13 PILE DRIVING

This example involves driving a concrete pile through an 11 m thick clay layer into a sand layer, see Figure 13.1. The pile has a diameter of 0.4 m. Pile driving is a dynamic process that causes vibrations in the surrounding soil. Moreover, excess pore pressures are generated due to the quick stress increase around the pile.

In this example focus is put on the irreversible deformations below the pile. In order to simulate this process most realistically, the behaviour of the sand layer is modelled by means of the HS small model.

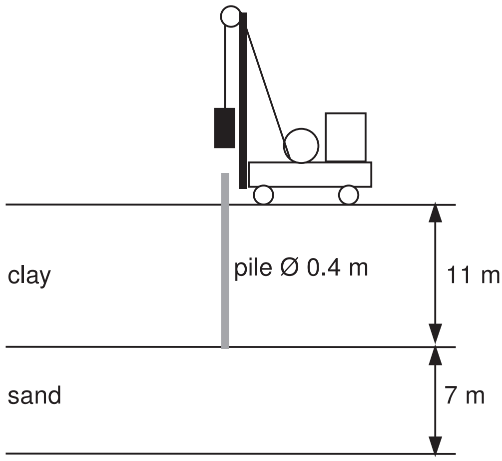

Figure 13.1 Pile driving situation

13.1 INPUT

To create the geometry model, follow these steps:

General settings

- Start the Input program and select the *Start a new project* from the *Quick select* dialog box.
- In the *Project* tabsheet of the *Project properties* window enter an appropriate title.
- In the *Model* tabsheet select the *Axisymmetry* option for *Model* and keep the default option for *Elements* (*15-Noded*).
- Keep the default units and constants and set the model dimensions to x_{min} = 0, x_{max} = 30, y_{min} = 0 and y_{max} = 18.

13.1.1 DEFINITION OF SOIL STRATIGRAPHY

The subsoil is divided into an 11 m thick clay layer and a 7 m thick sand layer. The phreatic level is assumed to be at the ground surface. Hydrostatic pore pressures are generated in the whole geometry according to this phreatic line. To define the soil stratigraphy:

- Create a borehole at x = 0.
- Create two soil layers extending from y = 18.0 to y = 7.0 and from y = 7.0 to y = 0.0.
- Set the *Head* in the borehole at 18.0 m.

The clay layer is modelled with the Mohr-Coulomb model. The behaviour is considered to be *Undrained (B)*. An interface strength reduction factor is used to simulate the reduced friction along the pile shaft.

In order to model the non-linear deformations below the tip of the pile in a right way, the sand layer is modelled by means of the HS small model. Because of the fast loading process, the sand layer is also considered to behave undrained. The short interface in the sand layer does not represent soil-structure interaction. As a result, the interface strength reduction factor should be taken equal to unity (rigid).

- Create the material data sets according to the information given in Table 13.1.

Table 13.1 Material properties of the subsoil and pile

Parameter	Symbol	Clay	Sand	Pile	Unit
General					
Material model	Model	Mohr-Coulomb	HS small	Linear elastic	-
Type of behaviour	Type	Undrained (B)	Undrained (A)	Non-porous	-
Unit weight above phreatic line	γ_{unsat}	16	17	24	kN/m^3
Unit weight below phreatic line	γ_{sat}	18	20	-	kN/m^3
Parameters					
Young's modulus (constant)	E'	$5.0\cdot 10^3$	-	$3\cdot 10^7$	kN/m^2
Secant stiffness in standard drained triaxial test	E_{50}^{ref}	-	$5.0\cdot 10^4$	-	kN/m^2
Tangent stiffness for primary oedometer loading	E_{oed}^{ref}	-	$5.0\cdot 10^4$	-	kN/m^2
Unloading / reloading stiffness	E_{ur}^{ref}	-	$1.5\cdot 10^5$	-	kN/m^2
Power for stress-level dependency of stiffness	m	-	0.5	-	-
Poisson's ratio	ν'_{ur}	0.3	0.2	0.1	-
Cohesion	c'_{ref}	-	0	-	kN/m^2
Undrained shear strength	$s_{u,ref}$	5.0	-	-	kN/m^2
Friction angle	φ'	0	31.0	-	°
Dilatancy parameter	ψ	0	0	-	°
Shear strain at which $G_s = 0.722G_0$	$\gamma_{0.7}$	-	$1.0\cdot 10^{-4}$	-	-
Shear modulus at very small strains	G_0^{ref}	-	$1.2\cdot 10^5$	-	kN/m^2
Young's modulus inc.	E'_{inc}	$1.0\cdot 10^3$	-	-	kN/m^2
Reference level	y_{ref}	18	-	-	m
Undrained shear strength inc.	$s_{u,inc}$	3	-	-	kN/m^2
Reference level	y_{ref}	18	-	-	m
Interface					
Interface strength type	Type	Manual	Rigid	Rigid	-
Interface strength	R_{inter}	0.5	1.0	1.0	-
Initial					
K_0 determination	—	Automatic	Automatic	Automatic	-
Lateral earth pressure coefficient	$K_{0,x}$	0.5000	0.4850	0.5000	-

13.1.2 DEFINITION OF STRUCTURAL ELEMENTS

The pile is defined as a column of 0.2 m width. The *Interface* elements are placed along the pile to model the interaction between the pile and the soil. The interface should be extended to about half a meter into the sand layer (see Figure 13.2). Note that the interface should be defined only at the side of the soil. A proper modelling of the pile-soil interaction is important to include the material damping caused by the sliding of the soil along the pile during penetration and to allow for sufficient flexibility around the pile tip.

Hint: Use the *Zoom in* feature to create the pile and the interface.

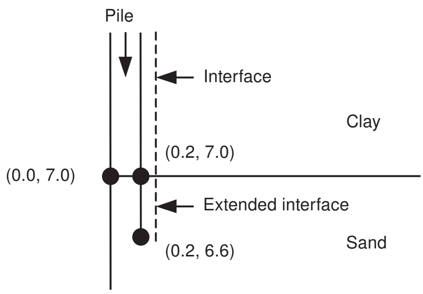

Figure 13.2 Extended interface

To define the concrete pile:

- Click the *Structures* tab to proceed with the input of structural elements in the *Structures* mode.
- Select the *Create polygon* feature in the side toolbar and click on (0.0 18.0), (0.2 18.0), (0.2 7.0) and (0.0 7.0).
- Create a negative interface to model the interaction of the pile with the surrounding soil by clicking on (0.2 6.6) and (0.2 18.0).

The pile is made of concrete, which is modelled by means of the linear elastic model considering non-porous behaviour (Table 13.1). In the beginning, the pile is not present, so initially the clay properties are also assigned to the pile cluster.

In order to model the driving force, a distributed unit load is created on top of the pile. To create a dynamic load:

- Define a distributed load by clicking on (0.0 18.0) and (0.2 18.0).
- The load components will be defined in the *Selection explorer*. Note that the static component of the load will not be used in this project. The program will neglect the static components of the load if it (static load) is not activated.
- Expand the *Dynamic load* subtree and specify a unit load in the gravity direction.
- Click the *Multiplier_y* drop down menu and click on the appearing plus button. The *Multipliers* window pops up and a new load multiplier is automatically added.
- Define a *Harmonic* signal with an *Amplitude* of 5000, a *Phase* of 0° and a *Frequency* of 50 Hz and as shown in Figure 13.3. During the pile driving phase, we

will only consider half a cycle (0.01 s) of this signal.

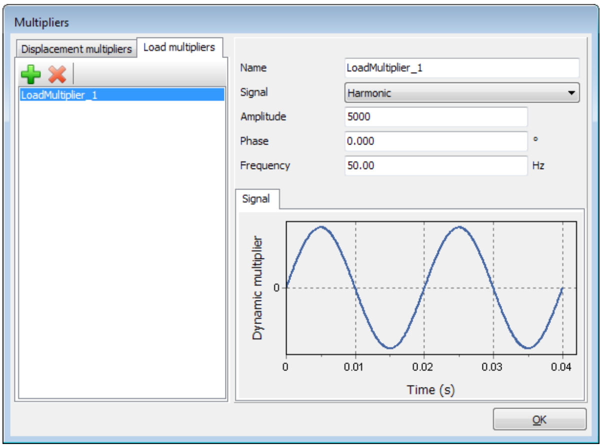

Figure 13.3 Definition of a *Harmonic* multiplier

Hint: Note that dynamic multipliers can be defined by right-clicking the *Dynamic multipliers* subtree under *Attributes library* in the *Model explorer*.

» Note that dynamic multipliers are attributes and as such it is possible to define them in all the program's modes.

The final geometry model is shown in Figure 13.4.

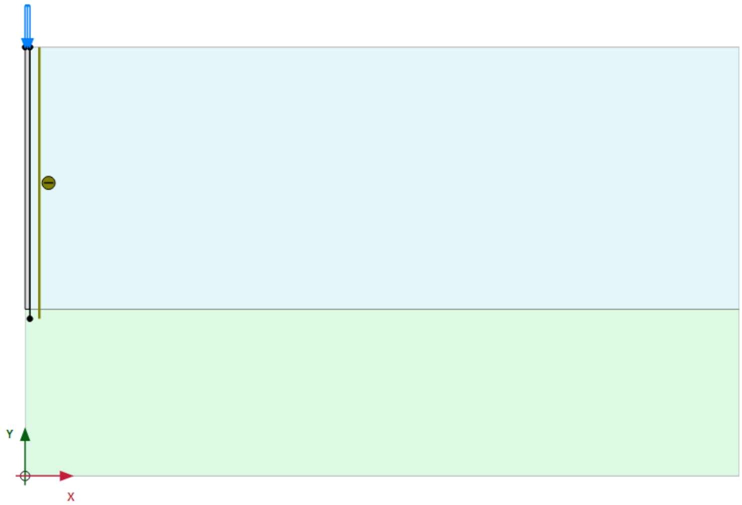

Figure 13.4 The geometry model

13.2 MESH GENERATION

- Proceed to the *Mesh* mode.
- Generate the mesh. Use the default option for the *Element distribution* parameter (*Medium*).
- View the generated mesh. The resulting mesh is shown in Figure 13.5.
- Click on the *Close* tab to close the Output program.

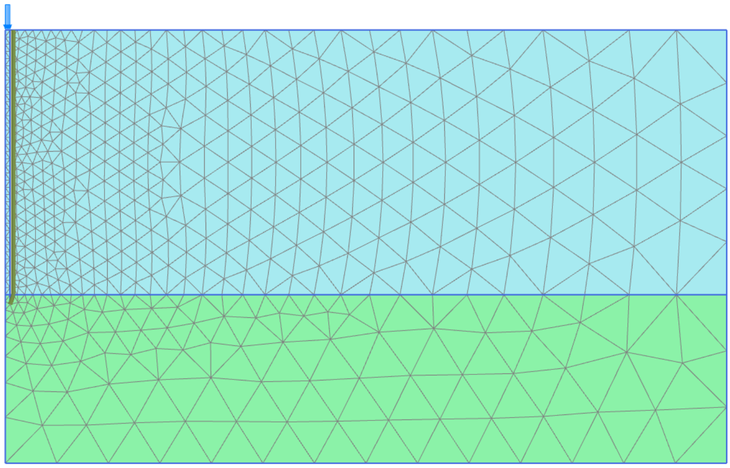

Figure 13.5 The generated mesh

13.3 CALCULATIONS

The calculation consists of 3 phases. In the Initial phase, the initial stress conditions are generated. In the Phase 1 the pile is created. In the Phase 2 the pile is subjected to a single stroke, which is simulated by activating half a harmonic cycle of load. In the Phase 3 the load is kept zero and the dynamic response of the pile and soil is analysed in time. The last two phases involve dynamic calculations.

Initial phase

Initial effective stresses are generated by the *K0 procedure*, using the default values. Note that in the initial situation the pile does not exist and that the clay properties should be assigned to the corresponding cluster. The phreatic level is assumed to be at the ground surface. Hydrostatic pore pressures are generated in the whole geometry according to this phreatic line.

Phase 1 - Pile activation

- Add a new calculation phase.
- In the *General* subtree in the *Phases* window, the *Plastic* option is selected as *Calculation type*.

- The *Staged construction* option is by default selected as *Loading type*.
- In the *Staged construction* mode assign the pile properties to the pile cluster.
- Activate the interface in the *Clay* layer. The model for the Phase 1 in the *Staged construction* mode is displayed in Figure 13.6.

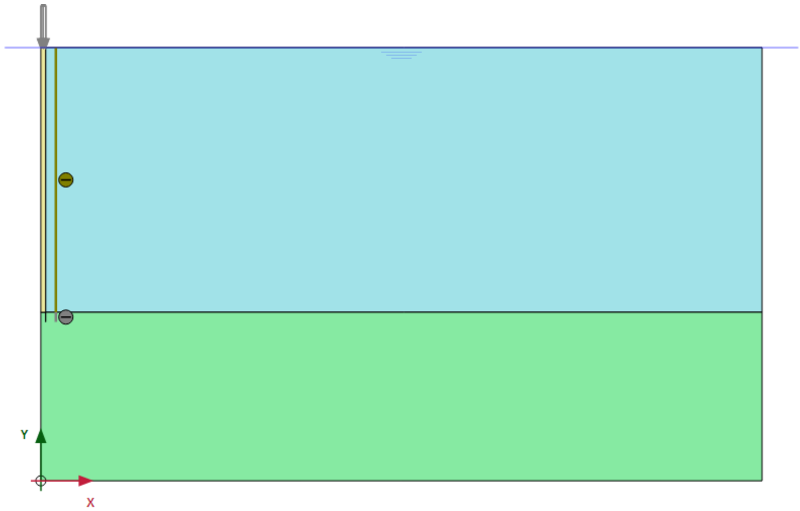

Figure 13.6 Configuration of Phase 1 in the *Staged construction* mode

Phase 2 - Pile driving

Add a new calculation phase.

- In the *General* subtree in the *Phases* window, select the *Dynamic* option as *Calculation type*.
- Set the *Dynamic time interval* to 0.01 s.
- In the *Deformation control parameters* subtree select *Reset displacements to zero*.
- In the *Staged construction* mode activate the dynamic component of the distributed load. The activated dynamic component of the load in *Selection explorer* is shown in Figure 13.7.
- Expand the *Dynamics* subtree under *Model conditions* in the *Model explorer*.
- Specify viscous boundaries at x_{max} and y_{min} (Figure 13.8).

The result of this phase is half a harmonic cycle of the external load. At the end of this phase, the load is back to zero.

Phase 3 - Fading

Add a new calculation phase.

- In the *General* subtree in the *Phases* window, select the *Dynamic* option as *Calculation type*.
- Set the *Dynamic time interval* to 0.19 s.

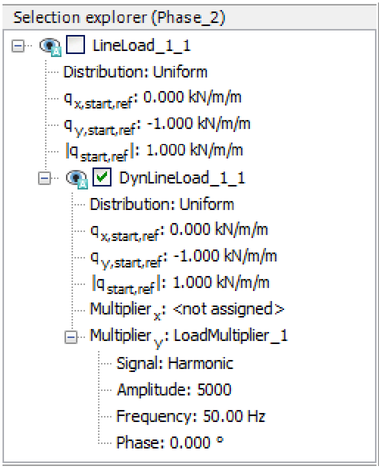

Figure 13.7 The dynamic load component in the *Selection explorer*

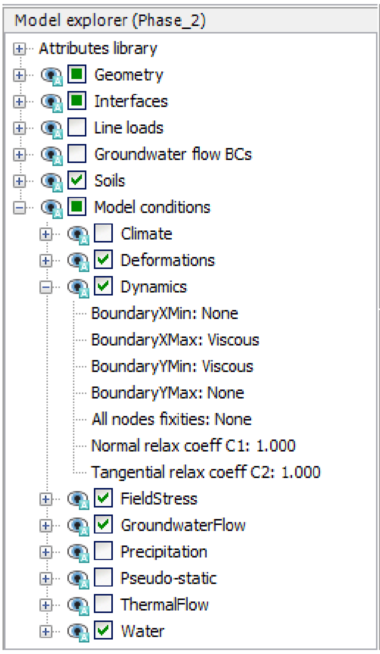

Figure 13.8 Boundary conditions for *Dynamic calculations*

- In the *Staged construction* mode de-activate the dynamic load.

Select a node at the top of the pile for load displacement curves.

Calculate the project.

Save the project.

13.4 RESULTS

Figure 13.9 shows the settlement of the pile (top point) versus time. From this figure the following observations can be made:

- The maximum vertical settlement of the pile top due to this single stroke is about 13 mm. However, the final settlement is almost 10 mm.
- Most of the settlement occurs in phase 3 after the stroke has ended. This is due to the fact that the compression wave is still propagating downwards in the pile, causing additional settlements.
- Despite the absence of Rayleigh damping, the vibration of the pile is damped due to soil plasticity and the fact that wave energy is absorbed at the model boundaries.

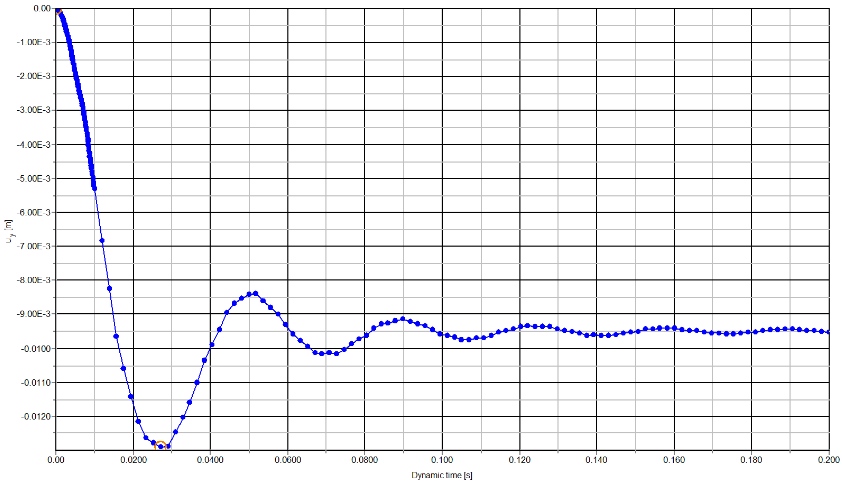

Figure 13.9 Pile settlement vs. time

When looking at the output of the second calculation phase (t = 0.01 s, i.e. just after the stroke), it can be seen that large excess pore pressures occur very locally around the pile tip. This reduces the shear strength of the soil and contributes to the penetration of the pile into the sand layer. The excess pore pressures remain also in the third phase since consolidation is not considered.

Figure 13.10 shows the shear stresses in the interface elements at t = 0.01 s. The plot shows that the maximum shear stress is reached all along the pile, which indicates that the soil is sliding along the pile.

When looking at the deformed mesh of the last calculation phase (t = 0.2 s), it can also be seen that the final settlement of the pile is about 10 mm. In order to see the whole dynamic process it is suggested to use the option *Create Animation* to view a 'movie' of the deformed mesh in time. You may notice that the first part of the animation is slower than the second part.

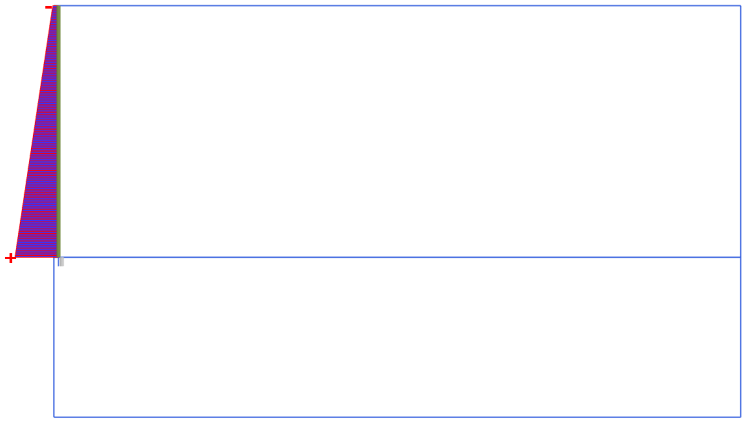

Figure 13.10 Maximum shear stresses in the interface at t = 0.01 s.