# Thermo-Pile

A software for the geotechnical design of energy piles

USER'S MANUAL
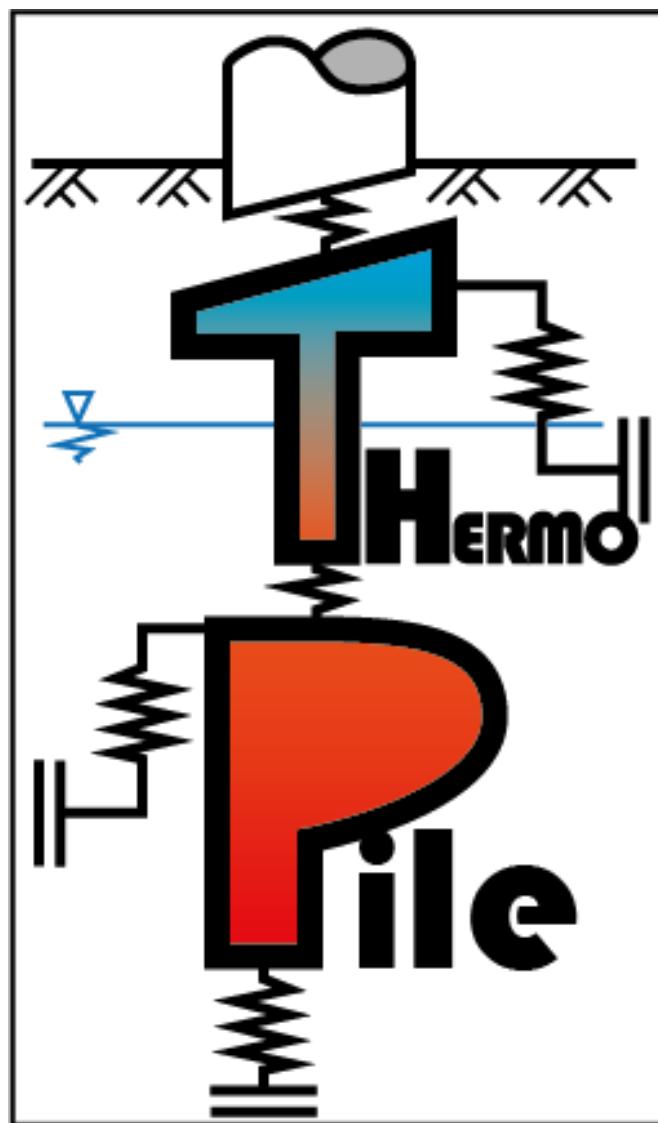
Laboratory of Soil Mechanics
Swiss Federal Institute of Technology Lausanne
http://lms.epfl.ch

EPFL

v1.022

Soil Mechanics Laboratory (LMS)
Prof. L. Laloui
Swiss Federal Institute of Technology Lausanne (EPFL)
Station 18, 1015 Lausanne, Switzerland

TABLE OF CONTENT

1 INTRODUCTION

1.1 IMPORTANT NOTICE

*Safety factors are not included in the calculation process.
*Only one pile with circular section is considered.
*Tensile mechanical solicitation and bending moments are not considered.
*Negative friction is not considered.

1.2 GOAL OF THERMO-PILE

The principal goal of the software *Thermo-Pile* is to determine the extra stresses and displacements that come from the temperature variations (thermal solicitations) in a heat exchanger foundation pile. Classical pile calculation (verification of the bearing capacity and settlement calculation) can also be performed, by setting the temperatures constant.

1.3 THE CONTENT OF THE TECHNICAL MANUAL

The manual named *Thermo-Pile_Documentation_Theory* explains in details the method used in *Thermo-Pile* and gives the necessary background to understand it. It is based on the paper: Knellwolf C., Peron H. and Laloui L. "Geotechnical analysis of heat exchanger piles". Journal of Geotechnical and Geoenvironmental Engineering, doi: 10.1061 / (ASCE) GT.1943-5606.0000513, 2011..

1.4 THE CONTENT OF THIS MANUAL

The main sections of this manual are:
Section 2: How to run *Thermo-Pile* on any machine.
Section 3: Overview of the Graphical User Interface of *Thermo-Pile*.
Section 4: Writing/loading file module of *Thermo-Pile*.
Section 5: Unit system and conventions used in *Thermo-Pile*.
Section 6: Available tools to design your project.
Section 7: Graphics menu to visualize results within *Thermo-Pile*.
Section 8: How to exit / close *Thermo-Pile*.
Section 9: Keyboard shortcuts of the menu.
Section 10: Some case studies with *Thermo-Pile*.
Section 11: FAQ.
Section 12: Known issues.

2 STARTING THERMO-PILE

2.1 INSTALLING THERMO-PILE

If not yet installed, *Thermo-Pile* requires the Java Runtime Environment (JRE 1.6 at least) which can be downloaded at java.com.

To install *Thermo-Pile* on a machine, launch the *Thermo-Pile Setup* and follow the instructions of the wizard. The specified folder during the installation will be the folder where all the projects will be saved.

Once *Thermo-Pile* is installed on a machine, the user needs to activate it on first start before using it (see Section 2.2).

2.2 FIRST START

To launch the software, just double click on the *Thermo-Pile.exe* file.

At the first start of *Thermo-Pile* on a machine, you will have to follow different steps in order to activate your *Thermo-Pile* version:

1. Communicate the red characters (see figure 0) and the name of your company by email to lms@epfl.ch with the object "Thermo-Pile Activation".
2. Copy and paste the activation key provided by your supplier in the *Activation key* box and click Activate.
3. Restart the *Thermo-Pile* application.
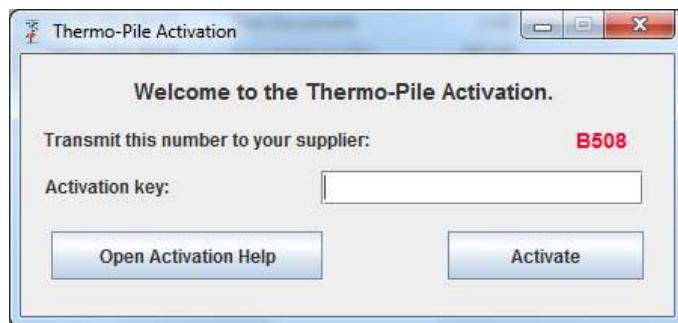
*Fig 0. Activation window of Thermo-Pile.*

3 GRAPHICAL USER INTERFACE (GUI)

The *Thermo-Pile* GUI is divided into four main panels:

- The main menu panel (1), from where all the menus are accessible;
- The project name (2), corresponding to the currently running project;
- The results panel (3) where a summary of the results is available;
- The graphics panel (4), where results profiles are plotted.
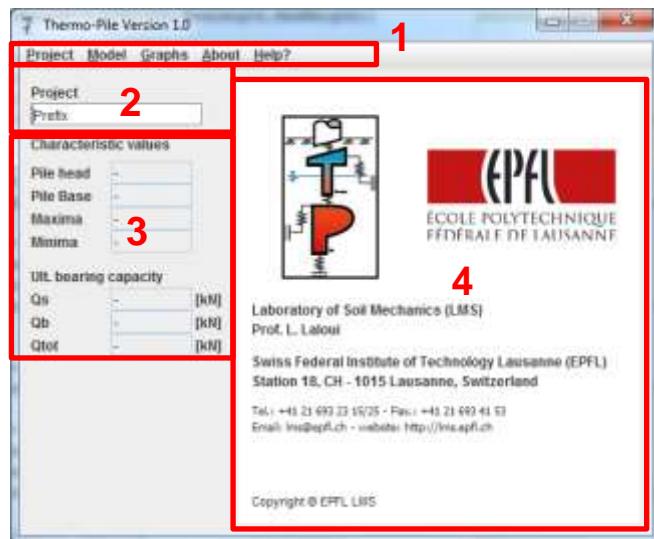
Fig.1. Main window with 1) Main menu, 2) Project name, 3) Summary of results and 4) Plot space.

4 READING AND WRITING FILES

Saved files (e.g. projects) from *Thermo-Pile*, which are parameters files (*E.txt*) or results (*Res.txt*), are located in the same folder as the software (e.g. the application). In order to load a file (*E.txt*), make sure it is located in the same folder as the application you are using.

4.1 READING AND WRITING PROJECTS FROM MAIN MENU

In the main menu, reading and writing a project is available in *Project > Save project* or *Load Project*. **Before writing or loading a project, make sure you gave the right prefix** (panel 2 in Fig. 1).

The prefix represents the name of your project. Then, parameters from your project will be saved in a file named *YourProjectNameE.txt*.

The *E.txt* exported files have the following template:

Table 1: Description of the rows of a E.txt file

#	# of Columns	Row Name	Comment
1	1	NBRLAY	Number of Layers
2	NBRLAY	DPTLAY	Lower depth of a layer on the z axis
3	NBRLAY	NBINCR	Number of increments per layer
4	NBRLAY	FRIANGINT	Internal friction angle

5	NBRLAY	COH	Cohesion
6	NBRLAY	SWGHTSOL	Specific weight of the soil
7	NBRLAY	FRIANGPS	Interface friction angle
8	NBRLAY	EPMEN	Menard pressuremeter elastic modulus
9	NBRLAY	PRELAT	Ultimate shear stress
10	1	PREBASE	Ultimate bearing capacity at the base
11	1	WATLEV	Groundwater table
12	1	LNGPIL	Pile length
13	1	DIAMPIL	Pile diameter
14	1	ELAPIL	Young's modulus of the pile
15	1	DILTHPIL	Thermal expansion coefficient of the pile
16	1	RIGPIST	Linear spring value for the pile structure Interaction
17	1	SOLICITH	Temperature variation from manual entry
18	1	SOLICIMEC	Mechanical solicitation
19	1	THECPUT	Theory used to assess the bearing capacity
20	1	CHI	Correction factor for Lang&Huder theory
21	1	EntryTemp	Kind of enter the thermal loading
22	1	TzCur	Theory for the t-z curves
23	NBRLAY	Ks1	Slope 1 for branch 1 of the ts-z curve
24	NBRLAY	Ks2	Slope 2 for branch 2 of the ts-z curve
25	NBRLAY	Ks3	Slope 3 for branch 3 of the ts-z curve
26	NBRLAY	ts1	Fraction of qs at the end of branch 1 (ts-z curve)
27	NBRLAY	ts2	Fraction of qs at the end of branch 2 (ts-z curve)
28	NBRLAY	ts3	Fraction of qs at the end of branch 3 (ts-z curve)
29	1	Kb1	Slope 1 for branch 1 of the ts-z curve
30	1	Kb2	Slope 2 for branch 2 of the ts-z curve
31	1	Kb3	Slope 3 for branch 3 of the ts-z curve
32	1	tb1	Fraction of qs at the end of branch 1 (ts-z curve)
33	1	tb2	Fraction of qs at the end of branch 2 (ts-z curve)
34	1	tb3	Fraction of qs at the end of branch 3 (ts-z curve)
35	1	nomFICHTEMP	ASCII code of the name of the temperature file

4.2 LOADING RESULTS

Once the calculation is done, *Thermo-Pile* automatically generates a file containing the results and named *YourProjectName**Res.txt*** with the template given in Tables 2 and 3. This file is automatically loaded into the software so you can directly visualize the results thanks to the *Graphs* menu. You can also reload results from an older project by specifying the right prefix and loading the results: *Graphs > Load Results file*. Once again, make sure the results file is in the same folder as the application.

Table 2: Description of the rows of a Res.txt file

Row 1	Names of the columns
Rows 2 to Line NumEle+1	Values of the results

Table 3: Description of the columns if a Res.txt file

#	Column Name	Significance
1	Depth 1	Position on the z axis for results of columns 2 to 10
2	AxialStressMec	Axial stress after mechanical loading
3	AxialStressTherm	Axial stress due to thermal loading
4	AxialStressTot	Axial stress after thermal loading (= Axial stressMec + AxialStressTherm)
5	AxialDisplMec	Axial displacement after mechanical loading
6	AxialDispTherm	Axial displacement due to thermal loading
7	AxialDispTot	Axial displacement after thermal loading (= Axial DisplMec + AxialDisplTherm)
8	MobBearForcesMec	Mobilised bearing forces after mechanical loading
9	MobBearForcesTot	Mobilised bearing forces after thermal loading
10	MobBearForcesUltime	Ultimate bearing capacity
11	Depth2	Position on the z axis for results of columns 12 to 10
12	AxialStrainMec	Axial strain after mechanical loading
13	AxialStrainTherm	Axial strain due to thermal loading
14	AxialStrainBlocked	Part of the free strain, which is blocked by external constraints (springs)
15	AxialFreeStrain	Free axial strain $\varepsilon_{th,f} = \alpha \cdot \Delta T$
16	ShearStressMec	Shear stress mobilised by mechanical loading
17	ShearStressTherm	Shear stress due to thermal loading
18	ShearStressTot	Shear stress mobilised after thermal loading
19	DegreeOffFreedom	Degree of freedom
20	qsUltime	Ultimate shear stress value
21	MenardElastic	Menard pressuremeter elastic modulus

	Modulus	
22	diffTemperature	Applied change in temperature

4.3 SPECIFYING THERMAL LOADING BY READING A FILE

You can specify the thermal field if it is not homogeneous along the pile. To do so, one must create a *.txt* file, which has the template as defined in Tables 4 and 5, in the same directory as your project and load it when specifying the thermal loading on the pile. Just select *Model > Loading*, "*Read from txt file*" in the *Thermal Loading* drop menu and give the right file name.

Table 4: Description of the rows of a temperature file

Rows 1 to the end	Data

Table 5: Description of the columns of a temperature file

#	Column Name	Significance
1	-	Position on the z axis
2	-	Change in temperature

The columns are delimited by a blank space. The number of rows and the position on the z axis do not need to correspond to the number of pile elements. The temperature change assigned to a pile element is that of the closest position from the temperature file. The comparisons are done with absolute values, so the sign does not influence the distances between pile elements and temperature file positions.

5 UNITS SYSTEM AND SIGN CONVENTIONS

Thermo-Pile uses the unit system with seconds, meters and kilograms for the input parameters and for the results. It cannot be changed. Each parameter unit is given in the GUI.
Upwards displacements and tensile stresses are taken as positive.

## 6 RUNNING A PROJECT – SPECIFYING GEOMETRIES AND PROPERTIES

In *Thermo-Pile*, a project consists in specifying a soil (geometry and physical properties), a pile (geometry and physical properties), the pile-structure and pile-soil interactions (parameters and curves) and the pile loading (mechanical and thermal loadings). Those parameters are set in the *Model* menu.

6.1 SOIL GEOMETRY AND PHYSICAL PROPERTIES (MODEL > SOIL PROPERTIES)
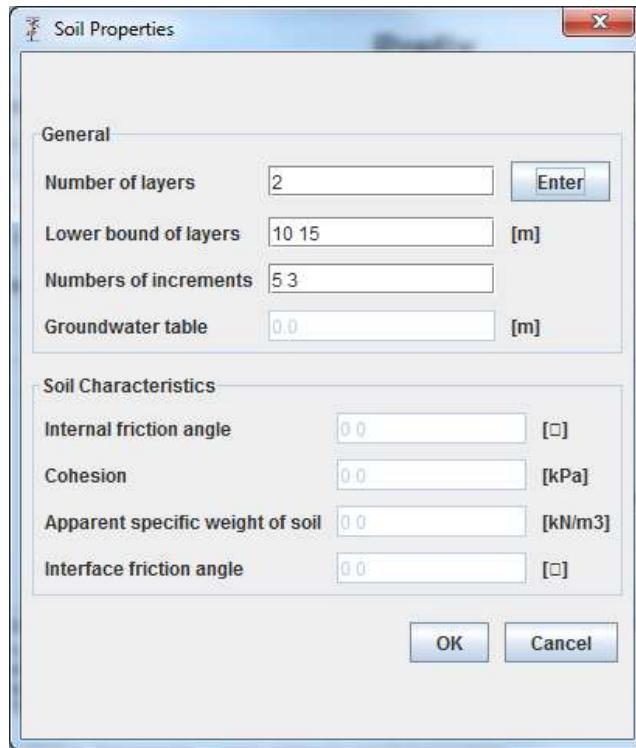
Fig. 2: Soil properties panel.

The *General* panel represents the geometry of the soil. The *Number of layers* will be useful to specify different layers with different physical properties. *Lower bound of layers* represents the depth at which each layer ends, the origin being the surface. *Numbers of increments* represents the needed number of elements. A value has to be specified for each layer. This parameter is important for the result accuracy (see Section 12.2).

The corresponding configuration of the Fig 2 is:

Groundwater table and Soil Characteristics are available when the Ultimate bearing capacity method is different from Manual (see Section 6.3 and Table 6).

Table 6: Soil properties, overview of the theories and their parameters

| Parameters	#	values	Lang Huder	DTU analytic	DTU empiric	Manual
Number of layer (n)	1		X	X	X	X
Lower bound of layers (m)	n		X	X	X	X
Number of increments	n		X	X	X	X
Groundwater table (m)	1		X	X	X	-
Internal friction angle (°)	n		X	X	X	-
Cohesion (kPa)	n		X	X	X	-
Specific weight of soil (kN m^{-3})	n		X	X	X	-
Interface friction angle (°)	n		X	X	X	-

6.2 PILE PROPERTIES (MODEL > PILE PROPERTIES)
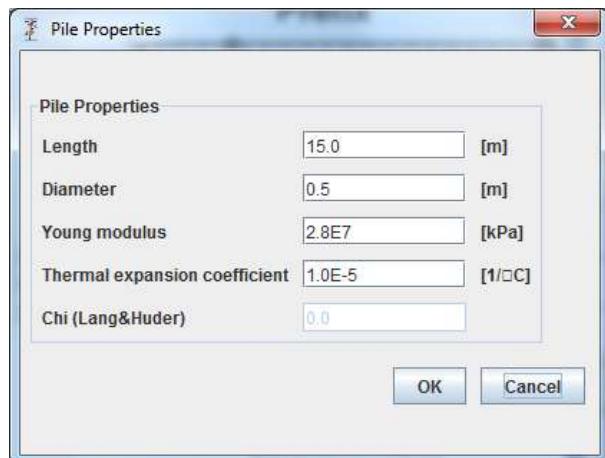
Fig. 3: Pile properties panel.

Length and *Diameter* are the geometric characteristics of the pile (only one cylindrical pile is considered). *Young modulus* and *Thermal expansion coefficient* are the pile physical properties. *Chi (Lang&Huder)* is a parameter available when the method *Lang&Huder: granular soils* is enabled for computing the Ultimate Bearing Capacity (see Section 6.3).

6.3 PILE-SOIL AND PILE-STRUCTURE INTERACTIONS (MODEL > INTERFACE PROPERTIES)
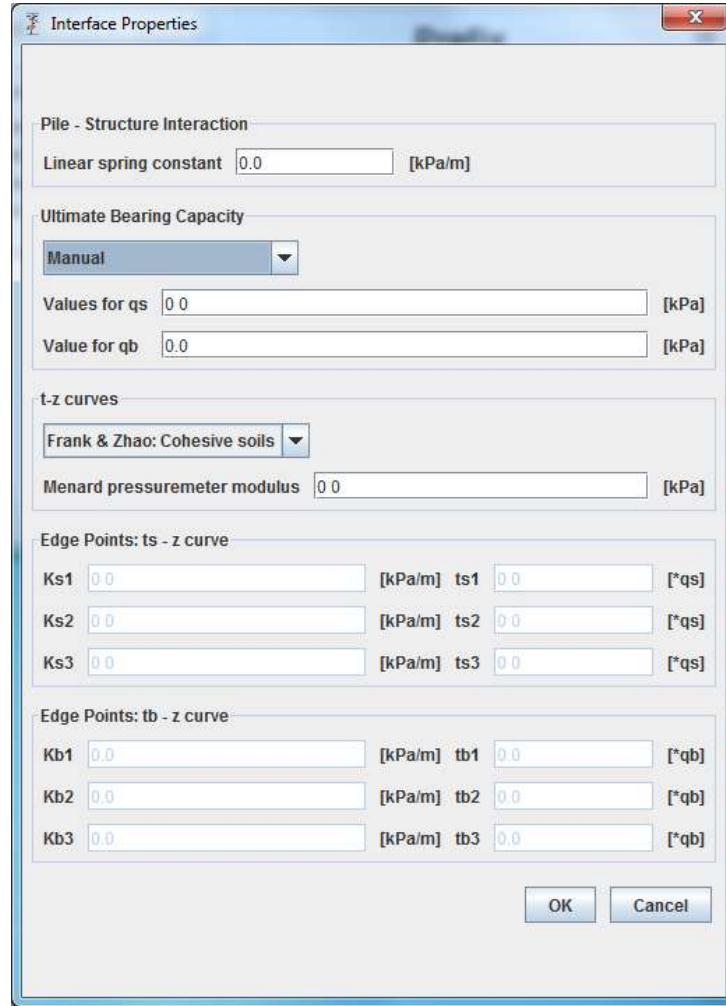
Fig. 4: Interface properties panel.

The interactions between the pile and the supported structure, as well as between the pile and the soil are modeled by equivalent springs. In this window the spring properties are defined (see also the technical manual).

The spring which models the interaction between the pile head and the supported structure (building) is linear elastic. The spring constant is defined by *Linear spring* value (see Fig. 4). It is important to underline that even if the mechanical loading is null, this stiffness is taken into account into the thermal effects calculation. Thus, to model free pile head, both mechanical loading and linear spring constant must be set to 0.

Ultimate shear stress q_s and ultimate bearing capacity at the pile base q_b can be calculated using *DTU analytic, DTU empiric* or *Lang&Huder* or they can be entered manually (*Manual*). If a theory is chosen, the soil characteristics (see Fig. 4) must be defined.

Table 7: Pile – soil interface Properties, ultimate bearing capacity

Parameter	#	values	Lang Huder	DTU analytic	DTU empiric	Manual
Value for q_s (kPa)	1		-	-	-	X
Value for q_b (kPa)	n		-	-	-	X

In the soil – pile interaction, the soil – pile shaft interaction (index s) and the soil pile base interaction (index b) are distinguished. The springs model the interaction between the soil and the pile, and have an elasto-plastic behaviour. The curves describing the spring behaviour are called t_s-z and t_b-z curves; their shape are defined by linear branches and a plateau value. t stands for the mobilised shear stress and z for the displacement. One can choose between predefined t-z curves, according to Frank and Zhao for *cohesive* or *granular* soils, and user defined t-z curves (*Manual*). The theory of Frank and Zhao is based on the *Menard pressuremeter elastic modulus* and must be entered for each layer. The manual entry allows defining a curve with 3 linear branches and a plateau value. The branches are defined by their slope *K* and a shear stress t. (see Fig. 5).The $t_{s,i}$ (resp. $t_{b,i}$) values are defined by a fraction of q_s (resp. q_b).
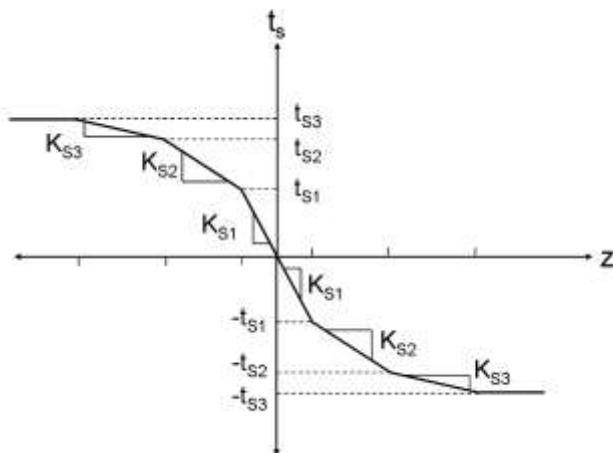

Table 8: Pile – soil interface t-z curves

Parameter	# values to enter	Frank &Zhao cohesive	Frank &Zhao granular soils	Manual
Menard pressuremeter modulus (kPa)	1	X	X	-
Ks1 (kPa m^{-1})	n	-	-	X

Ks2 (kPa^{-1})	n	-	-	X
Ks3 (kPa^{-1})	n	-	-	X
ts1 (kPa)	n	-	-	X
ts2 (kPa)	n	-	-	X
ts3 (kPa)	n	-	-	X
Kb1 (kPa^{-1})	1	-	-	X
Kb2 (kPa^{-1})	1	-	-	X
Kb3 (kPa^{-1})	1	-	-	X
tb1 (kPa)	1	-	-	X
tb2 (kPa)	1	-	-	X
tb3 (kPa)	1	-	-	X

6.4 MECHANICAL AND THERMAL LOADINGS (MODEL > LOADING)
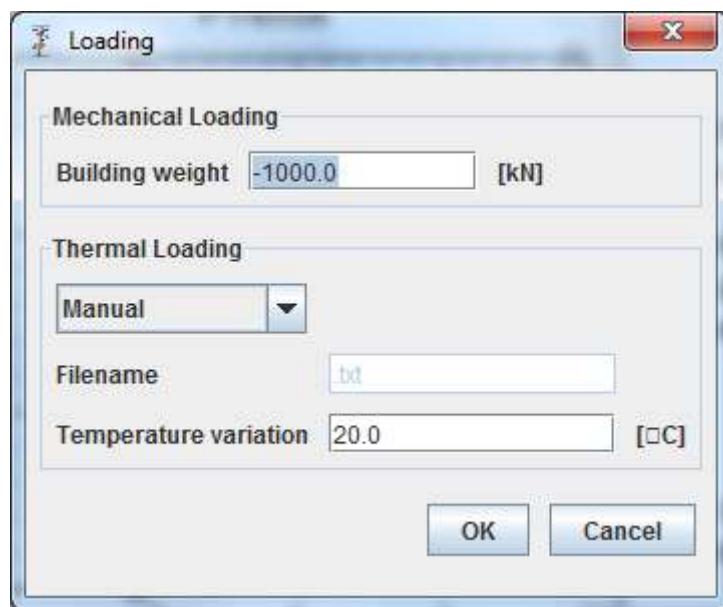
Fig. 6: Loading panel

Mechanical loading represents the building weight. Since no negative friction is taken into account, the mechanical loading magnitude taken into account is the absolute value of the input value and it is oriented downwards. This is the reason why specifying a positive or a negative value will not change the results. The thermal loading is relative and can be either a constant value or specified with a *.txt* file (see Section 4.3).

7. VISUALIZING RESULTS (GRAPHS)

Once the calculation is completed, *Thermo-Pile* saves a *Res.txt* file in the same folder as the project file. This file can then be used to postprocess the results and create figures (see Tables 2 and 3). To visualize the results within *Thermo-Pile*, use the *Graphs* menu. Several results versus depth can be displayed.

8. CLOSING THERMO-PILE (PROJECT > EXIT)

Thermo-Pile can be closed thanks to the usual red cross icon on the top right corner of the window. Nevertheless, it is recommended to close it with the commands in the *Project* menu *Project > Save Project and Exit* in order to save all changes in your project. If you want to quit without saving, use *Project > Close*.

9. SHORTCUTS FOR USING THERMO-PILE WITH KEYBOARD

Table 9: Menu shortcuts

Menu	Shortcut
Alt + A	About
Alt + G	Graphs
Alt + H	Help
Alt + M	Model
Alt + P	Project

10. EXEMPLES: SOME CASE STUDIES

10.1 EPFL CASE STUDY

10.1.1 DATA

The example chosen is a full scale in situ test carried out at the EPFL in Lausanne on a heat exchanger pile (see Laloui et al., 2003 and 2006). The heat exchanger pile, which was part of a pile raft supporting a four storey building (Bâtiment Polyvalent, « BP », 100 m in length and 30 m in width) built in 1998-1999 in EPFL Lausanne, was equipped on all its length with load cells, extensometers (both fiber optic and vibrating-wire) and temperature sensors (Laloui et al. 2003, 2006). This pile was subjected to a thermal load, generated by a heat carrying fluid circulating in polyethylene pipes embedded in the concrete pile. The pile tested was located at the side of the building. The drilled pile diameter was 88 cm on average, and its length was 25.8 m. Pile integrity tests revealed a slightly marked bulge in the bottom part of the pile. The Young modulus of the pile was estimated from laboratory tests and cross-hole ultrasonic transmission tests, yielding the value E_{pile} = 29.2 GPa at ambient temperature. The coefficient of thermal expansion of the pile was estimated to be $\alpha = 1 \times 10^{-5}$ °C^{-1}.

Figure 7 shows the location of the in situ test. The pile geometry and its properties are summarized in Table 10.

<div align="center">

Table 10: Pile characteristics

Length (m)	25.8
Diameter (m)	0.88
Young Modulus (kPa)	$2.82*10^7$
Thermal expansion coefficient (°C^{-1})	10^{-5}

</div>

A schematic foundation soil profile is presented in Figure 8 (there are five different soil layers). The parameters corresponding to the layers and their properties, namely the lower depth, the bearing capacity at the pile base q_b (layer D only), the ultimate shear frictions q_s and the rigidity of the soil-pile shaft interaction K_s and soil pile base interaction K_b are given in Table11.

The soil pile interaction is elasto-plastic, with one linear slope (K_s respectively K_b) starting from zero and ending in a plateau value (q_s respectively q_b).
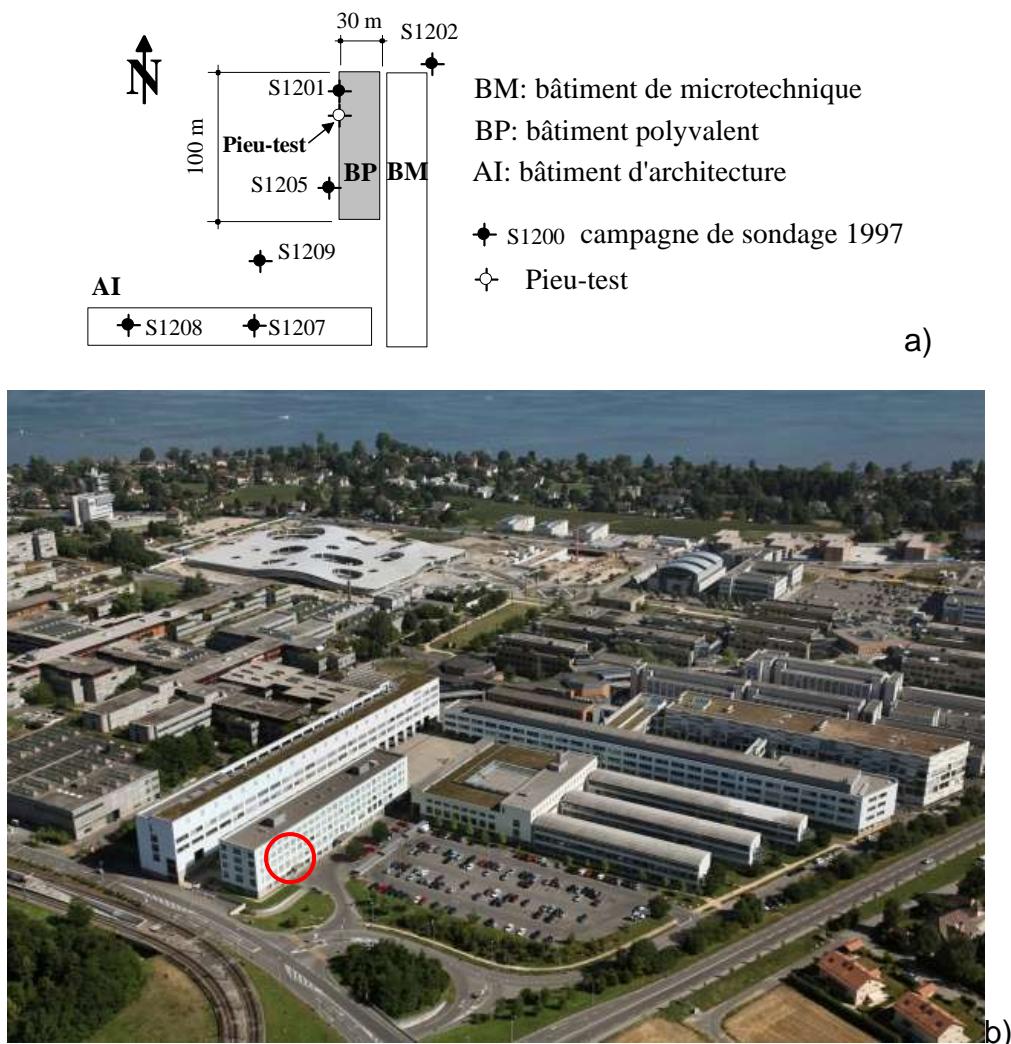
*Fig. 7 a) Schematic view of the test side b) Aerial view of the EPFL campus*
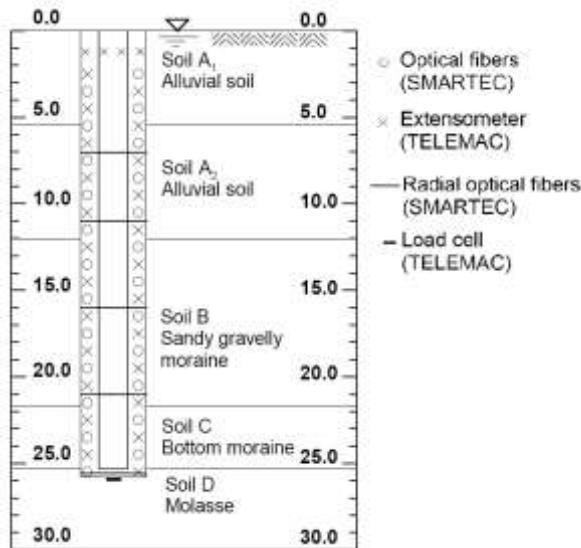
Fig. 8 Geological situation of the EPFL pile (Laloui et al. 2003)

Table 11: Soil pile interaction characteristics

Layer	A1	A2	B	C	D
Depth (m)	5.5	12	22	25	25.8
q_s (kPa)	102	70.8	74.7	160	300
q_b (kPa)					11000
K_s (MPa m^{-1})	16.7	10.8	18.2	121.4	121.4
K_b (MPa m^{-1})					-667.7

The pile head building interface spring constant is K= 2 GPa/m. The building weight represents a solicitation of 1000 kN for the pile. The profile of the thermal solicitation is given in Table 12.

Table 12: Profile of change in temperature

Depth (m)	ΔT (°C)
2.5	17.1
5.5	17.3
12.5	17.1
21.5	17.3
25.8	15.9

10.1.2 PROCEDURE

To open the application, double click on the Thermo-Pile.exe file, then enter the Project's name (e.g. Example_EPFL) in the text field "Project" as shown in Figure 9.
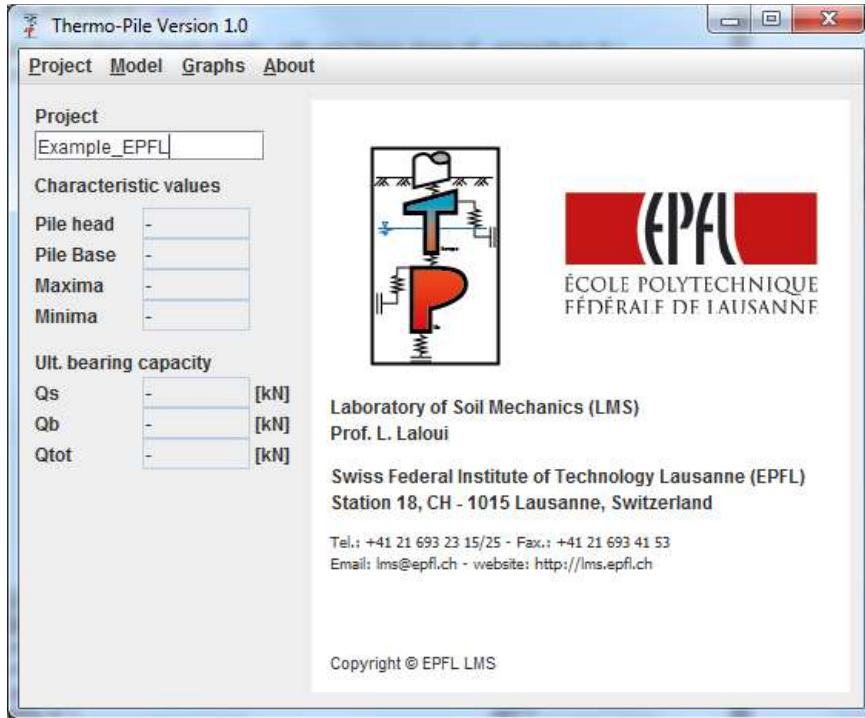

Fig.9 Thermo-Pile; Main window

10.1.2.1 DEFINITION OF THE MODEL AND SOILD PROPERTIES

To define the increments and to enter the soil properties click in the main menu on:
>*Model > Soil Properties*

There are 5 soil layers with the following number of increments: 11 for layer 1, 20 for layer 2, 32 for layer 3, 6 for layer 4 and 2 for layer 5.

The parameters of the *n* different layers should be sorted by increasing layer number (e.g. value for the layer 1 up to the value for the layer n) separated with a blank space in the corresponding text field. Figure 10 shows the completed window "Soil Properties". To save the values and close the window, click on the OK button.

Each text field should contain data for each layer (even if they are disabled). By clicking on Enter after entering the number of layers, all fields are automatically set to the correct amount of zeroes which indicates the number of parameters that one has to specify.
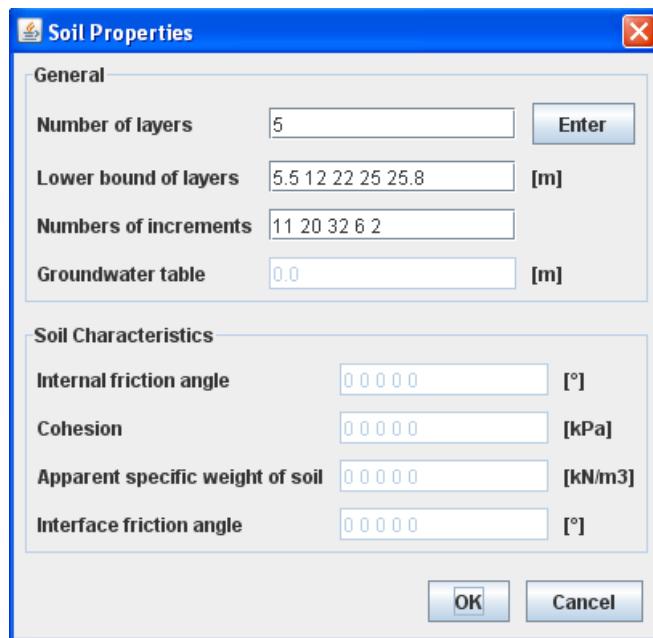
Fig. 10 Thermo-Pile; Window Soil Properties (Model > Soil Properties)

Remark:

By default, in the Interface Properties window, the option for the assessment of the bearing capacity is set to "Manual". This means that the parameters for the Groundwater table and the Soil Characteristics are not used for calculation and thus disabled. To enable them, one has to select a given theory instead of the manual entry option.

10.1.2.2 DEFINITION OF THE PILE PROPERTIES

All pile characteristics are constant, so only one value per parameter has to be defined in the Pile Properties window (Figure 11)

> *Model > Soil Properties*
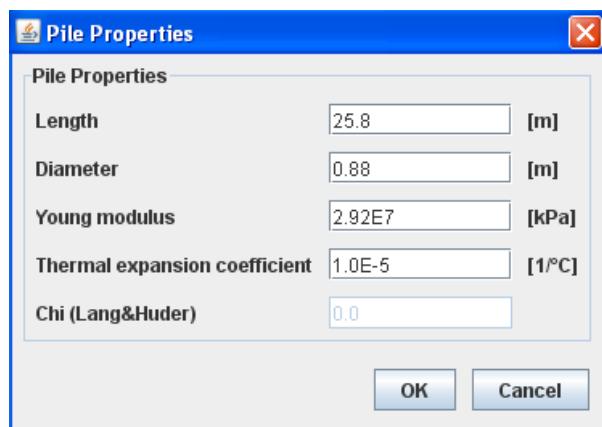
Fig. 11 Thermo-Pile; Window Pile Properties (Model > Pile Properties)

To save the values and close the window click on the OK button.

10.1.2.3 DEFINITION OF THE INTERFACE PROPERTIES

The interfaces are defined in the Interface Properties window:

> *> Model > Interface Properties*

The Pile – Structure Interaction Linear spring constant is set to 1'500'000 kPa/m. Since the bearing capacities q_s and q_b are already known, they can be entered manually (the option Manual must then be chosen). The t-z curves for the pile shaft soil interaction are also entered manually. The Manual option must therefore be chosen. The shape of the t-z curve is explained in Figure 5. In the present example, it consists of only one linear branch with the slope K_s (respectively K_b), followed by a plateau value. Consequently, all K_s slopes of the t-z curves are set equal ($K_{s1} = K_{s2} = K_{s3}$). The values t_{s1} and t_{s2} can be chosen arbitrary between 0 and 1, t_{s3} has to be set equal to 1 to introduce the plateau. The same procedure is followed to define the t-z curves for the soil pile base reaction. The complete soil pile interface configuration is shown in Figure 12.
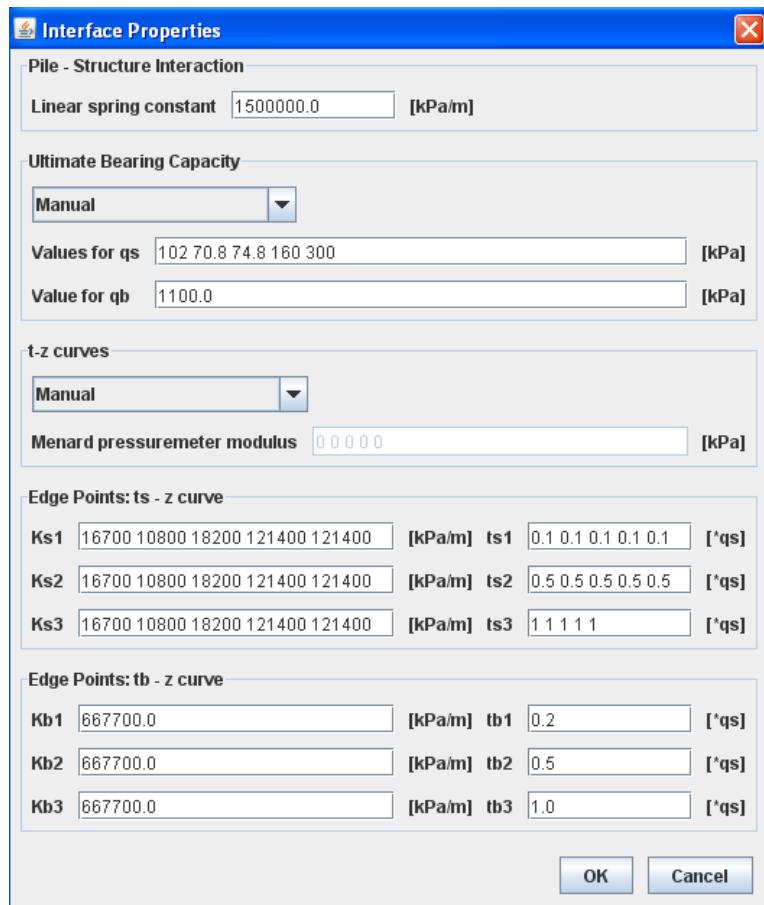
Fig. 12 Thermo-Pile; Window Interface Properties (Model > Interface Properties)

To save the values and close the window click on the OK button.

Notes:

1. If the bearing stresses q_b and shear stress q_s are assessed by using one of the options "Lang&Huder: granular soil", "DTU analytic: granular soil" or "DTU empiric: granular soil", the groundwater table and the soil characteristics in *>Model > Soil Interface* have to be defined.

2. If the t-z curves are not defined manually but by the options "Frank&Zhao granular soils" or "Frank&Zhao cohesive soils" the text field corresponding to the Menard pressuremeter elastic modulus for each layer has to be filled in.

10.1.2.4 DEFINITION OF LOADS

The mechanical and thermal loads are defined in:

> *> Model > Loading*

The mechanical loading corresponds to the solicitation of the pile induced by the building weight. According to the sign convention gravity forces are negative.

There are two possibilities to enter the thermal loading:

1) Choose the manual option and put the average value from the given changes in temperature into the corresponding text field.

2) Create a text file containing the given changes of temperature as showed in Figure 13, with the depths in column 1 and the corresponding temperatures in column 2. The two columns are separated by a blank space. The name of the text file can be chosen arbitrary; here it's called "thermal_Loading".
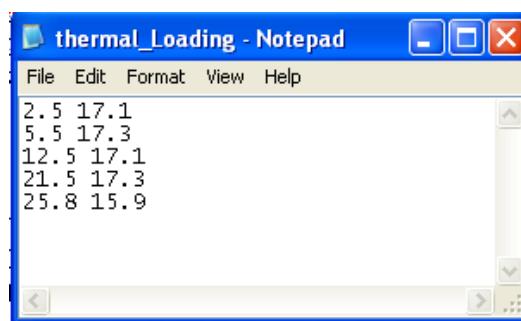
Fig. 13   Notepad; txt file containing the thermal loading, column 1: depth, column 2: thermal loading

Then select the option "Read from txt file" and enter the name of the txt field in the corresponding text field, as shown in Figure 14.
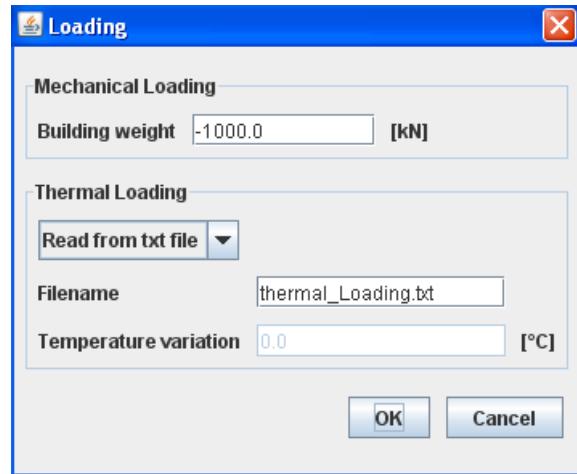
Fig. 14 Thermo-Pile; window Loading (Model > Loading)

10.1.2.5 WRITING OF THE E.TXT FILE

In order to save the Model parameters, they must be written in a separate txt file. To do so, click on:

> *Project > Save Project*

Now, a *.txt* file with the name Example_EPFLE.txt should appear in the directory in which the *Thermo-Pile* executable file is stored.

10.1.2.6 RUNNING THE CALCULATION

To run the calculation click on

> *Project > Run Project*

First the software reads the E.txt file. With the gained information it computes the calculation and writes the results in a second text file with the ending Res.txt. In our case, the file containing the results is named Example_EPFLRes.txt.

Once the calculation is completed, the message "the calculation has successfully completed" appears in the main window.

Remark: because the software takes the information from the E.txt file and not directly from the text fields in the Model windows, it is important to write the information right after modifying parameters. For this reason the Run option is disabled when the parameters are changed, it becomes enabled only after writing the E.txt file.

10.1.2.7 PLOTTING GRAPHS

To get the graph, the results are first uploaded form the Res.txt file. To do so, click on:

> *> Graphs > Load Results*

To plot a specific a graph, click on his name. For example, to plot the graph Axial stress versus depth, click on

> *> Graphs > Axial stress vs. Depth*

The plot appears in the main window as shown in Figure 15.
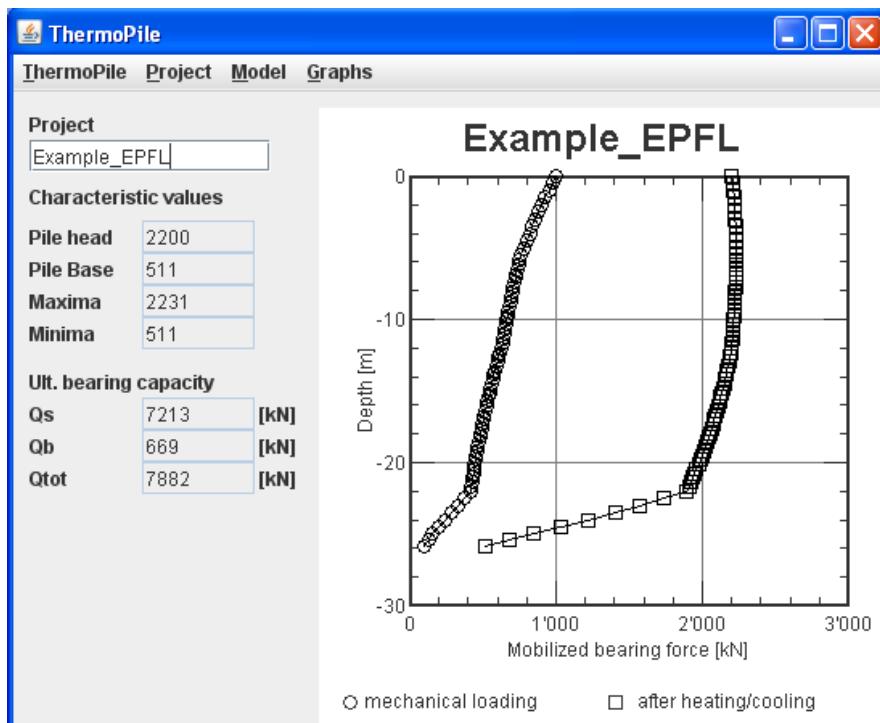
Fig. 15 Thermo-Pile; Main window with Axial stress – Depth Plot

10.1.2.8 MODIFICATIONS

Once the software is closed, if one wants to modify an existing Project, it can be done by modifying directly the E.txt file. However the recommended way is to re-launch the software and to load the existing E.txt file:

1) write the projects name in the text field in the main window
2) import the file: *> Project > Load Results*

All parameters in the Model windows are then updated and modifications are easy to handle. Before running the next computation, do not forget to (re-)write the E.txt file.

10.1.2.9 PLOTTING RESULTS FROM EXISTING RESULT FILE

Before plotting the graphs, the software reads the file Res.txt. To plot results from existing projects you should write the project name in the text field from the main window and import the Res.txt file:

> *> Graphs > Load Results*

Then you can choose a graph listed in the Graph menu.

If you need to visualize plots from different projects, the plot space must be cleared first.

> *> Graphs > Clear Results*

Then the *Res.txt* file from a new or modified project can be loaded again.

10.2 PARAMETRIC STUDIES

In this section, a configuration is declined into several cases: floating and semi-floating pile cases are studied.

10.2.1 GLOBAL CONFIGURATION

The configuration studied here is made of one ten meters-long pile with a 0.5 m diameter whose characteristic are its Young's modulus E_{pile} (= 30GPa) and its thermal expansion α (=1.10^{-5} °C^{-1}). This pile is plugged into one single and homogeneous layer of soils whose characteristics are varying according to the case of interest (floating or semi-floating).

10.2.2 FLOATING PILE

In the case of a floating pile, almost the entire weight of the building is transferred to the soil through friction along the pile shaft. For this case, soil-pile interactions characteristics are listed in table 13.

Table 13: Soil-pile interactions parameters for the floating pile case

Parameter	Value
qs (kPa)	50
qb (MPa)	0
P (kN)	650
E_M (MPa)	20
K_h (GPa m^{-1})	10
ΔT (°C)	+/- 15

Results from the computation are shown in figure 16.
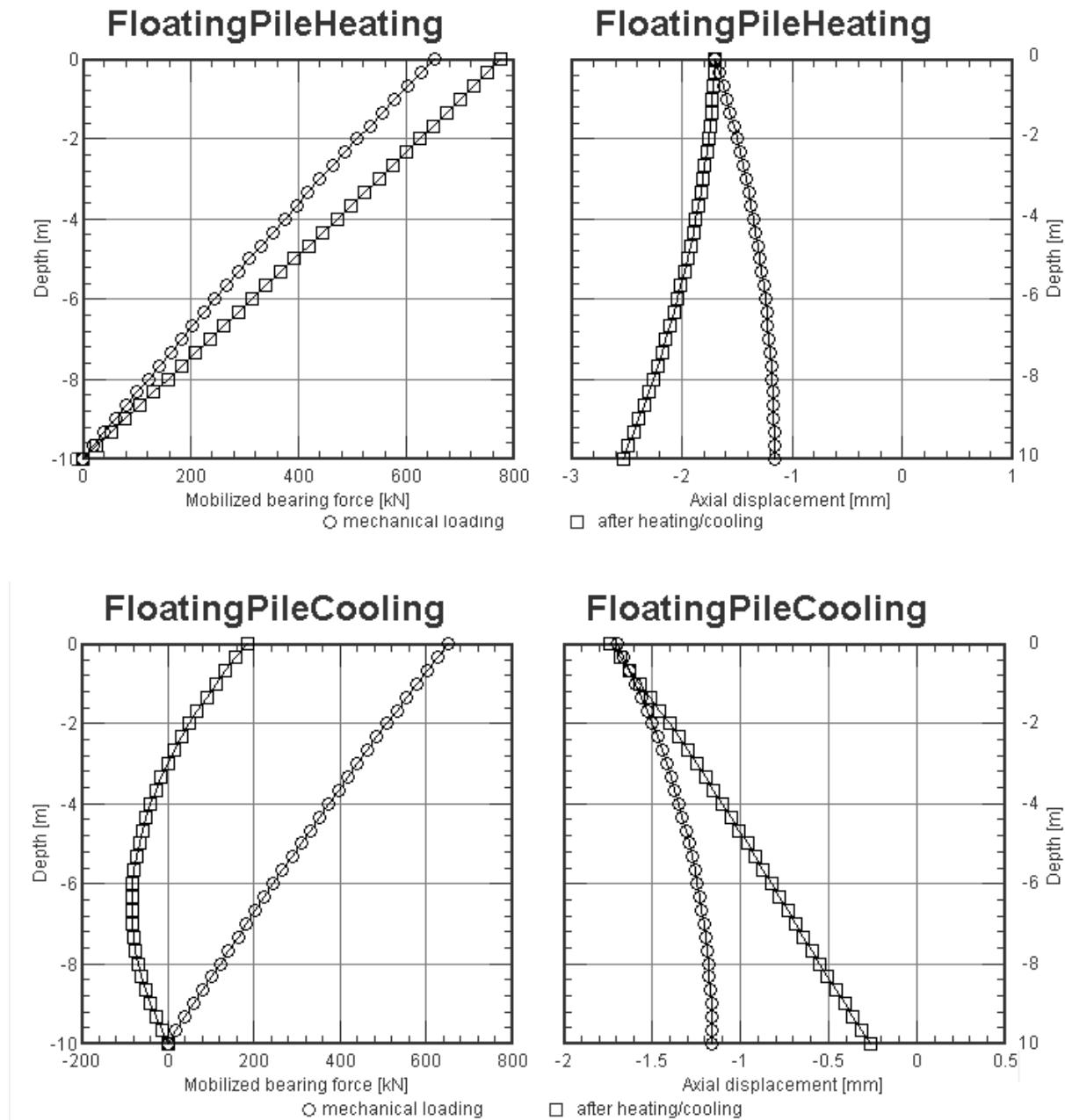
Fig. 16: Results from the floating pile computation for heating (top) and cooling (bottom) cases.

12.2.3 SEMI-FLOATING PILE

Semi-floating pile is the most practical case where the building weight is transferred to the soil by the pile through shaft friction and base reaction. The parameters used are listed in table 14.

Table 14: Parameters for the semi-floating pile case

Parameter	Value
q_s (kPa)	250
q_b (MPa)	38.2
P (kN)	2500
E_M (MPa)	60
K_h (GPa m^{-1})	45
ΔT (°C)	+/- 50

The results for this case are presented in figure 17. They can be compared to the results of the previous case in figure 16.
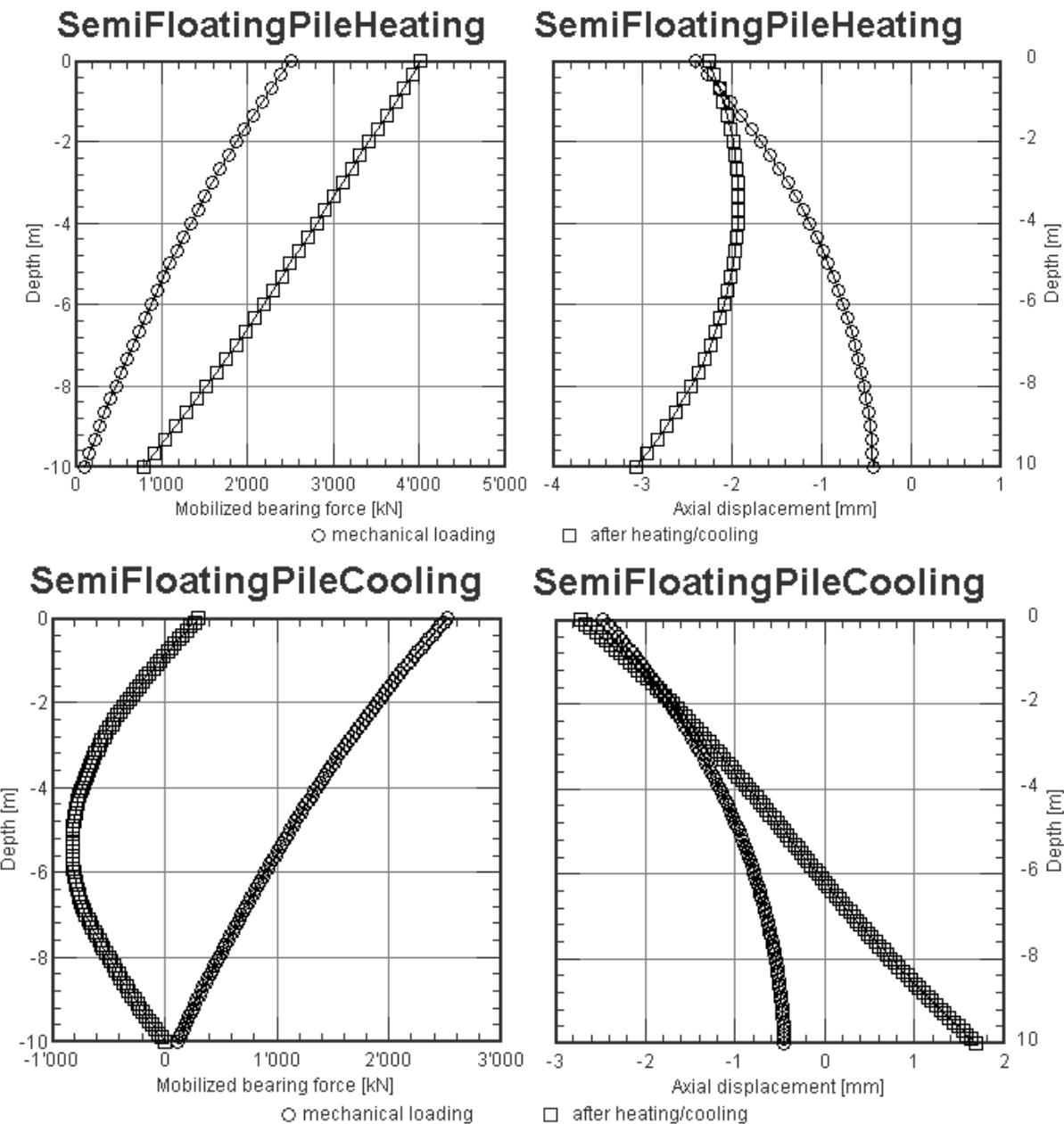

Fig. 17: Results from the semi-floating pile computation for heating (top) and cooling (bottom) cases.

11 FAQ

1) The Run button is not available

- *After any modification or even opening the Model menu, you must write the project before running your simulation. Then the Run option will be available in the Project menu.*

2) I load the E.txt file or the Res.txt file but nothing happens.

- Does a corresponding file exist? If not, proceed as follows: > *Project* > *Save Project* for writing the E.txt file or run the calculation to write the Res.txt file.
- Have you entered the full name of the file, including "E.txt" respectively "Res.txt"? In fact only the name of the project without the endings "E.txt" or "Res.txt" must be written in the text field.

3) I have written an E.txt file and I want to run the calculation but it doesn't start

- If you have entered different layers, in the text fields requiring a value for each layer you should have one value of parameter per layer, even if these values are not used.

4) The disabled text fields does not show the correct amount of zeros

- If you are in the soil parameter window, click on the Enter button to update the disabled text fields.
- If you are in the soil interaction parameter window, change the corresponding theory and change back, to update the disabled text fields.

5) The code doesn't read the txt file containing the temperature profile

- The file is read properly only if it is encoded in ANSI or Unicode (UTF-8).

6) The sign of my mechanical loading doesn't affect the results

- See Section 6.2.

12. KNOWN ISSUES

12.1 INCREMENT SIZE CRITERIA

The method used in *Thermo-Pile* forbids one set of values for the Young modulus *E*, the diameter of the pile *D*, the ts-z curve slope value K_S and any height if increment h_i:

$$h_i \neq \sqrt{2\frac{E.D}{K_S}}$$

When this criterion is not fulfilled for at least one increment, an error message is popped-up and the calculation is aborted.

12.2 ABOUT ACCURACY AND PILE DISCRETIZATION

Since *Thermo-Pile* is a numerical code, it solves a continuous physical problem over a user defined grid whose size influences the accuracy of the results. Moreover, since *Thermo-Pile* solves thermal loading effects by finding the closer grid point to the null point and computing all the thermally induced displacements along the pile from it, results can be really affected by coarse mesh. The accuracy of the null point localization is equal to half of the height of the larger increment. If N represents the number of increments and L le height of the pile, this accuracy is equal to L/(2N).

No rules exist to take the right number of increments. Nevertheless, do not attempt to lead a study with grids of 10 points or so! You can start from an **increment size around one hundredth of the pile height (e.g. 100 increments)** and modify it according to the study's requirements.

Since *Thermo-Pile* is low CPU requiring, it is recommended to run several simulations and to compare the different results. The goal is to reach a (quasi) non-mesh-dependent result.

12.3 SOFTWARE'S LIMTATIONS

Limitations of *Thermo-Pile* are about the really low displacements and deformations, when the shaft friction is relatively high compared to the mechanical loading. In this case, the software can require a huge CPU time and even never converge since the displacements are too small. To solve this kind of problem, try to increase the number of increment per layer. Increasing the number of increment per layer is often the solution to the accuracy/convergence matters.

Remember that in order to model really small displacements/deformations you will need thin mesh.

13 THERMO-PILE MESSAGES

13.1 ERROR MESSAGES

Error messages are made to guide the Thermo-Pile user. They also provide information about the quality of the simulations.

Message	Meaning
	The project file, containing all the project parameters was not found. Check if the project file is in the same folder as the executive *Thermo-Pile* file, or if the project name is correct.
	The results file, containing the results from the simulation, was not found. Make sure it is in the same folder as the *Thermo-Pile* executive file or check the project name.
	The calculation did not succeed to converge correctly. This is usually due to the thermal loading. Try to change the increments number along the pile. Be careful with the obtained results which might be wrong.
	If a part of the thermal loading is null, then the mathematical definition of the degree of freedom is not correct anymore. See [Knellwolf et al. (2011)](#) for further details.

13.2 OTHER MESSAGES

Message	Meaning
	The overwrite window is useful to preserve projects from bad overwriting. However, it can be disabled by unselecting the checkbox on the down left corner entitled "Always ask".
	This message is made to announce the successful end of a simulation. However, never forget to review the results.

References

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Knellwolf C., Peron H. and Laloui L. "Geotechnical analysis of heat exchanger piles". Journal of Geotechnical and Geoenvironmental Engineering, doi: 10.1061 / (ASCE) GT.1943-5606.0000513, 2011.

Laloui L., Moreni M. and Vulliet L. 2003. Comportement d'un pieu bi-fonction, fondation et échangeur de chaleur. Canadian Geotechnical Jounrnal, Issue. 40, p. 388-402.

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