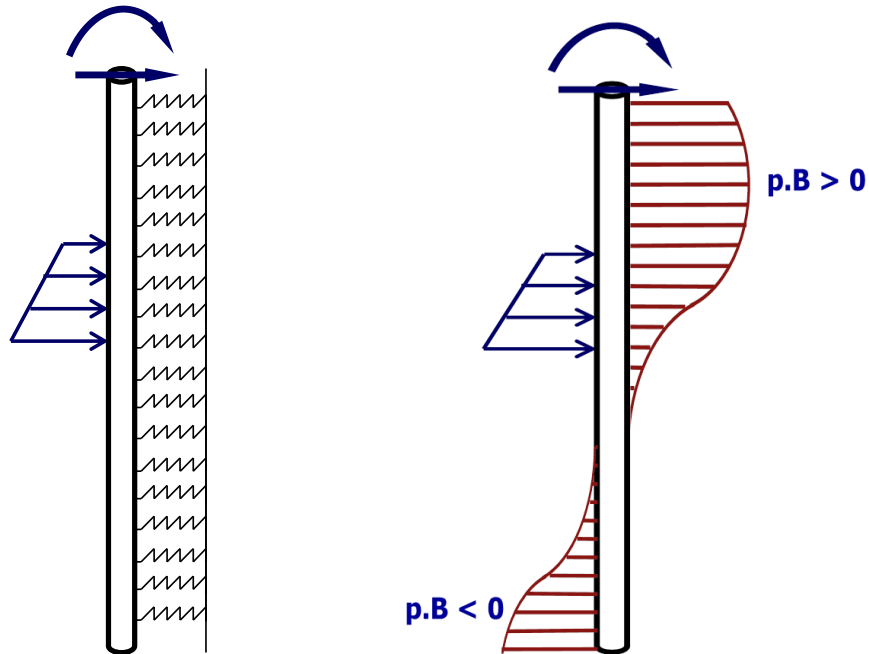


Figure G.1 : Piecoef+ model

It applies to the case of a variable inertia pile, in multilayer soil with elastoplastic behaviour under various loading conditions.

It allows the plastification of the soil, a free displacement of "g(z)" type and the contribution of shear force displacements to be taken into account.

The used method also allows the critical buckling forces as well as additional forces and 2nd order displacements to be assessed under an axial force.

Lastly, Piecoef+ allows the stiffness matrix at pile head to be calculated, which can for instance constitute the preliminary step of a Groupie+ calculation for a pile group.

G.2. Theoretical aspects

G.2.1. Pile modelling

The pile is considered as a beam with linear elastic behaviour. We consider the case of beams with uniform cross-sections which allows bending behaviour to be dissociated from the tensile/compression behaviour.

Bending behaviour of the beam representative of the pile can be addressed using the so-called Bernoulli model which consists in neglecting the contribution of the shear force displacements. With this assumption, the combination of the balance and behaviour equations gives the following general equation:

$$EI \frac{d^4 y(z)}{dz^4} = q(z) - r(z) \quad (1)$$

Where:

- $y(z)$ lateral displacement of the pile
- $EI(z)$ product of inertia
- $q(z)$ transverse load density on the pile (other than soil reaction)
- $r(z)$ soil reaction density

This equation can be solved numerically by discretising the pile into beam finite elements. To this aim, we use "conventional" elements with 2 nodes and 4 degrees of freedom: two displacements and two rotations. At any points, the rotation of the beam coincides with the lateral displacement field derivative (Bernoulli approximation). In the context of this discretisation, the balance of the pile is represented by an equivalent matrix system of size $2(p+1) \times 2(p+1)$ where p refers to the total number of elements:

$$\mathbf{K}^e \cdot \mathbf{y} = \mathbf{F}^{\text{ext}} - \mathbf{R}^s \quad (2)$$

Where:

- \mathbf{K}^e : stiffness matrix of the pile consisting of the assembly of elementary stiffness matrices;
- \mathbf{F}^{ext} : load vector related to the transverse loads on the pile other than the soil reaction;
- \mathbf{R}^s : load vector related to soil reaction;
- \mathbf{y} : equivalent displacement vector consisting of the displacement and rotation at each node.

G.2.2. Modelling of soil reaction

Each layer of soil is considered as a distribution of adjacent springs with elastoplastic behaviour according to a mobilisation law with three plateaux as shown on the figure below.

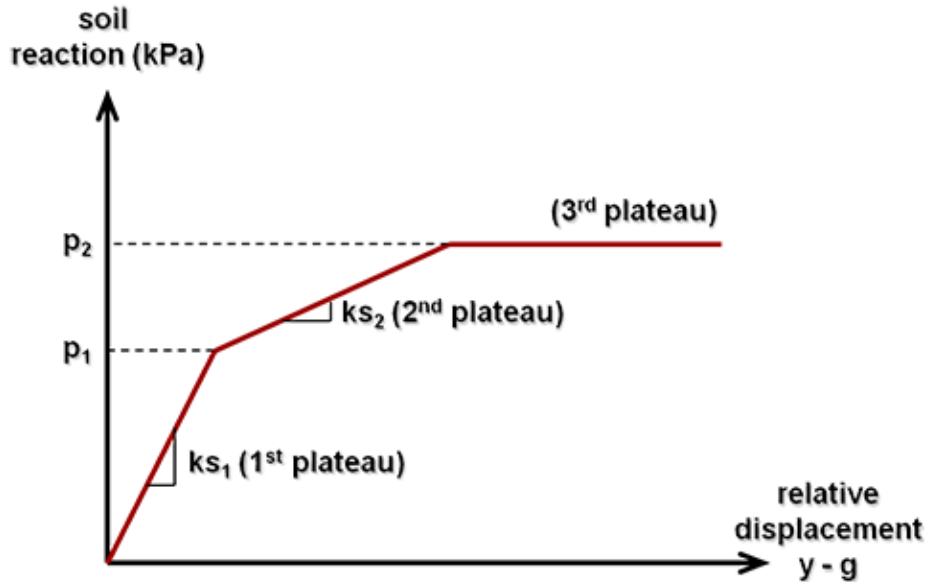


Figure G.2 : Lateral reaction mobilisation law

As shown on the above figure, the lateral reaction mobilisation law is expressed versus the relative displacement of the pile with respect to the soil. This allows the case of a free displacement $g(z)$ developing in one or more layers of the soil to be directly processed. According to the notations of the above figure, the lateral reaction of the soil $r(z)$ is expressed as follows:

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

Where:

- For the 1st plateau: $\alpha = Es_1$ & $\beta = 0$;
- For the 2nd plateau: $\alpha = Es_2$ & $\beta = p_1 \left(1 - \frac{Es_2}{Es_1}\right)$;
- For the 3rd plateau: $\alpha = 0$ & $\beta = p_2$;

For the discretisation of the finite element model chosen for the pile, the soil reaction vector is thus expressed according to following general formula:

$$\mathbf{R}^s = \mathbf{K}^s \cdot (\mathbf{y} - \mathbf{g}) + \mathbf{c}^e \quad (3)$$

Where:

- \mathbf{K}^s : soil stiffness matrix corresponding to elastic part of mobilisation curve in each element;
- \mathbf{c}^e : equivalent load vector corresponding to the "constant" part of the mobilisation curve in each element;
- \mathbf{g} : equivalent displacement vector corresponding to the free displacement of the soil.

The combination of equations (2) and (3) leads to the global formulation of the "pile + soil" system:

$$(\mathbf{K}^s + \mathbf{K}^e) \cdot \mathbf{y} = \mathbf{F}^{\text{ext}} + \mathbf{K}^s \cdot \mathbf{g} - \mathbf{c}^e \tag{4}$$

The management of the soil plastification is done by an iterative process during which the terms \mathbf{K}^s and \mathbf{c}^e change until a compatible solution is obtained, at all points of the pile, with the soil lateral reaction mobilisation law.

G.2.3. Implementation

The use of the model is based on the establishment and solving of the equation system (4). The elements of this system can be completed by support conditions introduced at any point of the pile in the form of a point elastic support characterised by a stiffness in lateral translation and a rotational force.

The solving of the final system gives the displacements, rotations and reactions at all points of the pile. Knowing the reactions, moments M and shear forces T are then calculated by integration according to the following general formula:

$$T(z) = \int_0^z [q(t) - r(t)] dt + T(0)$$

$$M(z) = \int_0^z T(t) dt + M(0)$$

The model also allows an equivalent **tangent** stiffness system at the pile head to be defined which is then used as input parameter for a global balance calculation of a footing on piles with the Groupie+ module. The head stiffness system consists of a symmetrical 2 x 2 stiffness "matrix" and a "constant" term according to following general formula:

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

G.2.4. Buckling calculation

G.2.4.1. Introduction

Buckling is the occurrence of a non-null lateral displacement under the effect of an axial load and in absence of lateral loads. This form of elastic instability appears at precise values of the axial load applied, which are called "buckling forces". The minimum value of these forces is called "critical buckling force".



Figure G.3 : Buckling

A direct analogy exists between buckling as elastic instability and "resonance" as dynamic instability which appears for precise values of the excitation frequency.

The approach introduced into Piecoef+ is based on this analogy and leads to the search for buckling forces according to the eigenvalue method benefiting from the matrix formulation obtained from discretisation into finite elements.

G.2.4.2. Formulation

Let us consider the case of a pile submitted to two opposite compression forces at its two ends. The 2nd order lateral balance of the pile is represented by the equation below:

$$EI \frac{d^4 y(z)}{dz^4} + F \frac{d^2 y(z)}{dz^2} = q(z) - r(z) \quad (5)$$

We search for the values of F allowing a non-null $y(z)$ solution to be obtained for this equation with no transverse loads on the pile $q(z) = 0$. Here, we are in the case of a locally elastic behaviour of the soil ($r = E_s \cdot y$) which leads to the following equation:

$$EI \frac{d^4 y(z)}{dz^4} + E_s \cdot y(z) + F \frac{d^2 y(z)}{dz^2} = 0 \quad (6)$$

By adopting the finite element model presented previously, equation (6) is represented by an equivalent matrix system:

$$(\mathbf{K}^s + \mathbf{K}^e) \cdot \mathbf{y} - F \cdot \mathbf{M} \cdot \mathbf{y} = \mathbf{0} \tag{7}$$

Where:

- \mathbf{K}^s : stiffness matrix of soil (1st order)
- \mathbf{K}^e : stiffness matrix of pile (1st order)
- \mathbf{M} : "rotations" matrix (2nd order)

System (7) can be rewritten as follows:

$$\mathbf{A} \cdot \mathbf{y} = F \cdot \mathbf{y} \text{ where } \mathbf{A} = \mathbf{M}^{-1} \cdot (\mathbf{K}^s + \mathbf{K}^e) \tag{8}$$

By definition, F is a buckling force if and only if equation (6) and therefore (8) allows a non-null solution \mathbf{y} . Mathematically, this means that F is an eigenvalue of matrix \mathbf{A} . Thus, to search for the buckling forces of the "pile + soil" system, all we need to do is to search for the eigenvalues of the associated \mathbf{A} matrix. The critical buckling force is then nothing more than the smallest eigenvalue of matrix \mathbf{A} .

Piecoef+ program thus automatically constitutes matrix A and outputs all of its eigenvalues (= buckling forces) and the associated eigenvectors (characteristic displacements of the potential buckling mechanisms).

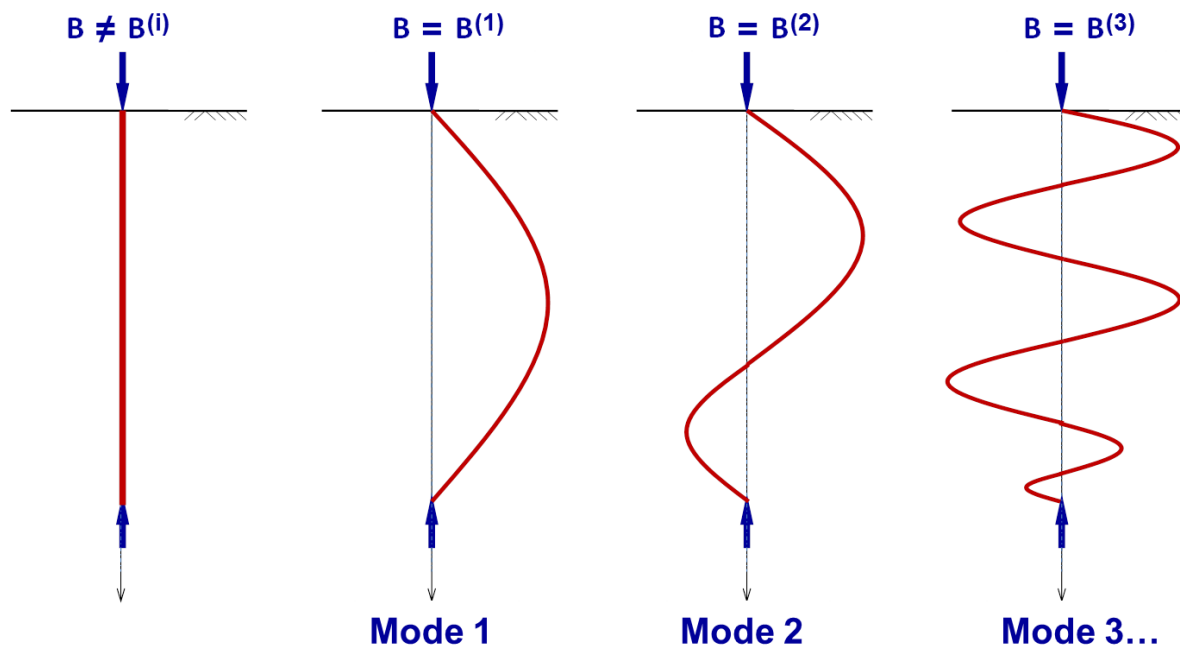


Figure G.4 : Buckling modes and associated critical loads

This additional calculation is done at the end of the pile balance solving iterative process. It therefore takes into account the stiffness of the pile, any support conditions, and the elastic part of the soil reaction (E_{s1} or E_{s2}) obtained on balance under the considered load conditions. In particular, in zones where the soil is completely plastified (3rd plateau), no additional reaction is taken into account.

The results obtained are identical to those from bibliography for simple cases (Souche, Mandel, Euler, etc.) or to those obtained by large displacement "step-by-step" numerical processing.

G.2.4.3. Taking 2nd order displacements into account

The search for buckling forces and associated displacements can be used as a basis for the estimation of 2nd order displacements generated in the pile under the effect of an axial force.

We consider the case of a pile initially having a non-null y_0 displacement corresponding either to a transverse load or, for example, to a defect in shape. This pile is then submitted to an axial force which is supposed to be entirely recovered at base (failsafe approach). The application of force F leads to an additional 2nd order displacement " y " as shown on the figure below.

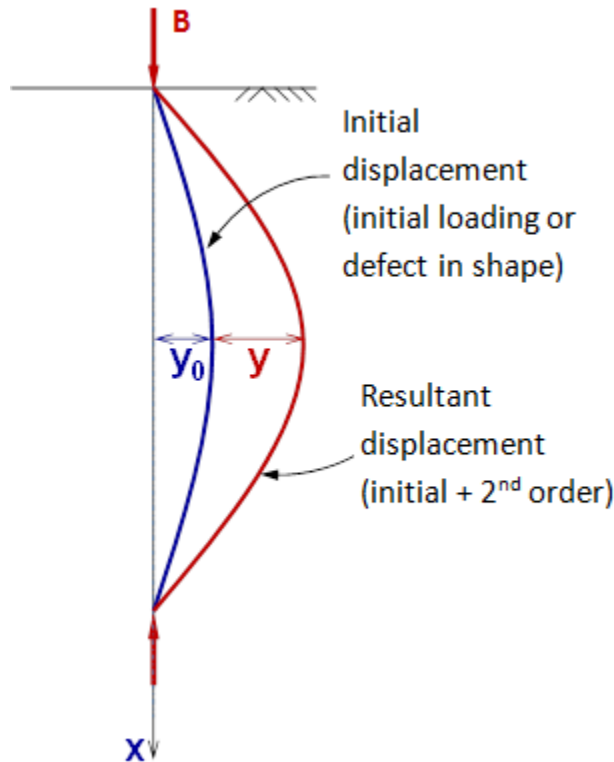


Figure G.5 : 2nd order displacement under an axial load

The 2nd order balance of the pile can thus be written:

$$EI \frac{d^4 y}{dz^4} + E_s y + F \frac{d^2}{dz^2} (y + y_0) = 0 \quad (9)$$

The discretisation of the pile into finite elements allows the previous equation to be expressed in the form of a homogeneous matrix system without second member:

$$(\mathbf{K}^s + \mathbf{K}^e) \cdot \mathbf{y} - F \mathbf{M} (\mathbf{y} + \mathbf{y}_0) = \mathbf{0} \quad (10)$$

That is with the notations of system (8):

$$\mathbf{A} \cdot \mathbf{y} = F \cdot (\mathbf{y} + \mathbf{y}_0) \quad (11)$$

With no initial displacement ($y_0 = 0$), we find system (8) verified by buckling forces F_i and associated displacements \mathbf{y}_i^c which are simply the eigenvectors of matrix \mathbf{A} :

$$\mathbf{A} \cdot \mathbf{y}_i^c = F_i \cdot \mathbf{y}_i^c \quad (12)$$

As matrix **A** is defined positive, its eigenvectors form an orthogonal base according to which it is possible to split any vector of the same space. In particular, solution "y" of equation (11) and initial displacement "y₀" can thus be expressed as follows:

$$\mathbf{y} = \sum_{i=1}^n \alpha_i \mathbf{y}_i^c \quad \& \quad \mathbf{y}_0 = \sum_{i=1}^n \alpha_i^0 \mathbf{y}_i^c \tag{13}$$

The α_i 's being the unknowns of the problem, whereas the α_i^0 's are known and can be evaluated by projection according to the formula below:

$$\alpha_i^0 = \frac{{}^t \mathbf{y}_i^c \cdot \mathbf{y}_0}{\|\mathbf{y}_i^c\|^2}$$

By combining equations (11), (12) and (13), we obtain the following system:

$$\sum_{i=1}^n \alpha_i F_i \mathbf{y}_i^c = F \sum_{i=1}^n (\alpha_i + \alpha_i^0) \mathbf{y}_i^c \tag{14}$$

That is, by projecting along each of the \mathbf{y}_i^c :

$$\alpha_i F_i = F(\alpha_i + \alpha_i^0) \quad i = 1..n \tag{15}$$

Or again:

$$\alpha_i = \frac{F}{F_i - F} \alpha_i^0 \quad i = 1..n \tag{16}$$

We therefore deduce the expression of the "resulting" displacement taking 2nd order terms into account:

$$\mathbf{y} + \mathbf{y}_0 = \sum_{i=1}^n (\alpha_i + \alpha_i^0) \mathbf{y}_i^c = \sum_{i=1}^n \frac{F_i}{F_i - F} \alpha_i^0 \mathbf{y}_i^c \tag{17}$$

Thus, for each eigendisplacement \mathbf{y}_i^c , the resulting displacement is amplified by an amplification factor $\frac{F_i}{F_i - F} > 1$ with respect to the initial displacement.

In particular, we can see that when F tends towards one of the values of F_i , the corresponding amplification factor tends towards infinity. The pile thus fails under composed bending before the critical buckling force is reached.

These developments are covered by a publication in the context of JNGG 2012 (F. Cuira – A simple method for studying buckling of a flexible pile in a multilayer soil – JNGG Bordeaux 2012).

G.2.5. Taking shear force displacements into account

All of the developments described previously are based on a discretisation of the pile into thin beam elements. The thin beam assumption is implicitly introduced by adopting Bernoulli model which consists in neglecting the contribution of the shear displacements (shear force). The validity of this assumption requires a pile length/diameter ratio at least higher than 10 in general or even 20 in certain support conditions. For a "short" or stiff pile and, generally, for a pile where shear displacements cannot be neglected when compared with the bending displacements, use of "Timoshenko" behaviour model adapted to thick beams is required.

The representation of this model by equations requires the definition, in addition to the product of inertia, of the shear stiffness called GS' . For a pile of uniform section, this can be estimated by the product of shear module G and "reduced" section S' (see user's manual, chapter G.3.3.2). The combination of the balance and behaviour equations gives the following equation system:

$$\begin{aligned}
 GS' \frac{d}{dz} \left(\theta - \frac{dy}{dz} \right) &= q(z) - r(z) \\
 GS' \left(\theta - \frac{dy}{dz} \right) + EI \frac{d^2 \theta}{dz^2} &= 0
 \end{aligned}
 \tag{18}$$

Where θ designates the distortion (or rotation) which, unlike the Bernoulli model, no longer coincides with the first derivative of the lateral displacement y .

This system is solved numerically by introducing a discretisation of the pile into thick beam elements. The elements used are 2-node elements with 8 degrees of freedom: two displacements, two rotations and their first 4 respective derivatives.

For this discretisation, the balance of the pile is represented by a matrix system similar to (2), of size $4(p+1) \times 4(p+1)$ where p designates the total number of elements.

G.3. User's manual

This chapter presents:

- the input parameters of Piecoef+ module.

Certain zones can only receive data with a physical signification (for example, an EI stiffness modulus must always be strictly positive).

Piecoef+ calculation parameter input window has 4 separate tabs. The data to be completed at each tab depends sometimes on certain choices made by the user: for example, the data to be completed for a pile calculation under transverse loads are not all the same as for a specific buckling calculation.

Note: in Piecoef+ module, the user can process either a single pile or several piles corresponding to different pile configurations for a given project (see paragraph G.3.1 below).

- the results supplied by Piecoef+ module. Here again, they depend in part on the data entered by the user and especially the type of calculation.

This chapter does not detail the users' interface itself and its handling operations (buttons, menus, etc.): these aspects are dealt with in part C of the manual.

G.3.1. Pile management

Piecoef+ module allows one or more piles to be processed in the context of a given Foxta project. However, the user works only on one of these piles at a time: the "active" pile is displayed above the tabs of the data input window.

- When Piecoef+ module is first opened for a given project, the module has only one pile (Pile 1/1). The user must therefore complete this first pile and can then, if required, create additional piles (see below).
- When a previously completed Piecoef+ module is opened, the pile displayed by default is pile 1/n (n being the total number of piles already created in the module). The user can then select another pile, add or delete piles.

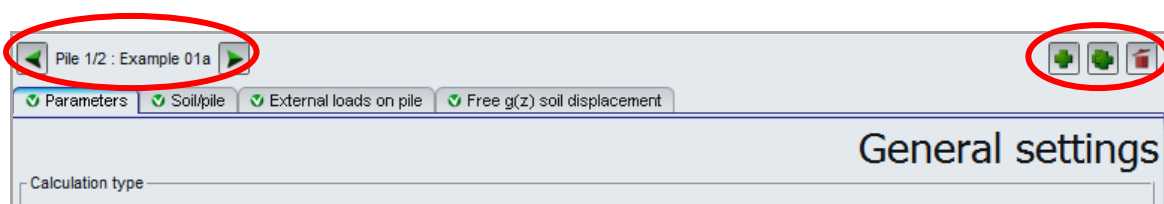







Figure G.6 : Management of piles in Piecoef+ module

The following operations can be done on the piles in Piecoef+ module:

- Add a pile: click  button: Foxta adds a new pile to the project, independent of the first one, with the same data input fields. Its number will be automatically incremented:
- To duplicate the current pile, click  button: Foxta will add a pile identical to the current pile to the project. The data is duplicated in this new pile but can be modified.
- To delete the current pile, click  button.
- To display the next pile or the previous pile, click  or  button.

As stated previously, "work" can be done on only one pile at a time: the procedure is therefore to select a pile, complete/modify its data, start the calculation then display the results for this pile. The user can then select another existing pile or create another pile and repeat these steps.

The following chapters describe the use of Piecoef+ for a given pile.

G.3.2. "Parameters" tab

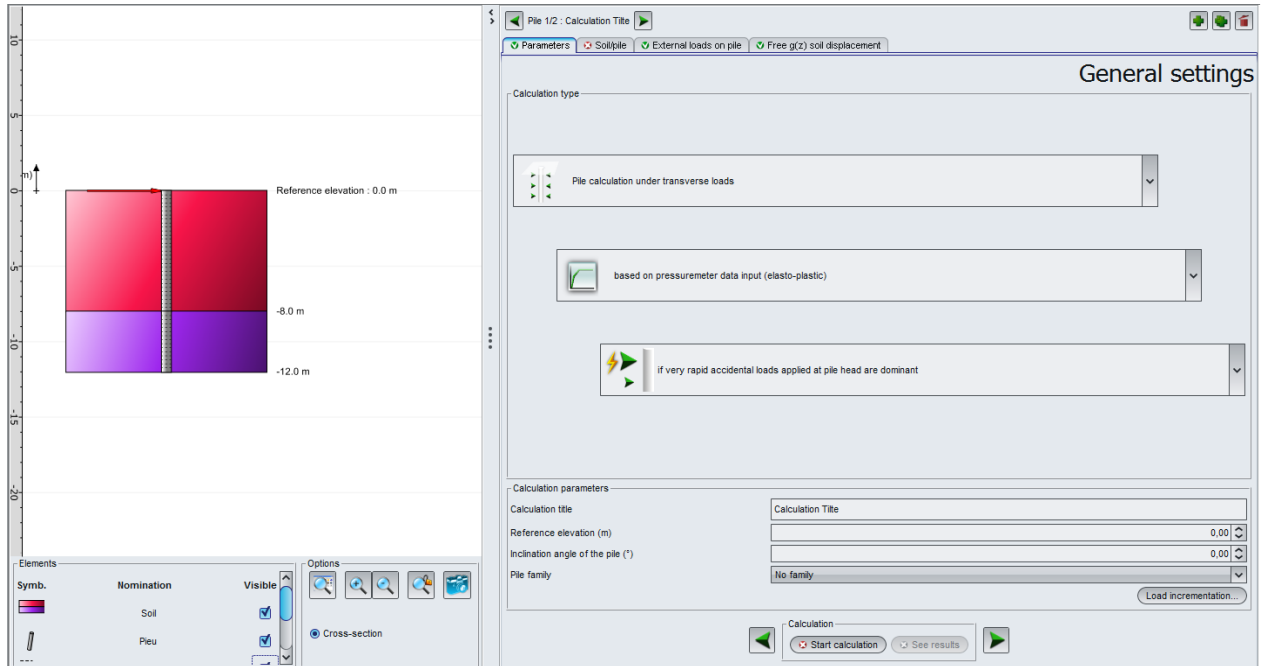


Figure G.7 : "Parameters" tab

G.3.2.1. "Calculation type" box

The **Calculation type** box allows several options to be selected thanks to 3 choice levels (cf. Figure G.7). The first choice level fixes the framework for the calculation, the next two levels control the definition mode for the mobilisation laws of the soil lateral reaction.

G.3.2.1.1. Pile calculation under transverse loads

This is the basic calculation mode (by default) allowing the modelling of a pile anchored in soil with elastoplastic behaviour and submitted to the application of various transverse loading conditions (point, distributed loads, free displacement $g(z)$, 2nd order effects under the effect of an axial force, etc.).

Four possibilities are then proposed to characterise the soil lateral reaction mobilisation law:

⇒ **From pressuremeter data (elastic)**: elastic mobilisation law characterised by a reaction coefficient k_s (kPa/m) defined from pressuremeter parameters:

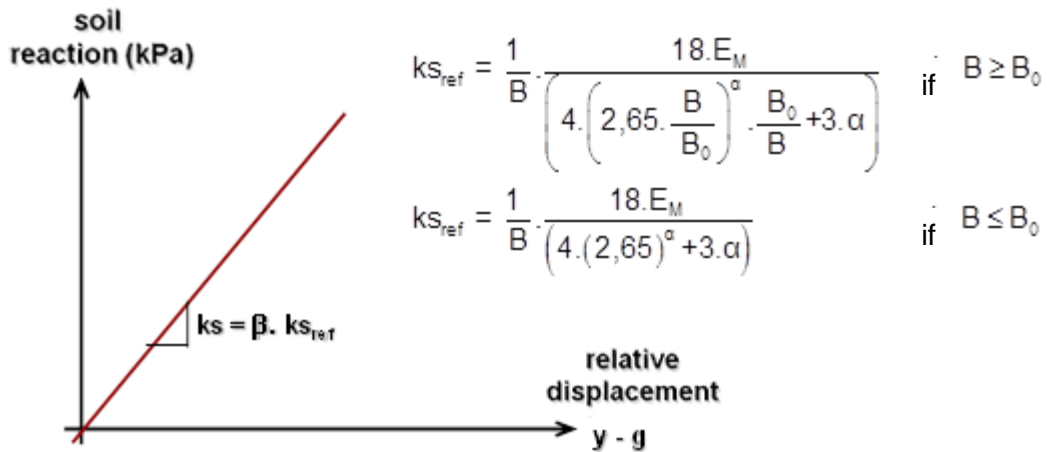


Figure G.8 : Soil lateral reaction mobilisation law: "from pressuremeter data (elastic)"

Where E_M refers to the pressuremeter modulus, α the rheological factor, B the diameter (equivalent) of the pile and B_0 the reference diameter taken as being equal to 0.6 m. Parameter β depends on the types of loads and is controlled by the 3rd choice level available:

- Under permanent loads: $\beta = 1$
- Under short term loads: $\beta = 2$

⇒ **From pressuremeter data (elastoplastic):** elastoplastic mobilisation law with three plateaux characterised from pressuremeter values according to the figure below:

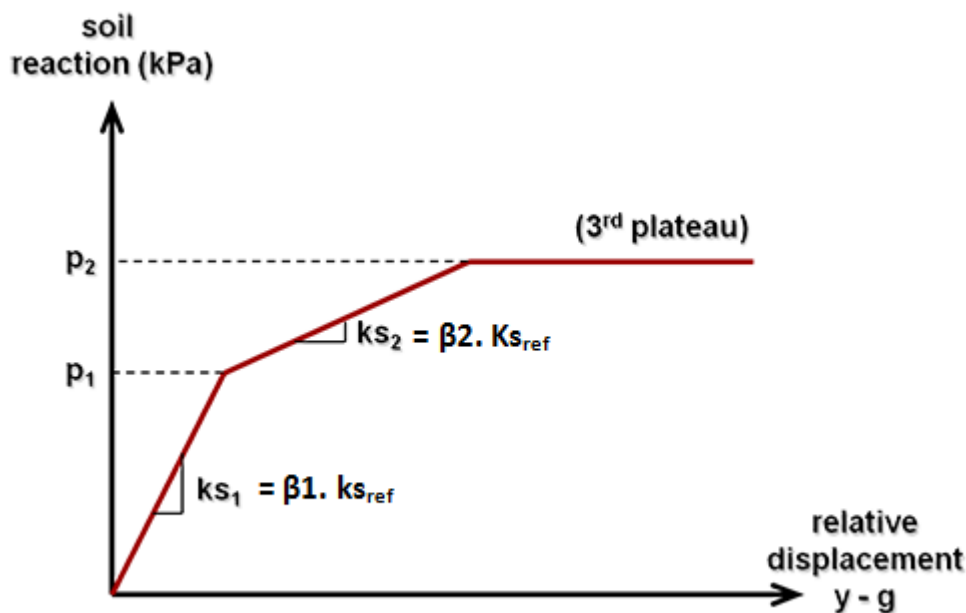


Figure G.9 : Soil lateral reaction mobilisation law: "from pressuremeter data (elastoplastic)"

The 3rd choice level allows values β_1 , β_2 , p_1 and p_2 to be fixed according to the types of loads:

Types of loads	β_1	β_2	p_1	p_2
If permanent loads applied at pile head are dominant	1	0	p_f^*	p_f^*
If loads due to transverse earth pressure are dominant		1/2		p_i^*
If short term loads applied at pile head are dominant	2	0		p_f^*
If very rapid accidental loads applied at pile head are dominant		1		p_i^*

Where p_f^* and p_i^* respectively refer to the net creep pressure and the net limit pressure of the soil from the pressuremeter test. Note that for the case where $p_1 = p_2$, $\beta_2 = 0$ and the mobilisation curve has two plateaux (elastic perfectly plastic).

⇒ **By manual input with 2 plateaux:** this option enables the user to define a "manual" mobilisation law with two plateaux (elastic perfectly plastic) by directly entering the values of k_s and p_{max} as shown on the figure below:

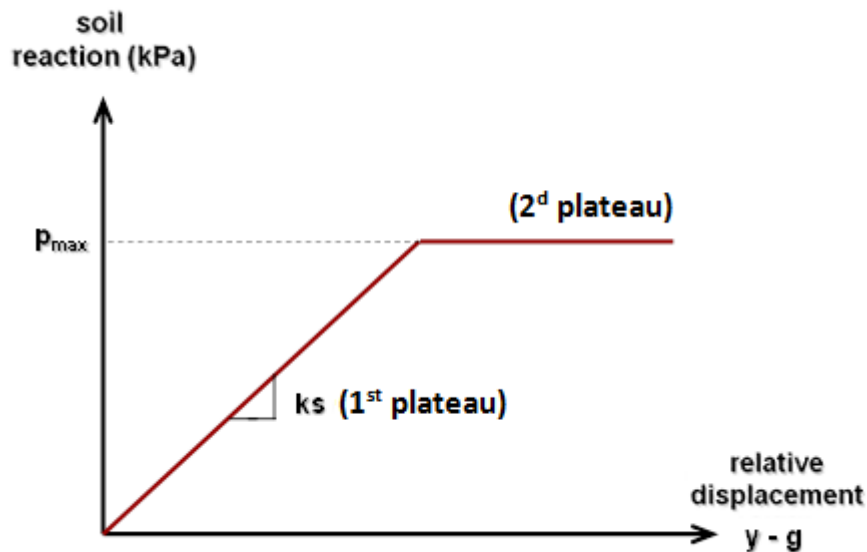


Figure G.10 : Soil lateral reaction mobilisation law: "by manual input with 2 plateaux"

⇒ **By manual input with 3 plateaux:** this option allows the user to define a "manual" mobilisation law with three plateaux (two slopes and a plastification plateau) by directly entering the values of k_{s1} , k_{s2} , p_1 and p_2 as shown on the figure below.

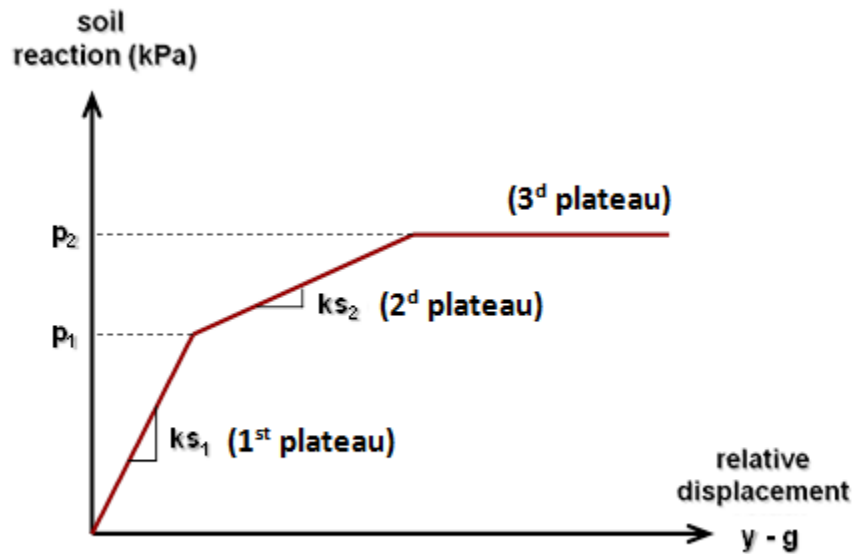


Figure G.11 : Soil lateral reaction mobilisation law: "by manual input with 3 plateaux"

Note: Piecoef+ does not take the group effect into account. The user shall adapt the mobilisation laws or the characteristics of the layers to simulate this effect.

G.3.2.1.2. Specific buckling calculation

This is a calculation mode specific to the calculation of the critical buckling load and of the associated failure mechanism knowing that this result is also accessible from a "calculation under transverse loads". The interest of this option is that the user shall only enter the data required for the buckling calculation.

This calculation is done considering an elastic apparent response from the soil. This is characterised by a reaction coefficient which can be estimated in two ways:

- ⇒ From the pressuremeter data (elastic): where $k_s = k_{s_{ref}}$.
- ⇒ By manual input (elastic)

G.3.2.2. "Calculation parameters" box

The **Calculation parameters** box allowing the following to be entered:

Designation	Units	Default value	Display condition	Mandatory value	Local checks
Calculation title	-	-	Always	Yes	-
Reference elevation	m	0.00	Always	Yes	-
Inclination angle of the pile (with respect to the vertical)	°	0.00	Always	Yes	-
Pile family	-	"No family"	Always	Yes	-

Table G.1 : "Parameters" tab: "Calculation parameters" box

The "Pile family" data is useful for a pile group calculation in combination with the Groupie+ module. In this case, the family allows a pile configuration to be identified and used for a Groupie+ calculation (also refer to the Groupie+ manual – Part H and especially its tutorial examples).

The "Load incrementation" button in the "Calculation parameters" box gives access to the following window:

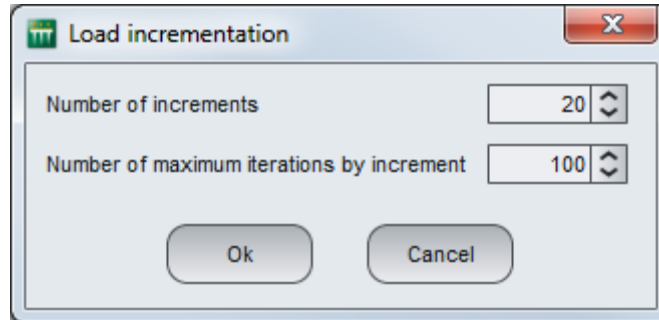


Figure G.12 : Load incrementation

These parameters allow the iterative process related to the soil plastification management to be controlled:

- The external load on the pile is subdivided into several "increments" (20 by default);
- For each increment, the soil reaction mobilisation level in each element is adjusted by an iterative process (limited by default to 100 iterations).

Designation	Units	Default value	Display condition	Mandatory value	Local checks
Number of increments	-	20	Always	Yes	-
Number of maximum iterations by increment	-	100	Always	Yes	-

Table G.2 : "Parameters tab: "Load incrementation"

The values proposed by default are sufficient for most situations. However, the user can check the convergence of the calculations by ensuring that an increase in the proposed default values does not affect the results. If it does, the user shall increase the number of increments.

G.3.3. "Soil/pile" tab

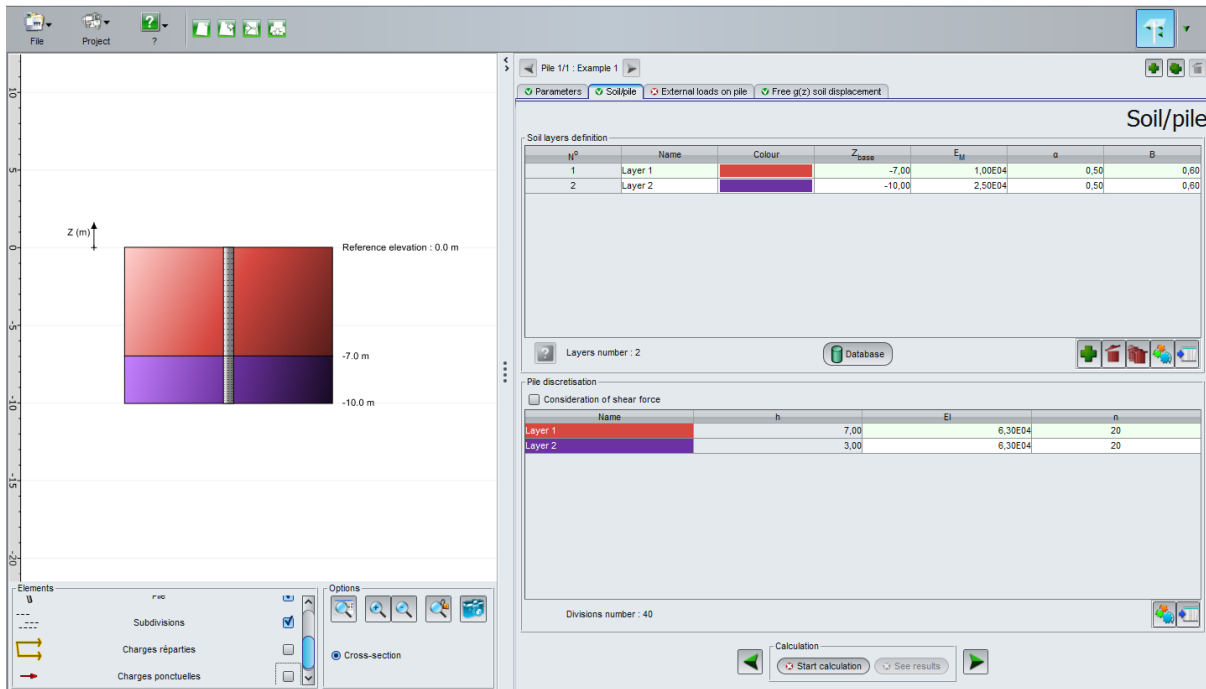



Figure G.13 : "Soil/Pile" tab

This tab includes the soil layers definition box and the pile definition and pile discretisation box.

Foxta offers the possibility of saving soil layers in the soil database of the project and/or in the global soil database by clicking  button.

This saves the soil layers with their parameters to avoid re-entering them when creating a new pile in Piecoef+ module or another Foxta project.

Use of the soil database is described in detail in part C of the manual.

G.3.3.1. "Soil layers definition" box

Here, the soil cross-section is defined around the studied pile: the first table below lists all of the soil parameters, independent of the type of calculation chosen. The correspondence between the type of calculation chosen and the data to be effectively completed is given in the second table below.


IMPORTANT: by convention, in Piecoef+, the base of the piles is defined at base of the last soil layer. For example, to define a 12 m long pile, the soil cross-section must be defined down to a depth of 12 m.

Designation of parameters	Units	Default value	Display condition	Mandatory value	Local checks
Z_{base} : bottom level of the layer	m	1 m lower than the layer base above	Always	Yes if displayed	Separate values decreasing with the depth
E_M : pressuremeter modulus	kPa	-	According to type of calculation	Yes if displayed	> 0
α : Menard's rheologic coefficient	-	-	According to type of calculation	Yes if displayed	$0 < \alpha \leq 1$
B : drilling diameter	m	-	Always	Yes if displayed	> 0
P_f^* : net creep pressure	kPa	-	According to type of calculation	Yes if displayed	> 0
P_l^* : net limit pressure	kPa	-	According to type of calculation	Yes if displayed	$\geq P_f$
K_s : reaction coefficient of the soil	kPa/m	-	According to type of calculation	Yes if displayed	≥ 0
P_{max} : plastification pressure of soil	kPa	-	According to type of calculation	Yes if displayed	≥ 0
K_{s1} : reaction coefficient of soil for the first plateau	kPa/m	-	According to type of calculation	Yes if displayed	> 0 and $\geq K_{s2}$
P_1 : soil plastification pressure at the 1st plateau	kPa	-	According to type of calculation	Yes if displayed	≥ 0 and $\leq P_2$
K_{s2} : reaction coefficient of soil for the 2nd plateau	kPa/m	-	According to type of calculation	Yes if displayed	≥ 0
P_2 : plastification pressure of soil at the 2nd plateau	kPa	-	According to type of calculation	Yes if displayed	≥ 0

Table G.3 : "Soil/Pile" tab: "Soil layers definition" box

Type of calculation	Type of data	Soil data to be entered
Pile calculation under transverse loads	From pressuremeter data (elastic)	Z_{base}, B, E_M, α
	From pressuremeter data (elastoplastic)	$Z_{base}, B, E_M, \alpha, p_f^*, p_l^*$
	By manual input 2 plateaux	$Z_{base}, B, K_s, P_{max}$
	By manual input 3 plateaux	$Z_{base}, B, K_{s1}, P_1, K_{s2}, P_2$
Specific buckling calculation	From elastic data	Z_{base}, B, E_M, α
	By manual input	Z_{base}, B, K_s

Table G.4 : "Soil/Pile" tab: "Soil layers definition" box – Data required according to type of calculation chosen

Note: help diagrams are available for the "manual" input modes. An example of a help diagram is given below. To access these diagrams, click  button below the table.

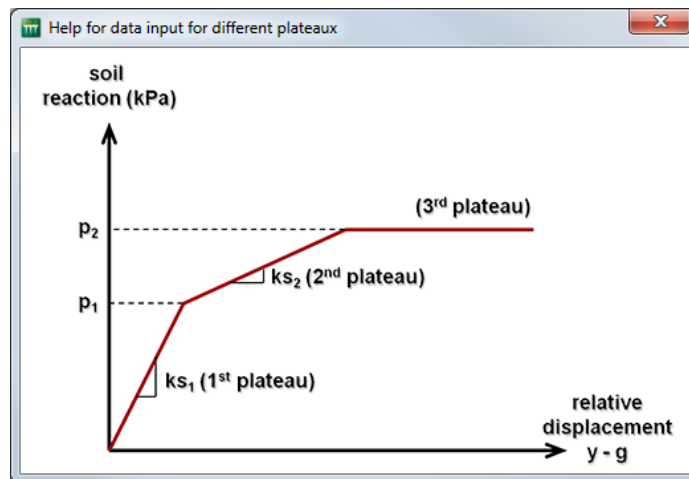


Figure G.14 : Help diagram illustrating the parameters of the 3-plateau "manual" behaviour law

G.3.3.2. "Pile discretisation" box

Here, the aim is to define the characteristics of the pile within each soil layer.

The number of subdivisions n controls the density of the finite element mesh considered for the pile. It is recommended to refine the mesh as this does not greatly affect the calculation time and guarantees a sufficiently accurate result.

Concerning the consideration of shear force, the contribution of these displacements is generally negligible when the "length/diameter" ratio is higher than 10 or even 20 (thin beam assumptions). For low slenderness ratio piles such as shafts for example, this assumption is not valid and it may be necessary to adopt the general thick beam model which requires the definition, in addition to the product of inertia, of the shear stiffness GS' equal to the product of the shear modulus G and the reduced section S' .

Designation of parameters	Units	Default value	Display condition	Mandatory value	Local checks
Tick box 'consideration of shear force'	-	Unticked	For calculations of "Pile calculation with lateral load" type	Yes if displayed	
H : soil thickness	m	-	Always	Completed automatically	-
EI : product of inertia of pile	kN.m ²	-	Always	Yes	> 0
n : subdivisions number inside the layer	-	10	Always	Yes	5 ≤ n < 4000
GS' : shear stiffness	kN	-	If the 'Consideration of shear force' box is ticked	Yes	> 0

Table G.5 : "Soil/Pile" tab: "Pile discretisation" box

For a homogeneous material, the shear modulus is expressed as a function of the Young's modulus E and the Poisson ratio ν by relation: $G = E/2(1+\nu)$. The reduced section S' is expressed as the section of the pile S multiplied by a reduction factor k depending on the geometrical shape of the section, that is $S' = k \times S$. The figure below gives the values of k to be considered for several current cases:






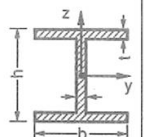
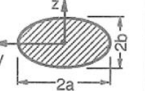
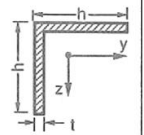
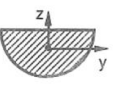
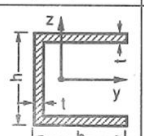
Sections pleines		Sections à parois minces	
	Rectangle $k = \frac{5}{6} = 0.833$		Tube circulaire $k = 0.5$
	Cercle $k = \frac{6}{7} = 0.857$		Tube carré $k = 0.416$
	Tube épais $k = \frac{6}{7 + 20 \alpha^2}$ $\alpha = \frac{b/a}{1 + b^2/a^2}$		Section I (b = h) EF: $k_z = 0.32$ $k_y = 0.69$
	Ellipse $k_z = \frac{12(3a^2 + b^2)}{40a^2 + 16b^2}$		Cornière (b = h) EF: $k = 0.358$
	Demi-cercle $k_z = 0.766$ $k_y = 0.863$		Section U (b = h) EF: $k_z = 0.235$ $k_y = 0.618$

Figure G.15 : Values k to be considered for calculation of reduced section S' for several current cases

Solid sections
 Rectangle
 Circle
 Thick tube
 Ellipse
 Half circle

Thin wall sections
 Circular tube
 Square tube
 Section I
 Angle
 U section

Note: consideration of shear force is not accessible for a specific buckling calculation.

G.3.4. "External loads on pile" tab

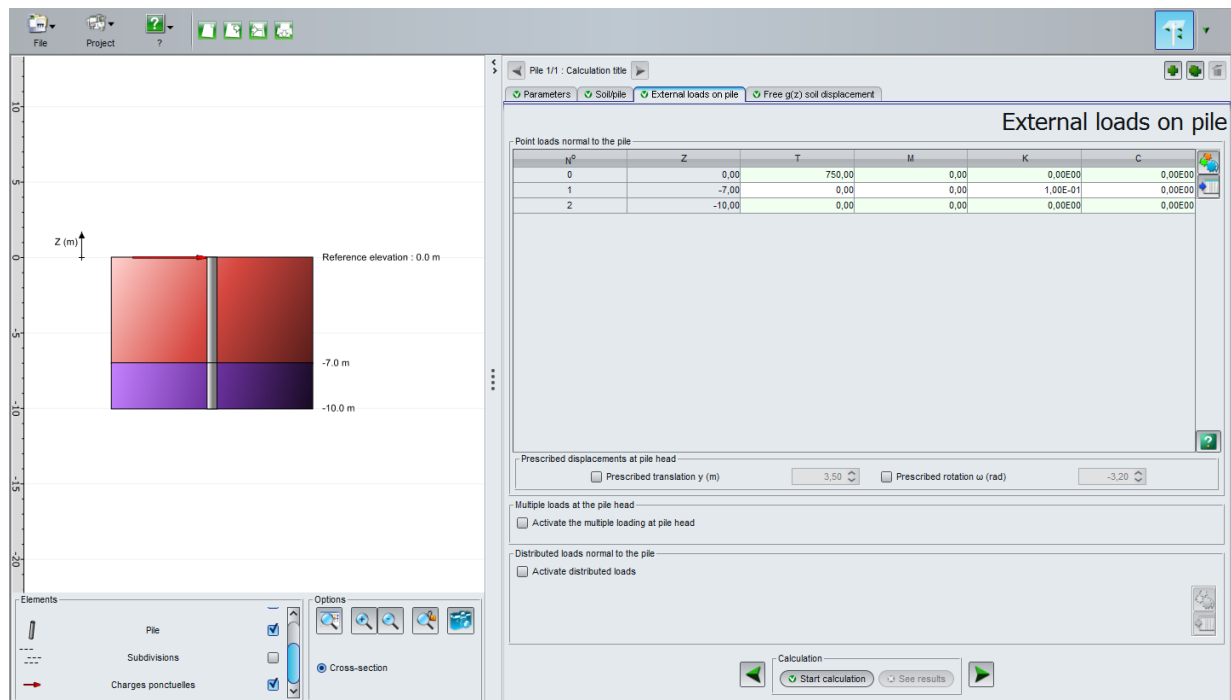


Figure G.16 : "External loads on pile" tab

This tab is used to define the various types of loads applied to the pile. Each type of load is associated to a specific box.

Note: for a specific buckling calculation, only the "point loads normal to the pile" box is accessible and only the point stiffnesses (K, C) can be defined.

G.3.4.1. "Point loads normal to the pile" box

This box is used to define the point loads on the pile. These are expressed in the pile local coordinate system and include 4 components: a side force T (perpendicular to the pile), a bending moment M, a point translation stiffness K and a point rotational stiffness C. These stiffnesses are to be defined (if necessary) in addition to those (surface) representative of the soil and defined in the previous tab.

The number of rows in this table is equal to the number of layers defined in the soil cross-section plus one: indeed, the point loads normal to the pile can be applied only at the upper and lower limits of the layer.

REMINDER: the side force T is expressed in the pile local coordinate system; in particular, for an inclined pile, this force remains perpendicular to the pile and is therefore not horizontal.

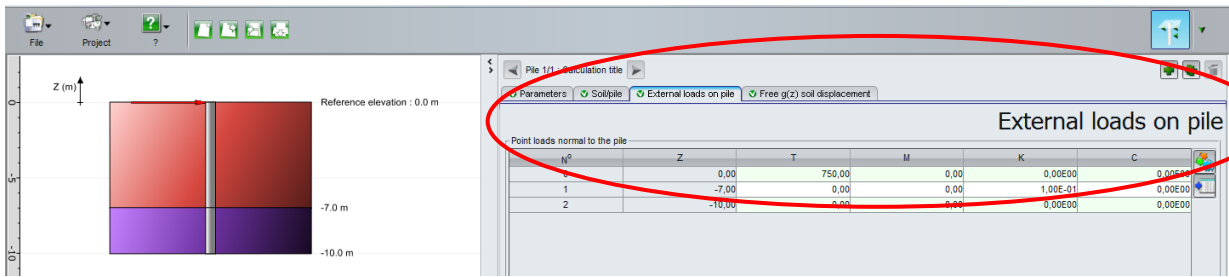



Figure G.17 : "External loads on pile" tab – Point loads normal to the pile

Designation of parameters	Units	Default value	Display condition	Mandatory value	Local checks
N° : loads order	-	-	Always	Completed automatically	-
Z : load elevation	M	-	Always	Completed automatically	-
T : point side force	kN	0.00	Always	Yes but all can be null	-
M : point bending moment	kN.m	0.00	Always		-
K : restoring point stiffness in lateral translation, normal to pile axis (*)	kN/m	0.00	Always		≥ 0
C : restoring point stiffness in rotation (**)	kN.m/rad	0.00	Always		≥ 0

(*): To simulate a hinge, take $K=1^{e}10$ kN/m.

(**): To simulate a beam clamping, take $K=1^{e}10$ kN/m and $C= 1^{e}10$ kN.m/rad.

Table G.6 : "External loads on pile" tab: "Point loads normal to the pile" box

Clicking  button opens the load definition help window:

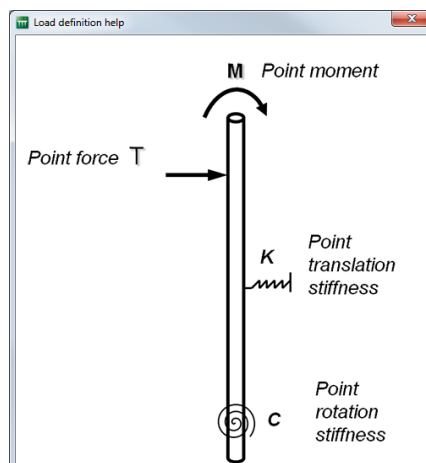


Figure G.18 : Load definition help

G.3.4.2. "Prescribed displacements at pile head" box

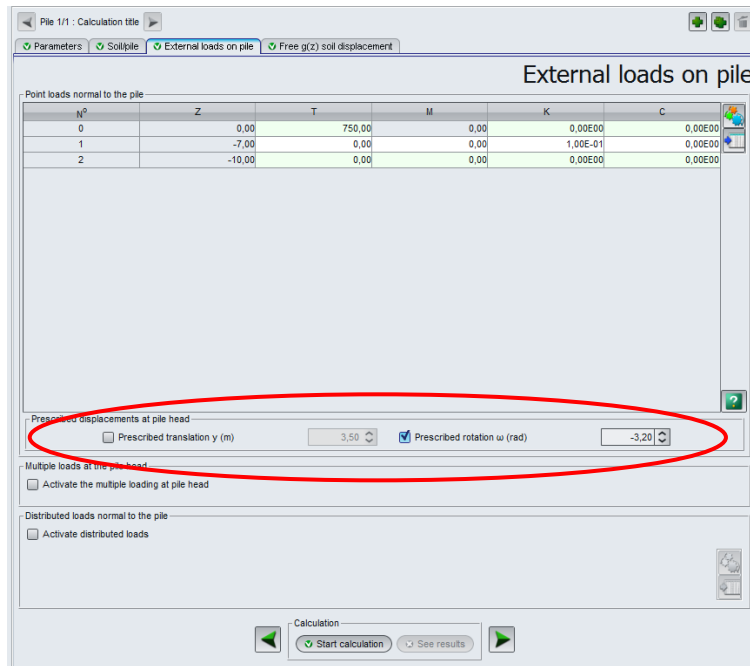


Figure G.19 : "External loads on pile" tab – Prescribed displacements at pile head

With this box, the user can impose a translation or a rotation at pile head. The definition of a prescribed translation (resp. rotation) at the head deactivates the prescribed side force (resp. moment) at the head in the previous box.

Designation of parameters	Units	Default value	Display condition	Mandatory value	Local checks
y : imposed translation at pile head: tick box and value	m	-	-	Value to be defined if the tick box is ticked	-
ω : imposed rotation at pile head: tick box and value	Rad	-	-	Value to be defined if the tick box is ticked	-

Table G.7 : "External loads on pile" tab: "Prescribed displacements at pile head" box

Note: the prescribed displacements at pile head will not be displayed or considered if multiple loads at the pile head are activated.

G.3.4.3. "Multiple loads at the pile head" box

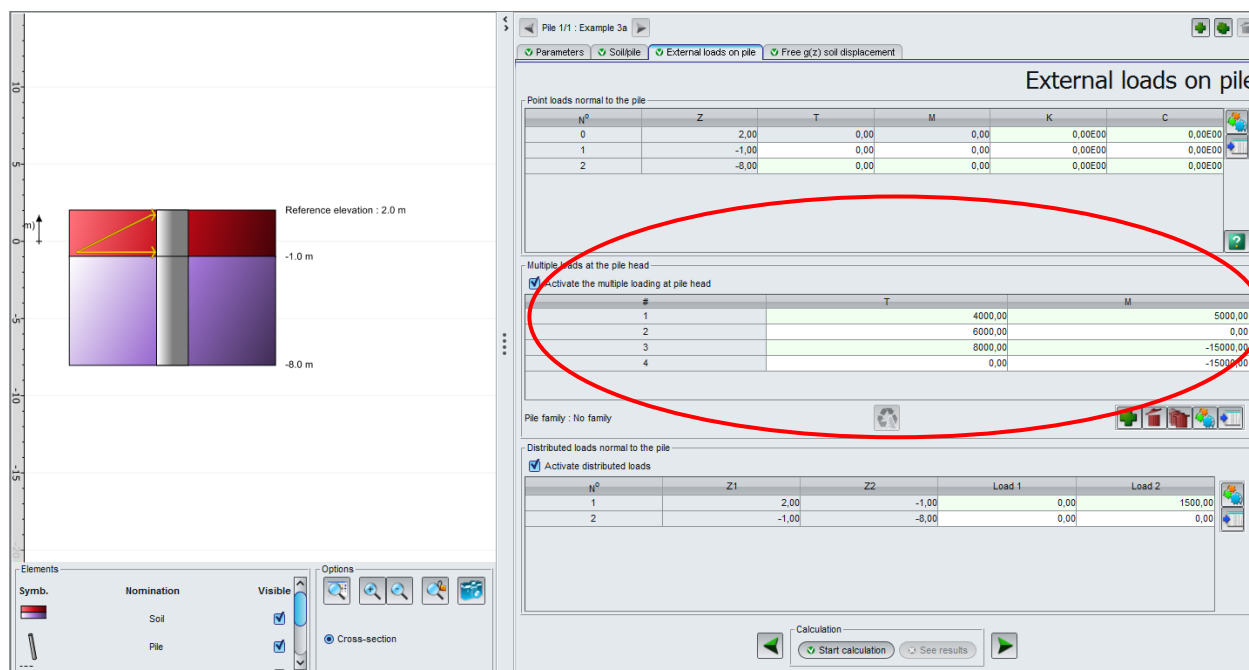


Figure G.20 : "External loads on pile" tab – Multiple loads at the pile head

This box allows the user to define several load cases (T, M) at pile head.


G.3.4.3.1. Activate the multiple loading at pile head

The data below is to be completed if the "Activate the multiple loading at pile head" tick box is activated. In this case, at least one row must be entered in the corresponding table. Also, all defined rows must be completed.


Designation of parameters	Units	Default value	Display condition	Mandatory value	Local checks
N°: load case number at pile head	-	-	For each line created in the table	Incremented automatically	-
T: side force at pile head	kN	-		Yes	On each row, one of the 2 values must not be null
M: bending moment at pile head	kN.m	-		Yes	


Table G.8 : "External loads on pile" tab: "Multiple loads at the pile head" box

Reminder: the prescribed displacements at pile head will not be displayed or considered if multiple loads at the pile head are activated.


The pile family is displayed under the table of this box (according to the data entered for the "Parameters" tab). If a family has effectively been defined in "Parameters" tab, "load cases import from Groupie+ wizard" is accessible by clicking  button. Its use is described in the next subchapter.

G.3.4.3.2. Load cases import from Groupie+

As stated previously, if a family has been defined in "Parameters" tab, "Load cases import from Groupie+ wizard" is accessible by clicking  button. A specific wizard is then displayed (cf. Figure G.21).

- In "Import directory" box, indicate the directory where the Groupie+ calculation to be imported is found. By default, the wizard displays the directory of the current project. If need be, use Browse  button. In the left hand box, Foxta displays the piles available in the selected directory.
- Select the chosen pile and the import axis (along Ox or along Oy): the calculation date is displayed on the right. A warning message may tell that the calculation date is old and ask the user to check the content of the imported values.

The values of the T and M pairs (Side force - kN - and Bending moment - kN.m) contained in the selected file are displayed in the right hand box: these are the pairs which will be imported if the user validates this window.

- Indicate whether the existing pairs (T, M) in the current project must be replaced or whether pairs (T, M) are to be added to the existing pairs of the current project.
- Click  button.

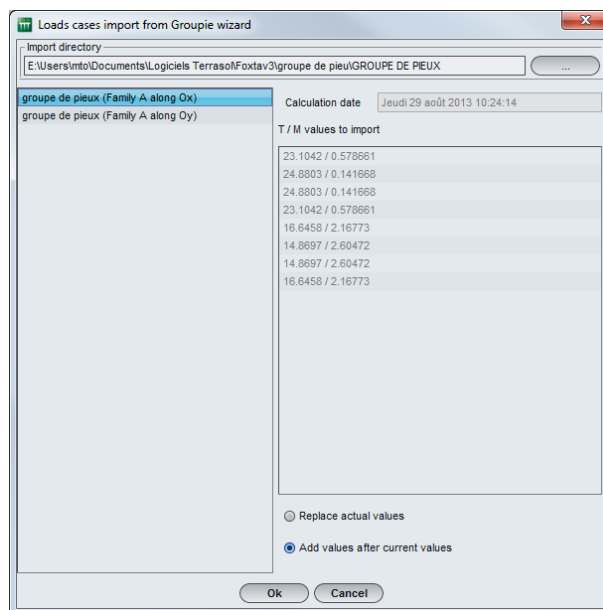


Figure G.21 : Load cases import from Groupie+ wizard

The data imported is now available in the form of load cases at the pile head (T, M) in Piecoef+ module.

G.3.4.4. "Distributed loads normal to the pile" box

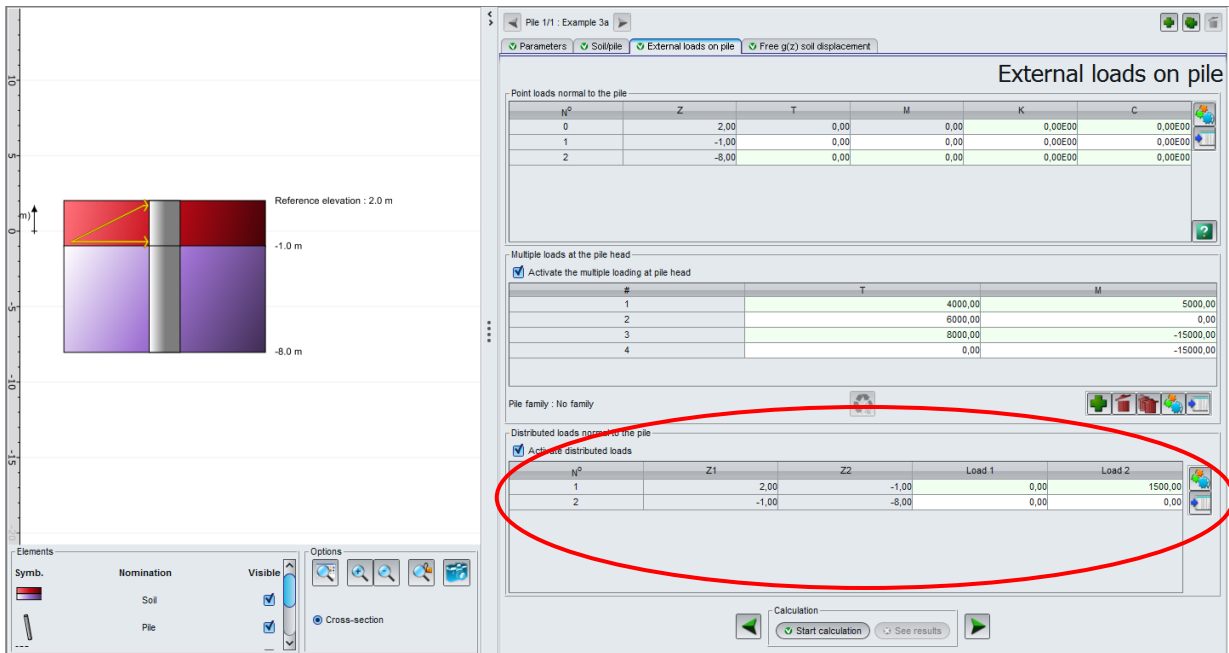


Figure G.22 : "External loads on pile" tab – Distributed loads normal to the pile

This box allows the user to define the distributed loads normal to the pile (local coordinate system) in the form of a trapezoidal load on the thickness of each layer. These loads are taken as positive from left to right.

The data below is to be completed if the "Activate distributed loads" tick box is activated:

Designation of parameters	Units	Default value	Display condition	Mandatory value	Local checks
N°: loads order	-	-	If 'Activate distributed loads' is ticked	Completed automatically	-
Z1: top level of the load	m	-		Completed automatically	-
Z2: base level of the load	m	-		Completed automatically	-
Ch. 1: load value at the top of the layer	kPa	0.00		Yes but all can be null	-
Ch. 2: load value at the bottom of the layer	kPa	0.00			-

Table G.9 : "External loads on pile" tab: "Distributed loads normal to the pile" box

The number of rows in this table is therefore fixed: it is equal to the number of layers defined in the soil cross-section and some data is completed automatically according to the soil cross-section (however, it is possible not to define distributed loads in the table if the project has none).

G.3.5. "Free g(z) soil displacement " tab

Note: This tab is accessible only for a pile calculation under transverse loads.

This function (optional) allows the user to define a free g(z) soil displacement around the pile: considering such a displacement implies that the lateral reaction of the soil does not depend on the lateral displacement of the pile but on the relative displacement of the pile $y(z)$ with respect to the (free) displacement of the soil $y(z)-g(z)$.

This free soil displacement generally occurs within a compressible layer under the effect of a backfill built after the implementation of the piles as shown on the figure below.

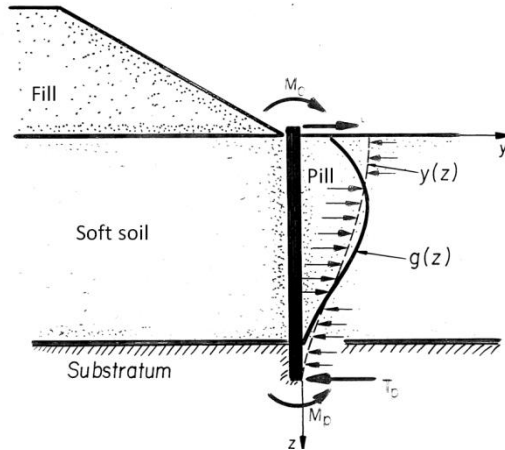


Figure G.23 : Example of development of a free g(z) displacement

Layer	z	g(z)
Argiles molles	-2.67	0.0200
Argiles molles	-3.00	0.0324
Argiles molles	-3.33	0.0348
Argiles molles	-3.67	0.0370
Argiles molles	-4.00	0.0392
Argiles molles	-4.33	0.0412
Argiles molles	-4.67	0.0431
Argiles molles	-5.00	0.0448
Argiles molles	-5.33	0.0463
Argiles molles	-5.67	0.0476
Argiles molles	-6.00	0.0486
Argiles molles	-6.33	0.0494
Argiles molles	-6.67	0.0498
Argiles molles	-7.00	0.0500
Argiles molles	-7.33	0.0498
Argiles molles	-7.67	0.0493
Argiles molles	-8.00	0.0484
Argiles molles	-8.33	0.0471
Argiles molles	-8.67	0.0454
Argiles molles	-9.00	0.0432
Argiles molles	-9.33	0.0406
Argiles molles	-9.67	0.0374
Argiles molles	-10.00	0.0338
Argiles molles	-10.33	0.0296
Argiles molles	-10.67	0.0249
Argiles molles	-11.00	0.0196
Argiles molles	-11.33	0.0137

Figure G.24 : "Free g(z) soil displacement" tab

G.3.5.1. "Free g(z) soil displacement" box

The data below is to be completed if the "Define a g(z) displacement" tick box is activated:

Designation of parameters	Units	Default value	Display condition	Mandatory value	Local checks
Layer	-	-	If "Define a g(z) displacement" is ticked	Completed automatically according to Z	-
Z: elevation	m	-		Yes	The series of values must be strictly decreasing
g(z): free displacement of soil	m	-		Yes	-

Table G.10 : "Free g(z) soil displacement" tab "Free g(z) soil displacement" box

This table can be completed manually or automatically by the g(z) wizard described below.

Note: the free g(z) displacement can be introduced directly by any (z, g(z)) pairs. In particular, Z values need not be compatible with the pile mesh. Indeed, the calculation engine systematically applies a re-interpolation of these values to express the g(z) values at the calculation points.

The free g(z) displacement is shown on the graphical representation:

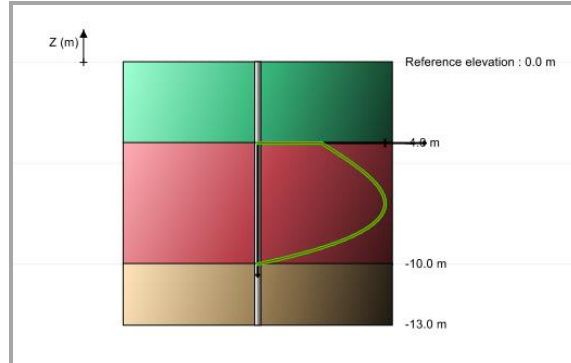


Figure G.25 : Graphical representation of the free g(z) displacement

G.3.5.2. g(z) wizard using Eurocode 7

This wizard generates, over the height of a given layer, a free g(z) soil displacement in compliance with the provisions of the Eurocode 7 standard for deep foundations (NF P 94 262): this is a third degree polynomial function characterised by an amplitude g_{max} and 4 coefficients A1 to A4. The deep foundation standard proposes an empirical method for evaluating the g_{max} amplitude of the g(z) function expressed as a percentage of the height of the compressible layer. This percentage depends on the geometry of the backfill, the relative position of the pile with respect to the base of the backfill and the available safety vis-à-vis the stability of the whole.

For coefficients A1 to A4, the deep foundation standard proposes two sets of coefficients (curves I and II in the interface) according to the presence or not of a less deformable layer at the surface:

- Set 1: to be used in the general case;
- Set 2: to be used in the case of a less deformable layer of significant height at the surface (greater than 30% of the height of the compressible layer).

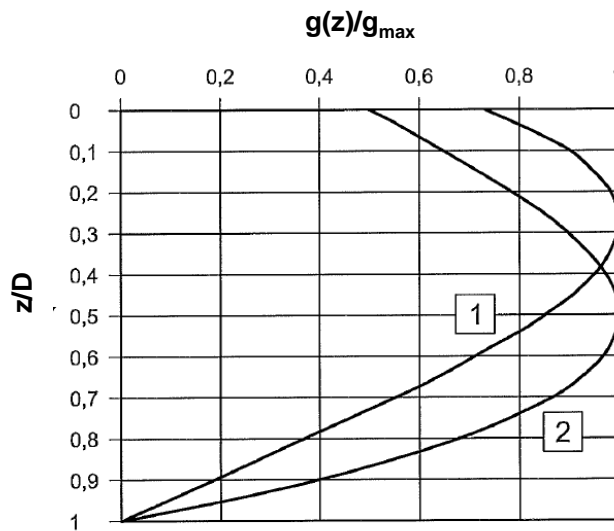



Figure G.26 : $g(z)$ function - Curves 1 and 2 as defined in Eurocode 7

This wizard is accessible by  button:

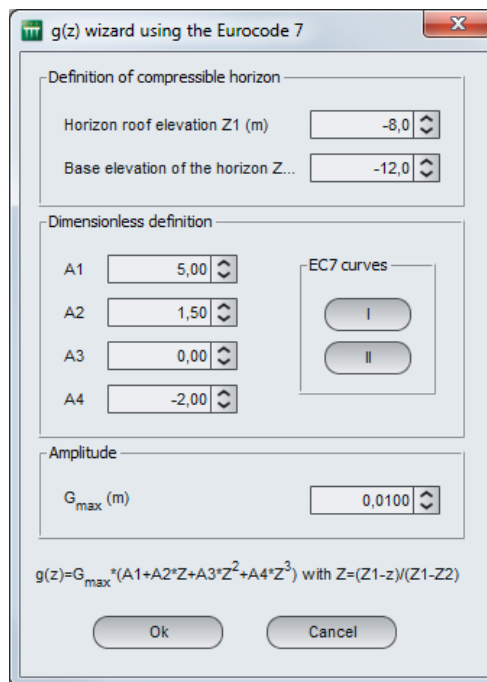


Figure G.27 : $g(z)$ wizard using the Eurocode 7

"Definition of compressible horizon" box

Designation of parameters	Units	Default value	Display condition	Mandatory value	Local checks
Z1: horizon roof elevation	m	0.00	Always	Yes	Z1>Z2
Z2: base elevation of the horizon	m	0.00	Always	Yes	Z1>Z2

Table G.11 : g(z) wizard: "Definition of compressible horizon" box

"Dimensionless definition" box

Designation of parameters	Units	Default value	Display condition	Mandatory value	Local checks
A1	-	Coefficients A1 to A4 are proposed according to the deep foundation standard	Always	Yes	-
A2	-		Always	Yes	-
A3	-		Always	Yes	-
A4	-		Always	Yes	-


Table G.12 : g(z) wizard: "Dimensionless definition" box

"Amplitude" box

Designation of parameters	Units	Default value	Display condition	Mandatory value	Local checks
G _{max} : maximum amplitude of free displacement of soil in compliance with the deep foundation standard	m	-	Always	Yes	-

Table G.13 : g(z) wizard: "Amplitude" box

G.3.5.3. Import wizard for a Piecoef+ displacement

The user can import a Piecoef+ displacement by clicking  button under the g(z) table:

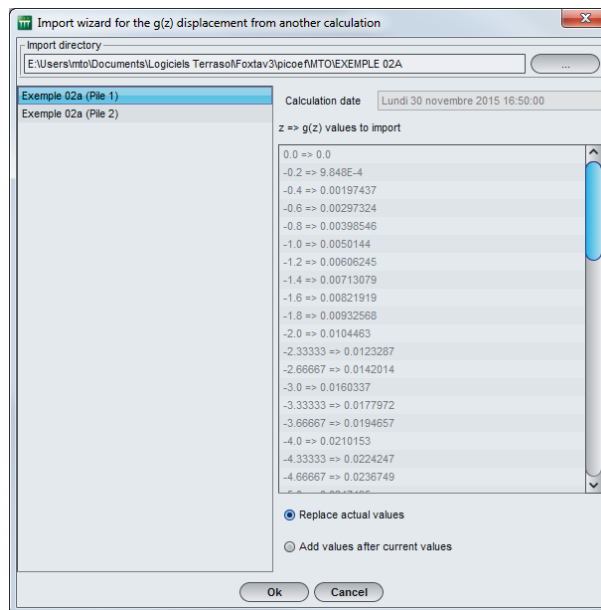




Figure G.28 : Import wizard for a Piecoef+ displacement

- On the top of the window, Foxta indicates by default the directory and the name of the current project. By clicking Browse  button, the user can select another project in the same directory or in a different directory.
- Select a pile in the left hand box: the calculation date of this pile is displayed on the right. A warning message may indicate that the calculation date is old and ask the user to check the content of the imported values.
- Foxta displays the values to be imported in the right hand frame "z => g(z) values to import".
- Indicate whether the existing g(z) values of the current project are to be replaced or whether imported values are to be added after the existing values of the current project.
- Click  button.

The imported values are now available in the project.

The number of rows in this table is therefore fixed: it is equal to the number of layers defined in the soil cross-section and some data is completed automatically according to the soil cross-section (however, it is possible not to define distributed loads in the table if the project has none).

G.3.6. "Initial displacement of pile $y_0(z)$ " tab

Note: this tab is accessible only for a specific buckling calculation.

This function (optional) allows the user to define an initial displacement $y_0(z)$ for the pile (for a defect in shape for example). On the basis of this displacement, Piecoef+ evaluates the bending loads and the 2nd order displacements generated by applying an axial force at the head of the pile.

The data below is to be completed if "Define a $y_0(z)$ displacement" tick box is activated:

Designation of parameters	Units	Default value	Display condition	Mandatory value	Local checks
Layer	-	-	If "Define a $y_0(z)$ displacement" is ticked	Completed automatically according to Z	-
Z: elevation	m	-		Yes	The set of values must be strictly decreasing
$y_0(z)$: initial deflection of the pile	m	-		Yes	-

Table G.14 : "Free $g(z)$ soil displacement" tab "Free $g(z)$ soil displacement" box

This table can be completed manually or automatically by an import wizard the use of which is identical to the one described in chapter G.3.5.3.

Note: the initial displacement $y_0(z)$ can be introduced directly by any pair $(z, y_0(z))$. In particular, Z values needn't to be compatible with the pile mesh. Indeed, the calculation engine systematically applies a re-interpolation of these values to express the $y_0(z)$ values at calculation points.

The free $y_0(z)$ displacement is shown on the graphical representation:

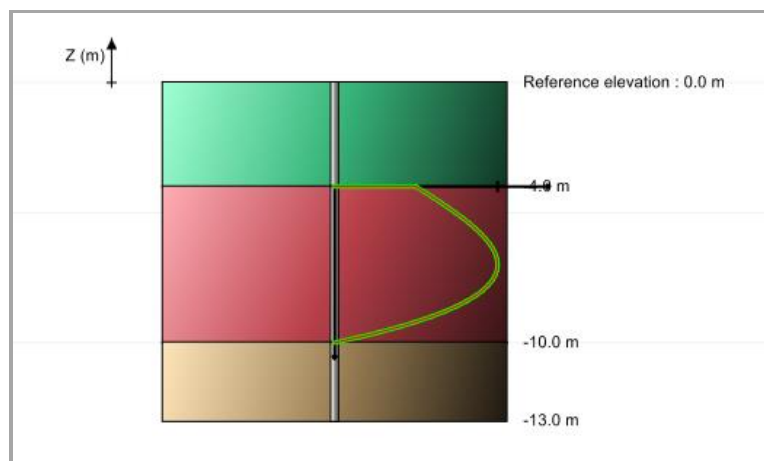




Figure G.29 : Graphical representation of the initial $y_0(z)$ displacement

G.3.7. Calculation and Results

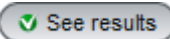
G.3.7.1. Calculation

The calculation can be launched from any tab provided that the tabs are correctly completed, that is when they are all marked by a green cross (for example: ).

These tabs are marked by a red cross (for example: ) whilst not correctly completed (missing data or not complying with expected values).

To launch the calculation, click  button.

G.3.7.2. Results

To display the calculation results, click  button.

The window below is then displayed and proposes different types of results accessible after a Piecoef+ calculation:

- 2 types of numerical results: formatted results and result tables.
- 2 types of graphical results: main curves and curves related to buckling.



Figure G.30 : Results window

The chapters below detail the various results for a calculation case without multiple loads at pile head. See chapter G.3.7.3 for the results of a calculation with multiple loads at pile head.

G.3.7.2.1. Formatted numerical results

```

File : E:\Users\mto\Documents\Foxtav3\picoef\EXEMPLE 01A\Exemple 01a[PC]-1.resu

Calcul réalisé le : 27/02/2012 à 14h20
par : Terrasol

-----

nb d'incréments : 020
itération : 003

Cote de référence : 0.000
Inclinaison(°) : 0.000

Type de calcul : Calcul de Pieu sous sollicitations latérales
Loi élastoplastique de mobilisation de la réaction latérale du sol définie à partir des caractéristiques pressiométriques
Type de sollicitations : 1. Cas où les sollicitations permanentes en tête dominant

Caractéristiques des couches (données utilisateur)
-----
couche base EI EM alpha B pf p1
01 -8.00 0.636E+05 5000.00 0.33 0.600 300.00 500.00
02 -12.00 0.636E+05 20000.00 0.50 0.600 2000.00 3000.00

Discretisation du pieu (Paramètres du calcul)
-----
Elément XL EI ks1*B p1*B ks2*B p2*B
001 0.267 0.6360E+05 0.1383E+05 0.1800E+03 0.0000E+00 0.1800E+03
002 0.267 0.6360E+05 0.1383E+05 0.1800E+03 0.0000E+00 0.1800E+03
003 0.267 0.6360E+05 0.1383E+05 0.1800E+03 0.0000E+00 0.1800E+03
004 0.267 0.6360E+05 0.1383E+05 0.1800E+03 0.0000E+00 0.1800E+03
005 0.267 0.6360E+05 0.1383E+05 0.1800E+03 0.0000E+00 0.1800E+03
006 0.267 0.6360E+05 0.1383E+05 0.1800E+03 0.0000E+00 0.1800E+03
007 0.267 0.6360E+05 0.1383E+05 0.1800E+03 0.0000E+00 0.1800E+03
008 0.267 0.6360E+05 0.1383E+05 0.1800E+03 0.0000E+00 0.1800E+03
009 0.267 0.6360E+05 0.1383E+05 0.1800E+03 0.0000E+00 0.1800E+03
010 0.267 0.6360E+05 0.1383E+05 0.1800E+03 0.0000E+00 0.1800E+03
011 0.267 0.6360E+05 0.1383E+05 0.1800E+03 0.0000E+00 0.1800E+03
012 0.267 0.6360E+05 0.1383E+05 0.1800E+03 0.0000E+00 0.1800E+03
013 0.267 0.6360E+05 0.1383E+05 0.1800E+03 0.0000E+00 0.1800E+03
014 0.267 0.6360E+05 0.1383E+05 0.1800E+03 0.0000E+00 0.1800E+03
015 0.267 0.6360E+05 0.1383E+05 0.1800E+03 0.0000E+00 0.1800E+03
016 0.267 0.6360E+05 0.1383E+05 0.1800E+03 0.0000E+00 0.1800E+03
017 0.267 0.6360E+05 0.1383E+05 0.1800E+03 0.0000E+00 0.1800E+03
018 0.267 0.6360E+05 0.1383E+05 0.1800E+03 0.0000E+00 0.1800E+03
019 0.267 0.6360E+05 0.1383E+05 0.1800E+03 0.0000E+00 0.1800E+03
020 0.267 0.6360E+05 0.1383E+05 0.1800E+03 0.0000E+00 0.1800E+03
021 0.267 0.6360E+05 0.1383E+05 0.1800E+03 0.0000E+00 0.1800E+03
022 0.267 0.6360E+05 0.1383E+05 0.1800E+03 0.0000E+00 0.1800E+03
023 0.267 0.6360E+05 0.1383E+05 0.1800E+03 0.0000E+00 0.1800E+03
024 0.267 0.6360E+05 0.1383E+05 0.1800E+03 0.0000E+00 0.1800E+03
025 0.267 0.6360E+05 0.1383E+05 0.1800E+03 0.0000E+00 0.1800E+03
026 0.267 0.6360E+05 0.1383E+05 0.1800E+03 0.0000E+00 0.1800E+03
027 0.267 0.6360E+05 0.1383E+05 0.1800E+03 0.0000E+00 0.1800E+03
028 0.267 0.6360E+05 0.1383E+05 0.1800E+03 0.0000E+00 0.1800E+03
  
```

Figure G.31 : Formatted numerical results (reminder of data)

The formatted results contain:

- A reminder of the data: general parameters, soil data, pile discretisation, defined loads, etc. This first section also includes the list of calculation points (nodes) defined along the pile in its local coordinate system.

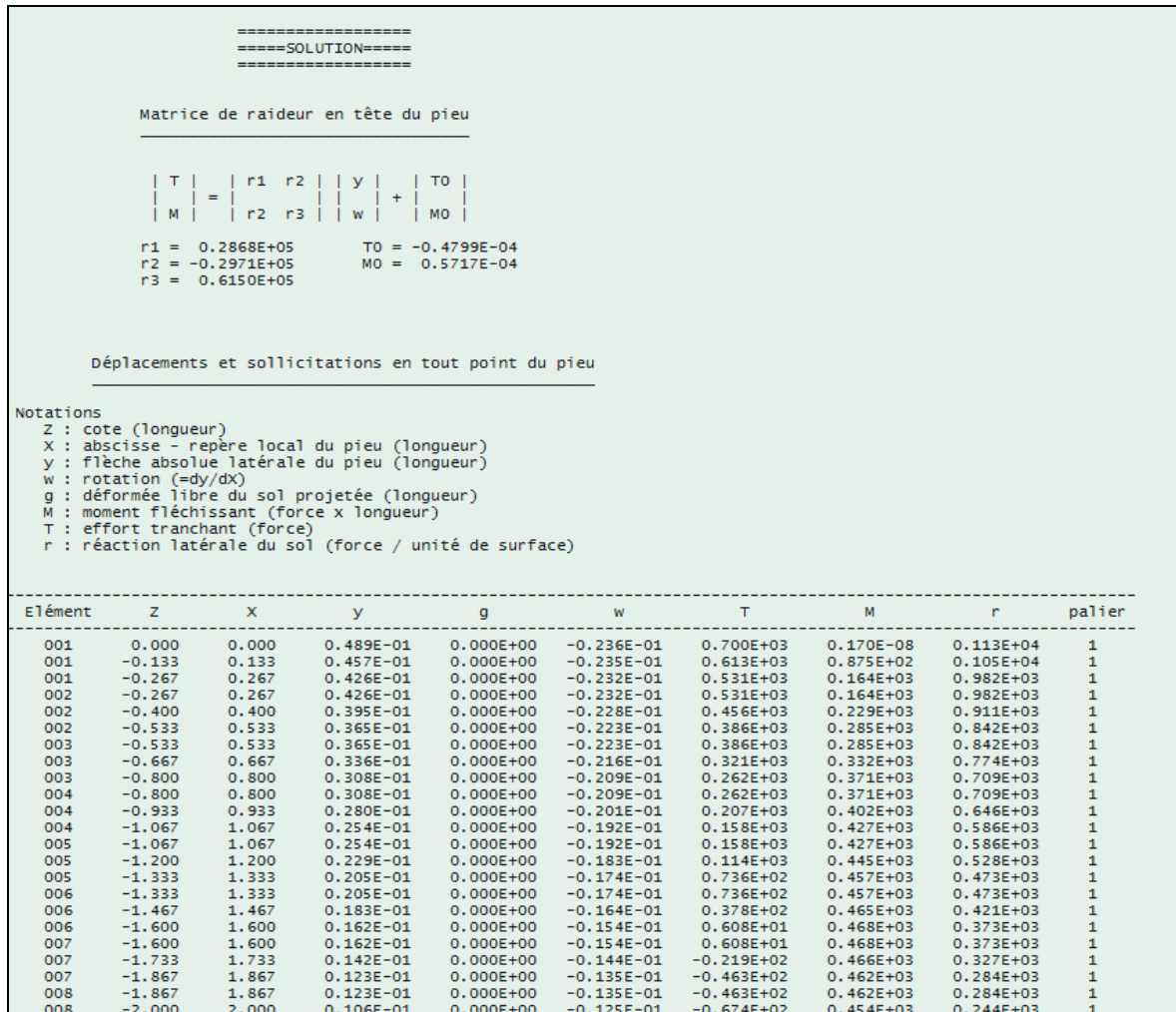


Figure G.32 : Formatted numerical results (start of results section)

• Results:

- ✓ The stiffness matrix at pile head: stiffness coefficients ρ_1 , ρ_2 and ρ_3 and the values of constants T_0 and M_0 at the head of the pile at point C_0 . These stiffnesses are expressed in the local coordinate system of the pile, where:
 - ρ_1 (kN/m): translation stiffness
 - ρ_2 (kN): "crossed" translation/rotational stiffness
 - ρ_3 (kN.m/rad): rotational stiffness
 - T_0 (kN): translation force
 - M_0 (kN.m): moment

This stiffness matrix can then be used for the Groupie+ calculation on a group of piles (importation into Groupie+ possible, see part H of the manual).

- ✓ The table of displacements and loads at all points on the pile:
 - Z: elevation (m)
 - X: abscissa in the pile local coordinate system (m)
 - y: absolute lateral deflection of the pile (m)
 - g: projected soil free displacement (m)
 - w: rotation (rad)
 - T: shear force (kN)
 - M: bending moment (kN.m)
 - r: soil lateral reaction (kPa)
 - palier (plateau): indication of reached plateau

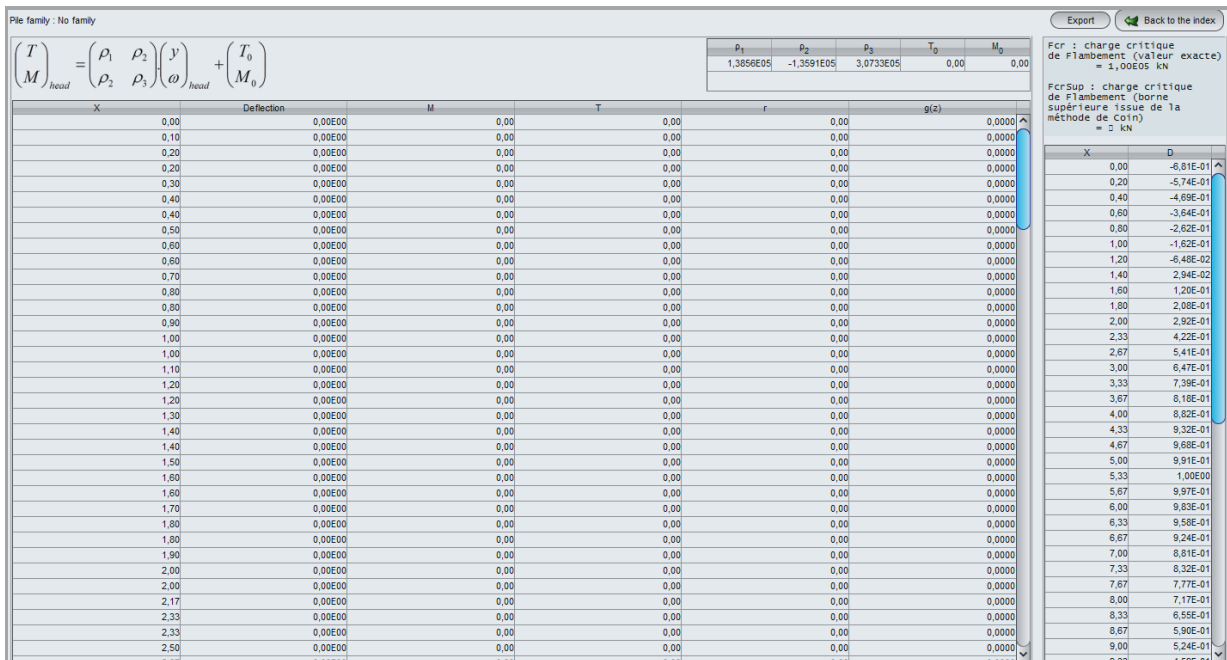
At the end of this table, the extreme values are displayed for each type of result.

- ✓ The buckling loads for each mode.

SOLUTION	
Charges de flambement pour chaque mode	
Mode	Charge
001	0.273E+04
002	0.303E+04
003	0.473E+04
004	0.556E+04
005	0.615E+04
006	0.749E+04
007	0.861E+04
008	0.106E+05
009	0.125E+05
010	0.149E+05
011	0.169E+05
012	0.191E+05
013	0.203E+05
014	0.226E+05
015	0.244E+05
016	0.280E+05
017	0.291E+05
018	0.324E+05
019	0.353E+05
020	0.390E+05
021	0.429E+05
022	0.471E+05
023	0.516E+05
024	0.563E+05
025	0.612E+05
026	0.664E+05
027	0.718E+05
028	0.776E+05
029	0.836E+05
030	0.898E+05
031	0.963E+05
032	0.103E+06
033	0.110E+06
034	0.118E+06
035	0.125E+06
036	0.134E+06

Figure G.33 : Formatted numerical results (start of results section for a buckling calculation)

G.3.7.2.2. Numerical results - Results tables



X	Deflection	M	T	r	g(z)
0.00	0.00E00	0.00	0.00	0.00	0.0000
0.10	0.00E00	0.00	0.00	0.00	0.0000
0.20	0.00E00	0.00	0.00	0.00	0.0000
0.30	0.00E00	0.00	0.00	0.00	0.0000
0.40	0.00E00	0.00	0.00	0.00	0.0000
0.50	0.00E00	0.00	0.00	0.00	0.0000
0.60	0.00E00	0.00	0.00	0.00	0.0000
0.70	0.00E00	0.00	0.00	0.00	0.0000
0.80	0.00E00	0.00	0.00	0.00	0.0000
0.90	0.00E00	0.00	0.00	0.00	0.0000
1.00	0.00E00	0.00	0.00	0.00	0.0000
1.10	0.00E00	0.00	0.00	0.00	0.0000
1.20	0.00E00	0.00	0.00	0.00	0.0000
1.30	0.00E00	0.00	0.00	0.00	0.0000
1.40	0.00E00	0.00	0.00	0.00	0.0000
1.50	0.00E00	0.00	0.00	0.00	0.0000
1.60	0.00E00	0.00	0.00	0.00	0.0000
1.70	0.00E00	0.00	0.00	0.00	0.0000
1.80	0.00E00	0.00	0.00	0.00	0.0000
1.90	0.00E00	0.00	0.00	0.00	0.0000
2.00	0.00E00	0.00	0.00	0.00	0.0000
2.17	0.00E00	0.00	0.00	0.00	0.0000
2.33	0.00E00	0.00	0.00	0.00	0.0000
2.50	0.00E00	0.00	0.00	0.00	0.0000

Figure G.34 : Numerical results – Table of results

These are the same results as those detailed for the formatted results in chapter G.3.7.2.1, but presented this time in table form and without the data reminder part. Some results are not displayed in these tables, such as the rotations for example.

G.3.7.2.3. Graphical results - Main curves

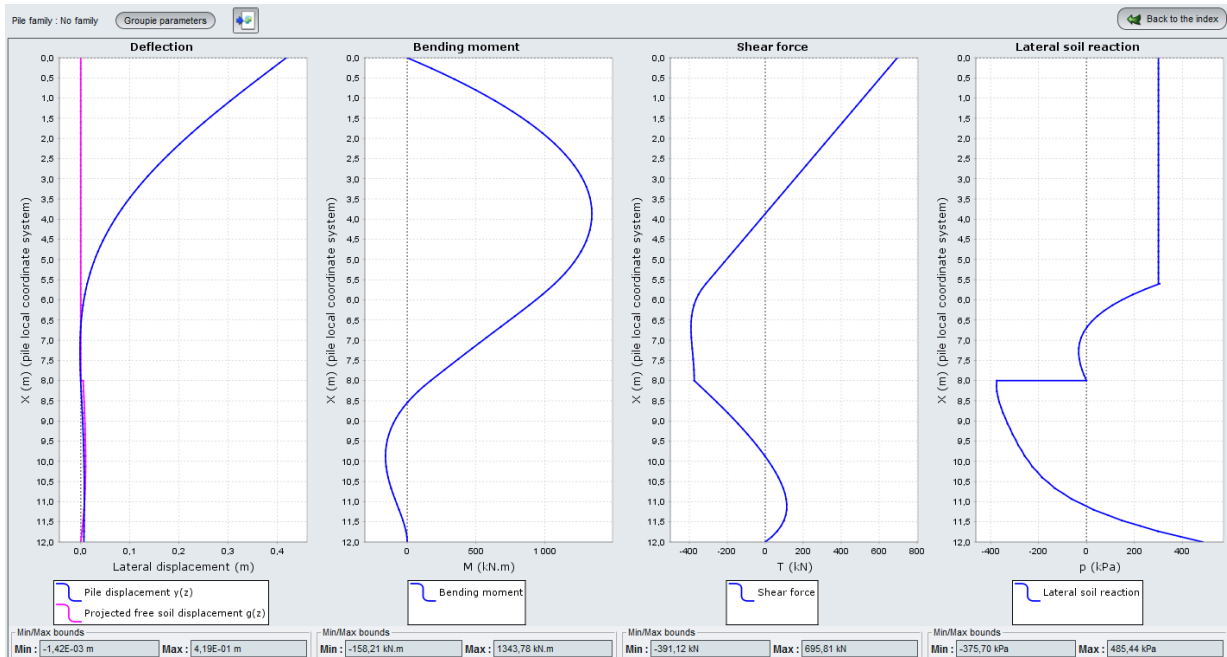


Figure G.35 : Graphical results – Main curves

Note: these main curves are not accessible for a "specific buckling calculation".

The main curves are the graphical display of 4 types of results:

- the **lateral displacement** of the pile (m) versus the local abscissa of the pile x(m);
- the **bending moment** of the pile (kN.m) versus the local abscissa of the pile x(m);
- the **shear force** in the pile (kN) versus the local abscissa of the pile x(m);
- the **lateral soil reaction** (kPa) versus the local abscissa of the pile x(m).

The minimum and maximum values of the curve are given under each curve.

This window also includes a reminder of the family defined for the pile (on top of the window), and a **Groupie parameters** button to access the pile head stiffness matrix (stiffness coefficients ρ_1 , ρ_2 and ρ_3 and the values of pile head constants T_0 and M_0):

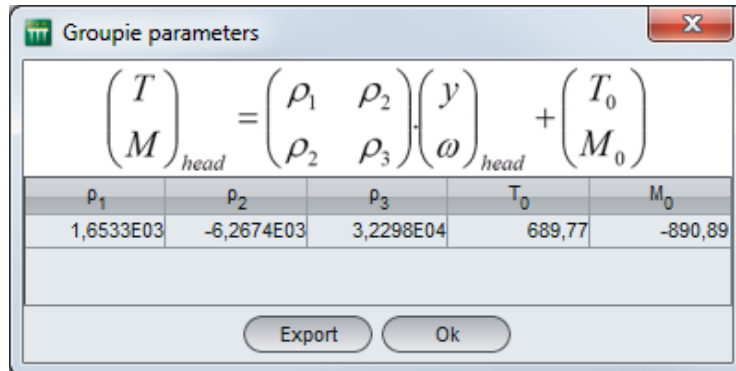


Figure G.36 : Groupie+ parameters

G.3.7.2.4. Graphical results - Curves related to buckling

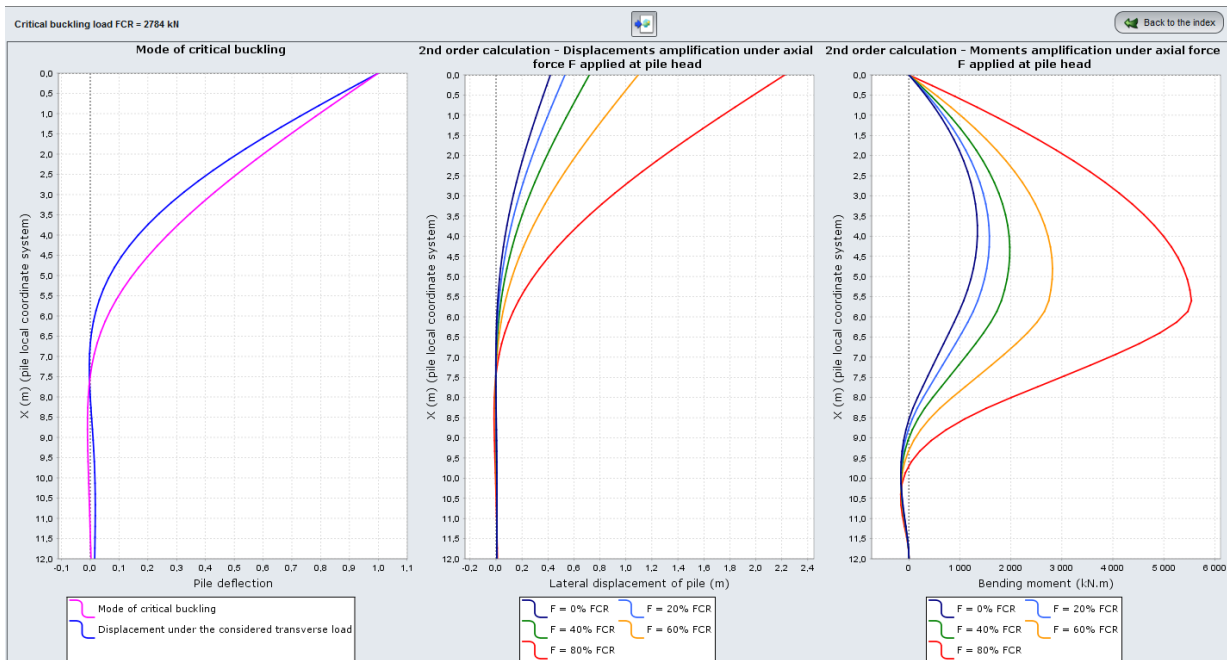


Figure G.37 : Graphical results: Curves related to buckling

In this window, Piecoef+ gives the critical buckling load value FCR (kN) and three sets of curves:

- the critical buckling mode;
- the 2nd order calculation with amplification of the displacements under an axial force F applied at pile head, expressed as a fraction of the critical buckling load;
- the 2nd order calculation with amplification of the moments under an axial force F applied at pile head.

G.3.7.3. Results for multiple loads at pile head

For a calculation with multiple loads at pile head, the results are presented in a slightly different way:

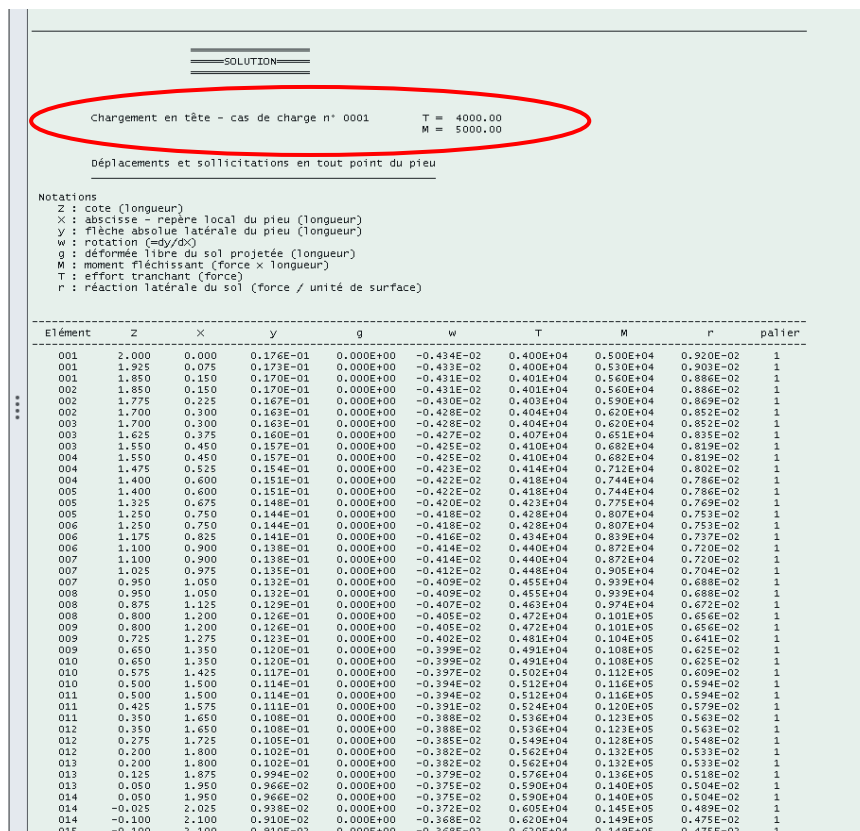
- on the one hand, Piecoef+ displays the results for the various load cases at pile head,
- on the other hand, the Groupie+ parameters (stiffness matrix at the head of the pile) and the curves related to buckling are not available.

The subchapters below detail the modifications in the display of the results (with respect to the calculation cases without multiple loads at pile head) for each type of results presentation.

G.3.7.3.1. Formatted numerical results

With respect to the results given in chapter G.3.7.2.1:

- The formatted file includes no stiffness matrix at pile head.
- The formatted file successively includes detailed results for each of the load cases at pile head.
- The formatted file does not include additional results related to buckling.



=====

SOLUTION

=====

Chargement en tête - cas de charge n° 0001 T = 4000.00
M = 5000.00

Déplacements et sollicitations en tout point du pieu

Notations
z : cote (longueur)
x : abscisse - repère local du pieu (longueur)
y : flèche absolue latérale du pieu (longueur)
w : rotation (rad/deg)
g : déformée libre du sol projetée (longueur)
M : moment fléchissant (force x longueur)
T : effort tranchant (force)
r : réaction latérale du sol (force / unité de surface)

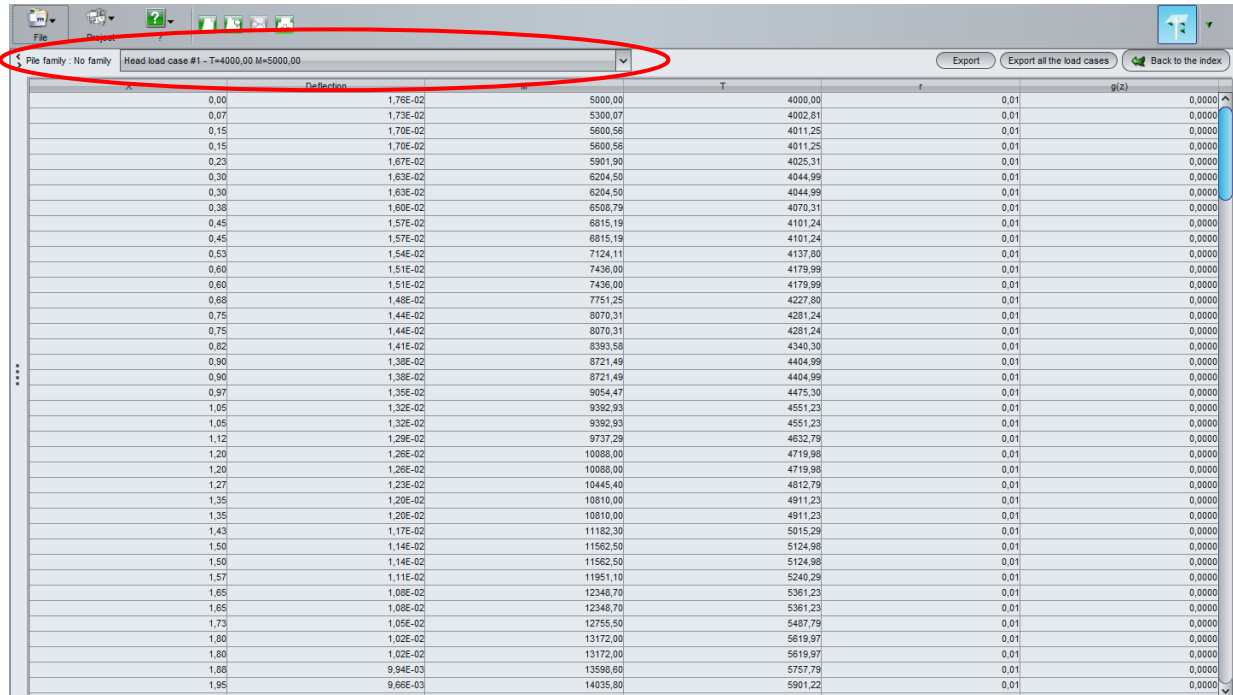
Elément	z	x	y	g	w	T	M	r	palier
001	2.000	0.000	0.173E-01	0.000E+00	-0.434E-02	0.400E+04	0.530E+04	0.920E-02	1
001	1.925	0.075	0.173E-01	0.000E+00	-0.433E-02	0.400E+04	0.530E+04	0.903E-02	1
001	1.850	0.150	0.170E-01	0.000E+00	-0.431E-02	0.401E+04	0.560E+04	0.886E-02	1
002	1.850	0.150	0.170E-01	0.000E+00	-0.431E-02	0.401E+04	0.560E+04	0.886E-02	1
002	1.775	0.225	0.167E-01	0.000E+00	-0.430E-02	0.403E+04	0.590E+04	0.869E-02	1
002	1.700	0.300	0.163E-01	0.000E+00	-0.428E-02	0.404E+04	0.620E+04	0.852E-02	1
003	1.700	0.300	0.163E-01	0.000E+00	-0.428E-02	0.404E+04	0.620E+04	0.852E-02	1
003	1.625	0.375	0.160E-01	0.000E+00	-0.427E-02	0.407E+04	0.651E+04	0.835E-02	1
003	1.550	0.450	0.157E-01	0.000E+00	-0.425E-02	0.410E+04	0.682E+04	0.819E-02	1
004	1.550	0.450	0.157E-01	0.000E+00	-0.425E-02	0.410E+04	0.682E+04	0.819E-02	1
004	1.475	0.525	0.154E-01	0.000E+00	-0.423E-02	0.414E+04	0.712E+04	0.802E-02	1
004	1.400	0.600	0.151E-01	0.000E+00	-0.422E-02	0.418E+04	0.744E+04	0.786E-02	1
005	1.400	0.600	0.151E-01	0.000E+00	-0.422E-02	0.418E+04	0.744E+04	0.786E-02	1
005	1.325	0.675	0.148E-01	0.000E+00	-0.420E-02	0.423E+04	0.775E+04	0.769E-02	1
005	1.250	0.750	0.144E-01	0.000E+00	-0.418E-02	0.428E+04	0.807E+04	0.753E-02	1
006	1.250	0.750	0.144E-01	0.000E+00	-0.418E-02	0.428E+04	0.807E+04	0.753E-02	1
006	1.175	0.825	0.141E-01	0.000E+00	-0.416E-02	0.434E+04	0.839E+04	0.737E-02	1
006	1.100	0.900	0.138E-01	0.000E+00	-0.414E-02	0.440E+04	0.872E+04	0.720E-02	1
007	1.100	0.900	0.138E-01	0.000E+00	-0.414E-02	0.440E+04	0.872E+04	0.720E-02	1
007	1.025	0.975	0.135E-01	0.000E+00	-0.412E-02	0.448E+04	0.905E+04	0.704E-02	1
007	0.950	1.050	0.132E-01	0.000E+00	-0.409E-02	0.455E+04	0.939E+04	0.688E-02	1
008	0.950	1.050	0.132E-01	0.000E+00	-0.409E-02	0.455E+04	0.939E+04	0.688E-02	1
008	0.875	1.125	0.129E-01	0.000E+00	-0.407E-02	0.463E+04	0.974E+04	0.672E-02	1
008	0.800	1.200	0.126E-01	0.000E+00	-0.405E-02	0.472E+04	0.101E+05	0.656E-02	1
009	0.800	1.200	0.126E-01	0.000E+00	-0.405E-02	0.472E+04	0.101E+05	0.656E-02	1
009	0.725	1.275	0.123E-01	0.000E+00	-0.402E-02	0.481E+04	0.104E+05	0.641E-02	1
009	0.650	1.350	0.120E-01	0.000E+00	-0.399E-02	0.491E+04	0.108E+05	0.625E-02	1
010	0.650	1.350	0.120E-01	0.000E+00	-0.399E-02	0.491E+04	0.108E+05	0.625E-02	1
010	0.575	1.425	0.117E-01	0.000E+00	-0.397E-02	0.502E+04	0.112E+05	0.609E-02	1
010	0.500	1.500	0.114E-01	0.000E+00	-0.394E-02	0.512E+04	0.116E+05	0.594E-02	1
011	0.500	1.500	0.114E-01	0.000E+00	-0.394E-02	0.512E+04	0.116E+05	0.594E-02	1
011	0.425	1.575	0.111E-01	0.000E+00	-0.391E-02	0.524E+04	0.120E+05	0.579E-02	1
011	0.350	1.650	0.108E-01	0.000E+00	-0.388E-02	0.536E+04	0.123E+05	0.563E-02	1
012	0.350	1.650	0.108E-01	0.000E+00	-0.388E-02	0.536E+04	0.123E+05	0.563E-02	1
012	0.275	1.725	0.105E-01	0.000E+00	-0.385E-02	0.549E+04	0.128E+05	0.548E-02	1
012	0.200	1.800	0.102E-01	0.000E+00	-0.382E-02	0.562E+04	0.132E+05	0.533E-02	1
013	0.200	1.800	0.102E-01	0.000E+00	-0.382E-02	0.562E+04	0.132E+05	0.533E-02	1
013	0.125	1.875	0.994E-02	0.000E+00	-0.379E-02	0.576E+04	0.136E+05	0.518E-02	1
013	0.050	1.950	0.966E-02	0.000E+00	-0.375E-02	0.590E+04	0.140E+05	0.504E-02	1
014	0.050	1.950	0.966E-02	0.000E+00	-0.375E-02	0.590E+04	0.140E+05	0.504E-02	1
014	-0.025	2.025	0.938E-02	0.000E+00	-0.372E-02	0.605E+04	0.145E+05	0.489E-02	1
014	-0.100	2.100	0.910E-02	0.000E+00	-0.368E-02	0.620E+04	0.149E+05	0.475E-02	1
015	-0.100	2.100	0.910E-02	0.000E+00	-0.368E-02	0.620E+04	0.149E+05	0.475E-02	1

Figure G.38 : Formatted numerical results for a multiple load case at pile head

G.3.7.3.2. Numerical results - Results tables

With respect to the results given in chapter G.3.7.2.2:

- this time, a selection list is available at the top of the window to select the load case which results shall be displayed.
- the stiffness matrix at pile head is not displayed.



	Deflection	T	f	g(z)
0,00	1,76E-02	5000,00	4000,00	0,01
0,07	1,73E-02	5300,07	4002,81	0,01
0,15	1,70E-02	5600,56	4011,25	0,01
0,15	1,70E-02	5600,56	4011,25	0,01
0,23	1,67E-02	5901,90	4025,31	0,01
0,30	1,63E-02	6204,50	4044,99	0,01
0,30	1,63E-02	6204,50	4044,99	0,01
0,36	1,60E-02	6506,79	4070,31	0,01
0,45	1,57E-02	6815,19	4101,24	0,01
0,45	1,57E-02	6815,19	4101,24	0,01
0,53	1,54E-02	7124,11	4137,80	0,01
0,60	1,51E-02	7436,00	4179,99	0,01
0,60	1,51E-02	7436,00	4179,99	0,01
0,68	1,48E-02	7751,25	4227,80	0,01
0,75	1,44E-02	8070,31	4281,24	0,01
0,75	1,44E-02	8070,31	4281,24	0,01
0,82	1,41E-02	8393,58	4340,30	0,01
0,90	1,38E-02	8721,49	4404,99	0,01
0,90	1,38E-02	8721,49	4404,99	0,01
0,97	1,35E-02	9054,47	4475,30	0,01
1,05	1,32E-02	9392,93	4551,23	0,01
1,05	1,32E-02	9392,93	4551,23	0,01
1,12	1,29E-02	9737,29	4632,79	0,01
1,20	1,26E-02	10088,00	4719,98	0,01
1,20	1,26E-02	10088,00	4719,98	0,01
1,27	1,23E-02	10445,40	4812,79	0,01
1,35	1,20E-02	10810,00	4911,23	0,01
1,35	1,20E-02	10810,00	4911,23	0,01
1,43	1,17E-02	11182,30	5015,29	0,01
1,50	1,14E-02	11562,50	5124,98	0,01
1,50	1,14E-02	11562,50	5124,98	0,01
1,57	1,11E-02	11951,10	5240,29	0,01
1,65	1,08E-02	12346,70	5361,23	0,01
1,65	1,08E-02	12346,70	5361,23	0,01
1,73	1,05E-02	12755,50	5487,79	0,01
1,80	1,02E-02	13172,00	5619,97	0,01
1,80	1,02E-02	13172,00	5619,97	0,01
1,88	9,94E-03	13598,60	5757,79	0,01
1,95	9,66E-03	14035,80	5901,22	0,01

Figure G.39 : Table of results for a multiple load at pile head case

G.3.7.3.3. Graphical results - Main curves

With respect to the results given in chapter G.3.7.2.3:

- this time, a choice list is available at the top of the window to select the load case which results shall be displayed.
- the "Groupie+ parameters" button is shaded: the stiffness matrix at pile head is not accessible.

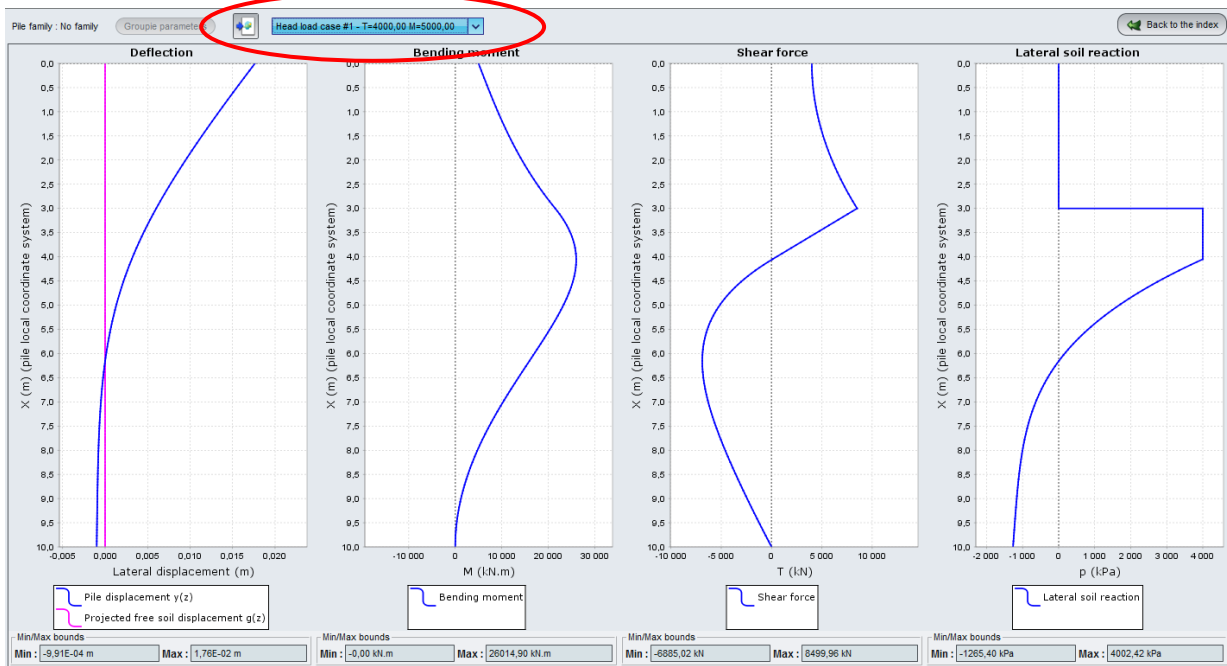


Figure G.40 : Main curves for a multiple loads at pile head case

G.3.7.3.4. Graphical results - Curves related to buckling

The buckling results are not available for the calculation case with multiple loads at pile head: these types of results are therefore not accessible in this case (button shaded).

G.4. EXAMPLES OF PIECOEF+ CALCULATIONS

Piecoef+ module can perform several types of calculations related to a pile submitted to transverse loads:

- the stiffness coefficients calculation (for further use in combination with Groupie+ module);
- calculation of the loads and displacements along a pile (considering a $g(z)$ soil displacement or not);
- the buckling and the second order effects calculation.

The 4 examples below illustrate these types of calculations.

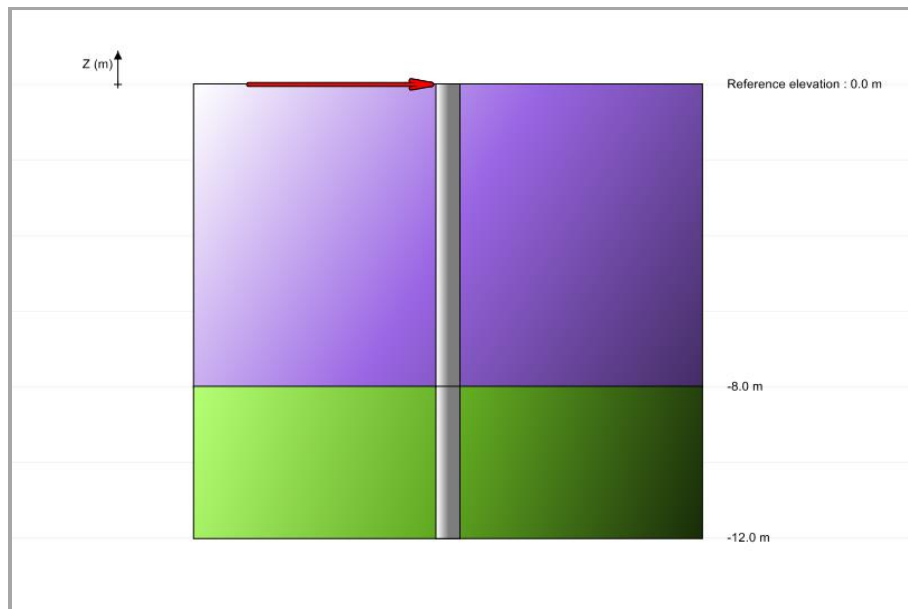
G.4.1. Example 1: Calculation of a pile submitted to (T, M) loading at pile head

This example studies a pile submitted to side forces at the head.

- Firstly, we will study this pile assuming that the pile is vertical and that the behaviour of the soil is elastic.
- Secondly, we will consider the same pile with an elastoplastic behaviour of the soil.
- Lastly, we will introduce an inclination for the pile.

G.4.1.1. Step 1: Vertical pile and elastic behaviour of the soil

- For this first step, we will consider a vertical pile with a diameter of 60 cm and a length of 12 m, passing through 2 soil layers (sandy fill then marly substratum) the behaviour of which is considered as elastic. This pile will be submitted to a horizontal force at pile head of 700 kN and we assume null prescribed rotation at pile head (beam clamping in a footing).



G.4.1.2. Data input

When the application is opened, Foxta proposes to:

- create a new project,
- open an existing project,
- automatically open the last project used.

For this example:

- Choose to create a new project by selecting **New project** radio-button.
- Click button.

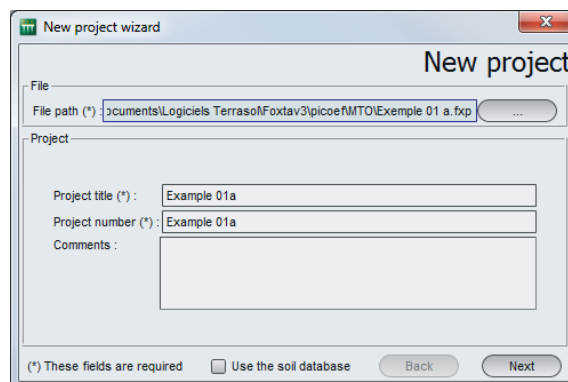
G.4.1.2.1. New project wizard

"File" box

- Complete the path of the project by clicking button.
- Give and save the name of the file.

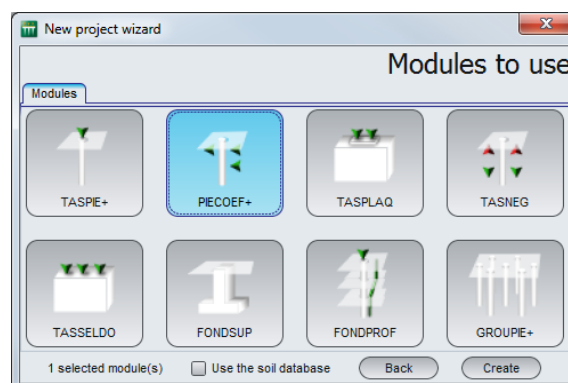
"Project" box

- Enter a project title
- Enter a project number
- Add a comment if necessary
- Leave "Use the soil database" box unticked (the database will not be used in this example), and click button.



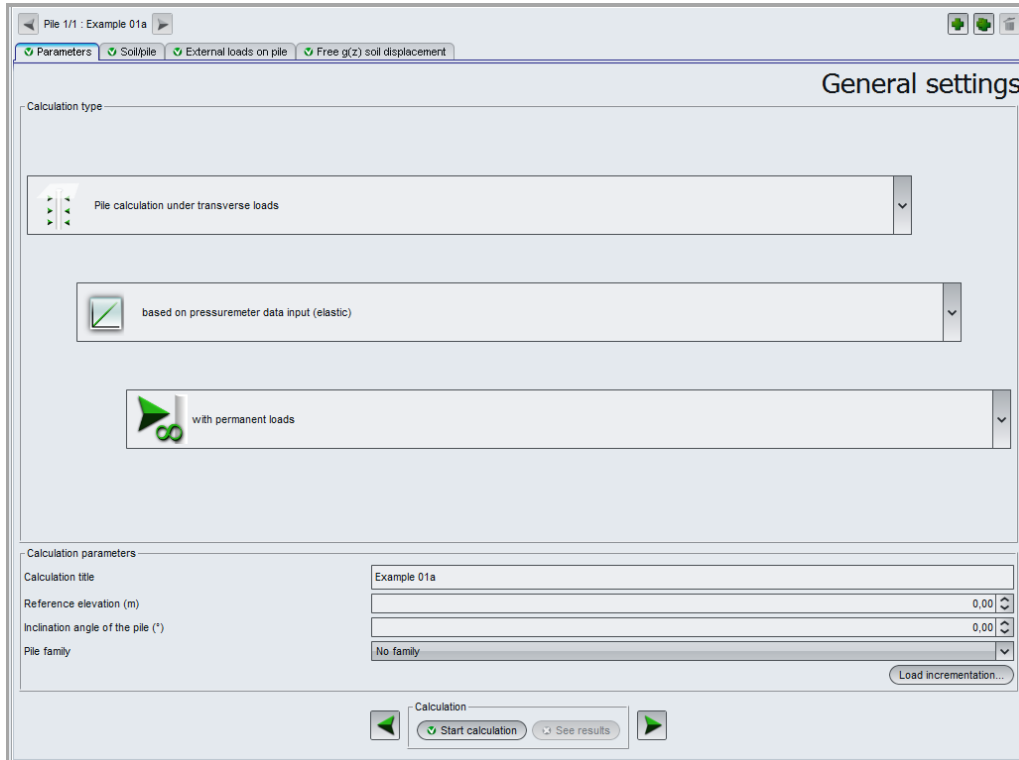
G.4.1.2.2. New project wizard: Choice of modules

In "Modules to use" window, select Piecoef+ module then click button.



Piecoef+ data input window is then displayed.
 Complete the various tabs with the data proposed.

G.4.1.2.3. "Parameters" tab




This tab includes two boxes:

"Calculation type" box: select

- drop-down list 1: Pile calculation under transverse loads
- drop-down list 2: based on pressuremeter data input (elastic)
- drop-down list 3: with permanent loads

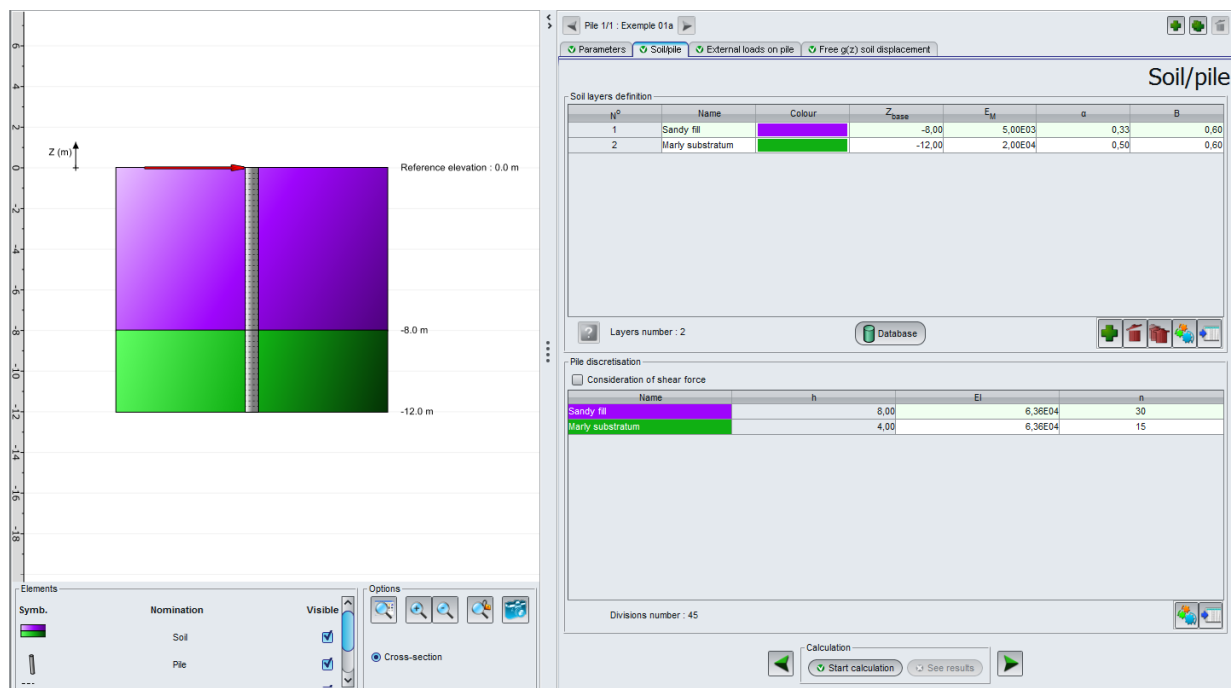
"Calculation parameters" box:

- Calculation title: Example 01a
- Reference elevation (m): 0.0 m
- Inclination angle of the pile: 0° (corresponding to a vertical pile)
- Pile family: none for this example
- Load incrementation: here, we will conserve the values proposed by default.

To go to the next tab, click either the name of the "Soil/Pile" tab or  button.

G.4.1.2.4. "Soil/Pile" tab

This tab concerns the definition of the soil layers and the discretisation of the pile.




"Soil layers definition" box:

In this example, there are 2 soil layers to be defined.

The data to be entered is given in the table below.

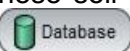
Important: by convention, in Piecoef+, the base of the piles is defined at the base of the last soil layer. To define a pile with a length of 12 m, define the soil cross-section down to a depth of 12 m.

Click  button to create each layer.

The data to be entered is as follows:

Name	Z _{base} (m) Bottom level of the layer	E _M (kPa) Pressuremeter modulus	α Menard's rheologic coefficient	B (m) Drilling diameter
Sandy fill	-8.0	5,000	0.33	0.60
Marly substratum	-12.0	20,000	0.50	0.60

Note: the colour of each layer is proposed automatically but can be modified.

Piecoef+ allows saving these soil layers in the database of the project and/or in the global soil database by clicking  button.

This allows the soil layers to be saved with their parameters to avoid re-entering them when using another module for the same Foxta project or when creating another Foxta project.

The database will not be used in this example. Its use is however described in detail in part C of the manual.

"Pile discretisation" box:

The layers defined previously are automatically transferred to this table.

The data to be entered is given in the table below.

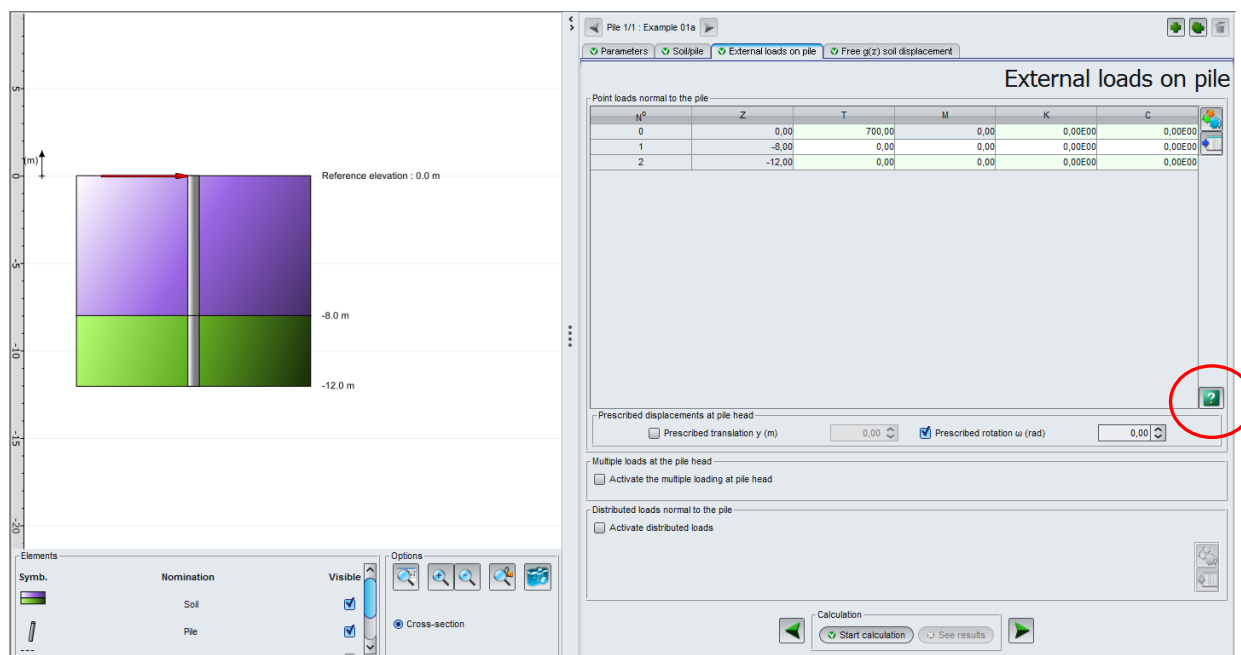
Here the "Consideration of shear force" box is left unticked.

Name	h (m) Soil thickness (completed automatically)	EI (kN/m ²) Product of inertia of pile	n Subdivisions number inside the layer
Sandy fill	8.0	63600	30
Marly substratum	4.0	63600	15

The EI product defined here corresponds to a 60 cm diameter pile with a modulus of 10 GPa.

The number of subdivisions n controls the density of the finite element mesh considered for the pile. Do not hesitate to refine the mesh as this does not greatly affect the calculation time and guarantees a sufficiently accurate result. For this example, the number of subdivisions has been defined as proportional to the thickness of each layer so that a constant calculation step of $4/15 = 0.27$ m can be used.

G.4.1.2.5. "External loads on pile" tab




"Point loads normal to the pile" box:

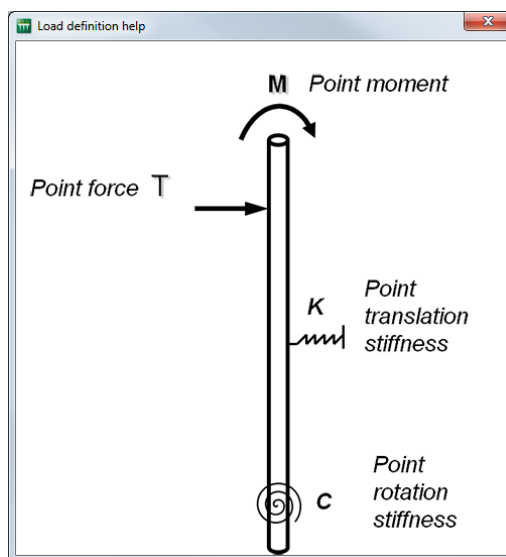
The data to be entered is as follows:

- load elevation Z (m) (deduced from the elevations entered in the "Soil/Pile" tab)
- point side force T (kN)
- point bending moment M (kN.m)
- restoring point stiffness in lateral translation K (kN/m)
- restoring point stiffness in rotation C (kN.m/rad)

To apply a horizontal force of T = 700 kN to the head of the pile, the data to enter is as follows:

N°	Z (m)	T (kN)	M (kN.m)	K (kN.m)	C (kN.m/rad)
0	0.00	700.00	0.00	0.00	0.00
1	-8.00	0.00	0.00	0.00	0.00
2	-12.00	0.00	0.00	0.00	0.00

Note:  button displays a help diagram which gives the sign convention and the meanings of the parameters required:



"Prescribed displacements at pile head" box:

The data to be entered is as follows:

- prescribed translation y (m)
- prescribed rotation ω (rad)

Here, a null rotation condition is imposed on the head of the pile:

	Tick box	Values
y (m)	No	-
ω (rad)	Yes	0.00

"Multiple loads at the pile head" box:

- Keep "Activate the multiple loads at pile head" box unticked.

"Distributed loads normal to the pile" box:

- Keep "Activate distributed loads" box unticked.

G.4.1.2.6. "Free g(z) soil displacement" tab

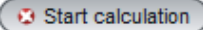
"g(z) definition" box:

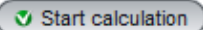
- Keep the "Define a g(z) displacement" box unticked.

Indeed, this function will not be used here.

G.4.1.3. Calculation and results

G.4.1.3.1. Calculation

Whilst the tabs are not all correctly completed, the button starting the calculation is marked with a red cross: 

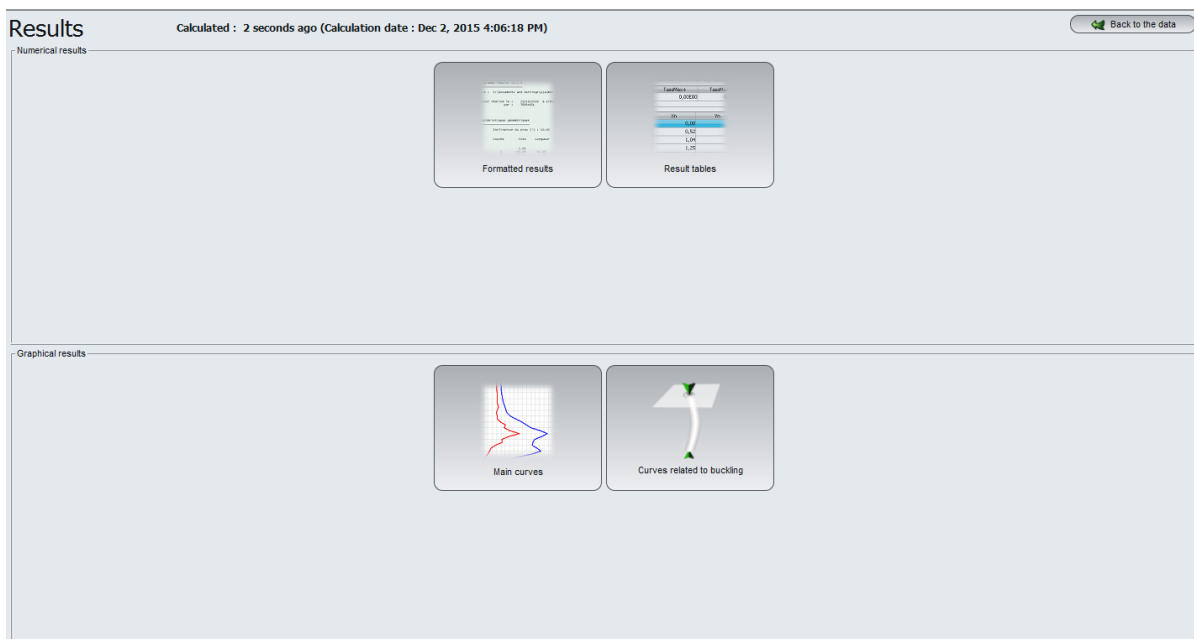
Once all the data is correctly entered,  button becomes active (this button is accessible from all the tabs).

Clicking this button starts the calculation.

To access the results in table and graphical form, click  button.

G.4.1.3.2. Results

The types of results available (numerical and graphical) are given below:

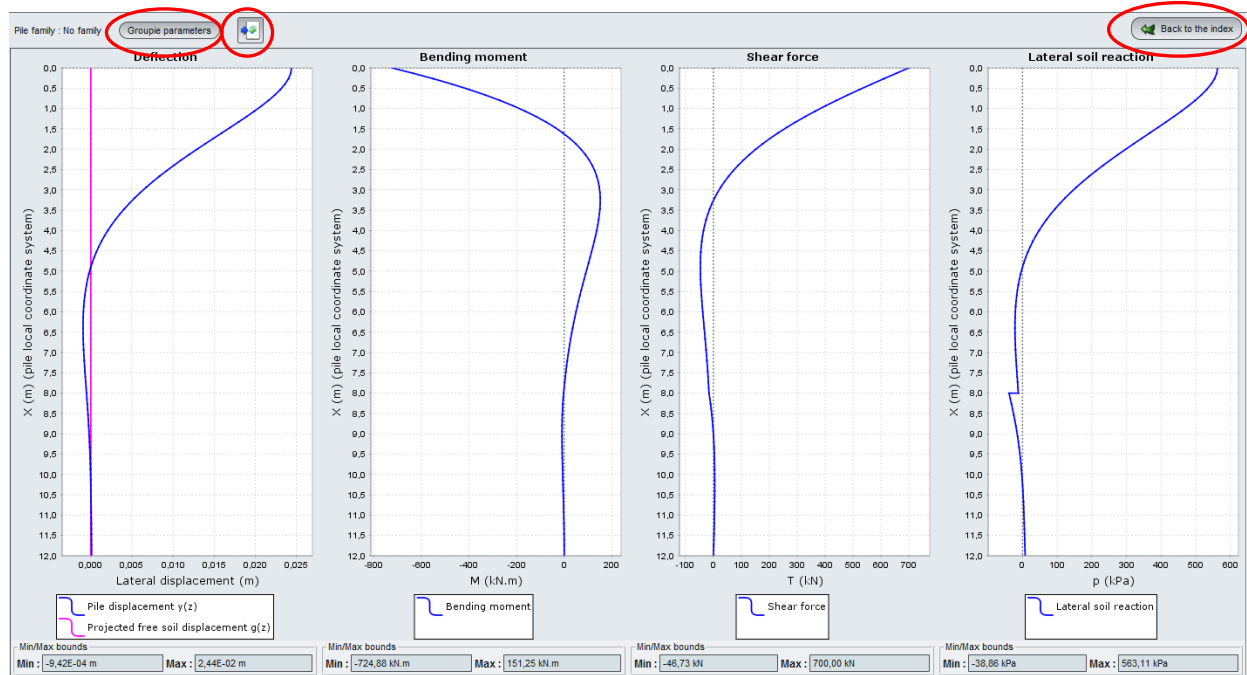


The screenshot shows a 'Results' window with the following elements:

- Header: Results, Calculated : 2 seconds ago (Calculation date : Dec 2, 2015 4:06:18 PM), [Back to the data](#)
- Section: Numerical results
 - Formatted results (icon showing a document)
 - Result tables (icon showing a table with columns: Length, Eigen, 0.0000, 0.0000, 0.0000, 0.0000)
- Section: Graphical results
 - Main curves (icon showing a graph with red and blue lines)
 - Curves related to buckling (icon showing a 3D model of a pile with a buckling curve)

For example, click "Main curves" button.

Forces and displacements




Results obtained:

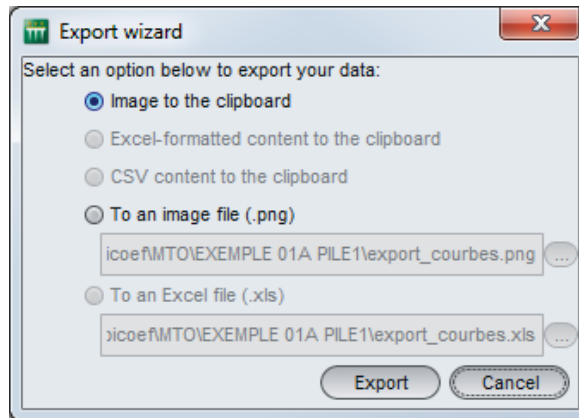
Deflection: lateral displacement (cm)		Bending moment M (kN.m)		Shear force T (kN)		Lateral soil reaction p (kPa)	
Min	Max	Min	Max	Min	Max	Min	Max
0.1	2.4	-725	151	-47	700	-39	563

The results obtained are consistent with those expected for a pile submitted to a horizontal force at the head, with simulation of an elastic behaviour of the soil and null rotation condition at the head. Indeed:

- We find the prescribed horizontal force of 700 kN at the head.
- The lateral displacement is maximum, as expected, at the head of the pile, with 2.4 cm.
- The moment is also maximum at the head of the pile with an absolute value of 725 kN.m (beam clamping moment).
- Lastly, the lateral reaction is also maximum at the head of the pile with 563 kPa.

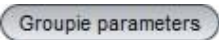
Exporting data:

The  button allows the user to export the curves to an image:



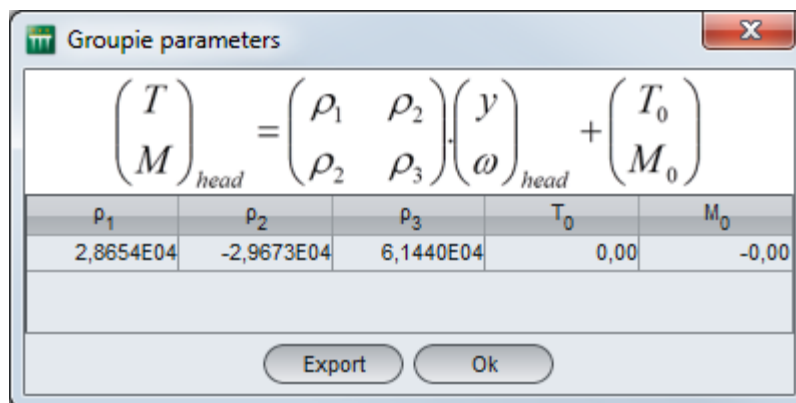
G.4.1.3.3. Stiffness coefficients

These coefficients will not be used in this example (as we are not considering the behaviour of a pile studied within a group of piles with the Groupie+ module), but we will nevertheless comment on them for information purposes.

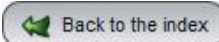
To obtain the stiffness results, click  button.

These stiffnesses are expressed in the local coordinate system of the pile, where:

- ρ_1 (kN/m): translation stiffness
- ρ_2 (kN): "crossed" translation/rotation stiffness
- ρ_3 (kN.m/rad): rotational stiffness
- T_0 (kN): translation force
- M_0 (kN.m): moment



Return to the window presenting the various results:

Click  button to return to the screen allowing the various types of results to be selected.

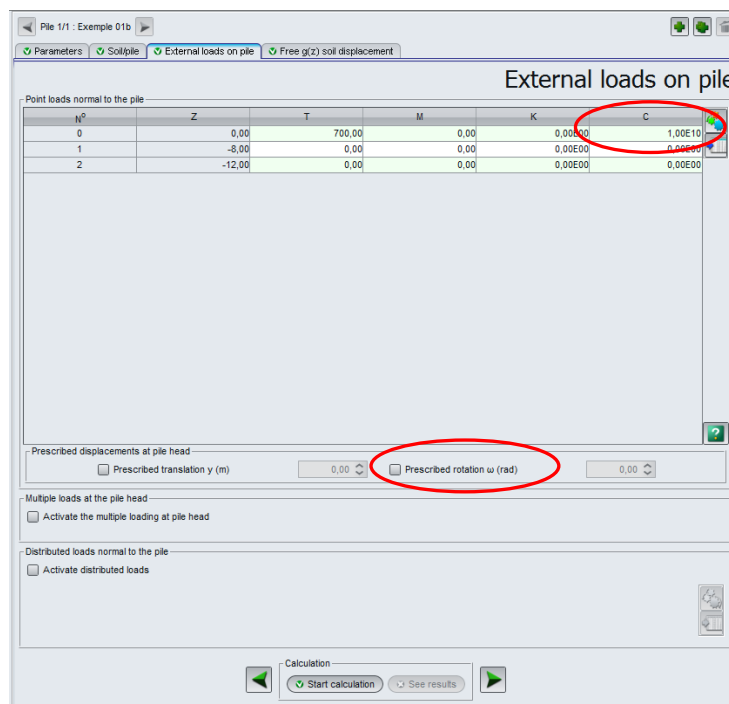
G.4.1.3.4. Calculation variant

We will now do the same calculation, but replacing the prescribed rotation condition (null) at the head of the pile by a very high restoring stiffness value for head rotation.

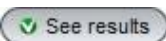
Record your project, then do a "save as" giving it a different name: "Example 01abis" for example.

To modify the data, click  button and return to "External loads on pile" tab:

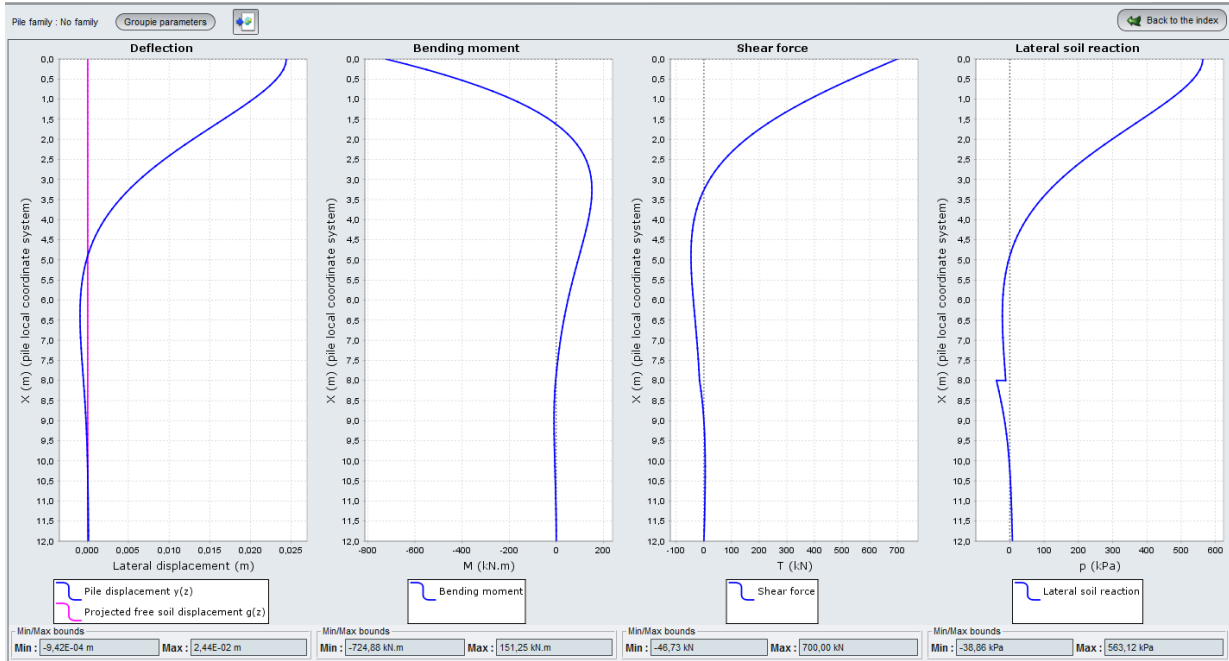
- Untick "Prescribed rotation ω " box to eliminate the null rotation condition at the head.
- Define $C = 1^{e}10$ kN.m/rad at $Z = 0$ m (at the head of the pile): very high value for the restoring stiffness for head rotation. This is an alternative way of simulating blocking in rotation.



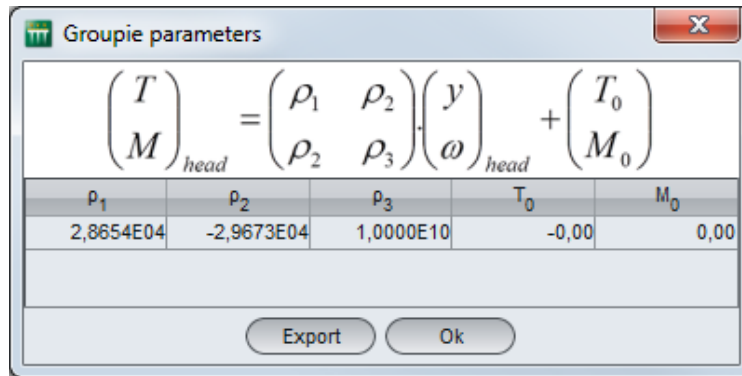
Start the calculation by clicking  button.

Then click  button:

The graphical results, "Main curves" show that the results are identical for the forces and displacements: indeed a very high restoring stiffness at the head leads to the same behaviour for the pile as a prescribed null rotation at the head.



However, certain "Stiffness coefficients" ("Groupie+ parameters") have been affected:



In fact, these stiffness coefficients represent the apparent behaviour at the head of the "pile + soil + point supports" system. Thus, the values obtained represent the behaviour of a pile the head of which will always be blocked in rotation irrespective of the load applied.

However, when this blocking in rotation was simulated by a "null prescribed rotation", this was considered by the calculation engine as a "load case" and not as a support condition.

G.4.1.4. Step 2: Elastoplastic soil

We will now do the same example as above but adopting an elastoplastic behaviour for the soil (defined from pressuremeter results).

G.4.1.4.1. Modification of the data

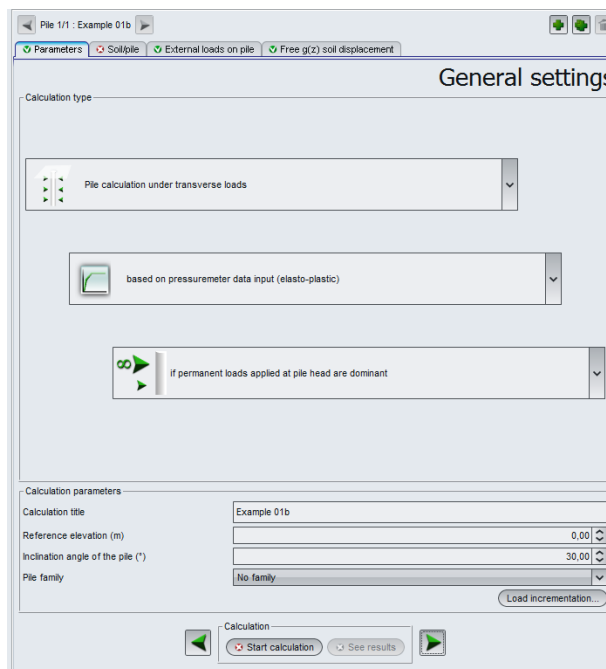
Click  button.

Save the example above with a new name ("Example 01b" for example), then modify the data as follows.

Return to "Parameters" tab:

"Calculation type" box:

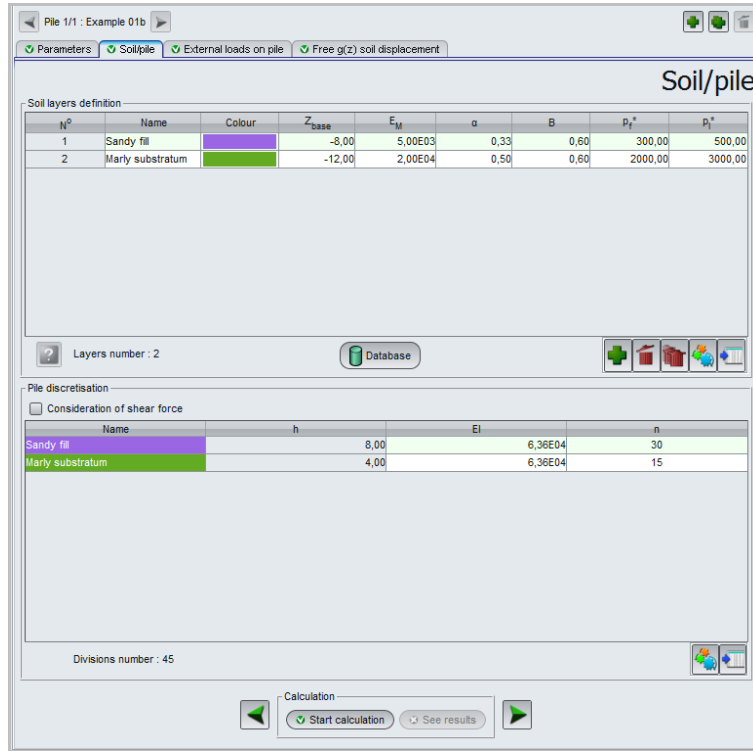
- In the second drop-down list, select "Based on pressuremeter data input (elasto-plastic)".
- In the third drop-down list, select "If permanent loads applied at pile head are dominant":



The definition of the soil layers must be completed to take the elastoplastic behaviour into account (moreover, the red cross on the "Soil/Pile" tab clearly indicates that the data is incomplete): click "Soil/Pile" tab.

New columns appear in the upper table and must be completed: these are the PI* (net limit pressure) and Pf* (net creep pressure) values for each layer.

Name	Z _{base} (m)	E _M (kPa)	α	B (m)	Pf* (kPa)	PI* (kPa)
Sandy fill	-8.00	5,000	0.33	0.60	300	500
Marly substratum	-12.00	20,000	0.50	0.60	2000	3000



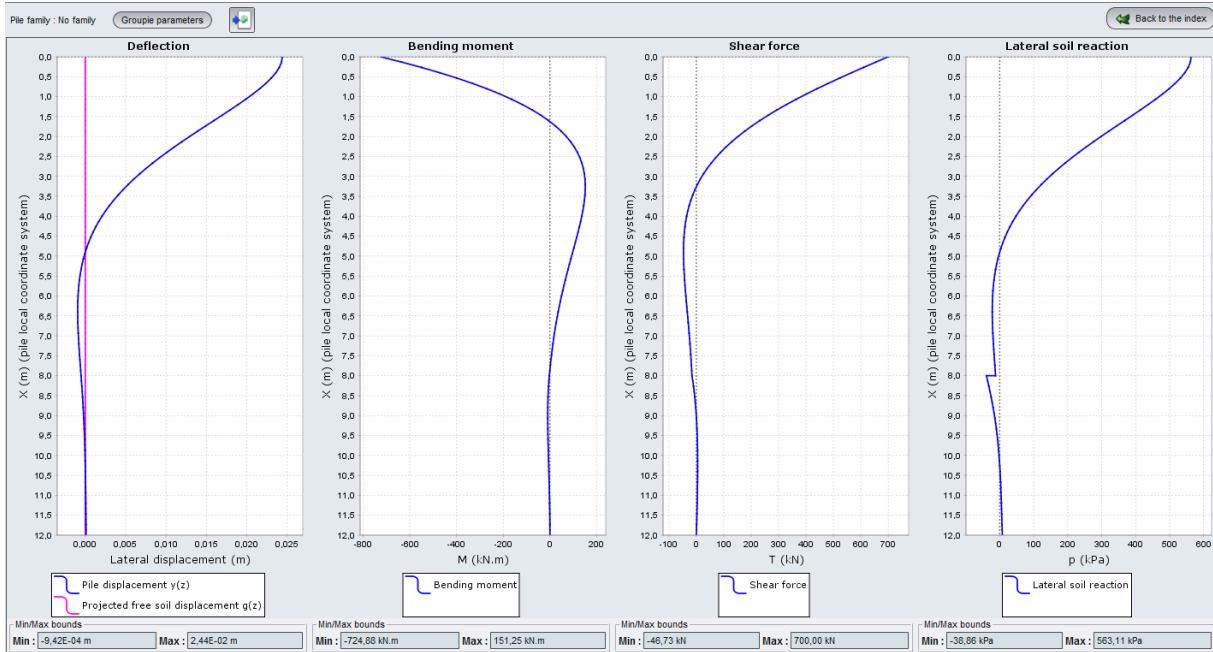
Now, start the calculation by clicking **Start calculation** button.

Then click **See results** button.

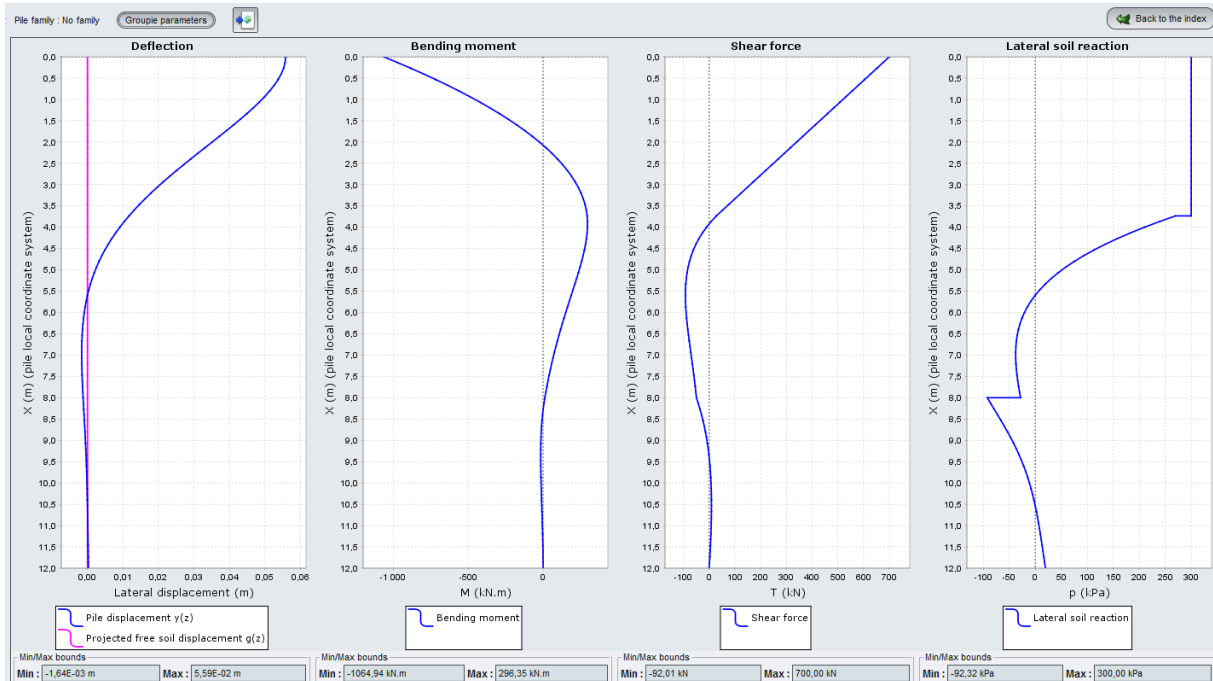
G.4.1.4.2. Results

Main curves: Forces and displacements

Elastic calculation (reminder of previous results):



Elastoplastic calculation (results of new calculation):



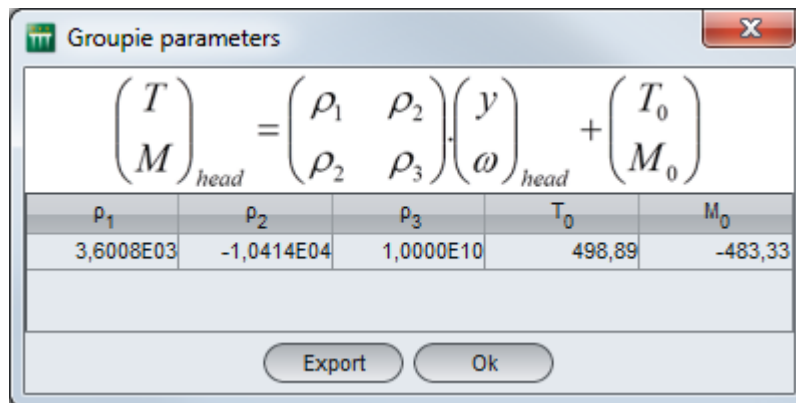
Comparison of forces and displacements: Elastic/elastoplastic calculation:

	Deflection: lateral displacement (cm)		Bending moment M (kN.m)		Shear force T (kN)		Lateral soil reaction p (kPa)	
	Min	Max	Min	Max	Min	Max	Min	Max
Elastic calculation	-0.1	2.4	-725	-151	-47	700	-39	563
Elasto-plastic calculation	-0.2	5.6	-1065	296	-92	700	-92	300

Note that the elastoplastic behaviour has introduced a "limit" for the soil's lateral passive earth pressure (plasticity): the soil cannot bear the same loading as in elastic behaviour:

- The lateral reaction is limited to the (net) creep pressure value and this limit is effectively reached over almost 4 m at the head of the pile.
- The displacements are higher (the displacement value at the head has more than doubled).
- The loads in the pile have also increased: moments and shear forces (except for the value at the head, corresponding to the 700 kN value prescribed in the data).

Stiffness coefficients:

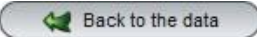


The stiffness coefficients have changed with respect to the previous step. The partial plastification of the soil has thus led to a reduction of the "elastic" part of this stiffness matrix, represented here by coefficients ρ_1 , ρ_2 and ρ_3 . Also, the nonlinearity of the behaviour of the system generates a non-null term at origin, represented here by terms T_0 and M_0 .

G.4.1.5. Step 3: Inclined pile case

We will now start from the previous example (with elastoplastic behaviour) and introduce a pile inclination of 30° from the vertical.

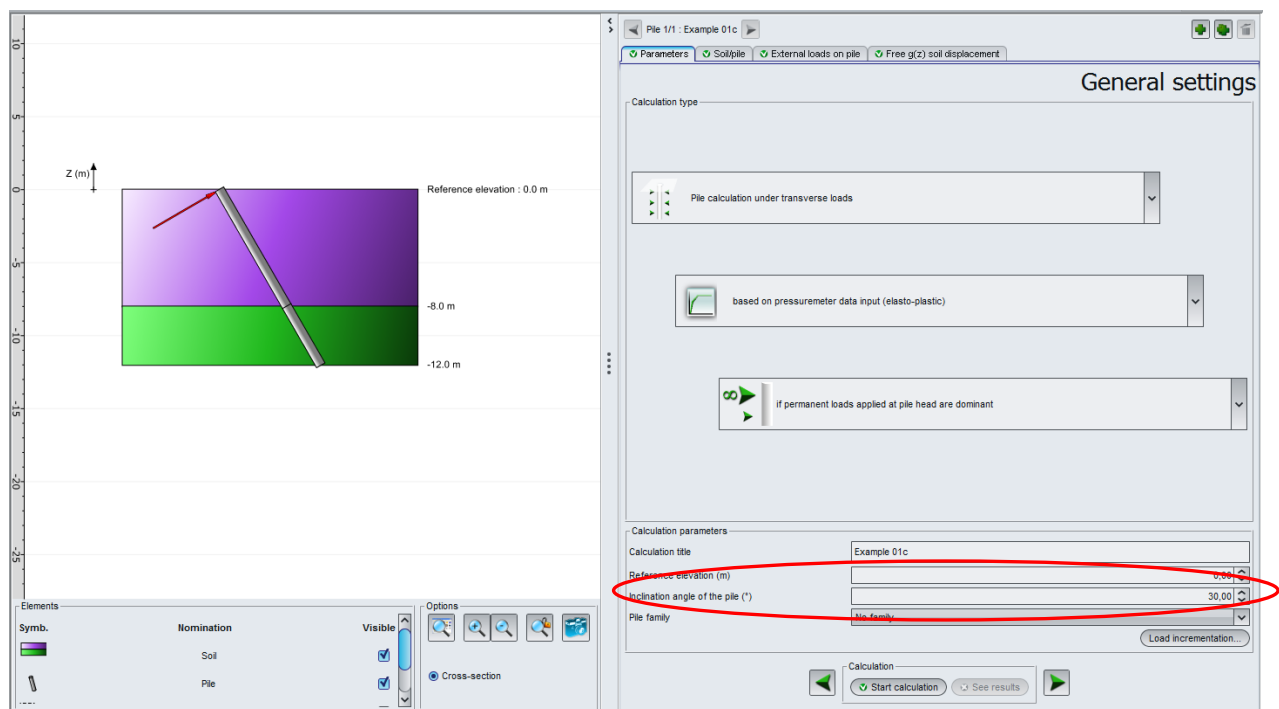
G.4.1.5.1. Taking 30° inclination into account

To modify the data, click  button and return to "Parameters" tab:

"Calculation parameters" box:

- Inclination angle of the pile (from the vertical): 30°

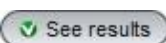
Caution: this means defining a pile longer than before as its base is located by convention level with the base of the last soil layer which is unchanged at elevation -12. The new length of the pile is therefore equal to $12/\cos(30^\circ) = 13.86$ m.



Also, the force applied to the head is a side force, expressed by convention in the local coordinate system of the pile and is therefore perpendicular to the pile: therefore, the force $T = 700$ kN is now also inclined by 30°.

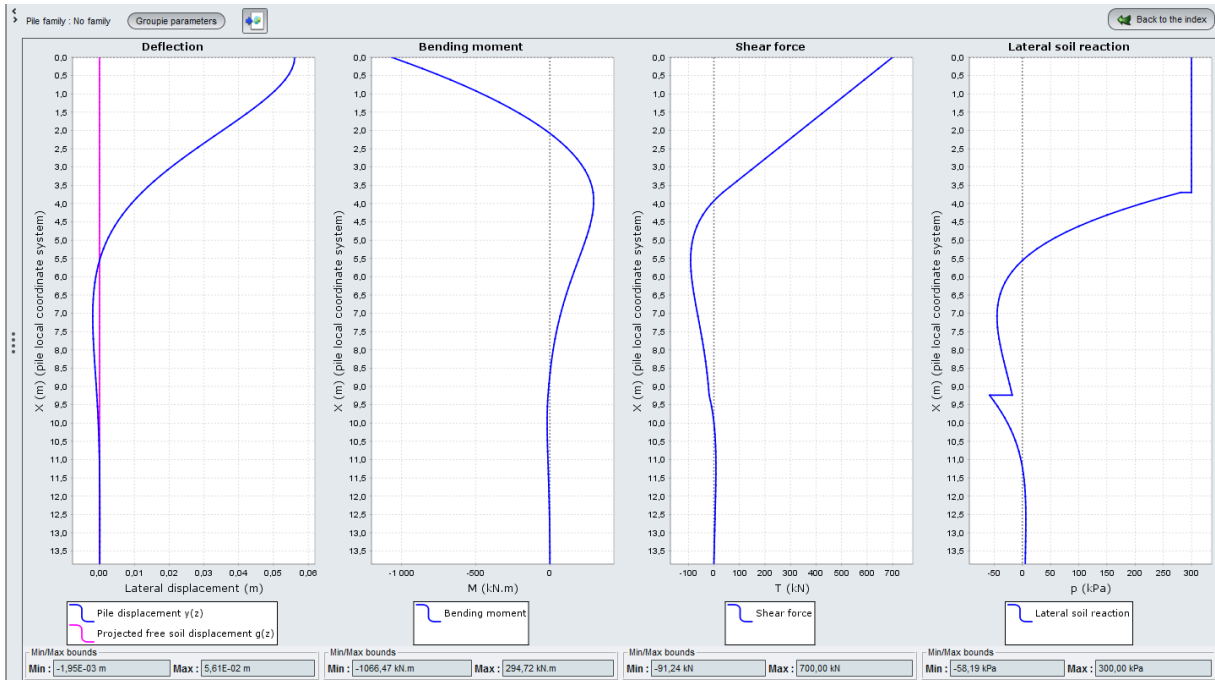
Save your project under a different name: "Example 01c" for example.

Start the calculation by clicking  button.

Then click  button.

G.4.1.5.2. Results

Main curves:



All the results are expressed in the local coordinate system of the pile: in particular, the lateral displacement is an upward displacement inclined 30° from the horizontal.

The formatted results are shown below.

They are also expressed in the local coordinate system. Note that the "palier" (plateau) column gives the mobilisation state of the lateral reaction of the soil in each element. It varies between 1 and 3 according to the total number of plateaux comprising the mobilisation curve. In particular, the value 1 always corresponds to a pure elastic state whereas a value higher than or equal to 2 corresponds to a partial or total plastification state.

Déplacements et sollicitations en tout point du pieu

Notations
 z : cote (longueur)
 x : abscisse - repère local du pieu (longueur)
 y : flèche absolue latérale du pieu (longueur)
 w : notation (∂y/∂x)
 g : déformée libre du sol projetée (longueur)
 M : moment fléchissant (force x longueur)
 T : effort tranchant (force)
 r : réaction latérale du sol (force / unité de surface)

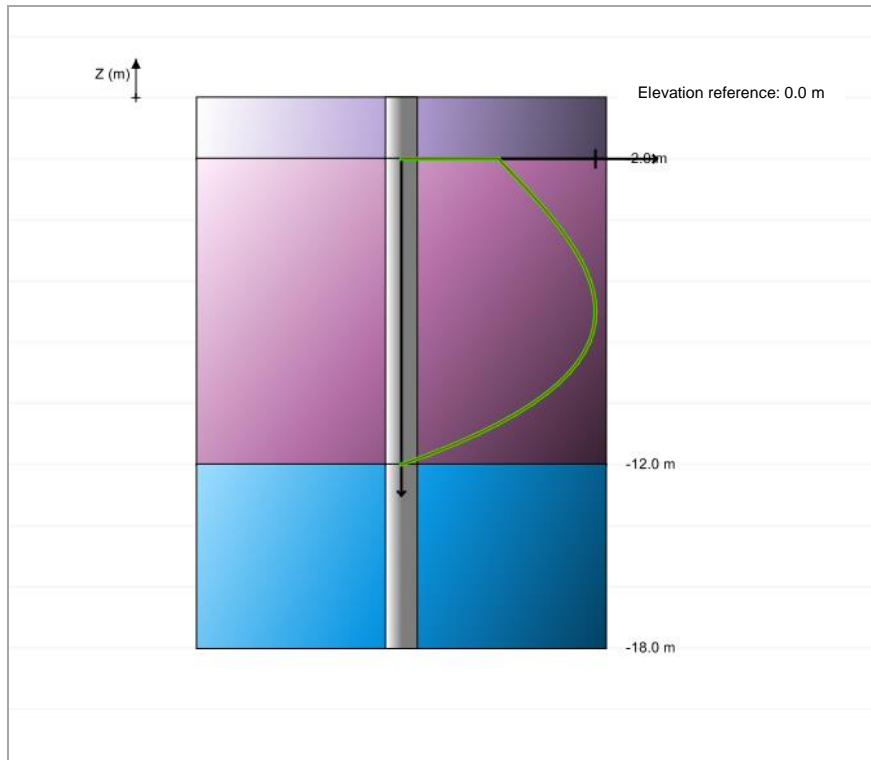
Elément	z	x	y	g	w	T	M	r	palier
001	0.000	0.000	0.561E-01	0.000E+00	0.000E+00	0.700E+03	-0.107E+04	0.300E+03	2
001	-0.133	0.154	0.559E-01	0.000E+00	-0.245E-02	0.672E+03	-0.561E+03	0.300E+03	2
001	-0.267	0.308	0.554E-01	0.000E+00	-0.466E-02	0.645E+03	-0.859E+03	0.300E+03	2
002	-0.267	0.308	0.554E-01	0.000E+00	-0.466E-02	0.645E+03	-0.859E+03	0.300E+03	2
002	-0.400	0.462	0.545E-01	0.000E+00	-0.662E-02	0.617E+03	-0.762E+03	0.300E+03	2
002	-0.533	0.616	0.533E-01	0.000E+00	-0.835E-02	0.589E+03	-0.669E+03	0.300E+03	2
003	-0.533	0.616	0.533E-01	0.000E+00	-0.835E-02	0.589E+03	-0.669E+03	0.300E+03	2
003	-0.667	0.770	0.519E-01	0.000E+00	-0.986E-02	0.561E+03	-0.581E+03	0.300E+03	2
003	-0.800	0.924	0.503E-01	0.000E+00	-0.112E-01	0.534E+03	-0.497E+03	0.300E+03	2
004	-0.800	0.924	0.503E-01	0.000E+00	-0.112E-01	0.534E+03	-0.497E+03	0.300E+03	2
004	-0.933	1.078	0.485E-01	0.000E+00	-0.123E-01	0.506E+03	-0.417E+03	0.300E+03	2
004	-1.067	1.232	0.465E-01	0.000E+00	-0.132E-01	0.478E+03	-0.341E+03	0.300E+03	2
005	-1.067	1.232	0.465E-01	0.000E+00	-0.132E-01	0.478E+03	-0.341E+03	0.300E+03	2
005	-1.200	1.386	0.444E-01	0.000E+00	-0.139E-01	0.451E+03	-0.269E+03	0.300E+03	2
005	-1.333	1.540	0.423E-01	0.000E+00	-0.145E-01	0.423E+03	-0.202E+03	0.300E+03	2
006	-1.333	1.540	0.423E-01	0.000E+00	-0.145E-01	0.423E+03	-0.202E+03	0.300E+03	2
006	-1.467	1.694	0.400E-01	0.000E+00	-0.149E-01	0.395E+03	-0.139E+03	0.300E+03	2
006	-1.600	1.848	0.377E-01	0.000E+00	-0.152E-01	0.367E+03	-0.804E+02	0.300E+03	2
007	-1.600	1.848	0.377E-01	0.000E+00	-0.152E-01	0.367E+03	-0.804E+02	0.300E+03	2
007	-1.733	2.001	0.353E-01	0.000E+00	-0.153E-01	0.340E+03	-0.259E+02	0.300E+03	2
007	-1.867	2.155	0.330E-01	0.000E+00	-0.153E-01	0.312E+03	0.242E+02	0.300E+03	2
008	-1.867	2.155	0.330E-01	0.000E+00	-0.153E-01	0.312E+03	0.242E+02	0.300E+03	2
008	-2.000	2.309	0.306E-01	0.000E+00	-0.152E-01	0.284E+03	0.702E+02	0.300E+03	2
008	-2.133	2.463	0.283E-01	0.000E+00	-0.150E-01	0.257E+03	0.112E+03	0.300E+03	2
009	-2.133	2.463	0.283E-01	0.000E+00	-0.150E-01	0.257E+03	0.112E+03	0.300E+03	2
009	-2.267	2.617	0.260E-01	0.000E+00	-0.146E-01	0.229E+03	0.149E+03	0.300E+03	2
009	-2.400	2.771	0.238E-01	0.000E+00	-0.142E-01	0.201E+03	0.182E+03	0.300E+03	2
010	-2.400	2.771	0.238E-01	0.000E+00	-0.142E-01	0.201E+03	0.182E+03	0.300E+03	2
010	-2.533	2.925	0.216E-01	0.000E+00	-0.138E-01	0.173E+03	0.211E+03	0.300E+03	2
010	-2.667	3.079	0.196E-01	0.000E+00	-0.132E-01	0.146E+03	0.236E+03	0.300E+03	2
011	-2.667	3.079	0.196E-01	0.000E+00	-0.132E-01	0.146E+03	0.236E+03	0.300E+03	2
011	-2.800	3.233	0.176E-01	0.000E+00	-0.126E-01	0.118E+03	0.256E+03	0.300E+03	2
011	-2.933	3.387	0.157E-01	0.000E+00	-0.120E-01	0.903E+02	0.272E+03	0.300E+03	2
012	-2.933	3.387	0.157E-01	0.000E+00	-0.120E-01	0.903E+02	0.272E+03	0.300E+03	2
012	-3.067	3.541	0.139E-01	0.000E+00	-0.113E-01	0.626E+02	0.284E+03	0.300E+03	2
012	-3.200	3.695	0.122E-01	0.000E+00	-0.106E-01	0.349E+02	0.291E+03	0.300E+03	2
013	-3.200	3.695	0.122E-01	0.000E+00	-0.106E-01	0.349E+02	0.291E+03	0.281E+03	1
013	-3.333	3.849	0.106E-01	0.000E+00	-0.991E-02	0.106E+02	0.295E+03	0.245E+03	1
013	-3.467	4.003	0.914E-02	0.000E+00	-0.919E-02	-0.104E+02	0.295E+03	0.211E+03	1
014	-3.467	4.003	0.914E-02	0.000E+00	-0.919E-02	-0.104E+02	0.295E+03	0.211E+03	1
014	-3.600	4.157	0.778E-02	0.000E+00	-0.849E-02	-0.284E+02	0.292E+03	0.179E+03	1
014	-3.733	4.311	0.653E-02	0.000E+00	-0.778E-02	-0.436E+02	0.286E+03	0.151E+03	1
015	-3.733	4.311	0.653E-02	0.000E+00	-0.778E-02	-0.436E+02	0.286E+03	0.151E+03	1
015	-3.867	4.465	0.538E-02	0.000E+00	-0.710E-02	-0.563E+02	0.278E+03	0.124E+03	1
015	-4.000	4.619	0.434E-02	0.000E+00	-0.644E-02	-0.666E+02	0.269E+03	0.100E+03	1
016	-4.000	4.619	0.434E-02	0.000E+00	-0.644E-02	-0.666E+02	0.269E+03	0.100E+03	1
016	-4.133	4.773	0.340E-02	0.000E+00	-0.580E-02	-0.748E+02	0.258E+03	0.784E+02	1
016	-4.267	4.927	0.255E-02	0.000E+00	-0.519E-02	-0.812E+02	0.246E+03	0.589E+02	1
017	-4.267	4.927	0.255E-02	0.000E+00	-0.519E-02	-0.812E+02	0.246E+03	0.589E+02	1
017	-4.400	5.081	0.180E-02	0.000E+00	-0.462E-02	-0.858E+02	0.233E+03	0.415E+02	1
017	-4.533	5.235	0.113E-02	0.000E+00	-0.406E-02	-0.889E+02	0.220E+03	0.261E+02	1
018	-4.533	5.235	0.113E-02	0.000E+00	-0.406E-02	-0.889E+02	0.220E+03	0.261E+02	1
018	-4.667	5.389	0.546E-03	0.000E+00	-0.355E-02	-0.907E+02	0.206E+03	0.126E+02	1
018	-4.800	5.543	0.370E-04	0.000E+00	-0.306E-02	-0.913E+02	0.192E+03	0.854E+01	1
018	-4.800	5.543	0.370E-04	0.000E+00	-0.306E-02	-0.913E+02	0.192E+03	0.854E+01	1

G.4.2. Example 2: Pile submitted to a lateral displacement $g(z)$ of soil

This second example allows us to consider the case of a pile with elastoplastic behaviour of the soil, submitted not to loads at head, but to a lateral earth pressure represented by a "free displacement" called $g(z)$.

The example will be first run for 18 m long and 1 m diameter vertical piles with imposed null displacement at head. A variant will also be proposed with more flexible piles (35 cm in diameter).

A last part of the example illustrates the manual input of a 3-plateau behaviour law rather than the use of pressuremeter parameters.



G.4.2.1. Step 1: Elastoplastic behaviour and $g(z)$ curve

We will first define 1 m diameter and 18 m long piles with an elastoplastic behaviour of the soil (defined from pressuremeter test results).

G.4.2.2. Data input

- Choose to create a new project by selecting New project radio-button.
- Click button.

If Foxta is already open, click "File", "New project" menu.

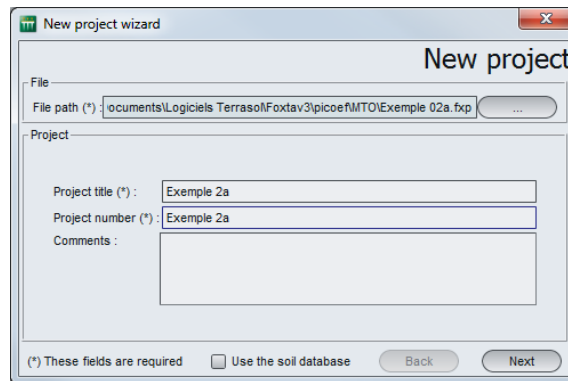
G.4.2.2.1. New project wizard

File box

- Complete file path by clicking button.
- Give a name to the file and save it.

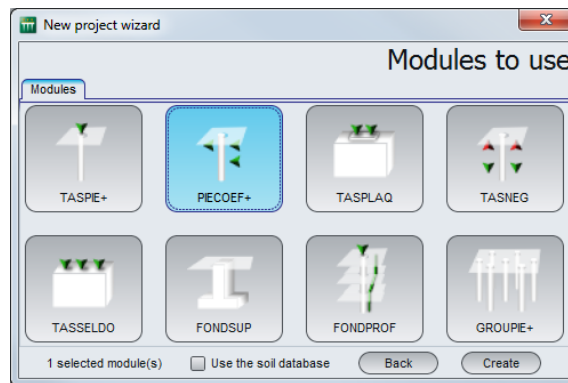
"Project" box

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



G.4.2.2.2. New project wizard: Modules to use

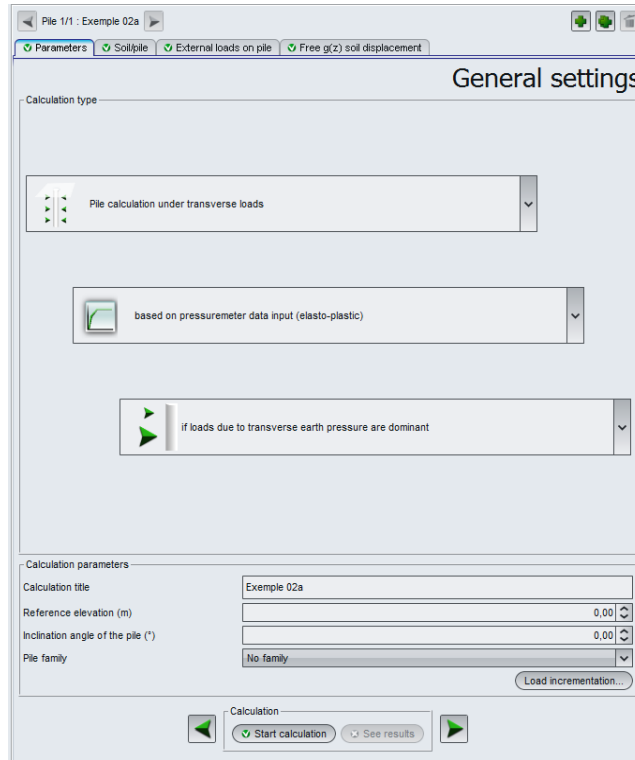
In "Modules to use" window, select Piecoef+ module then click button.



The Piecoef+ data input window is displayed.

Complete the data tabs on right-hand zone of screen.

G.4.2.2.3. "Parameters" tab




This tab includes two boxes:

"Calculation type" box: select

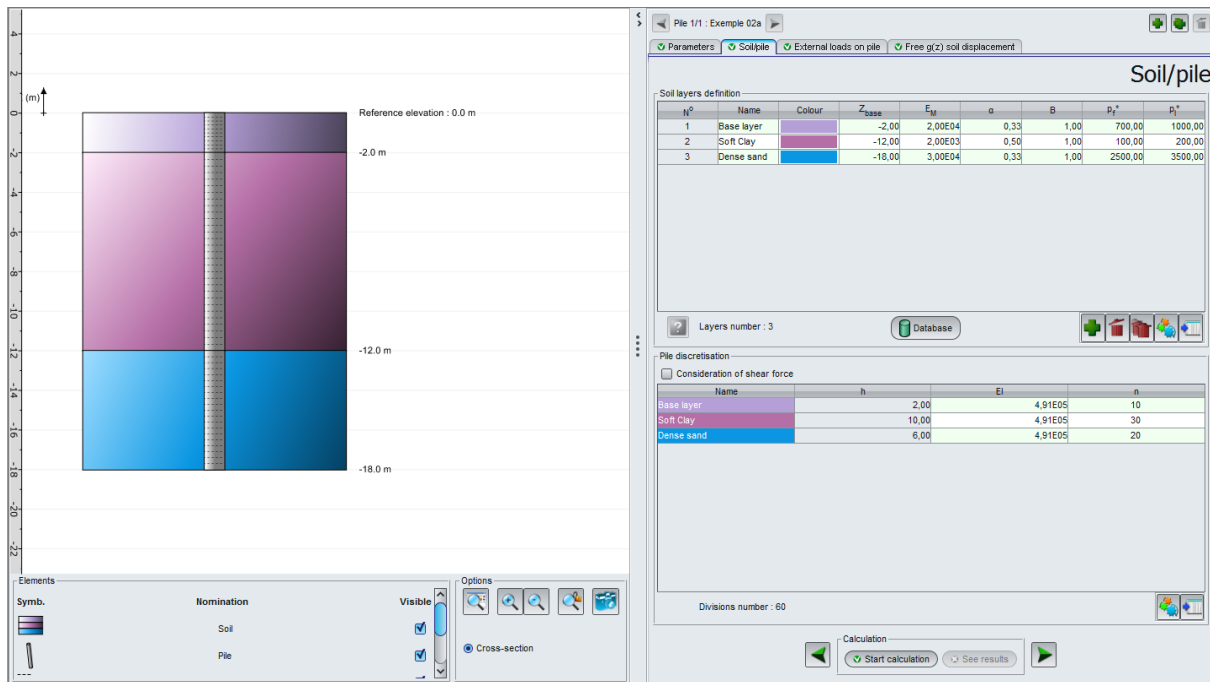
- drop-down list 1: Pile calculation under transverse loads
- drop-down list 2: Based on pressuremeter data input (elasto-plastic)
- drop-down list 3: If loads due to transverse earth pressure are dominant

"Calculation parameters" box:

- Calculation title: Example 02a
- Reference elevation: 0,0 m
- Inclination angle of the pile: 0° (vertical pile)
- Pile family: no family
- Load incrementation: here, we will keep the default values.


To go to the next tab, click either name of "Soil/Pile" tab or  button.

G.4.2.2.4. "Soil/Pile" tab



This tab is used to define the soil characteristics and the pile discretisation.

"Soil layers definition" box:

Create three soil levels by clicking  button to add each layer. The data to be input is as follows:

Name	Z _{base} (m)	E _M (kPa)	α	B (m)	Pf* (kPa)	Pl* (kPa)
Subgrade	-2,0	20000	0,33	1,0	700	1000
Soft clay	-12,0	2000	0,50	1,0	100	200
Dense sand	-18,0	30000	0,33	1,0	2500	3500

Note: We will not use the database for this example.

"Pile discretisation" box:

The data to be input is as follows:

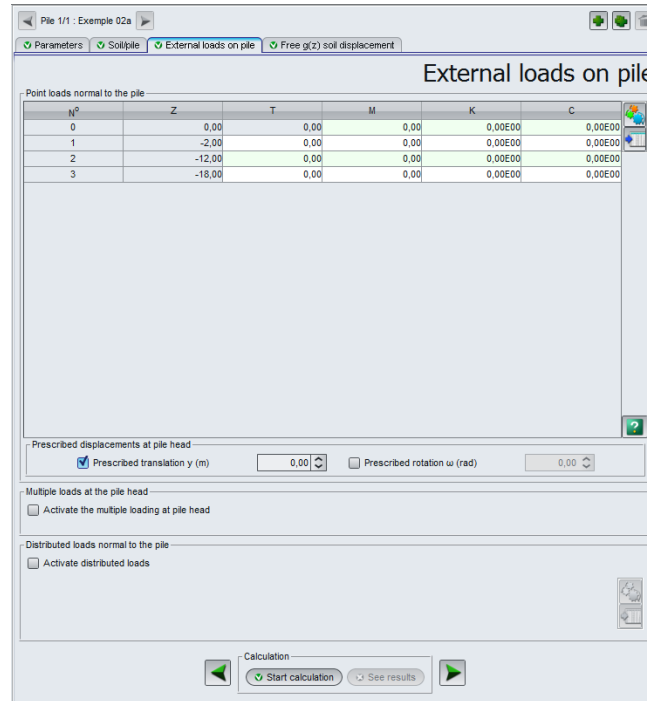
- Leave "Consideration of shear force" box unticked

Layer	h (m)	EI (kN.m ²)	n
Subgrade	2,0	491000	10
Soft clay	10,0	491000	30
Dense sand	6,0	491000	20

The EI product defined here corresponds to a concrete pile, with a solid circular section of 1 m in diameter. The concrete modulus is taken as equal to 10,000 MPa.

The discretisation has been defined with respect to the thickness of each layer but without attempting to find the same calculation step in each layer as this is not mandatory and does not affect the results provided the mesh is sufficiently refined.

G.4.2.2.5. "External loads on pile" tab



"Point loads normal to the pile" box:

There is no load to be defined for this example (the only load applied to the pile is curve g(z)).

"Prescribed displacements at pile head" box:

We will prescribe a null displacement at pile head.

The data to be input is therefore as follows:

	Tick box	Values
y (m)	Yes	0,00
ω (rad)	No	-

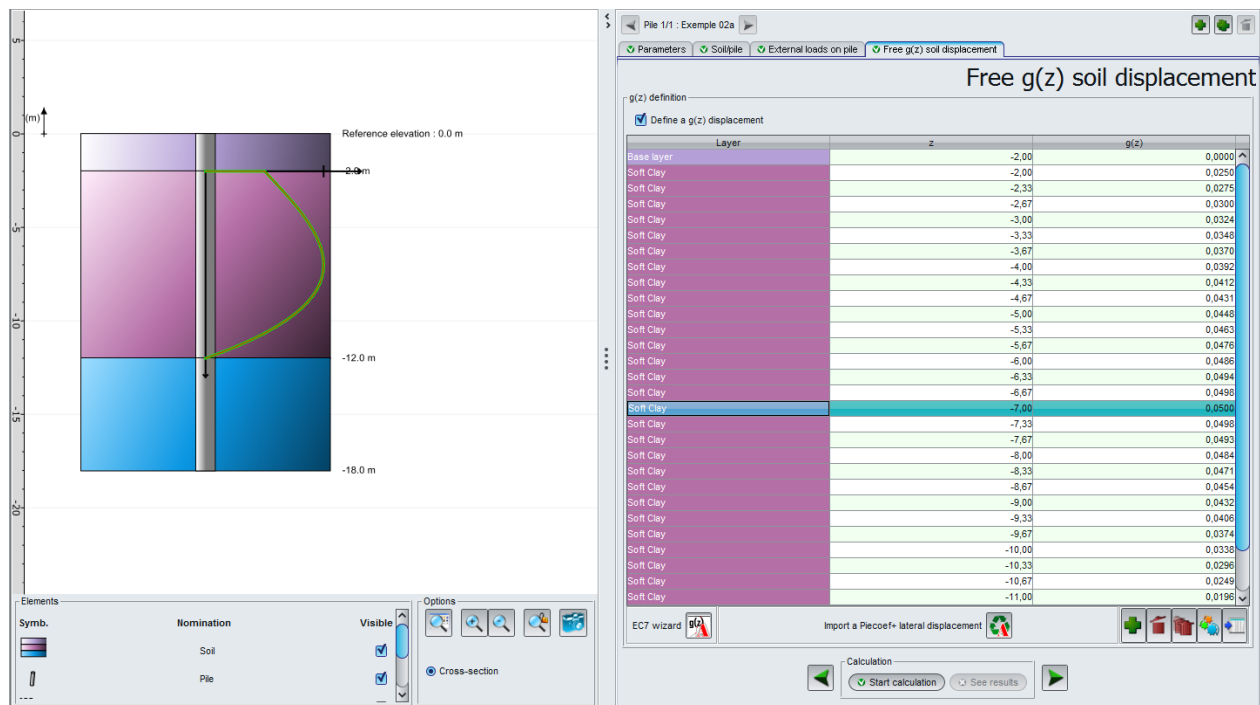
"Multiple loads at the pile head" box:

- Leave "Activate the multiple loading at pile head" box unticked.


"Distributed loads normal to the pile" box:

- Leave "Activate distributed loads" box unticked.

G.4.2.2.6. "Free g(z) soil displacement" tab



"g(z) definition" box:

- Click "Define a g(z) displacement" box.
- Open g(z) wizard by clicking  button to calculate the displacement values. The data to be input is described below.

Note: The free g(z) displacement can be input directly by any (z, g(z)) pairs. In particular, the "z" values need not be compatible with the pile mesh. Indeed, the calculation engine systematically applies a re-interpolation of these values to express the g(z) values at the calculation points.

"Definition of compressible horizon" box:

- Horizon roof elevation Z1 (m): here, this is the roof of the soft clay layer (elevation -2,0 m).
- Base elevation of the horizon Z2 (m): here, this is the base of the soft clay layer (elevation -12,0 m). The prescribed g(z) curve therefore concerns only the thickness of the soft clay layer.

"Dimensionless definition" box:

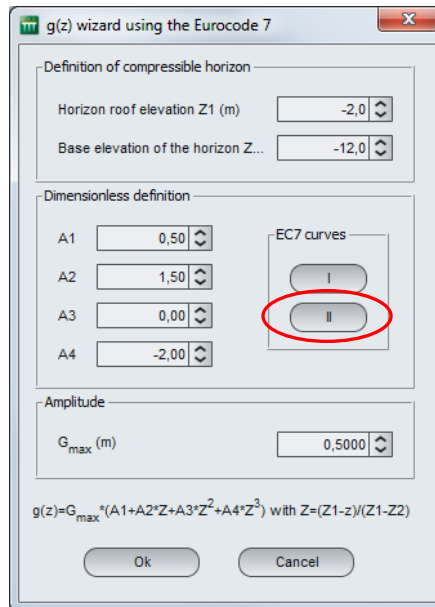
- Polynomial coefficients A1, A2, A3 and A4 (values proposed by default as a function of curve type (I or II)).
- EC7 curve:
 - ✓ I: General case
 - ✓ II: Case of a layer less deformable on surface of a substantial height ($\geq 0.3 \times D$) which is the case here.

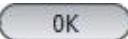
Amplitude box:

- G_{max} (m) = maximum horizontal displacement of soil, taken equal to 5 cm.

The data to be input is as follows:

Z1 (m)	Z2 (m)	Curve	A1	A2	A3	A4	G _{max} (m)
-2,0	-12,0	II	0,50	1,50	0,00	-2,00	0,05

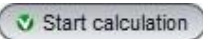


Click  button to import g(z) curve thus generated into current project.

This g(z) curve is represented (in green) on the project cross-section.

G.4.2.3. Calculation and Results

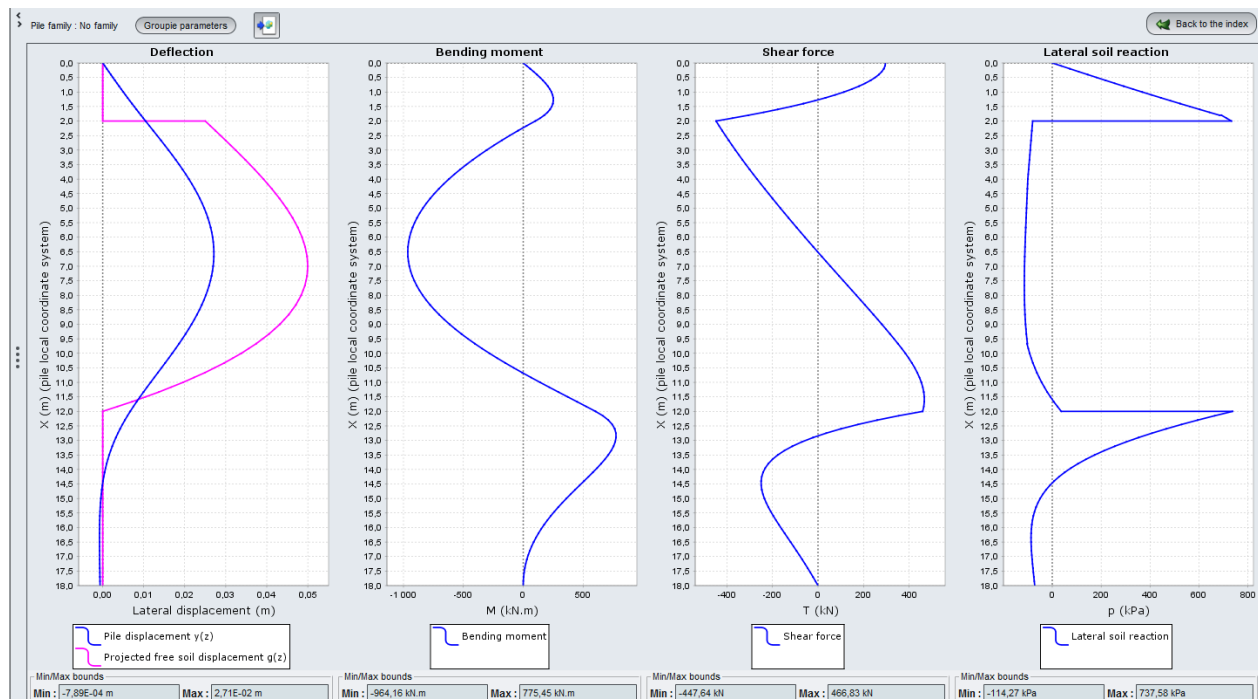
G.4.2.3.1. Calculation

Click  button.

To see the results in table and graph form, click  button.

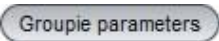
G.4.2.3.2. Results

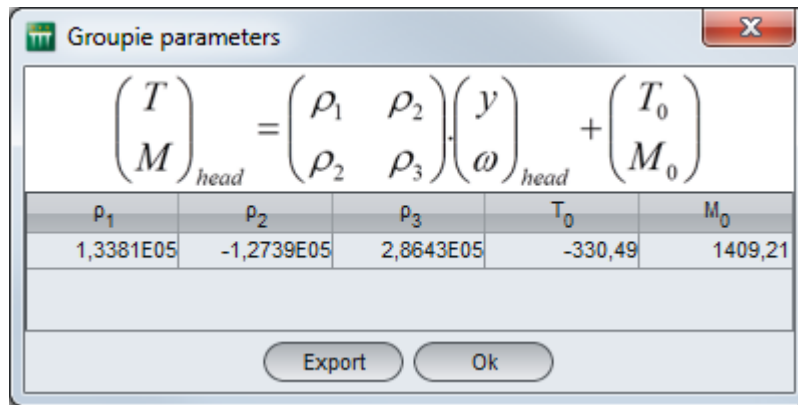
Main curves:



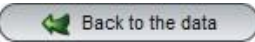
Deflection: lateral displacement (cm)		Bending moment M (kN.m)		Shear force T (kN)		Lateral soil reaction p (kPa)	
Min	Max	Min	Max	Min	Max	Min	Max
-0,1	2,7	-964	776	-448	467	-114	737

The introduction of a free $g(z)$ soil displacement is represented in the calculation by a lateral reaction not proportional to the pile displacement $y(z)$ but to the relative displacement of the pile with respect to the soil $y(z) - g(z)$, which explains why a negative reaction is obtained on the height of the clay layer as the obtained displacement of the pile is lower than the free soil displacement.

Click  button to obtain the stiffness coefficients (as in example 1, these are given here for information purposes but will not be used for example 2):



The obtaining of a non null term at origin (T_0 , M_0) is synonymous with a nonlinearity of the apparent behaviour at pile head. This can be explained both by a partial plastification of the soil or by the application of a load on the pile other than the one at the head.

Click  button to return to presentation of various types of results, then click "Formatted results".

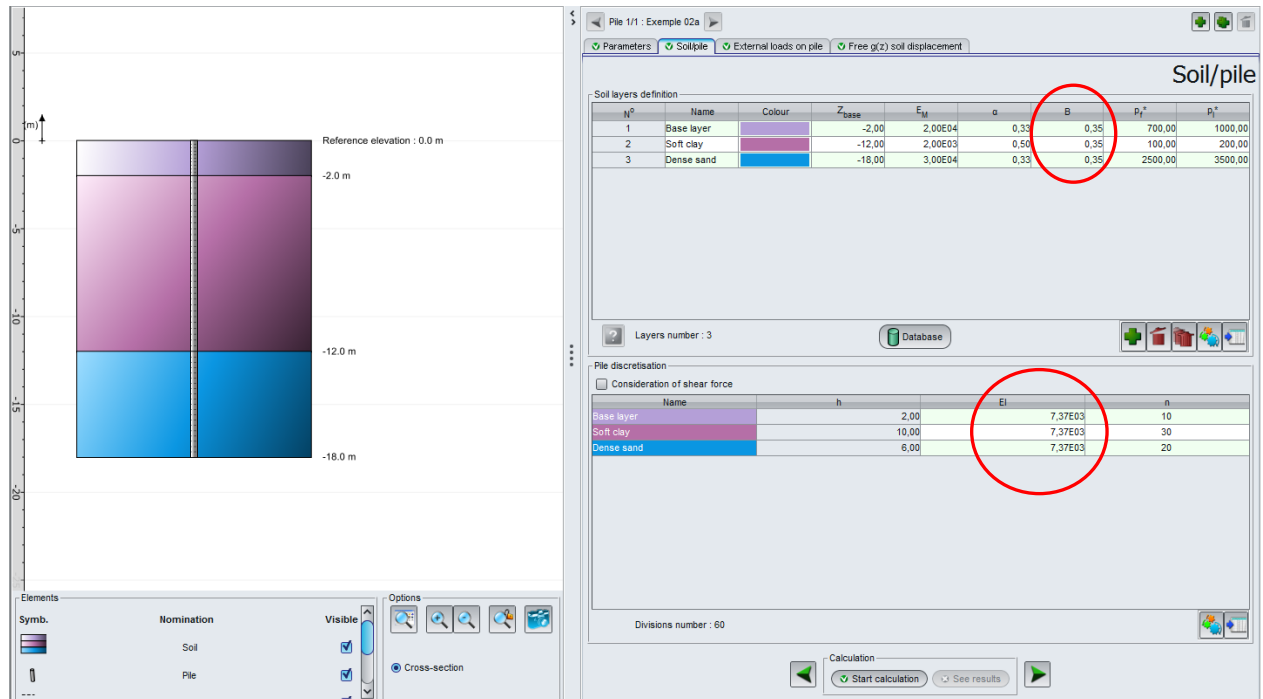
These results notably include the detail of the $g(z)$ curve.

Déformée libre du sol				
Noeud	cote	abscisse	$g(z)$	$g(z)$ -projetée
011	-2.000	2.000	0.0250	0.0250
012	-2.333	2.333	0.0275	0.0275
012	-2.333	2.333	0.0275	0.0275
013	-2.667	2.667	0.0300	0.0300
013	-2.667	2.667	0.0300	0.0300
014	-3.000	3.000	0.0324	0.0324
014	-3.000	3.000	0.0324	0.0324
015	-3.333	3.333	0.0348	0.0348
015	-3.333	3.333	0.0348	0.0348
016	-3.667	3.667	0.0370	0.0370
016	-3.667	3.667	0.0370	0.0370
017	-4.000	4.000	0.0392	0.0392
017	-4.000	4.000	0.0392	0.0392
018	-4.333	4.333	0.0412	0.0412
018	-4.333	4.333	0.0412	0.0412
019	-4.667	4.667	0.0431	0.0431
019	-4.667	4.667	0.0431	0.0431
020	-5.000	5.000	0.0448	0.0448
020	-5.000	5.000	0.0448	0.0448
021	-5.333	5.333	0.0463	0.0463
021	-5.333	5.333	0.0463	0.0463
022	-5.667	5.667	0.0476	0.0476
022	-5.667	5.667	0.0476	0.0476
023	-6.000	6.000	0.0486	0.0486
023	-6.000	6.000	0.0486	0.0486
024	-6.333	6.333	0.0494	0.0494
024	-6.333	6.333	0.0494	0.0494
025	-6.667	6.667	0.0498	0.0498
025	-6.667	6.667	0.0498	0.0498
026	-7.000	7.000	0.0500	0.0500
026	-7.000	7.000	0.0500	0.0500
027	-7.333	7.333	0.0498	0.0498
027	-7.333	7.333	0.0498	0.0498
028	-7.667	7.667	0.0493	0.0493
028	-7.667	7.667	0.0493	0.0493
029	-8.000	8.000	0.0484	0.0484
029	-8.000	8.000	0.0484	0.0484
030	-8.333	8.333	0.0471	0.0471
030	-8.333	8.333	0.0471	0.0471
031	-8.667	8.667	0.0454	0.0454
031	-8.667	8.667	0.0454	0.0454
032	-9.000	9.000	0.0432	0.0432
032	-9.000	9.000	0.0432	0.0432
033	-9.333	9.333	0.0406	0.0406
033	-9.333	9.333	0.0406	0.0406
034	-9.667	9.667	0.0374	0.0374
034	-9.667	9.667	0.0374	0.0374
035	-10.000	10.000	0.0338	0.0338
035	-10.000	10.000	0.0338	0.0338
036	-10.333	10.333	0.0296	0.0296
036	-10.333	10.333	0.0296	0.0296
037	-10.667	10.667	0.0249	0.0249
037	-10.667	10.667	0.0249	0.0249
038	-11.000	11.000	0.0196	0.0196
038	-11.000	11.000	0.0196	0.0196
039	-11.333	11.333	0.0137	0.0137
039	-11.333	11.333	0.0137	0.0137
040	-11.667	11.667	0.0072	0.0072
040	-11.667	11.667	0.0072	0.0072
041	-12.000	12.000	0.0000	0.0000

G.4.2.4. Calculation variant with a more flexible pile

Click  button to modify the data.

G.4.2.4.1. Modification of pile characteristics



In the "Soil/Pile" tab, modify the diameter of the pile and its EI product:

"Soil layers definition" box:

- Drilling diameter B: 0.35 m for the three soil layers.

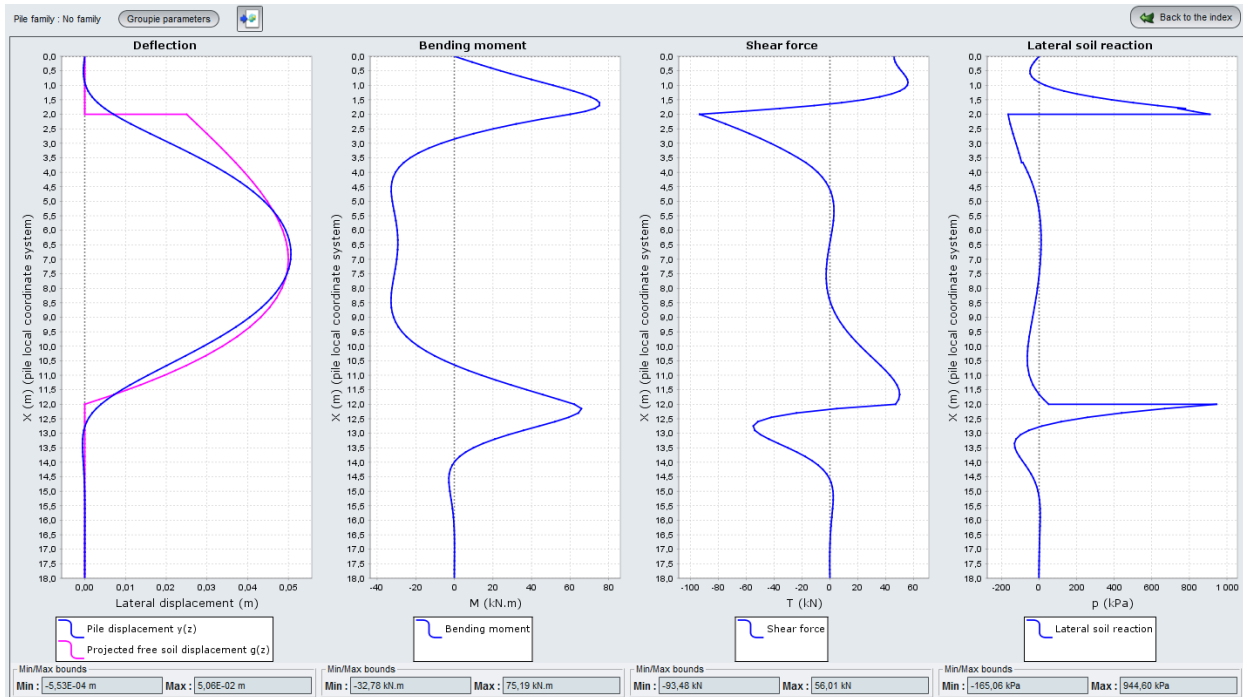
"Pile discretisation" box:

- Pile product of inertia EI = 7366 kN.m² over complete height (always calculated for a 10,000 MPa modulus).

Save the project with a different name: "Example 02ab" for example.

Start the calculation by clicking  button.

G.4.2.4.2. Results

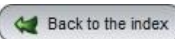
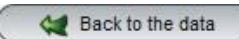


Comparison of results:

	Deflection: lateral displacement (cm)		Bending moment M (kN.m)		Shear force T (kN)		Lateral soil reaction p (kPa)	
	Min	Max	Min	Max	Min	Max	Min	Max
B = 1,0 m	-0,1	2,7	-964	776	-448	467	-114	737
B = 0,35 m	-0,1	5,1	-33	75	-93	56	-165	945

Note that the 0,35 m diameter pile is more flexible and therefore more closely follows the free soil displacement: the maximum pile displacement of 5.06 cm is very close to that of the free $g(z)$ soil displacement. This is also represented by a low reaction mobilised in the clay layer.

Also, the pile "takes" lower loads and the moments and shear forces are therefore much lower in the pile.

Click  button then  button to go back to the data.

G.4.2.5. Step 2: Manual input of mobilisation law

We will now take the previous example (variant with B = 0,35 m), but opting for manual input of the 3-plateau mobilisation law (rather than for an elastoplastic behaviour based on the results of the pressuremeter test).

Let us start by displaying the formatted results of the previous step (calculation for flexible pile, where B = 0,35 m).

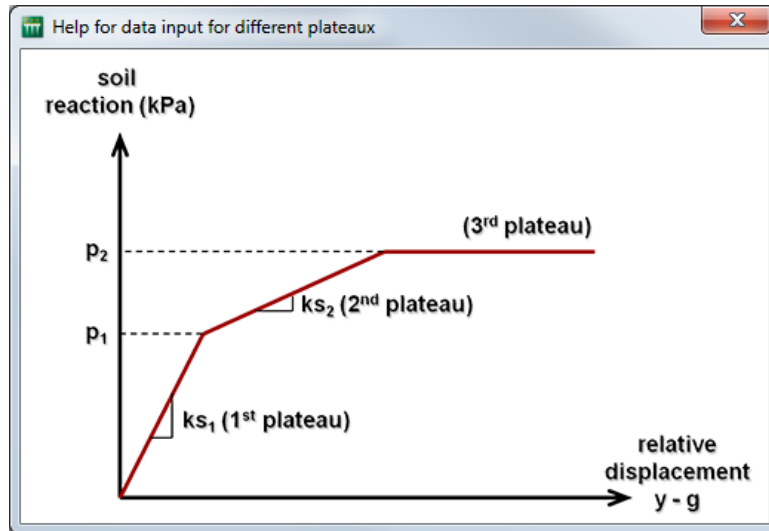
Caractéristiques des couches (données utilisateur)							
couche	base	EI	EM	alpha	B	pf	p1
01	-2.00	0.737E+04	20000.00	0.33	0.350	700.00	1000.00
02	-12.00	0.737E+04	2000.00	0.50	0.350	100.00	200.00
03	-18.00	0.737E+04	30000.00	0.33	0.350	2500.00	3500.00

Discretisation du pieu (Paramètres du calcul)						
Elément	XL	EI	k _{s1} *B	p1*B	k _{s2} *B	p2*B
001	0.200	0.7366E+04	0.5532E+05	0.2450E+03	0.2766E+05	0.3500E+03
002	0.200	0.7366E+04	0.5532E+05	0.2450E+03	0.2766E+05	0.3500E+03
003	0.200	0.7366E+04	0.5532E+05	0.2450E+03	0.2766E+05	0.3500E+03
004	0.200	0.7366E+04	0.5532E+05	0.2450E+03	0.2766E+05	0.3500E+03
005	0.200	0.7366E+04	0.5532E+05	0.2450E+03	0.2766E+05	0.3500E+03
006	0.200	0.7366E+04	0.5532E+05	0.2450E+03	0.2766E+05	0.3500E+03
007	0.200	0.7366E+04	0.5532E+05	0.2450E+03	0.2766E+05	0.3500E+03
008	0.200	0.7366E+04	0.5532E+05	0.2450E+03	0.2766E+05	0.3500E+03
009	0.200	0.7366E+04	0.5532E+05	0.2450E+03	0.2766E+05	0.3500E+03
010	0.200	0.7366E+04	0.5532E+05	0.2450E+03	0.2766E+05	0.3500E+03
011	0.333	0.7366E+04	0.4494E+04	0.3500E+02	0.2247E+04	0.7000E+02
012	0.333	0.7366E+04	0.4494E+04	0.3500E+02	0.2247E+04	0.7000E+02
013	0.333	0.7366E+04	0.4494E+04	0.3500E+02	0.2247E+04	0.7000E+02
014	0.333	0.7366E+04	0.4494E+04	0.3500E+02	0.2247E+04	0.7000E+02
015	0.333	0.7366E+04	0.4494E+04	0.3500E+02	0.2247E+04	0.7000E+02
016	0.333	0.7366E+04	0.4494E+04	0.3500E+02	0.2247E+04	0.7000E+02
017	0.333	0.7366E+04	0.4494E+04	0.3500E+02	0.2247E+04	0.7000E+02
018	0.333	0.7366E+04	0.4494E+04	0.3500E+02	0.2247E+04	0.7000E+02
019	0.333	0.7366E+04	0.4494E+04	0.3500E+02	0.2247E+04	0.7000E+02
020	0.333	0.7366E+04	0.4494E+04	0.3500E+02	0.2247E+04	0.7000E+02
021	0.333	0.7366E+04	0.4494E+04	0.3500E+02	0.2247E+04	0.7000E+02
022	0.333	0.7366E+04	0.4494E+04	0.3500E+02	0.2247E+04	0.7000E+02
023	0.333	0.7366E+04	0.4494E+04	0.3500E+02	0.2247E+04	0.7000E+02
024	0.333	0.7366E+04	0.4494E+04	0.3500E+02	0.2247E+04	0.7000E+02
025	0.333	0.7366E+04	0.4494E+04	0.3500E+02	0.2247E+04	0.7000E+02
026	0.333	0.7366E+04	0.4494E+04	0.3500E+02	0.2247E+04	0.7000E+02
027	0.333	0.7366E+04	0.4494E+04	0.3500E+02	0.2247E+04	0.7000E+02
028	0.333	0.7366E+04	0.4494E+04	0.3500E+02	0.2247E+04	0.7000E+02
029	0.333	0.7366E+04	0.4494E+04	0.3500E+02	0.2247E+04	0.7000E+02
030	0.333	0.7366E+04	0.4494E+04	0.3500E+02	0.2247E+04	0.7000E+02
031	0.333	0.7366E+04	0.4494E+04	0.3500E+02	0.2247E+04	0.7000E+02
032	0.333	0.7366E+04	0.4494E+04	0.3500E+02	0.2247E+04	0.7000E+02
033	0.333	0.7366E+04	0.4494E+04	0.3500E+02	0.2247E+04	0.7000E+02
034	0.333	0.7366E+04	0.4494E+04	0.3500E+02	0.2247E+04	0.7000E+02
035	0.333	0.7366E+04	0.4494E+04	0.3500E+02	0.2247E+04	0.7000E+02
036	0.333	0.7366E+04	0.4494E+04	0.3500E+02	0.2247E+04	0.7000E+02
037	0.333	0.7366E+04	0.4494E+04	0.3500E+02	0.2247E+04	0.7000E+02
038	0.333	0.7366E+04	0.4494E+04	0.3500E+02	0.2247E+04	0.7000E+02
039	0.333	0.7366E+04	0.4494E+04	0.3500E+02	0.2247E+04	0.7000E+02
040	0.333	0.7366E+04	0.4494E+04	0.3500E+02	0.2247E+04	0.7000E+02
041	0.300	0.7366E+04	0.8298E+05	0.8750E+03	0.4149E+05	0.1225E+04
042	0.300	0.7366E+04	0.8298E+05	0.8750E+03	0.4149E+05	0.1225E+04
043	0.300	0.7366E+04	0.8298E+05	0.8750E+03	0.4149E+05	0.1225E+04
044	0.300	0.7366E+04	0.8298E+05	0.8750E+03	0.4149E+05	0.1225E+04
045	0.300	0.7366E+04	0.8298E+05	0.8750E+03	0.4149E+05	0.1225E+04
046	0.300	0.7366E+04	0.8298E+05	0.8750E+03	0.4149E+05	0.1225E+04
047	0.300	0.7366E+04	0.8298E+05	0.8750E+03	0.4149E+05	0.1225E+04
048	0.300	0.7366E+04	0.8298E+05	0.8750E+03	0.4149E+05	0.1225E+04
049	0.300	0.7366E+04	0.8298E+05	0.8750E+03	0.4149E+05	0.1225E+04
050	0.300	0.7366E+04	0.8298E+05	0.8750E+03	0.4149E+05	0.1225E+04
051	0.300	0.7366E+04	0.8298E+05	0.8750E+03	0.4149E+05	0.1225E+04
052	0.300	0.7366E+04	0.8298E+05	0.8750E+03	0.4149E+05	0.1225E+04
053	0.300	0.7366E+04	0.8298E+05	0.8750E+03	0.4149E+05	0.1225E+04
054	0.300	0.7366E+04	0.8298E+05	0.8750E+03	0.4149E+05	0.1225E+04
055	0.300	0.7366E+04	0.8298E+05	0.8750E+03	0.4149E+05	0.1225E+04
056	0.300	0.7366E+04	0.8298E+05	0.8750E+03	0.4149E+05	0.1225E+04
057	0.300	0.7366E+04	0.8298E+05	0.8750E+03	0.4149E+05	0.1225E+04
058	0.300	0.7366E+04	0.8298E+05	0.8750E+03	0.4149E+05	0.1225E+04

This screen shows the values of the parameters defining the mobilisation law constituted by the calculation engine based on the pressuremeter data. This is a three-plateau law (see figure below) characterised by:

- Soil reaction coefficient at 1st plateau k_{s1} (kPa/m)
- Creep pressure (net) of soil P1 at 1st plateau (kPa)
- Soil reaction coefficient at 2nd plateau k_{s2} (kPa/m)
- Limit pressure (net) of soil P2 at 2nd plateau (kPa)

In the formatted results, each of these values is given multiplied by the pile diameter B (0,35 m in this case).



We will now reintroduce these parameters into Piecoef+ in mobilisation law manual input mode to illustrate this functionality.

G.4.2.5.1. "Parameters" tab

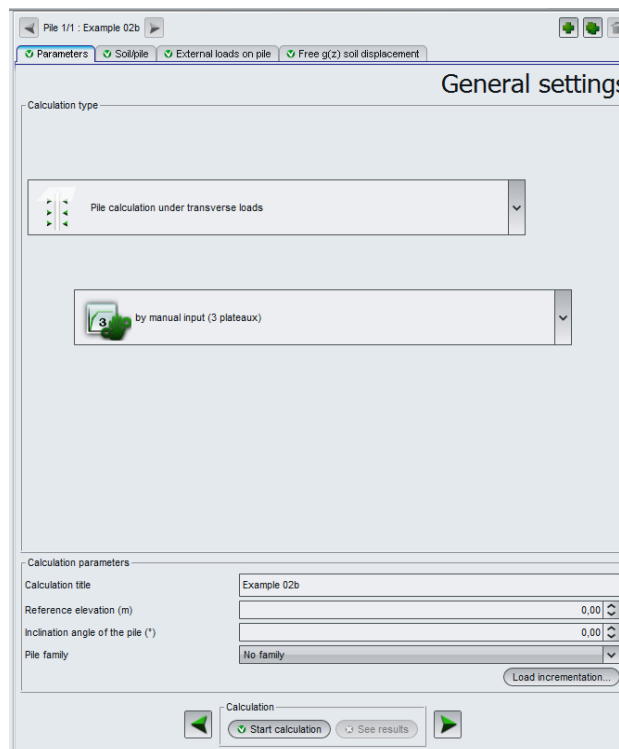
Return to data definition and to "Parameters" tab.

Calculation type box:

- drop-down list 1: conserve "Pile calculation under transverse loads"
- drop-down list 2: select "by manual input (3 plateaux)"

"Calculation parameters" box:

- Modify the title of the calculation.
- Leave the other parameters unchanged.

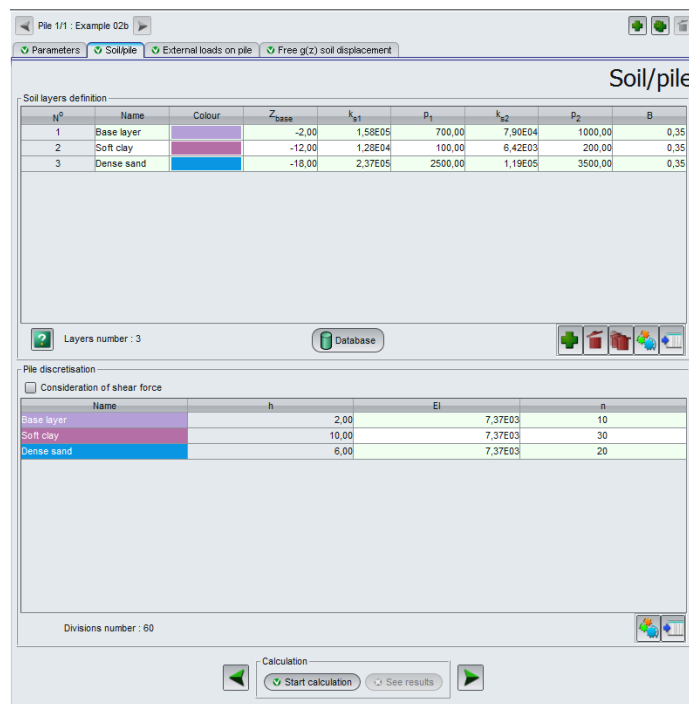


G.4.2.5.2. "Soil/Pile" tab

The data to be input is that described previously: P1 (kPa), P2 (kPa), k_s1 (kPa/m) and k_s2 (kPa/m).

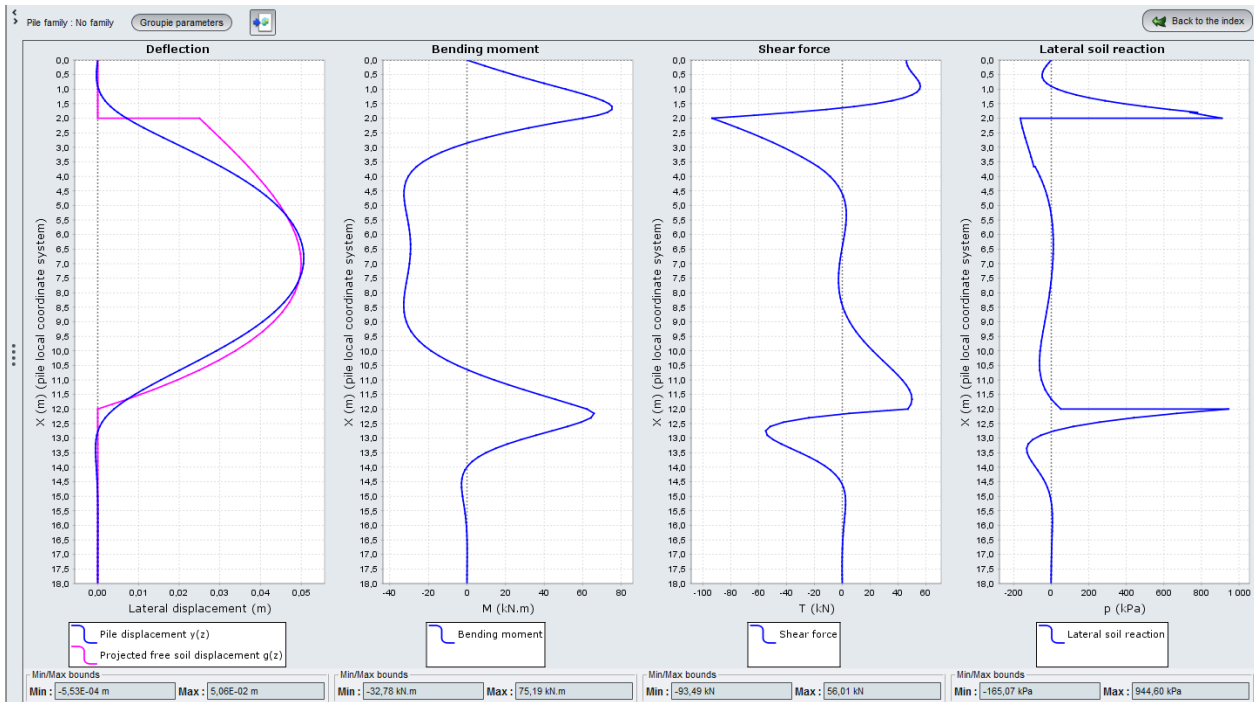
The values to be input have been calculated from the formatted results given on screen copy (by dividing each of the terms presented by B):

	k_s1 (kPa/m)	P1 (kPa)	k_s2 (kPa/m)	P2 (kPa)
Subgrade	158057	700	79028,5	1000
Soft clay	12840	100	6420,0	200
Dense sand	237086	2500	118543	3500



Start the calculation by clicking  button.

G.4.2.5.3. Results



To within one or 2 roundings-off (small differences due to the rounding off of ks_1 and ks_2 values), the results are the same as those of the previous calculation as can be expected.

This functionality can be used in the situation where the soil reaction mobilisation law is defined using data other than pressuremeter data.

Moreover, let us point out that the law constituted by default by the calculation engine is valid for a slightly slender single pile of circular or rectangular envelope section. Considering a group effect or a slender rectangular section (rectangular pile) can affect the calculation of the various plateaux and require either a correction of the pressuremeter parameters to be input into the model or a direct manual definition (refer to User's manual).

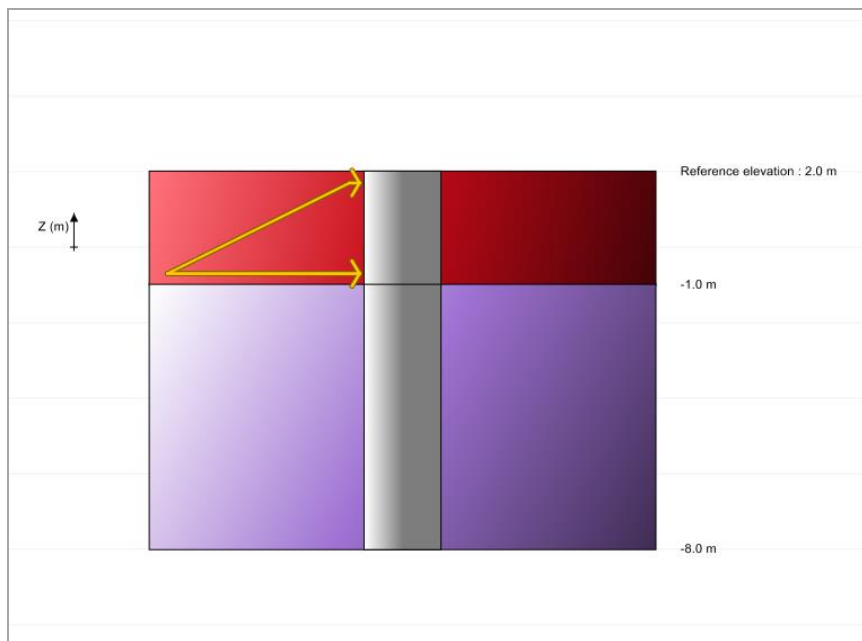
G.4.3. Example 3: Calculation of a metallic shaft under multiple loads at head

This example considers the case of a metallic shaft of hollow circular section (2 m in diameter and 5 cm thick) submitted to a transverse trapezoidal distributed load at its upper part and to different head load cases.

This metallic shaft is 10 m deep and passes through 2 soil layers: alluvium at head then a substratum.

We neglect the lateral reaction of the soil on the alluvium layer thickness (3 m at head).

The example is done first without considering the shear force displacements then, in a second step, considering the shear force displacements.



G.4.3.1. Data input

- Choose to create a new project by selecting New project radio-button.
- Click button.

If Foxta is already open, click "File", "New project" menu.

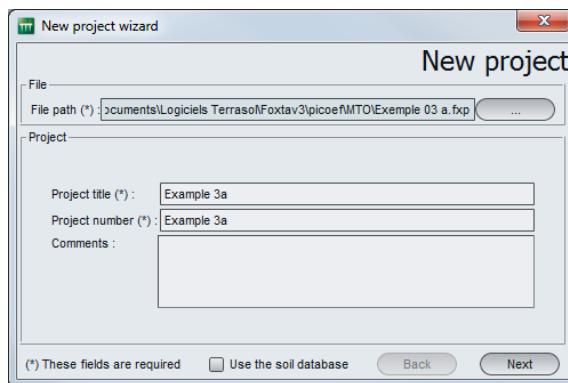
G.4.3.1.1. New project wizard

"File" box

- Complete file path by clicking button.
- Give a name to the file and save it.

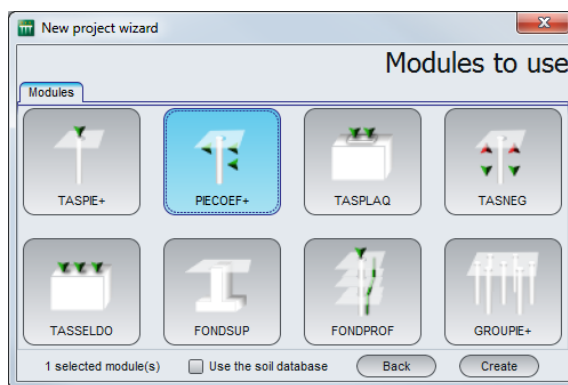
"Project" box

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



G.4.3.1.2. New project wizard: Modules to use

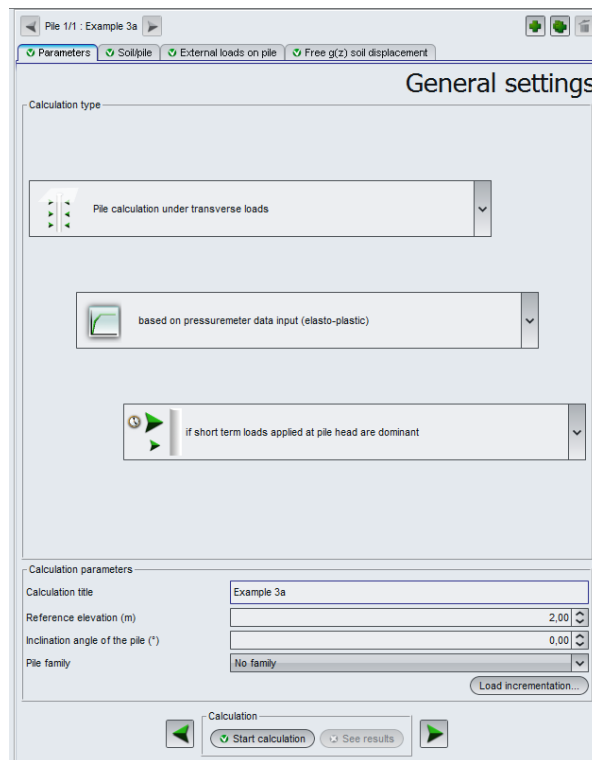
In "Modules to use" window, select Piecoef+ module then click **Create** button.



The Piecoef+ data input window is displayed.

Complete the various data tabs on the right-hand zone of the screen.

G.4.3.2. "Parameters" tab




"Calculation type" box: select

- drop-down list1: Pile calculation under transverse loads
- drop-down list2: Based on pressuremeter data input (elasto-plastic)
- drop-down list3: If short term loads applied at pile head are dominant (the load cases studied correspond here to variable loads and not to permanent loads)

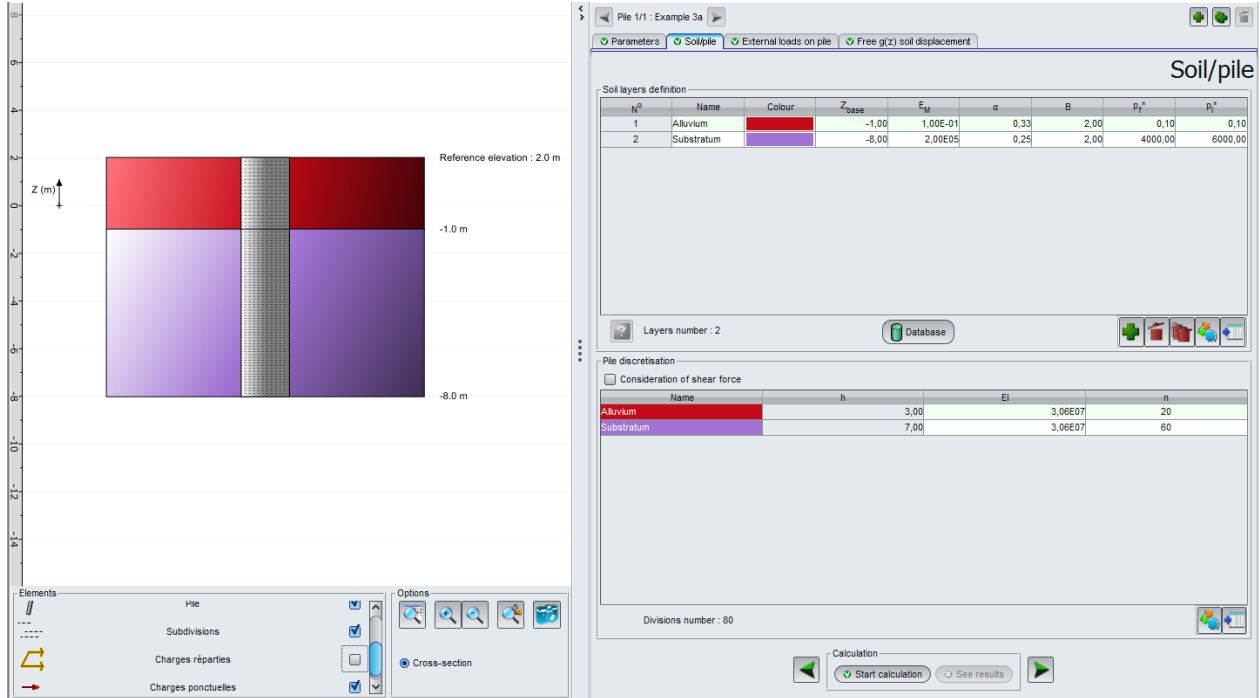
"Calculation parameters" box:

- Calculation title: Exemple 3a
- Reference elevation: 2,0 m
- Inclination angle of the pile: 0° (vertical pile)
- Pile family: no family
- Load incrementation: here, we will conserve the default values.

To go to the next tab, click either name of "Soil/Pile" tab or  button.

G.4.3.3. "Soil/Pile" tab

This tab is used to define soil layer characteristics and pile discretisation.



"Soil layers definition" box:

The data to be input is:

Name	Z _{base} (m)	E _M (kPa)	α	B (m)	Pf* (kPa)	PI* (kPa)
Alluvium	-1,0	0,1	0,33	2,00	0,10	0,10
Substratum	-8,0	200000	0,25	2,00	4000	6000

Note that the characteristics have been voluntarily reduced in the alluvium thickness (first 3 metres from surface): this corresponds to the neglected lateral reaction assumption in this 3 m thickness.

Note: It is preferable to input very low values rather than null values.

"Pile discretisation" box:

The data to be input is as follows:

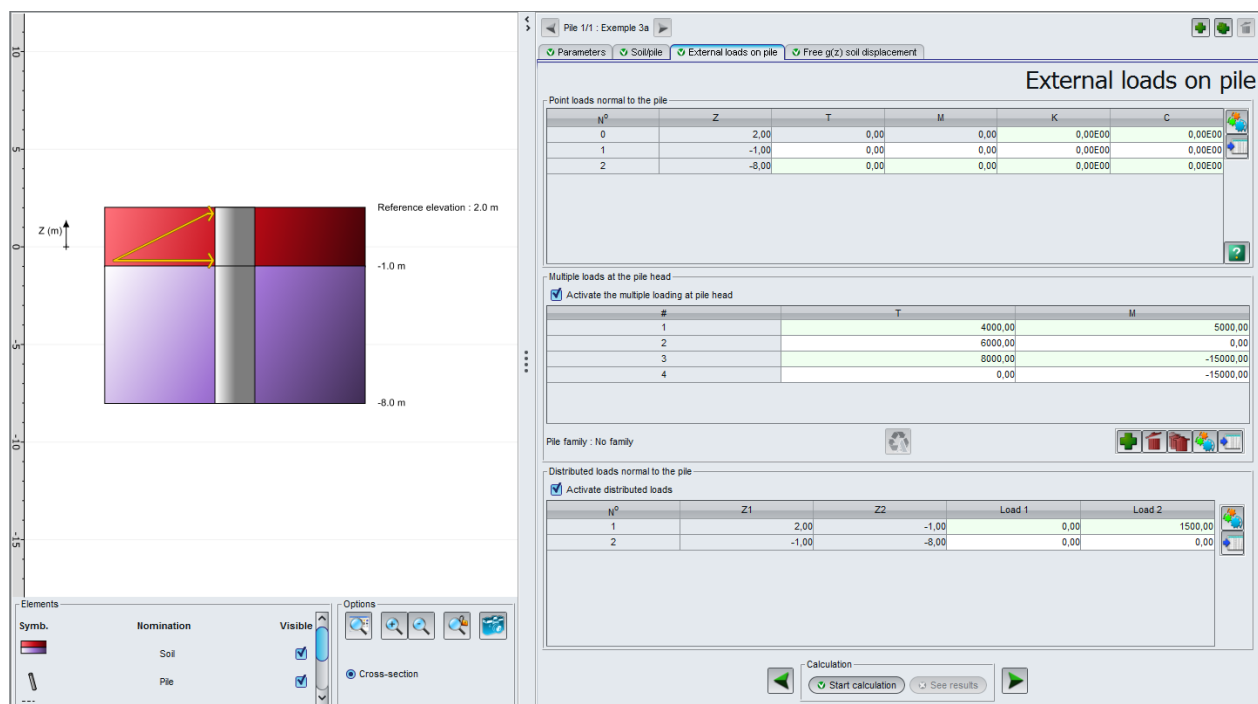
- Keep "Consideration of shear force" box unticked.

Name	h (m)	EI (kN.m ²)	n
Alluvium	3,0	3,06E7	20
Substratum	7,0	3,06E7	60

EI product is calculated here as follows for a 2 m hollow circular metallic section with a thickness of 5 cm:

$$EI = E_{steel} \left[\frac{\pi D_{ext}^4}{64} - \frac{\pi D_{int}^4}{64} \right] = 3.06 \times 10^7 \text{ kN.m}^2$$

G.4.3.4. "External loads on pile" tab



The screenshot displays the 'External loads on pile' tab in the software. On the left, a vertical axis shows the pile's position with a reference elevation of 2.0 m and soil layers extending down to -8.0 m. The main interface contains three data tables:

- Point loads normal to the pile:**

Nº	Z	T	M	K	C
0	2,00	0,00	0,00	0,00E00	0,00E00
1	-1,00	0,00	0,00	0,00E00	0,00E00
2	-8,00	0,00	0,00	0,00E00	0,00E00
- Multiple loads at the pile head:**

Activate the multiple loading at pile head

#	T	M
1	4000,00	5000,00
2	6000,00	0,00
3	8000,00	-15000,00
4	0,00	-15000,00
- Distributed loads normal to the pile:**

Activate distributed loads


Nº	Z1	Z2	Load 1	Load 2
1	2,00	-1,00	0,00	1500,00
2	-1,00	-8,00	0,00	0,00

For our example, we will define a distributed load normal to the pile between elevations 2 and -1, and several different load cases at pile head ("multiple loads at the pile head").

"Point loads normal to the pile" box:

There is no data to be input in this box for this example.

"Multiple loads at the pile head" box:

- Tick "Activate the multiple loading at pile head" box and add a line for each load case with  button.

The data to be input is as follows:

N°	T (kN)	M (kN.m)
1	4000	5000
2	6000	0,00
3	8000	-15000
4	0	-15000

"Distributed loads normal to the pile" box:

The data to be input is:

- Top level of the load Z1 (m) (elevations proposed automatically at layer limits)
- Base level of the load Z2 (m) (elevations proposed automatically at layer limits)
- Load value at the head of the layer Load 1 (kPa)
- Load value at the base of the layer Load2 (kPa)

The data to be input is as follows:

N°	Z1 (m)	Z2 (m)	Load 1 (kPa)	Load 2 (kPa)
1	2,0	-1,0	0	1500
2	-1,0	-8,0	0	0

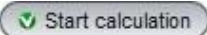
The defined distributed load corresponds to a trapezoidal load applied between elevations 2 and -1. This load is represented on the project cross-section.

G.4.3.5. "Free g(z) soil displacement" tab

No data to be input in this tab.

G.4.3.6. Calculation and Results

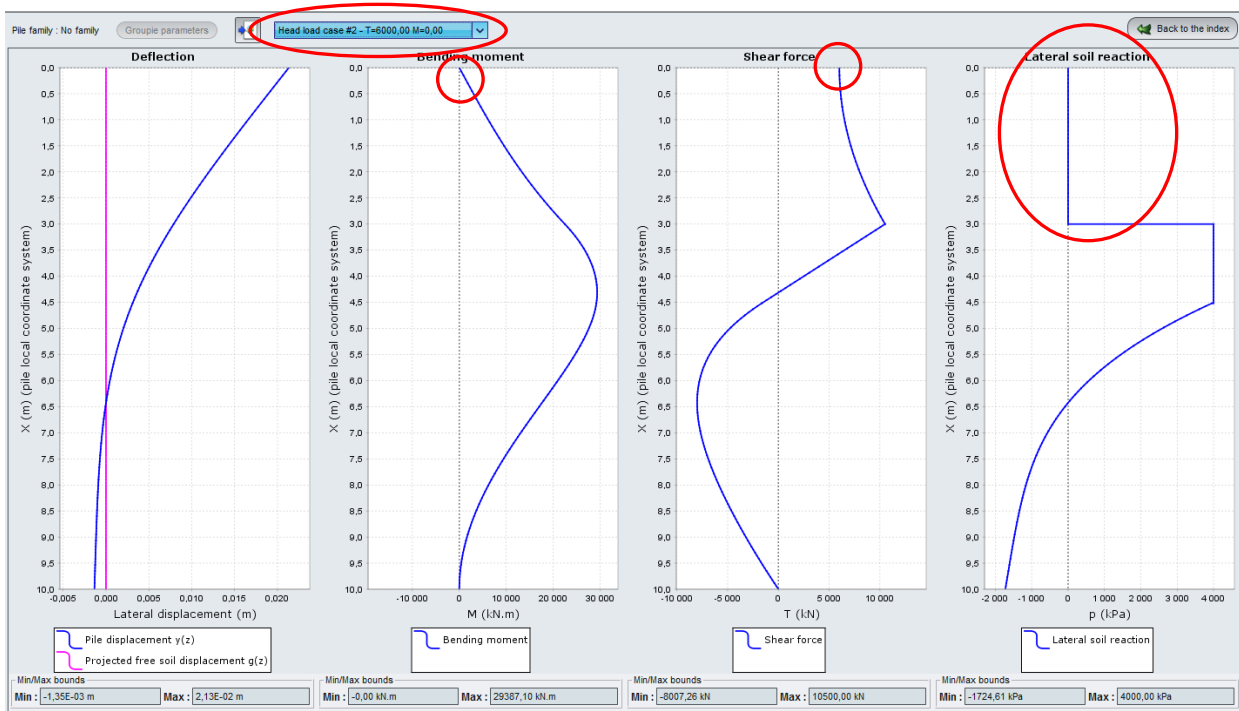
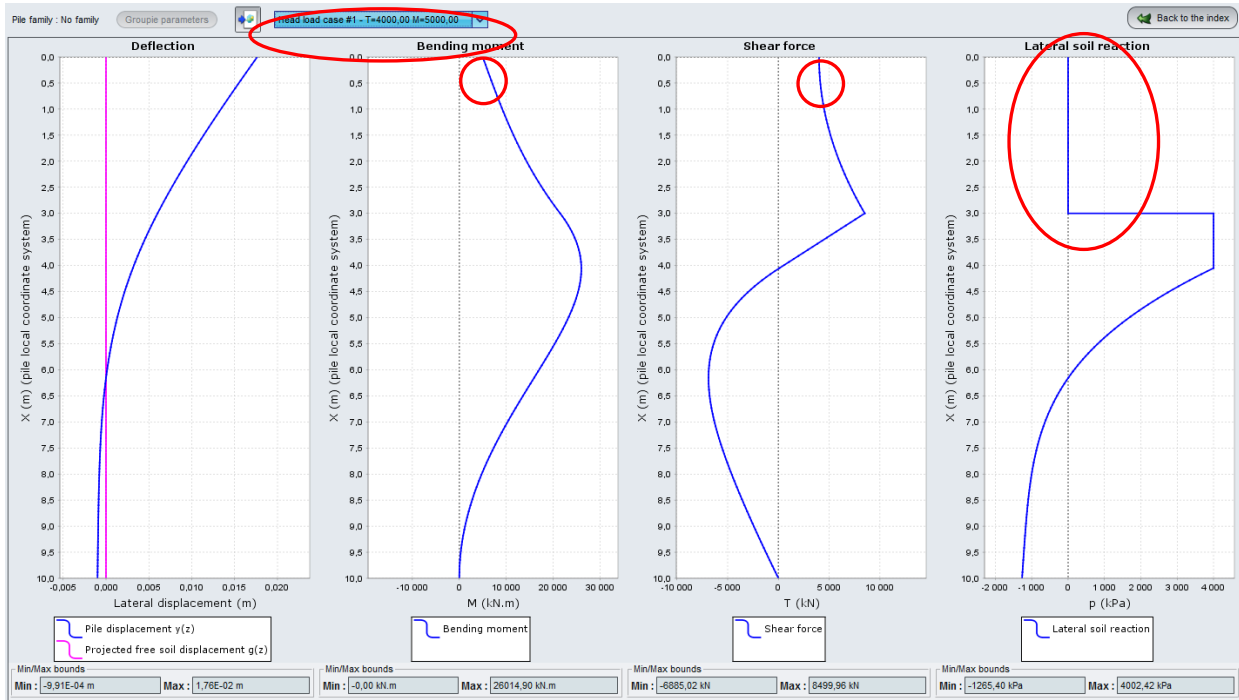
G.4.3.6.1. Calculation

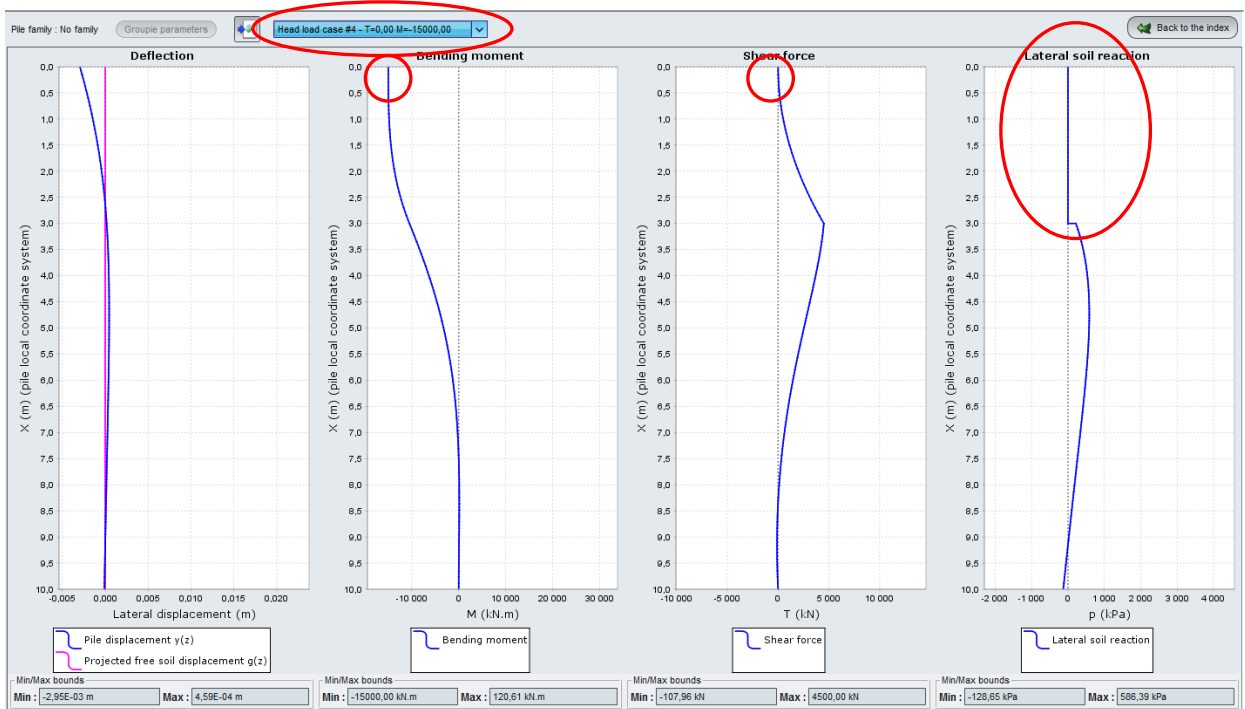
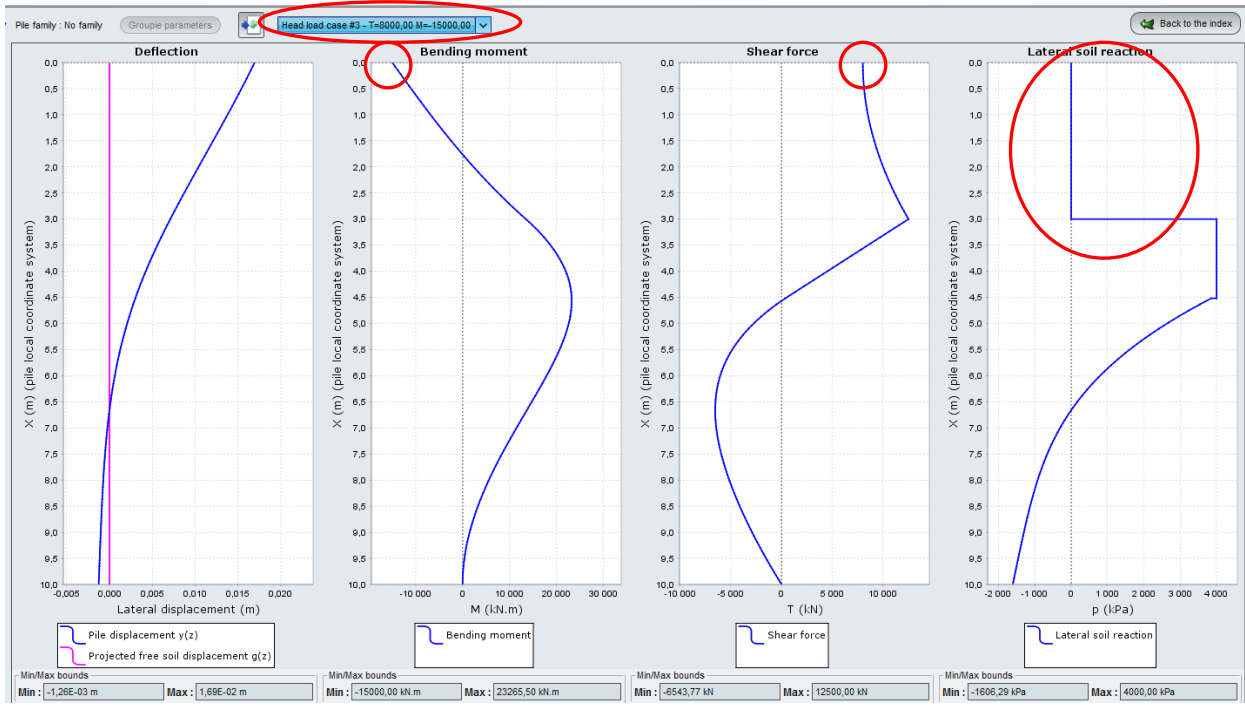
Click  button.

To see the results in table and graph form, click  button.

G.4.3.6.2. Results

Main curves





Comments on results:

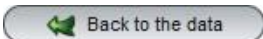
- For the 3 load cases, we find that the lateral reaction is null between a depth of 0 and 3 m.
- For each load case, we find the prescribed conditions (T, M) at pile head.
- The first 3 load cases (T value not null) lead to same type of pile behaviour: maximum displacement at pile head, oriented towards the right (in direction of prescribed force T), maximum moment at the antinode, null moment and shear force at pile base, saturation of lateral reaction (plastification) of the soil over a thickness from 1.0 to 1.5 m under the neglected lateral reaction area.
- The last load case (high negative moment at pile head with T=0) gives a different behaviour: maximum lateral displacement at pile head but oriented towards the left (due to negative moment at pile head), maximum moment at pile head (corresponding to the prescribed value of 15000 kN.m), no soil plastification (the pile moves in the other direction and much less than for the first 3 load cases).

G.4.3.7. Step 2: Considering shear force displacements

Here, we take the same example, but this time considering the shear force displacements.

The contribution of these displacements is generally negligible when the "length/diameter" ratio is higher than 10 or event 20 (thin beam assumption). For slightly slender piles such as shafts for example, this assumption is no longer valid and the general thick beam model may need to be adopted which requires the definition, in addition to the product of inertia, of the shear stiffness GS' taken as equal to the product of the shear modulus G and the reduced section S' (refer to User's manual).

G.4.3.7.1. Data modification

To modify data, click  button and return to "Soil/Pile" tab:

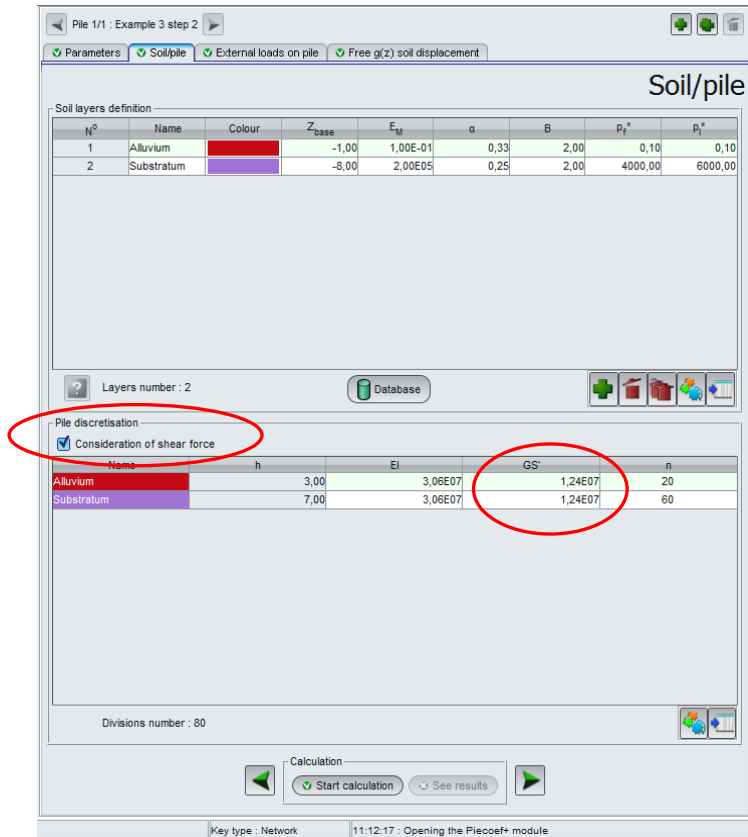
"Pile discretisation" box:

- Tick "Consideration of shear force" box.
The GS' column (Shear stiffness - kN) is displayed.
- Input value 1,237^{e7} kN in this column for the two layers.

This value is obtained by the product of shear modulus G of the pile and its reduced section S' (for a hollow circular section, the reduced section S' is taken as equal to half of the total pile section, $k = 0.5$).

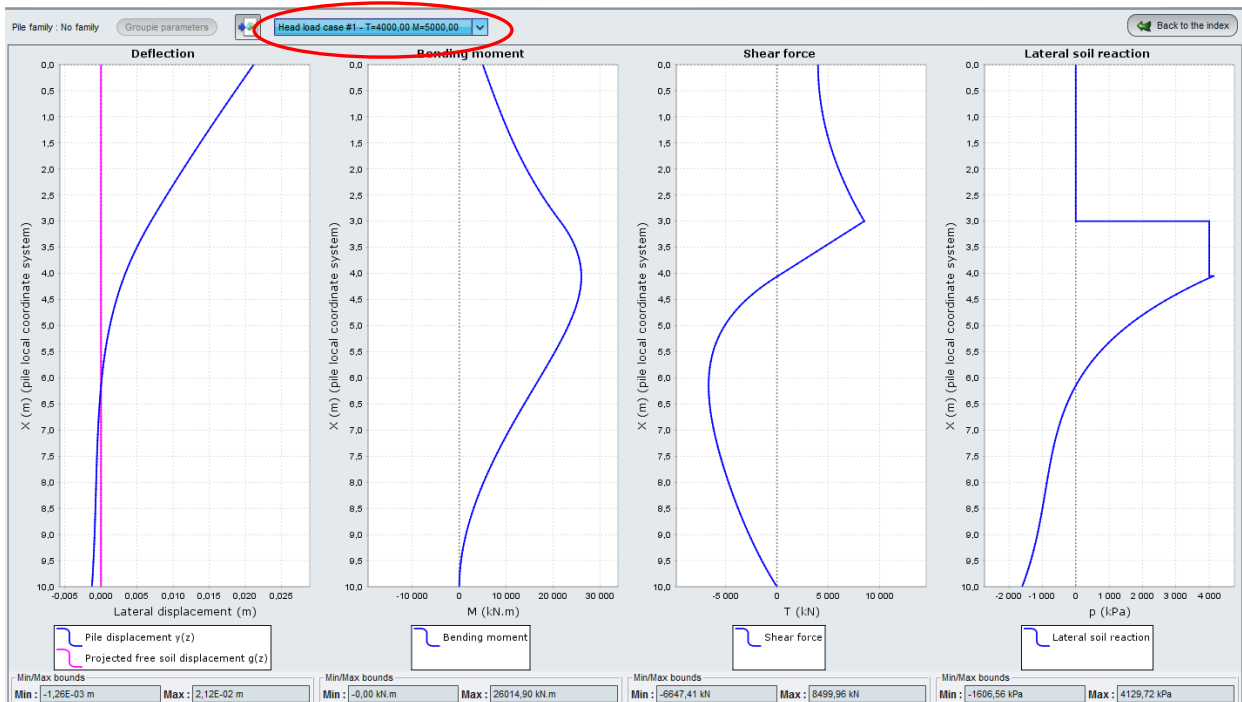
$$G = \frac{E}{2(1+\nu)} = \frac{210 \cdot 10^6}{2(1+0,3)} = 80\,770 \text{ MPa}$$

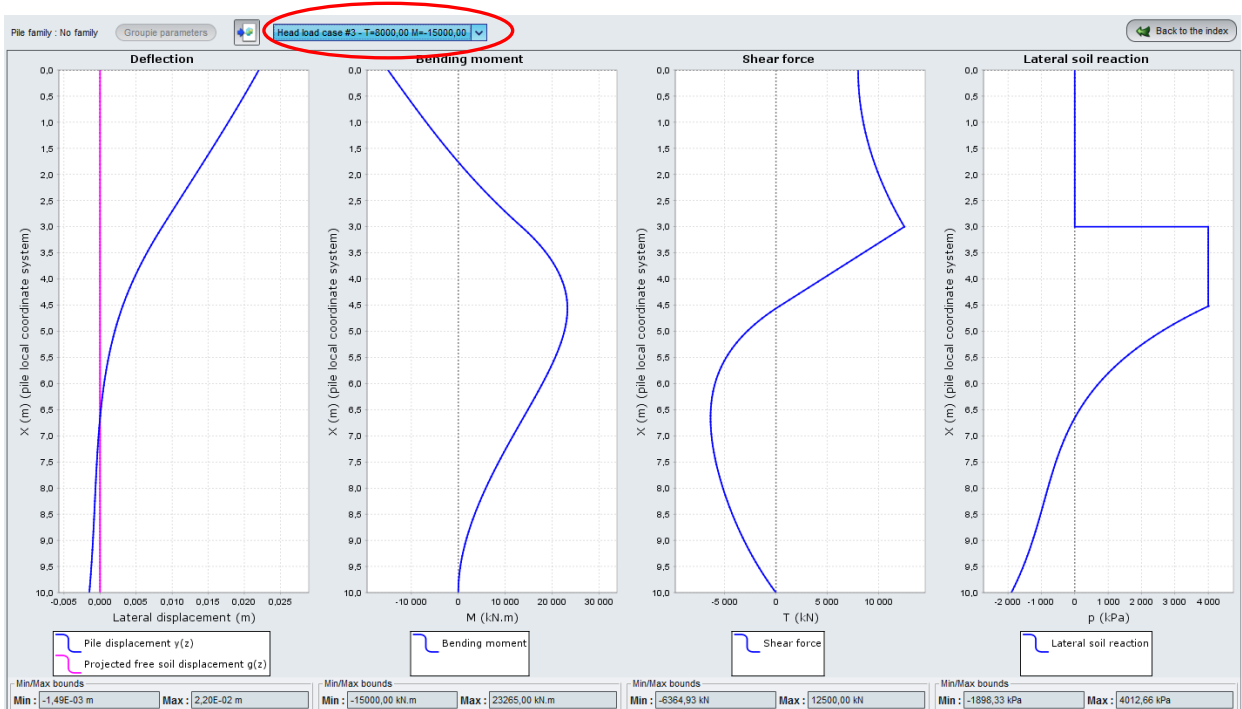
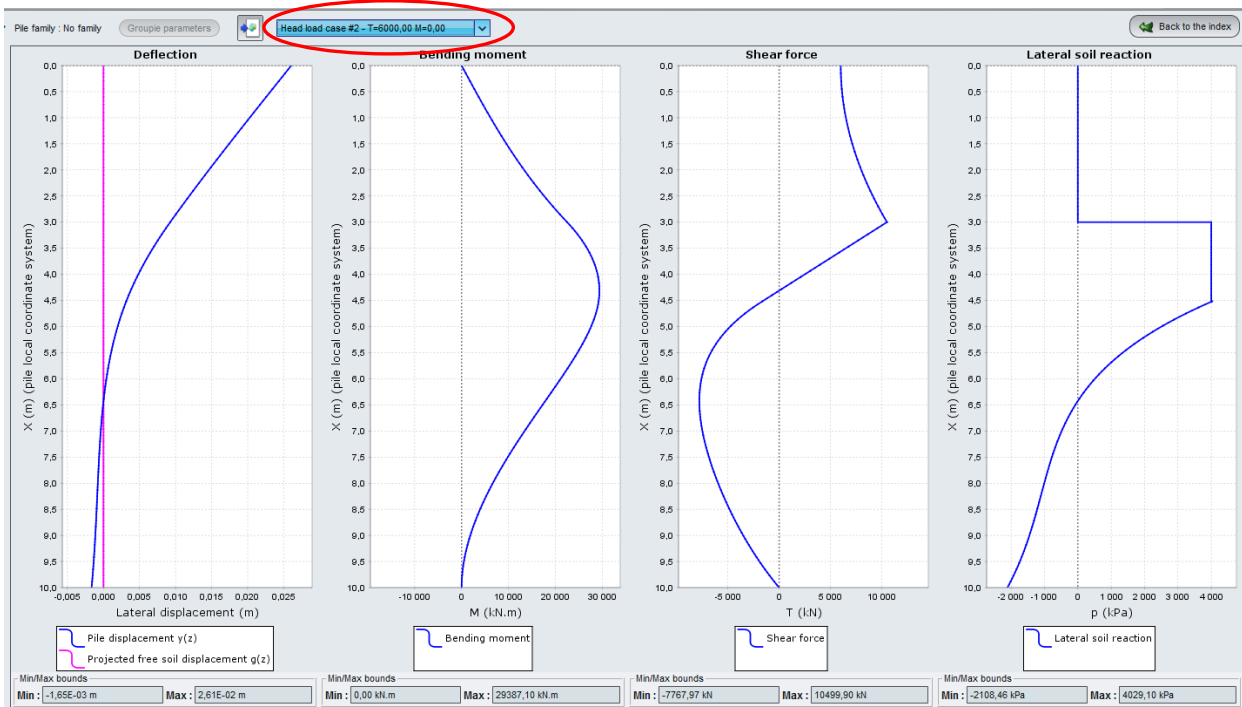
$$S' = \frac{S}{2} = \frac{\pi}{8} (D_{ext}^2 - D_{int}^2) = 0,1531 \text{ m}^2$$

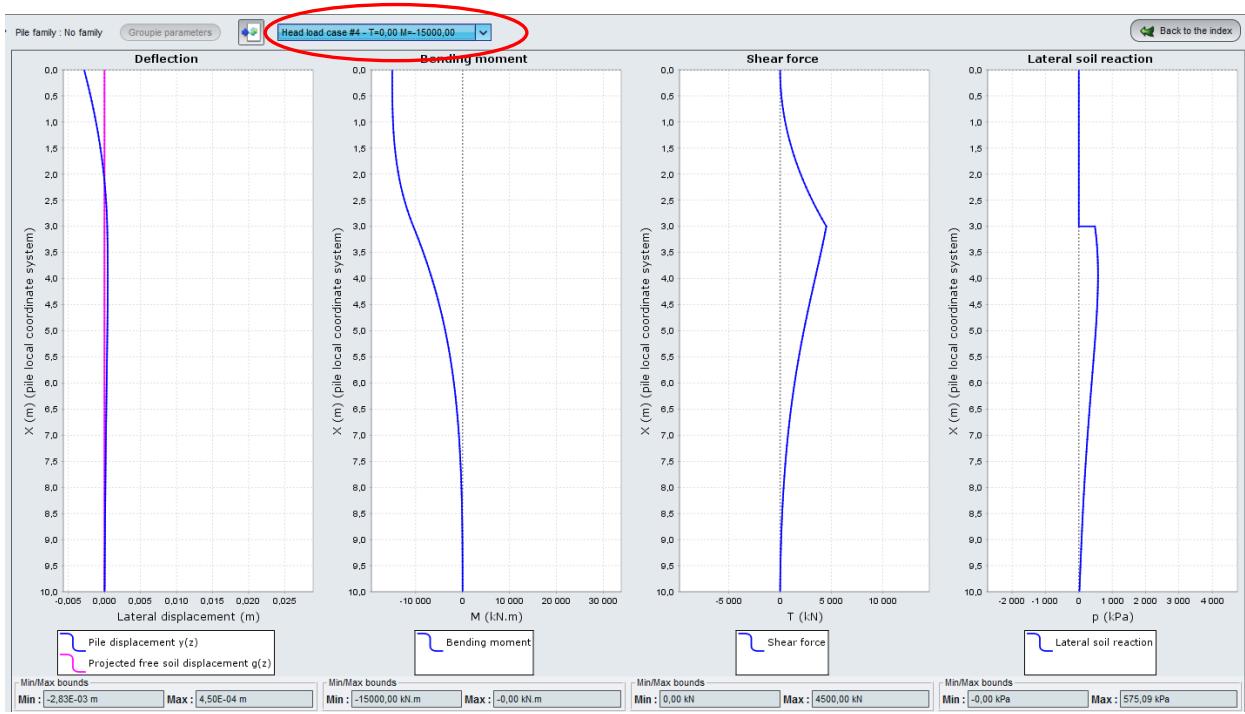


Save the project under a different name: "Example 03b" for example.

Start the calculation by clicking  button.







Comparison of results:

	Deflection: lateral displacement (cm)		Bending moment M (kN.m)		Shear force T (kN)	
	Min	Max	Min	Max	Min	Max
Load No. 1 Without shear force displacements	-0,1	1,76	0,00	26015	-6885	8500
Load No. 1 With shear force displacements	-0,1	2,12	0,00	26015	-6647	8500
Load No. 2 Without shear force displacements	-0,1	2,13	0,00	29387	-8007	10500
Load No. 2 With shear force displacements	-0,2	2,61	0,00	29387	-7768	10500
Load No. 3 Without shear force displacements	-0,1	1,69	-15000	23265	-6544	12500
Load No. 3 With shear force displacements	-0,1	2,20	-15000	23265	-6365	12500
Load No. 4 Without shear force displacements	-0,3	0,1	-15000	121	108	4500
Load No. 4 With shear force displacements	-0,3	0,0	-15000	0	0	4500

Consideration of shear force displacements has only a small influence on the loads. However, the amplitude of the displacements is increased by around 25% which implies a reduction of apparent stiffness at pile head of 25%.

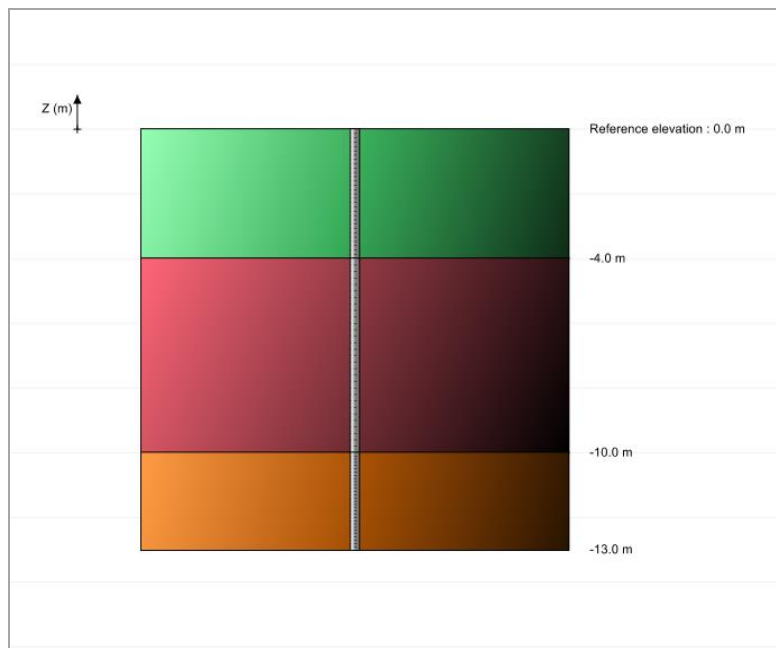
Moreover, note that by considering the shear force displacements, the distortion and the first derivative of the deflection are no longer equal.

G.4.4. Example 4: Buckling and 2nd order: study of buckling of a micro-pile

Here, we consider a micro-pile made in a 0.25 m diameter and 13 m long borehole assumed perfectly clamped at pile head.

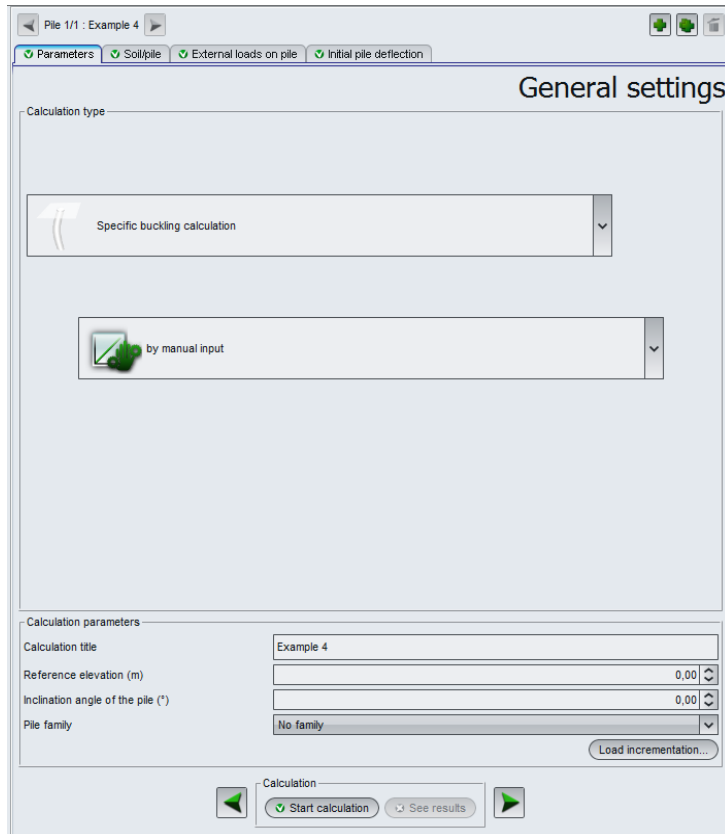
This example illustrates 2 aspects (dealt with in 2 steps):

- A specific buckling calculation (evaluation of critical buckling load).
- A quantification calculation of the second-order effects under the effect of a transverse load.



G.4.4.1. Step 1: Buckling calculation

G.4.4.1.1. "Parameters" tab




"Calculation type" box: select

- drop-down list1: Specific buckling calculation
- drop-down list2: By manual input

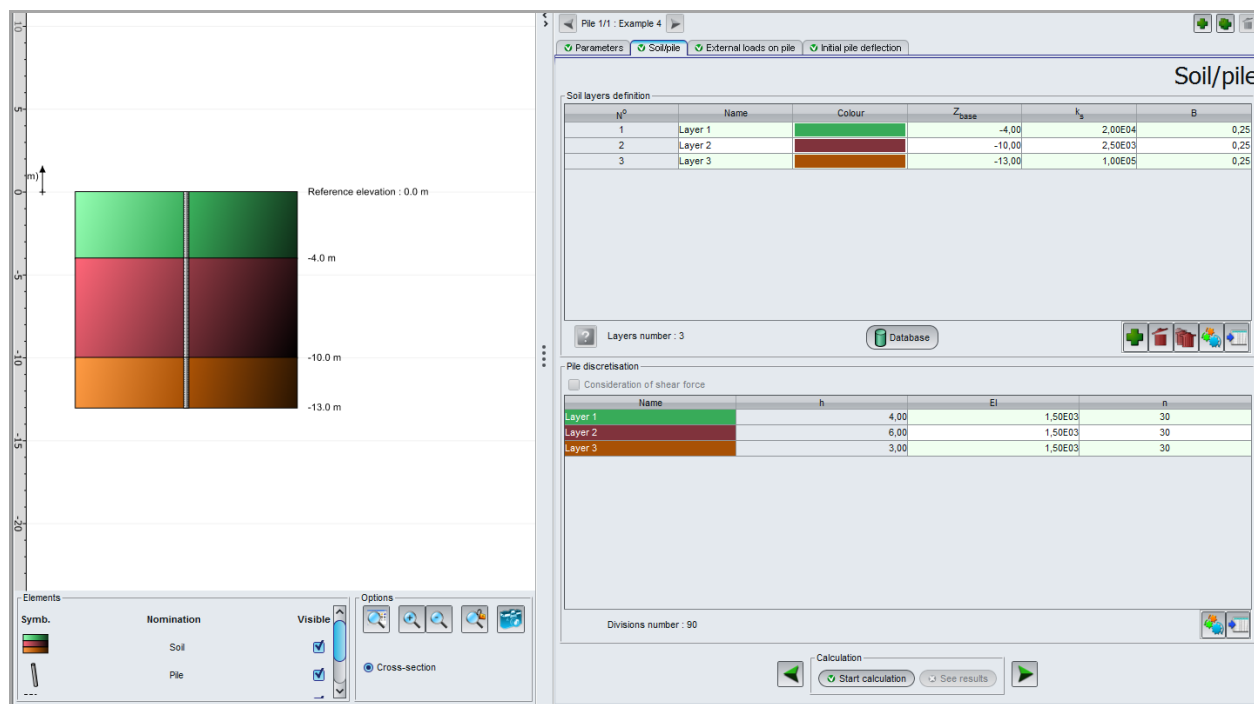
"Calculation parameters" box:

- Calculation title: Example 4a
- Reference elevation: 0,0 m
- Inclination angle of the pile: 0° (vertical pile)
- Pile family: no family
- Load incrementation: here, we will conserve the default values.


To go to the next tab, click either the name of "Soil/Pile" tab or  button.

G.4.4.1.2. "Soil/Pile" tab

This tab is used to define the soil layers and the pile discretisation.



"Soil layers definition" box:

Create three soil layers by clicking  button to add each soil layer. The data to be input is as follows:

Name	Z _{base} (m)	k _s (kPa/m)	B (m)
Layer 1	-4,0	20000	0,25
Layer 2	-10,0	2500	0,25
Layer 3	-13,0	100000	0,25

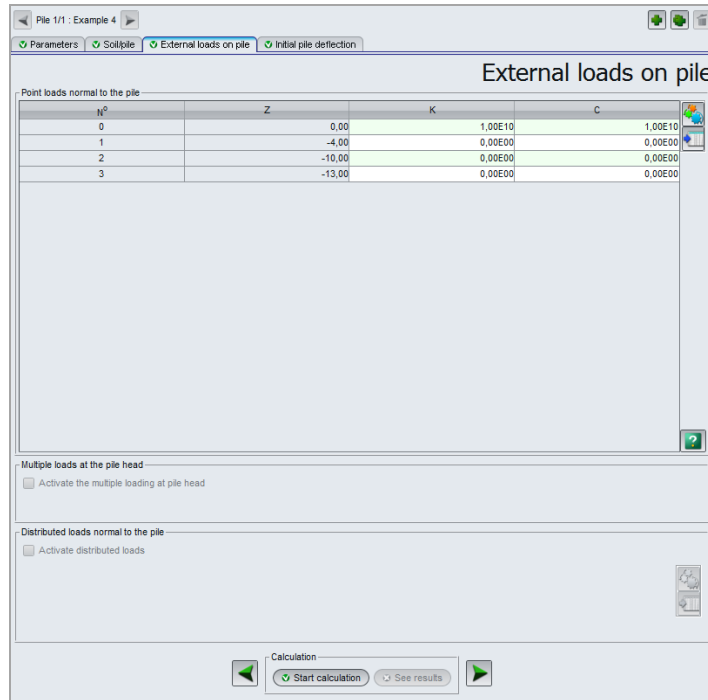
"Pile discretisation" box:

The "Consideration of shear force" box is not accessible in this type of calculation.

The data to be input is as follows:

Name	h (m)	EI (kN.m ²)	n
Layer 1	4,0	1500	30
Layer 2	6,0	1500	30
Layer 3	3,0	1500	30

G.4.4.1.3. "External loads on pile" tab



"Point loads normal to the pile" box:

Here we wish to define a clamping at pile head: we define therefore at pile head (elevation 0) very high values for K and C to prevent displacements and rotations (here, this is a support condition and not a load condition).

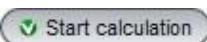
The values to be input are as follows:

N°	Z (m)	K (kN.m)	C (kN.m/rad)
0	0,00	1,0 ^e 10	1,0 ^e 10
1	-4,00	0,00	0,00
2	-10,00	0,00	0,00
3	-13,00	0,00	0,00

G.4.4.1.4. Free g(z) soil displacement tab

This tab is not accessible here.

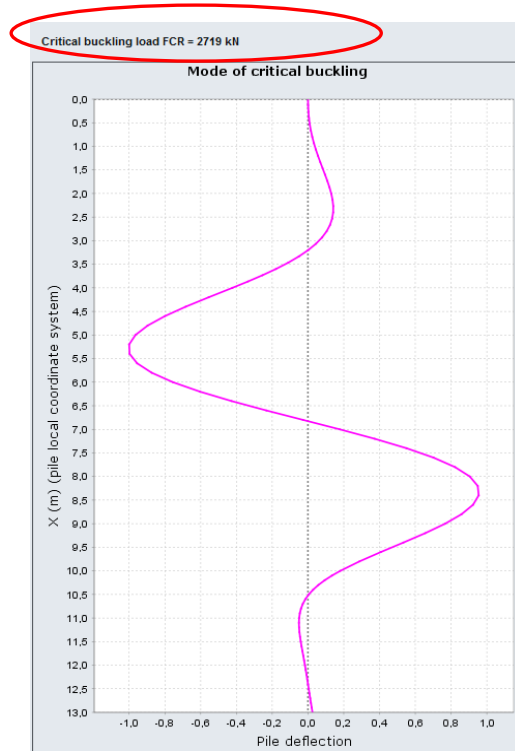
G.4.4.1.5. Calculation and Results

Click  button.

To see the results in table and graph form, click  button.

Curves related to buckling

The only curve available in the results for this calculation is the one below (the main curves are not available here). This window gives the potential buckling mechanism and the corresponding critical buckling load which here is equal to 2719 kN.



Additional results are also accessible from the formatted results file which especially gives all of the buckling loads for each mechanism. The buckling phenomenon is liable to occur when the axial force is close to one of these buckling loads (generally, we make sure that the axial force remains lower, with sufficient safety, than the smallest buckling load called critical load).

Charges de flambement pour chaque mode

Mode	Charge
001	0.272E+04
002	0.303E+04
003	0.471E+04
004	0.553E+04
005	0.613E+04
006	0.744E+04
007	0.853E+04
008	0.105E+05
009	0.123E+05
010	0.147E+05
011	0.166E+05
012	0.188E+05
013	0.201E+05
014	0.221E+05
015	0.238E+05
016	0.273E+05
017	0.285E+05
018	0.316E+05
019	0.340E+05
020	0.374E+05
021	0.410E+05
022	0.448E+05
023	0.488E+05
024	0.530E+05
025	0.573E+05
026	0.619E+05
027	0.666E+05
028	0.715E+05
029	0.766E+05
030	0.819E+05
031	0.874E+05
032	0.931E+05
033	0.989E+05
034	0.105E+06
035	0.111E+06
036	0.118E+06
037	0.124E+06
038	0.131E+06
039	0.138E+06
040	0.145E+06
041	0.152E+06
042	0.160E+06
043	0.168E+06
044	0.176E+06
045	0.184E+06
046	0.192E+06
047	0.201E+06
048	0.210E+06
049	0.219E+06
050	0.228E+06
051	0.237E+06
052	0.247E+06
053	0.257E+06
054	0.267E+06
055	0.277E+06
056	0.288E+06

Mode de flambement critique

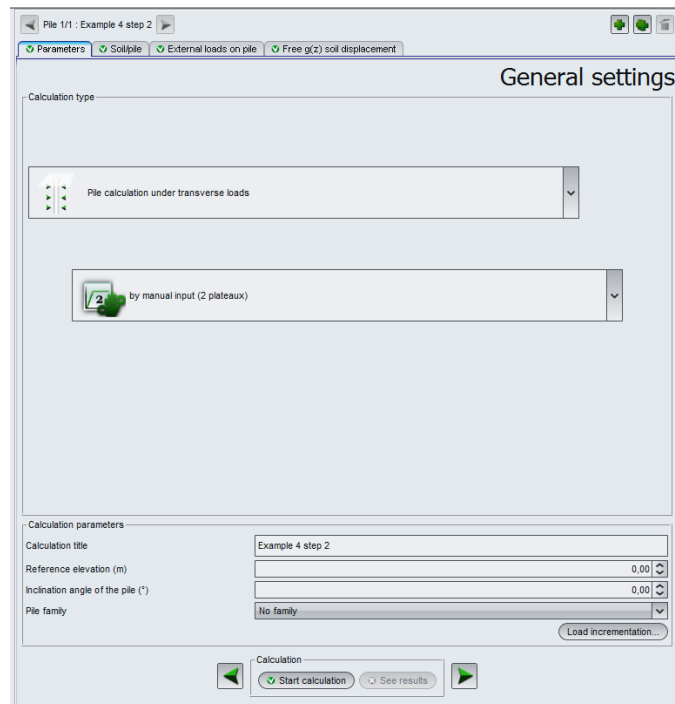
Xn	Yn
0.000	-0.149E-07
0.133	0.523E-03
0.267	0.223E-02
0.400	0.530E-02
0.533	0.987E-02
0.667	0.160E-01
0.800	0.238E-01
0.933	0.330E-01
1.067	0.437E-01
1.200	0.556E-01
1.333	0.685E-01
1.467	0.818E-01
1.600	0.952E-01
1.733	0.108E+00
1.867	0.120E+00
2.000	0.130E+00
2.133	0.137E+00
2.267	0.141E+00
2.400	0.141E+00
2.533	0.135E+00
2.667	0.123E+00
2.800	0.105E+00
2.933	0.785E-01
3.067	0.441E-01
3.200	0.118E-02
3.333	-0.504E-01
3.467	-0.111E+00
3.600	-0.179E+00
3.733	-0.255E+00
3.867	-0.336E+00
4.000	-0.423E+00
4.200	-0.555E+00
4.400	-0.684E+00
4.600	-0.800E+00
4.800	-0.897E+00
5.000	-0.965E+00
5.200	-0.100E+01
5.400	-0.997E+00
5.600	-0.955E+00
5.800	-0.874E+00
6.000	-0.756E+00
6.200	-0.605E+00
6.400	-0.428E+00
6.600	-0.232E+00
6.800	-0.275E-01
7.000	0.177E+00
7.200	0.373E+00
7.400	0.551E+00
7.600	0.702E+00
7.800	0.822E+00
8.000	0.905E+00
8.200	0.949E+00
8.400	0.955E+00
8.600	0.923E+00
8.800	0.859E+00
9.000	0.767E+00
9.200	0.656E+00
9.400	0.534E+00

G.4.4.2. Step 2: Quantification of 2nd order effects under the effect of a transverse load

We will use the same soil cross-section and the same pile but we will this time focus on the quantification of the second order effects under the effect of a transverse load.

We will therefore modify the data with respect to the first step of this example.

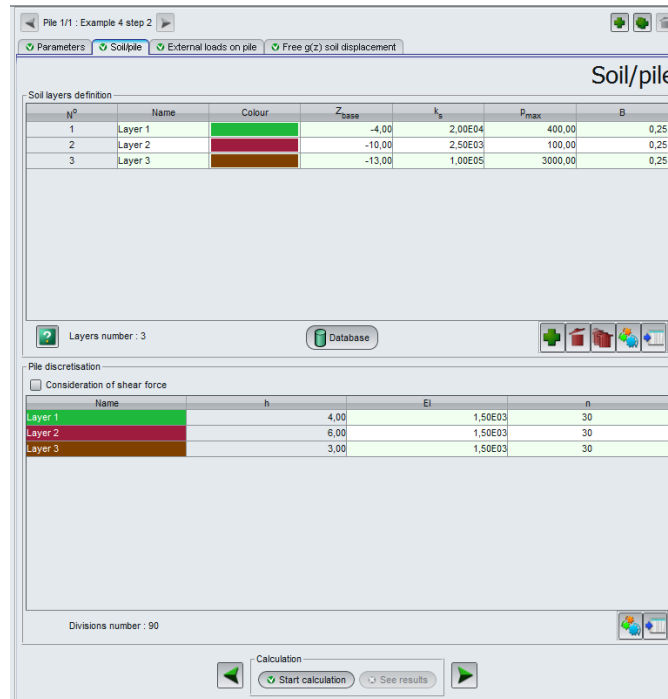
G.4.4.2.1. "Parameters" tab



"Calculation type" box:

- Select: "Pile calculation under transverse loads"
⇒ "By manual input (2 plateaux)"

G.4.4.2.2. "Soil/pile" tab



"Soil layers definition" box:

The "Plastification pressure of soil" column P_{max} (kPa) has appeared (due to choice of manual input of a 2-plateau mobilisation law).

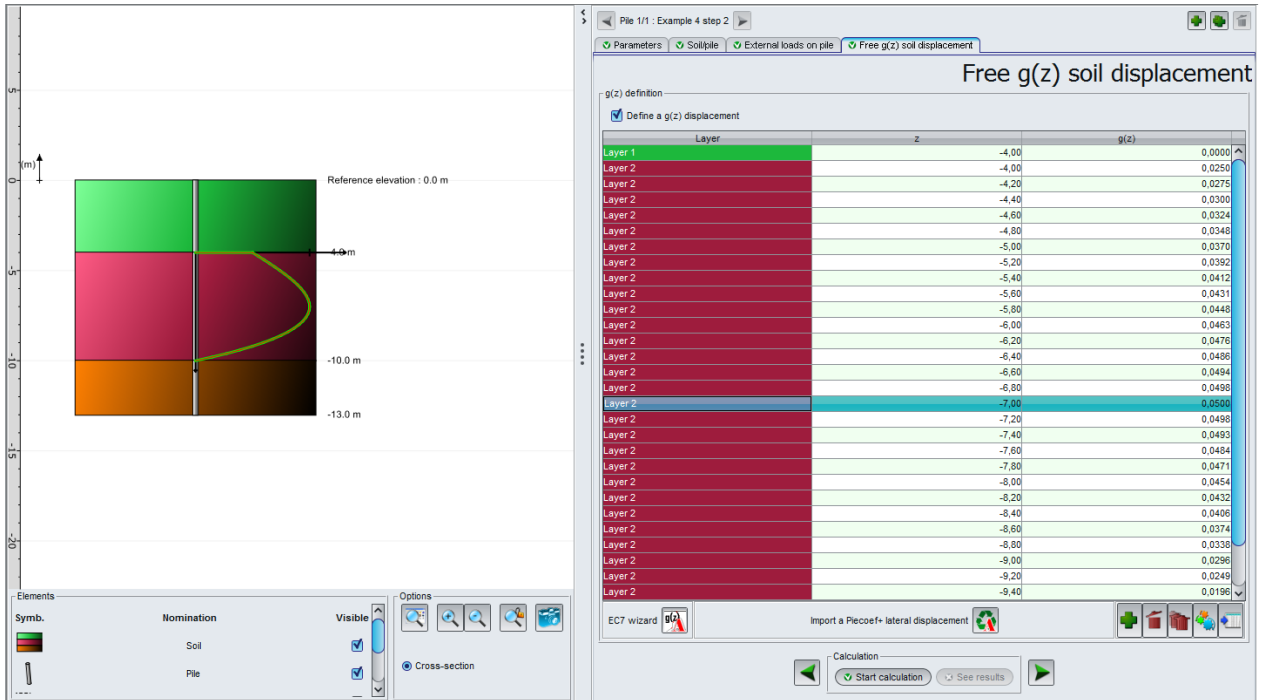
The data to be completed is as follows:

Name	Z _{base} (m)	k _s (kPa/m)	P _{max} (kPa)	B (m)
Layer 1	-4,0	20000	400	0,25
Layer 2	-10,0	2500	100	0,25
Layer 3	-13,0	100000	3000	0,25

G.4.4.2.3. "External loads on pile" tab

The data of this tab remains unchanged with respect to the previous example (clamping at pile head defined in the form of high values for K and C).

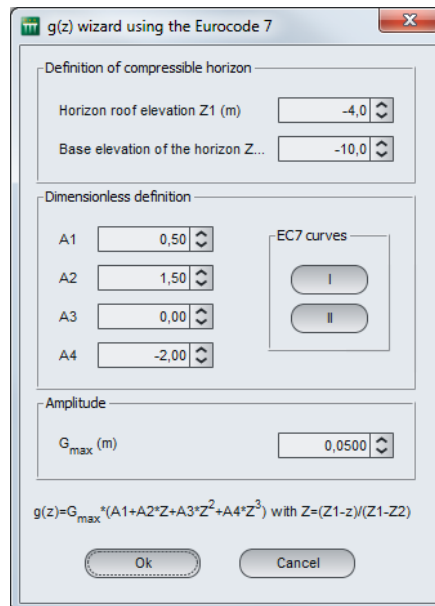
G.4.4.2.4. "Free g(z) soil displacement" tab




The tab is again accessible ("Pile calculation under transverse loads" mode) and we will activate this option to impose on the pile a load in the form of an imposed soil displacement.

"Define a g(z) displacement" box:

- Tick the "Define a g(z) displacement" box.



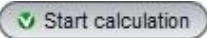
- To obtain the values of curve II in 2nd layer (here, g(z) is defined between elevations -4 and -10 m), click "Wizard"  button.

The values to be input are as follows:

Z1 (m)	Z2 (m)	Curve	A1	A2	A3	A4	G _{max} (m)
-4,0	-10,0	II	0,50	1,50	0,00	-2,00	0,05

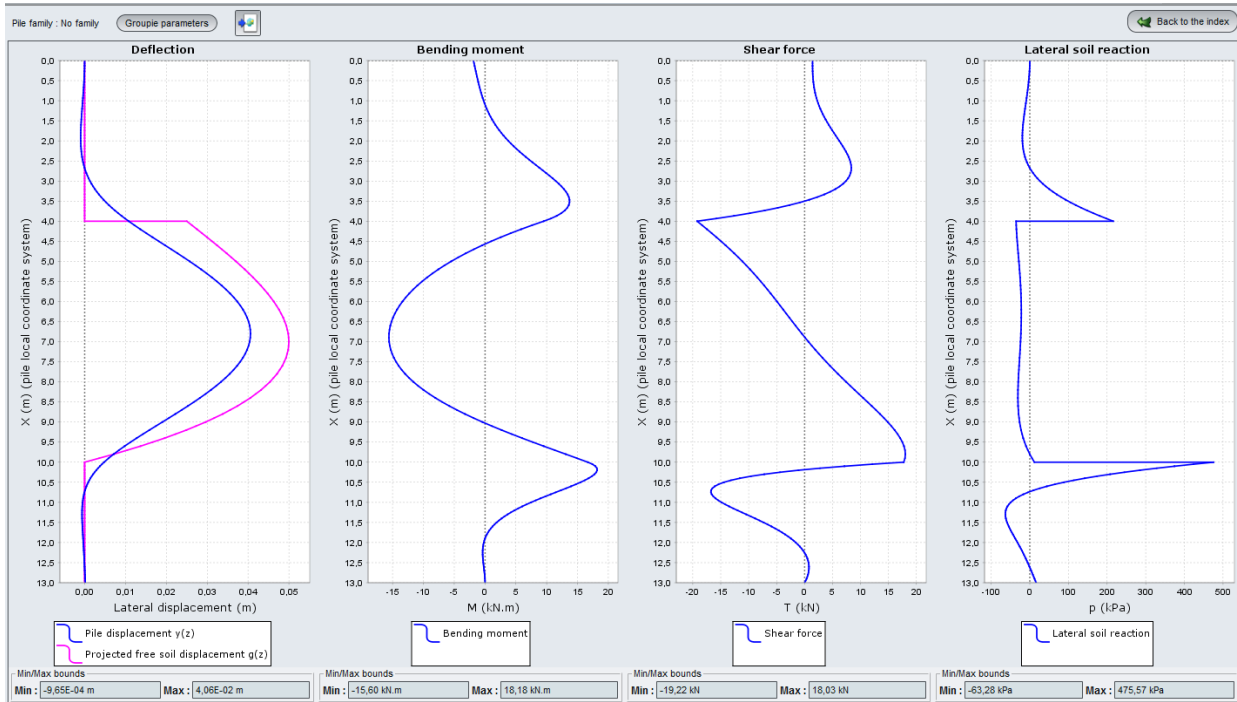
Save the project under a different name: "Example 04b" for example.

G.4.4.2.5. Calculation and results

Start the calculation by clicking  button then display the results.

The results obtained call for following comments:

- ⇒ Main results: these illustrate the strains and loads generated under the effect of the lateral earth pressures. The loads obtained (bending moment) are around 18 kN.m.
- ⇒ Buckling and 2nd order effects
 - ✓ We can see that the critical load is unchanged with respect to the calculation of the first step. This implicitly indicates absence of any soil plastification;
 - ✓ The first graph compares the critical buckling mechanism with the initial displacement of the pile obtained under the imposed transverse load. If the pile must take high axial loads, the case of an initial displacement "imitating" the potential buckling mechanism must be avoided as this is a situation which favours the development of 2nd order effects;
 - ✓ The 2nd and 3rd graphs give the amplification of the displacements and loads under the (2nd order) effect of an axial load from 0 to 80% of the critical buckling load. Especially, for an axial load equal to 80% of the critical load, the maximum bending moment is around 70 kN.m, that is around 4 times its initial value. This observation is representative of situations where 2nd order effects affect the design of the pile and can lead to failure by composed bending of the material constituting the pile for axial load levels well below the critical buckling load.



Curves related to buckling:

