SOLPLAN

FOUNDATION ANALYSIS SOFTWARE

PILE GROUP ANALYSIS · THREE-DIMENSIONAL, NONLINEAR

# Solgroup

## User Manual

Building, running and reporting three-dimensional pile group analyses with Solgroup.

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| SPL-SG-001 | Solgroup — End-User Licence Agreement | Terms under which Solgroup is licensed to its users. |
| SPL-SG-002 | Solgroup — User Manual | Building, running and reporting three-dimensional pile group analyses with Solgroup. |
| SPL-SG-003 | Solgroup — Technical Reference | Pile-group mechanics, soil-response curves, cap models, numerical solution and verification. |
| SPL-SG-004 | Solgroup — Release Notes | Scope, requirements and known limitations of release 1.0.8. |
| SPL-SG-005 | Solgroup — Third-Party Software Notices | Open-source components distributed with Solgroup and their licences. |

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# 1 Introduction

## 1.1 Purpose and scope of this manual

This manual explains how to use Solgroup 1.0.8: how to lay out a group of piles and its cap, how to describe the piles and the ground, how to apply loads, how to run the analysis, and how to read, check and report the results. It is written for geotechnical and structural engineers who design pile foundations. It assumes familiarity with the analysis of laterally loaded piles, but not with Solgroup.

The engineering model, the soil-response curves, the numerical solution and the verification of the program are described in the Technical Reference (SPL-SG-003). This manual refers to it where a choice in the program depends on the theory.

## 1.2 What Solgroup computes

Solgroup analyses a group of piles connected by a pile cap and loaded in three dimensions. It answers the questions that govern the design of such a foundation:

- **Movement of the cap.** For each load case the program finds the three translations and three rotations of the cap that bring the cap into equilibrium with the forces exerted on it by the piles.
- **Distribution of the load.** It reports the axial force, the two shear forces, the two bending moments and the torque at the head of every pile, so that the most heavily loaded piles can be identified.
- **Response along each pile.** It reports the deflection, slope, bending moment, shear force, axial force and soil reaction along every pile, with the depth and value of the maximum moment.

Each pile is a beam-column supported by nonlinear soil springs: lateral p-y curves along the pile, axial load–settlement curves along the shaft and at the tip, and torsional curves. The cap is either rigid, with six degrees of freedom, or flexible, represented by a mesh of plate elements. The soil can also move horizontally and load the piles (free-field soil movement). Two special analyses complete the program: a pushover of the group under increasing load, and the stiffness of the foundation for use in a structural model.

## 1.3 Conventions used in this manual

**Table 1.1 — Typographic conventions**

| Convention | Meaning |
|---|---|
| **Define ▸ Load Cases…** | a menu command, a button or a field in the program |
| C:\Program Files\Solplan | a file, a folder or an address |
| F5 | a key or a key combination |
| *p*, *y*, *t*, *z* | a symbol of the Technical Reference |

The figures show Solgroup with SI units. Notes marked as such contain information that prevents an error or explains a result that may otherwise look surprising.

## 1.4 Documentation set

**Table 1.2 — Solgroup documents**

| No. | Title | Use |
|---|---|---|
| SPL-SG-001 | End-User Licence Agreement | Terms of use, licence and session rules |
| SPL-SG-002 | User Manual | This document |
| SPL-SG-003 | Technical Reference | Pile and cap models, soil curves, numerical method, verification |
| SPL-SG-004 | Release Notes | Content of the release, requirements, known limitations |
| SPL-SG-005 | Third-Party Software Notices | Open-source components and their licences |

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# 2 Installation, licence and start-up

## 2.1 Requirements

Solgroup runs on 64-bit Windows 10 or Windows 11. The minimum and recommended configurations are listed in the Release Notes (SPL-SG-004). A display of at least 1280 × 720 pixels is needed so that every data window fits on the screen. The analyses of the piles of a group run in parallel; a processor with four or more cores shortens the run of a large group.

## 2.2 Installing

Install Solgroup with the Setup program supplied by Solplan (Solgroup-1.0.8-Setup.exe). Setup needs administrator rights and installs the program into C:\Program Files\Solplan\Solgroup. No separate Python installation is needed. Setup offers two options: to open .ggp project files with Solgroup (on by default) and to create a desktop shortcut (off by default). The documentation is installed in the docs folder of the installation.

## 2.3 Licence and sign-in

Use of Solgroup is governed by the End-User Licence Agreement (SPL-SG-001). A Solgroup licence is separate from a licence of another Solplan program. The rules that affect daily work are these:

1. Each user signs in inside Solgroup with a personal solplan.id account: the e-mail address and password registered at solplan.id, or **Continue with Google**, which opens the browser to sign in there and confirm a short code. When the account holds more than one Solgroup licence, Solgroup asks which one to use.
2. An account can be signed in on one computer at a time. Signing in on a second computer ends the session on the first one; the first computer offers to save open work before it closes.
3. A multi-seat (Team) licence lets as many members work at the same time as it has seats; each seat admits up to five members.
4. Solgroup checks the licence every few minutes while it runs. If the licence server cannot be reached, it warns and tries again after three minutes; after a second failure it offers to save open work and closes.
5. To work without a connection, borrow the licence beforehand in **Help ▸ Licence…** for 1 to 30 days (never beyond the end of the licence). Return it there when you are back on-line.
6. Changing the computer date or time, or using tools that misrepresent it, is not permitted. When Solgroup detects an inconsistency it asks for an on-line validation; it never deletes or changes project files.

**Table 2.1 — Licence types**

| Type | Who uses it | What differs |
|---|---|---|
| Personal | one user | full use |
| Team | members of an organisation, five per seat | full use; as many users at a time as seats |
| Academic | a university, per campus: any number of users who sign in with an e-mail address of the university | teaching and non-commercial research; reports and exported images are marked “Student version” |
| Trial | anyone, seven days, once per program for each account and computer | results can be viewed and projects saved, but nothing can be exported, printed or copied |

Licences and trials are managed under **Account ▸ Licences** at solplan.id. The type of the licence in use is shown on the right of the status bar.

**Help ▸ Licence…** shows the **Account** that is signed in and the **Licence** in use with its end date (Figure 2.1). While a session is active it offers borrowing the licence for work without a connection and returning it; **Manage account…** opens the account page at solplan.id, and **Sign out** ends the session on this computer.

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If the account that is signed in has no active Solgroup licence, Solgroup says so at start-up and offers **My licences** (the licence page of the account, where a trial is started or a licence is bought), **Check again**, **Sign out** (to sign in with a different account) and **Close**. When the account holds more than one licence, **Use another account** in the licence choice signs out in the same way. Signing out of the website does not sign out the program.

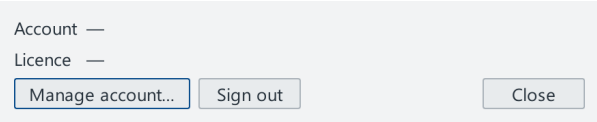



**Figure 2.1 —** Licence, before signing in

**NOTE** Project files are always stored on your own computer. The licence service receives account and session data only, never project data (EULA, clause 10).

## 2.4 Starting the program

Start Solgroup from the Start menu (**Solplan ▸ Solgroup**) or by double-clicking a .ggp file. After the start screen, Solgroup asks you to sign in if no valid sign-in is stored, and then offers the templates of Chapter 4 for a new model. **Cancel** in that window starts a blank model with a grid only.

## 2.5 Files and folders

**Table 2.2 — Files and folders used by Solgroup**

| File or folder | Content |
|---|---|
| `*.ggp` | Project. Compressed JSON text with the complete input, but no results: results are recomputed when the project is analysed. |
| `*.autosave.ggp` | Recovery copy written while a model is edited. After an interruption, Solgroup offers to restore it the next time it starts. |
| `%APPDATA%\Geostruktur\Solgroup` | Recovery copies of unnamed models and the folder logs with the diagnostic log. |

Saving is atomic: Solgroup writes a temporary file and replaces the previous file only when the write has succeeded. An interrupted save therefore never damages the existing project. When you close a project with unsaved changes, Solgroup asks whether to save them.

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# 3 The Solgroup window

Figure 3.1 shows the main window with a rectangular group in the plan view and in a 3D view. Its parts are:

- **Menu bar and tool bars** with every command. The **Main** tool bar holds the file, view and analysis commands; the **Draw & Select** tool bar holds the drawing and selection tools. **Options ▸ Reset Toolbar Layout** restores their positions.
- **View panes.** One, two or four panes (**View ▸ Pane Layout**), each showing the plan (**XY**), an elevation (**XZ**, **YZ**) or a 3D view. Each pane can show the model, the loads, the assigns or the results.
- **Model Explorer**: the objects of the model in a tree (piles, cap, sections, soil, loads, cases). A click selects the object; a double click opens its data.
- **Properties**: the data of the selected object, which can be edited directly.
- **Workflow**: the steps of an analysis in order, with the state of each step and a command to open it.
- **Messages**: the findings of Check Model and the messages of the last run. A click on a message selects the objects it concerns.
- **Command**: the Command Line, in a tab beside *Messages*, where the model is built, changed and analysed with text commands (Section 12.6).
- **Status bar**: the selection, the snap mode, the **Command** button that shows the Command Line, the units of the model (which can be changed there), the progress of a run and the licence type.

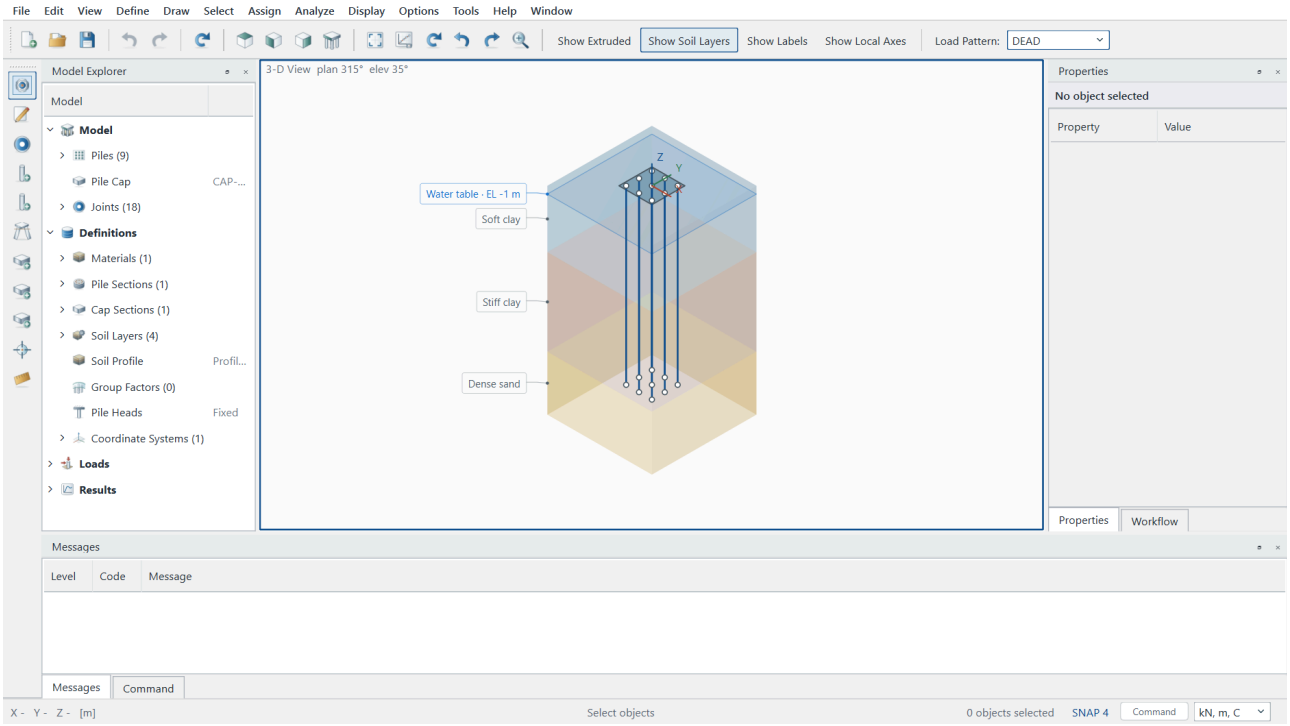



**Figure 3.1 —** Main window with a rectangular group

The panels are shown or hidden with the **Window** menu. Their arrangement is kept between sessions.

## 3.1 The workflow of an analysis

An analysis follows the order of the **Workflow** panel and of the menus:

1. **Lay out the piles and the cap**: from a template (Chapter 4) or by drawing (Chapter 8).
2. **Define the properties**: materials, pile and cap sections, soil layers and soil profile (**Define** menu, Chapter 9).

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3. **Assign** the properties to the piles and the cap: sections, head connection, batter, length, cap behaviour (**Assign** menu).
4. **Define the loading**: load patterns, load cases and load combinations, and assign the loads (Chapter 11).
5. **Set the analysis options, check the model and run** (**Analyze** menu, Chapter 12).
6. **Review and report the results** (**Display** menu, Chapter 13).

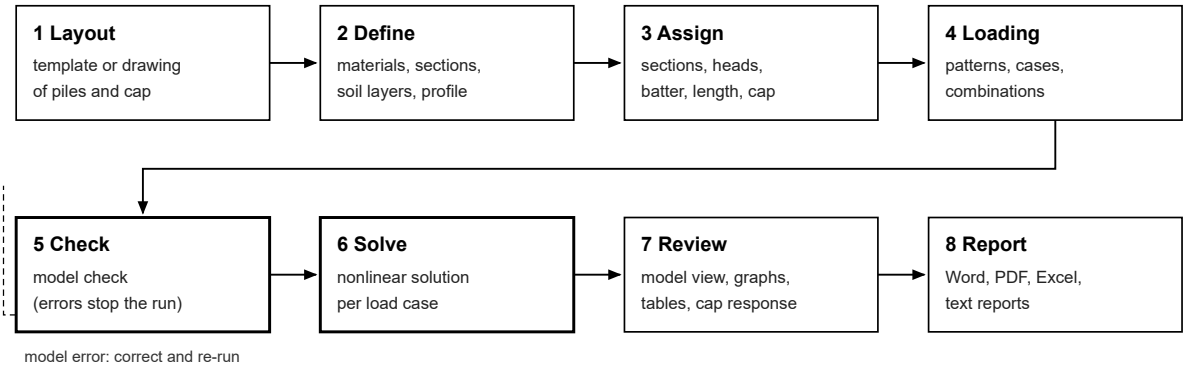



**Figure 3.2 —** Workflow of an analysis

## 3.2 The menus

The menu bar holds every command of the program; the most frequent ones are repeated on the tool bars. Table 3.1 gives the content of each menu, and the figures show the menus as they open, with a model that has results, so that the commands for results are available. A command followed by … opens a dialog; a triangle opens a submenu. The commands are described in the chapters that follow.

**Table 3.1 — Content of the menus**

| Menu | Content |
|---|---|
| File | new, open and save models; import and export of model tables and of a single-pile model; reports; printing |
| Edit | undo and redo; cut, copy, paste and delete; move, replicate, divide and join piles; labels; duplicate piles; shifting the piles, the soil elevations and the loading together |
| View | plan, elevations and 3D view; pane layout; zoom and rotation; what the panes show (grid, axes, extruded piles, soil layers, labels, local axes) and its transparency |
| Define | materials and sections, soil layers, profiles and curves, coordinate systems and grids, groups, load patterns, load cases and load combinations |
| Draw | drawing of piles, caps, special joints, reference points and lines; snap; labels; the grid; default draw properties |
| Select | selection by window, line or polygon, by property, by object type, by coordinates and by group |
| Assign | properties of piles and cap; joint, cap and pile loads; free-field soil movement; copying assigns between piles |
| Analyze | analysis options, cases to run, Check Model, Run Analysis and the analysis of several model files |
| Display | loads, assigns, tables, soil and moment-curvature curves, results in the canvas, result graphs, text reports and the Report Builder |
| Options | preferences, rebuilding the layout from a template, colours, display options and graph settings |
| Tools | model statistics and the folder of the model |
| Help | licence and version |
| Window | showing and hiding the panels and the tool bars |

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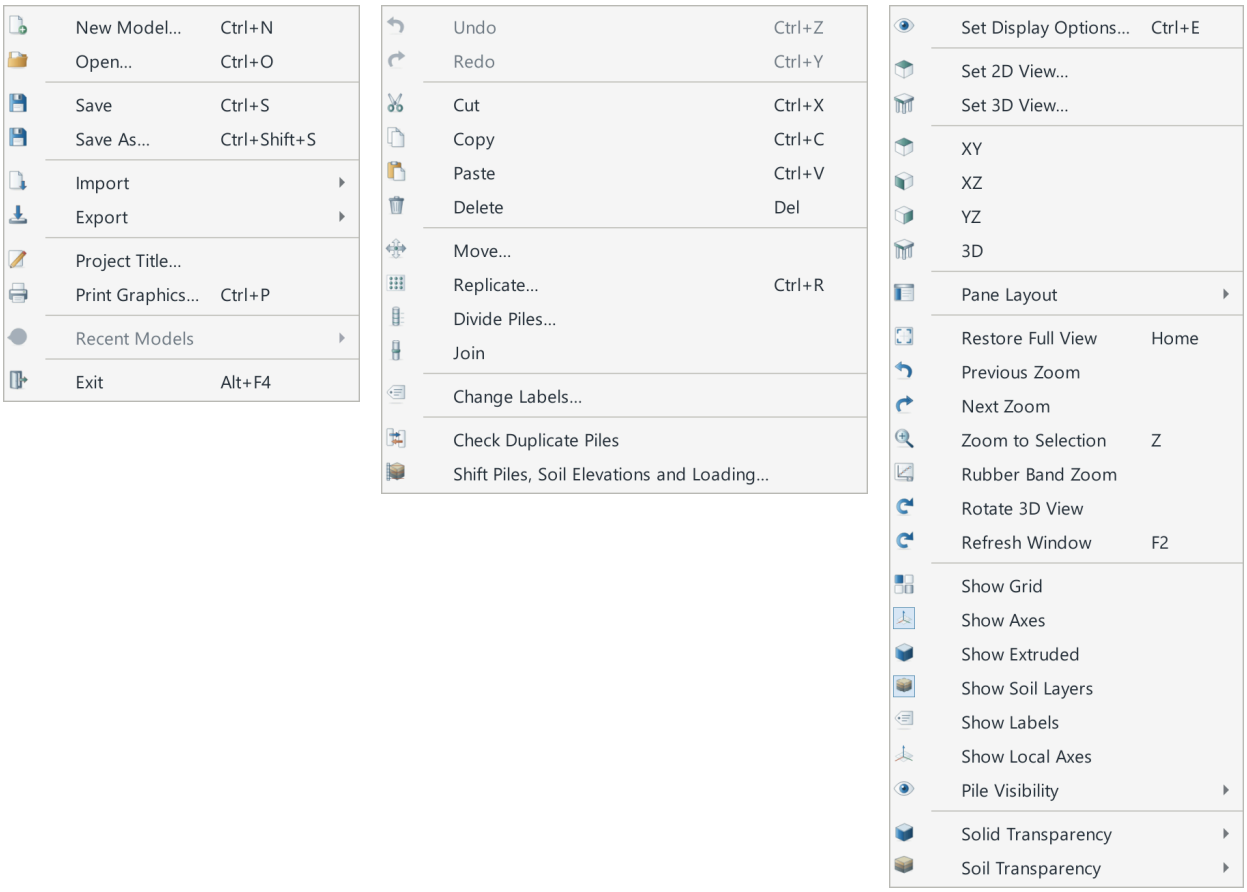



**Figure 3.3 —** The File, Edit and View menus

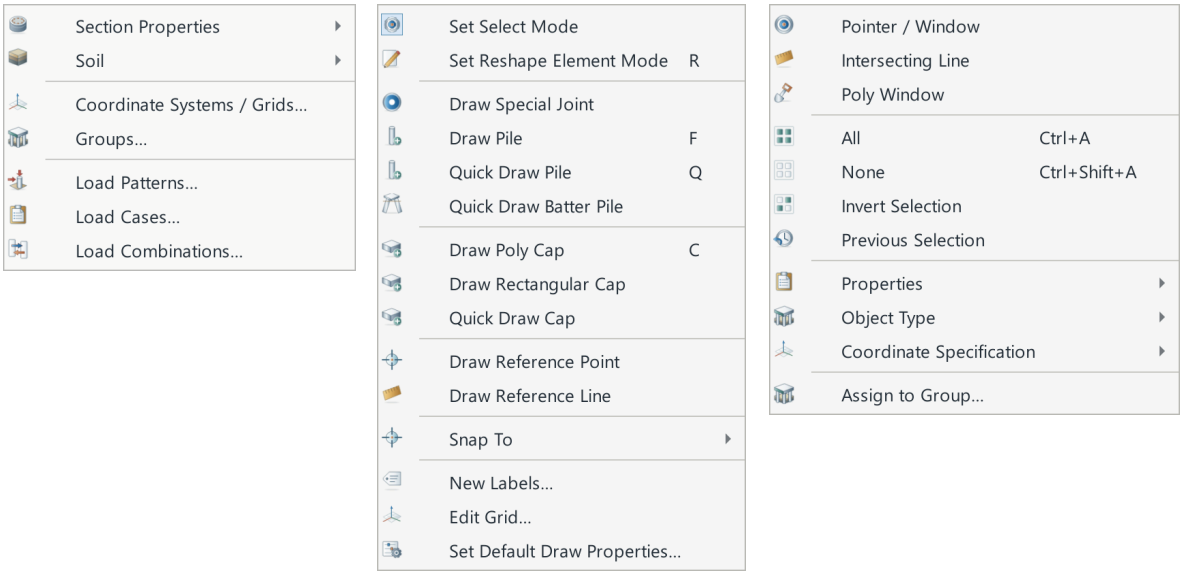



**Figure 3.4 —** The Define, Draw and Select menus

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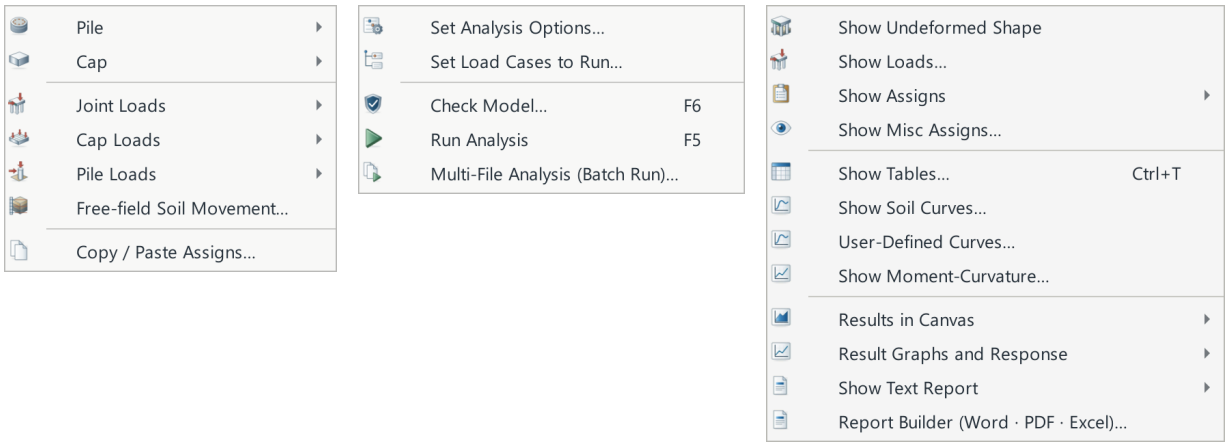



**Figure 3.5 —** The Assign, Analyze and Display menus

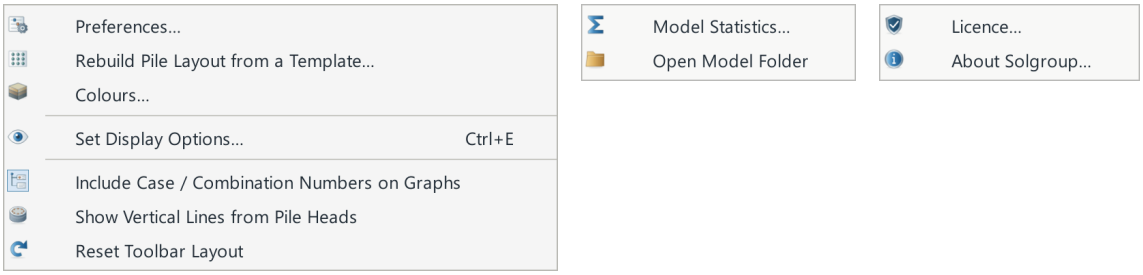



**Figure 3.6 —** The Options, Tools and Help menus

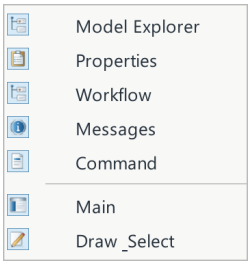



**Figure 3.7 —** The Window menus

## 3.3 The File menu

The **File** menu holds the commands for model files, data exchange and output:

**Table 3.2 — Commands of the File menu**

| Command | Use |
|---|---|
| New Model… (Ctrl+N) | starts a model from a template (Chapter 4) |
| Open… (Ctrl+O), Save (Ctrl+S), Save As… (Ctrl+Shift+S) | open and save model files (Section 2.5). Unsaved changes are offered for saving before another model is opened or the program is closed. |
| Import ▸ Model Tables (CSV / Excel)… | reads model tables edited in a spreadsheet back into the model; the values of matching rows are updated, and a summary lists the values updated, the rows matched, the rows not found and any problem (Section 9.12) |
| Import ▸ Solpile Model (.lpx)… | one Solpile pile becomes the section catalogue, the soil profile and one pile at the origin |
| Export ▸ Report Builder (Word · PDF · Excel)… | choose the report sections, preview them and export a Word, PDF or Excel report (Chapter 14) |
| Export ▸ Model Tables (CSV)…; Model Tables (Excel)… | every table of Show Tables, as CSV files or in one Excel workbook with one sheet per table, to be edited and read back |

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| Command | Use |
|---|---|
| Export ▸ Text Reports (.txt)… | the input echo, the output results and the summary results reports as three text files |
| Export ▸ View Bitmap… | saves the active view as a PNG or BMP image, by default named after the model in its folder |
| Project Title… | the title of the project, shown in the window title and the reports |
| Print Graphics… (Ctrl+P) | prints the active view |
| Exit (Alt+F4) | closes the program |

The export and print commands need a licence that allows output; with a trial licence they report that output is not available (Section 2.3).

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# 4 Starting a model from a template

**File ▸ New Model…** opens the template window (Figure 4.1). Choose a layout, enter its dimensions and confirm with **OK**. The preview on the right is updated as the values change. The templates are:

**Table 4.1 — Templates for a new model**

| Template | Layout and parameters (defaults) |
|---|---|
| Blank | a grid only, without objects |
| Grid Only | a grid with the number of bays and the bay spacing in X and Y (4 bays of 3 m each way) |
| Rectangular Pile Group | $n_x \times n_y$ piles at spacings $s_x$, $s_y$ (3 × 3 at 1.8 m), the most common case |
| Staggered / Zig-zag Group | rows of piles with alternate rows offset: piles per row, number of rows, spacing, row spacing and offset (3 × 3 at 1.8 m, offset 0.9 m) |
| Circular (Single Ring) | a ring of piles for a dolphin, a stack or a circular pier: radius, number of piles, start angle (3 m, 8 piles) |
| Circular (Multi Ring) | several rings: number of rings, radius of the first ring and increment of radius, piles in the first ring and increment of piles per ring (2 rings, 2 m + 2 m, 6 + 6 piles) |
| Radial Batter Group | a ring of piles battered outward or inward (3 m, 8 piles, outward) |
| Triangular Pile Group | three piles under a triangular cap with clipped corners, or more rows for larger groups (2 rows, spacing 1.8 m) |
| Line / Single Row Group | one row of piles: number, spacing and direction of the row (5 piles at 1.8 m) |
| Trestle / Bent (jetty) | a row of jetty bents whose outer pile pair is battered: number of bents, bent spacing, piles per bent, pile spacing within a bent, batter of the outer pair (4 bents at 6 m, 4 piles at 3 m, 9.46°); its pile heads and deck are 4 m above the seabed (ground at 0) and a new model puts the water 1 m below the deck |
| Custom from Table | X, Y, batter and length of each pile pasted from the clipboard or read from a CSV file |

Every template that creates piles also takes the **Pile length** (24 m), the **Pile head elevation** (0; 4 m for the jetty), the **Batter angle from vertical** (0) and the **Cap edge offset** (0.5 m), the distance from the outer piles to the edge of the cap; **Create cap automatically from pile extent** creates a cap that encloses the piles. For the rectangular group, the layout is given by the **Number of piles in X**, the **Number of piles in Y**, the **Spacing in X** and the **Spacing in Y**. The preview can show the layout in 3D or in Plan (X-Y).

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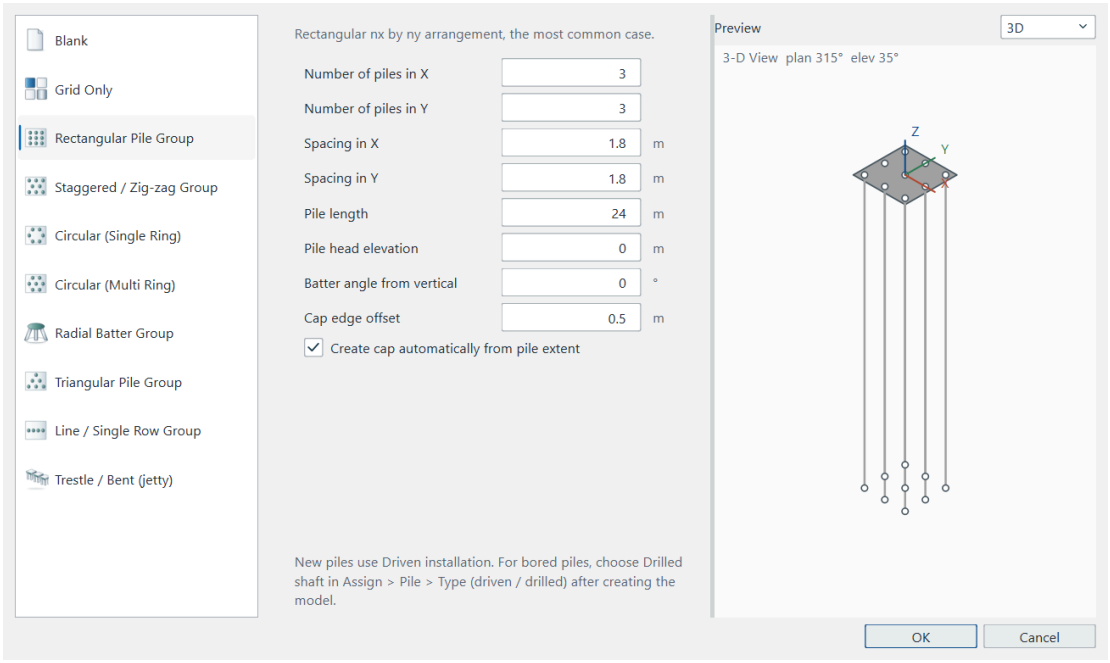



**Figure 4.1 —** Template window for a new model

A new model contains one concrete material, one soil layer over the whole soil profile, and no pile or cap section; the piles and the cap are drawn grey until a section is assigned. The steps of Chapter 9 and Chapter 10 complete it.

**Options ▸ Rebuild Pile Layout from a Template…** replaces the piles of an existing model by a new layout and keeps the soil, the sections and the load cases. Its window is the template window, with the pile section of the new piles chosen from the sections of the model.

**NOTE** A group can contain at most 2 500 piles. The template window rejects a layout above that limit before it is built.

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# 5 Units

Every value is entered and displayed in the units of the model. Six unit systems are available: kN, m; kgf, m; tonf, m; N, mm; kip, in; and kip, ft. The values are stored in kN and m, so that a change of units converts the display without loss. The units are chosen in **Options ▸ Preferences…** (**Display units**) and on the status bar, and they are saved with the model. Results are always shown in the units of the model.

The preferences also set the joint merge tolerance, the sign convention of moments in graphs, the autosave interval, the number of undo steps kept, and the snap tolerance and fine grid of the drawing tools (Section 15.1).

**NOTE** Switching between an SI-based unit system and a US customary one also switches the unit system in which the dimensional constants of the published soil relations are evaluated. The results can therefore differ slightly between the two, and they are cleared when the switch is made.

The same window sets the joint merge tolerance, the sign convention of moments in the reports, the autosave interval, the number of undo steps kept, and the snap tolerance and fine grid of the drawing tools.

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# 6 Getting started

This chapter builds and analyses a small pile group from start to finish, so that the main steps of every analysis are seen once in order. The model is a group of six bored piles of 0.8 m diameter, two in X and three in Y at 2.4 m spacing, 20 m long, under a rigid cap, in a layered soil of soft clay, stiff clay and dense sand. It carries a dead load and a live load at the cap, and the factored combination 1.2 D + 1.6 L is analysed. Each step names the command, the values to type and what the window shows afterwards. The dialogs themselves are described in detail in the following chapters; the references point to them. All numbers below were computed by Solgroup 1.0.8 with this model.

## 6.1 Step 1: lay out the piles

1. Choose **File** ▸ **New Model…** (Ctrl+N) and select *Rectangular Pile Group*.
2. Type Number of piles in X = 2, Number of piles in Y = 3, Spacing in X = 2.4 m, Spacing in Y = 2.4 m, Pile length = 20 m and Cap edge offset = 0.6 m. Leave the pile head elevation at 0, the batter at 0 and *Create cap automatically from pile extent* ticked, and click **OK**.

The window shows the six piles and the cap in a 3D view, inside the soil of the new model: one layer of soft clay, drawn transparently, which Step 3 divides into three (Figure 6.1). The piles and the cap are grey because a new model has no section yet. The **Model Explorer** on the left lists the objects and the definitions; the **Properties** panel on the right shows the data of the selected object.

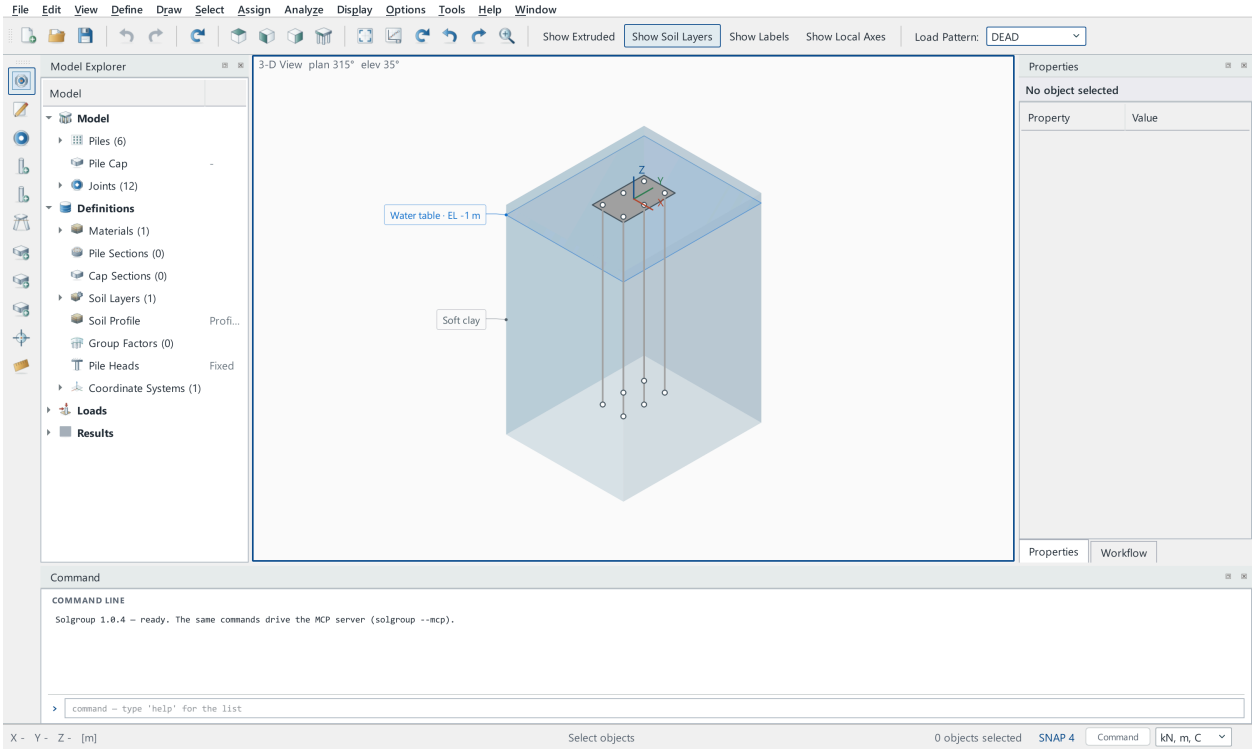



**Figure 6.1 —** The new model in the 3D view

Click **XY** on the tool bar (or **View** ▸ **XY**) to see the plan (Figure 6.2). The piles are labelled P1 to P6 from the corner with the smallest X and Y; the cap is centred on the global origin. The reference point of the cap loads is the centroid of the cap at its elevation, here the origin.

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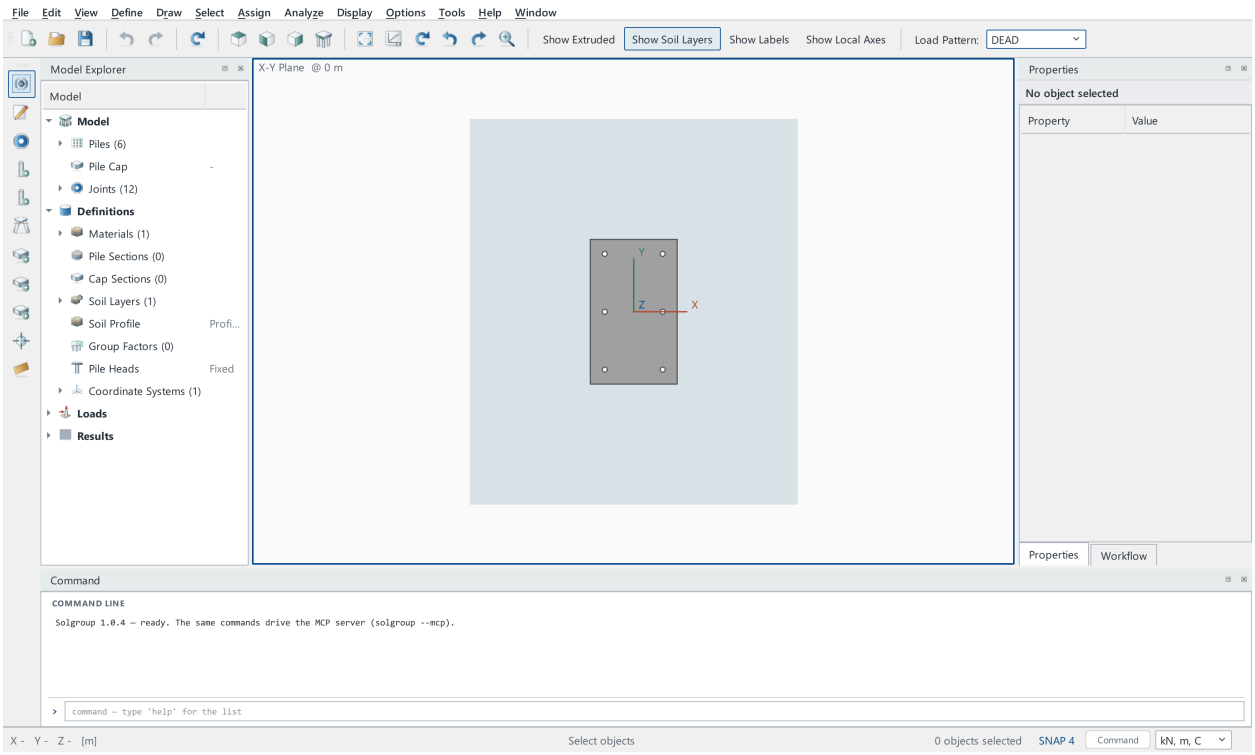



**Figure 6.2 —** Plan view with the pile labels

## 6.2 Step 2: define the pile and cap sections

A new model has one concrete material and no section: the piles and the cap stay grey, and **Check Model** reports them as errors, until a section is assigned to them. The bored piles are modelled with a nonlinear reinforced-concrete section, which needs a reinforcing steel:

1. **Define** ▸ **Section Properties** ▸ **Materials…**, **Add New…**: name *Rebar 420*, type Rebar, Yield strength Fy = 420 MPa (420 000 kN/m$^2$), Ultimate strength Fu = 525 MPa; **OK** (Section 9.2).
2. **Define** ▸ **Section Properties** ▸ **Pile Sections…**, **Add New…**: family Concrete, shape Round, **OK**. Name *Bored pile D800*; Dimensions: Outside diameter, D = 0.8 m; Material: the concrete and *Rebar 420*; Rebars: pattern Circle, 16 bars, cover 0.075 m; Nonlinear: *Enter values manually* with the thrusts 0, 1 500 and 3 000 kN, which span the axial forces expected in the piles (Section 9.3). Check the curves with **Show moment-curvature…** and click **OK** twice.
3. Select every pile (**Select** ▸ **All**, Ctrl+A). Choose **Assign** ▸ **Pile** ▸ **Section…**, select *Bored pile D800* and click **Apply**. Then **Assign** ▸ **Pile** ▸ **Type (driven / drilled)…**, select *Drilled shaft* and click **Apply**: the installation type selects the axial load-transfer curves of bored piles.
4. **Define** ▸ **Section Properties** ▸ **Cap Sections…**, **Add New…**: name *CAP-1000*, thickness 1.0 m, material the concrete; **OK** twice. Select the cap (**Select** ▸ **All** selects it with the piles, or click *Pile Cap* in the Model Explorer), then **Assign** ▸ **Cap** ▸ **Cap Section…**, select *CAP-1000* and click **OK**. For a rigid cap the thickness only places the cap and draws it; it matters for a flexible cap (Section 16.3).

**Display** ▸ **Show Assigns** ▸ **Pile Section** colours the piles by section, with a legend, so that the assignment can be checked at a glance (Figure 6.3); the piles are drawn as extruded solids with **Show Extruded**.

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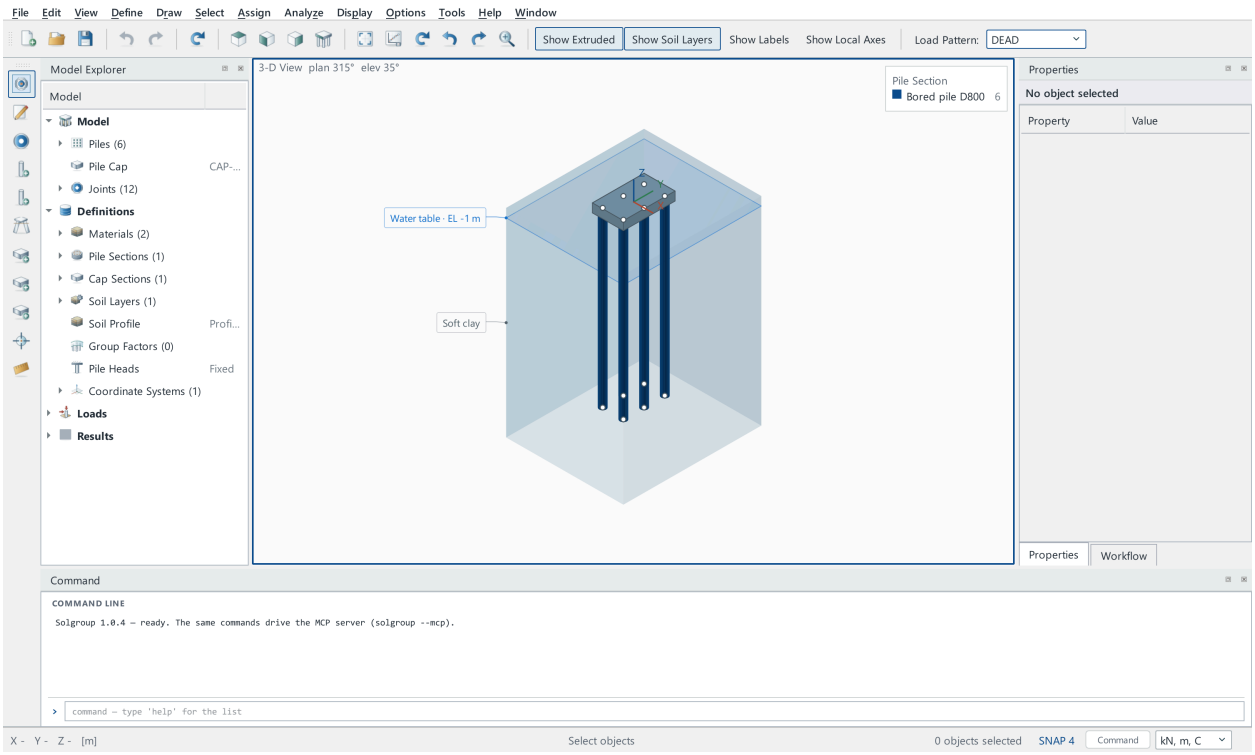



**Figure 6.3 —** Piles coloured by their section

## 6.3 Step 3: define the soil

A new model has one soil layer, *Soft clay* (Soft Clay (Matlock), unit weight 15 kN/m³ above and 16 kN/m³ below the water table, $c_u$ = 25 kPa, $\varepsilon_{50}$ = 0.02), over the whole profile from the ground surface at elevation 0 to −40 m, with the water table at −1 m. Two layers are added below it:

1. **Define** ▸ **Soil** ▸ **Soil Layers…**, **Add New…**: name *Stiff clay*, model Stiff Clay without Free Water, unit weight 17.5 / 19 kN/m³, $c_u$ = 120 kPa, $\varepsilon_{50}$ = 0.005; **OK**. **Add New…** again: name *Dense sand*, model API Sand (O'Neill), unit weight 18 / 20.5 kN/m³, $\varphi$ = 38°, $k$ = 61 000 kN/m³; **OK** twice. The preview of each layer draws its p-y curve (Section 9.5).
2. **Define** ▸ **Soil** ▸ **Soil Profile…**: three rows, soft clay from 0 to −8 m, stiff clay from −8 to −20 m and dense sand from −20 to −40 m; the water table stays at −1 m (Section 9.6). **OK**.

In the 3D view the layers are drawn around the piles with their names, and the water table is marked (Figure 6.4).

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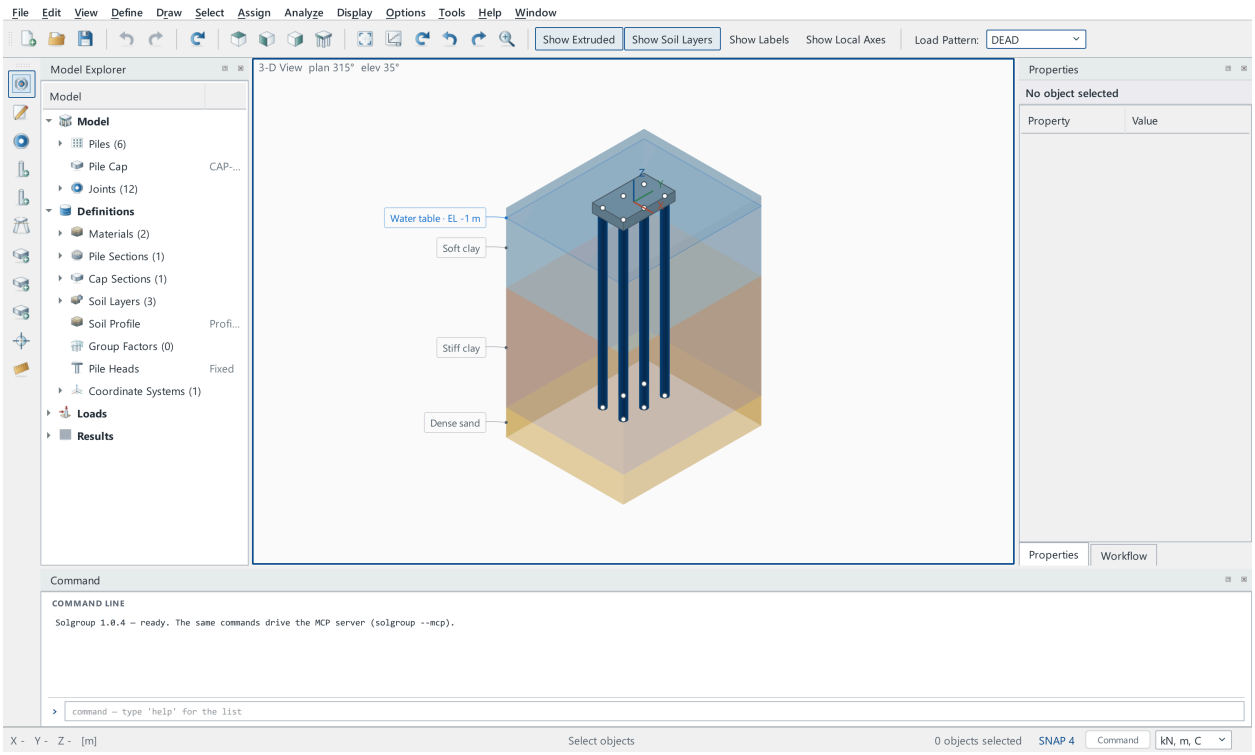



**Figure 6.4 —** The soil layers around the group

## 6.4 Step 4: apply the loads

A new model has the load patterns DEAD and LIVE. DEAD carries the self weight of the cap (self weight multiplier 1): the unit weight of its concrete times its volume, computed by Solgroup. Nothing else is typed into DEAD. The column, which stands 0.5 m off the middle of the cap in X, brings the weight of the floors, finishes and services above it: a superimposed dead load, in a pattern of its own.

1. **Define ▸ Load Patterns…**, **Add New…**: name *SDL*, type SUPERDEAD, self weight multiplier 0 (Section 11.1). SUPERDEAD takes the dead-load factors in the ACI 318 and ASCE 7 combinations and the DW factors under AASHTO LRFD.
2. The column is marked by a reference point: **View ▸ XY**, **Draw ▸ Draw Reference Point**, a click near the column, then its exact position in the Properties panel: X = 0.5 m, Y = 0.
3. Pick the reference point in the Model Explorer and choose **Assign ▸ Cap Loads ▸ Point Forces / Moments…** with *Apply at* = **Selected points / pile-head joints**. Pattern SDL: FZ = −4,500 kN (downward is negative); **Apply**. Apply clears the selection, so the point is picked again for the pattern LIVE: FX = 300 kN and FZ = −1,200 kN; **Apply** (Section 11.2).

No moment is typed. Acting 0.5 m off the centre, the 4,500 kN also turn the cap with 2,250 kN·m about Y: Solgroup takes it from the position of the load. **Display ▸ Show Loads…** with *All loads / all patterns* and *Show load values* draws the loads with their values at the reference point (Figure 6.5).

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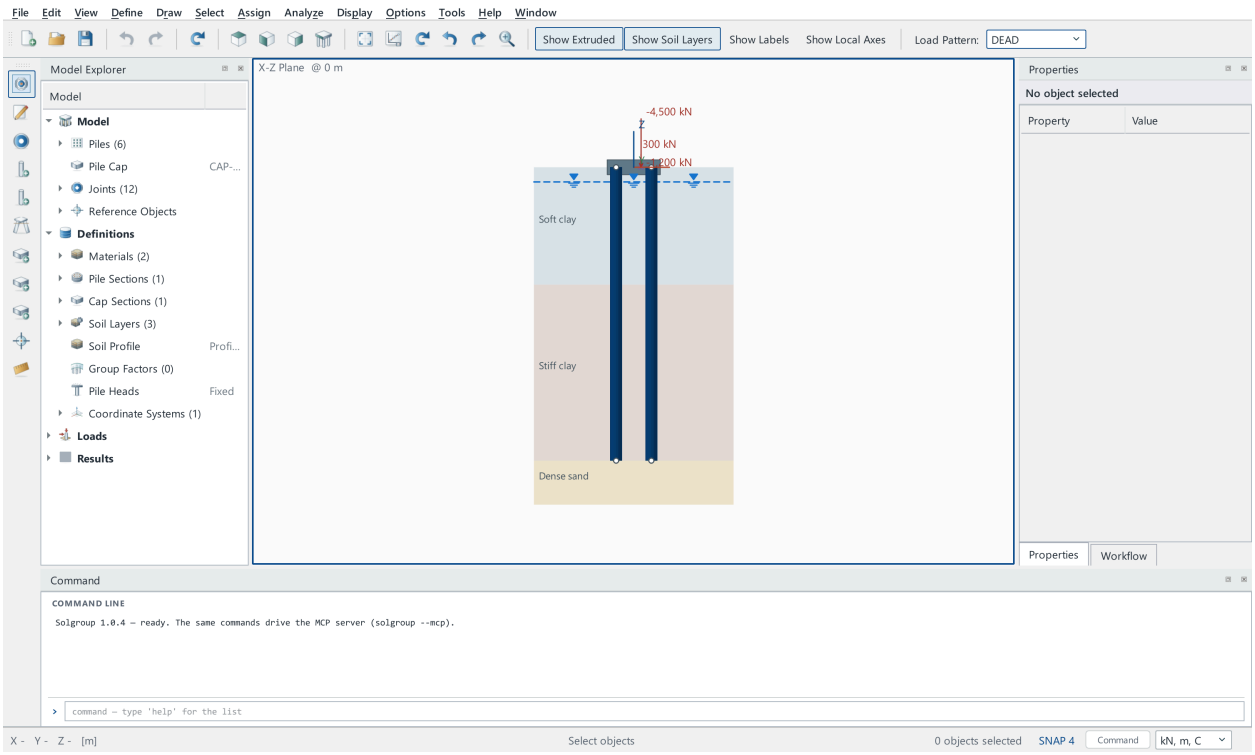



**Figure 6.5 —** The column loads of the patterns SDL and LIVE at the reference point, 0.5 m off the centre of the cap

## 6.5 Step 5: define the load cases and the combinations

1. **Define ▸ Load Cases…**, **Add One per Pattern**: one nonlinear static case per pattern, DEAD, SDL and LIVE, each with its pattern at a factor of 1 (Section 11.3). Click **OK**.
2. **Define ▸ Load Combinations…**, **Add Default Design Combos**: the combinations of ACI 318 for the pattern types of the model, *COMB1* = 1.4 DEAD + 1.4 SDL and *COMB2* = 1.2 DEAD + 1.2 SDL + 1.6 LIVE (Section 11.4). **Design Combo Options** switches to ASCE 7 or AASHTO LRFD. A Linear Add combination is analysed as one load set with the factored loads: because the soil is nonlinear, its result is not the sum of the results of its cases.
3. **Analyze ▸ Set Load Cases to Run…**: untick *Run all load cases*, which runs the load cases but not the combinations, keep the three cases ticked and tick both combinations (Section 12.2).

## 6.6 Step 6: check and run

**Analyze ▸ Check Model** (F6) lists its findings in the **Command** panel; here there is nothing to fix. **Analyze ▸ Run Analysis** (F5) runs the three cases and the two combinations. At the end a message reports the outcome and the **Command** panel gives a summary of each case (Figure 6.6): all five converged.

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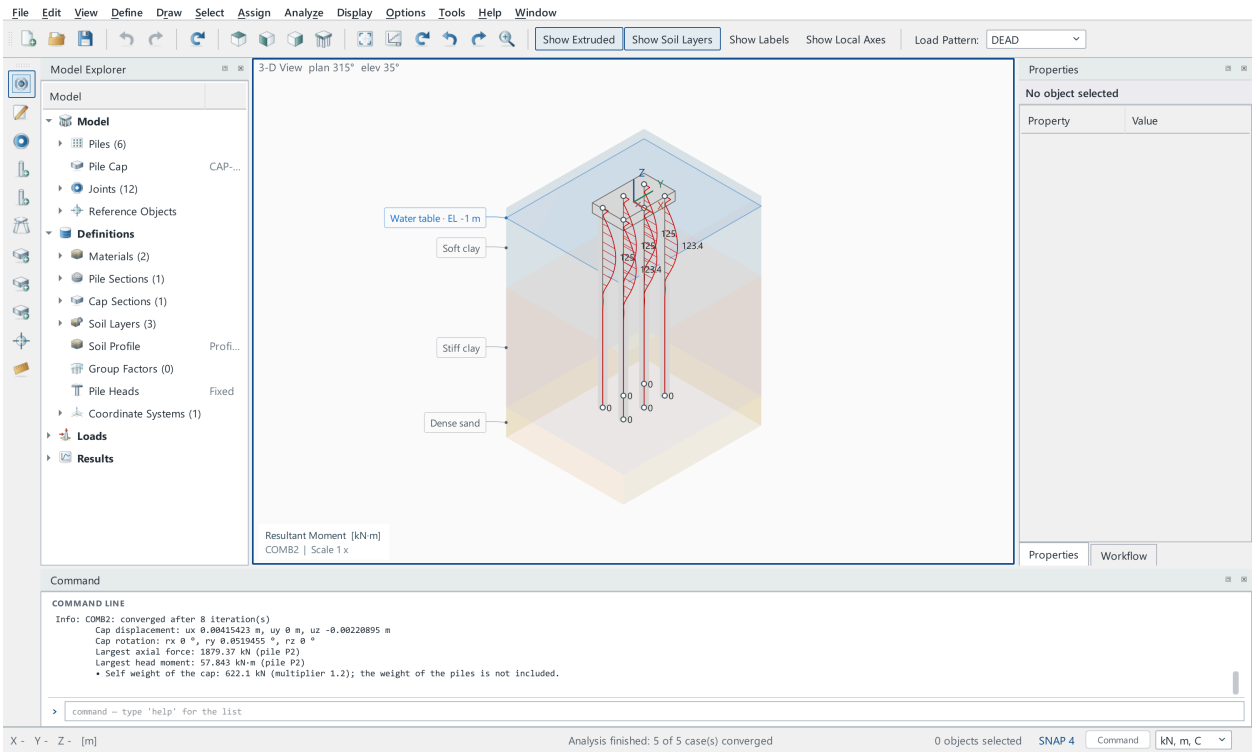



**Figure 6.6 —** After the run: a summary of each case in the Command panel

## 6.7 Step 7: review the results

**Display ▸ Results in Canvas ▸ Show Deformed Shape…** with the combination COMB2 draws the deflected group, magnified for visibility; in the X-Z elevation the cap moves in the direction of the horizontal load and rotates, and the piles bend near their heads (Figure 6.7).

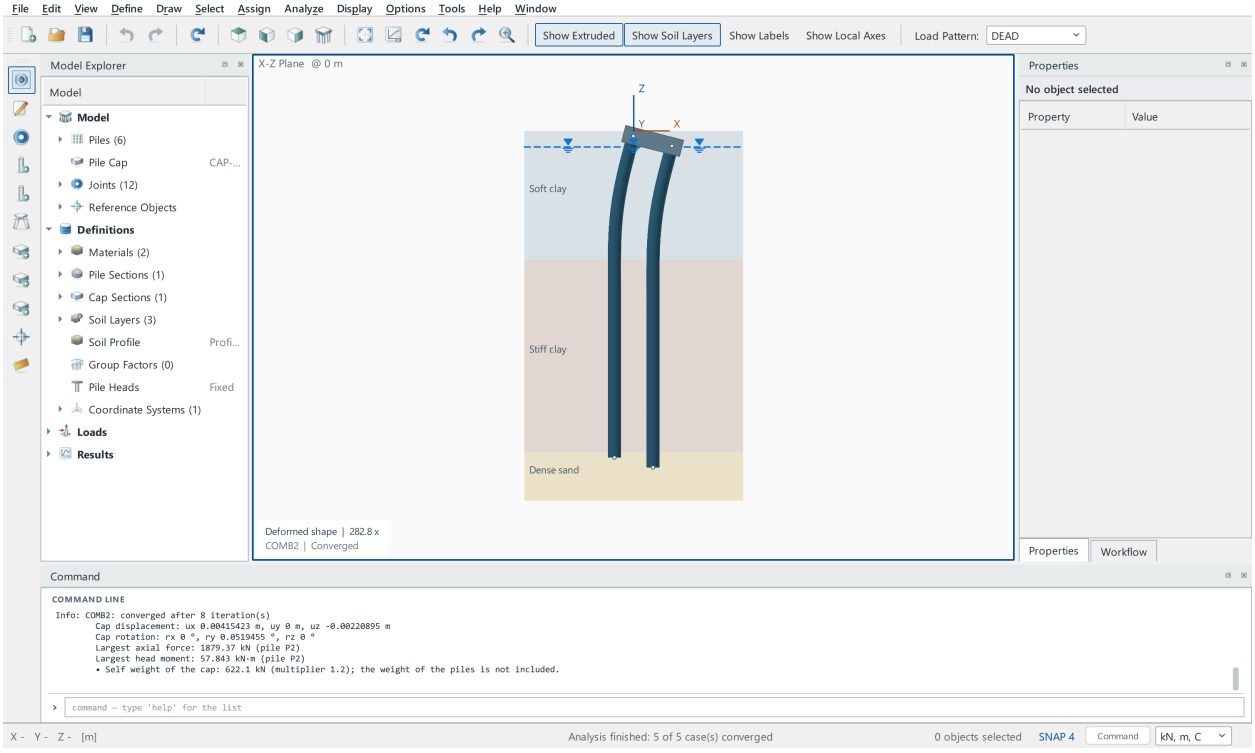



**Figure 6.7 —** Deformed shape of COMB2 in the X-Z plane

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Under the DEAD case alone, the weight of the cap at its centre, every pile takes the same 86.4 kN and no moment. For COMB2 the cap moves 4.15 mm horizontally and −2.21 mm vertically and rotates $0.907\times10^{-3}$ rad, mostly because the column is off centre (**Display ▸ Result Graphs and Response ▸ Show Cap Response…**). The axial forces of the piles range from 768 kN on the far side to 1,879 kN on the side of the column.

**Display ▸ Results in Canvas ▸ Force Diagrams in Canvas…** draws the bending moment along every pile (Figure 6.8). At the head of pile P1 the turn of the cap and the push of the live load act against each other, so the head moment is small, 55.8 kN·m; the moment changes sign at about 0.8 m below the head and reaches its largest value, 125 kN·m, at 4.2 m, in the soft clay, before it dies out further down. **Show Contour Plot…** colours the piles by the same quantity, with a colour scale (Figure 6.9).

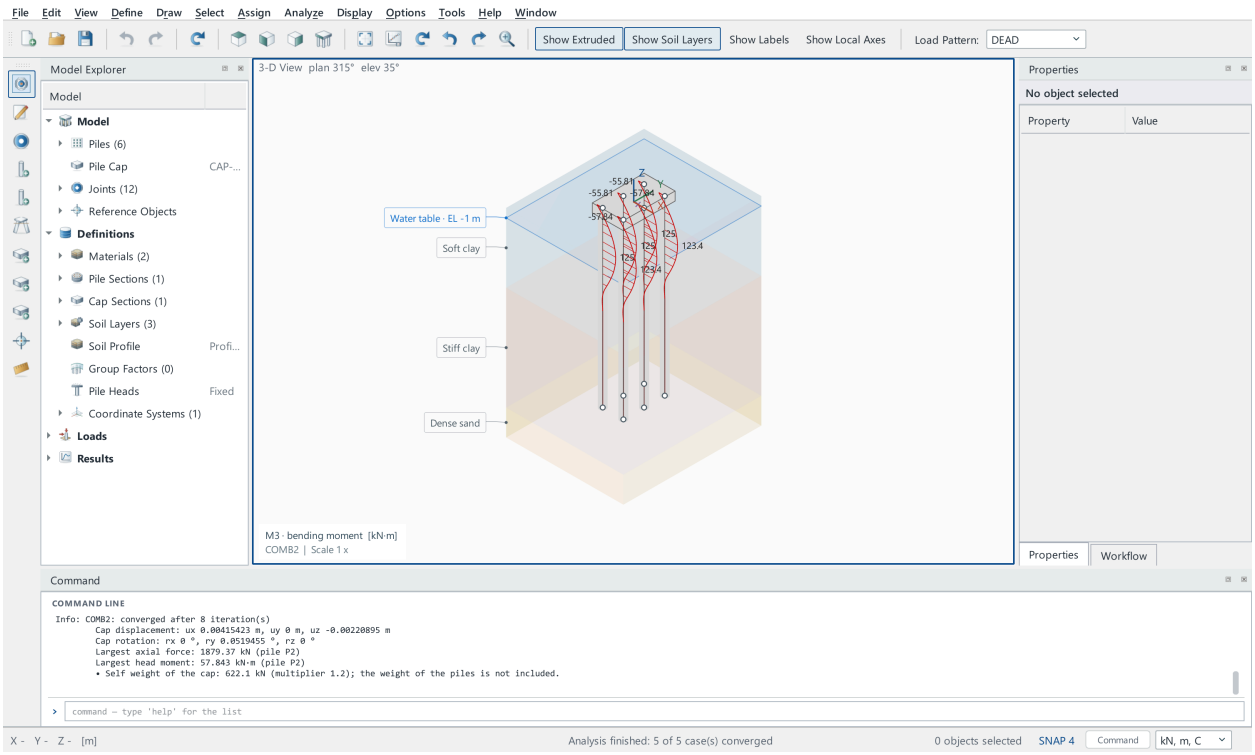



**Figure 6.8 —** Bending moment along the piles for COMB2

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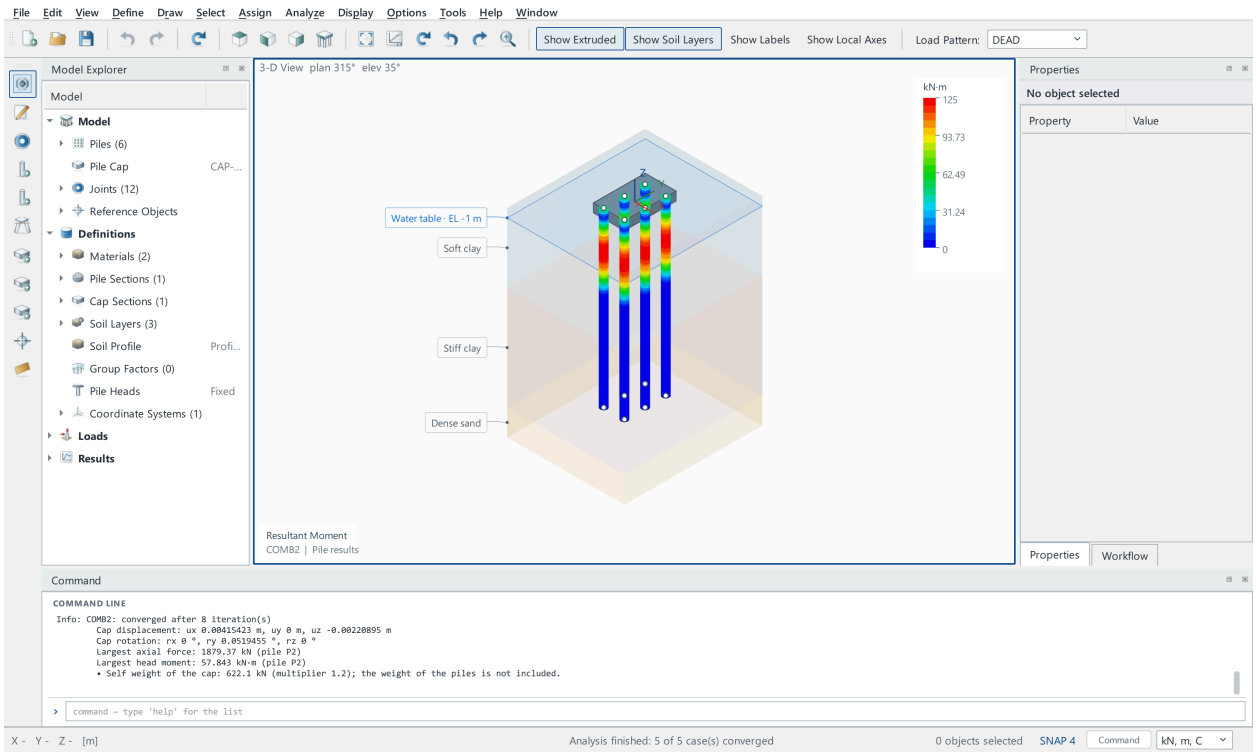



**Figure 6.9 —** Resultant moment as a contour plot

## 6.8 Step 8: check equilibrium and report

Before results are used, check that the pile-head forces balance the loads. For COMB2 the vertical load is 1.2 × (4,500 + 518.4) + 1.6 × 1,200 = 7,942.1 kN, the column loads plus the weight of the cap, and the sum of the axial forces of the piles is 7,942.1 kN; the horizontal load is 1.6 × 300 = 480 kN and the sum of the pile-head shears is 480.0 kN. The values are listed in the summary results (**Display ▸ Show Text Report ▸ Summary Results…**) and in the tables of **Display ▸ Show Tables…** (Section 13.5).

Finally, **File ▸ Export ▸ Report Builder (Word · PDF · Excel)…** assembles a report of the model and its results, and **File ▸ Save** (Ctrl+S) keeps the model in a .ggp file; the results are computed again by a run (Chapter 14).

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# 7 Tutorial: a jetty trestle on battered piles

This second tutorial builds a marine structure: three bents of a jetty trestle on steel pipe piles, the outer pair of each bent battered, standing in water above a soft seabed. It adds to the first tutorial the template of a trestle, a steel section, a soil profile with the water above the ground, a load pattern of its own for the berthing load, and the reading of the results of battered piles. The steps that are the same as in the first tutorial are given briefly; all numbers were computed by Solgroup 1.0.8 with this model.

## 7.1 Step 1: lay out the bents

1. Choose **File** ▸ **New Model…** and select *Trestle / Bent (jetty)*.
2. Type Number of bents = 3, Bent spacing = 6.0 m, Piles per bent = 4, Pile spacing within a bent = 3.0 m and Batter of outer pile pair = 9.46°, which is a batter of 1:6. Type Pile length = 32 m, Pile head elevation = 4.0 m and Cap edge offset = 0.8 m, and click **OK**.

The bents run in Y and the piles of a bent in X (Figure 7.1). The template numbers the piles bent by bent: P1 to P4 in the first bent, P5 to P8 in the second and P9 to P12 in the third. The outer piles of each bent, P1, P4, P5, P8, P9 and P12, are battered outward: the tips of P1, P5 and P9 point to −X, those of P4, P8 and P12 to +X. The X-Z elevation shows the batter (Figure 7.2); at this stage the soil is still that of a new model.

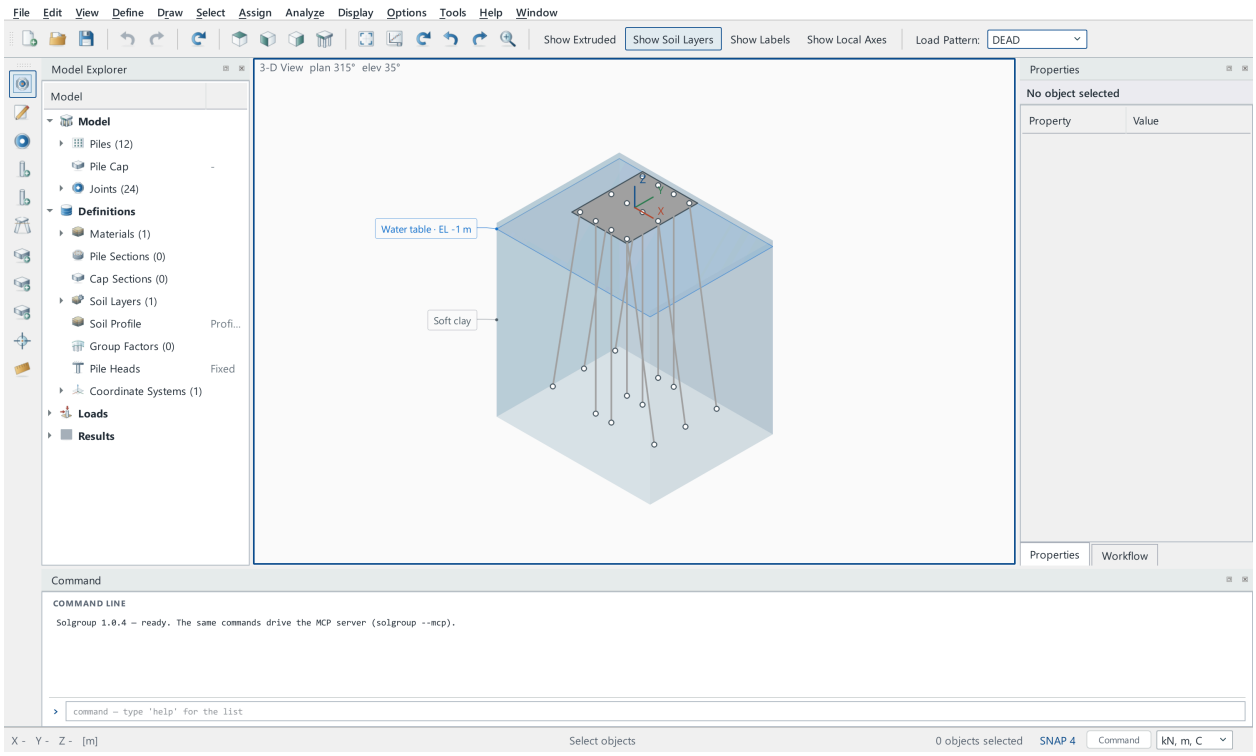



**Figure 7.1 —** The trestle in the 3D view

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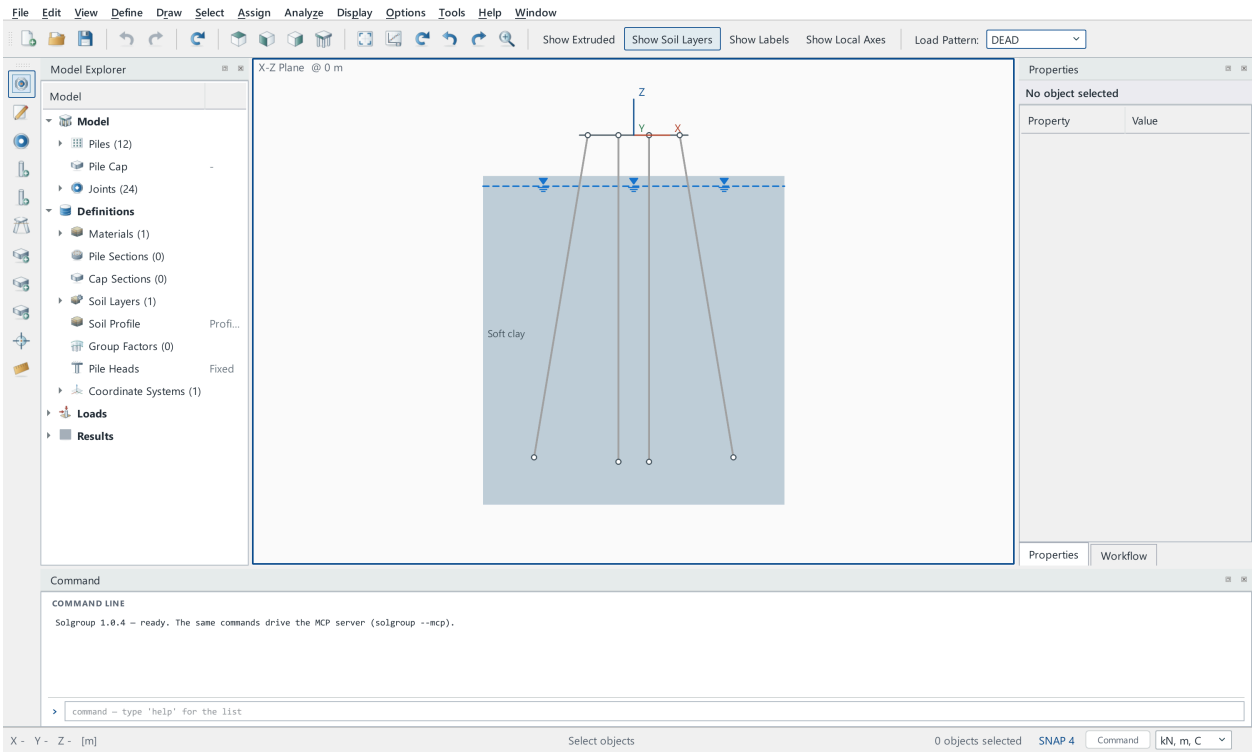



**Figure 7.2 —** X-Z elevation of a bent with the battered outer pair

## 7.2 Step 2: define the steel pipe

1. **Define** ▸ **Section Properties** ▸ **Materials…**, **Add New…**: name *Steel 355*, type Steel, modulus of elasticity 200 000 MPa, Poisson's ratio 0.3, Yield strength Fy = 355 MPa, Ultimate strength Fu = 490 MPa.
2. **Define** ▸ **Section Properties** ▸ **Pile Sections…**, **Add New…**: family Steel, shape Pipe. Name *Pipe 812x16*; Outside diameter, D = 0.812 m; Wall thickness, t = 0.016 m; material *Steel 355*; behaviour *Elastic (no yield)*. The area, the moments of inertia and the perimeter are computed from the dimensions.
3. Select all piles and assign the section with **Assign** ▸ **Pile** ▸ **Section…**. The piles are driven, which is the type of a new pile.
4. As in the first tutorial, the cap needs a section: **Define** ▸ **Section Properties** ▸ **Cap Sections…**, **Add New…**: name *CAP-1000*, thickness 1.0 m, the concrete; then select the cap and assign it with **Assign** ▸ **Cap** ▸ **Cap Section…**.

The piles are now drawn in the colour of their section (Figure 7.3).

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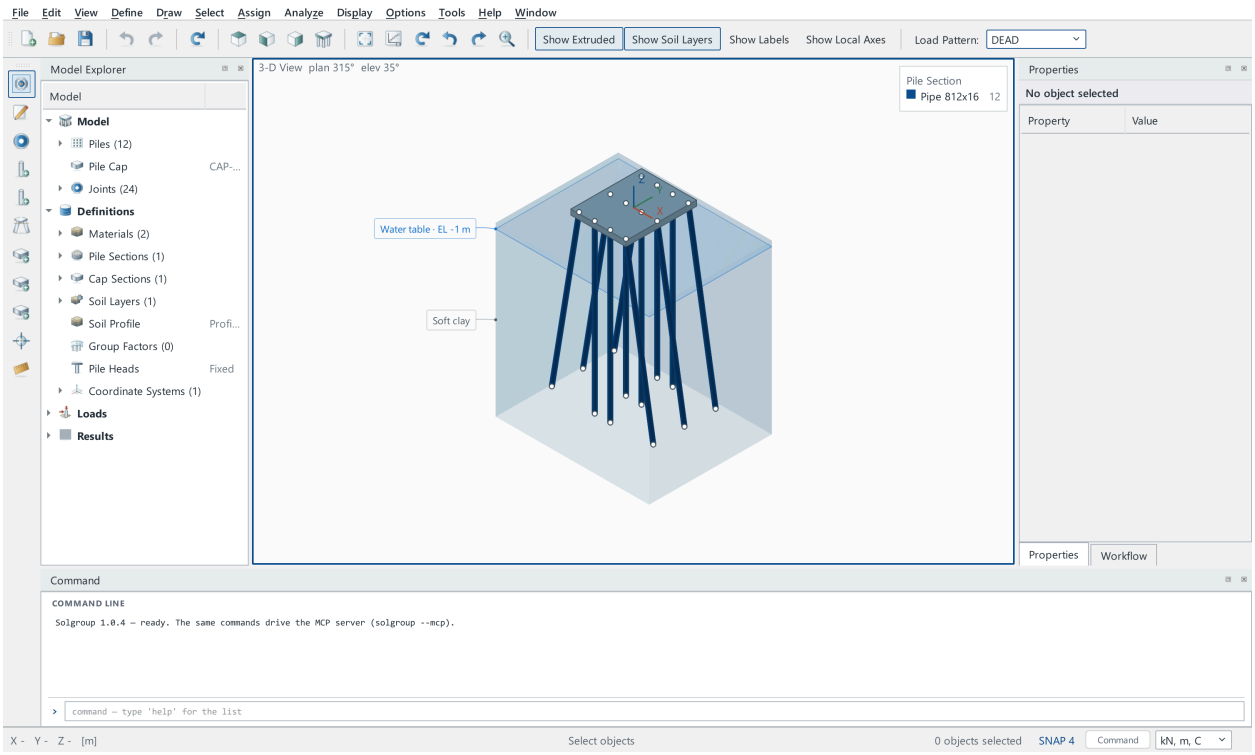



**Figure 7.3 —** The piles coloured by their section

## 7.3 Step 3: describe the seabed

The seabed is at elevation 0, with 6 m of soft clay over medium sand, and the water stands 3 m above the seabed. The soft clay is the layer of the new model, with $c_u$ = 25 kPa and $\varepsilon_{50}$ = 0.02; the medium sand is added:

1. **Define ▸ Soil ▸ Soil Layers…**, **Add New…**: name *Medium sand*, model Sand (Reese), unit weight 17 / 19.5 kN/m$^3$, $\varphi$ = 33° and $k$ = 24,400 kN/m$^3$ (Section 9.5).
2. In **Define ▸ Soil ▸ Soil Profile…** (Section 9.6) keep the Ground surface at 0 and type the Water table at +3.0 m, above the ground: the whole soil is then below water and its unit weight below water is used.
3. Set the rows to *Soft clay* from 0 to −6 m and *Medium sand* from −6 to −60 m.

The piles stand 4 m free above the seabed, through the water, which gives no lateral resistance (Figure 7.4).

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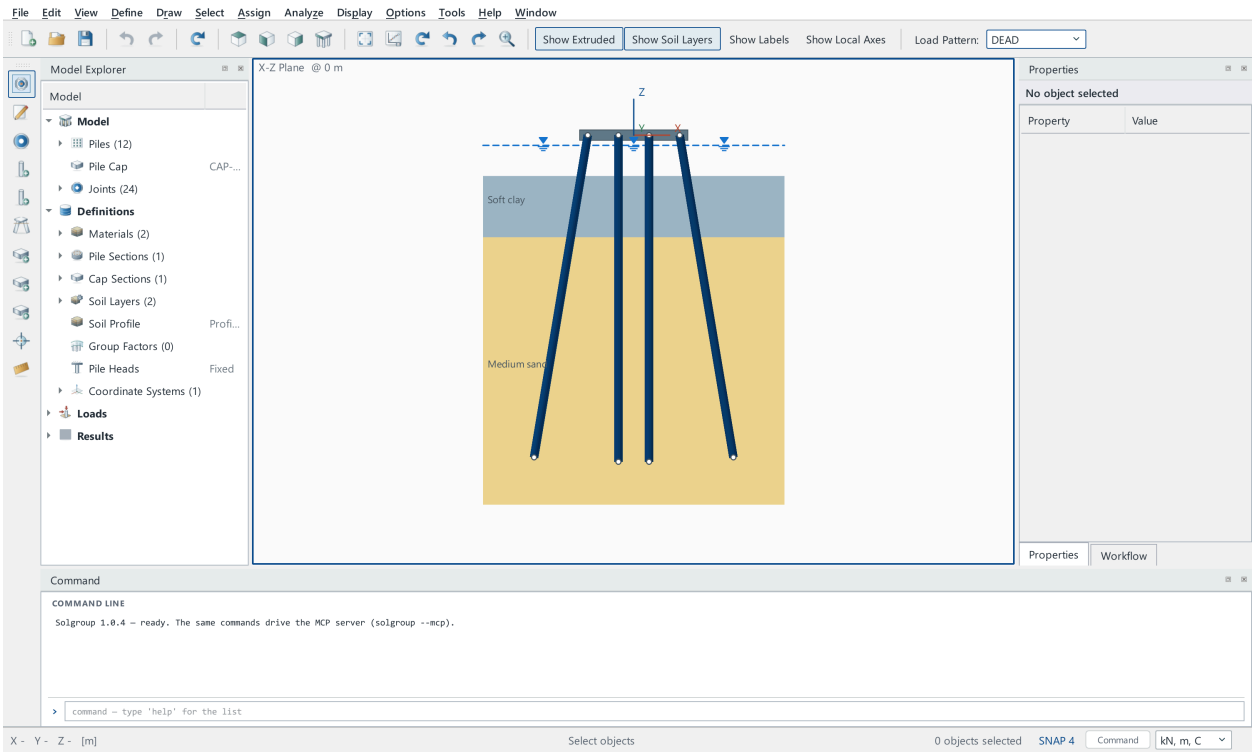



**Figure 7.4 —** The seabed profile with the water table above the ground

## 7.4 Step 4: berthing, mooring and current

The dead load needs nothing typed: the deck of this trestle is the cap itself, one metre of concrete, and its weight enters the pattern DEAD through the self weight multiplier of 1. A deck load typed as well would count the same concrete twice. The ship does not push on the middle of the cap: it hits a fender on the berthing face, and the mooring line pulls from a bollard on the same face. The current loads the piles themselves, in the water.

1. **Define ▸ Load Patterns…**, **Add New…**: *BERTH*, type BERTHING; *MOOR*, type MOORING; *CURRENT*, type CURRENT. Select LIVE, which this model does not use, and click **Delete**.
2. Two reference points (**View ▸ XY**, **Draw ▸ Draw Reference Point**, then the exact position, label and elevation in the Properties panel): *Fender* at (−5.3, 3.0, +4) m, on the minus X edge three metres along the jetty, and *Bollard* at (−5.3, −6.0, +4) m, at the first bent. A click can snap to a battered pile below the cap, so check the elevation.
3. Pick *Fender* in the Model Explorer, **Assign ▸ Cap Loads ▸ Point Forces / Moments…** at **Selected points / pile-head joints**: pattern BERTH, FX = 700 kN, across the jetty. Pick *Bollard*: pattern MOOR, FX = −400 kN. The fender lies three metres off the middle line of the cap, so the berthing force also twists the cap about Z with 2,100 kN·m: nothing to type, Solgroup takes it from the position.
4. Select all piles, **Assign ▸ Pile Loads ▸ Distributed Lateral Load…**: pattern CURRENT, Global X, from elevation +4 (the heads) to 0 (the seabed), 3.0 kN/m at the top and 1.5 kN/m at the bottom (Section 11.2).
5. **Define ▸ Load Cases…**, **Add One per Pattern**: DEAD, BERTH, MOOR and CURRENT. **Define ▸ Load Combinations…**, **Add New…**: *D+B+C* = DEAD + BERTH + CURRENT and *D+M+C* = DEAD + MOOR + CURRENT, Linear Add, factors 1.0; tick the cases and both combinations in **Analyze ▸ Set Load Cases to Run…**.

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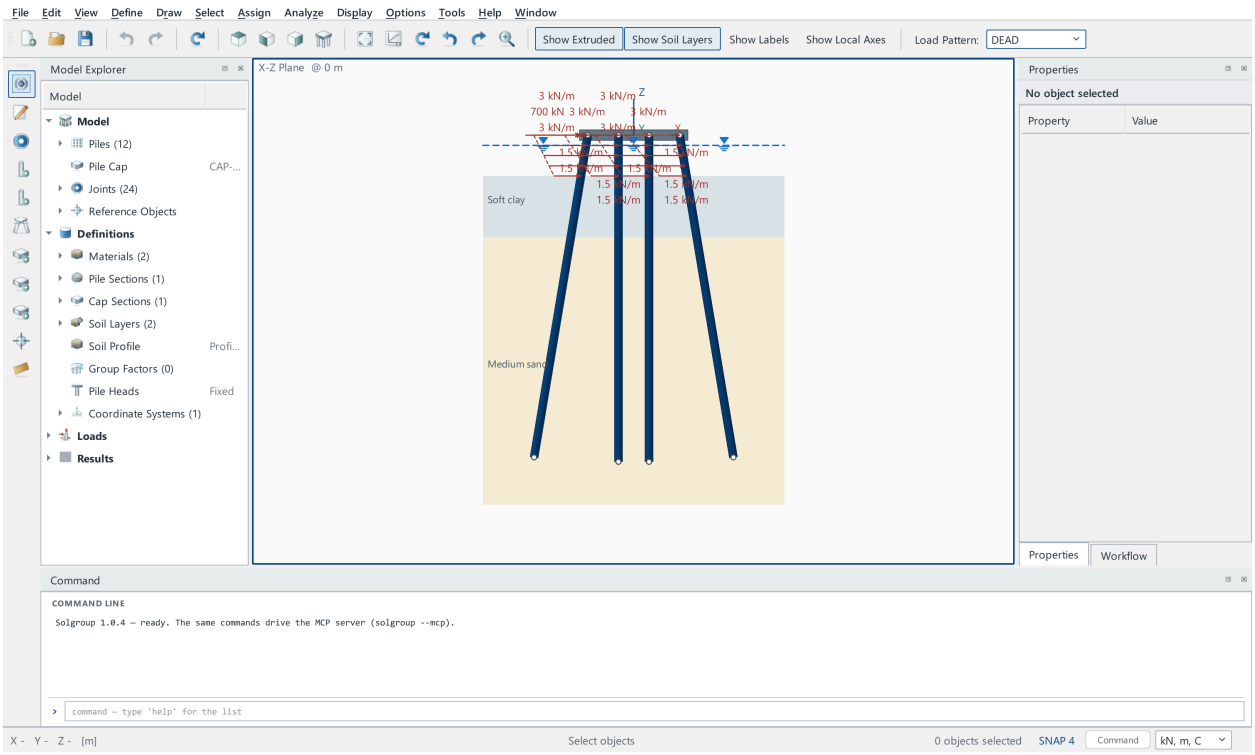



**Figure 7.5 —** The berthing and mooring forces at the fender and the bollard, and the current on the piles through the water (X-Z elevation)

## 7.5 Step 5: run and review

**Analyze** ▸ **Check Model** finds nothing to fix: a water table above the ground is normal for a marine structure. **Analyze** ▸ **Run Analysis** runs the cases and combinations; the Command panel lists them as converged (Figure 7.6).

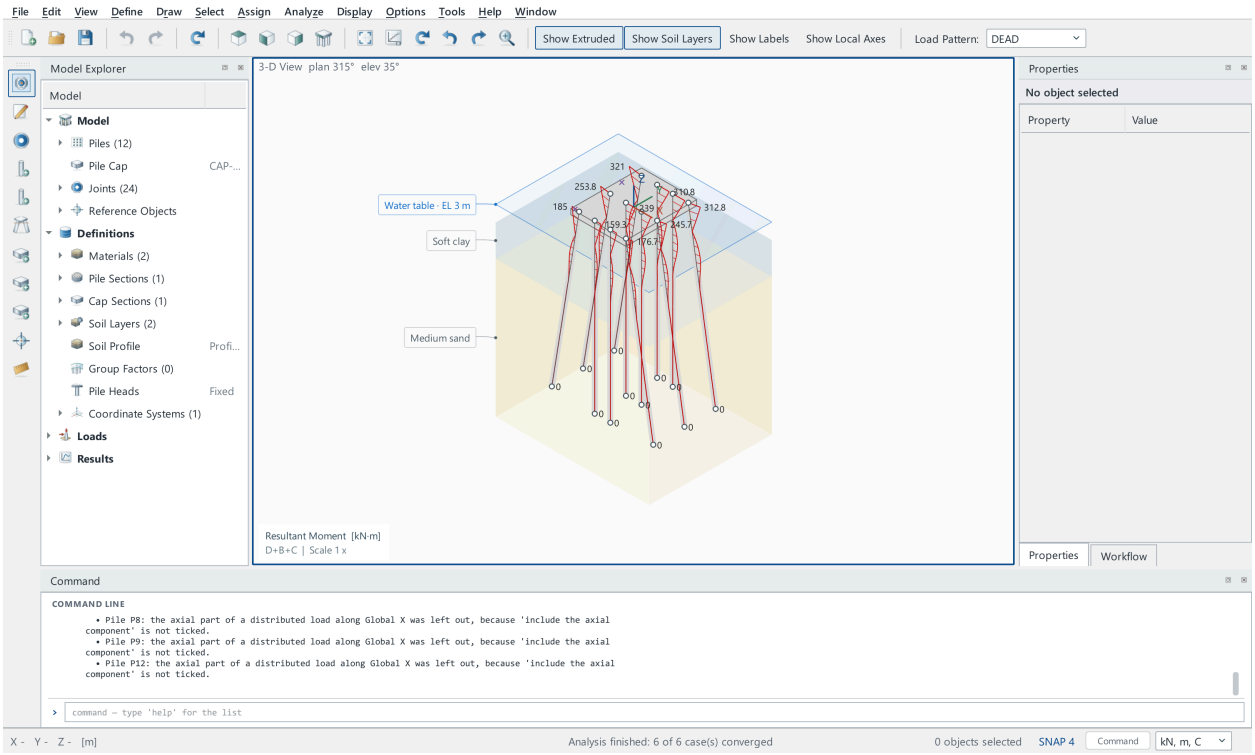



**Figure 7.6 —** After the run

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Under DEAD alone, the weight of the deck, every pile carries about 288 kN. In the X-Z elevation of the deformed shape of D+B+C (Figure 7.7) the cap moves 4.68 mm in X and turns −0.020° about Z; the piles bend over their free length and in the soft clay, and the bending dies out in the sand (Figure 7.8).

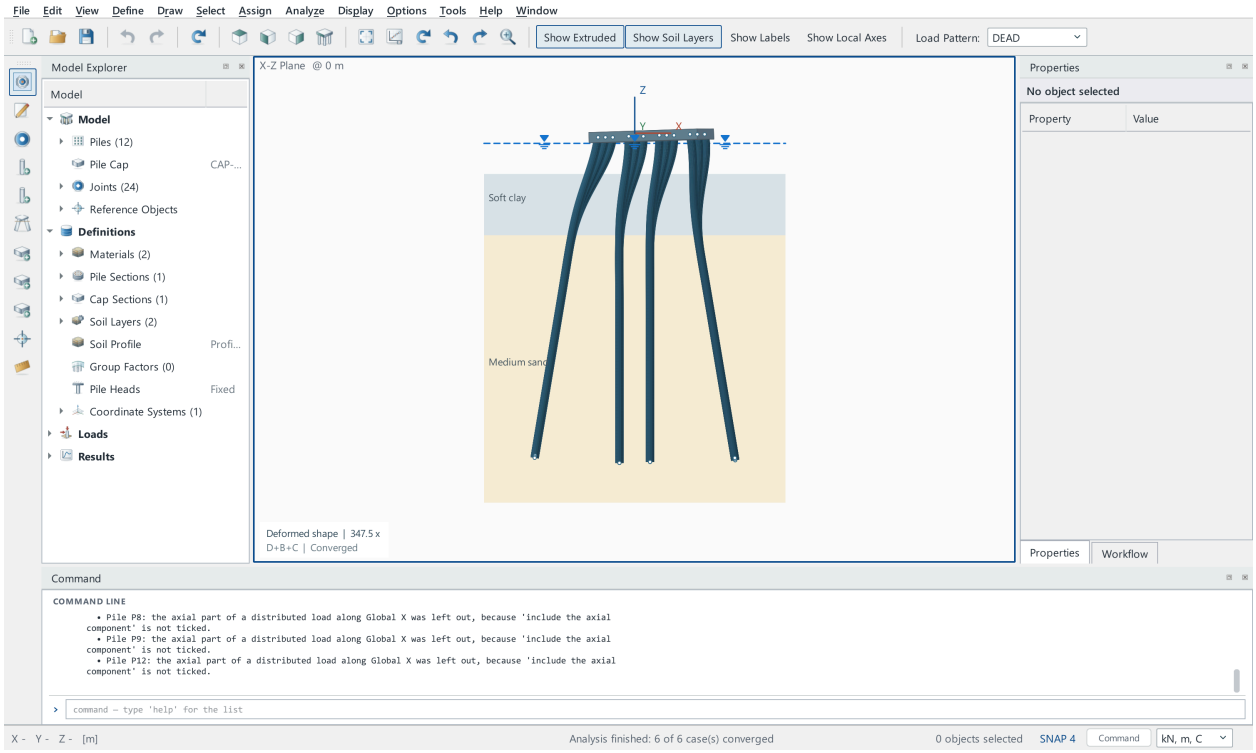



**Figure 7.7 —** Deformed shape of D+B+C in the X-Z plane

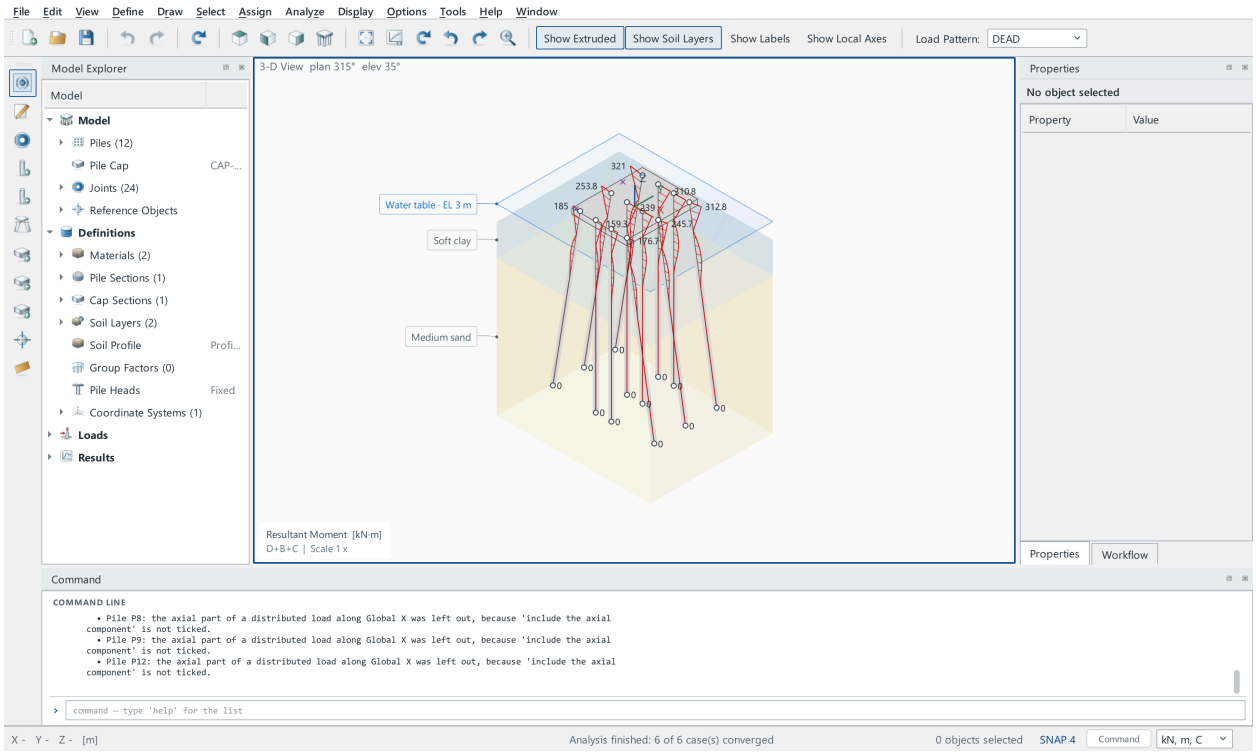



**Figure 7.8 —** Resultant moment along the piles for D+B+C, with the largest and smallest value of each pile

The pile-head forces are listed by **Display ▸ Show Tables…**, table *Pile Head Results*, one row per case and pile (Figure 7.9). For the first bent, far from the fender, and the third bent, next to it:

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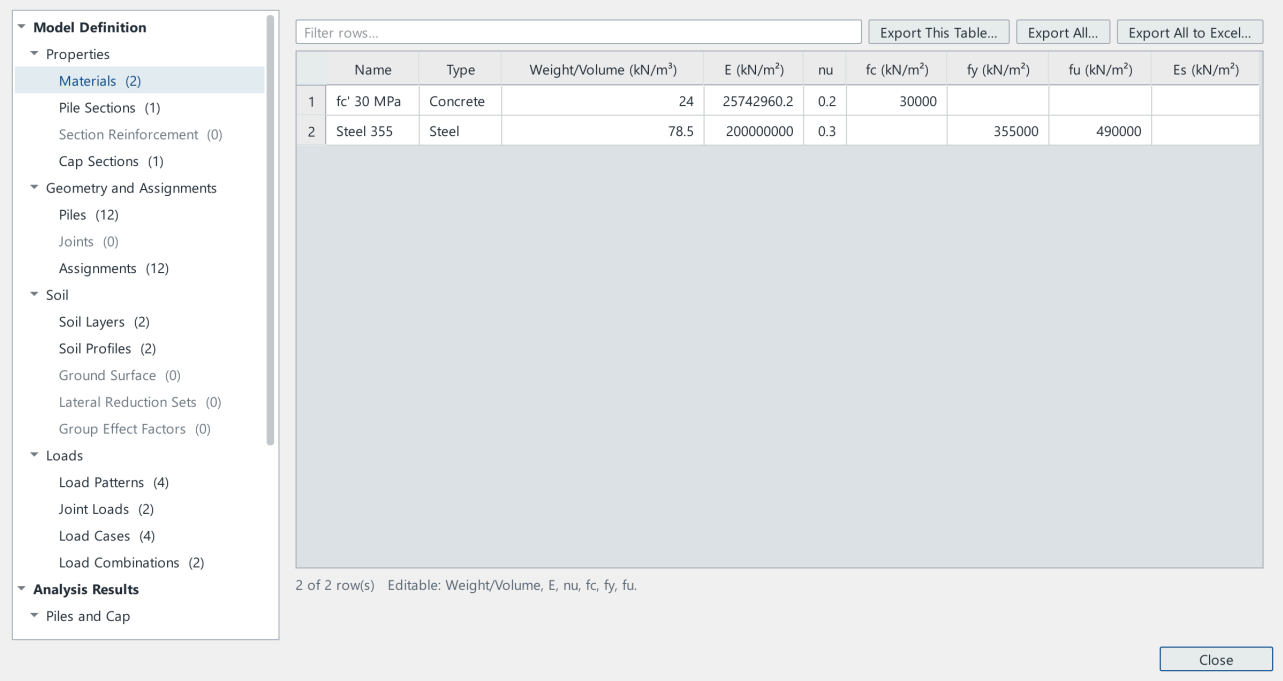



**Figure 7.9 —** Show Tables, Pile Head Results

**Table 7.1 — Pile-head forces of the first and third bents**

| Pile | Batter | Axial, BERTH (kN) | Axial, D+B+C (kN) | Shear, D+B+C (kN) | Axial, D+M+C (kN) |
|---|---|---|---|---|---|
| P1 | tip to −X | 8.4 | 287.3 | 38.7 | 453.9 |
| P4 | tip to +X | −9.5 | 288.9 | 37.0 | 121.4 |
| P9 | tip to −X | −243.5 | 23.1 | 66.5 | 227.9 |
| P12 | tip to +X | 244.3 | 546.0 | 64.5 | 349.0 |

The case BERTH shows how the battered pairs work, and the twist. Under the force in +X the pile whose tip points to +X is compressed and the pile whose tip points to −X is pulled (a negative axial force is tension): the horizontal components of their axial forces resist the load together with the shears. The third bent, next to the fender, takes most of it, P12 compressed with 244.3 kN and P9 pulled with −243.5 kN, while the first bent, nine metres from the fender, hardly feels it. In D+B+C the weight of the deck and the current are added: P12 carries 546.0 kN against 288.9 kN in P4 at the far end, and the head shears grow towards the fender as well. Mooring turns it around: the bollard is at the first bent, and in D+M+C the pile P1, leaning towards minus X, takes the most, 453.9 kN.

The batter of 1:6 is gentle, so in this trestle the shears still carry most of the berthing force; a steeper batter, or battered piles in both directions of the load as in Example 19 (Section 16.19), would shift more of it to axial forces. To continue, compute the foundation stiffness of the trestle for the deck model (Example 6, Section 16.6), or apply the berthing load in steps with a pushover case (Example 7, Section 16.7).

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# 8 Drawing, selecting and editing

Piles, caps and the other objects of a model are drawn in the model view and edited with the commands of the **Draw**, **Select**, **Edit** and **View** menus. A model started from a template (Chapter 4) already contains the piles and the cap; this chapter is needed to change the layout or to build an irregular one.

## 8.1 Coordinates, grids and coordinate systems

The coordinates of the model are global: X and Y horizontal, Z vertical and positive upward. Site coordinates, for example of a map grid, can be used directly; the results do not depend on the position of the group. The status bar shows the coordinates of the cursor and of the point it snaps to; a marker at the cursor (Joint, Grid Intersection, End, Midpoint, Intersection) shows the kind of point, in the drawing tools and in the selection mode alike.

**Define ▸ Coordinate Systems / Grids…** (also **Draw ▸ Edit Grid…**) lists the coordinate systems of the model with the System name, its Type and the number of Grid lines. **Add New…**, **Add Copy…** and **Modify…** open *Coordinate System / Grid Data* (Figure 8.1):

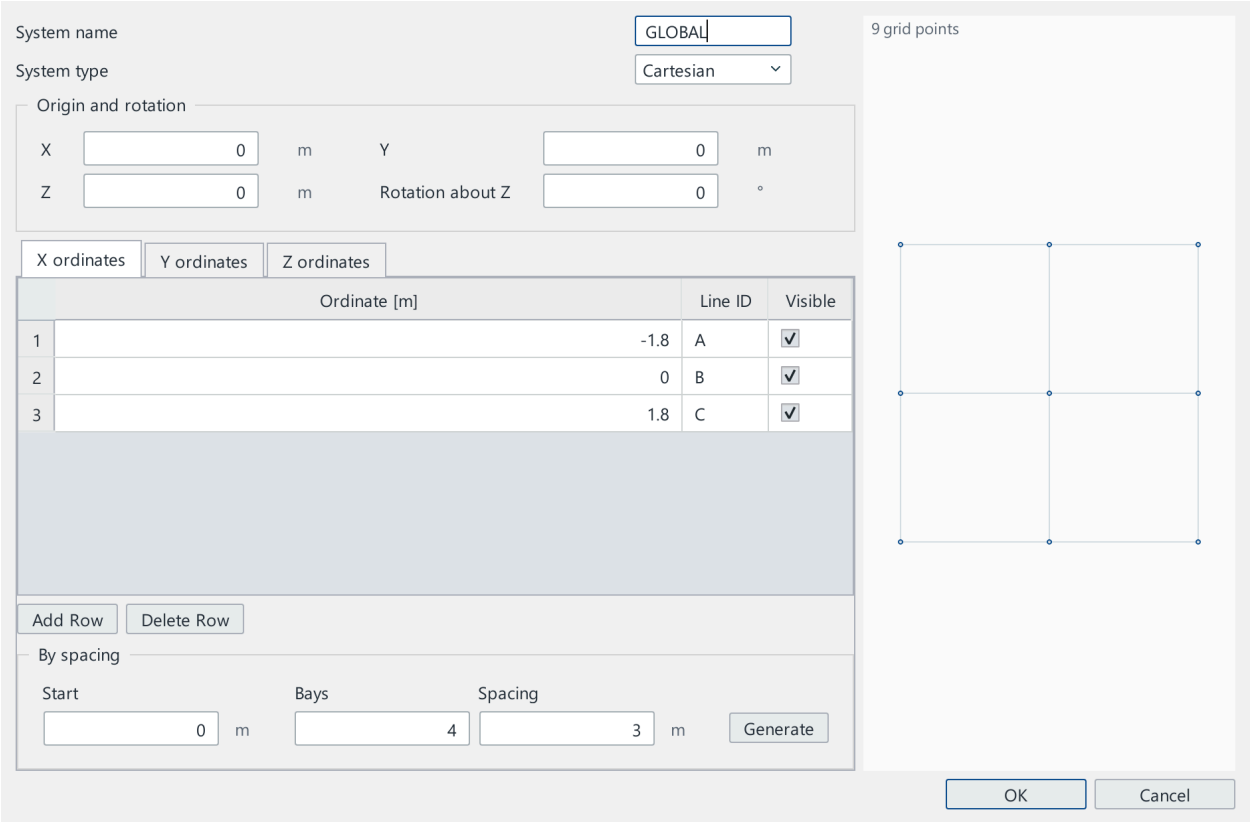



**Figure 8.1 —** Coordinate System / Grid Data, X ordinates

**Table 8.1 — Coordinate System / Grid Data**

| Field | Meaning |
|---|---|
| System name | name of the system; the system GLOBAL always exists and cannot be deleted |
| System type | Cartesian (grid lines at X and Y ordinates) or Cylindrical (radii and angles) |
| Origin X, Y, Z; Rotation about Z | position and orientation of the system relative to the global axes |
| X ordinates, Y ordinates, Z ordinates | one tab for each direction. Each row is a grid line: its **Ordinate**, its **Line ID** (the label drawn at the end of the line) and **Visible** (whether it is drawn). **Add Row** and **Delete Row** edit the list. |
| Start, Bays, Spacing; Generate | replace the ordinates of the tab with an evenly spaced set: the first ordinate, the number of bays and their spacing |

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The grid lines of the active system are drawn in the model view and are used by the drawing tools to snap objects. Z ordinates define the elevations at which grid points exist; a plan grid without Z ordinates has no grid points.

## 8.2 Drawing tools

A drawing tool stays active until another tool is chosen or Esc is pressed, which returns to selection. The status bar tells what to click next; Backspace removes the last clicked point.

**Table 8.2 — Commands of the Draw menu**

| Command | Use |
|---|---|
| Set Select Mode | ends drawing; clicks select objects |
| Set Reshape Element Mode (R) | select a handle (the head or tip of a pile, a vertex of the cap) and drag it to a new position |
| Draw Special Joint | click a point to place a joint, for example a point at which loads are applied |
| Draw Pile (F) | click the pile head, then the pile tip; the pile may be inclined |
| Quick Draw Pile (Q) | click a grid point to place a vertical pile with the default length and section |
| Quick Draw Batter Pile | click the pile head, then drag in the direction of the batter; the batter ratio is the default ratio |
| Draw Poly Cap (C) | click the corners of the cap outline; click the first corner again or right-click to finish |
| Draw Rectangular Cap | click two opposite corners of the cap |
| Quick Draw Cap | click to create a cap around the pile heads at the elevation of the click, with the default overhang |
| Draw Reference Point, Draw Reference Line | place construction aids, which are not part of the analysis model but can serve as load points and snap targets |
| Snap To | the points the cursor snaps to, each switched on or off: *Joints & Grid Points*, *Midpoints & Ends*, *Intersections*, *Perpendicular*, *Lines & Edges* and *Fine Grid* |
| New Labels… | renumber the piles (Table 8.6) |
| Edit Grid… | the coordinate systems and grids (Table 8.1) |
| Set Default Draw Properties… | the properties given to new piles and caps (Table 8.3) |

Piles can be placed anywhere, at any spacing and in any direction; the analysis needs no regular layout, and the group effects are worked out from the actual position of each pile. Every pile head is, however, tied to the cap: there is no pile that stands on its own. A pile drawn outside the cap outline is still tied to a rigid cap, which ignores its outline, and Check Model warns about it; with a flexible cap, a head that is neither at a node nor inside a plate of the mesh stops the run. A pile without a cap is analysed in a separate single-pile model. Two heads at the same point, and a pile that starts on the axis of another, are errors; crossing piles and piles closer than 2.5 diameters are warnings.

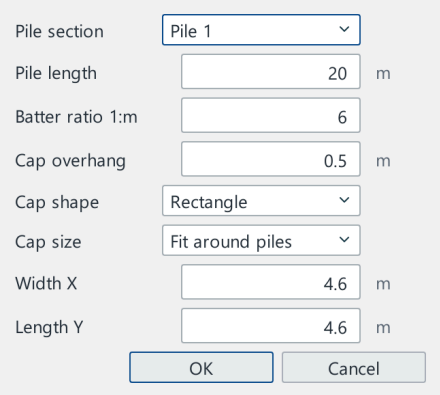



**Figure 8.2 —** Set Default Draw Properties

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**Table 8.3 — Set Default Draw Properties**

| Field | Meaning |
|---|---|
| Pile section | section of new piles |
| Pile length | length of piles placed with the quick tools |
| Batter ratio 1:*m* | batter of piles placed with Quick Draw Batter Pile: one horizontal to *m* vertical |
| Cap overhang | distance from the outermost pile heads to the edge of a cap drawn with Quick Draw Cap |
| Cap shape | Rectangle or Circle |
| Cap size | Fit around piles (from the pile heads and the overhang) or Specify dimensions |
| Width X, Length Y; Diameter | dimensions of a rectangular or circular cap when they are specified |

## 8.3 Selecting

Most commands of the **Assign** and **Edit** menus act on the selected objects. A click selects an object; a window drawn from left to right selects the objects inside it, and a window drawn from right to left also selects the objects it crosses. The **Select** menu offers further ways:

**Table 8.4 — Commands of the Select menu**

| Command | Use |
|---|---|
| Pointer / Window | click or window selection, as above |
| Intersecting Line | draw a line across the objects to select |
| Poly Window | click the corners of a polygon; right-click to select the objects inside it |
| All (Ctrl+A), None (Ctrl+Shift+A), Invert Selection, Previous Selection | select all objects, clear the selection, invert it, or restore the previous selection |
| Properties ▸ by Pile Section, by Material, by Head Connection, by p-y Set | select the piles that have the chosen property |
| Object Type ▸ All Piles | select every pile |
| Coordinate Specification ▸ by Specified Plane… | the objects on a plane: XY (constant Z), XZ (constant Y) or YZ (constant X), at the ordinate of the current view, within a tolerance |
| Coordinate Specification ▸ by Group…, by Label Range… | the piles of a named group, or the piles whose labels fall between two labels |
| Coordinate Specification ▸ by Row / Ring… | a row along X (constant Y), a row along Y (constant X) or a ring around the plan centre, within a tolerance |
| Coordinate Specification ▸ Batter Piles Only, Vertical Piles Only | reduce the selection to the battered or to the vertical piles |
| Assign to Group… | add the selection to a named group, remove it from the group, or replace the group by it; a new name creates a group |

The number of selected objects is shown on the status bar. Groups are listed and edited with **Define ▸ Groups…**.

The selection dialogs are small (Figure 8.3). *Select by Specified Plane* asks for the **Plane** (XY plane (constant Z), XZ plane (constant Y) or YZ plane (constant X)) and a **Tolerance**; the ordinate is that of the current view. *Select by Row / Ring* asks how to **Group piles by** (Rows along X (constant Y), Rows along Y (constant X) or Rings around the plan centre) and a **Tolerance** within which piles count as one row, and then lists the rows to choose from. *Select by Group* lists the groups, and *Select by Label Range* asks for the first and the last label. *Assign to Group* asks for the **Group**, an existing one or a new name typed in the box, and the **Action**: Add the selection to the group, Remove the selection from the group, or Replace the group with the selection; the number of selected objects is shown.

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**Figure 8.3 —** Select by Specified Plane

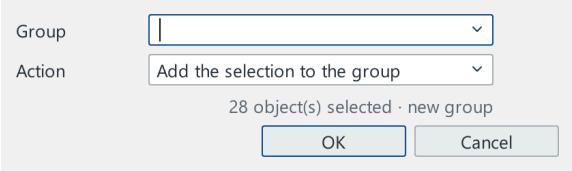



**Figure 8.4 —** Assign to Group

## 8.4 Editing

Every change of the model can be undone with **Edit** ▸ **Undo** (Ctrl+Z) and restored with **Redo** (Ctrl+Y); the number of steps kept is set in the preferences. **Cut**, **Copy** and **Paste** copy the selected objects, and **Delete** removes them.

**Table 8.5 — Editing commands**

| Command | Fields and use |
|---|---|
| Move… | *dx*, *dy*, *dz*: the translation of the selected objects |
| Replicate… (Ctrl+R) | copies the selected objects (Figure 8.5). **Linear**: *dx*, *dy*, *dz* and the Number of copies. **Radial**: Rotation axis X and Rotation axis Y of a vertical axis, the Angle per copy and the Number of copies. **Mirror**: the Mirror plane (Y-Z plane (mirror about X), X-Z plane (mirror about Y) or X-Y plane (mirror about Z)) and the Plane ordinate. The local axes rotation of each pile is copied unchanged: for a section that is not symmetric, check the orientation of the copies. |
| Divide Piles… | divides each selected pile into a number of segments of equal length, joined at new joints |
| Join | joins selected piles that lie on one line, the tip of each meeting the head of the next, into one pile; piles that are not collinear are not joined |
| Change Labels… | renumbers the piles (Table 8.6) |
| Check Duplicate Piles | finds piles identical to an earlier one, with the same geometry and assignments, and offers to delete them |
| Shift Piles, Soil Elevations and Loading… | moves the model vertically (Table 8.7) |

The dialogs of the Edit menu act on the selected objects:

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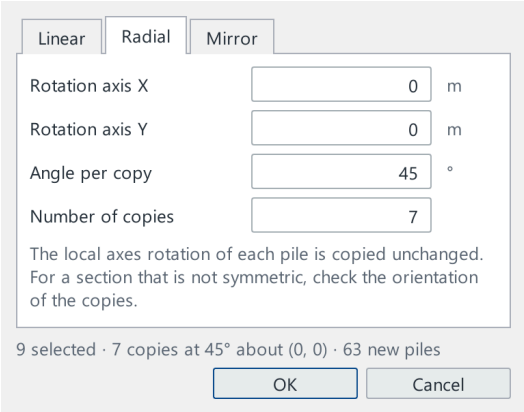



**Figure 8.5 —** Replicate, Radial tab

*Move* asks for the translation **dx**, **dy** and **dz**. *Divide Piles* asks for the **Number of segments**. *Change Labels* (Table 8.6) shows the labels that will result before they are applied.

**Table 8.6 — Change Labels**

| Field | Meaning |
|---|---|
| Ordering | order of numbering: Order by X, then Y; Order by Y, then X; or Order by radius, then angle |
| Label prefix | text before the number, for example P |
| Start number | number of the first pile; the dialog shows the labels that will result |

**Table 8.7 — Shifting Options**

| Field | Meaning |
|---|---|
| Absolute Coordinates | the shift is the difference between the Target point elevation and the Reference point elevation |
| Relative Coordinates | the shift is an Increment (up +), positive upward |
| Shift All Piles, Shift Soil Layering, Shift Loading | what is moved: the piles with the cap, its mesh, the joints and the elevations assigned to the piles; the boundaries of the soil layers; the elevations of the loads along the piles and the point of application of the cap loads. Only the vertical coordinate changes. |

**NOTE** Moving or replicating the objects of a flexible cap moves its mesh with it. When a later change of the cap outline, the piles or the element size no longer matches the stored mesh, Check Model reports it; generate the mesh again before the run (Section 10.2).

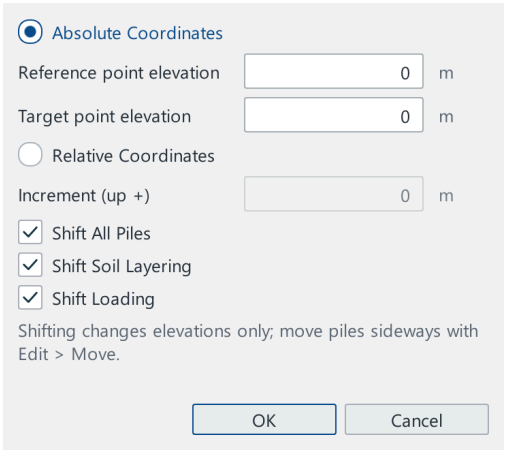



**Figure 8.6 —** Shifting Options

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## 8.5 Views and display

The model view has up to four panes, each with its own view: **View ▸ Pane Layout** offers Single Pane, Two Panes (stacked), Two Panes (side by side) and Four Panes. The **View** menu applies to the active pane:

**Table 8.8 — Commands of the View menu**

| Command | Use |
|---|---|
| Set Display Options… (Ctrl+E; also in the Options menu) | every display switch of the active pane in one place (Figure 8.7): the transparency of solids and soil; the assigns shown; the loads shown (point forces, moments, loads along piles, cap area loads, soil movement) with the arrow scale and the number of arrows of a distributed load; grid lines, global axes, bounding box, object labels (optionally hiding overlapping labels), local axes of the piles, extruded solids, soil layers, labels of soil, water and scour, ground and scour markers of each pile, load values beside the arrows; and whether grid lines can be dragged |
| Set 2D View… | a plan or elevation view: the X-Y, X-Z or Y-Z plane at an ordinate; **Previous ordinate** and **Next ordinate** step through the grid lines |
| Set 3D View… | the plan and elevation angles of the 3D view and the aperture (0° for an orthographic view; larger values give stronger perspective); buttons for standard views |
| XY, XZ, YZ, 3D | switch the pane to a standard view |
| Restore Full View (Home), Previous Zoom, Next Zoom, Zoom to Selection (Z), Rubber Band Zoom, Rotate 3D View | zoom and rotate; the mouse wheel zooms and a drag with the middle button pans |
| Refresh Window (F2) | redraws the panes |
| Show Grid, Show Axes, Show Extruded, Show Soil Layers, Show Labels, Show Local Axes | switch these elements on or off; the labels of the piles are hidden in a new model and appear with Show Labels |
| Pile Visibility | Hide Selected Piles, Hide Other Piles, Invert Pile Visibility or Show All Piles; hidden piles stay in the model and in the analysis |
| Solid Transparency | opacity of the extruded piles and cap: 100% opaque, 85% opaque, 70% opaque, 55% opaque or 40% opaque; a fully opaque cap hides the pile heads underneath |
| Soil Transparency | opacity of the soil layers: 0% opaque (hidden), 15% opaque, 30% opaque, 50% opaque or 70% opaque |

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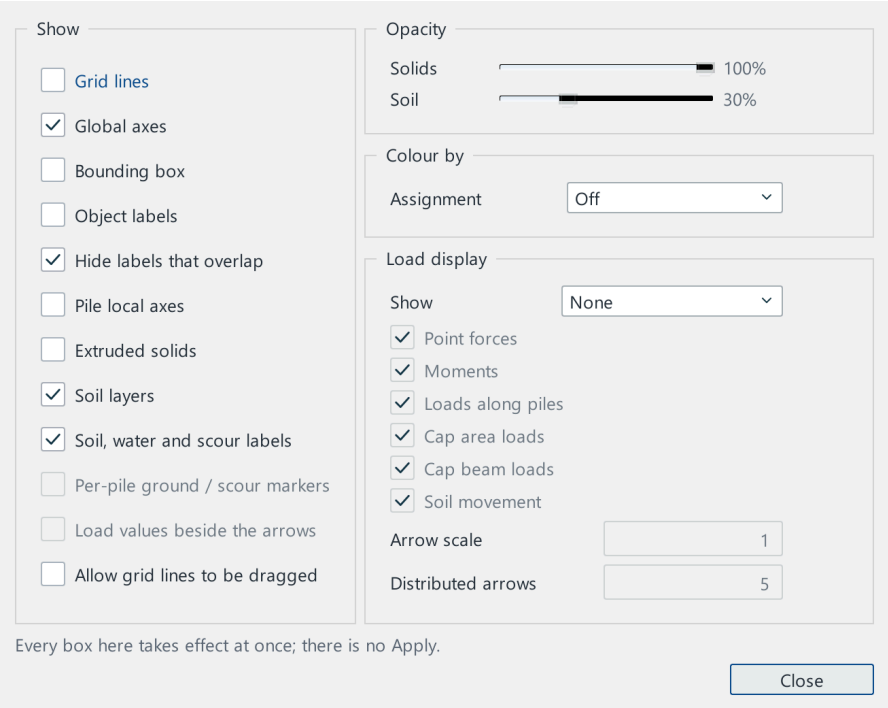



**Figure 8.7 —** Set Display Options

In *Set Display Options*, **Solids** and **Soil** set the transparency; **Assignment** chooses the assign shown on the piles (Off, Pile Number, Generated L-D Curve, Generated T-R Curve, Pile Section, Material, Pile Type, p-y Set, Head Connection or Lateral Reduction Set); **Show** chooses the loads shown (None, All loads / all patterns, or one load pattern), with the kinds of load (Point forces, Moments, Loads along piles, Cap area loads, Cap beam loads, Soil movement), the **Arrow scale** and the number of **Distributed arrows**. The switches under *Show* are Grid lines (of the active coordinate system), Global axes (the X, Y, Z triad at the origin), Bounding box (the box that encloses every object), Object labels, Hide labels that overlap (labels that would print on top of each other are dropped), Pile local axes (axes 1, 2 and 3 of every pile), Extruded solids (the real section swept along each pile instead of a thick line), Soil layers, Soil, water and scour labels (names and elevations beside the soil model), Per-pile ground / scour markers (the assigned ground and scour elevations around each pile; display only, and unavailable while no pile has a ground elevation of its own; the ground surface itself is always drawn, sloping where the profile has a sloping shape), Load values beside the arrows, and Allow grid lines to be dragged (off by default: a grid line dragged by accident moves everything snapped to it).

*Set 2D View* asks for the **Plane** (X-Y Plane, X-Z Plane or Y-Z Plane) and the **Plane ordinate**; **Previous ordinate** and **Next ordinate** step through the grid lines. *Set 3D View* asks for the **Plan angle**, the **Elevation angle** and the **Aperture** (0° = orthographic; larger values give stronger perspective); **Home**, **Top**, **Front**, **Side** and **Iso** set standard views.

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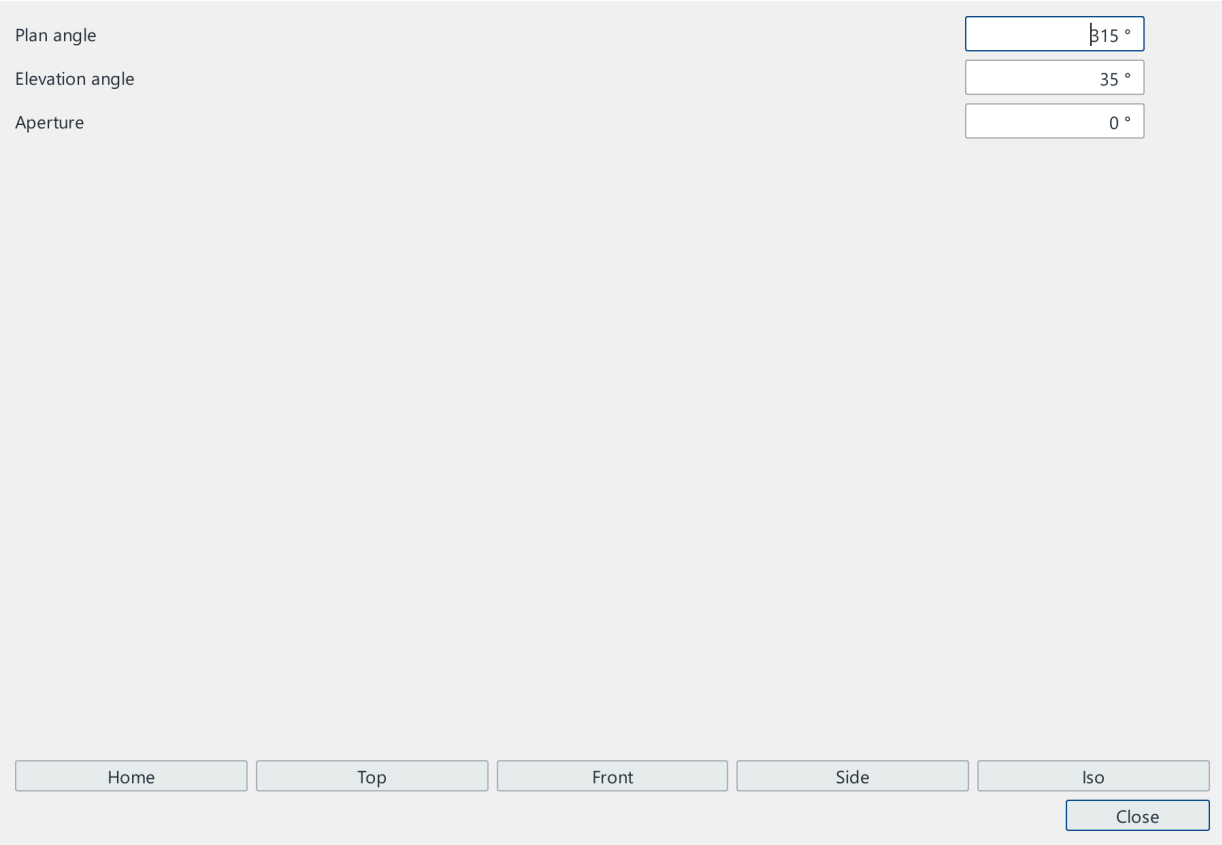



**Figure 8.8 —** Set 3D View

**Display** ▸ **Show Assigns** colours the piles by Pile Number, Generated L-D Curve, Generated T-R Curve, section, material, Pile Type, p-y set, head connection, lateral reduction set, axial reduction or group, with a legend. **Show Misc Assigns…** shows the **Object labels** (with **Hide labels that overlap**), the **Local axes of each pile**, and the piles coloured by group membership (**Colour piles by group membership**, available once a group is defined in Define ▸ Groups).

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# 9 Defining the model

The **Define** menu holds the definitions that piles, the cap and the loads refer to by name: materials, sections, soil layers and profiles, curves, group factors, load patterns, cases and combinations, coordinate systems and groups. A definition does nothing until it is used: a pile section acts only on the piles to which it is assigned, a soil layer only where a soil profile places it. This chapter describes the definitions of the structure and the soil, in the order of the menu; load patterns, cases and combinations are described in Chapter 11.

## 9.1 Definition lists

Every command of the **Define** menu that manages named items opens a definition list (Figure 9.1). The table lists the items with their main properties; the buttons on the right act on the selected item:

**Table 9.1 — Buttons of a definition list**

| Button | Action |
|---|---|
| Add New… | opens the data form with default values for a new item |
| Add Copy… | opens the data form with a copy of the selected item, under a new name |
| Modify… | opens the data form of the selected item (F2, or a double click on the row) |
| Delete | removes the selected item. An item that is in use cannot be deleted: the button is dimmed and its tooltip names the users, for example the sections that use a material or the piles to which a section is assigned. The GLOBAL coordinate system can never be deleted. |

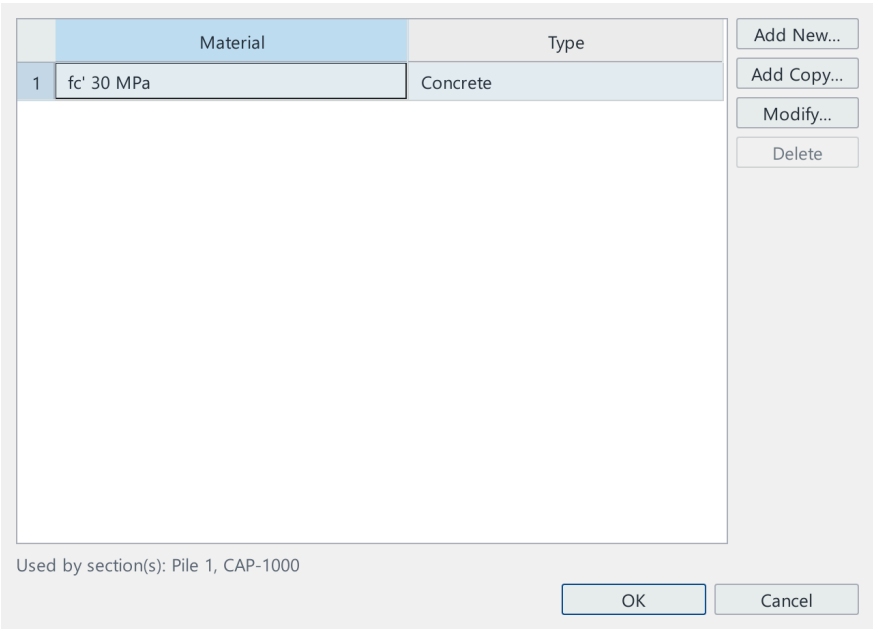



**Figure 9.1 —** A definition list: Define Materials

Every data form checks its data while it is typed: a missing or duplicate name, or a value outside its range, marks the field with a red border and a message under it, and **OK** stays disabled, with the reason in its tooltip, until the data are valid. Names have at most 64 characters and must be unique within their list. The list works on a copy of the definitions: the changes are written to the model once, when the list is closed with **OK**, so **Cancel** discards the whole editing session, and the session can be undone as one step with **Edit ▸ Undo**.

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## 9.2 Materials

**Define ▸ Section Properties ▸ Materials…** lists the materials of the model with their type (Figure 9.1). Materials are used by the pile sections (the section material, the reinforcement, the casing and the core) and by the cap sections. The data form, *Material Property Data* (Figure 9.2), contains:

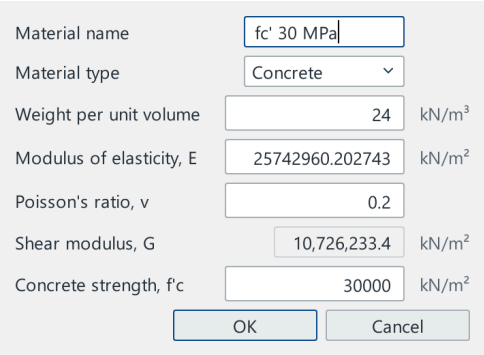



**Figure 9.2 —** Material Property Data of a concrete

**Table 9.2 — Material Property Data**

| Field | Unit | Description |
|---|---|---|
| Material name | | name by which the sections refer to the material |
| Material type | | Concrete, Steel, Rebar (reinforcing steel) or Other. The type decides which strengths are asked for. When the type is changed while the unit weight, the modulus and Poisson's ratio still hold the defaults of the previous type, they are replaced by the defaults of the new type; values that have been edited are kept. |
| Weight per unit volume | force/volume | unit weight of the material, greater than zero. It is stored with the material; the analysis applies no self weight of the piles or the cap (Chapter 11). |
| Modulus of elasticity, E | stress | Young's modulus, greater than zero. For a rebar material the label reads *Modulus of elasticity, Es*. It gives the elastic bending stiffness *EI* and the axial stiffness *EA* of the sections that use the material. |
| Poisson's ratio, v | | between 0 and 0.5 |
| Shear modulus, G | stress | computed, $G = E/2(1 + v)$; it gives the torsional stiffness *GJ* of the sections |
| Concrete strength, f'c | stress | compressive strength of concrete; shown for type Concrete only and required there. It is used by the moment–curvature analysis of concrete and prestressed sections. |
| Yield strength, Fy | stress | shown for types Steel and Rebar only and required there; used by nonlinear steel sections, by the reinforcement and by the plastic moment of steel sections |
| Ultimate strength, Fu | stress | shown for types Steel and Rebar; zero or not less than $F_y$ |

To define a material:

1. Choose **Define ▸ Section Properties ▸ Materials…** and click **Add New…**.
2. Type the name and choose the type; the defaults of the type are filled in.
3. Enter the unit weight, the modulus and the strengths of the material, and click **OK** twice.

## 9.3 Pile sections

**Define ▸ Section Properties ▸ Pile Sections…** lists the cross-sections of the piles with their shape and material (Figure 9.3). A section describes the structural shape, the materials and the bending behaviour of a pile; it is assigned to piles with **Assign ▸ Pile ▸ Section…**, or along the length of a pile with **Assign ▸ Pile ▸ Section along Length…**

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(Chapter 10).

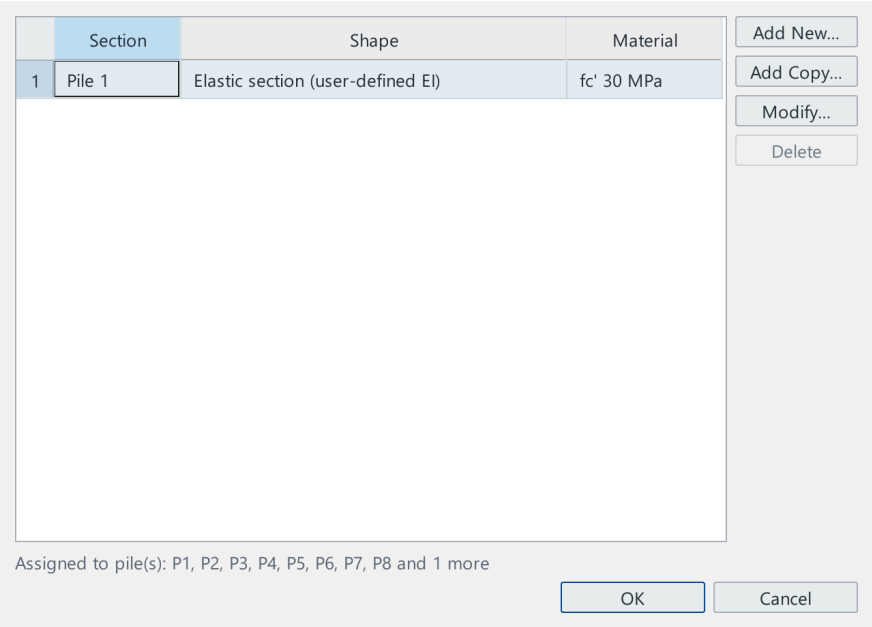



**Figure 9.3 —** Define Pile Sections

### 9.3.1 Choosing the shape

**Add New…** first opens *Add New Pile Section* (Figure 9.4): choose the **Section family** (Concrete, Steel, Prestressed or Other) and click the drawing of the shape; the large drawing on the right and the note under it describe the selected shape. The same window opens from **Change…** in the section form, to change the shape of an existing section: values with the same meaning, such as the diameter or the reinforcement, are kept, and the others take the defaults of the new shape.

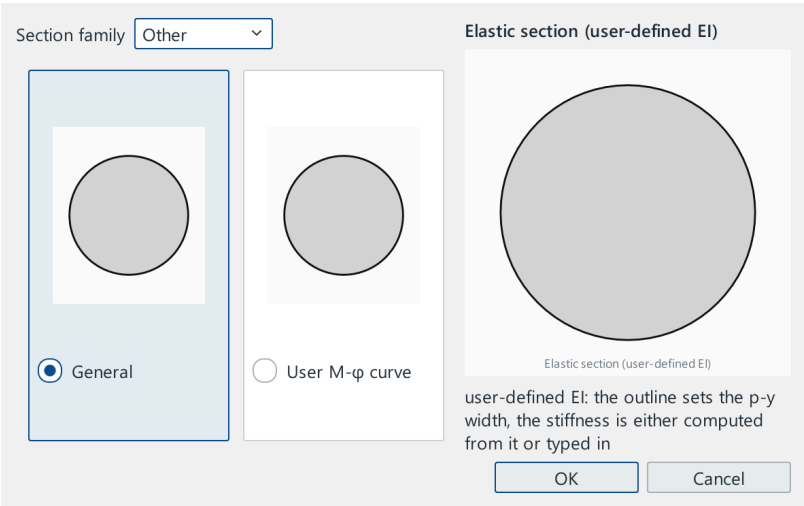



**Figure 9.4 —** Add New Pile Section

**Table 9.3 — Section shapes**

| Family | Shape | Description | Behaviours |
|---|---|---|---|
| Concrete | Round | bored pile or drilled shaft, solid circular reinforced concrete | nonlinear |
| | Round with casing | circular concrete inside a steel casing left in place | nonlinear |
| | Casing and core | steel casing with an embedded steel pipe, H section or catalogue shape | nonlinear |

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| Family | Shape | Description | Behaviours |
|---|---|---|---|
| | Rectangular | rectangular or square reinforced concrete | nonlinear |
| | Box (any material) | rectangular hollow section of concrete or steel; the void is rectangular and centred | elastic; elastic with moment capacity |
| Steel | Pipe | driven steel pipe or tubular pile | elastic; elastic with moment capacity; nonlinear |
| | H or I section | dimensions typed; unrotated, the section bends about its weak axis | elastic; elastic with moment capacity; nonlinear |
| | Catalog shape | AISC shape (W, M, S, HP, HSS, Pipe) from the steel shape database; dimensions read-only | elastic; elastic with moment capacity; nonlinear |
| Prestressed | Round; Round with void | solid or hollow (spun pile) circular prestressed concrete | nonlinear |
| | Square; Square with void | square prestressed concrete with chamfered corners, solid or with a circular void | nonlinear |
| | Octagonal; Octagonal with void | regular octagon, solid or with a circular void | nonlinear |
| Other | General | elastic section with user-defined *EI*: the outline sets the p-y width, the stiffness is computed from it or typed | elastic; elastic with moment capacity |
| | User M-φ curve | user nonlinear bending: moment–curvature or *EI*–moment data typed for each axial thrust | nonlinear |

### 9.3.2 The section form

The form *Pile Section Data* (Figure 9.5) has a header, a column of tabs on the left, the data of the selected tab in the middle, and on the right a scaled drawing of the section with its computed properties. The tabs that are shown depend on the shape and the behaviour; a tab that does not apply is not shown.

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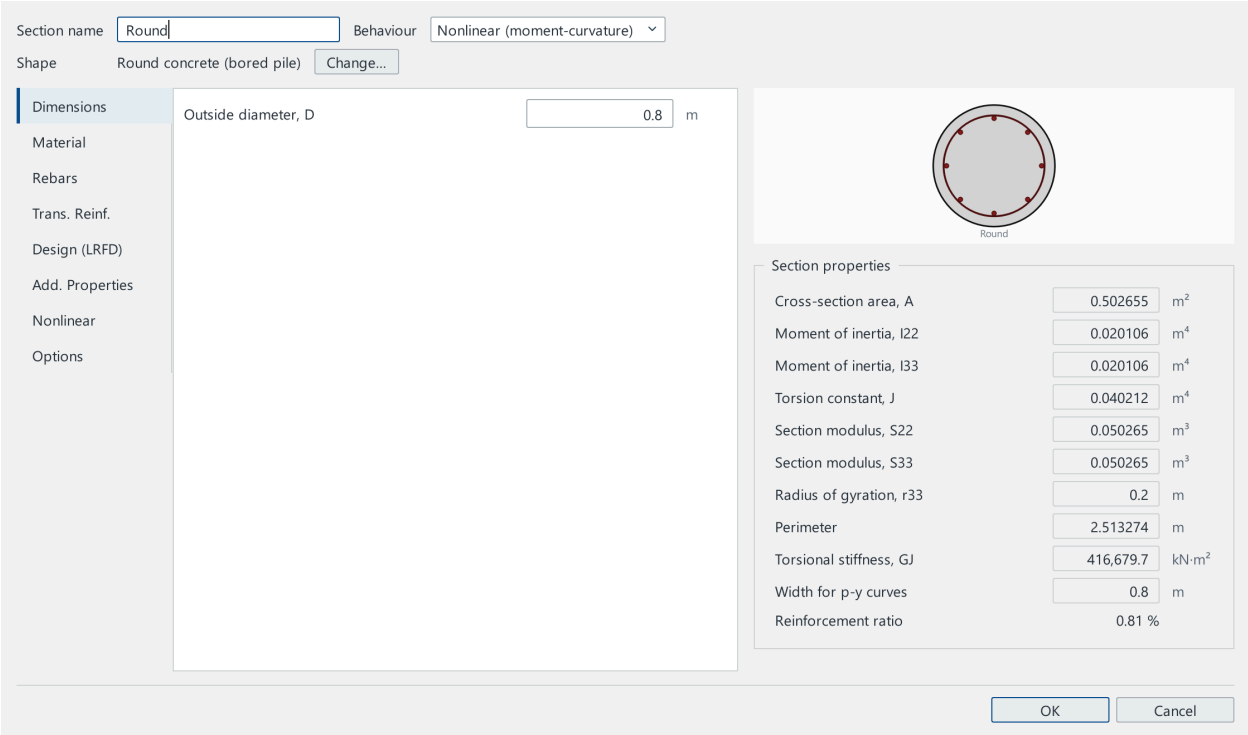



**Figure 9.5 —** Pile Section Data of a round reinforced concrete section, Dimensions tab

**Table 9.4 — Header and section properties**

| Field | Description |
|---|---|
| Section name | name used by the assignments |
| Behaviour | how the bending stiffness is obtained: *Elastic (no yield)* uses the gross properties of the section at every moment; *Elastic with specified moment capacity* adds a plastic hinge where the moment reaches the capacity entered in the Design (LRFD) tab; *Nonlinear (moment-curvature)* computes the moment–curvature relation of the section for a list of axial thrusts, and the bending stiffness of each node follows its bending moment (Technical Reference, chapter “Section mechanics”). Only the behaviours of the shape are offered (Table 9.3). |
| Shape; Change… | the shape of the section; **Change…** chooses another shape (Section 9.3.1) |
| Cross-section area, A | gross area, used for the axial stiffness and the tip resistance |
| Moment of inertia, I22; Moment of inertia, I33 | about local axes 2 and 3; $I_{33}$ governs bending in the plane of axis 2, the usual strong direction |
| Torsion constant, J; Torsional stiffness, GJ | used for the torsional response of the pile |
| Section modulus, S22; Section modulus, S33; Radius of gyration, r33 | elastic section moduli, for the combined stress, and the radius of gyration |
| Perimeter | used for the side friction of the axial curves |
| Width for p-y curves | the width *b* used for the soil curves: the diameter of a round section; for a non-circular section, the value of *Width for p-y curves (0 = face width)* or, when it is zero, the face width across the bending plane (for example the flange width when an H section bends about its strong axis) |
| Reinforcement ratio | area of longitudinal steel divided by the gross area, for concrete sections |

The axes of a section follow the local axes of the pile: a width *b* lies along local axis 2 and a depth *h* along local axis 3. The drawing shows the axes, the reinforcement and the strands, so that the orientation can be checked before the section is assigned.

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### 9.3.3 Dimensions

The Dimensions tab holds the dimensions of the shape; the area and the inertias follow from them, except for the General shape when the computation is switched off.

**Table 9.5 — Dimensions of each shape**

| Shape | Fields |
|---|---|
| Round; Round (prestressed) | Outside diameter, D |
| Round with casing | Casing outside diameter, D; Casing wall thickness |
| Casing and core | Casing outside diameter, D; Casing wall thickness; Core / insert (Steel pipe; H section, strong axis; H section, weak axis; AISC shape, strong axis; AISC shape, weak axis); for a pipe core: Core outside diameter and Core wall thickness; for an H core: depth, flange width and thickness, web thickness; for an AISC core: the family and designation; **Fill Core with Concrete** (only for a pipe or a box core) |
| Rectangular | Width (axis 2), b; Depth (axis 3), h; Rotate 90° |
| Box (any material) | Outside width (axis 2), b; Outside depth (axis 3), h; Internal width, bi; Internal depth, hi; Width for p-y curves (0 = face width); Tapered; Rotate 90° |
| Pipe (steel) | Outside diameter, D; Wall thickness, t; Tapered (elastic behaviours) |
| H or I section | Section depth, d; Flange width, bf; Flange thickness, tf; Web thickness, tw; Width for p-y curves (0 = face width); Rotate 90° |
| Catalog shape | Shape family (W, M, S, HP, HSS, Pipe); Shape designation; the Depth, d, Flange width, bf, Flange thickness, tf and Web thickness, tw of the shape are shown; Width for p-y curves (0 = face width); Rotate 90° |
| Round with void (prestressed) | Outside diameter, D; Void diameter, Di |
| Square; Square with void | Side, b; Corner chamfer; Void diameter (with void); Rotate 90° |
| Octagonal; Octagonal with void | Width across flats; Void diameter (with void). The corner chamfer is computed so that the shape is a regular octagon. |
| General | Structural shape (Circular; Pipe (circular hollow); Rectangular; H or I section; General (no outline; type every property)) and the dimensions of that outline, for example Diameter, D; **Compute area and inertia from the dimensions** (ticked: computed and read-only; unticked: typed); Area, A; Moment of inertia, I22 and I33; Torsion constant, J; Perimeter; the Torsional stiffness, GJ = G × J is shown; Tapered |
| User M-φ curve | Width for p-y curves; Area, A (0 = solid circle of the width); Perimeter (0 = circle of the width); Torsion constant, J (0 = solid circle) |

**Rotate 90°** turns the section 90° about the pile axis: the sides along axes 2 and 3 swap, so the strong and the weak axis swap; the drawing shows the result. An H section that is not rotated bends about its weak axis under a load along axis 2. **Tapered** (elastic behaviours) makes the section change linearly from the pile head to the pile tip: a second set of fields marked — *at tip* holds the dimensions at the tip, for example *Outside diameter, D — at tip* or *Area, A — at tip*, and the properties at each node are interpolated. A nonlinear section cannot be tapered.

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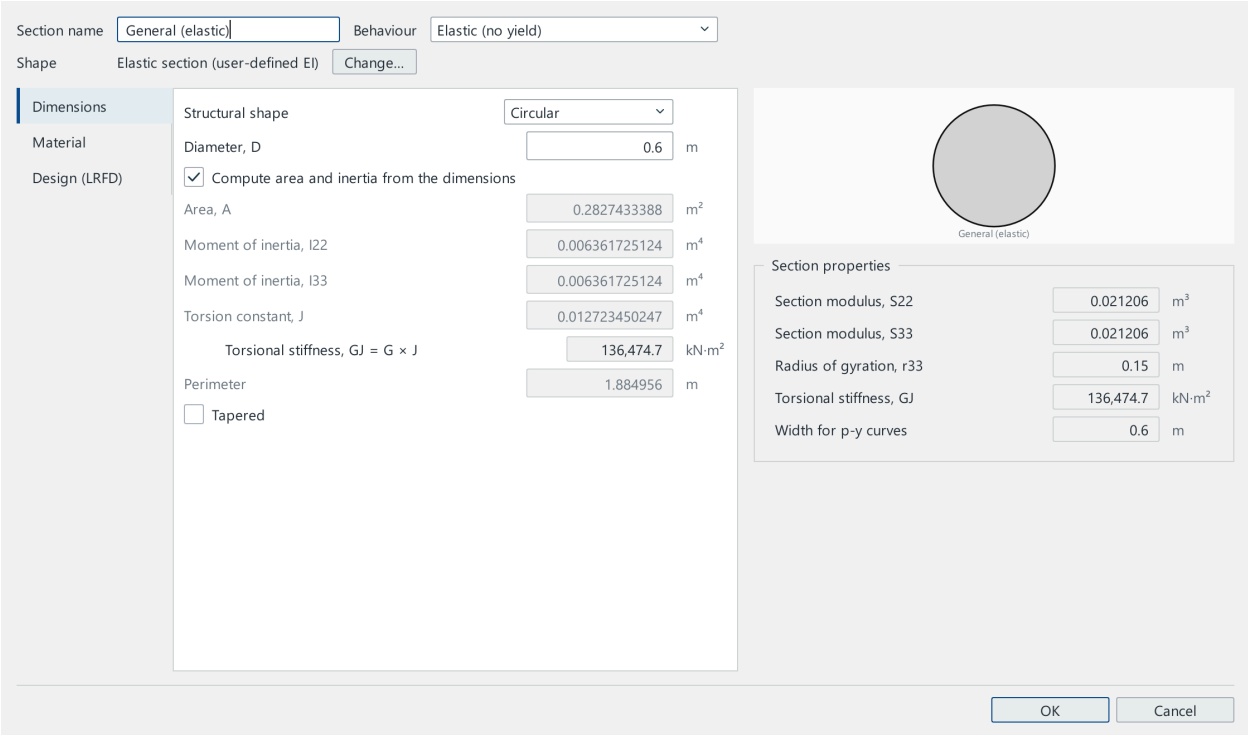



**Figure 9.6 —** Dimensions of a General (user-defined *EI*) section

### 9.3.4 Material

The Material tab selects the materials from the material list (Section 9.2) and shows the strengths that the analysis takes from them: the **Section material** (concrete or steel); for reinforced concrete, the **Rebar material**; for cased shafts, the **Casing material** and the **Core material**. The values shown, for example *Concrete strength, f′c*, *Concrete modulus of elasticity, E*, *Reinforcement yield, fy*, *Reinforcement modulus, Es*, *Yield strength, Fy* and *Modulus of elasticity, E*, are read-only: they are changed in the material. **View stress-strain curve…** opens *Stress-Strain Curve* (Figure 9.8), which draws the stress–strain relation of each material of the section used by the moment–curvature analysis; the material is chosen in the list at the top, and the note under the graph names the model and its constants. Negative strain is tension: the concrete carries tension up to cracking and none after it.

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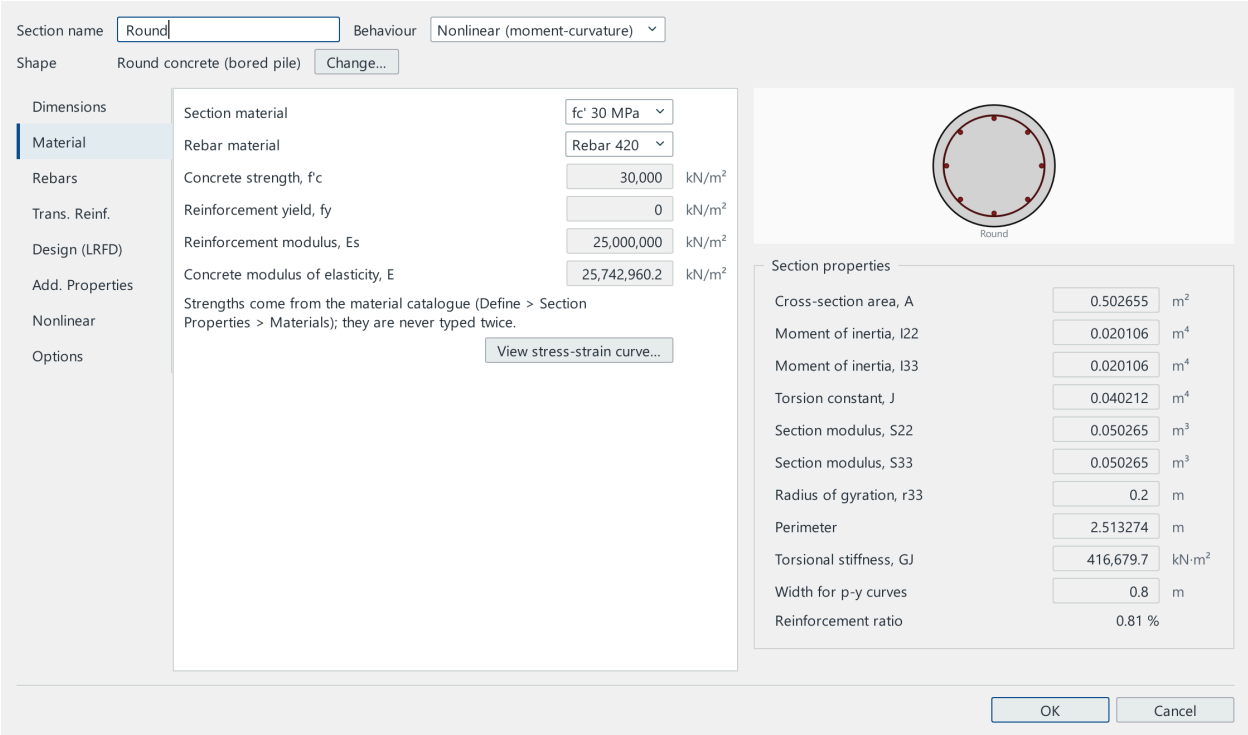



**Figure 9.7 —** Material tab

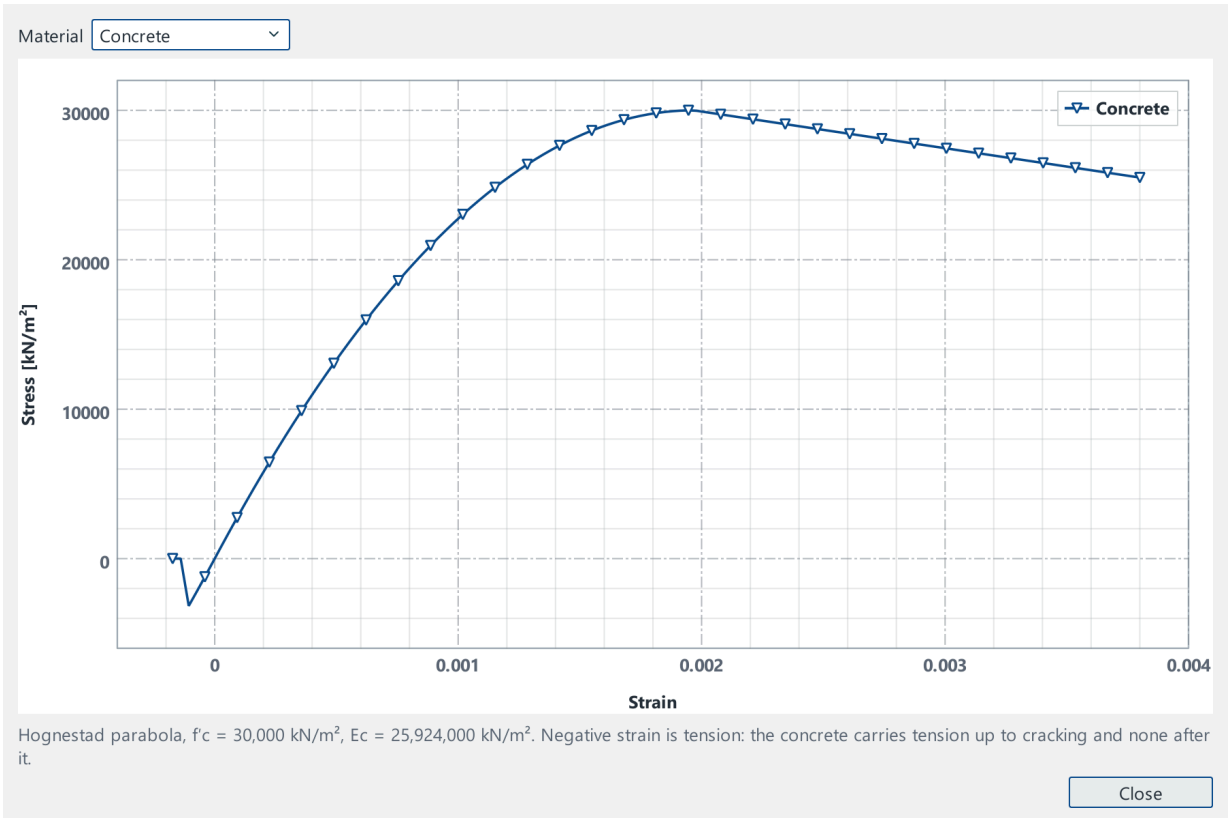



**Figure 9.8 —** Stress-Strain Curve of the concrete of a bored pile

### 9.3.5 Rebars

The Rebars tab (concrete shapes) describes the longitudinal reinforcement (Figure 9.9):

**Table 9.6 — Rebars tab**

| Field | Description |
|---|---|

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| Field | Description |
|---|---|
| Plain Concrete – No Rebars | an unreinforced section; the other fields are dimmed |
| Bar Size | US (#3 to #18), Canadian (10M to 55M), metric and other bar sizes, each listed with its diameter; for a user-defined size the **Bar Area** is typed and the **Bar Diameter** follows from it |
| Rebar Pattern | *Circle*: bars equally spaced around a circle; *Rectangle*: bars along the faces of a rectangle, with the numbers of bars on the top and bottom faces and on the left and right faces; *Manual*: bars at coordinates typed in the table |
| Number of bars | for the circle pattern, the number of bars around the circle |
| Concrete Cover to Edge of Bar | clear cover from the concrete surface to the outside of the bars |
| Manual bars table | Bar size, X and Y of each bar from the centre of the section. **Add bar** adds a bar of the section bar size (Insert), **Remove** deletes the selected bars (Delete), and **Fill from circle** replaces the table with the bars of the circle pattern, which can then be edited. |

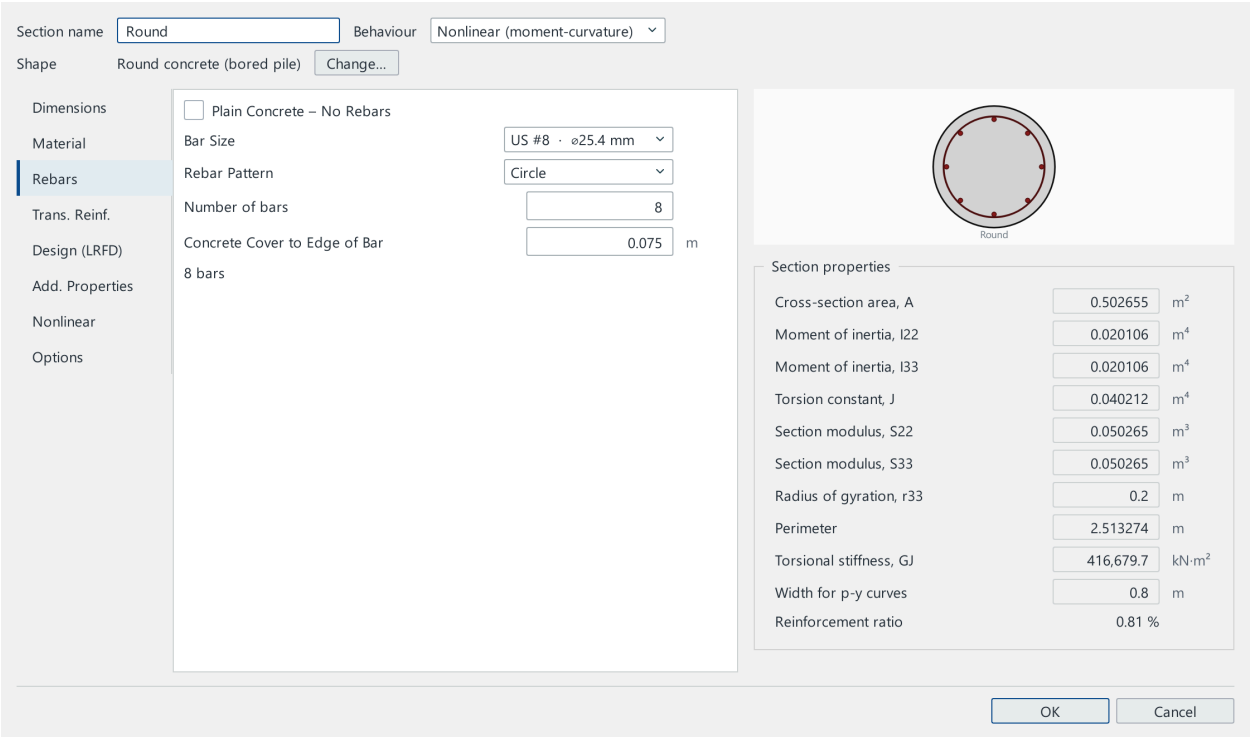



**Figure 9.9 —** Rebars tab

### 9.3.6 Trans. Reinf.

The Trans. Reinf. tab (round and rectangular concrete) describes the transverse reinforcement and the options of the confined-concrete and strain-hardening models (Figure 9.10):

**Table 9.7 — Trans. Reinf. tab**

| Field | Description |
|---|---|
| Consider Confined Concrete (Mander et al. 1988) | uses the confined-concrete model of Mander et al. for the core inside the transverse reinforcement; off, the concrete is unconfined |
| Rebar Type | Spiral or Hoop. Only confined round sections read it: hoops lower the confinement effectiveness. Rectangular sections always use ties. |
| Bar Size | size of the transverse bars |
| Number of Transverse Reinf.; Number of Legs X; Number of Legs Y | for a round section, the number of transverse bars; for a rectangular section, the number of legs of the ties in X and in Y |
| Spacing of Transv. Reinf. | centre-to-centre spacing along the pile |

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| Field | Description |
|---|---|
| fys of Transv. Reinf. (0 = fy) | yield strength of the transverse steel; zero uses $f_y$ of the longitudinal bars |
| Use Strain Hardening (longitudinal) | available with confined concrete only (dimmed otherwise): adds strain hardening to the stress–strain curve of the longitudinal bars, with **f_u / f_y**, the strain at the onset of hardening **ε_sh (strain at hardening)** and the **ε_su (ultimate strain)** |

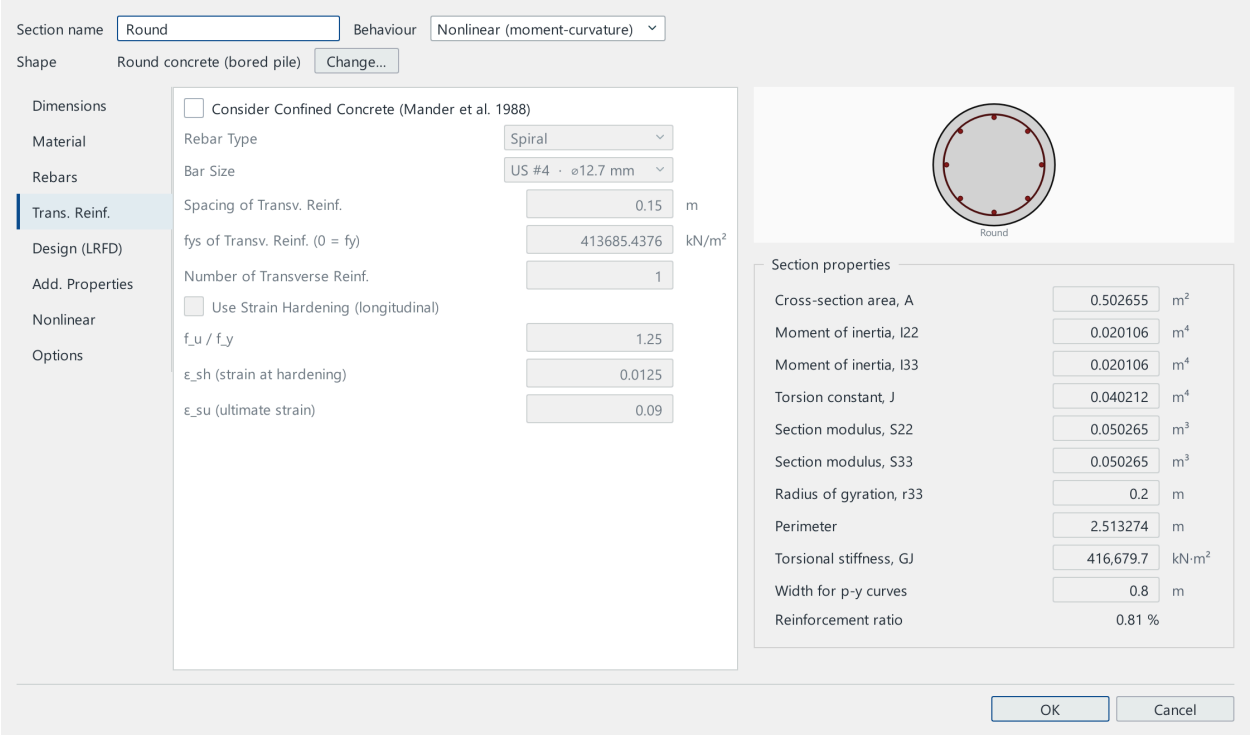



**Figure 9.10 —** Trans. Reinf. tab

### 9.3.7 Prestressing

The Prestressing tab (prestressed shapes) describes the strands (Figure 9.11):

**Table 9.8 — Prestressing tab**

| Field | Description |
|---|---|
| Prestressing Strand Type | User-defined strand; Grade 250, 270 or 300 ksi low-relaxation strand; smooth bars 145 or 160 ksi; deformed bars 150, 157 or 160 ksi; CFCC. A user-defined strand takes the ultimate strength, the modulus and the area typed below the list. |
| Strand/Bar Size | nominal size with its area |
| Number of Strands/PS Bars | number of strands in the section |
| Strand Pattern | Circle or Square. The square layout puts the same number of strands on every side, corners included, so the number of strands is a multiple of 4. |
| Cover Over Strands | clear cover to the strands |
| Automatically position strand | places the strands on the pattern from the cover; off, the coordinates are typed in the strand table (X, Y and Area of each strand). **Add strand** and **Remove** edit the table, and **Fill from pattern** replaces it with the strands of the automatic layout. |
| Prestress Force Before Losses | total jacking force of the strands |
| Fraction of Loss of Prestress | long-term loss as a fraction of the force before losses, typically 0.10 to 0.20; the value is given by the pile supplier |

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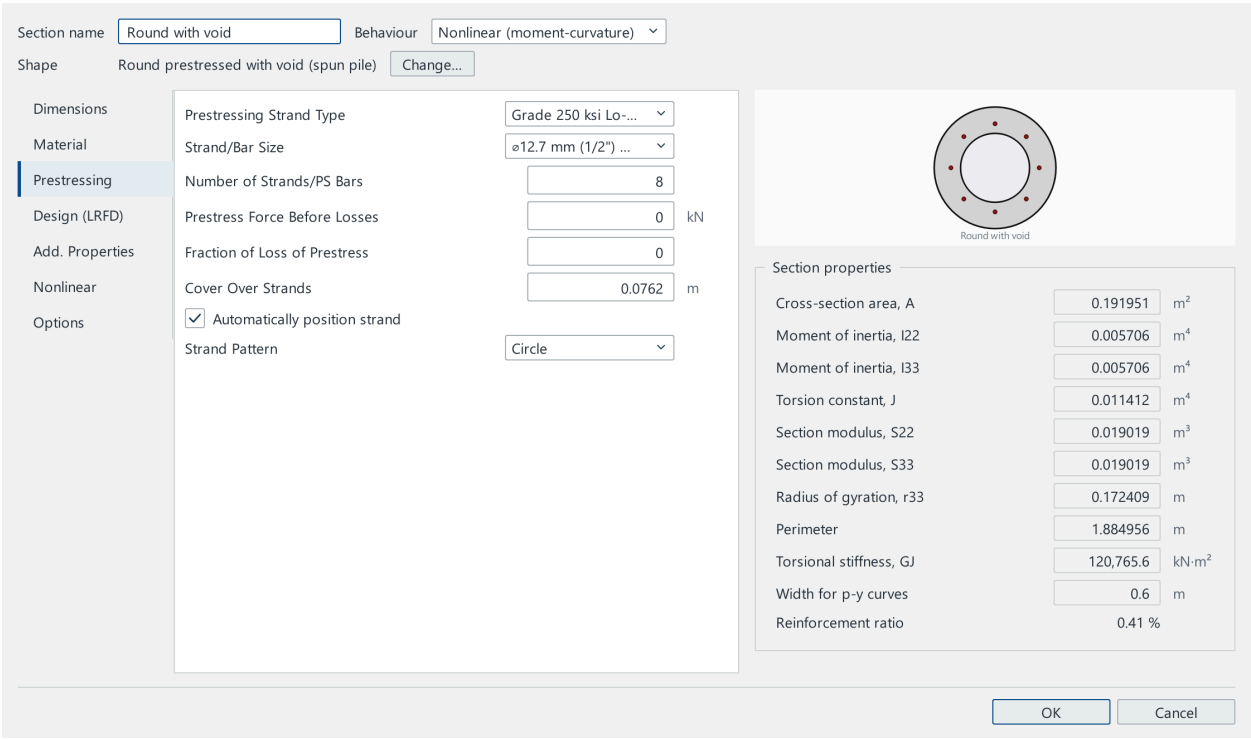



**Figure 9.11 —** Prestressing tab of a spun pile

### 9.3.8 Design (LRFD)

The Design (LRFD) tab holds the **Moment capacity about axis 3**, the **Moment capacity about axis 2**, the **Shear capacity, axis 2** and the **Shear capacity, axis 3** of the section. For the behaviour *Elastic with specified moment capacity*, the moment capacities are the plastic hinges of the pile and both must be positive. For every behaviour, the capacities are used for the demand/capacity ratios of load combinations (Chapter 11). A nonlinear section takes its moment capacity from its moment–curvature curve: **Compute moment capacity from M-φ** fills the moment fields from the curves, and the fields are dimmed with that reason in their tooltip.

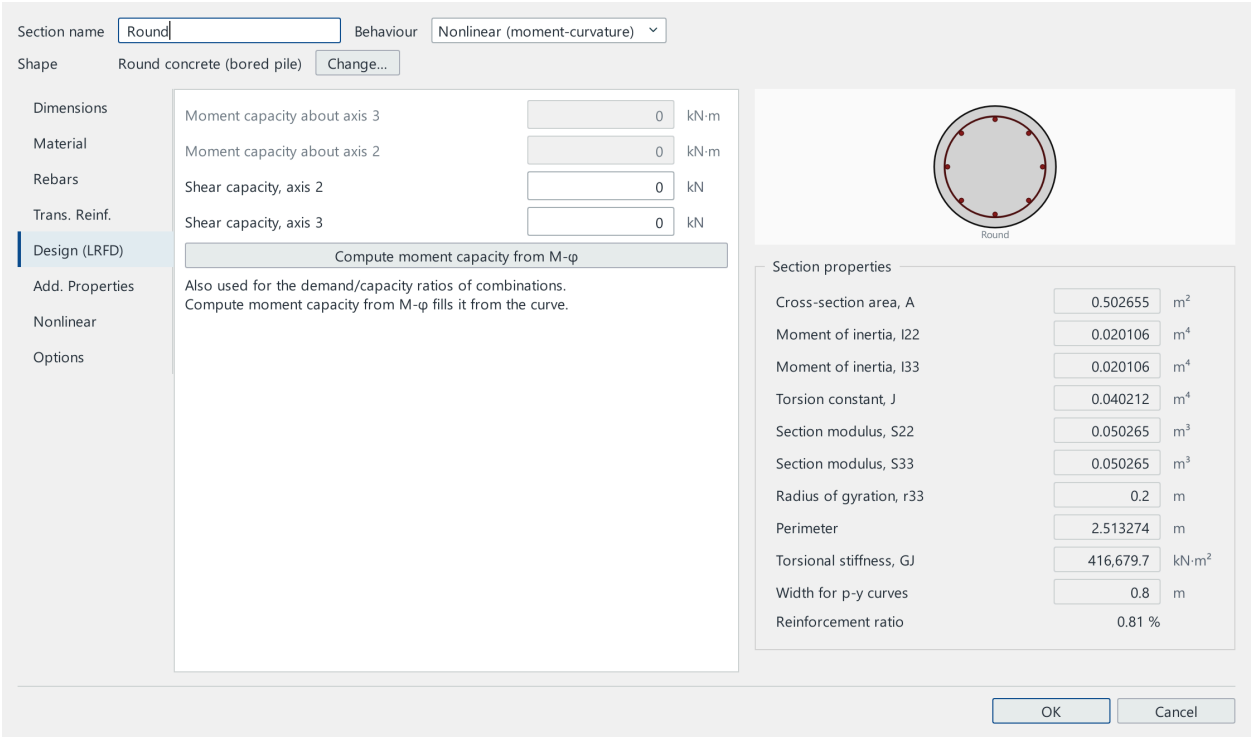



**Figure 9.12 —** Design (LRFD) tab

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### 9.3.9 Add. Properties

For a nonlinear section, the analysis uses the bending stiffness of the moment–curvature curves and, for the other quantities, a set of equivalent properties shown in the Add. Properties tab. With **Enter the values** off, every value is computed from the section and its material and shown dimmed; ticked, the values can be typed:

**Table 9.9 — Add. Properties tab**

| Field | Use |
|---|---|
| Eq. diameter | width used by the p-y curves, greater than zero; not used by round shapes, which use their own diameter |
| Perimeter | side friction of the axial curves; zero means no side friction |
| Area | tip resistance and axial stiffness |
| GJ (torsional stiffness) | torsional response |
| E eq. | axial stiffness = E eq. × Area, and the elastic pile of the equivalent-springs foundation stiffness; bending under load comes from the M-φ curves |
| Izz (0 = from the eq. diameter); Iyy (0 = from the eq. diameter) | elastic pile of the equivalent-springs foundation stiffness, bending about axes 3 and 2 |

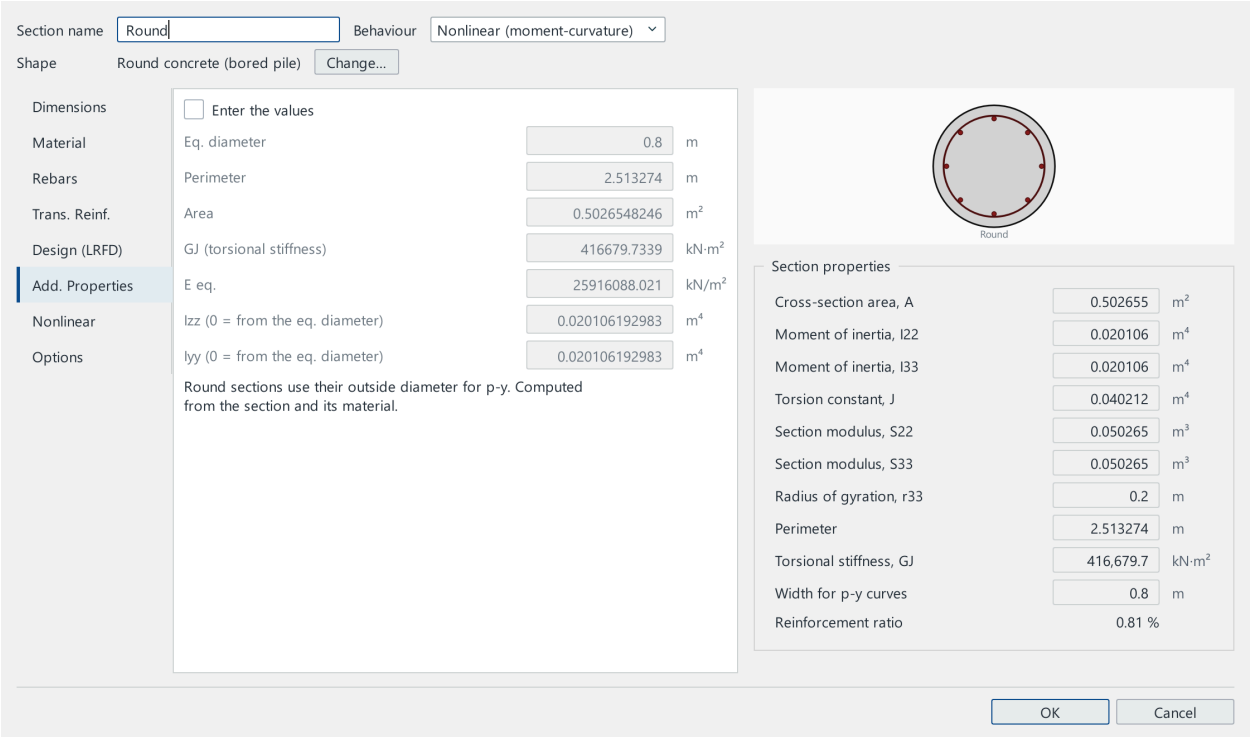



**Figure 9.13 —** Add. Properties tab

### 9.3.10 Nonlinear

The Nonlinear tab sets the axial thrusts for which moment–curvature curves are computed. In the analysis, the curve of each node is interpolated linearly between the two thrusts that bracket the axial force of the node, and beyond the first or the last thrust the nearest curve is used, so the list should span the axial forces expected in the piles, tension included where it can occur. The thrusts are given in one of three ways:

- **Set values from the axial capacity**: the list runs between the tension and the compression capacities of the section, moved inward by a small fraction of the range, with **Number of forces** values;
- **Set values from a maximum and a minimum**: **Number of forces** values between **Maximum** and **Minimum**;
- **Enter values manually**: the thrusts are typed in the table (**Add Row**, **Delete Row**); **Number of forces** follows the number of rows.

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The two generated lists have at least two values; **Include the zero value** adds a thrust of zero. The **Compression capacity** and the **Tension capacity** of the section are shown. **Show moment-curvature…** computes and draws the curves (Figure 9.15).

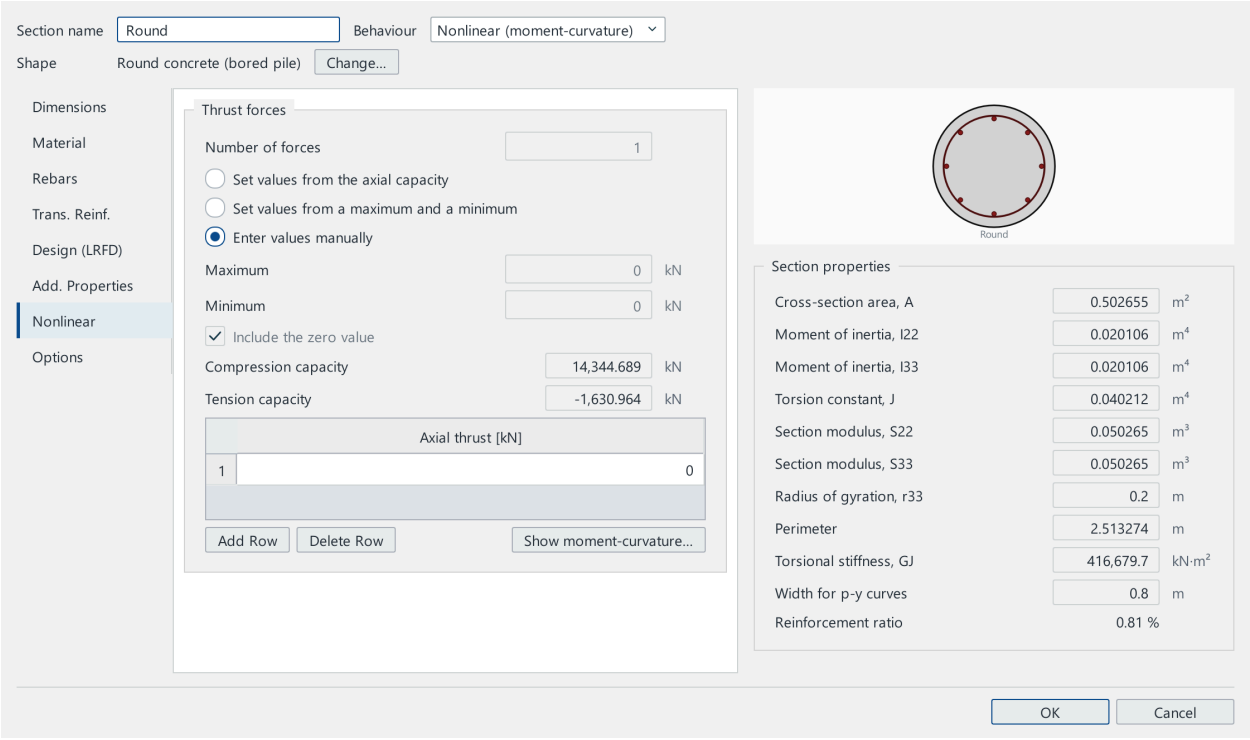



**Figure 9.14 —** Nonlinear tab

The window *Moment-Curvature* draws one curve for each axial thrust, for bending about axis 3 or about axis 2 as chosen in the list at the top, and states the peak moment. A curve that rises more steeply belongs to a larger compression; the flat part of a curve after cracking is the softening adjustment of the Options tab.

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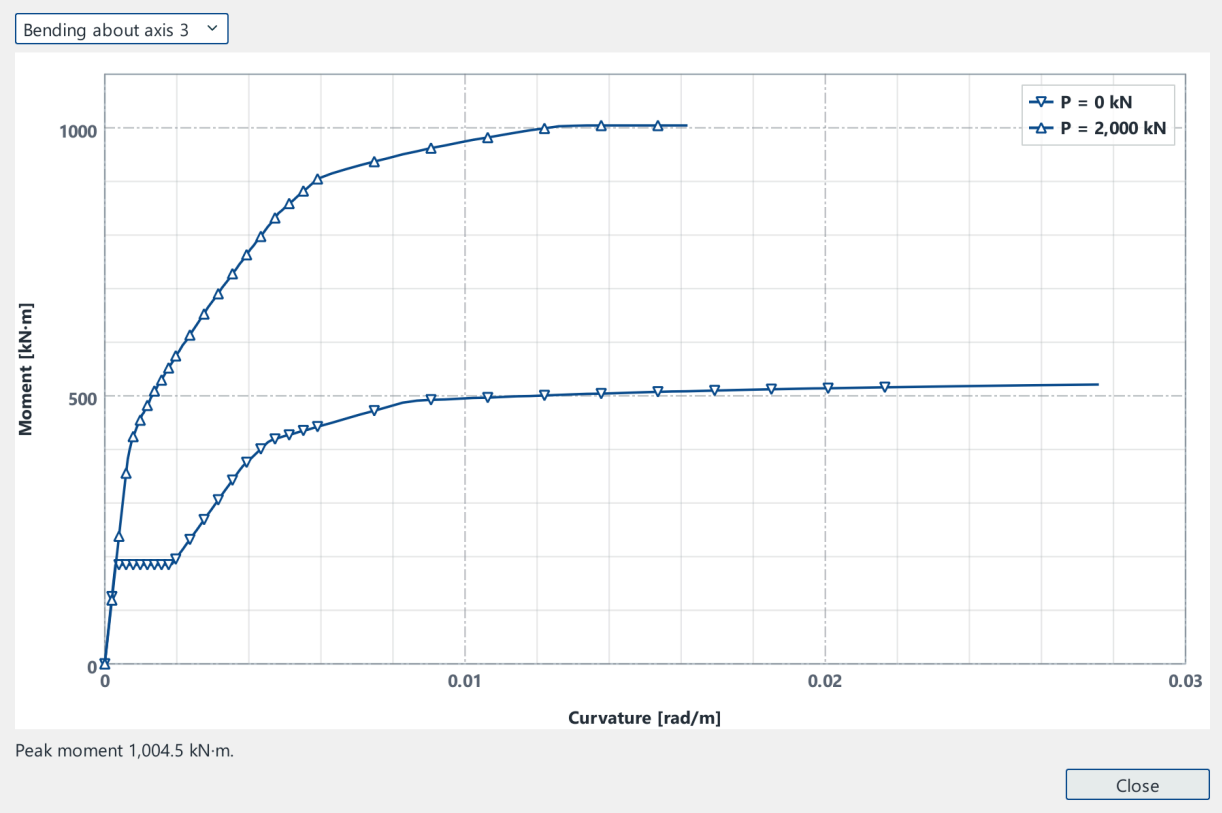



**Figure 9.15 —** Moment-Curvature of a bored pile at thrusts of 0 and 2 000 kN

For a **User M-φ curve** section, the tab also holds the bending data of the section (Figure 9.16): for axis 3, *Moment-curvature data* or *Elastic, I33*; for axis 2, *Same data as axis 3*, *Its own moment-curvature data* or *Elastic, I22*. The data are typed either as *Moment-curvature sets, one per axial thrust*, or as *User-defined EI against moment*. The set to edit is chosen in the list, and its points are typed in the table, **Curvature, φ** and **Moment, M** (or *EI* and *M*), with **Add Point** and **Delete Point**.

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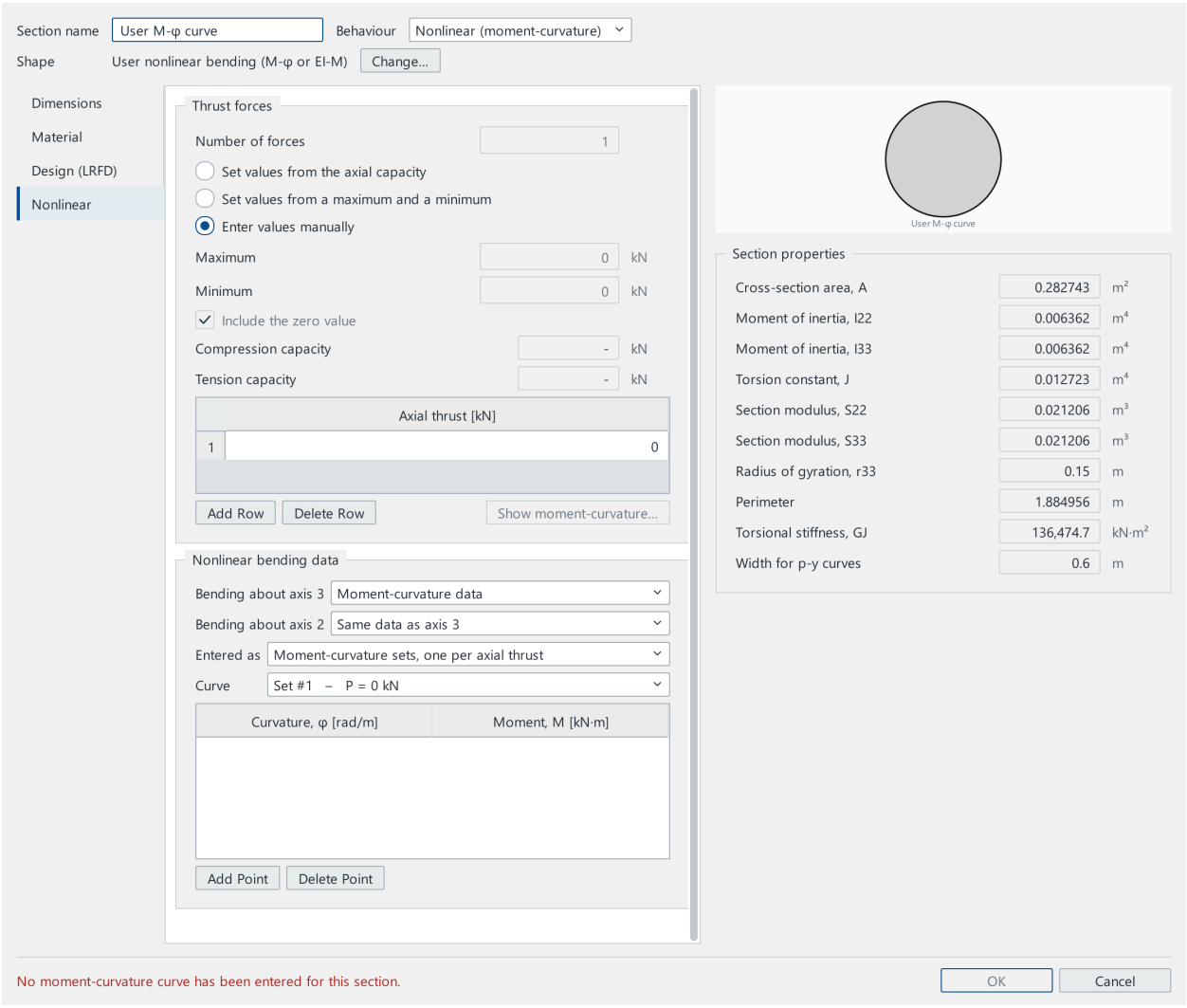



**Figure 9.16 —** Nonlinear tab of a User M-φ curve section

### 9.3.11 Options

The Options tab holds the options of the moment–curvature analysis, for the shapes that use them:

- **Adjust softening of the moment-curvature curve** (concrete and prestressed shapes, on by default): the moment of the curve is not allowed to fall once it has reached its peak; points at larger curvature keep the peak moment, so the curve has no descending branch;
- **Compute the equivalent elastoplastic curve (CALTRANS)** (concrete, prestressed and steel shapes): replaces the curve with its equivalent elastoplastic idealisation, with the yield point and the plastic moment of the Caltrans procedure. The idealisation is computed from the raw curve, so the softening adjustment is switched off and dimmed while it is ticked.

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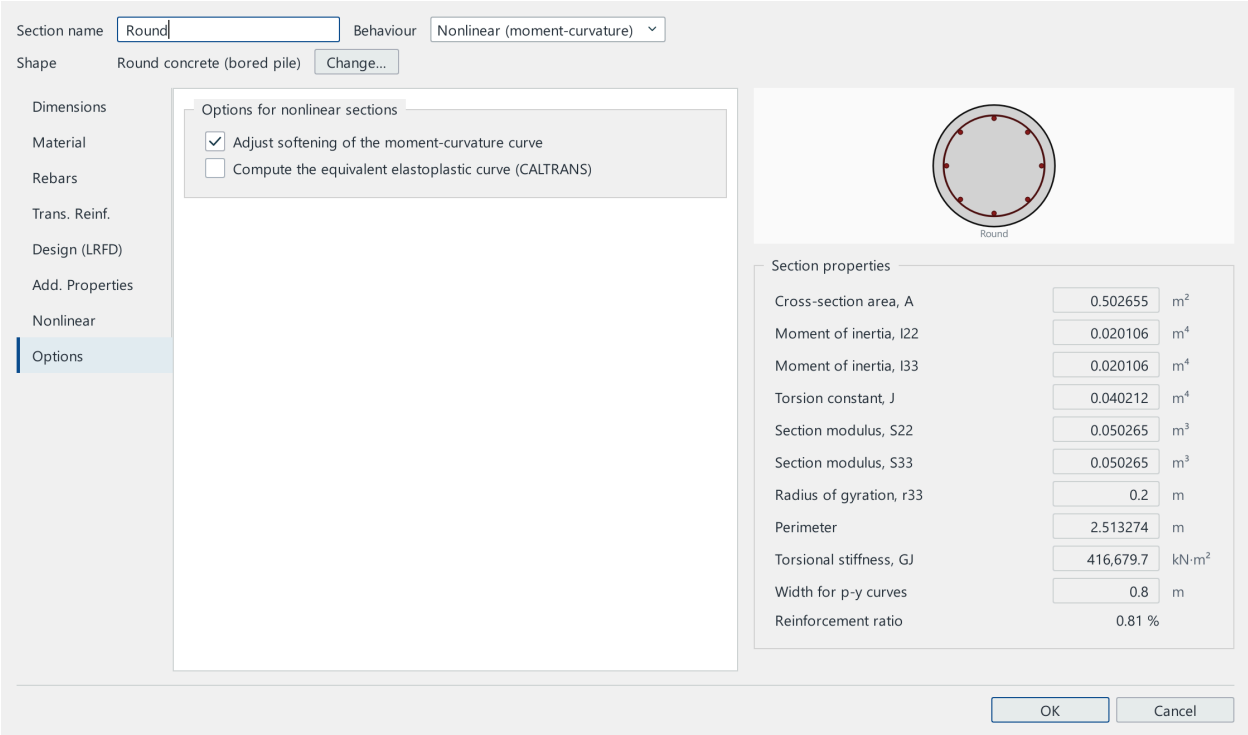



**Figure 9.17 —** Options tab

To define a bored pile section:

1. In Define Pile Sections click **Add New…**, choose the family *Concrete* and the shape *Round*, and click **OK**.
2. Type the name and the outside diameter in the Dimensions tab.
3. Select the concrete and the rebar materials in the Material tab.
4. Choose the bar size, the pattern, the number of bars and the cover in the Rebars tab, and the transverse reinforcement in the Trans. Reinf. tab.
5. Choose how the axial thrusts are set in the Nonlinear tab, and check the curves with **Show moment-curvature…**.
6. Click **Compute moment capacity from M-φ** in the Design (LRFD) tab if the demand/capacity ratios are wanted, and click **OK**.

## 9.4 Cap sections

**Define ▸ Section Properties ▸ Cap Sections…** lists the cap sections with their Cap Section, Thickness and Material columns. The cap section of the model is selected with **Assign ▸ Cap ▸ Cap Section…**; whether the cap is rigid or flexible is set for the whole cap with **Assign ▸ Cap ▸ Cap Behaviour…** (Chapter 10).

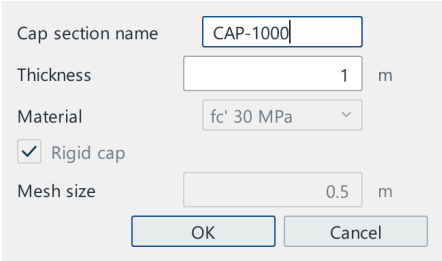



**Figure 9.18 —** Cap Section Data

**Table 9.10 — Cap Section Data**

| Field | Unit | Description |
|---|---|---|
| Cap section name | | name of the section |

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| Field | Unit | Description |
|---|---|---|
| Thickness | length | thickness of the cap, greater than zero. It is the thickness of the plate elements of a flexible cap, and the default height of the embedded part of a cap whose top elevation is not entered (Chapter 10). |
| Material | | material of the plate elements of a flexible cap; required for a flexible cap and dimmed for a rigid cap |
| Rigid cap | | shows the behaviour of the cap. When the form is opened from the model it is dimmed: the behaviour is set for the whole cap with Assign ▸ Cap ▸ Cap Behaviour. |
| Mesh size | length | target size of the plate elements when a flexible cap mesh is generated; greater than zero for a flexible cap and dimmed for a rigid cap |

A flexible cap whose mesh has been generated keeps the mesh size, the thickness and the material it was generated with: after changing them, regenerate the mesh with **Assign ▸ Cap ▸ Generate Flexible Cap Mesh**. A note in the form says so. A mesh read from another file carries its own plate thickness and material, and the cap section is used only if the mesh is regenerated.

## 9.5 Soil layers

**Define ▸ Soil ▸ Soil Layers…** lists the soil layers of the model, with the Layer name and the p-y curve of each. A soil layer is a material without a position: it describes the soil, and the soil profile places it between two elevations (Section 9.6). The same layer may be used more than once in the profile. The data form, *Soil Layer Data* (Figure 9.19), contains the common fields below and the parameters of the chosen p-y curve, described model by model in the following sections.

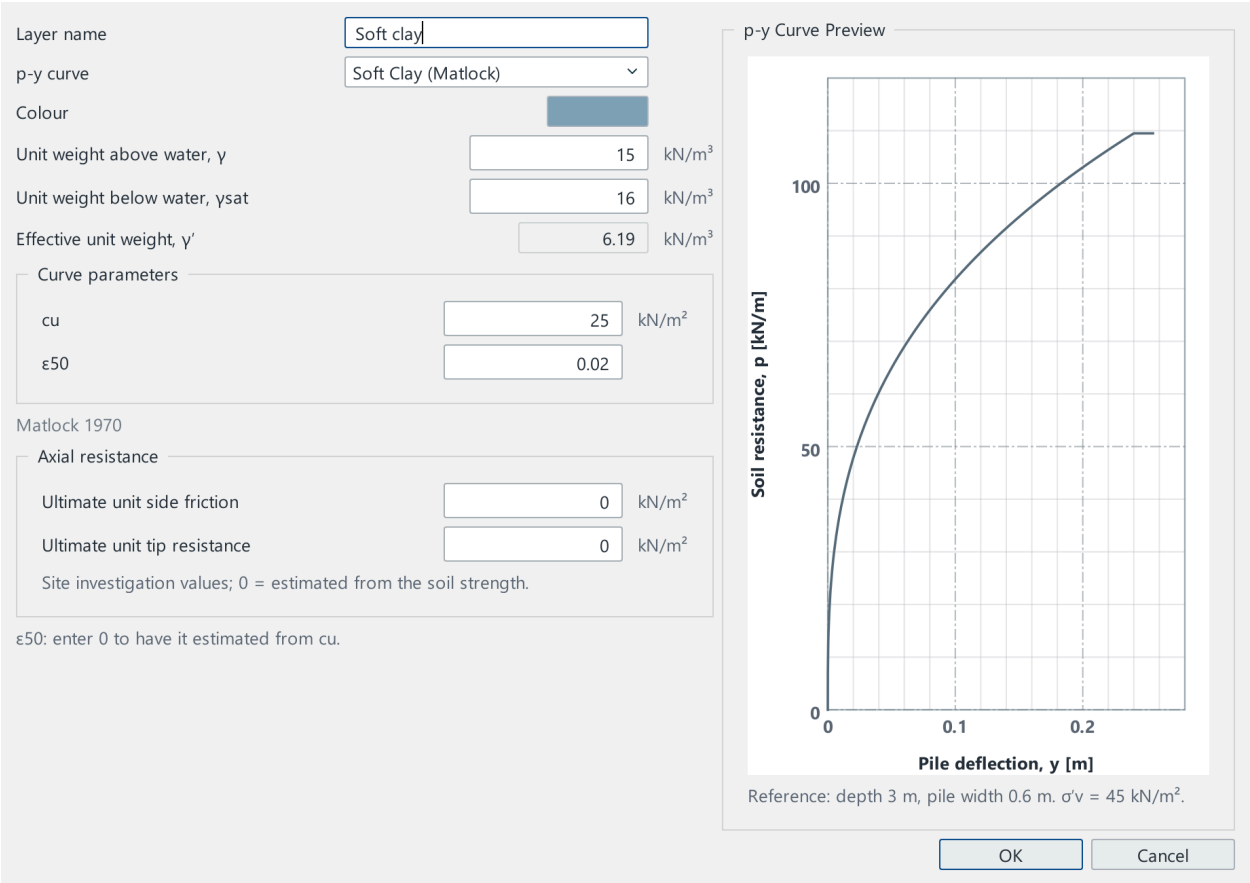



**Figure 9.19 —** Soil Layer Data with the preview of the p-y curve

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**Table 9.11 — Soil Layer Data, common fields**

| Field | Unit | Description |
|---|---|---|
| Layer name | | name used by the soil profile |
| p-y curve | | the lateral soil model of the layer (Table 9.12). Changing the model keeps the parameters typed for each model during the session, so switching back restores them. |
| Colour | | display colour of the layer in the profile, the views and the reports |
| Unit weight above water, γ | force/volume | total unit weight above the water table. In a profile without a water table it is used at every depth as the effective unit weight. |
| Unit weight below water, γsat | force/volume | total unit weight below the water table; used only where the profile has a water table |
| Effective unit weight, γ′ | force/volume | computed, γsat − γw; never entered |
| Curve parameters | | the parameters of the chosen model, with the publication on which the model is based written under them; a note states which values may be entered as zero to have them estimated |
| Ultimate unit side friction; Ultimate unit tip resistance | stress | site investigation values for the axial load-transfer curves of the piles in this layer; 0 = estimated from the soil strength (Technical Reference, chapter “Soil response for axial loading”) |

The **p-y Curve Preview** draws the curve that the analysis builds for the layer, at the reference depth, pile width and vertical effective stress stated under the graph, so that the effect of a parameter can be seen while it is typed. The preview is a check of the input; the curves of the analysis are built at every node with the actual depth, width and stress.

**Table 9.12 — Lateral soil models (p-y curves)**

| Model | Parameters | Reference |
|---|---|---|
| Soft Clay (Matlock) | $c_u$, $\varepsilon_{50}$ | Matlock (1970) |
| Soft Clay (API), User J | $c_u$, $\varepsilon_{50}$, $J$ | Matlock (1970); API RP 2A |
| Mod. Soft Clay with Initial k | $c_u$, $\varepsilon_{50}$, $k$, $J$ | Matlock (1970) |
| Stiff Clay with Free Water | $c_u$, $\varepsilon_{50}$, $k$ | Reese, Cox & Koop (1975) |
| Stiff Clay without Free Water | $c_u$, $\varepsilon_{50}$ | Welch & Reese (1972) |
| Stiff Clay with User k | $c_u$, $\varepsilon_{50}$, $k$ | Welch & Reese (1972) |
| Sand (Reese) | $\varphi'$, $k$ | Reese, Cox & Koop (1974) |
| API Sand (O’Neill) | $\varphi'$, $k$ | O’Neill & Murchison (1983) |
| Liquefied Sand (Rollins) | unit weight only | Rollins et al. (2005) |
| Liquefied Sand Hybrid | $(N_1)_{60cs}$, $S_{ur}$, $\varepsilon_{50}$ | Franke & Rollins (2013) |
| Silt / c-phi Soil (Cemented Sand) | $c$, $\varphi'$, $\varepsilon_{50}$, $k$ | Reese & Van Impe (2011) |
| Weak Rock | $q_u$, $E_{ir}$, $k_{rm}$, RQD | Reese (1997) |
| Strong Rock (Vuggy Limestone) | $q_u$ | Reese & Nyman (1978) |
| Piedmont Residual | field test and its value: $N_{60}$, $q_c$, $E_D$ or $E_M$ | Simpson & Brown (2006) |
| Massive Rock | $q_u$, $m_i$, $v$, GSI, $E_i$ or $E_m$, $\varepsilon_{50}$ | Liang, Yang & Nusairat (2009) |
| Loess | $q_c$ | Johnson et al. (2006) |
| Elastic Subgrade | $E_s$, $\sigma_{max}$ | linear spring |
| User-defined p-y | none (curves of the p-y set of the pile) | Section 9.7 |

**NOTE** A value of 0 for $\varepsilon_{50}$ or $k$ lets the program estimate it from the strength of the layer, as the note under the parameters states. Fields that the chosen model does not use are not shown.

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To define a soil layer:

1. Choose **Define** ▸ **Soil** ▸ **Soil Layers…** and click **Add New…**.
2. Type the name, choose the p-y curve and enter the unit weights.
3. Enter the parameters of the model; check the curve in the preview.
4. Enter the ultimate unit side friction and tip resistance if they are known from the site investigation, or leave them at zero, and click **OK**.

The following sections give, for each p-y curve, the parameters asked for in *Soil Layer Data*, with their units in the SI system, their default values and their meaning, and the notes that the form shows. The equations of the models are given in the Technical Reference, chapter "Soil response: p-y curves".

### 9.5.1 Soft Clay (Matlock)

Reference: Matlock 1970.

**Table 9.13 — Parameters of Soft Clay (Matlock)**

| Parameter | Unit | Default | Description |
|---|---|---|---|
| cu | kN/m² | 50 | undrained shear strength; about half the unconfined compressive strength qu |
| ε50 | | 0 | strain at 50 percent of the maximum stress; 0 = estimated from cu |

ε50: enter 0 to have it estimated from cu.

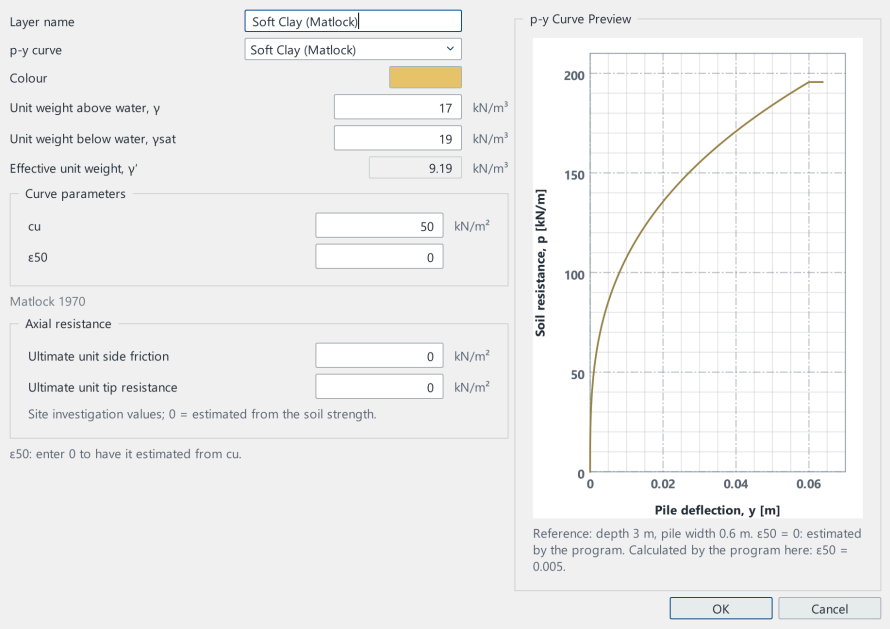



**Figure 9.20 —** Soil Layer Data, Soft Clay (Matlock)

### 9.5.2 Soft Clay (API), User J

Reference: Matlock 1970 / API RP-2A, J entered by the user.

**Table 9.14 — Parameters of Soft Clay (API), User J**

| Parameter | Unit | Default | Description |
|---|---|---|---|
| cu | kN/m² | 50 | undrained shear strength; about half the unconfined compressive strength qu |
| ε50 | | 0 | strain at 50 percent of the maximum stress; 0 = estimated from cu |
| J | | 0.25 | empirical constant in Np = 3 + sigma'v/cu + J z/b; Matlock publishes 0.5 for soft clay |

ε50: enter 0 to have it estimated from cu. J: values from 0.25 to 0.50 are usual.

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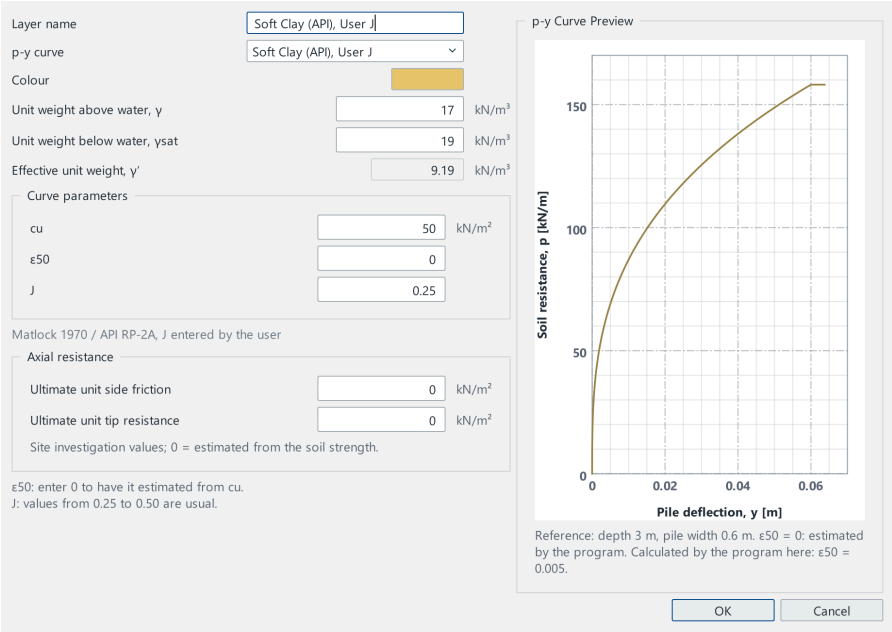



**Figure 9.21 —** Soil Layer Data, Soft Clay (API), User J

### 9.5.3 Mod. Soft Clay with Initial k

Reference: Matlock 1970 with an initial straight line of slope k times depth.

**Table 9.15 — Parameters of Mod. Soft Clay with Initial k**

| Parameter | Unit | Default | Description |
|---|---|---|---|
| cu | kN/m² | 50 | undrained shear strength; about half the unconfined compressive strength qu |
| ε50 | | 0 | strain at 50 percent of the maximum stress; 0 = estimated from cu |
| k | kN/m³ | 0 | subgrade reaction modulus; Es = k·x; 0 = estimated from cu or φ' |
| J | | 0.5 | empirical constant in Np = 3 + sigma'v/cu + J z/b; Matlock publishes 0.5 for soft clay |

k and ε50: enter 0 to have them estimated from cu. J: values from 0.25 to 0.50 are usual. J = 0.50 suits soft clay.

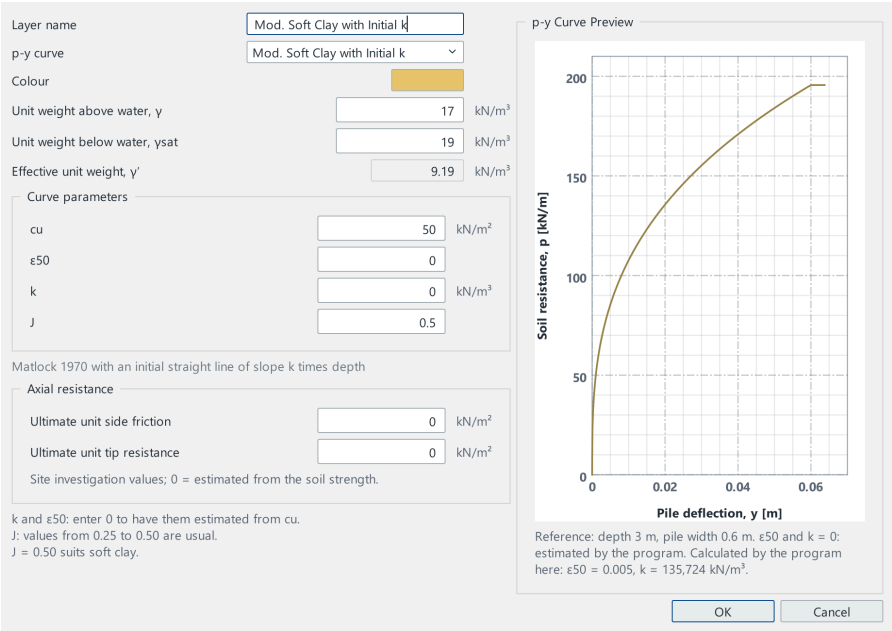



**Figure 9.22 —** Soil Layer Data, Mod. Soft Clay with Initial k

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### 9.5.4 Stiff Clay with Free Water

Reference: Reese, Cox & Koop 1975.

**Table 9.16 — Parameters of Stiff Clay with Free Water**

| Parameter | Unit | Default | Description |
|---|---|---|---|
| cu | kN/m² | 50 | undrained shear strength; about half the unconfined compressive strength qu |
| ε50 | | 0 | strain at 50 percent of the maximum stress; 0 = estimated from cu |
| k | kN/m³ | 0 | subgrade reaction modulus; Es = k·x; 0 = estimated from cu or φ' |

k and ε50: enter 0 to have them estimated from cu.

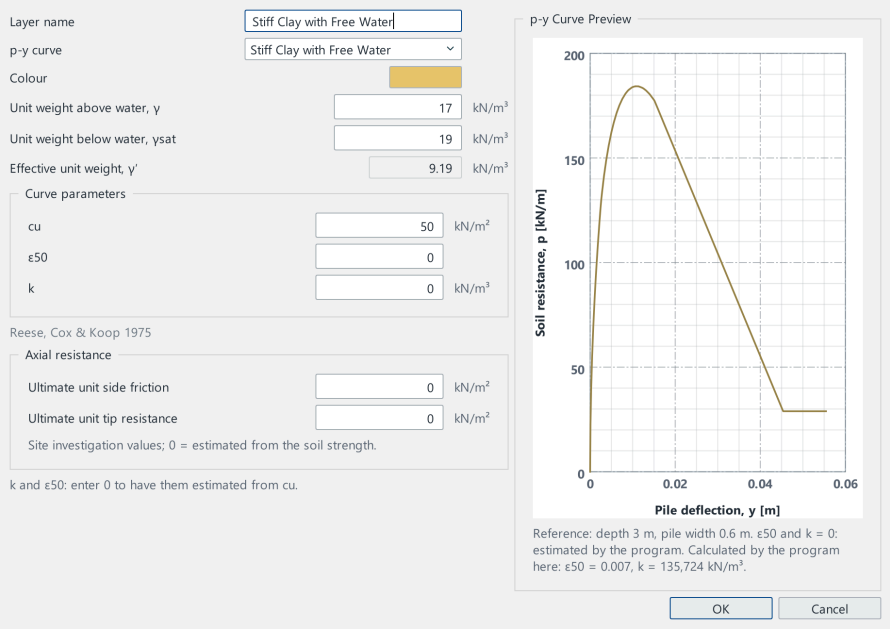



**Figure 9.23 —** Soil Layer Data, Stiff Clay with Free Water

### 9.5.5 Stiff Clay without Free Water

Reference: Welch & Reese 1972.

**Table 9.17 — Parameters of Stiff Clay without Free Water**

| Parameter | Unit | Default | Description |
|---|---|---|---|
| cu | kN/m² | 50 | undrained shear strength; about half the unconfined compressive strength qu |
| ε50 | | 0 | strain at 50 percent of the maximum stress; 0 = estimated from cu |

ε50: enter 0 to have it estimated from cu.

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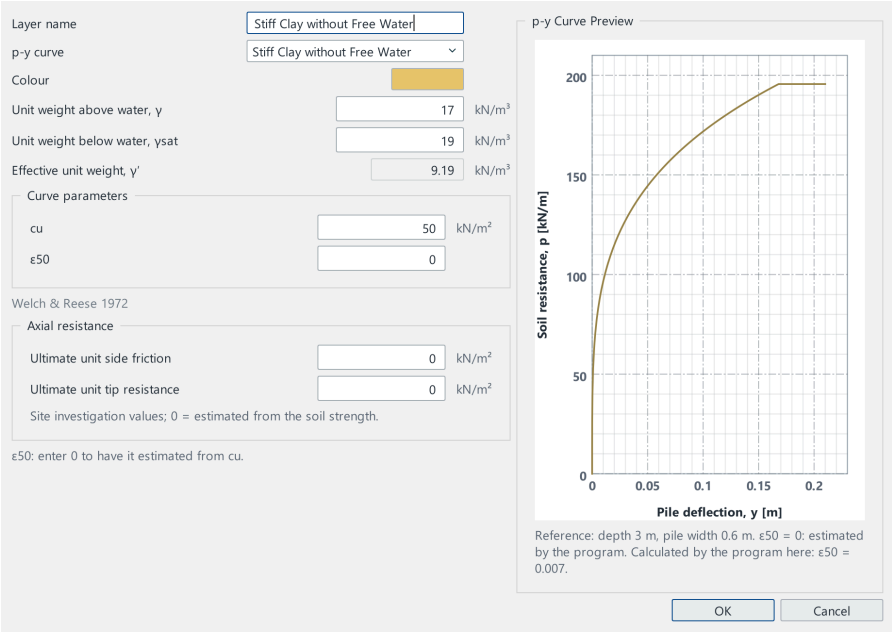



**Figure 9.24 —** Soil Layer Data, Stiff Clay without Free Water

### 9.5.6 Stiff Clay with User k

Reference: variant with user-specified k.

**Table 9.18 — Parameters of Stiff Clay with User k**

| Parameter | Unit | Default | Description |
|---|---|---|---|
| cu | kN/m² | 50 | undrained shear strength; about half the unconfined compressive strength qu |
| ε50 | | 0 | strain at 50 percent of the maximum stress; 0 = estimated from cu |
| k | kN/m³ | 0 | subgrade reaction modulus; Es = k·x; 0 = estimated from cu or φ' |

Like the stiff clay model without free water, but k sets the initial slope of the p-y curve. k should come from a lateral load test in the field. k and ε50: enter 0 to have them estimated from cu.

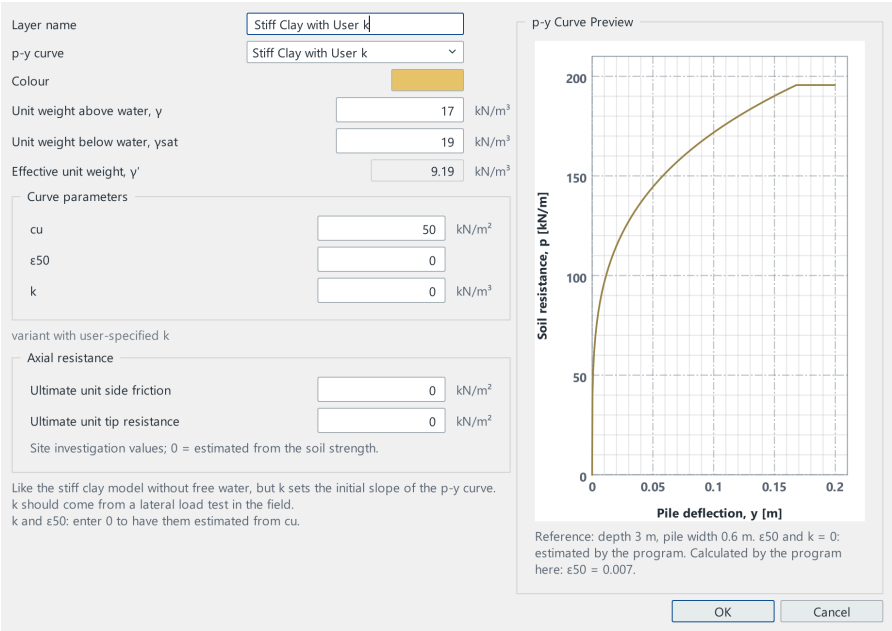



**Figure 9.25 —** Soil Layer Data, Stiff Clay with User k

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### 9.5.7 Sand (Reese)

Reference: Reese, Cox & Koop 1974.

**Table 9.19 — Parameters of Sand (Reese)**

| Parameter | Unit | Default | Description |
|---|---|---|---|
| φ' | ° | 30 | effective friction angle |
| k | kN/m³ | 0 | subgrade reaction modulus; Es = k·x; 0 = estimated from cu or φ' |

k: enter 0 to have it estimated from φ'.

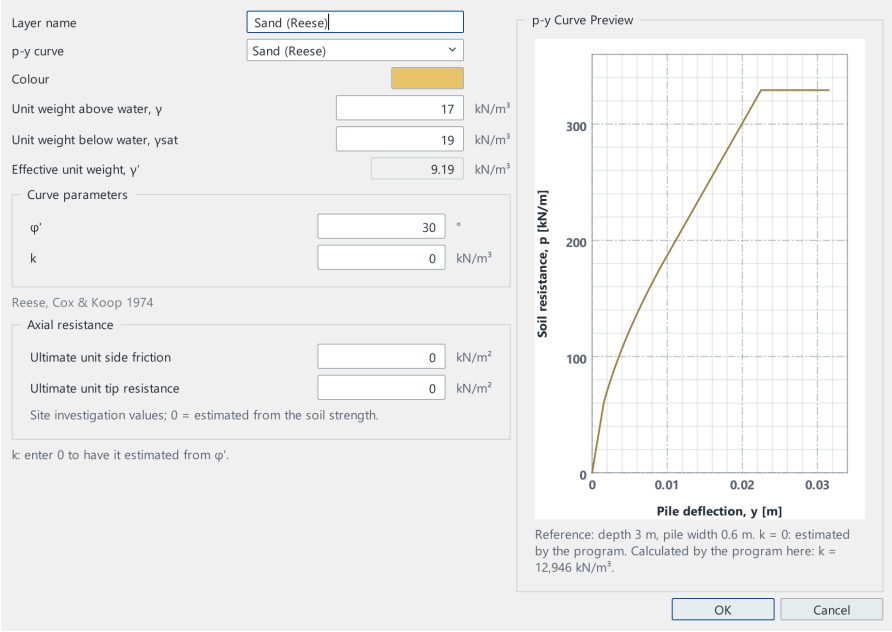



**Figure 9.26 —** Soil Layer Data, Sand (Reese)

### 9.5.8 API Sand (O'Neill)

Reference: O'Neill & Murchison 1983 / API RP-2A.

**Table 9.20 — Parameters of API Sand (O'Neill)**

| Parameter | Unit | Default | Description |
|---|---|---|---|
| φ' | ° | 30 | effective friction angle |
| k | kN/m³ | 0 | subgrade reaction modulus; Es = k·x; 0 = estimated from cu or φ' |

k: enter 0 to have it estimated from φ'.

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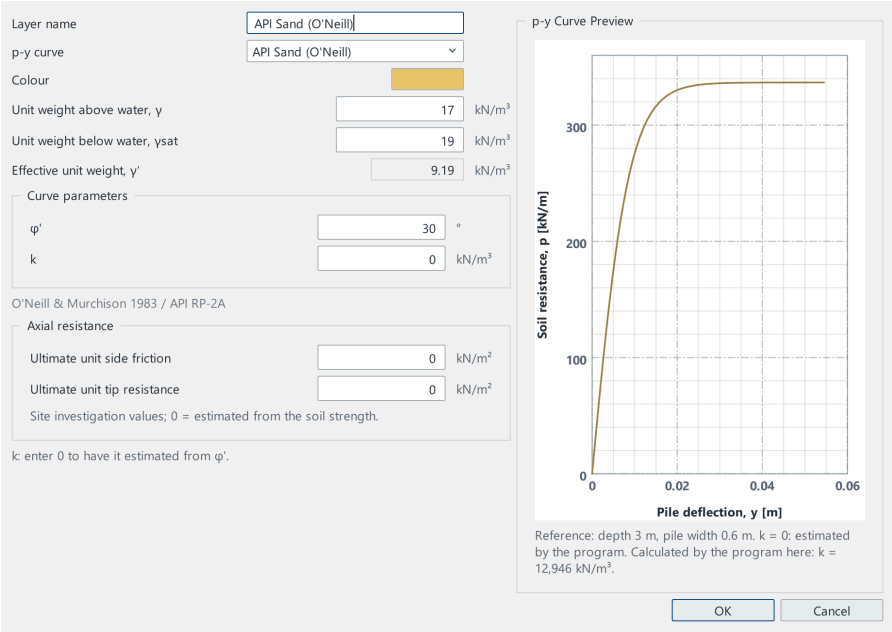



**Figure 9.27 —** Soil Layer Data, API Sand (O'Neill)

### 9.5.9 Liquefied Sand (Rollins)

Reference: Rollins et al. 2005.

The model has no parameters other than the unit weights.

For soil liquefied by earthquake shaking. Only the effective unit weight is used; no friction angle is needed. The model was calibrated for relative densities of about 45 to 55 percent.

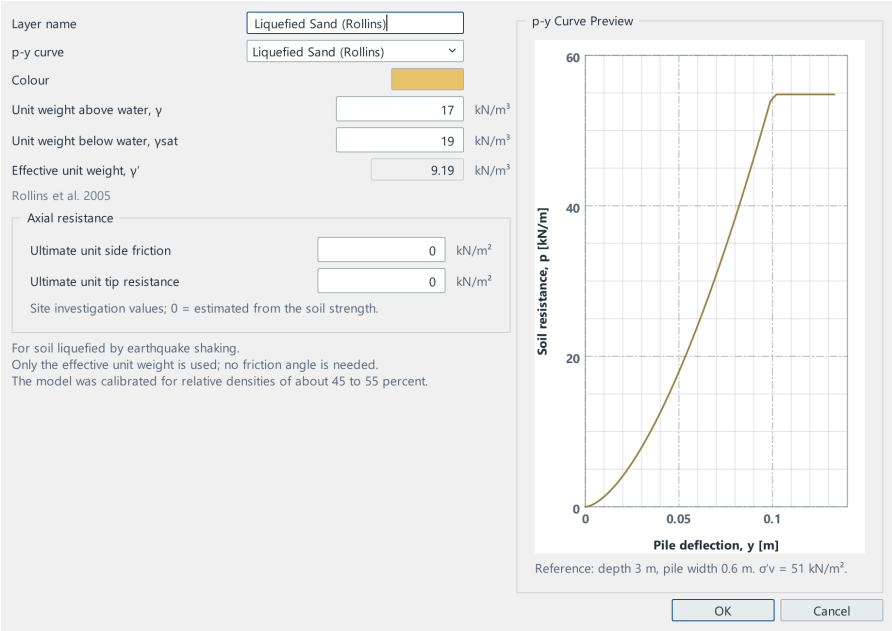



**Figure 9.28 —** Soil Layer Data, Liquefied Sand (Rollins)

### 9.5.10 Liquefied Sand Hybrid

Reference: Franke & Rollins 2013: lower of the dilative (Rollins et al. 2005) and residual (Matlock) curves.

**Table 9.21 — Parameters of Liquefied Sand Hybrid**

| Parameter | Unit | Default | Description |
|---|---|---|---|
| (N1)60cs | | 10 | corrected clean-sand SPT blow count; gives the residual strength and ε50 when those are 0 |

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| Parameter | Unit | Default | Description |
|---|---|---|---|
| Sur | kN/m² | 0 | residual shear strength of the liquefied sand; 0 = from (N1)60cs (33rd percentile; zero below 5 blows, which leaves the layer without lateral resistance) |
| ε50 | | 0 | strain at 50 percent of the residual strength; 0 = from (N1)60cs |

Calibrated for sand with a relative density of about 45 to 55 percent, to depths of about 6 m (19.7 ft). Option 1: enter the blow count (N1)60cs and 0 for the residual strength; the residual strength and ε50 are then computed from the blow count. Option 2: enter the residual strength and ε50 directly. ε50 usually ranges from 0.0005 for stronger soil to 0.05 for weaker soil.

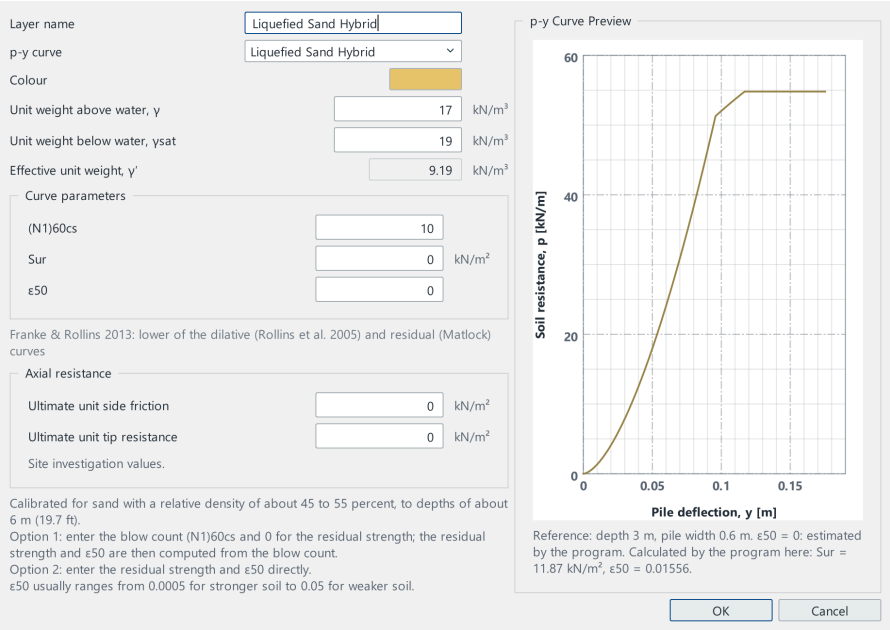



**Figure 9.29 —** Soil Layer Data, Liquefied Sand Hybrid

### 9.5.11 Silt / c-phi Soil (Cemented Sand)

Reference: Reese & Van Impe 2011.

**Table 9.22 — Parameters of Silt / c-phi Soil (Cemented Sand)**

| Parameter | Unit | Default | Description |
|---|---|---|---|
| cu | kN/m² | 50 | undrained shear strength; about half the unconfined compressive strength qu |
| φ' | ° | 30 | effective friction angle |
| ε50 | | 0 | strain at 50 percent of the maximum stress; 0 = estimated from cu |
| k | kN/m³ | 0 | subgrade reaction modulus; Es = k·x; 0 = estimated from cu or φ' |

Both the cohesion and the friction angle must be non-zero.

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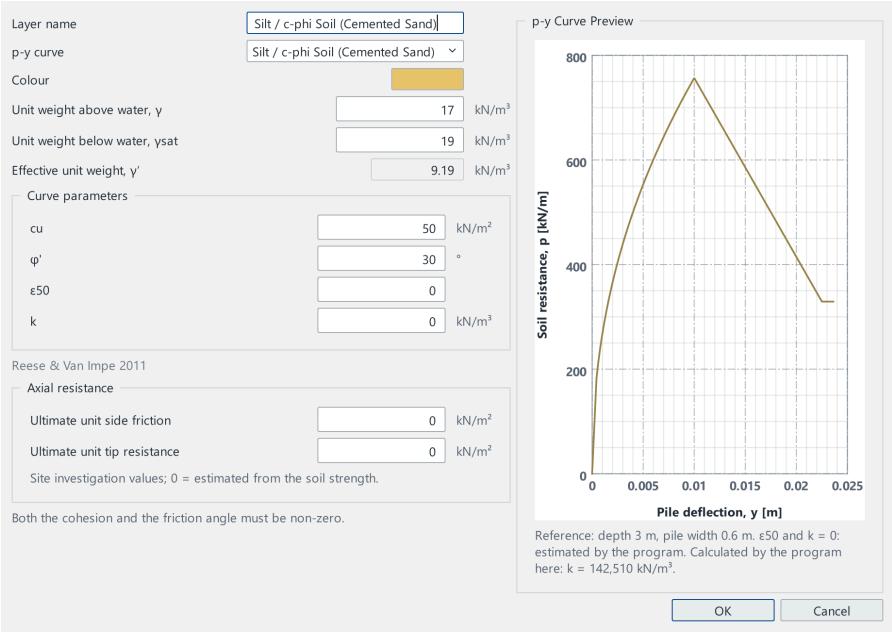



**Figure 9.30 —** Soil Layer Data, Silt / c-phi Soil (Cemented Sand)

### 9.5.12 Weak Rock

Reference: Reese 1997.

**Table 9.23 — Parameters of Weak Rock**

| Parameter | Unit | Default | Description |
|---|---|---|---|
| qu | kN/m² | 1,000 | uniaxial compressive strength of the rock |
| Eir | kN/m² | 500,000 | initial rock mass modulus |
| krm | | 0.0005 | strain factor for weak rock; 0 = linear p-y curve (no krm), and a pile tip in this layer then has no tip curve and cannot be analysed |
| RQD | % | 50 | rock quality designation |

Intended for cohesive intermediate geomaterials such as claystone and siltstone, with a uniaxial compressive strength of about 500 to 5,000 kPa (75 to 750 psi).

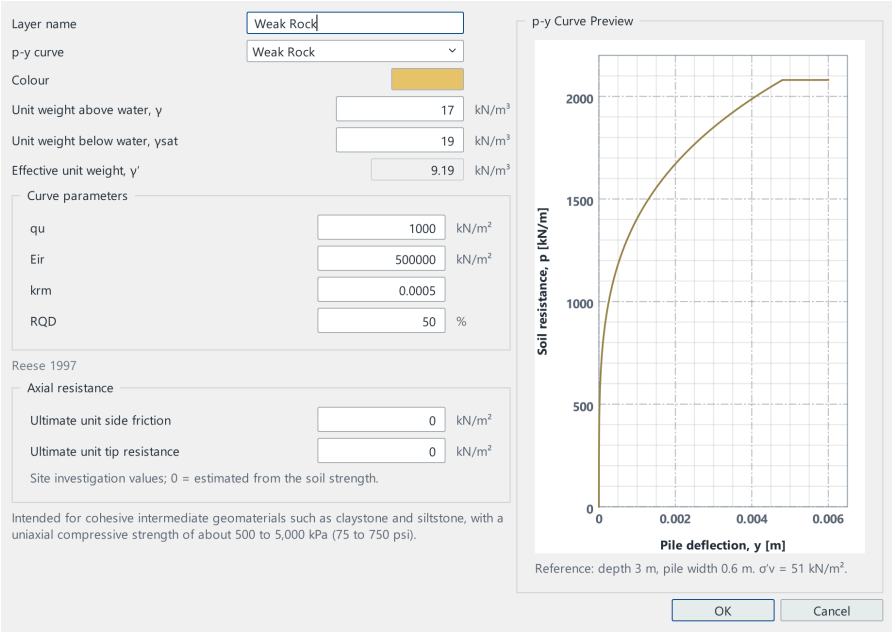



**Figure 9.31 —** Soil Layer Data, Weak Rock

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### 9.5.13 Strong Rock (Vuggy Limestone)

Reference: Reese & Nyman 1978.

**Table 9.24 — Parameters of Strong Rock (Vuggy Limestone)**

| Parameter | Unit | Default | Description |
|---|---|---|---|
| qu | kN/m² | 1,000 | uniaxial compressive strength of the rock |

The effective unit weight of this layer sets the vertical effective stress in the layers below it. Intended for limestone with a uniaxial compressive strength of about 5,000 to 16,700 kPa (750 to 2,500 psi).

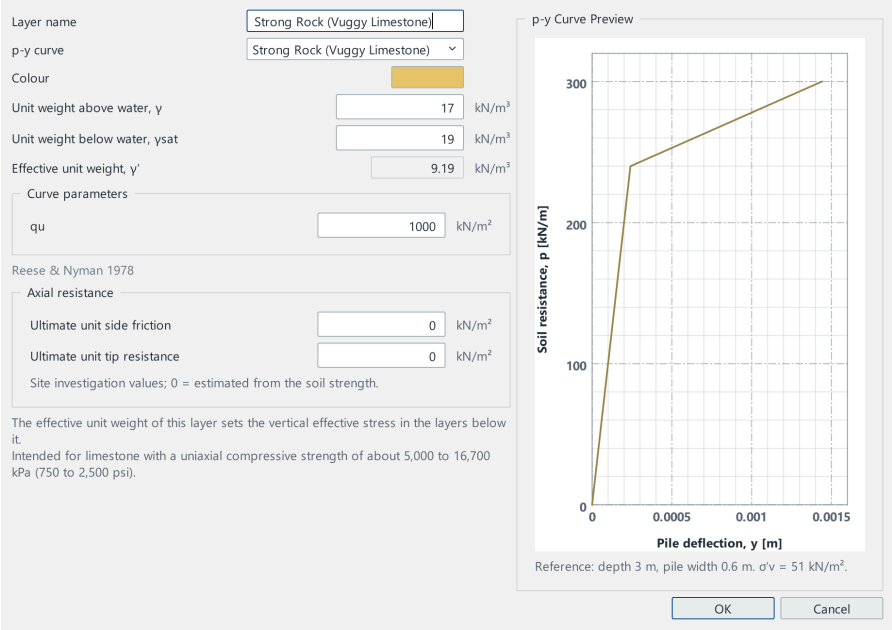



**Figure 9.32 —** Soil Layer Data, Strong Rock (Vuggy Limestone)

### 9.5.14 Piedmont Residual

Reference: Simpson & Brown 2006.

**Table 9.25 — Parameters of Piedmont Residual**

| Parameter | Unit | Default | Description |
|---|---|---|---|
| Field test | | 1 | field test that gives the initial p-y modulus Esi |
| N60 | | 20 | SPT blow count; Esi = 22 N60 lb/in³ |
| qc | kN/m² | 0 | cone tip resistance; Esi = 0.8136 qc per inch |
| ED | kN/m² | 0 | dilatometer modulus; Esi = 0.076 ED per inch |
| EM | kN/m² | 0 | Menard pressuremeter modulus; Esi = 0.235 EM per inch |

Only the value of the selected field test is used; the other test values are ignored.

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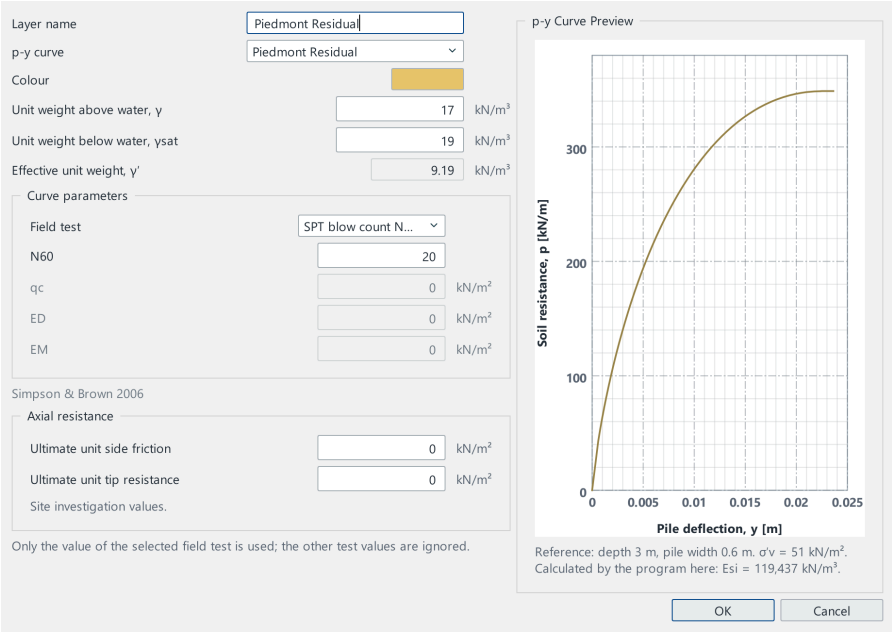



**Figure 9.33 —** Soil Layer Data, Piedmont Residual

### 9.5.15 Massive Rock

Reference: Liang, Yang & Nusairat 2009 (Hoek-Brown).

**Table 9.26 — Parameters of Massive Rock**

| Parameter | Unit | Default | Description |
|---|---|---|---|
| qu | kN/m² | 20,000 | uniaxial compressive strength of the intact rock |
| mi | | 10 | Hoek-Brown material index of the rock type (claystone 4 ... granite 32) |
| v | | 0.25 | Poisson's ratio of the rock mass |
| GSI | | 50 | geological strength index |
| Ei | kN/m² | 5,000,000 | intact rock modulus (option 1); used when the rock mass modulus is 0: Em = Ei/100 e^(GSI/21.7) |
| Em | kN/m² | 0 | rock mass modulus (option 2); 0 = from Ei and GSI |
| ε50 | | 0 | strain factor used only by the tip load-settlement curve of a driven pile ending in this layer; 0 = none, and such a pile cannot be analysed |

Em: enter 0 to compute it from Ei and GSI; a non-zero Em is used as entered and Ei is ignored.

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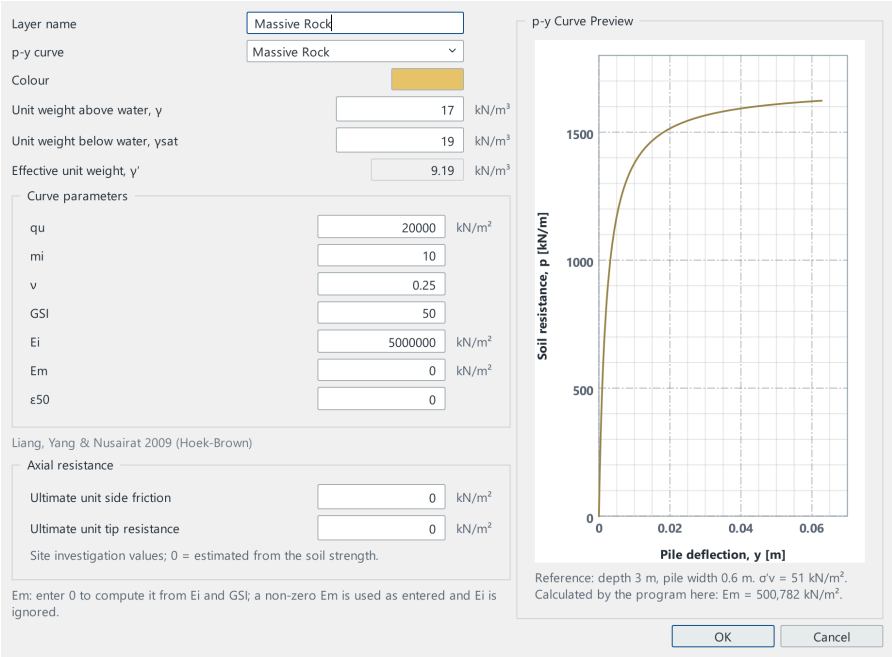



**Figure 9.34 —** Soil Layer Data, Massive Rock

### 9.5.16 Loess

Reference: Johnson, Parsons, Dapp & Brown 2006.

**Table 9.27 — Parameters of Loess**

| Parameter | Unit | Default | Description |
|---|---|---|---|
| qc | kN/m² | 3,000 | cone tip resistance |

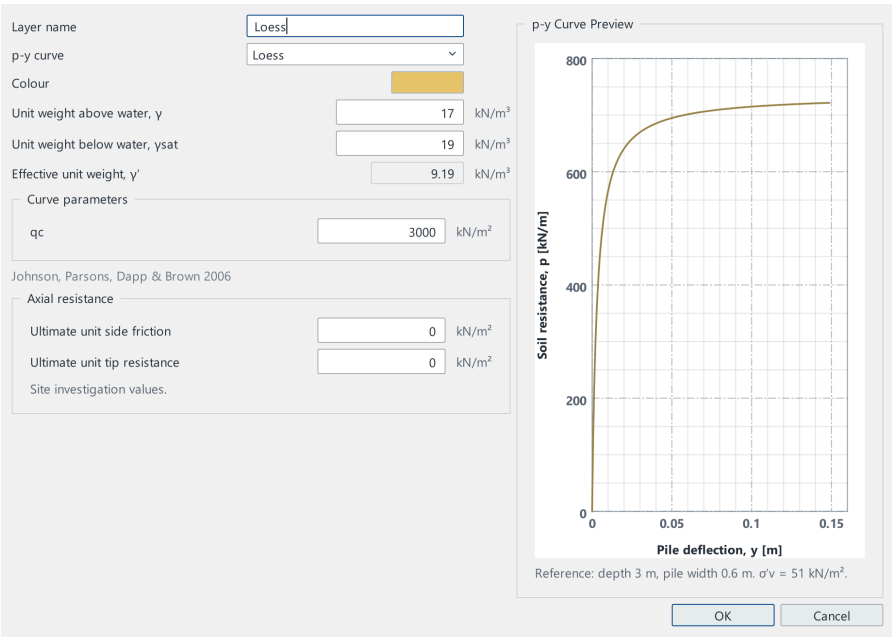



**Figure 9.35 —** Soil Layer Data, Loess

### 9.5.17 Elastic Subgrade

Reference: linear spring.

**Table 9.28 — Parameters of Elastic Subgrade**

| Parameter | Unit | Default | Description |
|---|---|---|---|

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| Parameter | Unit | Default | Description |
|---|---|---|---|
| Es | kN/m³ | 20,000 | constant subgrade reaction modulus |
| σmax | kN/m² | 0 | maximum stress transfer; p is limited to b times this value; 0 = no limit on stress transfer |

The effective unit weight of this layer sets the vertical effective stress in the layers below it. Maximum stress transfer: 0 means no limit.

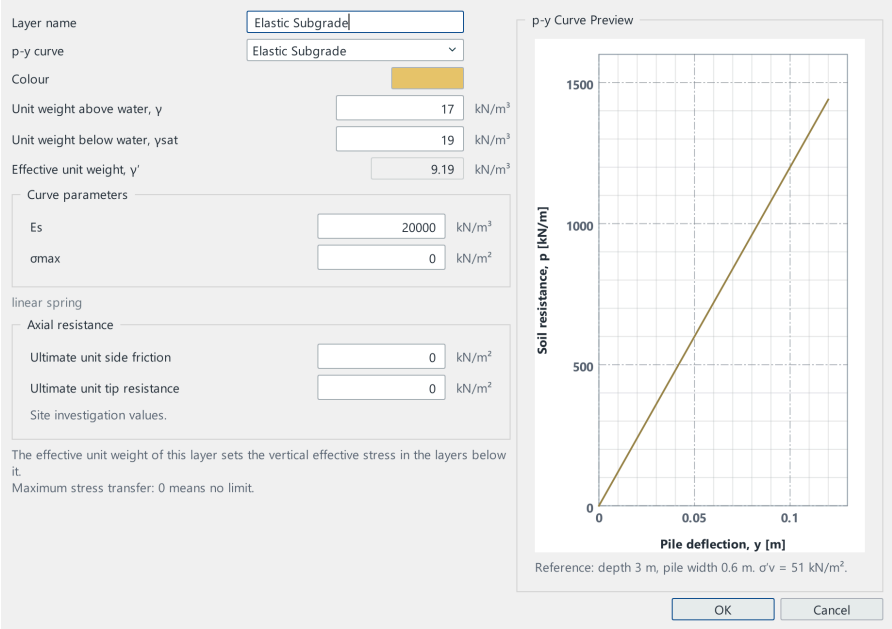



**Figure 9.36 —** Soil Layer Data, Elastic Subgrade

### 9.5.18 User-defined p-y

Reference: y-p table per depth, entered in the User Curves tab.

The model has no parameters other than the unit weights.

The effective unit weight of this layer sets the vertical effective stress in the layers below it. The lateral resistance of this layer comes from user-defined p-y curves. Type the p-y curves under Define > Soil > User p-y Curves, tick User-defined p-y curves in Analyze > Set Analysis Options and assign the set to the piles (Assign > Pile > p-y Set).

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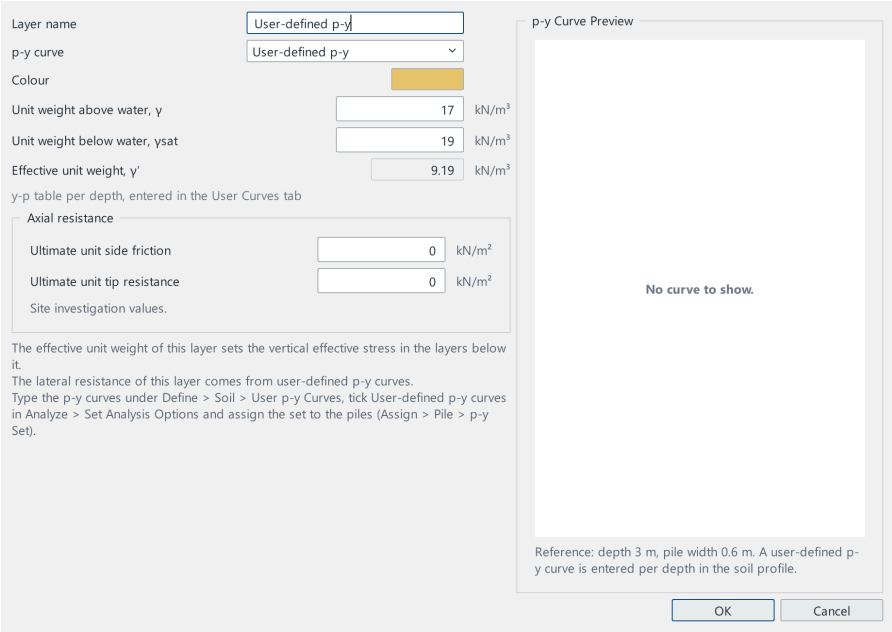



**Figure 9.37 —** Soil Layer Data, User-defined p-y

## 9.6 Soil profile

**Define** ▸ **Soil** ▸ **Soil Profile…** opens *Soil Profile Data* (Figure 9.38), which stacks the soil layers from the ground surface downward. The drawing on the right shows the stack to scale with the colours of the layers, the water table and the scoured zone. Every pile uses this profile. The ground surface is level, or it slopes when a shape is set with **Sloping…** (Section 9.6.1); a ground surface elevation assigned to a pile overrides both (Chapter 10).

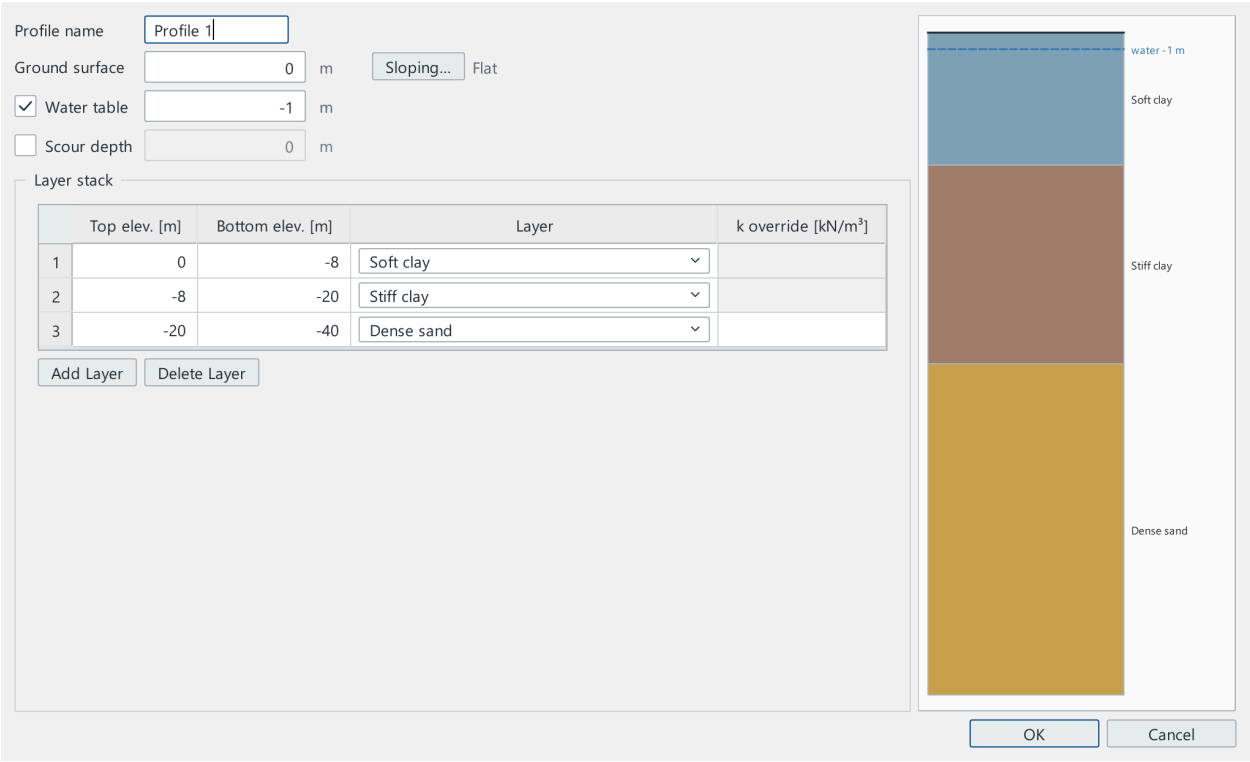



**Figure 9.38 —** Soil Profile Data

**Table 9.29 — Soil Profile Data**

| Field | Unit | Description |
|---|---|---|

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| Field | Unit | Description |
|---|---|---|
| Profile name | | name of the profile |
| Ground surface | length | elevation of the ground surface in the global system |
| Water table | length | ticked: the elevation of the water table; below it the unit weight below water of each layer is used. Unticked: a profile without a water table, in which the unit weight above water of each layer is the effective unit weight at every depth. |
| Scour depth | length | ticked: the depth of soil removed by scour below the ground surface. The removed soil gives no lateral resistance; the effective ground surface, ground surface minus scour depth, is shown. |
| Layer stack | | one row per layer: **Top elev.** and **Bottom elev.** of the layer, the soil **Layer** chosen from the soil layers, and **k override**, an optional p-y modulus *k* for this row. A blank override uses the value in Soil Layer Data; the override lets a shared layer use a different *k* here, and it is accepted only for models that use *k*. **Add Layer** adds a row under the last one; **Delete Layer** removes the selected row. |
| Sloping… | | opens *Sloping Ground* (Section 9.6.1) to give the ground surface of this profile a slope; the line beside the button summarises the current shape |

The profile needs at least one layer; every row needs its top above its bottom and a soil layer, and the layers must be contiguous: a gap between the bottom of one layer and the top of the next is reported with its elevations. The last layer should extend below the tips of the longest piles.

### 9.6.1 Sloping ground

**Sloping…** in *Soil Profile Data* opens *Sloping Ground* (Figure 9.39). The ground surface changes in one direction in plan: along a distance axis it is described by break points of distance and elevation, linear between two points. The soil layers keep their elevations, so on the lower side of a slope the upper layers are cut by the ground surface. The section on the right shows the ground, the layers, the water table and every pile, with the point where its axis meets the ground, before the shape is accepted.

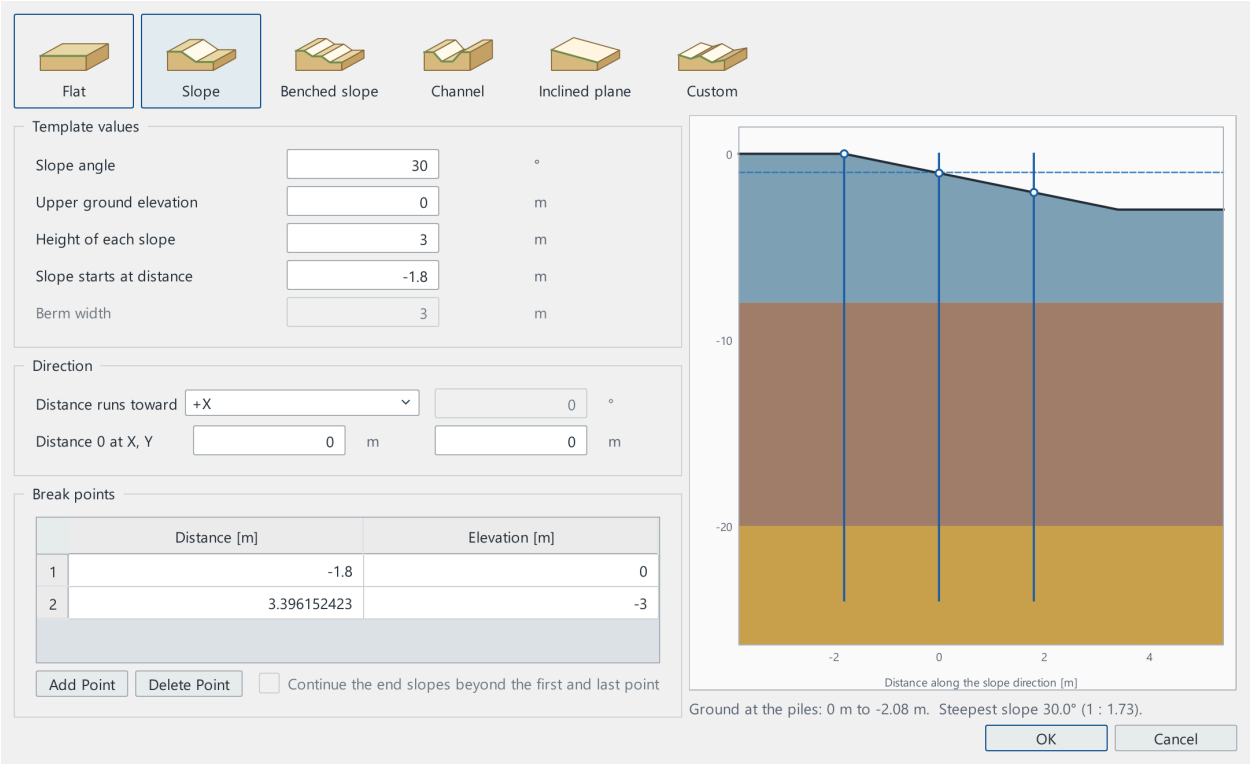



**Figure 9.39 —** Sloping Ground, template Slope

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**Table 9.30 — Sloping Ground**

| Field | Unit | Description |
|---|---|---|
| Templates | | **Flat** (level ground at the ground surface of the profile), **Slope** (level, one slope down, level again), **Benched slope** (two slopes with a level berm between them), **Channel** (a slope down to a level bed, then up again), **Inclined plane** (one constant slope across the model) and **Custom** (the break points are typed). A template fills the table of points; the points can then be edited, which makes the shape Custom. Only the fields that the chosen template uses are active. |
| Slope angle | ° | angle of each slope from the horizontal, 0.5° to 89.5° |
| Upper ground elevation | length | elevation of the ground before the first slope |
| Height of each slope | length | difference of elevation over one slope |
| Slope starts at distance | length | distance along the axis where the upper ground starts to fall; when the dialog opens it is the first row of piles |
| Berm width | length | width of the level part between two slopes (Benched slope) or of the bed (Channel) |
| Distance runs toward | ° | direction in plan in which the distance increases: +X, +Y, −X, −Y, or Other angle with the plan angle counter-clockwise from +X. The templates put the upper ground at the start and fall toward this side. |
| Distance 0 at X, Y | length | point in plan where the distance is zero |
| Points | length | table of break points, **Distance** and **Elevation**, with the distances increasing; **Add Point** and **Delete Point** edit it |
| Continue the end slopes beyond the first and last point | | unticked: the ground is level beyond the first and the last point; ticked: the end slopes continue |

The line under the table summarises the shape, for example *Level ground at the soil profile ground surface*. The ground surface of each pile is the point where the axis of the pile meets the sloping surface, so a battered pile takes the ground where it actually enters the soil. Next to a steep slope, a head above the ground takes the first point below the head, and a buried head takes the nearest point above it. The analysis treats the shape exactly as a ground surface elevation assigned to each pile; such an assignment is an exception that overrides the shape for the selected piles (Chapter 10), and the piles that carry one are drawn with a ring. Scour is measured from the ground of each pile. The table *Ground Surface* of **Display ▸ Show Tables** and section F of the output report list the ground of every pile.

In the soil that remains above the tip of a pile, the layers above the ground of that pile give no resistance, and the curves of the layers below are computed from the ground of that pile: the effective stress, and the depth used by the curves for sand, weak rock and liquefied sand, start at the ground of the pile, not at the ground surface of the profile. Check Model reports an error when the distances do not increase, when a value is not a number, or when the lowest point of the ground, less the scour depth, is below the bottom of the profile; a shape with a single point is not used (the ground is level) and is reported as a warning.

## 9.7 User-defined curves

Three kinds of curves can be entered instead of the curves generated from the soil. Each is used only when the corresponding option of **Analyze ▸ Set Analysis Options…** is ticked, and only by the piles to which it is assigned; the other piles use the curves generated from the soil.

### 9.7.1 Axial (L-D) curves

**Define ▸ Soil ▸ Axial (L-D) Curves…** lists the axial load–displacement curves, with the name (Axial Curve) and the number of Points of each. An axial curve gives the load at the pile head against the axial displacement of the head, for example from a load test, and replaces the curve that the program integrates from the load-transfer curves along the pile. The form *Axial (L-D) Curve* (Figure 9.40) holds the **Curve name** and a table of points, **Displacement** and **Load**, with positive values for compression and negative values for tension; **Add Point** and **Delete Point** edit the table, and

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the graph shows the curve. Piles without a curve use the load–displacement curve generated from the soil layers. The curve is assigned with **Assign ▸ Pile ▸ Axial (L-D) Curve…** and is used when the option *User-defined L-D curves* is ticked.

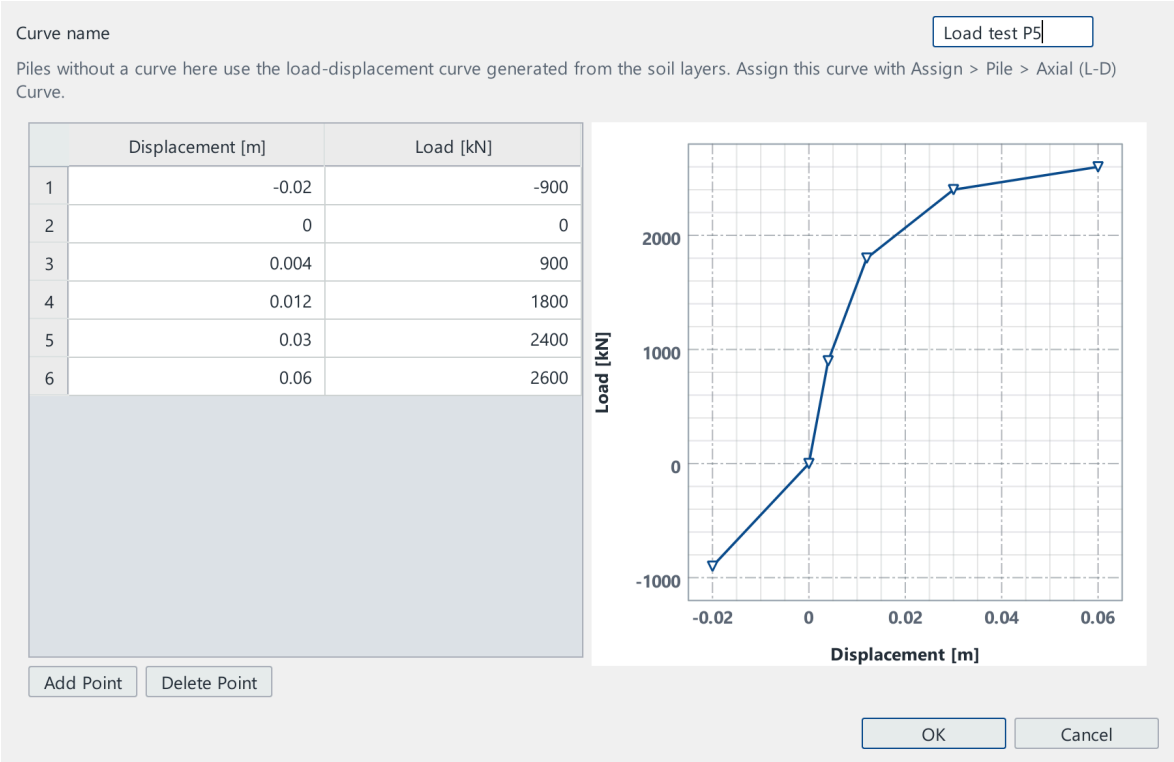



**Figure 9.40 —** Axial (L-D) Curve from a load test

### 9.7.2 Torsional (T-R) curves

**Define ▸ Soil ▸ Torsional (T-R) Curves…** lists the torque–rotation curves, with the name (Torsional Curve) and the number of Points of each. A torsional curve gives the torque at the pile head against the rotation of the head about the pile axis. The form *Torsional (T-R) Curve* holds the **Curve name** and the table of points, **Rotation** and **Torque**, edited with **Add Point** and **Delete Point**. Piles without a curve use the torque–rotation curve generated from the soil layers. The curve is assigned with **Assign ▸ Pile ▸ Torsional (T-R) Curve…** and is used when the option *User-defined T-R curves* is ticked.

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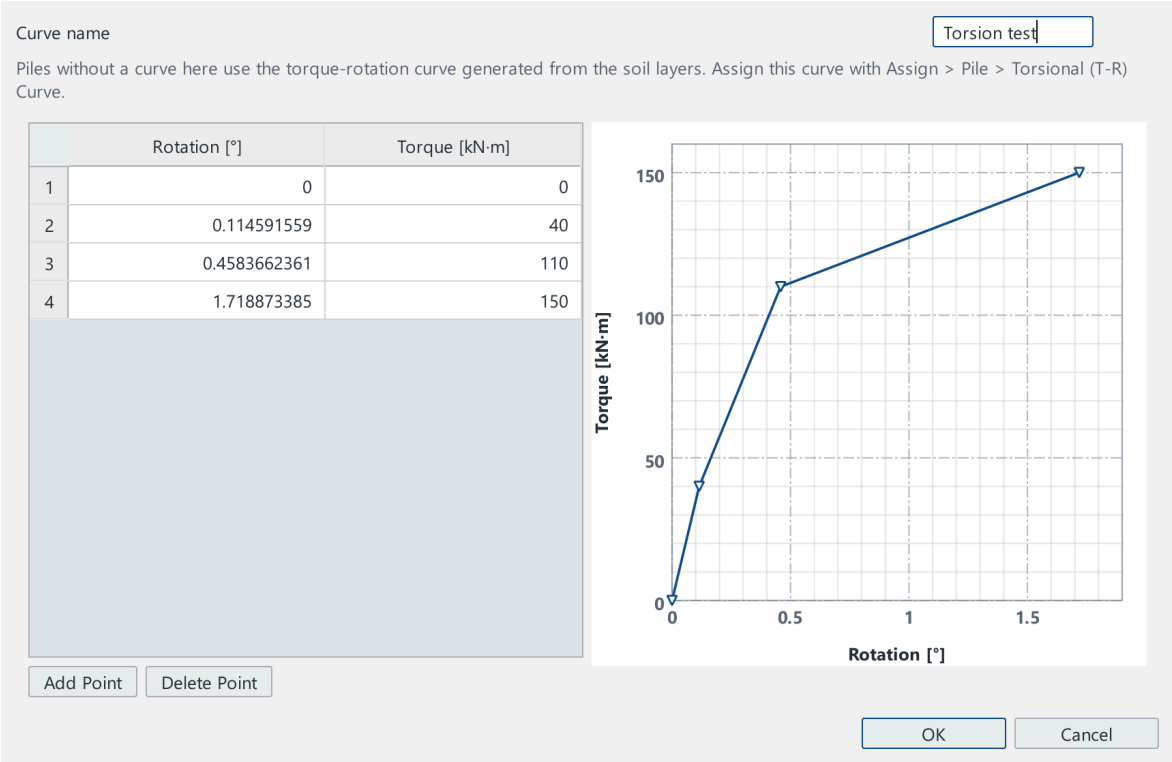



**Figure 9.41 —** Torsional (T-R) Curve

### 9.7.3 User p-y curves

**Define ▸ Soil ▸ User p-y Curves…** defines sets of p-y curves (Figure 9.42). The **p-y set** to edit is chosen in the list at the top; **Add Set** creates a set and **Delete Set** removes it. For each set:

- **Depth below origin**: the depths at which a curve is given, measured downward from the global elevation zero. Type a depth and click **Add Depth**; **Delete Depth** removes the selected depth.
- **Curve points**: the points of the curve at the selected depth, deflection **y** and soil resistance **p** per unit length of pile, edited with **Add Point** and **Delete Point**. The graph shows the curve.

Between two depths the curves are interpolated. A set must reach the pile tip. A set is assigned to piles with **Assign ▸ Pile ▸ p-y Set…** and is used when the option *User-defined p-y curves* is ticked; it then replaces the curves of the soil layers for those piles over the depth it covers. A soil layer whose p-y curve is *User-defined p-y* takes its resistance from the set of the pile (Section 9.5.18).

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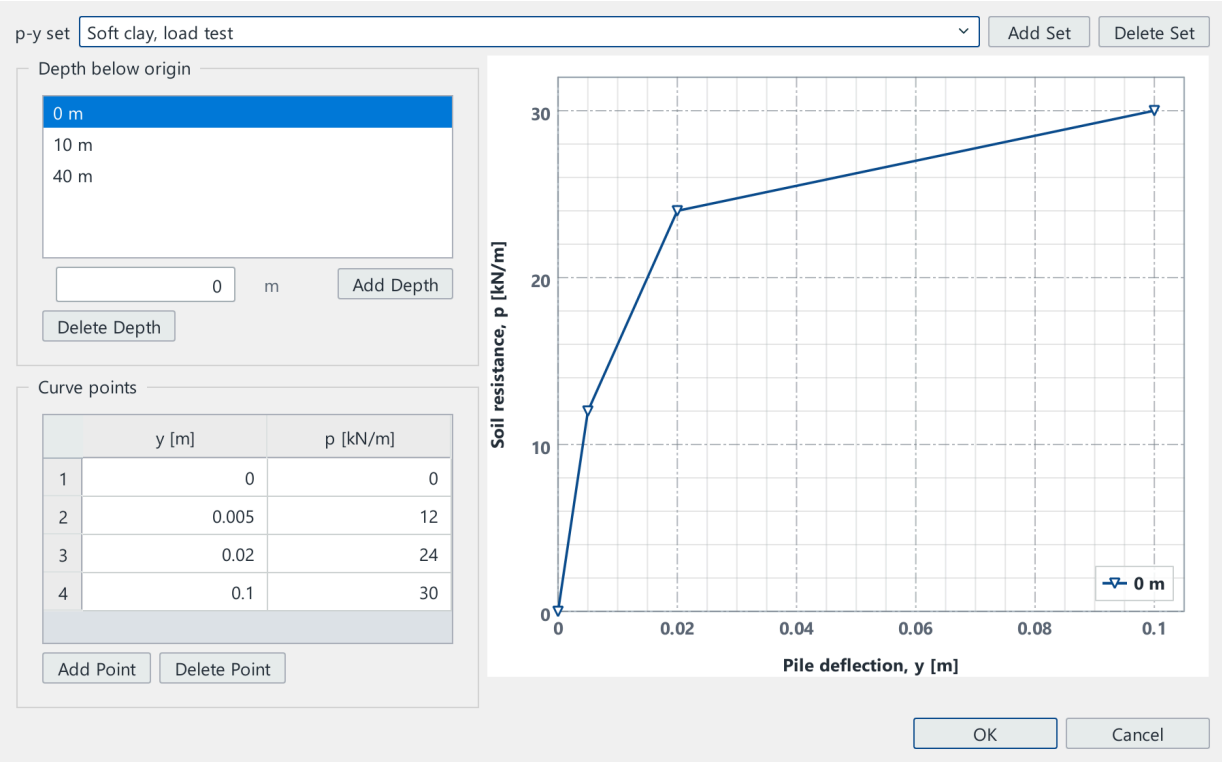



**Figure 9.42 —** Define User p-y Curves

## 9.8 Lateral group effect

**Define** ▸ **Soil** ▸ **Lateral Group Effect (p-y)…** defines sets of p-multipliers for closely spaced piles (Technical Reference, chapter “Group effects”). The list shows each Set with its Method and number of Rows. The set used by the whole model is chosen in the list under the table, either a set or *Ignore effects*, and confirmed with **Use selected set**; the same choice is offered in the analysis options, and a load case or a combination may use another set (Chapter 11).

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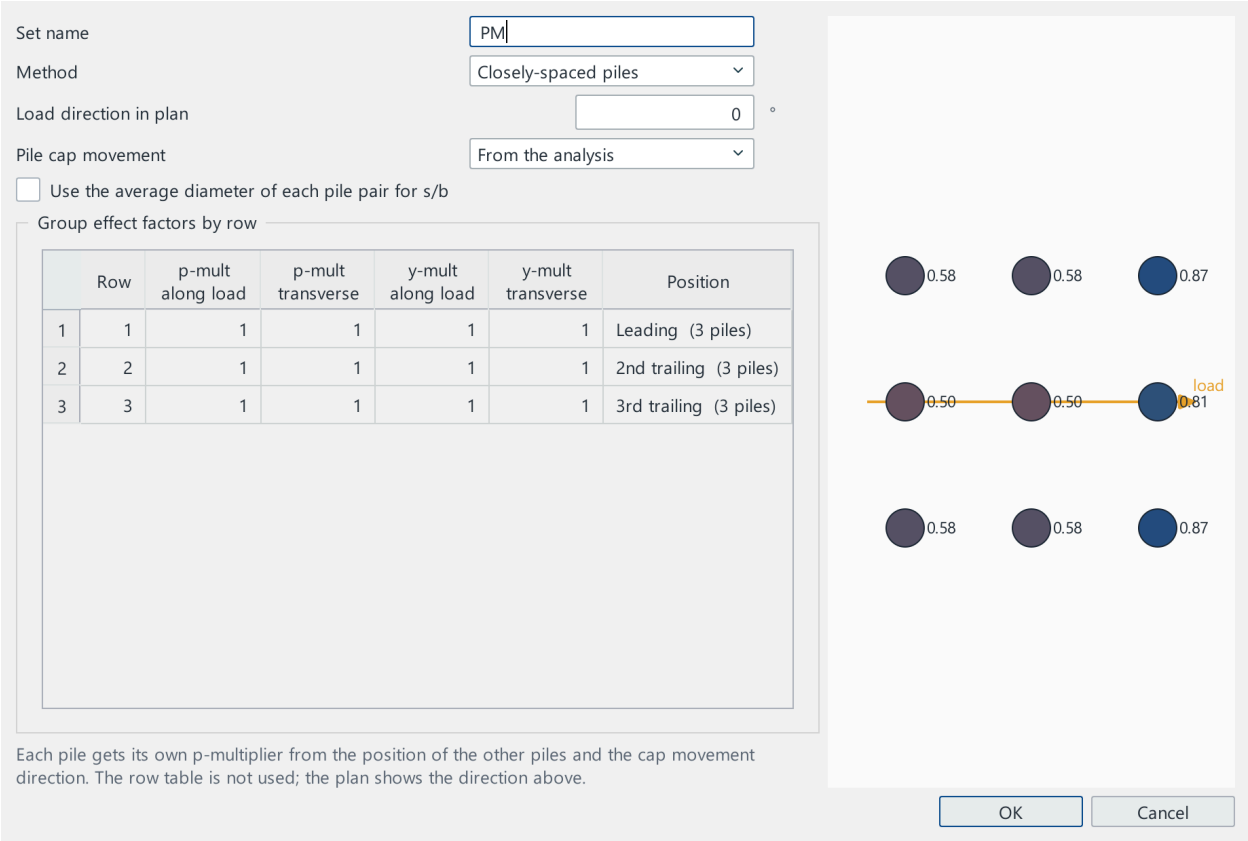



**Figure 9.43 —** Lateral Group Effect (p-y) with the method Closely-spaced piles

**Table 9.31 — Lateral Group Effect (p-y)**

| Field | Description |
|---|---|
| Set name | name of the set |
| Method | *Manual*: the factors of each row are typed. *AASHTO LRFD Table 10.7.2.4-1*, *Reese Van Impe* and *User table*: factors by rows from a table against the spacing ratio *s*/*D*. *Closely-spaced piles*: a factor for each pile from the positions of all piles. *Per pile, x/y directions*: factors typed for each pile, for movement along X and along Y. |
| Load direction in plan | direction, measured from the X axis, that defines the leading and trailing rows of the row methods; for *Closely-spaced piles*, the reference direction of the cap movement |
| Pile cap movement | for *Closely-spaced piles*: *From the analysis*, the factors follow the direction in which the pile cap moves, updated until they settle; *Reference direction*, the load direction above is used as a fixed pile cap movement |
| Use the average diameter of each pile pair for s/b | off: every pair of piles uses the diameter of the first pile in the model |
| Group effect factors by row | one row per row of piles: **Row** number, **p-mult along load** and **p-mult transverse**, **y-mult along load** and **y-mult transverse**, and the **Position** of the row (leading, 2nd trailing, …) with its number of piles. **Compute from spacing** recalculates the p-multipliers from the reference table and the pile spacing; **Edit these factors manually** copies the factors to the Manual method, so that the analysis uses the edited values. |

The plan on the right shows the piles with the factor of each pile and the load direction, so that the leading row can be checked. For *Closely-spaced piles* the row table is not used: each pile gets its own p-multiplier from the position of the other piles and the direction of the cap movement, as the note under the table states.

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## 9.9 Lateral reduction sets

**Define ▸ Soil ▸ Lateral Reduction Sets…** lists sets of factors on the lateral soil resistance that vary along the pile, with the Set name, the number of Depths and their Range. The form *Lateral Reduction Set* holds the **Set name** and a table of **Depth**, **P-Factor** and **Y-Factor**, edited with **Add Depth** and **Delete Depth**. The soil resistance is multiplied by P-Factor / Y-Factor. Between two depths the factors are interpolated linearly; above the first depth and below the last there is no reduction. The depths are measured vertically below the global elevation zero; for piles with user-defined p-y curves they are measured along the pile from its head. A set is assigned with **Assign ▸ Pile ▸ Lateral Reduction Set…** and is used when the option *Lateral reduction along depth* is ticked. The factors act together with the group factors.

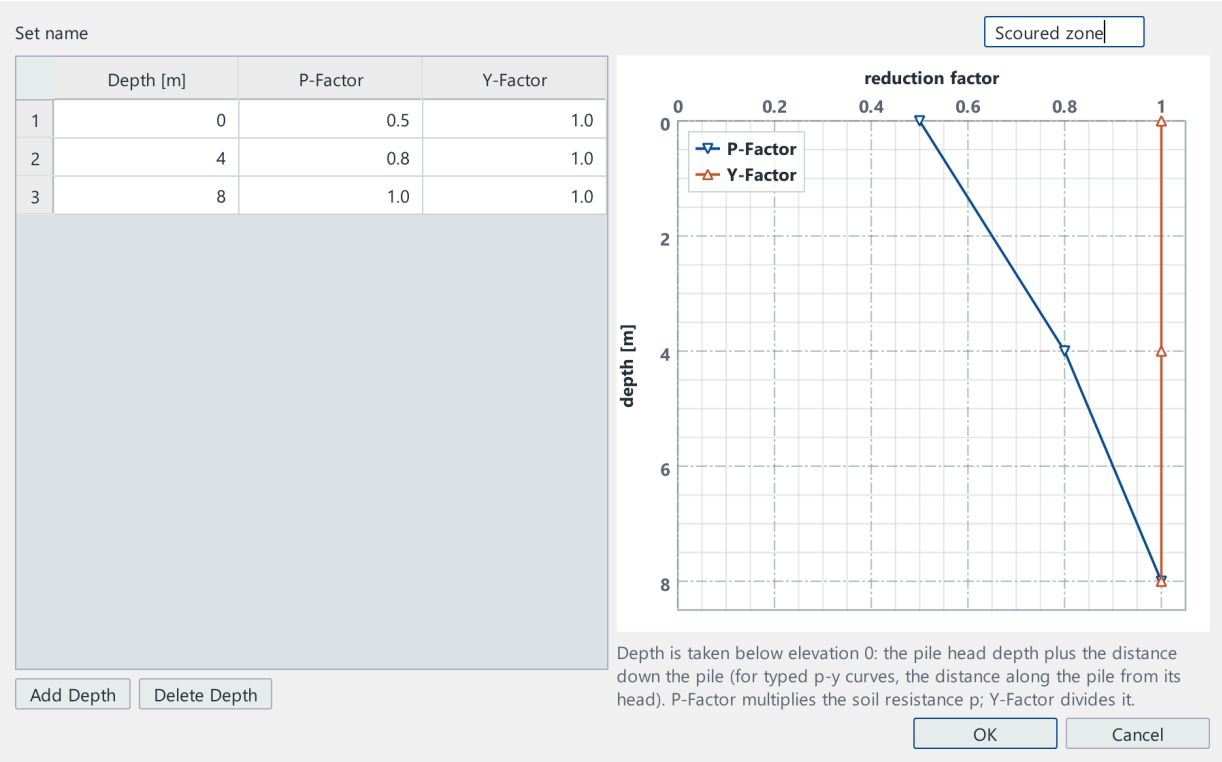



**Figure 9.44 —** Lateral Reduction Set

## 9.10 Printing depths for p-y curves

**Define ▸ Soil ▸ Printing Depths for p-y Curves…** lists the depths at which the p-y curves generated by the analysis are printed for verification (Figure 9.45). **Print internally generated p-y curves for verification** switches the printing on. Each row of the table gives the **Pile**, the **Depth below origin**, positive downward from the global origin ($z = 0$), and the **Displacements y, optional**, at which the curve is evaluated: up to 25 values, or empty for the 17 default points. The printout labels each curve with its depth below the ground line of that pile. **Add Row**, **Insert Row** and **Delete Row** edit the table; **Preview Curves** draws the curves. Printing does not change the analysis. The printed curves are shown with **Display ▸ Result Graphs and Response ▸ Show Printed p-y Curves…**.

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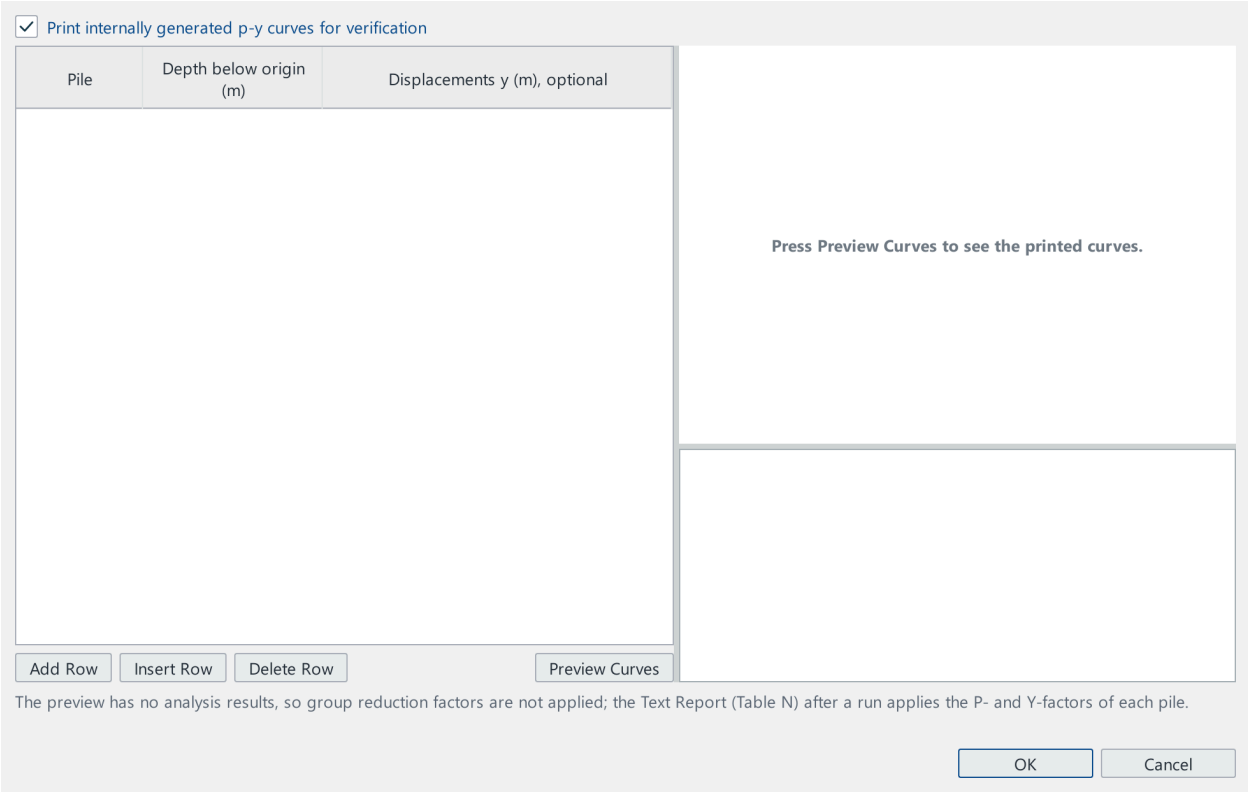



**Figure 9.45 —** Printing Depths for p-y Curves

## 9.11 Groups

**Define ▸ Groups…** lists named groups of objects, with the Group name and the number of Members. The form *Group* holds the **Group name** and shows the **Members**: the number of objects in the group and the number selected now. **Set to Current Selection** makes the group equal to the current selection, **Add Current Selection** adds the selected objects to it, and **Empty the Group** removes all members. A group is used to select its members again (**Select ▸ Coordinate Specification ▸ by Group…**) and to colour the piles; objects are also added to a group with **Select ▸ Assign to Group…**.

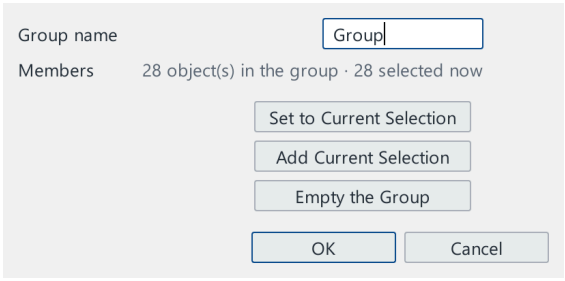



**Figure 9.46 —** Group

## 9.12 Model tables

**Display ▸ Show Tables…** lists the model in tables (Chapter 13). **File ▸ Export ▸ Model Tables (CSV)…** and **Model Tables (Excel)…** write them to files that can be edited in a spreadsheet, and **File ▸ Import ▸ Model Tables (CSV / Excel)…** reads them back. **File ▸ Import ▸ Solpile Model (.lpx)…** reads the sections and the soil of a single-pile model of Solpile.

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# 10 Assigning properties

The **Assign** menu gives properties to the selected objects. Select the piles first (Section 8.3); the **Apply** button of a dialog that acts on piles is dimmed while no pile is selected. When the selected piles have different values, the dialog says so, and a value is changed only when its field is edited. Assigned properties are shown with **Display ▸ Show Assigns** and in the **Properties** panel. Loads are assigned with the commands of Chapter 11.

## 10.1 Pile properties

Each command of **Assign ▸ Pile** opens a small dialog with the field of that property, an **Apply** button and a **Close** button; the dialog stays open, so that the property can be applied to several selections in turn. The number of selected piles is shown in the dialog (Figure 10.1).




**Figure 10.1 —** Assign Pile Batter

**Table 10.1 — Commands of Assign ▸ Pile**

| Command | Fields and effect |
|---|---|
| Section… | **Pile section**: the section of the whole pile |
| Section along Length… | segments of a pile with different sections, for example a cased upper part above an uncased lower part (Figure 10.2). For each segment: **Top** and **Bottom** elevations, the **Section**, and **E override**, a modulus of elasticity that replaces that of the material (empty: the material of the segment section). The column **Nonlinear EI from** is dimmed: the analysis uses the nonlinear *EI* of the segment's own section. **Add Segment** and **Delete Segment** edit the table; **Clear** removes every segment, so that the pile falls back to its single assigned section; **Use Values Shown** replaces the segments of every selected pile with those of the first selected pile shown in the table. |
| Type (driven / drilled)… | **Installation**: Driven pile or Drilled shaft. The type selects the axial load-transfer curves generated from the soil (Technical Reference, chapter "Soil response for axial loading"). New piles are driven; the shape of the section does not choose the installation, so bored piles must be assigned as drilled shafts. |
| Head Connection… | the connection of the pile head to the cap (Table 10.2) |
| Batter… | the inclination of the pile, entered as the **Angle from vertical**, the **Angle from horizontal** or the **Batter ratio 1 : m** (horizontal : vertical = 1 : *m*; enter *m* only, 0 selects a vertical pile), and the **Azimuth in plan** of the batter; the three inclination fields follow each other. The **Common batters** buttons set 1:3, 1:4, 1:6, 1:8, 1:12 and Vertical. The head stays in place and the tip moves. |
| Length… | **Pile length**: the length from the head to the tip, along the pile axis |
| Ground Surface Elevation Override… | **Assign an override** and the **Ground surface elevation**: a ground surface for the selected piles only, for example beside a scour hole or a local excavation; the soil layers keep their elevations, and the scour depth is subtracted from this level. It is an exception: the piles that carry it are drawn with a ring, and the ground between piles is not drawn through it. A slope of the whole site is entered once with **Sloping…** in the soil profile (Section 9.6.1). Unticked, the piles use the ground of the profile, level or sloping. |

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| Command | Fields and effect |
|---|---|
| Axial Load Reduction Factor… | **Axial load reduction factor**: a factor on the axial load–displacement curve of the pile, 1 = no reduction, 0.8 = 80 %; used when the option *Reduction factors for axial loads* is ticked. Named lateral reduction sets act on the p-y curves and are assigned separately. |
| Lateral Reduction Set… | **Reduction set**: a set of factors on the lateral soil resistance along the depth, or <none> (Section 9.9); used when the option *Lateral reduction along depth* is ticked |
| p-y Set… | **p-y set**: a set of user-defined p-y curves (Section 9.7), or Curves of the soil layers |
| Axial (L-D) Curve…, Torsional (T-R) Curve… | **Axial curve** or **Torsional curve**: a user-defined curve of the pile head, or Generated from soil |
| Local Axes… | **Rotation about axis 1**: the rotation of the cross-section about the pile axis, which turns local axes 2 and 3 |
| Segmentation… | **Number of increments** into which the pile is divided for the analysis (default 100). More increments give more accurate results near points of rapid change, at a higher cost. |
| Project Default Pile-Head Connection… | the dialog *Pile Head Connection*: the **Connection** used by every pile that has no connection of its own, with **Spring z-z** and **Spring y-y** for elastic connections; optionally clears the connections of individual piles |

**Table 10.2 — Pile-head connections**

| Connection | Meaning |
|---|---|
| Project | the project default connection |
| Fixed | the pile head rotates with the cap; it carries moments |
| Pinned | the pile head is free to rotate relative to the cap; no moment is transferred, and a pile pinned in both planes carries no torque |
| Elastic (rotational springs) | rotational springs between the pile head and the cap, with the stiffness *Spring z-z* and *Spring y-y* (moment per radian) in the two bending planes |
| Different per plane | Fixed, Pinned or Elastic separately in **Plane z-z** and **Plane y-y** |

In *Assign Pile Head Connection* the **Connection** list starts with *Project (…)*, which shows the project default in brackets; the spring fields are dimmed unless the connection is elastic.

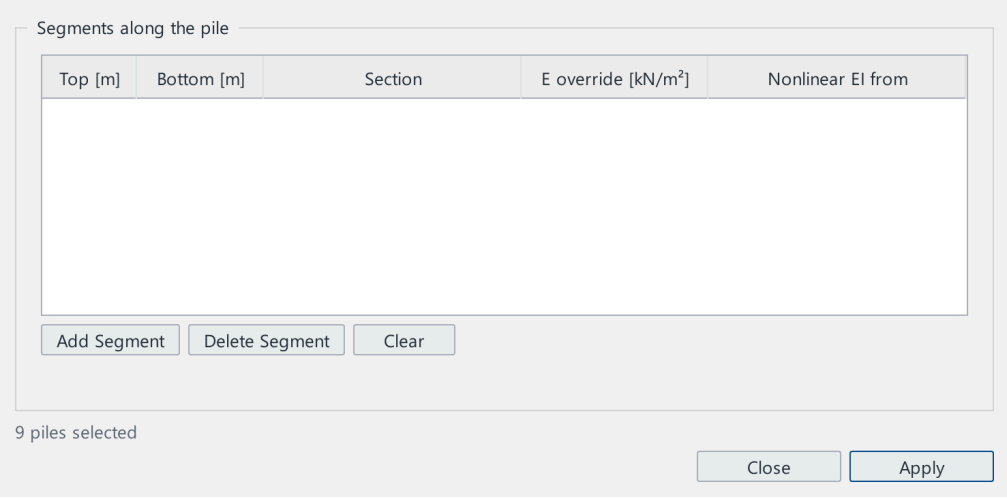



**Figure 10.2 —** Assign Section along Length

**Assign ▸ Copy / Paste Assigns…** copies chosen properties from one pile, chosen in **Copy assigns from**, to the selected piles (Figure 10.3). The **Assignments to paste** are ticked one by one, or all at once with **All** and **None**: Pile section, Pile type, Axial load reduction factor, Lateral reduction set, Section along length, Head connection, p-multiplier set, User p-y curve set, Axial curve, Torsional curve, Generated axial curve source, Generated torsional curve source, Ground elevation override, Local axes rotation, Segmentation, Batter (pile direction) and Pile length.

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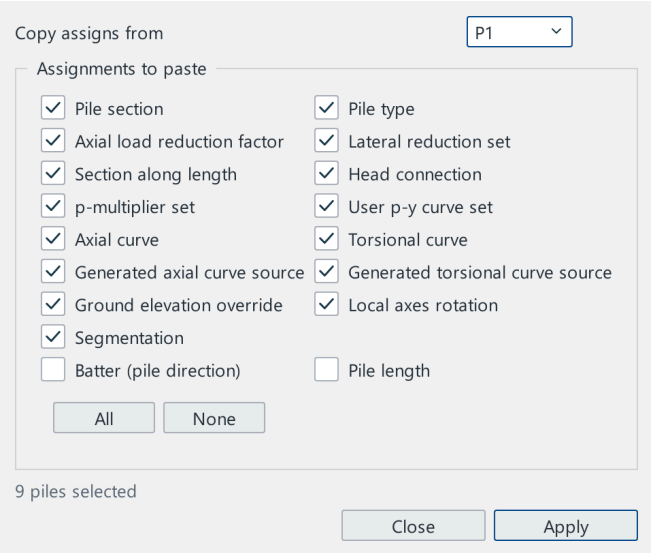



**Figure 10.3 —** Copy / Paste Assigns

## 10.2 Cap properties

**Table 10.3 — Commands of Assign ▸ Cap**

| Command | Fields and effect |
|---|---|
| Cap Section… | **Cap section**: the section of the cap (thickness, material and mesh size, Section 9.4); its material and thickness are shown |
| Cap Elevation… | **Mid-plane elevation** of the cap; the top and bottom elevations are shown. The cap and its mesh move; the pile heads keep their coordinates. |
| Cap Behaviour… | **Cap behaviour**. Rigid: the cap moves as a rigid body with three translations and three rotations, the usual model for a thick concrete cap. Flexible: the cap is a mesh of plate elements and bends under load; it shows how a thin or long cap spreads the load unevenly to the piles (Technical Reference, chapter “Mechanics of the pile group”). |
| Embedment & Soil Resistance… | the soil resistance on an embedded cap (Table 10.4) |
| Generate Flexible Cap Mesh | creates the plate mesh of a flexible cap from the outline of the cap, the pile heads, the point loads and the mesh size of the cap section |
| Clear Legacy Cap Restraints… | shown only for models that carry restraints of the cap from an older file; removes them |

**Table 10.4 — Assign Cap Embedment**

| Field | Meaning |
|---|---|
| Include soil resistance on the pile cap | switches the resistance on; it does not move the cap or add soil (set the cap position with Cap Elevation and the ground with the soil profile) |
| Soil resistance model | From the soil layer data: the p-y curves of the layers in contact with the cap |
| Method of analysis | Applying an equivalent lateral load, or Applying equivalent lateral springs |
| Override the soil-contact elevations; Top elevation, Bottom elevation | the range of contact; by default from the pile-head level to the pile-head level plus the cap thickness |
| Equivalent diameter | width of the cap face for the p-y curves; 0 = the diagonal of the cap in plan |
| Spring increments | number of increments over the contact range for the equivalent springs (1 to 20) |

**NOTE** After a change of the cap outline, the element size, the cap section or the piles, the stored mesh of a flexible cap may no longer match the model. Check Model warns in that case; generate the mesh again before the run.

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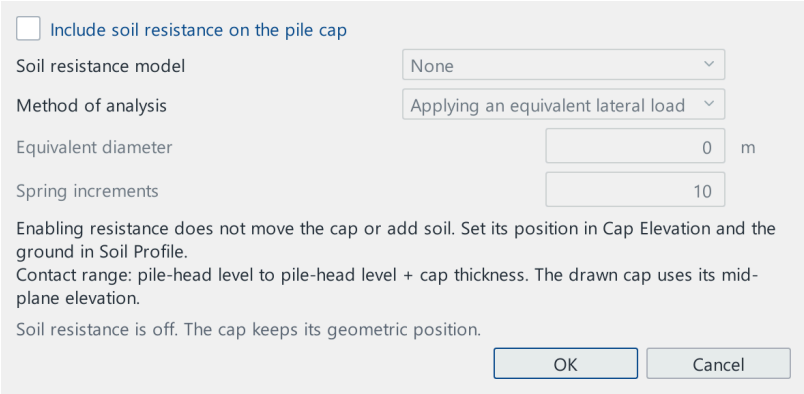



**Figure 10.4 —** Assign Cap Embedment

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# 11 Loads, load cases and combinations

Loads are entered in three levels. A **load pattern** groups loads of one kind. A **load case** multiplies patterns by factors and is analysed as one nonlinear problem. A **load combination** combines load cases. The results are produced for load cases and combinations.

## 11.1 Load patterns

**Define ▸ Load Patterns…** lists the patterns with the Load Pattern name, its Type and its Self Weight multiplier. The form *Load Pattern* holds the **Load pattern name** and the **Type**: DEAD, SUPERDEAD, LIVE, WIND, QUAKE, SNOW, BERTHING, MOORING, CURRENT, WAVE or OTHER. SUPERDEAD is the superimposed dead load (finishes, utilities, wearing surface). The type is used by the design combinations (Section 11.4); it does not change the analysis of a load case. Loads are always assigned to a pattern.

**NOTE** The **Self weight multiplier** of a pattern adds the weight of the pile cap to that pattern: the weight per unit volume of the cap material × the cap thickness × its plan area, times the multiplier (1 = full weight). The weight of the piles is not included.

## 11.2 Assigning loads

Loads are assigned with the commands of the **Assign** menu to the selected objects, for the **Load pattern** chosen in the dialog (Figure 11.1). Under *Apply to the selected objects*, every load dialog offers **Replace** (the new load replaces the loads of the pattern on the selection), **Add** (it is added to them) and **Delete** (the loads of the pattern are removed, after confirmation if **Ask before deleting loads** is ticked). Values are in global axes unless stated otherwise.

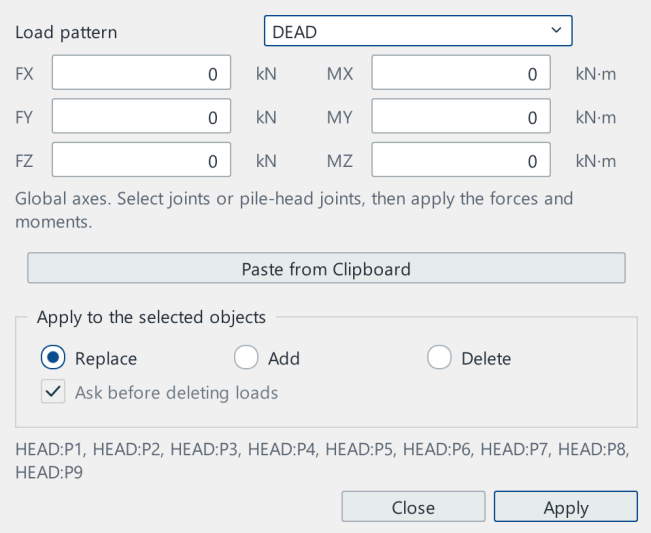



**Figure 11.1 —** Assign Joint Forces

The dialogs for point forces and moments have four helpers: **Point Coordinates…** types the point at which the load acts; **Pick Point** picks a joint, a pile head or a grid intersection on the canvas; **Equivalent Load…** moves a load given at another point to the selected point, with the moments that the move creates (exactly one target point must be selected); **Paste from Clipboard** reads six numbers per line in the current display units, FX FY FZ MX MY MZ. In *Assign Point Loads on Cap*, **Apply at** chooses Selected points / pile-head joints or the Cap reference point.

**Table 11.1 — Load commands**

| Command | Fields and effect |
|---|---|
| Joint Loads ▸ Point Forces / Moments… | forces $F_X$, $F_Y$, $F_Z$ and moments $M_X$, $M_Y$, $M_Z$ at the selected joints (pile heads or reference points); they act on the cap at the position of the joint |

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| Command | Fields and effect |
|---|---|
| Cap Loads ▸ Point Forces / Moments… | forces and moments on the cap, at the cap reference point or at the selected points |
| Cap Loads ▸ Distributed Load on Cap Plates… | forces per unit area $F_X$, $F_Y$, $F_Z$ on every plate, or the chosen plates, of the flexible-cap mesh; $F_Z$ points up, so a downward load is negative. Used only when the cap is flexible. |
| Pile Loads ▸ Distributed Lateral Load… | a load per unit length along the selected piles, in the **Direction** Global X, Global Y, Global Z, Local 2 or Local 3, between the **Elevation, top** and the **Elevation, bottom** (**Span the whole pile** fills them from the pile), varying linearly from the **Load at top** to the **Load at bottom**. For global loads on a battered pile, the part along the pile axis is dropped unless **Add the part along the pile axis as a force at the head** is ticked, in which case it is applied as one axial force at the pile head. |
| Pile Loads ▸ Point Force Along Pile… | a force **FX**, **FY**, **FZ** at an **Elevation** on the selected piles |
| Free-field Soil Movement… | a *Movement profile* of horizontal soil movement: **Depth** below the ground surface with the movements **UX** and **UY**, interpolated linearly between the points (**Add Point**, **Delete Point**), applied to the selected piles |

In *Assign Distributed Loads on Cap Plates*, **Apply to** shows the plates concerned, and the loads are **FX per unit area**, **FY per unit area** and **FZ per unit area**. **Cap Behaviour…** and **Generate Cap Mesh** open the cap behaviour and generate the mesh from the dialog.

**Display ▸ Show Loads…** draws the loads on the model (Figure 11.2): **Show** chooses None (do not draw loads), All loads / all patterns, or one pattern; the *Load types* Point forces, Moments, Loads along piles, Cap area loads, Cap beam loads and Soil movement are switched one by one, or all with **Show All Types**; **Show load values** writes the values beside the arrows; **Arrow scale** and **Distributed arrows** set the length of the arrows and their number along a distributed load. A free-field soil movement is drawn with arrows at evenly spaced depths between the points of its profile and a line through their tips, from the effective ground surface that the analysis uses. The number of loads of each kind is counted.

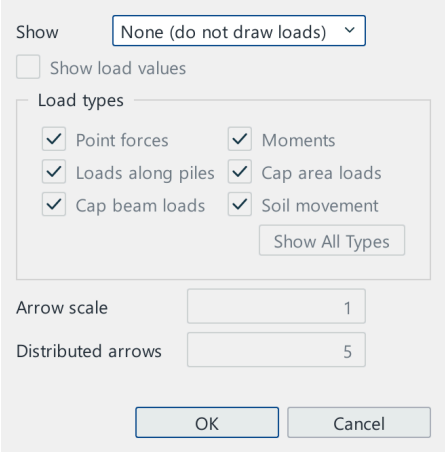



**Figure 11.2 —** Show Loads

## 11.3 Load cases

**Define ▸ Load Cases…** lists the load cases with the Load Case name, its Type, its Patterns and whether it is Run (Figure 11.3). Besides the usual buttons, the list has:

- **Add One per Pattern**: one nonlinear static case per load pattern, named after it;
- **Generate Load Levels…**: independent nonlinear static cases with increasing pattern factors, for the selected case and the number of levels asked for; each starts from zero (use Pushover for an incremental analysis);
- **Modify Selected…**: applies one setting to every selected case at once: follow the model default for every control, copy every control from the first selected case, run these cases, or do not run them;
- **Confirm Deletion**: ask before deleting a row.

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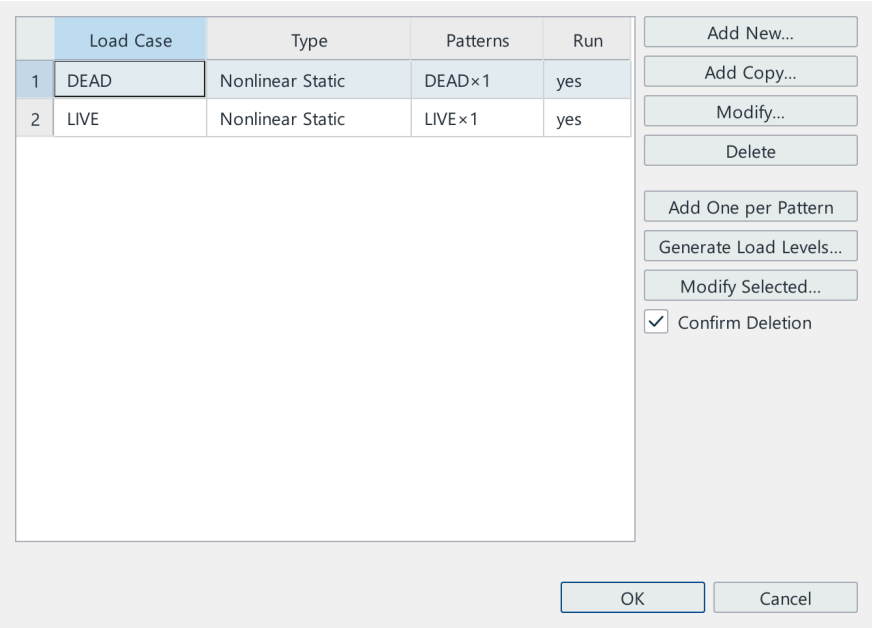



**Figure 11.3 —** Define Load Cases

The data of a load case are (Figure 11.4):

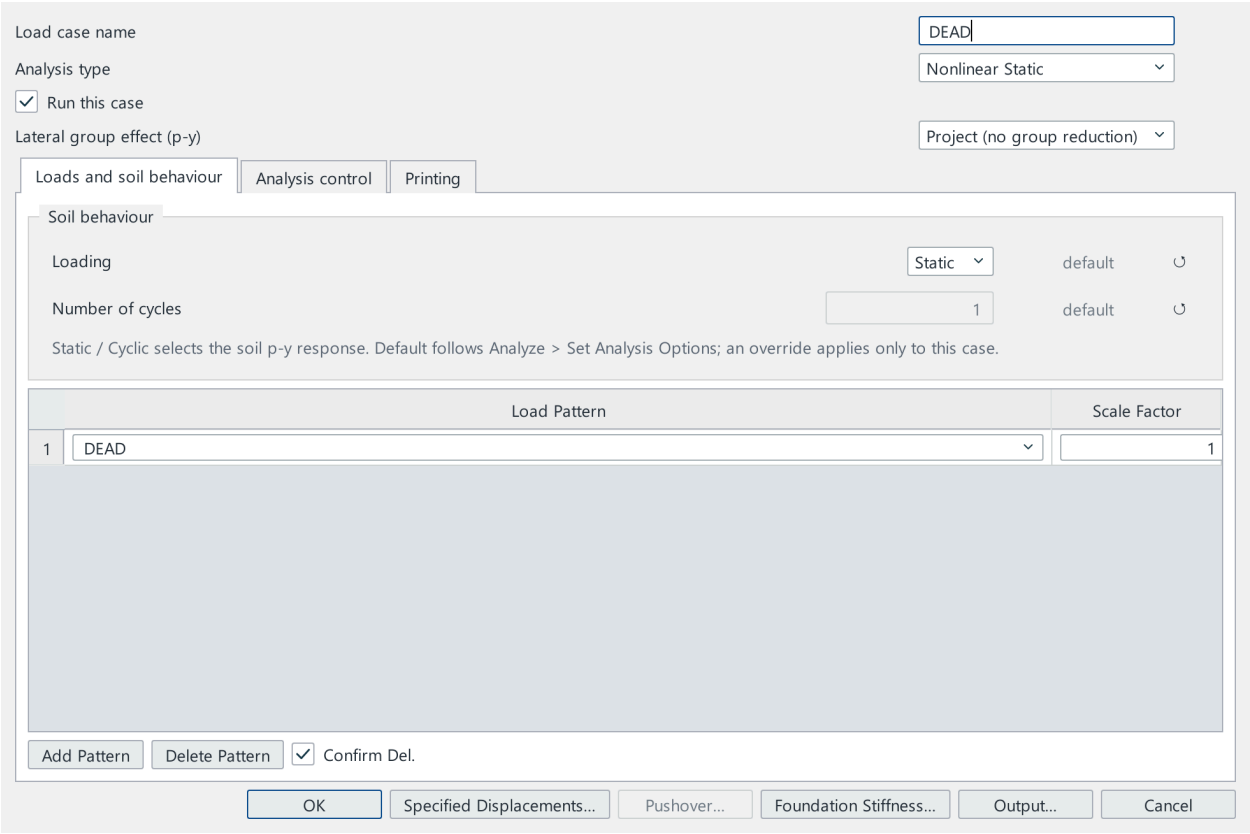



**Figure 11.4 —** Load Case Data, tab Loads and soil behaviour

**Table 11.2 — Load Case Data**

| Field | Meaning |
|---|---|
| Load case name | name of the case |

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| Field | Meaning |
|---|---|
| Analysis type | Nonlinear Static: the loads are applied and the nonlinear response of the group is found. Pushover: the loads are increased through a series of factors (Table 11.4). A case read from an older model as Linear Static or Nonlinear Staged is analysed as Nonlinear Static. |
| Run this case | unticked: the case stays in the model but is not run |
| Lateral group effect (p-y) | the group effect of the model, or another set for this case only, for example a table method whose leading row follows the load direction of this case |
| **Tab Loads and soil behaviour** | |
| Load Pattern; Scale Factor | the patterns of the case with their factors; **Add Pattern** and **Delete Pattern** edit the table, and **Confirm Del.** asks before a row is deleted |
| Loading; Number of cycles | Static or Cyclic soil curves; the number of cycles is part of the cyclic criteria of some models, not a load factor. The default follows Analyze ▸ Set Analysis Options; an override applies only to this case. |
| Initial conditions | shown only for a load case read from an older file that started from another case; every load case starts from zero. To start from the loads of another case, add both to a Linear Add combination, which is analysed as one load set. |
| **Tab Analysis control** | |
| Iterations, pile group; Iterations, single pile | limits on the iterations of the group (outer loop) and of one pile inside a group iteration (inner loop) |
| Tolerance, equilibrium | the relative change of the cap movement between iterations at which the group has converged |
| Tolerance, pile deflection | the change of the deflection of a pile at which a single-pile iteration has converged |
| Initial step; Minimum step | the first fraction of the load and the smallest step to which a step that does not converge is halved (Technical Reference, “Load steps”); 1 and 1 apply the load at once |
| Also stop on absolute cap movement; Absolute cap displacement, Absolute cap rotation | an additional convergence test on the absolute change of the cap movement |
| Include axial load variation along the piles | the axial thrust in the lateral analysis varies along each pile instead of being the head force |
| **Tab Printing** | |
| Printing code; Printing increment | what the output report lists for the case: the cap only, the cap and the pile heads, or the full length of every pile, printing every *N*th node |

Each control field shows whether it follows the default of the model (**Analyze ▸ Set Analysis Options…**), marked *default,* or overrides it for this case; the reset button beside a field returns it to the default. Four buttons open further data of the case:

**Table 11.3 — Further data of a load case**

| Button | Fields |
|---|---|
| Specified Displacements… | dialog *Specified Displacements or Forces*: **Prescribe cap degrees of freedom in this load case**; then, for each Degree of freedom of the cap, the Control (Force or Displacement) and the Value; and under *Point of application*, **Apply at a point other than the cap load reference point**, with its X, Y and Z |
| Pushover… | dialog *Pushover*, available when the Analysis type is Pushover (Figure 11.5): **Run this case as an incremental pushover**; the **Number of steps** (at most 25 load points), the **Ramp** (Arithmetic or Logarithmic), the **First factor** and the **Last factor**, **Generate Factors**, and the table of the **Load factor** of each step, edited with **Add Step** and **Delete Step**; the components held constant (Table 11.4) |
| Foundation Stiffness… | *Compute the 6×6 foundation stiffness matrix of this load case* (Table 11.5) |

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| Button | Fields |
|---|---|
| Output… | dialog *Output Variables*: the quantities listed in the reports along the piles. **Follow the model default**, or a choice of: *Local displacement* Along axis 1, Along axis 2, Along axis 3 and Resultant in plane 2–3; *Global displacement* Along X, Along Y, Along Z and Horizontal resultant; *Forces and stiffness* Moment about axis 3, Moment about axis 2, Resultant moment, Shear along axis 2, Shear along axis 3, Resultant shear, Soil reaction along axis 2, Soil reaction along axis 3, Resultant soil reaction, Axial force, Total stress, Bending stiffness EI about axis 3, Bending stiffness EI about axis 2, Distributed load along axis 2, Distributed load along axis 3 and Soil modulus Es; and *Demand / capacity (combinations)* Bending moment and Shear force. **Select All** and **Select None** set every box; **Save as Default** makes the choice the model default for every case that has not overridden its output. |

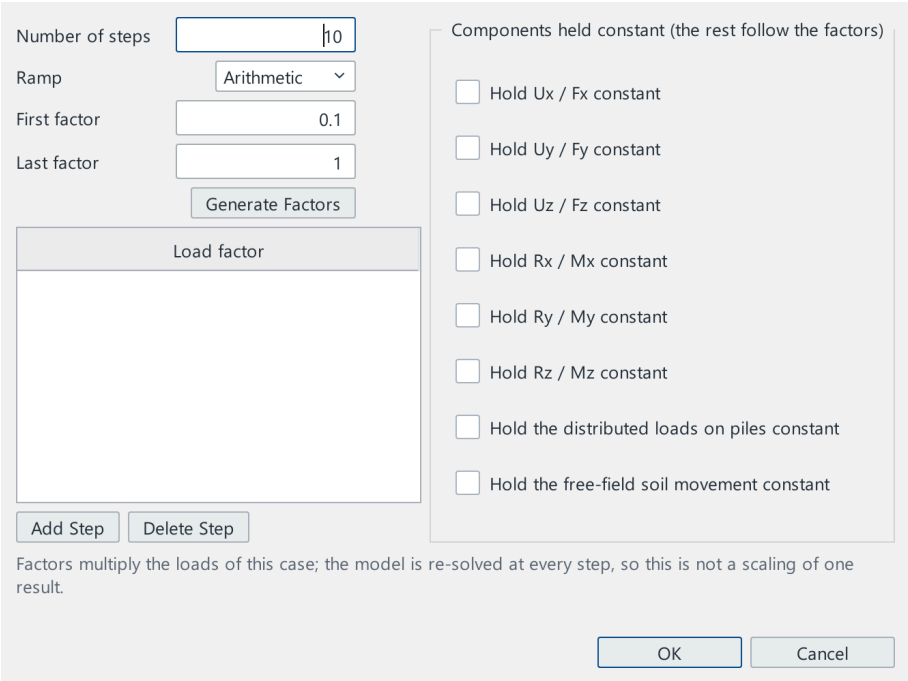



**Figure 11.5 —** Pushover

**Table 11.4 — Pushover: components held constant**

| Option | Effect |
|---|---|
| Hold Ux / Fx constant; Hold Uy / Fy constant; Hold Uz / Fz constant; Hold Rx / Mx constant; Hold Ry / My constant; Hold Rz / Mz constant | the component keeps its value in every step; the others are multiplied by the load factors |
| Hold the distributed loads on piles constant | loads along the piles are not factored |
| Hold the free-field soil movement constant | soil movements are not factored |

**Table 11.5 — Foundation Stiffness**

| Field | Meaning |
|---|---|
| Compute the 6x6 foundation stiffness matrix of this load case | switches the computation on; the other fields are dimmed until it is ticked |
| Based on nonlinear soil response | each loaded degree of freedom of the cap is pushed alone at the load levels, and the stiffness is the inverse of the secant flexibility; **Diagonal terms only** drops the coupling terms between translation and rotation, an approximation |
| Based on equivalent elastic springs | the analysed state is replaced by elastic springs and condensed to the cap; *Consider axial force in piles* adds the second-order effect of the axial forces |

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| Field | Meaning |
|---|---|
| Based on the applied load; Based on a target deflection at the pile cap | for equivalent springs: the state at the load of the case, or at a **Target** displacement or rotation of a chosen degree of freedom (Ux, Uy, Uz, Rx, Ry, Rz), reached within a **Tolerance** (%) and a number of **Maximum iterations** (analyses, the first one, with the load of the target direction removed, included); **Scale only the load associated with the deflection** scales only the load component of the target degree of freedom |
| Number of levels; Ramp; First level, Last level | up to 10 levels, as fractions of the load of the case (or of the target), Arithmetic or Logarithmic; **Generate Load Levels** fills the table of *Load / displacement levels* (Fraction of the case load), which can be edited with **Add Level** and **Delete Level** |

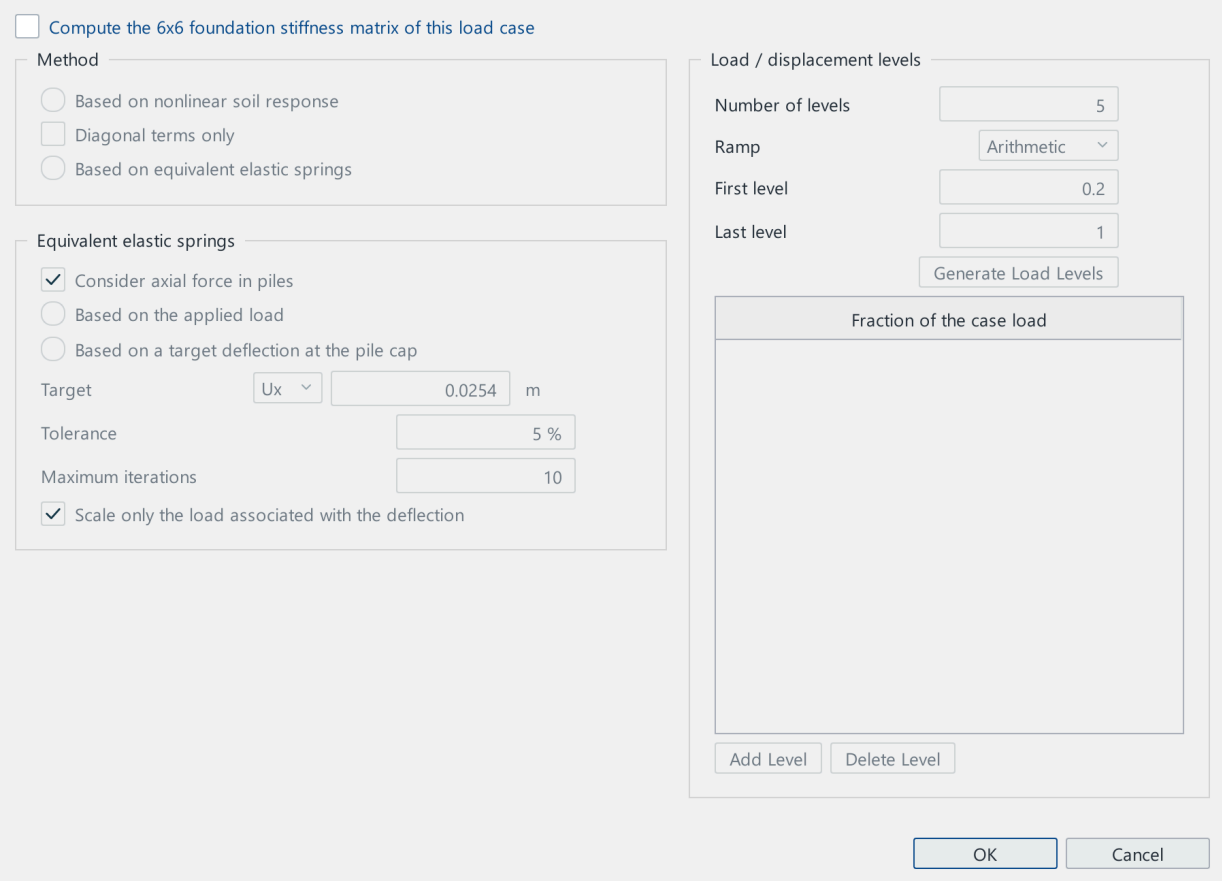



**Figure 11.6 —** Foundation Stiffness

Every load case starts from the unloaded state. To analyse the loads of two cases acting together, combine them in a Linear Add combination.

## 11.4 Load combinations

**Define** ▸ **Load Combinations…** combines load cases or other combinations with scale factors. The list shows each Combination with its Type and Members. Besides the usual buttons, it has:

- **Design Combo Options…**: the code and the parameters of the design combinations (Table 11.7);
- **Add Default Design Combos**: adds the strength combinations of the chosen code for the load patterns of the model;
- **Envelope All Cases**: one envelope combination over every load case in the model;
- **Load Factors…** reads a set of LRFD load factors from a CSV file, and **Save Factors…** writes the combinations out as a CSV of load factors;
- **Confirm Deletion**: ask before deleting a row.

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The data of a combination are (Figure 11.7):

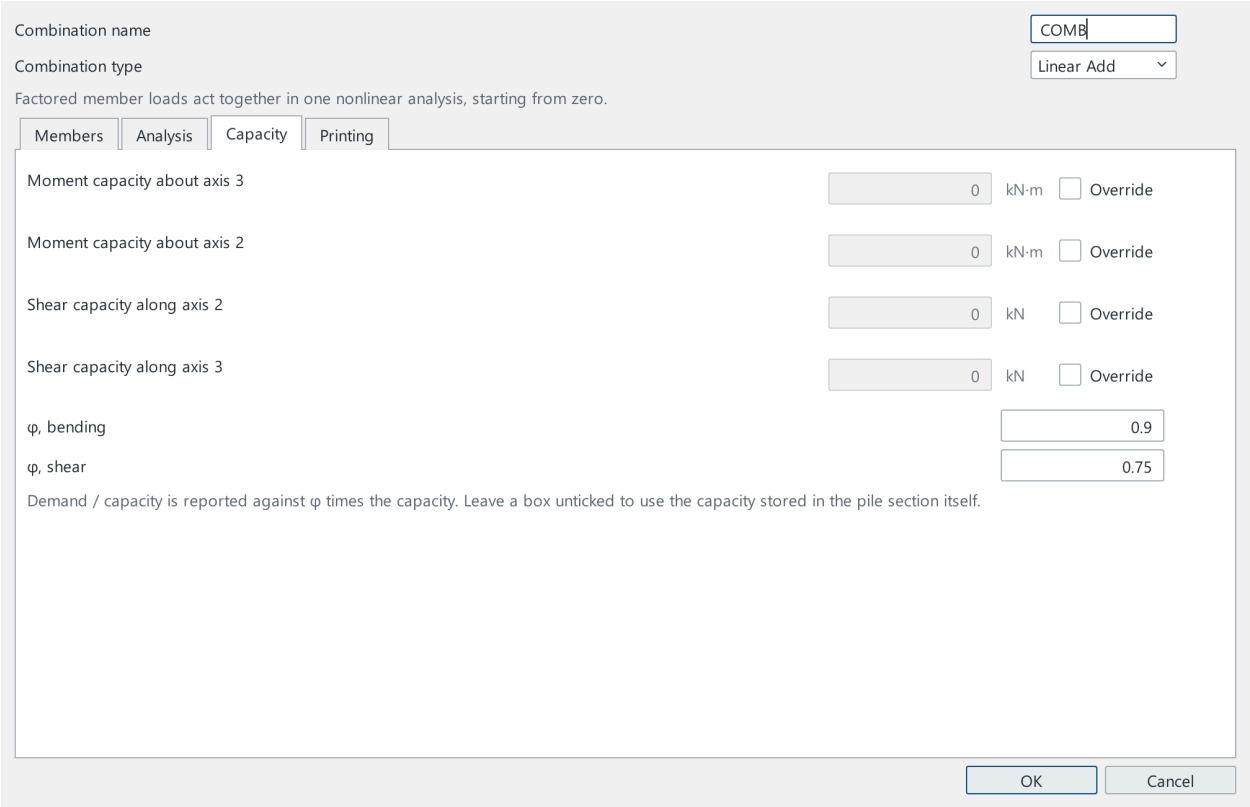



**Figure 11.7 —** Load Combination, tab Capacity

**Table 11.6 — Load Combination**

| Field | Meaning |
|---|---|
| Combination name | name of the combination |
| Combination type | Linear Add: the factored member loads act together in one nonlinear analysis, starting from zero. Envelope: the largest and smallest value of every quantity among the members. |
| Tab Members | the members, Load Case or Combination, with their Scale Factor; **Add Case** and **Delete Case** edit the table, and **Confirm Del.** asks before a row is deleted |
| Tab Analysis | the same controls as the Analysis control tab of a load case: Loading, Number of cycles, Iterations, pile group, Iterations, single pile, Tolerance, equilibrium, Tolerance, pile deflection, Initial step, Minimum step, Also stop on absolute cap movement with the Absolute cap displacement and the Absolute cap rotation, and Include axial load variation along the piles; each follows the model default or overrides it for this combination |
| Tab Capacity | **Moment capacity about axis 3**, **Moment capacity about axis 2**, **Shear capacity along axis 2** and **Shear capacity along axis 3**, each with **Override**: ticked, the value replaces that of the sections for this combination; and the resistance factors **φ, bending** (default 0.9) and **φ, shear** (default 0.75), for the demand/capacity check of the combination |
| Tab Printing | **Give this combination its own printing options**, with the Printing code and the Printing increment as for a load case; **Output Variables…** chooses the quantities printed along the piles for this combination, including the demand / capacity ratios |

**NOTE** Because the response of the soil is nonlinear, a Linear Add combination is analysed again with its factored loads; its result is not the sum of the results of its members. Combination types of older models that cannot be analysed (Absolute Add, SRSS, Range Add) are kept in the file; Check Model reports them when they are selected to run.

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**Table 11.7 — Design Combination Options**

| Field | Description |
|---|---|
| Code / template | ACI 318-19, ASCE 7-16 or AASHTO LRFD 9th: the strength combinations for DEAD, SUPERDEAD, LIVE, SNOW, WIND and QUAKE patterns; wind and earthquake patterns are separate alternatives. SUPERDEAD takes the DEAD factor under ACI 318-19 and ASCE 7-16; under AASHTO LRFD it is DW (1.50 with DC 1.25, 0.65 with DC 0.90, 1.00 in Service I and Extreme Event I) |
| QUAKE patterns contain | Total seismic effect E, or Horizontal seismic effect Eh; with Eh, the vertical earthquake effect 0.2 × $S_{DS}$ × DEAD is added |
| SDS (g); Redundancy factor, rho | the design spectral acceleration and the redundancy factor of the seismic combinations |
| LL factor with EQ | the factor on live load with earthquake (AASHTO $\gamma_{EQ}$, project-specific) |
| Include project marine templates | optional example factors for berthing, mooring, current and wave; they are project factors, not code combinations, and must be reviewed |

Use custom combinations for other load types or directional rules.

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# 12 Analysis

## 12.1 Analysis options

**Analyze ▸ Set Analysis Options…** holds the settings that apply to the whole model and the defaults of the load cases and combinations (Figure 12.1). The defaults are used wherever a case or a combination shows *default*.

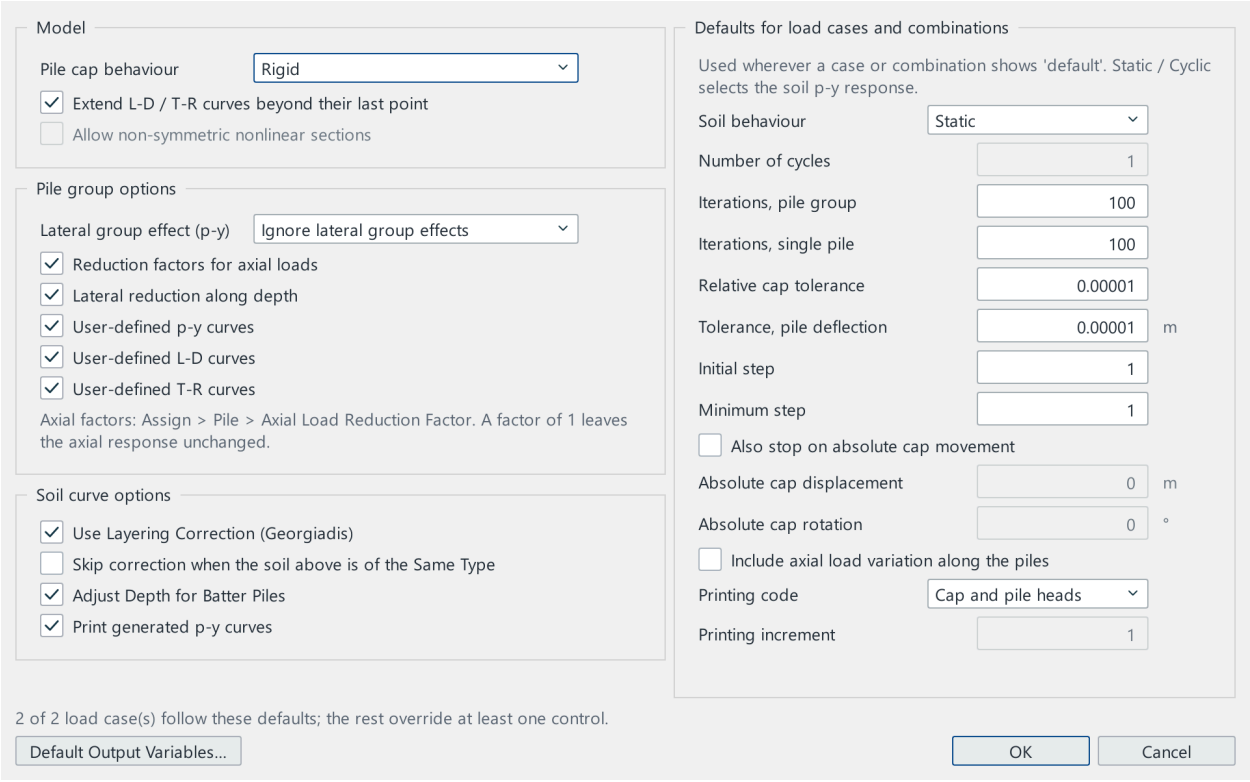



**Figure 12.1 —** Analysis Options

**Table 12.1 — Analysis options**

| Option | Meaning |
|---|---|
| **Model** | |
| Pile cap behaviour | Rigid or Flexible (the same setting as Assign ▸ Cap ▸ Cap Behaviour) |
| Extend L-D / T-R curves beyond their last point | off: a pile whose axial head displacement passes the end of its curve carries no axial load, and the analysis reports an apparent failure in bearing; on: its axial force is held at the value of the last point |
| Allow non-symmetric nonlinear sections | a separate negative moment–curvature branch for sections with unsymmetric reinforcement; off, such a section stops the run. Dimmed when the model has no such section. |
| **Pile group options** | |
| Lateral group effect (p-y) | the set of p-multipliers of the model, or Ignore lateral group effects |
| Reduction factors for axial loads | on: the axial L-D loads are multiplied by the factor assigned to each pile with Assign ▸ Pile ▸ Axial Load Reduction Factor (1 = unchanged); off: those factors are ignored. Independent of the lateral group effects. |
| Lateral reduction along depth | on: the lateral reduction sets assigned to the piles are used |
| User-defined p-y curves, User-defined L-D curves, User-defined T-R curves | on: the user-defined curves assigned to the piles replace the curves generated from the soil for those piles |
| **Soil curve options** | |
| Use Layering Correction (Georgiadis) | corrects the p-y curves near a layer boundary by the equivalent-depth method |

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| Option | Meaning |
|---|---|
| Skip correction when the soil above is of the Same Type | omits that correction below a layer of the same model |
| Adjust Depth for Batter Piles | measures the depth of the soil curves vertically for battered piles |
| Print generated p-y curves | prints the generated curves at the printing depths (Section 9.10) |
| **Defaults for load cases and combinations** | |
| Soil behaviour; Number of cycles | static or cyclic curves |
| Iterations, pile group; Iterations, single pile | iteration limits of the group (outer loop) and of one pile inside a group iteration (inner loop), default 100 each |
| Relative cap tolerance | relative change of the cap movement between iterations, $\Delta U/U$ (default 0.00001) |
| Tolerance, pile deflection | convergence of the single-pile analyses (default 0.00001 m) |
| Initial step; Minimum step | load stepping (default 1 and 1: the load is applied at once) |
| Also stop on absolute cap movement | an additional convergence test, with the Absolute cap displacement and the Absolute cap rotation |
| Include axial load variation along the piles | see Table 11.2 |
| Printing code; Printing increment | see Table 11.2 |
| Default Output Variables… | the default columns printed along each pile in the text report: the dialog *Output Variables*, with the same choices as for a load case (Table 11.3) and **Select All** and **Select None** |

The defaults are adequate for most models. A tighter tolerance makes the results more precise at the cost of more iterations; a larger iteration limit, or load steps smaller than 1, can help a heavily loaded group to converge.

## 12.2 Load cases to run

**Analyze ▸ Set Load Cases to Run…** chooses the cases and combinations that the next run analyses (Figure 12.2). **Run all load cases** runs every case, including cases added later; otherwise the cases are ticked one by one. Combinations are selected separately in the list below. **Select All** and **Select None** set every box of a list.

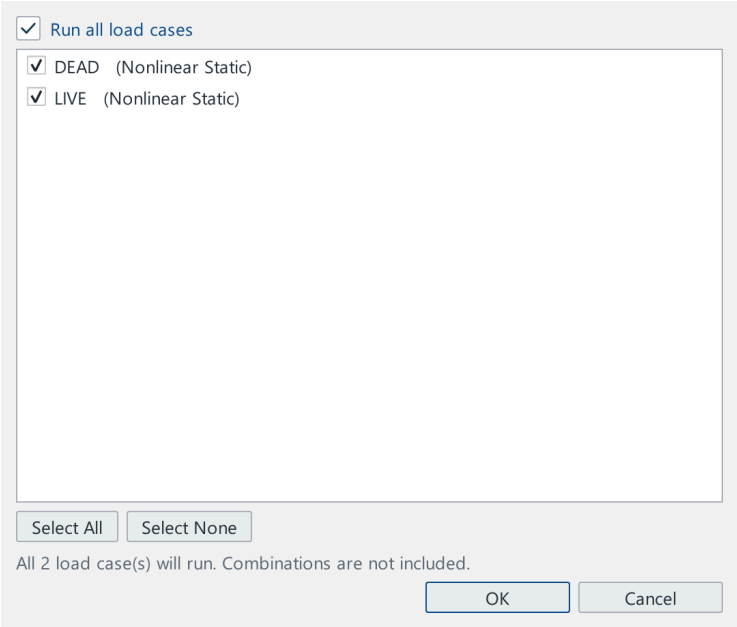



**Figure 12.2 —** Load Cases to Run

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## 12.3 Check Model

**Analyze ▸ Check Model…** (F6) examines the model before a run and lists its findings in the **Command** panel. A finding has a code, a level and the objects it concerns:

- **Error**: the model cannot be analysed as it is, for example a pile without a section, a pile that does not reach the soil, or a load on an object that no longer exists;
- **Warning**: the model can be analysed, but the result may not be what is intended, for example a flexible-cap mesh that no longer matches the cap;
- **Information**: a remark about the model, for example a field that the analysis does not use.

A click on a finding selects the objects concerned. The run starts only when the model has no errors. Check Model is also run automatically at the start of every run.

The values are checked as the analysis reads them. A field that the analysis does not read in the current setting, shown dimmed in its form, is not checked: for example the SPT blow count of a Piedmont residual soil whose test is a cone, or a field of a hybrid model that the other fields replace. Such a value cannot block a run. A value that is not a number in a field that the analysis reads, for example in a file or a table pasted from a spreadsheet, is an error.

## 12.4 Running the analysis

**Analyze ▸ Run Analysis** (F5) analyses the chosen cases and combinations. The progress is shown on the status bar, and the run can be cancelled. At the end, a summary lists one line per case: whether it converged, the movement of the cap and the largest pile force. The notes of each case are in the **Command** panel. The canvas then shows the bending moment diagram of the case with the largest moment, and the view is fitted to the whole model; with vertical loads only, and so no moment, it shows the deformed shape instead.

**NOTE** A case that does not converge is reported with its last iterate and a note that explains the cause, for example a load beyond the axial capacity of a pile. A case that converged only for part of its load reports the fraction reached. Results of a case that did not converge are not a solution and should not be used for design.

Any change of the model after a run clears its results, so that results always belong to the model as it is shown.

## 12.5 Multi-file analysis

**Analyze ▸ Multi-File Analysis (Batch Run)…** analyses a list of model files one after the other and writes the text reports next to each file (Figure 12.3). The list is built with **Add Files…** and **Remove Selected**, emptied with **Clear List**, saved and reopened with **Save List…** and **Open List…**, and checked with **Check Files**, which reports files that are missing or cannot be read. **Replace** changes the text typed in the first box to the text of the second box in every path of the list, for example after the files were moved. **Run All Analyses** analyses every file; **Run Moment-Curv.** only computes the moment–curvature curves of the nonlinear sections; **Stop Batch** stops the batch: the load case being analysed stops at its current iteration, no report is written for that file, and the remaining files are not run. The messages of the run are listed in the window; **Save Messages…**, **Open Messages…** and **Clear Messages** keep, reload and clear them.

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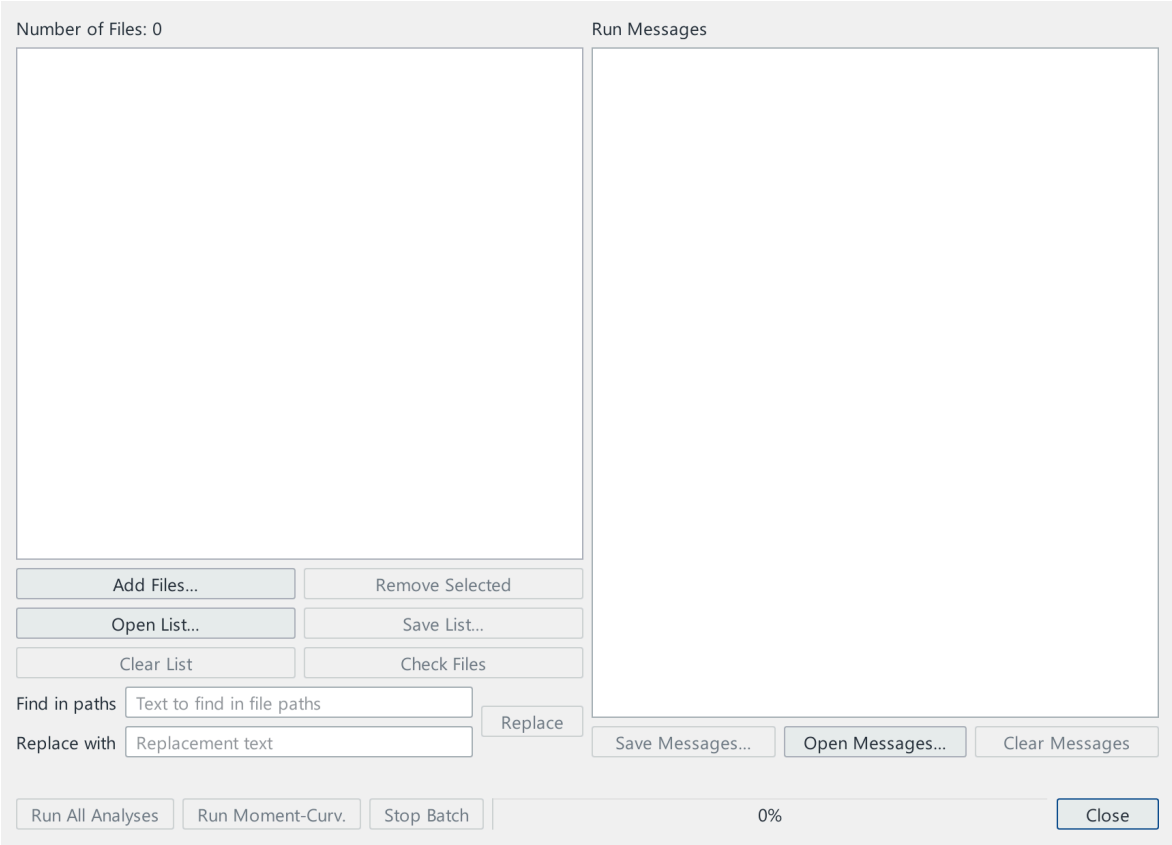



**Figure 12.3 —** Multi-File Analysis (Batch Run)

## 12.6 Command Line and the MCP server

Every model can also be built, changed, analysed and reported with short text commands. The same commands work in two places: the **Command Line** of the Solgroup window, which acts on the open project, and the **MCP server**, through which an AI assistant works on a project of its own in the background while the window is in use.

**Window ▸ Command**, or the **Command** button in the status bar, shows the Command Line in the panel at the bottom, beside *Messages*. A command is typed after the `>` prompt and run with Enter; the arrow keys recall earlier commands, and the answer is written above the prompt. Every change made by a command is one step of **Edit ▸ Undo**; a command that is refused leaves the model as it was, with the reason. `run` starts the same analysis as **Analyze ▸ Run Analysis**.

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**Table 12.2 — Commands**

| Command | Use |
|---|---|
| help [command] | the list of commands, or the details of one |
| new [template] [param=value…] | a new model from a layout template, for example `new rectangular nx=3 ny=3 sx=1.8`; `templates` lists the templates and their parameters |
| open, save, info, units | open or save a project, its summary, and the display unit system |
| tables, table <name> | the model and result tables of **Display ▸ Show Tables**, and one of them |
| set <table> <row> <column> <value> | one cell of a model table, with the same limits as its form, for example `set Piles 1 Length 20` |
| import <file> | read tables exported to CSV or Excel and edited |
| list, add, edit, delete | sections, piles, soil layers, profile rows, load patterns, loads on the cap, load cases (`add cases auto` makes one per pattern) and combinations, for example `add loads DEAD fz=-2700 fx=300` |
| types, fields | the p-y models, section shapes and templates, and their parameters with units, defaults and limits |
| check, run, results, pile <label> | Check Model, the analysis, the cap displacement and pile-head extremes of each case, and the forces at one pile head |
| export <file> | a project copy (.ggp), every table with the results (.xlsx), or the three text reports (.txt) |
| undo, redo | undo or redo the last change |

Numbers are read and written in the display unit system of the project, as in the tables; angles are in degrees.

Without the window, `solgroup-cli.exe --script commands.txt` runs a file of commands, one per line (a line starting with # is a note); it stops at the first command that fails, or goes on with `--keep-going`, and ends with exit code 0 only when every command succeeded. `solgroup-cli.exe --shell`, optionally followed by a project file, opens an interactive command prompt in the console; `quit` leaves it.

The sign-in of the program is also available in the console: `solgroup-cli.exe --login` asks for the e-mail and password of the solplan.id account (`--email` gives the e-mail, `--google` signs in with Google in the browser), `--licence` shows the account and its licences, and `--logout` signs out on this computer. The installer offers **Add the 'solgroup' command-line tool to PATH**; with it, the console tool is started as `solgroup` from any folder, for example `solgroup --script commands.txt`.

The MCP server starts with `solgroup-cli.exe --mcp` from the installation folder (or `python -m geogroup --mcp` from the source). An assistant that supports the Model Context Protocol registers it as a local server, for example `claude mcp add solgroup -- "C:\Program Files\Solplan\Solgroup\solgroup-cli.exe" --mcp`. The server offers tools for the project, the model tables and collections, Check Model, the run, the results and the export, and one tool that runs any text command. Its analyses use the licence of the signed-in account in the same way as the program.

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# 13 Results

The results of the last run are kept in the open model until the model is changed. They are shown in the units of the model, through the commands of the **Display** menu: on the model, in graphs, in tables and in text reports.

## 13.1 Results on the model

**Table 13.1 — Display ▸ Results in Canvas**

| Command | Fields and content |
|---|---|
| Show Deformed Shape… | the deflected piles and cap of the **Load case**; the **Scale factor** magnifies the displacements for visibility and changes no result (**Auto** suggests a scale that makes the largest displacement about 8 % of the model size). **Show Undeformed Shape** returns to the model. |
| Force Diagrams in Canvas… | tab *Result*: diagrams along every pile, or with **Selected piles only**, of the **Load case / combination**; the **Component** is M3 or M2 bending moment, Resultant Moment, V2 or V3 shear force, Resultant Shear, N axial force along pile, N axial force at pile head, T torsion at pile head, Soil Reaction y dir, Soil Reaction z dir or Resultant Soil Reaction. Tab *Appearance*: **Diagram scale**, **Diagram style** (Ordinates, Solid fill or Outline), **Diagram colour** (By component or a fixed colour) and **Show minimum and maximum values**. The axial force along the pile exists when **Analyze ▸ Analysis Options… Include axial load variation along the piles** was ticked for the run; without it the dialog says so. |
| Show Contour Plot… | window *Heat Map* (Figure 13.1). Tab *Result*: the **Load case / combination** and the **Result component** (U2 or U3 lateral deflection, Resultant Deflection, M3 or M2 bending moment, Resultant Moment, V2 or V3 shear force, Resultant Shear, soil reactions, Total Stress, Bending Stiffness, N axial force along pile, the axial force or torsion at the pile head, or a cap component for a flexible cap); **Show colour scale**; **All piles** or **Selected piles**; **Only piles containing the minimum or maximum**; **Show heat map in canvas**. Tab *Colour scale*: **Colour palette** (Spectrum, Sequential or Diverging), **Minimum** and **Maximum** (**Reset to Extremes** restores the minimum and maximum of the quantity over the piles), the number of **Colour bands** and the resulting **Increment**, and **Show cap mesh edges** (for cap results). |

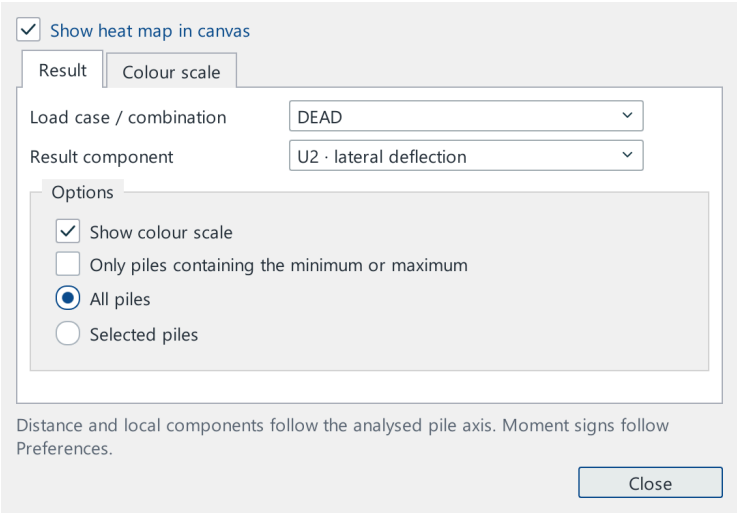



**Figure 13.1 —** Heat Map, Result tab

## 13.2 Result graphs and cap response

**Display ▸ Result Graphs and Response ▸ Show Forces Along Piles…** opens the result graphs (Figure 13.2). The **Load case / combination**, the **Pile** and the **Quantity** are chosen at the top; **Resultant of planes 2 and 3** plots the SRSS resultant, always positive, instead of the two local bending planes separately. **All load cases and**

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**combinations** overlays the chosen pile in every load case and combination that has results, one curve each, to compare them on one graph. Each page has a graph and a table of values that can be copied:

**Table 13.2 — Pages of the result graphs**

| Page | Content |
|---|---|
| Pile profile | the Quantity against the distance from the pile head, drawn upright like the pile: the distance on the vertical axis, increasing downward, and the value on the horizontal axis at the top. Lateral Deflection, Bending Moment, Shear Force, Soil Reaction p, Soil Modulus Es, Soil Reaction by Plane, Bending Stiffness EI, Demand / Capacity or Total Stress; in the two bending planes separately or as their resultant |
| Profile values | the same quantity in a table at every node of the pile: the Distance and the value in each plane, for example Lateral Deflection · plane 2 and Lateral Deflection · plane 3 |
| Pile heads | a pile-head **Component** for every pile, as a graph and a table: N axial compression, T torsion, V2 and V3 shear, M2 and M3 bending, Ux, Uy, Uz global displacement and Rx, Ry, Rz global rotation |
| Cap plates | for a flexible cap, the **Component** at the Gauss points of the chosen **Plate** (Gauss point and value, for example M11 · cap bending in kN·m/m): M11 and M22 cap bending, M12 cap twisting, V13 and V23 cap transverse shear, S11, S22 and S12 stresses at the top and at the bottom face |
| Combined D/M/V | deflection, moment and shear of one pile side by side, for Plane 2: D2 / M3 / V2, Plane 3: D3 / M2 / V3, or the Resultants |

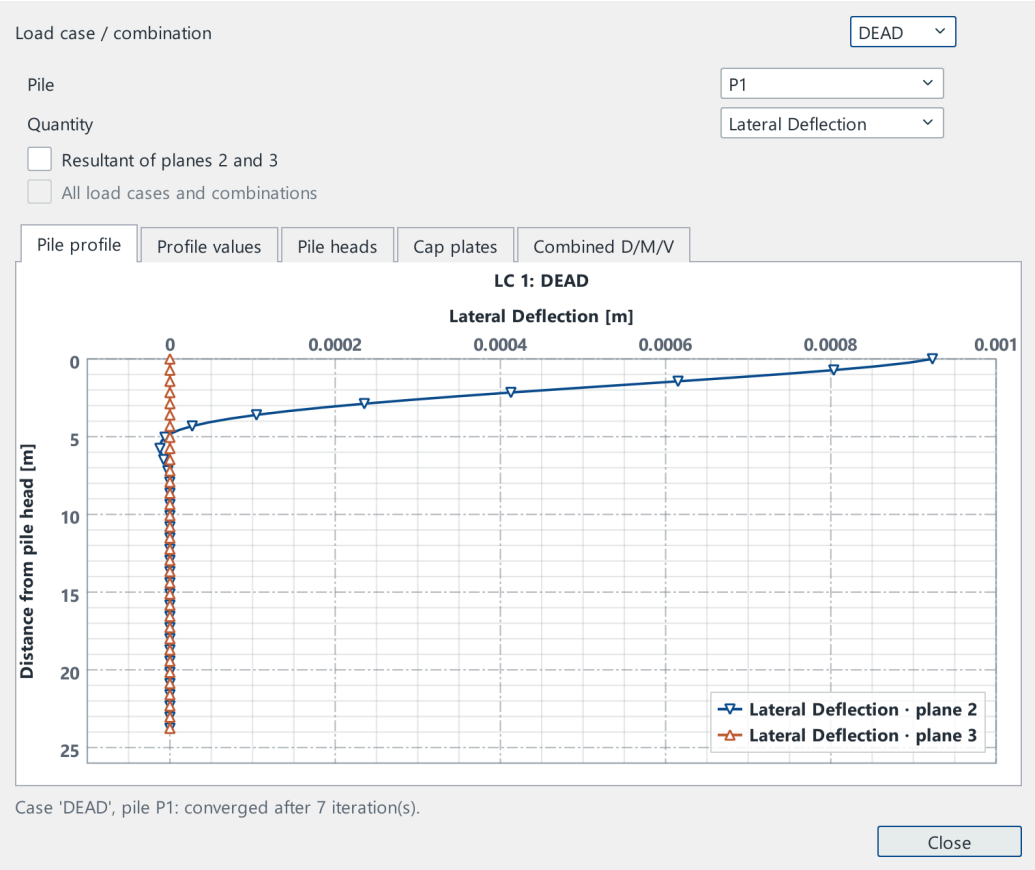



**Figure 13.2 —** Result Graphs: lateral deflection along a pile

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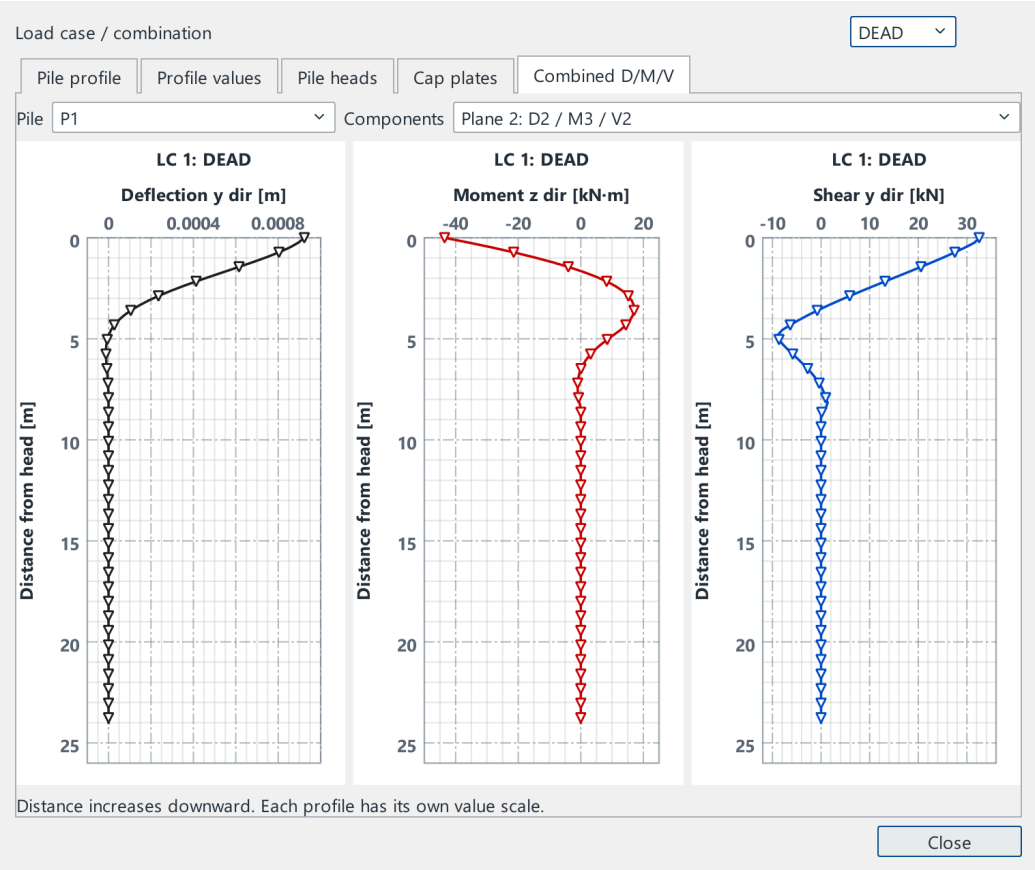



**Figure 13.3 —** Result Graphs: Combined D/M/V

**Table 13.3 — Other commands of Display ▸ Result Graphs and Response**

| Command | Content |
|---|---|
| Show Cap Response… | tabs: **Displacement** (Ux, Uy, Uz, Rx, Ry, Rz of the cap for each Load Case, with the number of Iterations and the Status); **Foundation** (the stiffness matrix **K** = $\mathbf{S}^{-1}$, the flexibility, or a graph of a diagonal term against the displacement, for cases with a foundation stiffness analysis); **Pushover** (a displacement against a load or the load factor); **Envelope** (the extremes of the envelope combinations: for each Envelope, Row and Item, the cap displacements Ux, Uy, Uz, Rx, Ry, Rz and the pile-head Axial, Shear-2, Shear-3, Moment-2, Moment-3 and Torsion, with the case that gives each); **Reduction** (the P-Factor and Y-Factor of every Pile); **Passive** (the soil resistance on an embedded cap for each Load Case: Force X, Force Y, Elevation, Width and Method). **Copy** copies the matrix as plain numbers followed by a table of their units, or every converged pushover step as text (factor, load and cap displacement). |
| Special Plots… | compares solved load states without combining them: a quantity along the piles (U2 or U3 lateral deflection, moments, shears, soil reactions, Total Stress, Bending Stiffness, the distributed loads, and with axial load variation the axial force and the global displacements) for several cases or combinations and several piles in one graph; the axial load of every pile against its head moment (*Pile Axial Load vs. Top Moment*); or the movement of the cap against the load acting on it, one point per case (*Pile Cap Movement vs. Acting Load*, with the *Horizontal* and *Vertical* components chosen) |
| Show Printed p-y Curves… | window *Printed p-y Curves*: the p-y curves printed at the printing depths (Section 9.10) |
| Export Graphs to Excel… | window *Export to Excel*: choose the case and the plots (**Select All**, **Unselect All**), **Add markers in plots**, and **Generate Excel File…** writes the data and the charts to a workbook; **Close Window** closes it |

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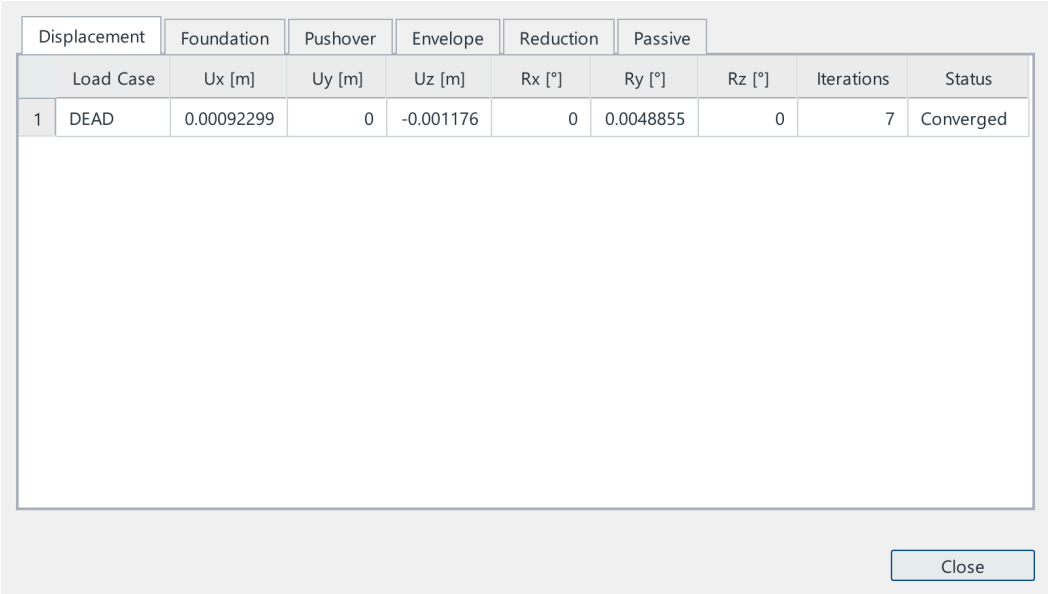



**Figure 13.4 —** Show Cap Response, Displacement tab

### 13.2.1 Results of special analyses

The pages of **Show Cap Response…** other than Displacement are filled by the analyses that produce them. The figures below were made with the 3 × 3 group of the examples, run with the corresponding options.

**Foundation.** For a case with a foundation stiffness analysis, the page shows the matrix of a chosen *Load Level*, as the *Stiffness* $K = S^{-1}$ or the *Flexibility* $u = S \cdot F$, with rows for the response and columns for the load, and a note on the load of the level and on the degrees of freedom that were not swept (Figure 13.5). *Kii vs displacement (graph)* draws each diagonal term against the movement of the cap, which shows how the stiffness falls with the load (Figure 13.6). **Copy** copies the matrix with its units for use in a structural program.

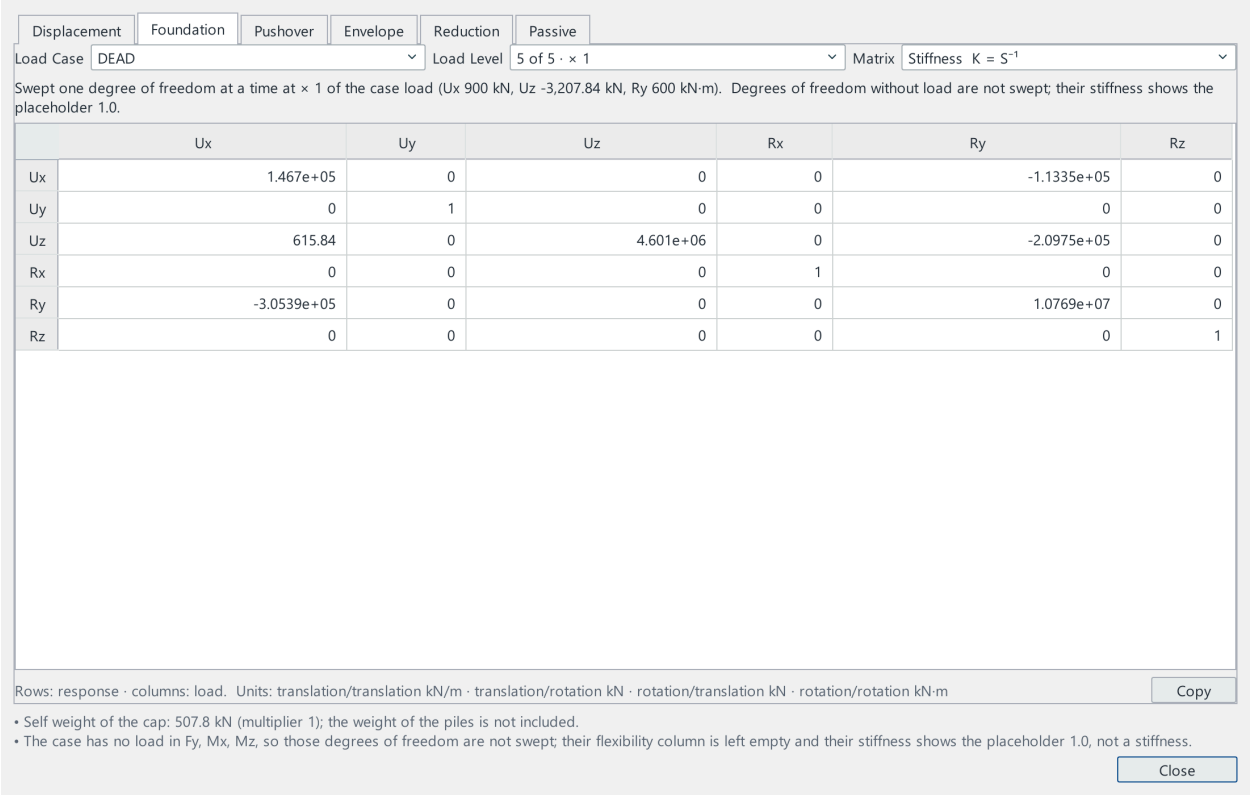



**Figure 13.5 —** Show Cap Response, Foundation: stiffness matrix at the full load

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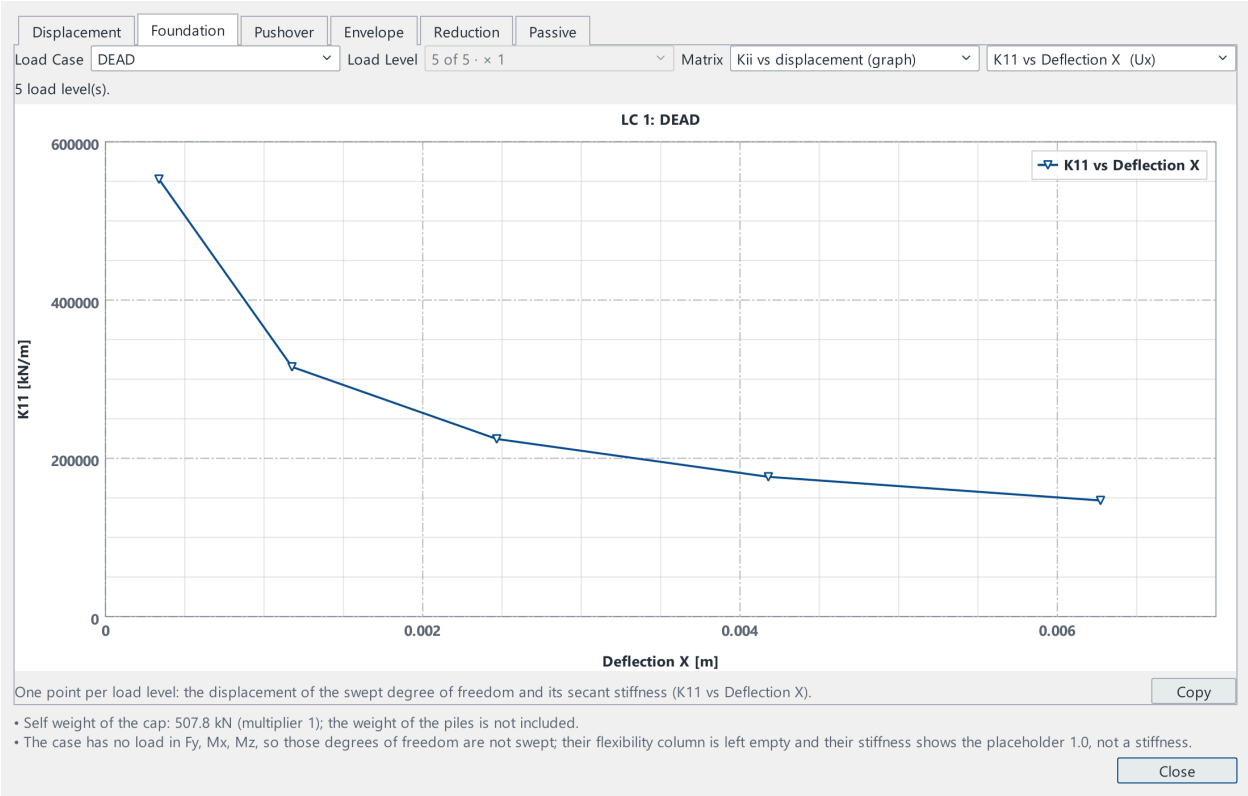



**Figure 13.6 —** Show Cap Response, Foundation: diagonal stiffness against the movement of the cap

**Pushover.** For a pushover case, the page plots a displacement of the cap (X) against a load component or the load factor (Y) over the converged steps, and states the number of steps and the components held constant (Figure 13.7).

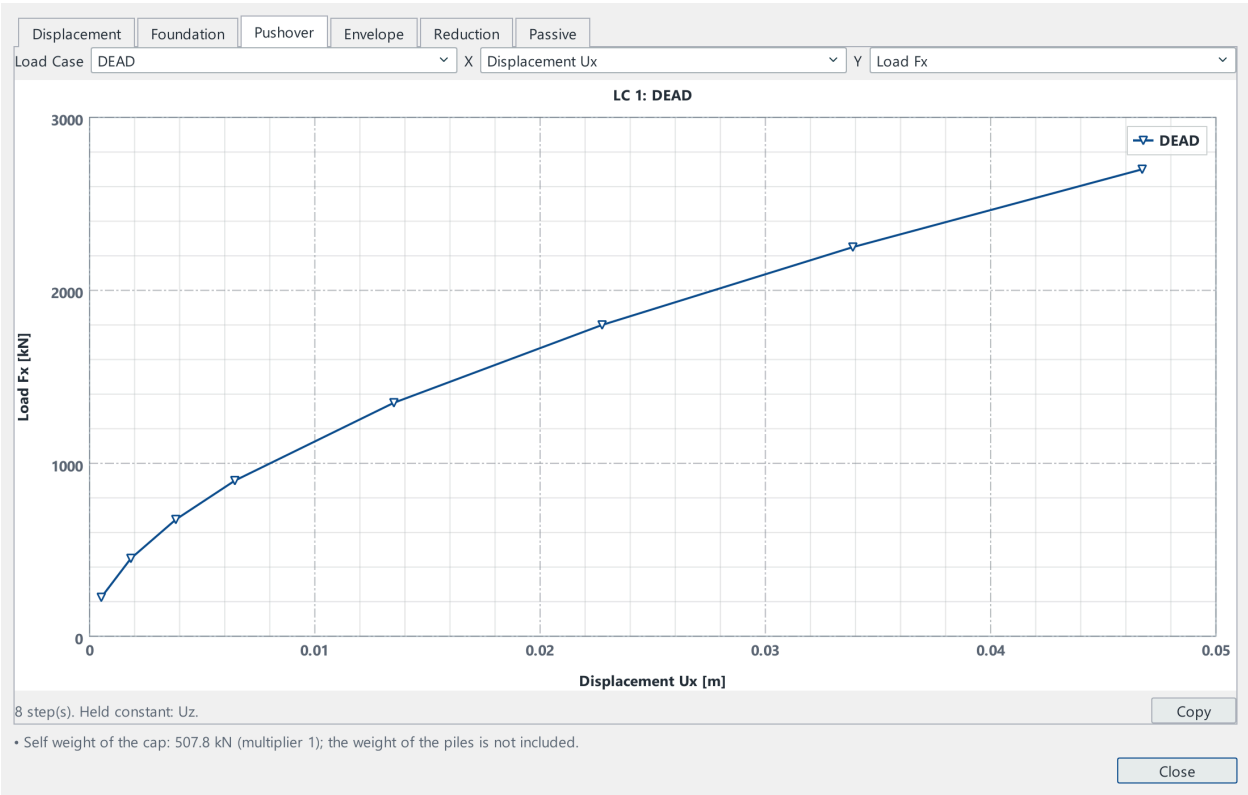
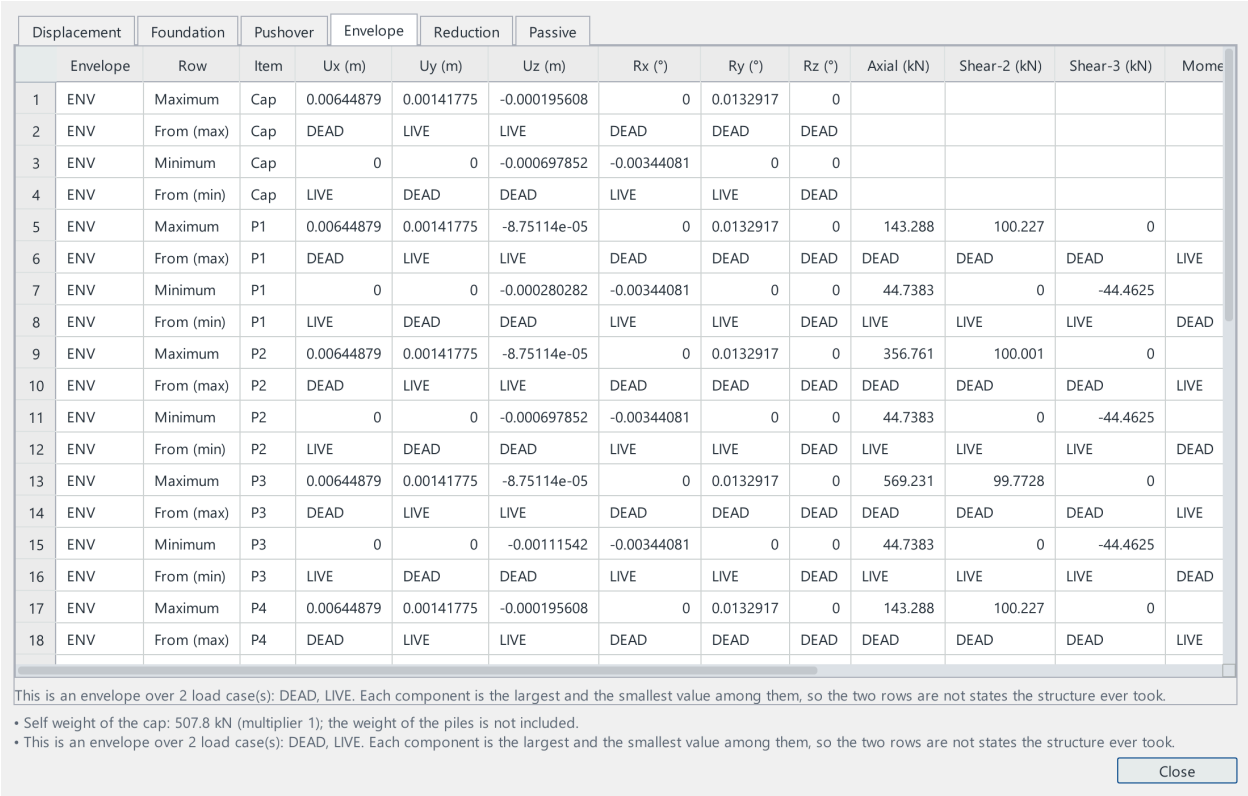



**Figure 13.7 —** Show Cap Response, Pushover

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**Envelope.** For an envelope combination, the page lists for each component the largest and the smallest value among the members and the member that gives it: the displacements of the cap and the forces at the head of each pile (Figure 13.8).

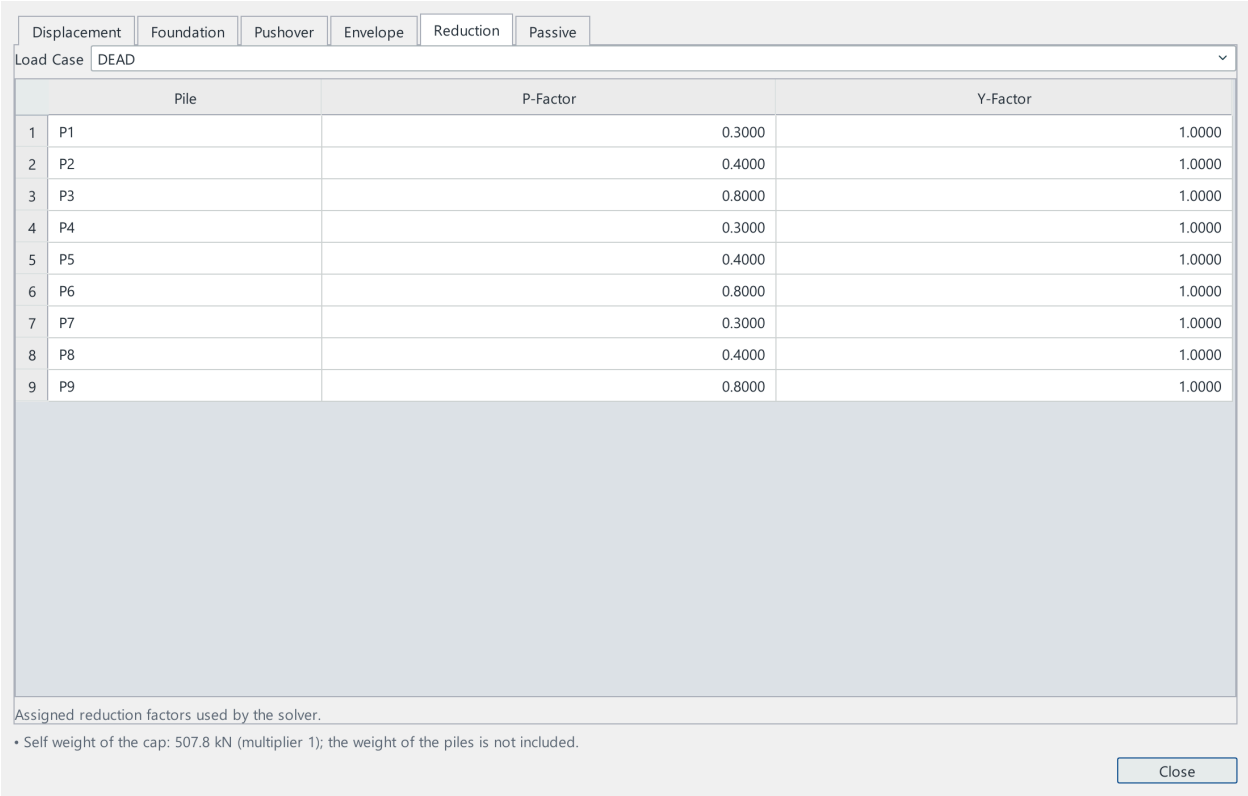



| | Envelope | Row | Item | Ux (m) | Uy (m) | Uz (m) | Rx (°) | Ry (°) | Rz (°) | Axial (kN) | Shear-2 (kN) | Shear-3 (kN) | Mome |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ENV | Maximum | Cap | 0.00644879 | 0.00141775 | -0.000195608 | 0 | 0.0132917 | 0 | | | | |
| 2 | ENV | From (max) | Cap | DEAD | LIVE | LIVE | DEAD | DEAD | DEAD | | | | |
| 3 | ENV | Minimum | Cap | 0 | 0 | -0.000697852 | -0.00344081 | 0 | 0 | | | | |
| 4 | ENV | From (min) | Cap | LIVE | DEAD | DEAD | LIVE | LIVE | DEAD | | | | |
| 5 | ENV | Maximum | P1 | 0.00644879 | 0.00141775 | -8.75114e-05 | 0 | 0.0132917 | 0 | 143.288 | 100.227 | 0 | |
| 6 | ENV | From (max) | P1 | DEAD | LIVE | LIVE | DEAD | DEAD | DEAD | DEAD | DEAD | DEAD | LIVE |
| 7 | ENV | Minimum | P1 | 0 | 0 | -0.000280282 | -0.00344081 | 0 | 0 | 44.7383 | 0 | -44.4625 | |
| 8 | ENV | From (min) | P1 | LIVE | DEAD | DEAD | LIVE | LIVE | DEAD | LIVE | LIVE | LIVE | DEAD |
| 9 | ENV | Maximum | P2 | 0.00644879 | 0.00141775 | -8.75114e-05 | 0 | 0.0132917 | 0 | 356.761 | 100.001 | 0 | |
| 10 | ENV | From (max) | P2 | DEAD | LIVE | LIVE | DEAD | DEAD | DEAD | DEAD | DEAD | DEAD | LIVE |
| 11 | ENV | Minimum | P2 | 0 | 0 | -0.000697852 | -0.00344081 | 0 | 0 | 44.7383 | 0 | -44.4625 | |
| 12 | ENV | From (min) | P2 | LIVE | DEAD | DEAD | LIVE | LIVE | DEAD | LIVE | LIVE | LIVE | DEAD |
| 13 | ENV | Maximum | P3 | 0.00644879 | 0.00141775 | -8.75114e-05 | 0 | 0.0132917 | 0 | 569.231 | 99.7728 | 0 | |
| 14 | ENV | From (max) | P3 | DEAD | LIVE | LIVE | DEAD | DEAD | DEAD | DEAD | DEAD | DEAD | LIVE |
| 15 | ENV | Minimum | P3 | 0 | 0 | -0.00111542 | -0.00344081 | 0 | 0 | 44.7383 | 0 | -44.4625 | |
| 16 | ENV | From (min) | P3 | LIVE | DEAD | DEAD | LIVE | LIVE | DEAD | LIVE | LIVE | LIVE | DEAD |
| 17 | ENV | Maximum | P4 | 0.00644879 | 0.00141775 | -0.000195608 | 0 | 0.0132917 | 0 | 143.288 | 100.227 | 0 | |
| 18 | ENV | From (max) | P4 | DEAD | LIVE | LIVE | DEAD | DEAD | DEAD | DEAD | DEAD | DEAD | LIVE |

**Figure 13.8 —** Show Cap Response, Envelope

**Reduction.** When a set of group factors is used, the page lists the p-factor and the y-factor of every pile for the chosen case, after the iteration on the direction of movement where the method uses it (Figure 13.9).

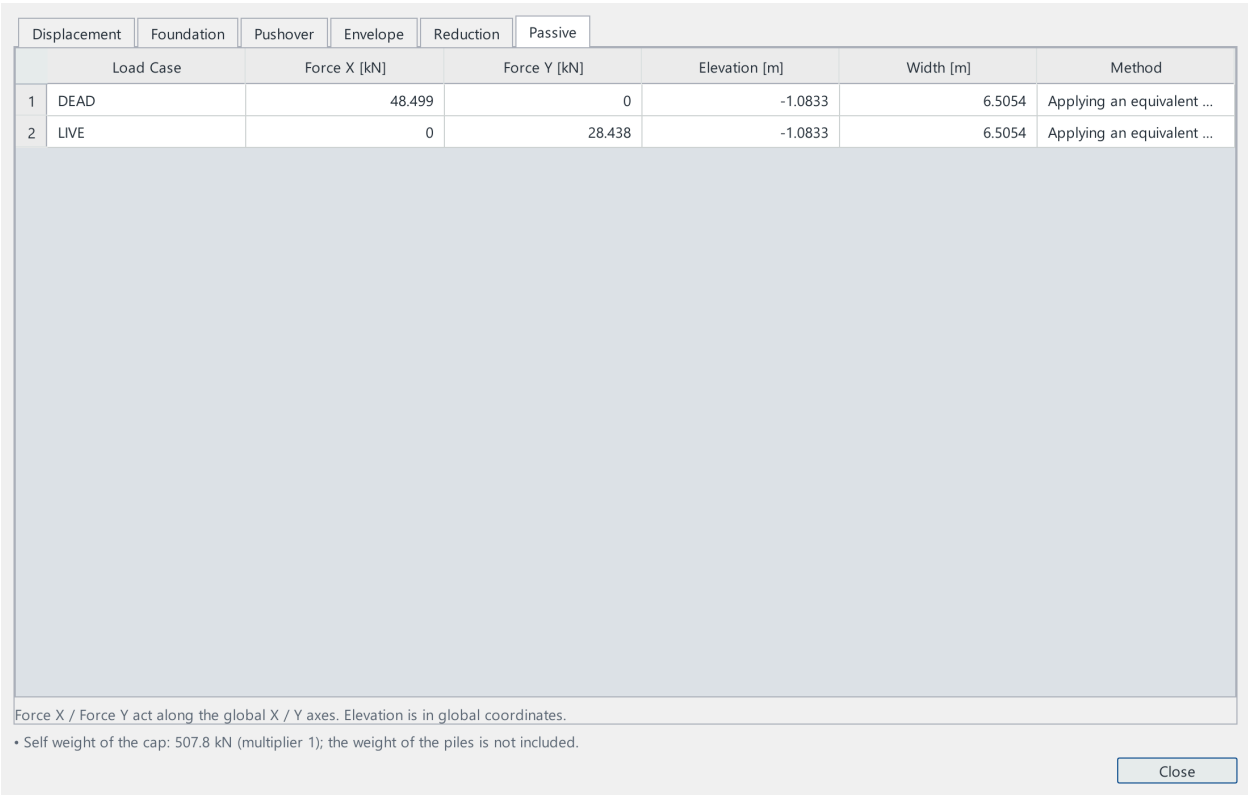
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| | Pile | P-Factor | Y-Factor |
|---|---|---|---|
| 1 | P1 | 0.3000 | 1.0000 |
| 2 | P2 | 0.4000 | 1.0000 |
| 3 | P3 | 0.8000 | 1.0000 |
| 4 | P4 | 0.3000 | 1.0000 |
| 5 | P5 | 0.4000 | 1.0000 |
| 6 | P6 | 0.8000 | 1.0000 |
| 7 | P7 | 0.3000 | 1.0000 |
| 8 | P8 | 0.4000 | 1.0000 |
| 9 | P9 | 0.8000 | 1.0000 |

**Figure 13.9 —** Show Cap Response, Reduction

**Passive.** For an embedded cap with soil resistance, the page lists for each case the force of the soil on the cap in X and Y, the elevation at which it acts, the width of the face and the method (Figure 13.10).




| | Load Case | Force X [kN] | Force Y [kN] | Elevation [m] | Width [m] | Method |
|---|---|---|---|---|---|---|
| 1 | DEAD | 48.499 | 0 | -1.0833 | 6.5054 | Applying an equivalent ... |
| 2 | LIVE | 0 | 28.438 | -1.0833 | 6.5054 | Applying an equivalent ... |

**Figure 13.10 —** Show Cap Response, Passive

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**Special Plots.** The window compares cases and piles in one graph (Figure 13.11): select the quantity at the top, the cases or combinations on the left and the piles on the right. A quantity along the piles is drawn like the pile profile, with the distance from the pile head on the vertical axis, increasing downward; Pile Axial Load vs. Top Moment and Pile Cap Movement vs. Acting Load have the load on the vertical axis.

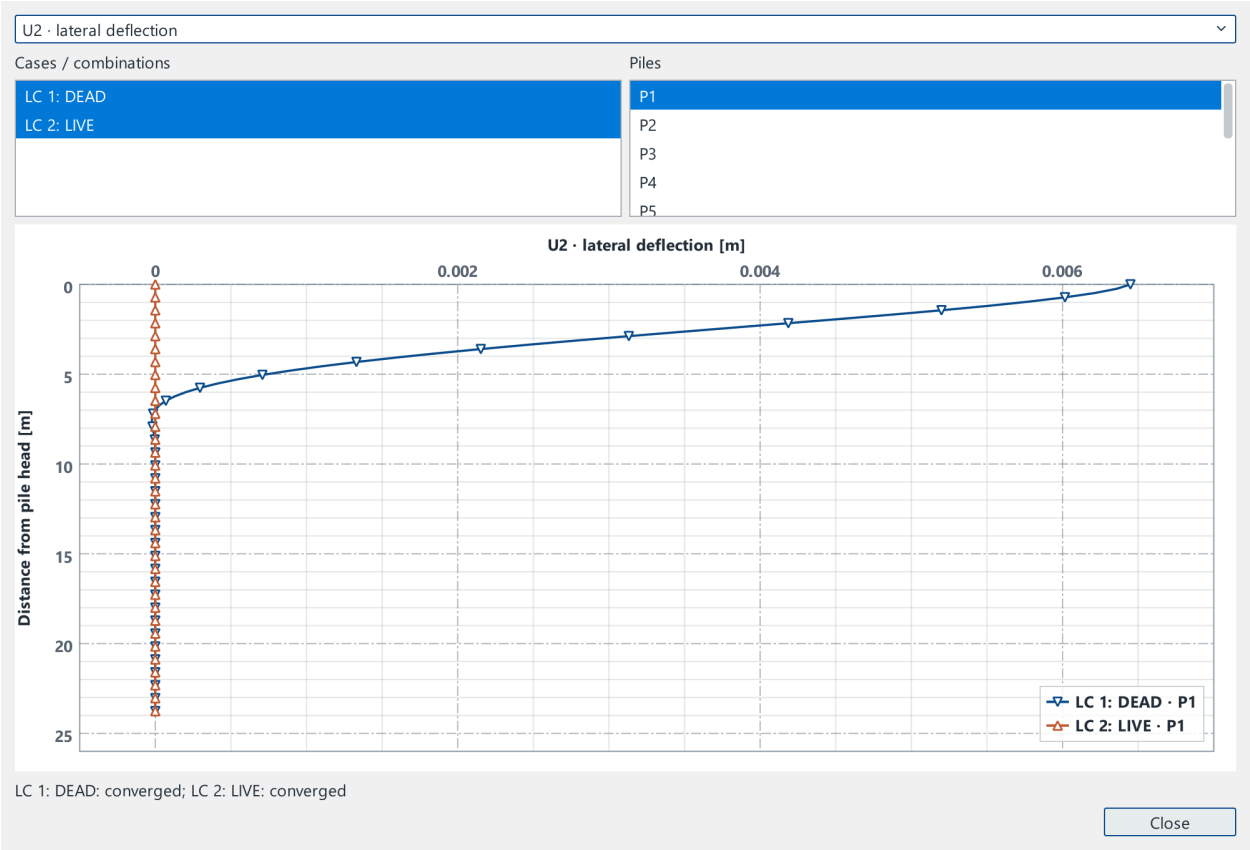



**Figure 13.11 —** Special Plots: lateral deflection U2 of pile P1 for two cases (LIVE acts in Y, so its U2 is zero)

### 13.2.2 Quantities along the piles

The figures below show each quantity of the page *Pile profile* for pile P1 of the model of Chapter 6 under the combination COMB2. The vertical axis is the distance from the pile head along the pile, increasing downward; the value is read on the axis at the top, and the legend names the plane of each curve.

**Lateral Deflection**: the movement of the pile axis normal to the pile, in the directions of local axes 2 (plane 2) and 3 (plane 3), measured from the undeformed position of the pile. With *Resultant of planes 2 and 3* the square root of the sum of their squares is shown instead.

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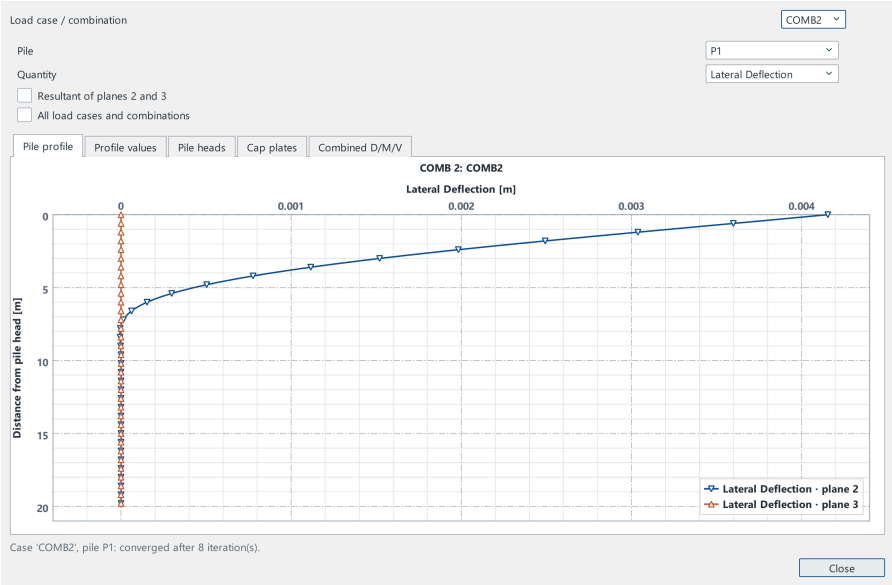



**Figure 13.12 —** Result Graphs, Lateral Deflection

**Bending Moment**: the moment $M3$ that bends the pile in plane 2 and the moment $M2$ that bends it in plane 3. The side on which a positive moment puts the pile in tension is set by the moment sign convention of the preferences. For fixed heads the largest moment is usually at the head; a second extreme of the opposite sign follows a few diameters below.

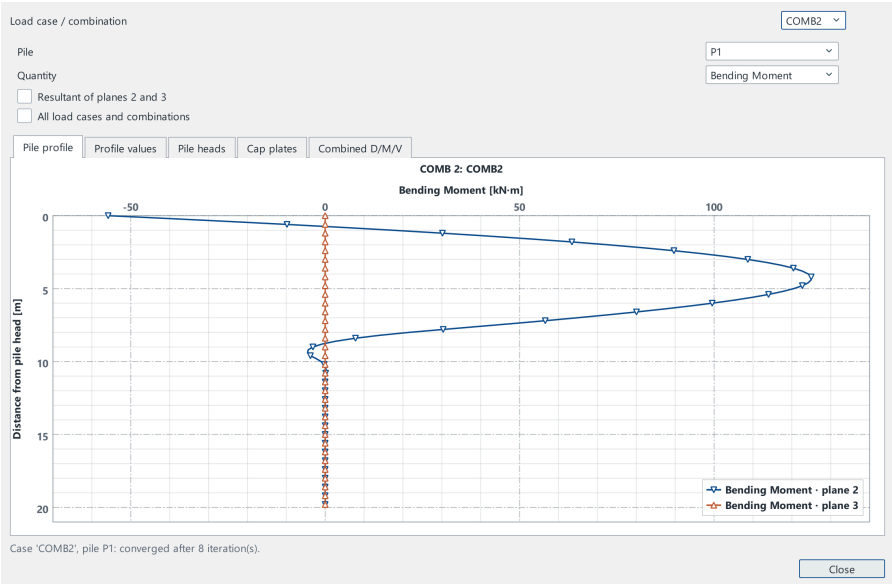



**Figure 13.13 —** Result Graphs, Bending Moment

**Shear Force**: the shear $V2$ along local axis 2 and $V3$ along axis 3. At the head it equals the lateral force that the cap transmits to the pile; below, it changes as the soil reaction is integrated along the pile.

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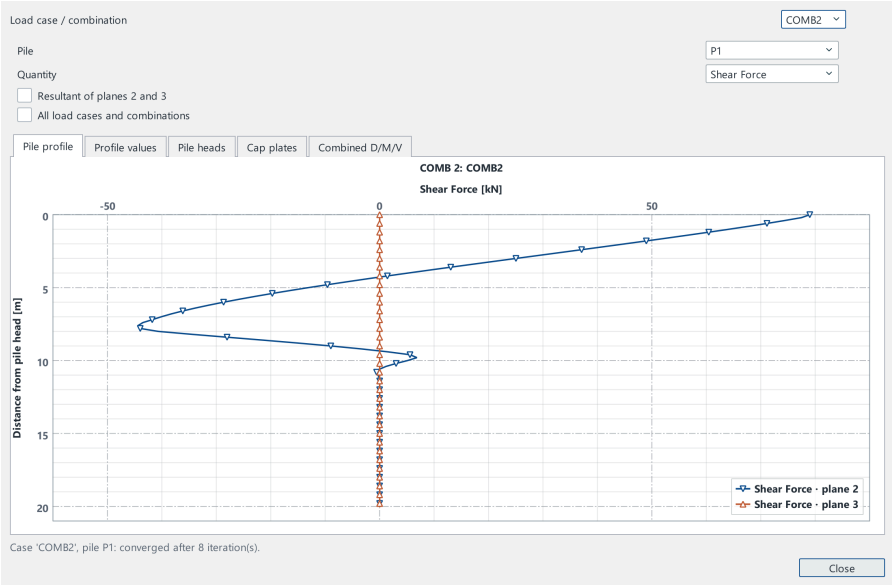



**Figure 13.14 —** Result Graphs, Shear Force

**Soil Reaction p**: the resultant soil reaction per unit length of the pile, the force that the soil exerts on the pile, opposing its movement relative to the soil. It is largest a short distance below the ground surface and changes sign where the deflection changes sign.

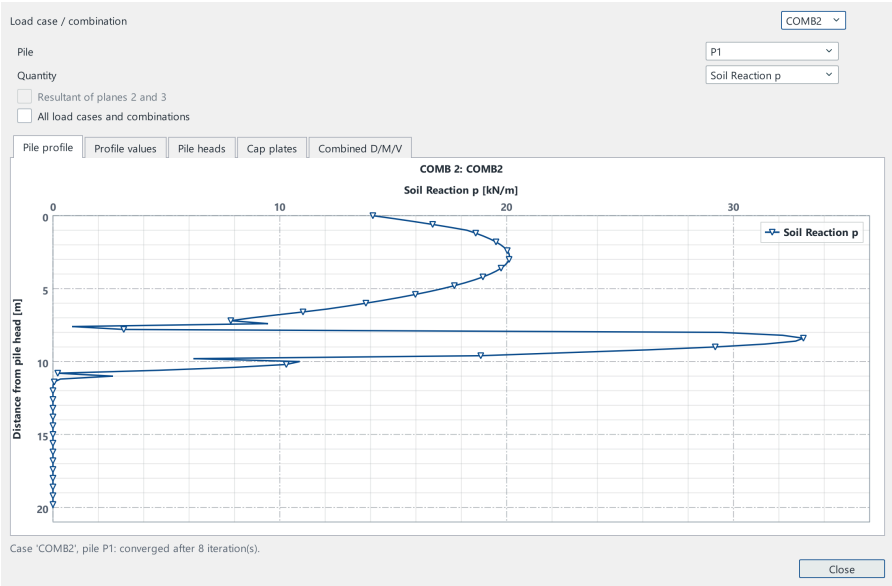



**Figure 13.15 —** Result Graphs, Soil Reaction p

**Soil Modulus Es**: the secant modulus of the p-y curve at each node, the soil reaction divided by the deflection, $E_s = p/y$. It shows how far the soil near the surface has softened: where the curve has reached its ultimate resistance the modulus is small; deeper, where the deflection is small, it approaches the initial stiffness of the curve.

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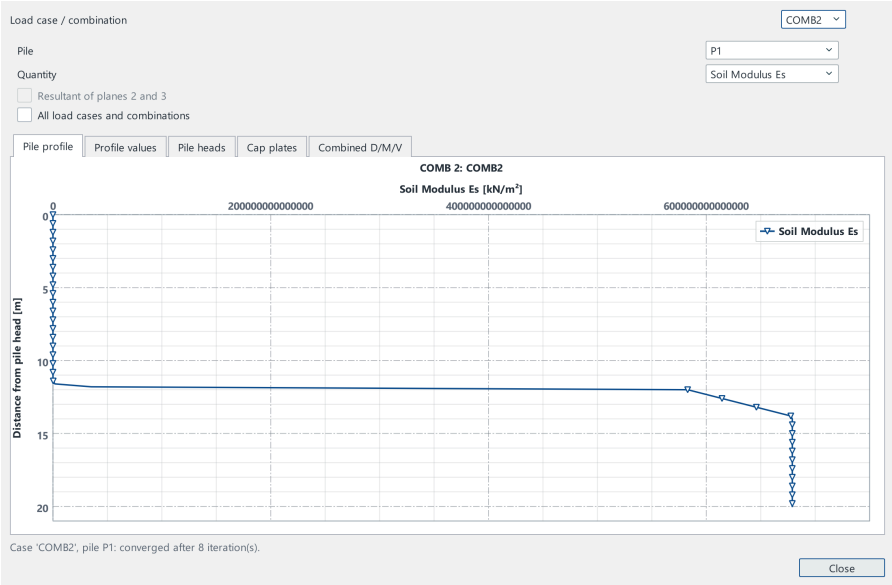



**Figure 13.16 —** Result Graphs, Soil Modulus Es

**Soil Reaction by Plane**: the soil reaction resolved into the two bending planes of the pile, to be compared with the deflection of each plane.

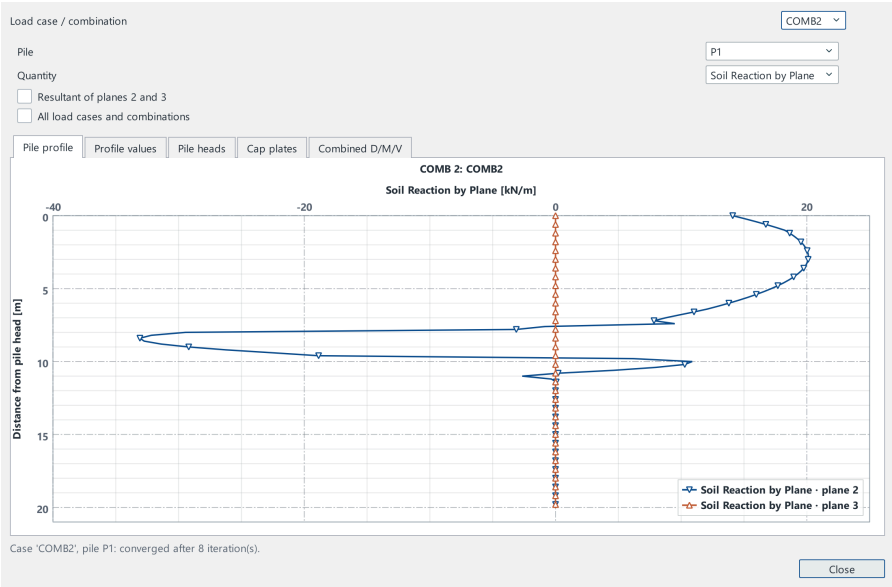



**Figure 13.17 —** Result Graphs, Soil Reaction by Plane

**Bending Stiffness EI**: the bending stiffness of the section at each node in each plane. For an elastic section it is constant; for a nonlinear section it is the secant stiffness $M/\varphi$ of the moment–curvature curve at the moment of the node, and drops where the section cracks or yields. In this example the moments stay below the cracking moment and the stiffness is that of the uncracked section along the whole pile.

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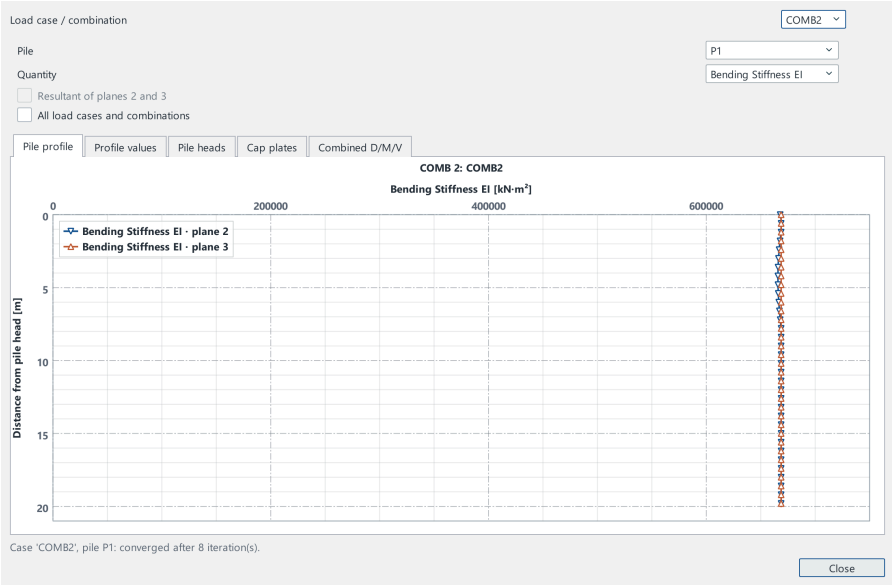



**Figure 13.18 —** Result Graphs, Bending Stiffness EI

**Demand / Capacity**: for a load combination, the ratio of the bending moment to the factored moment capacity of the section, $\sqrt{((M3/\varphi_{\mathrm{b}}M_{\mathrm{n33}})^2 + (M2/\varphi_{\mathrm{b}}M_{\mathrm{n22}})^2)}$, and the same ratio for the shear forces with $\varphi_{\mathrm{v}}$. The capacities are those of the Design (LRFD) tab of the section, or the overrides of the combination. Here the moment capacity of the section is 1,003 kN·m, computed from its moment–curvature curve, and the largest ratio, at the head, is well below one.

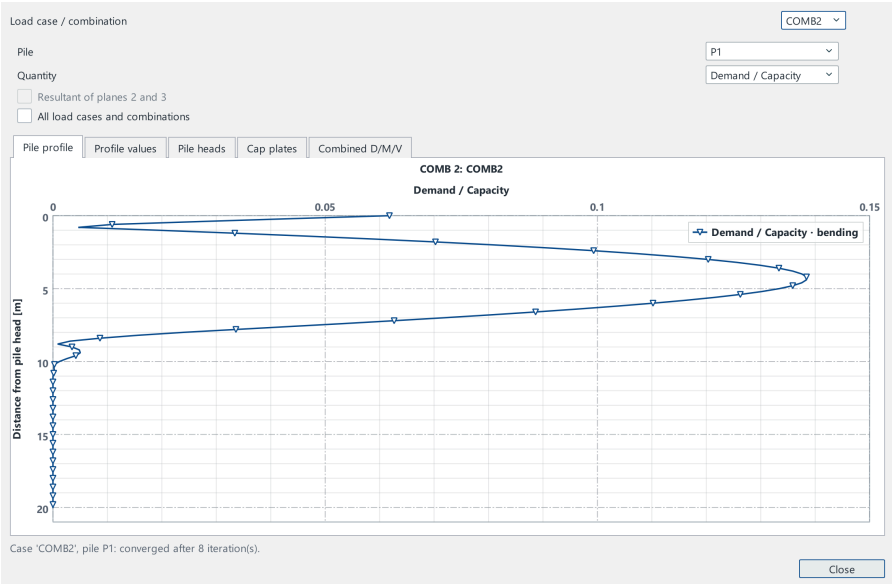



**Figure 13.19 —** Result Graphs, Demand / Capacity

**Total Stress**: the total normal stress, the axial stress plus the bending stress at the extreme fibre, for elastic sections; for nonlinear sections the stress is not computed and the graph is empty.

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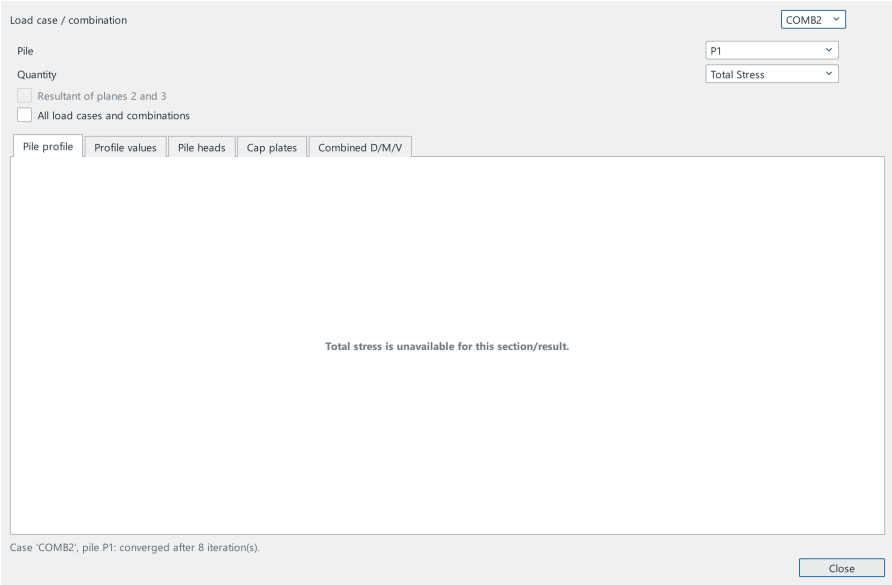



**Figure 13.20 —** Result Graphs, Total Stress

## 13.3 Tables and curves

**Display ▸ Show Tables…** lists the model and the results in tables (Figure 13.21). The table is chosen in the tree on the left, where the tables are grouped by subject; the box above the table filters its rows, and a right-click on a column heading filters or sorts the rows by that column. The cells can be copied (Ctrl+C), and **Export This Table…** and **Export All…** write one table or all of them. A table of more than 1 000 rows shows its first 1 000 rows; the export contains every row, and the status line states how many rows were written. Model tables can be edited in place where a cell is editable; a value that is not accepted is restored and the reason is shown under the table. A cell, and a table imported from CSV or Excel, accepts only the values that the corresponding form accepts, for example a Poisson's ratio from 0 to 0.499, a unit weight, modulus or mesh size not below zero, or an axial reduction factor above 0 and up to 1. The table *Ground Surface* lists the ground surface of every pile, from the profile, its sloping shape or the pile's own elevation (Section 9.6.1).

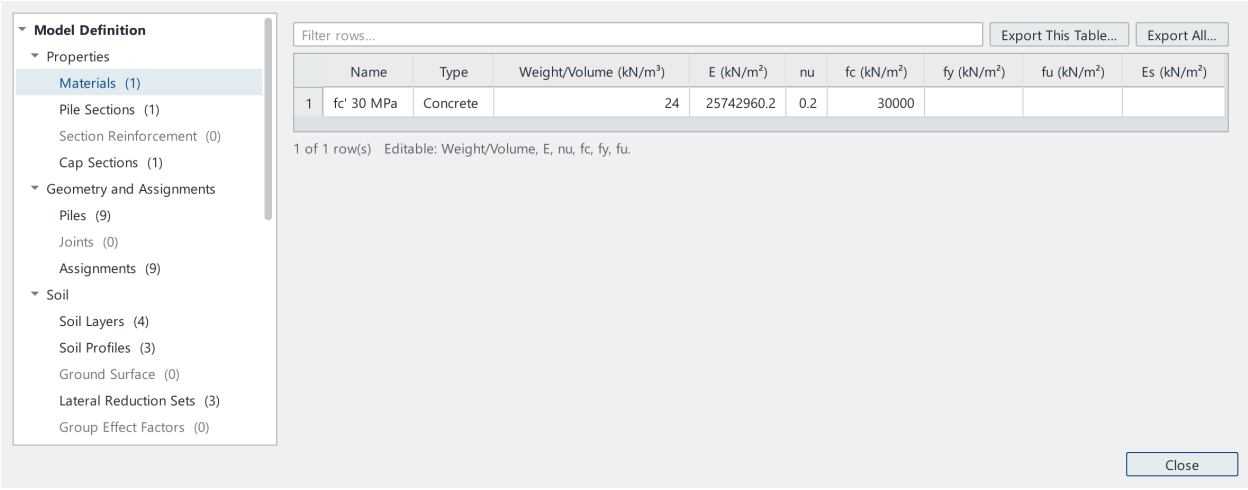



**Figure 13.21 —** Show Tables

**Display ▸ Show Soil Curves…** draws the curves that the analysis uses, on three tabs: p-y (lateral), L-D (pile head) and T-R (pile head) (Figure 13.22). With a **Pile** chosen it shows the curves that pile actually uses; for the p-y curves, **Apply p-multiplier, y-multiplier and lateral reduction** shows the curve after the group and reduction factors of the chosen **Load case** (p-multipliers are bound to a load case, because the leading row follows the load direction). With <none> it shows the plain layer curves of a **Soil profile** for a **Pile section**, of which only the diameter is used,

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at a **Number of curves** between **From depth** and **To depth**. **Display ▸ User-Defined Curves…** draws the user-defined p-y, Axial L-D and Torsional T-R curves, for a chosen set or curve and depth, on a Graph tab and a Values tab (Depth, y, p).

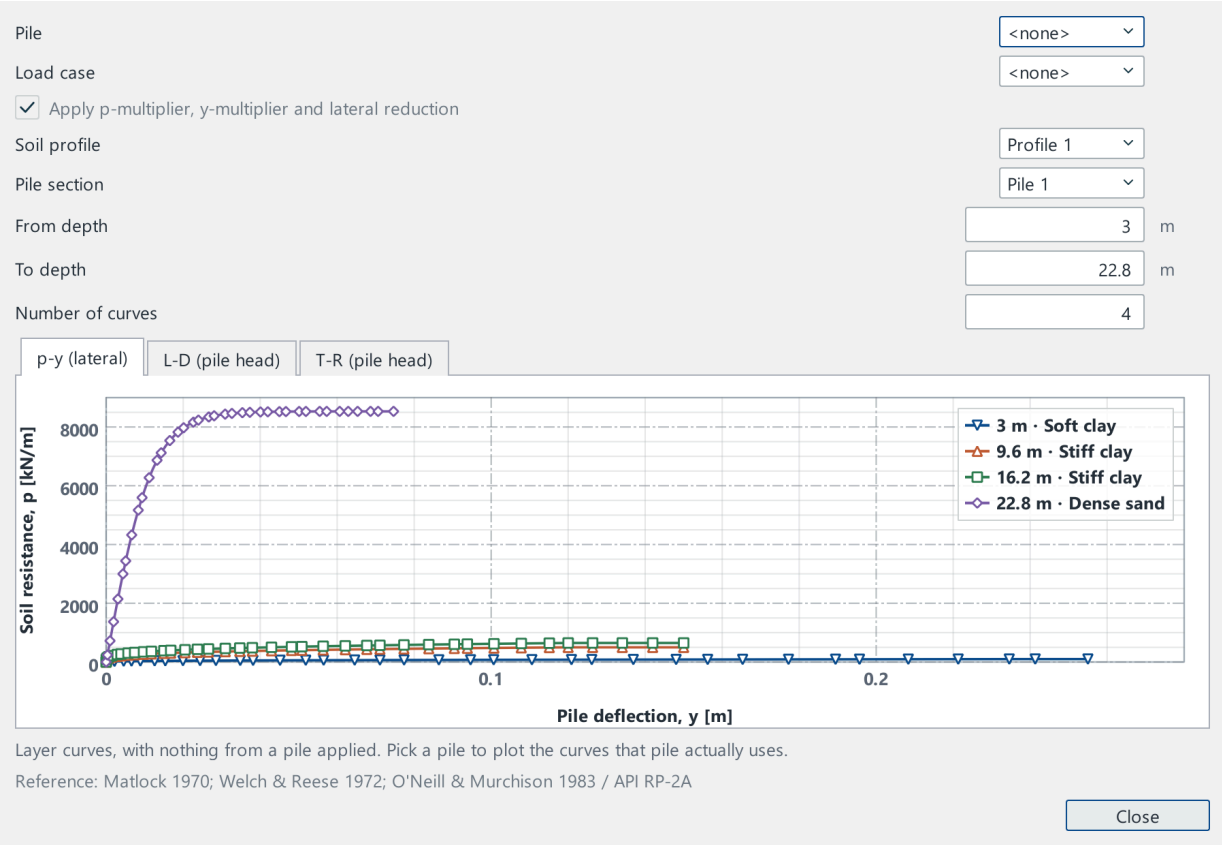



**Figure 13.22 —** Show Soil Curves, p-y tab

**Display ▸ Show Moment-Curvature…** draws the moment–curvature relation of the nonlinear sections, with its values.

## 13.4 Text reports

**Display ▸ Show Text Report** shows three plain-text reports, on three tabs (Figure 13.23):

- **Input Echo**: the complete input of the model, as read by the analysis;
- **Output Results**: the results of every case in full, pile by pile and node by node, as set by the printing code and the output variables;
- **Summary Results**: the cap displacement and the pile-head forces of every case, with the extreme values.

The report shown can be copied to the clipboard (**Copy**), saved as a text file (**Save…**), printed (**Print…**), or saved with the other two side by side (**Save All…**). **File ▸ Export ▸ Text Reports (.txt)…** writes the three reports to files.

### 13.4.1 Contents of the text reports

The three reports are plain text in a fixed-width layout, with the units of the model in the column heads. Each begins with a heading that names the program, the model, the report and the units. Their sections are:

**Table 13.4 — Sections of the text reports**

| Report | Section | Content |
|---|---|---|
| Input Echo | MODEL INPUT | title, three-dimensional model, rigid or flexible cap, and the analysis options in force (batter, generated axial and torsional curves, layering correction) |

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| Report | Section | Content |
|---|---|---|
| | PILE CAP; CAP SECTIONS | extent, thickness and elevation of the cap, the load reference point, restrained degrees of freedom, passive resistance, and the cap sections |
| | LOADING AND SOLUTION CONTROL | load patterns, joint and cap loads, load cases and combinations, the equivalent concentrated load of each case at the reference point, and the solution controls (iteration limits, tolerances, load steps) |
| | PILE LAYOUT; PILE HEAD CONNECTION | coordinates, batter, length and assignments of every pile, and the head connections |
| | MATERIALS AND PILE SECTIONS | materials and the properties of each section |
| | SOIL PROFILE; LAYER … | ground surface, water table, scour, and the parameters of every layer |
| | AXIAL LOAD-SETTLEMENT CURVES; TORQUE-TWIST CURVES; MOMENT-CURVATURE DATA | the user-defined curves and the moment–curvature data of the nonlinear sections, where present |
| | MULTIPLIERS AND REDUCTION FACTORS | group factors, axial and lateral reduction factors |
| Output Results | RESULTS BY LOAD CASE | for each case and combination: its type and status (converged, with the number of iterations), the equivalent load and the displacement of the cap at the reference point |
| | PILE RESPONSE › PILE … | for each pile: the head displacements in global axes, the head displacements and forces in the pile axes, and, as set by the printing code and the output variables, the values at the nodes along the pile |
| Summary Results | RESULTS BY LOAD CASE | for each case: the cap response, the head displacements and forces of all piles with their minimum and maximum, and the minimum and maximum values along every pile with their depths |
| | OVERVIEW OF ALL CASES AND COMBINATIONS | the displacement of the cap and the extreme pile-head forces of every case on one page |

For the case of Example 1 (Section 16.1) the cap response of the summary reads:

```
  FORCE X  FORCE Y  FORCE Z  MOMENT X  MOMENT Y  MOMENT Z
       kN       kN       kN      kN·m      kN·m      kN·m
  -------  -------  -------  --------  --------  --------
   300.00   0.0000  -5400.0    0.0000    450.00    0.0000

[ DISPLACEMENT OF PILE CAP AT REFERENCE POINT ]

     DISP. X  DISP. Y     DISP. Z  ROT. X     ROT. Y  ROT. Z
           m        m           m       °          °       °
  ----------  -------  ----------  ------  ---------  ------
  9.2299E-04   0.0000  -0.0011760  0.0000  0.0048855  0.0000
```

and the pile-head forces, in the local axes of each pile, with their extremes:

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```
[ PILE HEAD FORCES (LOCAL AXES) ]

     PILE   AXIAL  SHEAR 2  SHEAR 3  TORSION  MOMENT 2  MOMENT 3  STRESS
                kN       kN       kN     kN·m      kN·m      kN·m   kN/m²
  -------  ------  -------  -------  -------  --------  --------  ------
       P1  522.05   33.350   0.0000   0.0000    0.0000    43.536  3899.4
       P2  600.00   33.333   0.0000   0.0000    0.0000    43.537  4175.1
       P3  677.95   33.317   0.0000   0.0000    0.0000    43.539  4450.9
       P4  522.05   33.350   0.0000   0.0000    0.0000    43.536  3899.4
       P5  600.00   33.333   0.0000   0.0000    0.0000    43.537  4175.1
       P6  677.95   33.317   0.0000   0.0000    0.0000    43.539  4450.9
       P7  522.05   33.350   0.0000   0.0000    0.0000    43.536  3899.4
       P8  600.00   33.333   0.0000   0.0000    0.0000    43.537  4175.1
       P9  677.95   33.317   0.0000   0.0000    0.0000    43.539  4450.9

  MINIMUM  522.05   33.317   0.0000   0.0000    0.0000    43.536  3899.4
  AT PILE      P1       P3       P1       P1        P1        P1      P1
  MAXIMUM  677.95   33.350   0.0000   0.0000    0.0000    43.539  4450.9
  AT PILE      P3       P1       P1       P1        P1        P3      P3
```

The axial force is positive in compression. Shear 2 and moment 3 belong to bending in the plane of local axis 2; for the vertical piles of this group, plane 2 contains the global X axis, along which the load acts. The column STRESS is the total normal stress at the head, the axial stress plus the bending stress at the extreme fibre ($P/A + M/S$); it is given for elastic sections only. The reports can be read into a spreadsheet as fixed-width text.

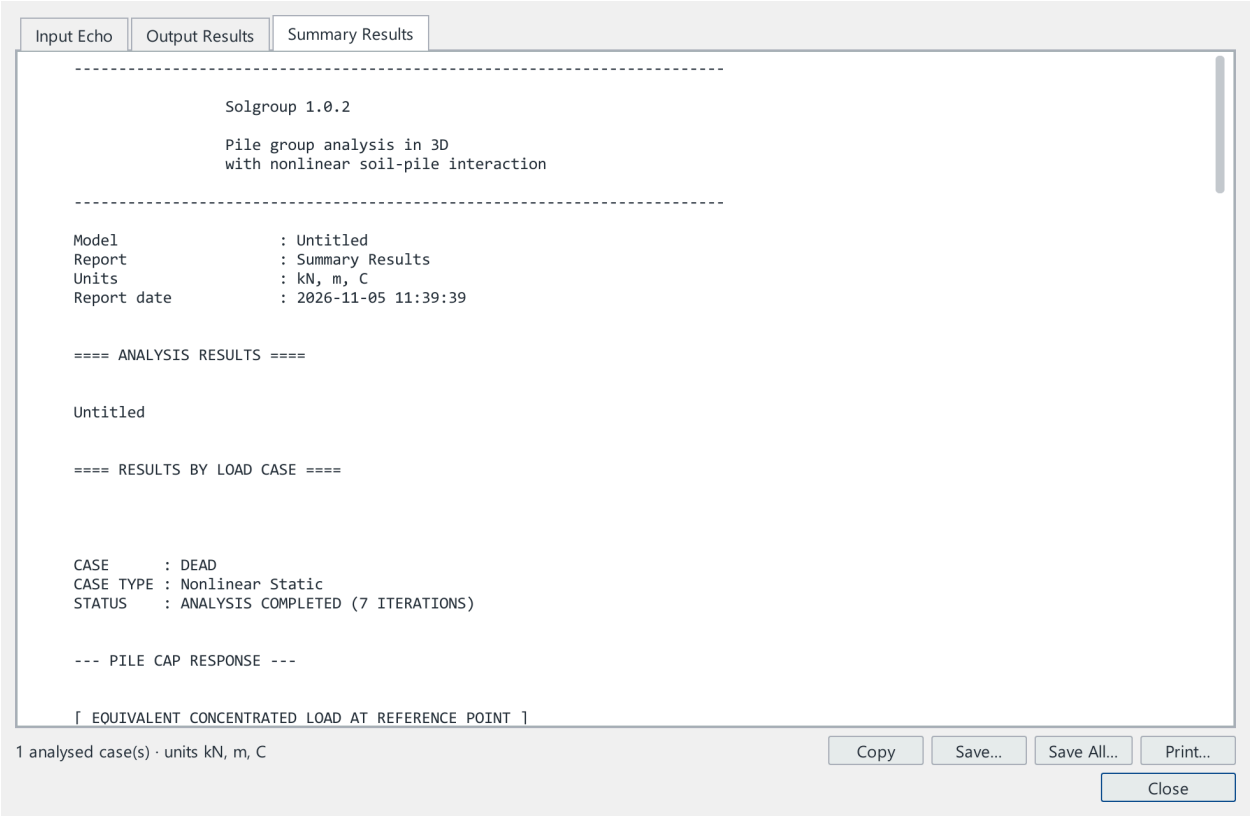



**Figure 13.23 —** Show Text Report, Summary Results

## 13.5 Checking the results

Before results are used for design, check at least the following:

1. Every case converged (summary of the run, **Command** panel), for the full load.
2. The sum of the pile-head forces balances the applied loads (summary results).
3. The deflections are within the range of the p-y curves used, and no pile has exceeded its axial capacity.

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4. The group effects and the cyclic or static soil behaviour match the design situation.
5. For a flexible cap, the mesh matches the model (no warning from Check Model) and is fine enough: a finer mesh should not change the pile-head forces noticeably.
6. The results are not sensitive, beyond what the design can accept, to the soil parameters that are uncertain.

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# 14 Reports and exports

## 14.1 Report Builder

**File ▸ Export ▸ Report Builder (Word · PDF · Excel)…** (also in the **Display** menu) builds a report of the model and its results (Figure 14.1). Choose the content, check it in the preview and export it:

**Table 14.1 — Content of the Report Builder**

| Group | Items |
|---|---|
| Report Sections | Analysis Options; Materials & Sections; Piles & Joints; Soil; Loading; Check Model; Results — Cap Response & Pile Heads; Results — Special Analyses; Results — Flexible Cap; Results — Run Notes |
| Result Charts | Deflection along piles; Bending moment along piles; Shear along piles; Soil reaction along piles; Pushover curves; Foundation stiffness curves. Each selected chart is drawn for every converged load case and combination with a response (envelopes excepted, as they are not states of the structure), case by case, up to 60 charts; the cases left out by that limit are named at the end of the chapter |
| Model Views | 3D model view; Plan view (X-Y) |
| Appendix | Input Echo (text); Output Results (text) |

An item without content in the model is dimmed, with the reason in its tooltip, for example *No load case ran a pushover or foundation stiffness analysis*. The report is exported with one of three buttons:

- **Export Word…** (.docx) for a report that will be edited further;
- **Export PDF…** for a finished report, with a table of contents and page numbers;
- **Export Excel…** (.xlsx) with one worksheet per table, for further calculation.

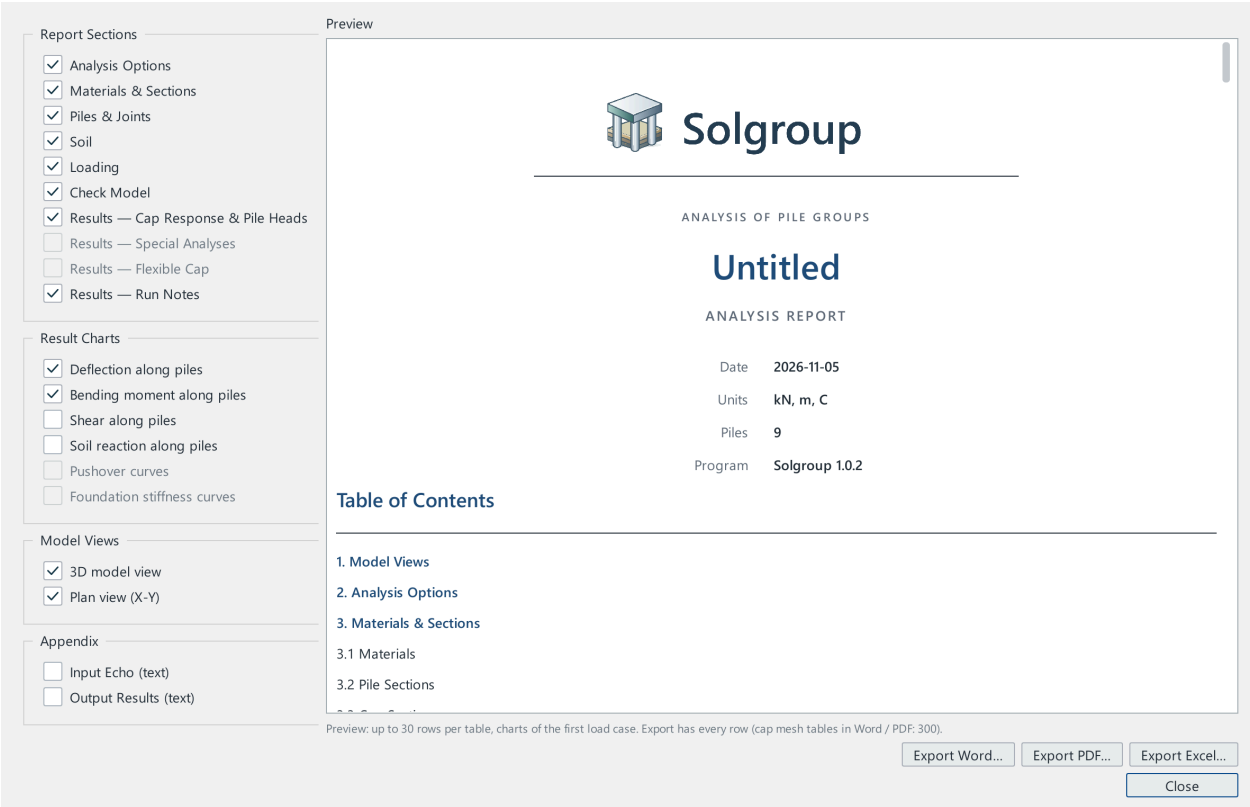



**Figure 14.1 —** Report Builder

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**NOTE** The mesh of a large flexible cap can have tens of thousands of plates. In Word and PDF reports its tables are limited to their first rows, with a sentence that says so; the Excel report contains every row.

## 14.2 Other exports

**Table 14.2 — Exports**

| Command | Content |
|---|---|
| File ▸ Export ▸ Model Tables (CSV)…, Model Tables (Excel)… | the model in tables, which can be edited and imported again |
| File ▸ Export ▸ Text Reports (.txt)… | the input echo, output and summary reports |
| File ▸ Export ▸ View Bitmap… | an image (PNG or BMP) of the active view |
| File ▸ Print Graphics… (Ctrl+P) | a print of the active view |
| Display ▸ Result Graphs and Response ▸ Export Graphs to Excel… | the data of result graphs |
| Copy commands in tables and graphs | values copied to the clipboard |

With a trial licence, results can be viewed and models saved, but the commands above do not export. With an academic licence, exported reports and images carry the watermark of the licence.

## 14.3 Contents of a report

Table 14.3 lists the sections of a report of Example 1 (Section 16.1) with every item of the Report Builder selected, and the tables and columns of each section; the PDF has 16 pages (Figure 14.2). A section appears only when it has content: Results — Special Analyses and Results — Flexible Cap are left out here because the example has neither. Wide tables are split into panels in Word and PDF and kept whole in Excel. The result charts are drawn for every converged load case and combination with a response, one curve per pile; the case LIVE of the example carries no load and has no chart.

**Table 14.3 — Sections, tables and columns of a report**

| Section | Content |
|---|---|
| Project Information | *Project Information*: Item, Value |
| Model Views | figures: Model view; Plan view (X-Y) |
| Analysis Options | *Analysis Options*: Option, Value |
| Materials & Sections | *Materials*: Name, Type, Weight/Volume (kN/m³), E (kN/m²), nu, fc (kN/m²), fy (kN/m²), fu (kN/m²), Es (kN/m²)<br>*Pile Sections*: Name, Shape, Behaviour, Material, A (m²), I22 (m⁴), I33 (m⁴), J (m⁴), Perimeter (m), p-y Width (m)<br>*Cap Sections*: Name, Thickness (m), Material, Rigid, Mesh Size (m) |
| Piles & Joints | *Piles*: ID, Label, X (m), Y (m), Z Head (m), Z Tip (m), Length (m), Batter from Vert (°), Batter Ratio 1:m, Azimuth (°)<br>*Assignments*: Pile, Section, Pile Type, Head Condition, p-y Set, L-D Curve, T-R Curve, Axial Reduction, Lateral Reduction Set, Segments, Ground Elev Override (m), Local Axis Rotation (°) |
| Soil | *Soil Layers*: Name, p-y Model, Gamma Unsat (kN/m³), Gamma Sat (kN/m³), Side Friction (kN/m²), Tip Resistance (kN/m²), Params<br>*Soil Profiles*: Profile, Top Elev (m), Bottom Elev (m), Layer, k Override (kN/m³), Ground Elev (m), Water Elev (m), Scour (m) |
| Loading | *Load Patterns*: Name, Type, Self Weight Multiplier<br>*Joint Loads*: Target, Pattern, Fx (kN), Fy (kN), Fz (kN), Mx (kN·m), My (kN·m), Mz (kN·m)<br>*Load Cases*: Name, Type, Initial Condition, Patterns, p-Mult Set, Steps, Soil Behaviour, Cycles, Tol Equilibrium, Tol Pile Deflection (m), Iter Group, Iter Pile, Processors, Printing, Output Variables, Overrides |
| Check Model | *Check Model*: Level, Code, Message |

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| Section | Content |
|---|---|
| Results — Cap Response & Pile Heads | *Cap Response*: Load Case, Ux (m), Uy (m), Uz (m), Rx (°), Ry (°), Rz (°), Converged, Iterations, Message<br>*Pile Head Results*: Load Case, Pile, Converged, Ux (m), Uy (m), Uz (m), Rx (°), Ry (°), Rz (°), Axial (kN), Shear-2 (kN), Shear-3 (kN), Moment-2 (kN·m), Moment-3 (kN·m), Torsion (kN·m) |
| Results — Charts | figures: Resultant Deflection vs Distance — DEAD; Resultant Moment vs Distance — DEAD; Resultant Shear vs Distance — DEAD; Resultant Soil Reaction vs Distance — DEAD |
| Results — Run Notes | the notes and warnings of the analysis, case by case |
| Appendix — Input Echo | the input echo of the text reports (Section 13.4), in a fixed-width font |
| Appendix — Output Results | the output report of the text reports, in a fixed-width font |

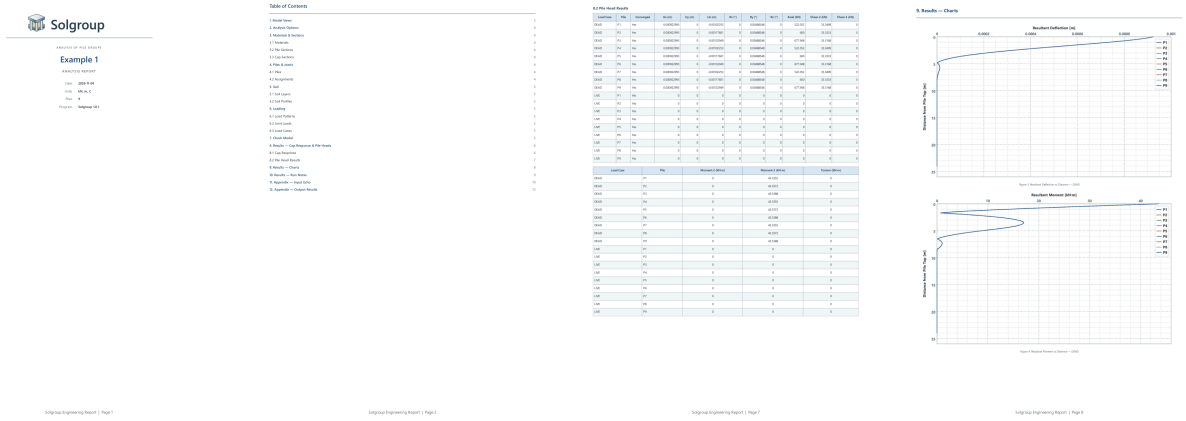



**Figure 14.2 —** Pages of the PDF report of Example 1: cover, table of contents, pile head results and result charts

# 15 Options, tools and help

## 15.1 Preferences

**Options ▸ Preferences…** holds the settings of the program (Figure 15.1):

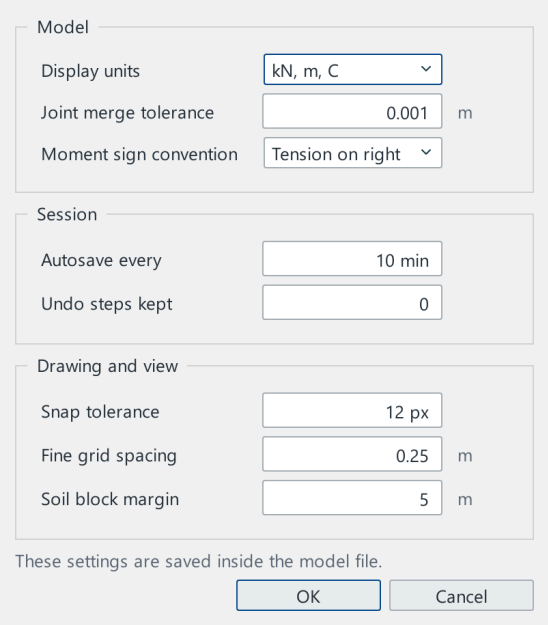



**Figure 15.1 —** Preferences

**Table 15.1 — Preferences**

| Setting | Meaning |
|---|---|
| Display units | the unit system for input and display (Chapter 5): kN, m; kgf, m; tonf, m; kip, in; kip, ft; or N, mm. The model is stored in kN and m. Switching between SI and English units clears the results, which are computed again by the next run. |
| Joint merge tolerance | distance within which two joints are merged |
| Moment sign convention | which side of the pile a positive moment puts in tension (tension on right or on left). It flips the sign of the moment diagrams in graphs, contour plots and exported graphs; tables and text reports keep the sign of the analysis. |
| Autosave every | interval at which a recovery copy (<name>.autosave.ggp next to the model) is written while there are unsaved changes; it is offered when the model is opened again. 0 turns autosave off. |
| Undo steps kept | 0 means unlimited; a new limit applies from the next model opened or created |
| Snap tolerance | distance in pixels within which the cursor snaps to a point |
| Fine grid spacing | spacing of the fine grid of the snap |
| Soil block margin | how far the drawn soil block extends past the model |

## 15.2 Other options

**Table 15.2 — Commands of the Options menu**

| Command | Use |
|---|---|
| Rebuild Pile Layout from a Template… | replaces the piles of the model by a layout from a template, with the same fields as the New Model window; the soil, the sections and the load cases are kept |

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| Command | Use |
|---|---|
| Colours… | the colours of the drawing, each chosen with its colour button: Pile; Pile, selected; Pile, hovered; Pile cap; Pile / cap without a section; Pile cap edge; Grid line; Grid bubble; Water table; Ground surface; Scour line; Object label; Global axis X; Global axis Y; Global axis Z; Joint; Reference point / line; Load arrow; Moment arrow; Free-field soil movement; Deformed shape. **Reset to Defaults** restores them. |
| Set Display Options… | see Table 8.8 |
| Include Case / Combination Numbers on Graphs | names the cases on graphs with their number, as LC *n* or COMB *n* |
| Show Vertical Lines from Pile Heads | draws from each pile head a vertical line of the length of the pile, a reference for battered piles |
| Reset Toolbar Layout | restores the toolbars and panels to their default positions |

## 15.3 Tools, Help and Window

- **Tools ▸ Model Statistics…** counts the objects and definitions of the model; **Open Model Folder** opens the folder of the model file.
- **Help ▸ Licence…** shows the account and the licence in use, and offers offline borrowing, returning a borrowed licence, managing the account and signing out (Section 2.3). **About Solgroup…** shows the version and the copyright notice (Figure 15.2).
- The **Window** menu shows or hides the panels (Model Explorer, Properties, Workflow, Messages) and the toolbars.




**Figure 15.2 —** About Solgroup

## 15.4 Keyboard shortcuts

**Table 15.3 — Keyboard shortcuts**

| Key | Command |
|---|---|
| Ctrl+N, Ctrl+O, Ctrl+S, Ctrl+Shift+S | New Model, Open, Save, Save As |
| Ctrl+P | Print Graphics |
| Ctrl+Z, Ctrl+Y | Undo, Redo |
| Ctrl+X, Ctrl+C, Ctrl+V, Del | Cut, Copy, Paste, Delete |
| Ctrl+R | Replicate |
| Ctrl+A, Ctrl+Shift+A | Select All, Select None |
| Ctrl+E | Set Display Options |
| Ctrl+T | Show Tables |
| Home, Z, F2 | Restore Full View, Zoom to Selection, Refresh Window |
| R, F, Q, C | Reshape, Draw Pile, Quick Draw Pile, Draw Poly Cap |
| F5, F6 | Run Analysis, Check Model |

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| Key | Command |
|---|---|
| Esc | cancel the current tool (drawing, line or polygon selection, zoom, rotate, reshape) and return to selection; with nothing to cancel, clear the selection |
| Backspace | while drawing, remove the last clicked point |

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# 16 Worked examples

This chapter follows eighteen analyses of pile groups and six analyses of pile sections from the input to the result. All numbers were computed with Solgroup 1.0.8; each model can be rebuilt from the steps given.

Unless an example states otherwise, its model has the soil profile and water table, the pile section *Pile 1* and the cap section *CAP-1000* of Example 1 (Section 16.1). A model started with **File ▸ New Model…** has one soil layer and no sections, so these are defined first, as Example 1 describes.

The loads follow one convention, as in Getting started (Chapter 6). The pattern DEAD carries only the self weight of the cap (self weight multiplier 1), computed by Solgroup; nothing is typed into it. The loads brought to the cap by the structure above it are typed into a pattern *SDL* of type SUPERDEAD (self weight multiplier 0), and the load case DEAD applies both patterns, DEAD and SDL, with a factor of 1 (**Define ▸ Load Cases…**, **Modify…**, **Add Pattern**). Environmental loads that are compared or combined (berthing, mooring, current, waves, an impact) have patterns of their own. Unless an example says so, "the load" of an example is the load in SDL, and the results are those of the load case DEAD, which includes the weight of the cap.

## 16.1 Example 1: rectangular group under combined load

### 16.1.1 Model

1. **File ▸ New Model…**, template **Rectangular Pile Group**: 3 × 3 piles at a spacing of 1.8 m in X and Y, pile length 24 m, pile heads at elevation 0, vertical piles, a cap created automatically with an edge offset of 0.5 m.
2. The new model is completed as in Getting started (Chapter 6): the soil profile with the ground surface at elevation 0, soft clay (Soft Clay (Matlock), 15 / 16 kN/m$^3$, $c_u$ = 25 kPa, $\varepsilon_{50}$ = 0.02) to −8 m, stiff clay (Stiff Clay without Free Water, 17.5 / 19 kN/m$^3$, $c_u$ = 120 kPa, $\varepsilon_{50}$ = 0.005) to −20 m and dense sand (API Sand (O'Neill), 18 / 20.5 kN/m$^3$, $\varphi$ = 38°, $k$ = 61 000 kN/m$^3$) to −40 m, with the water table at −1 m; the pile section *Pile 1*, an Elastic section (user-defined EI) of 0.6 m diameter in the concrete of 30 MPa, assigned to every pile; and the cap section *CAP-1000*, 1 m thick, assigned to the cap.
3. The cap is rigid (**Assign ▸ Cap ▸ Cap Behaviour…**) and the pile heads are fixed to it (project default).
4. One load on the cap (**Assign ▸ Cap Loads ▸ Point Forces / Moments…**), in the pattern SDL: $F_x$ = 300 kN, $F_z$ = −5400 kN (downward) and $M_y$ = 450 kN·m. The load case DEAD applies the patterns DEAD (the self weight of the cap) and SDL, each with a factor of 1.
5. **Analyze ▸ Check Model…** reports no error; **Analyze ▸ Run Analysis**.

After the run, **Display ▸ Results in Canvas ▸ Force Diagrams in Canvas…** draws the bending moment on the piles in the model view, with the values at the head and at the largest moment below it (Figure 16.1).

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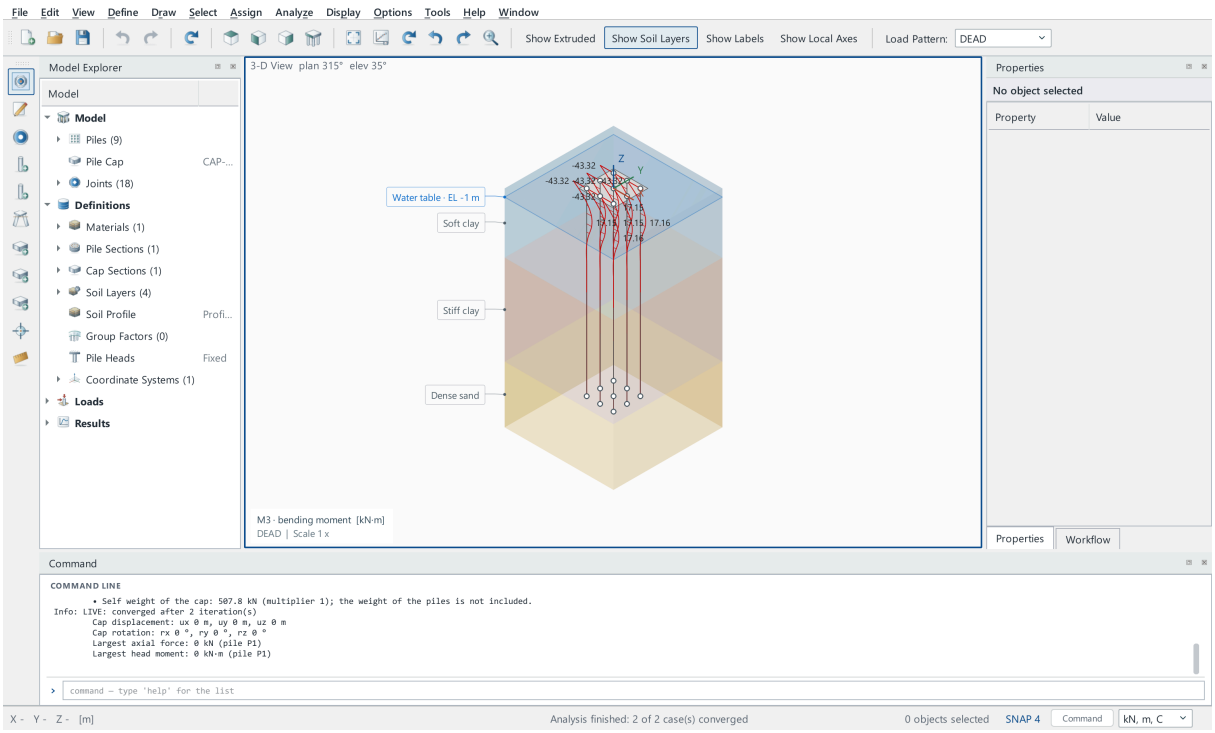



**Figure 16.1 —** Example 1 — bending moment *M*3 of the piles, case DEAD

### 16.1.2 Results

The case converged in 7 iterations. The cap moves 0.933 mm in X and −1.293 mm vertically, and rotates 0.0903 mrad about Y. Table 16.1 lists the forces at the head of each pile. The vertical load and the moment are shared between the rows: the moment adds compression to the piles on one side of the cap and relieves those on the other, while the lateral load is shared almost equally.

**Table 16.1 — Pile head forces of the example**

| Pile | X (m) | Y (m) | Axial (kN) | Shear (kN) | Head moment (kN·m) | Largest moment below the head (kN·m) |
|---|---|---|---|---|---|---|
| P1 | −1.8 | −1.8 | 577.1 | 33.35 | 43.32 | 17.15 |
| P2 | 0.0 | −1.8 | 659.6 | 33.33 | 43.32 | 17.15 |
| P3 | 1.8 | −1.8 | 732.6 | 33.32 | 43.32 | 17.16 |
| P4 | −1.8 | 0.0 | 577.1 | 33.35 | 43.32 | 17.15 |
| P5 | 0.0 | 0.0 | 659.6 | 33.33 | 43.32 | 17.15 |
| P6 | 1.8 | 0.0 | 732.6 | 33.32 | 43.32 | 17.16 |
| P7 | −1.8 | 1.8 | 577.1 | 33.35 | 43.32 | 17.15 |
| P8 | 0.0 | 1.8 | 659.6 | 33.33 | 43.32 | 17.15 |
| P9 | 1.8 | 1.8 | 732.6 | 33.32 | 43.32 | 17.16 |

The sum of the axial forces is 5907.8 kN and the sum of the shear forces 300.0 kN, which equal the applied vertical and lateral loads. Figure 16.2 shows the deflection and the bending moment along the piles of the first row. The moment is largest at the fixed head, changes sign a few metres below it, and reaches a smaller maximum of opposite sign; the deflection dies out within the upper five metres of soft clay.

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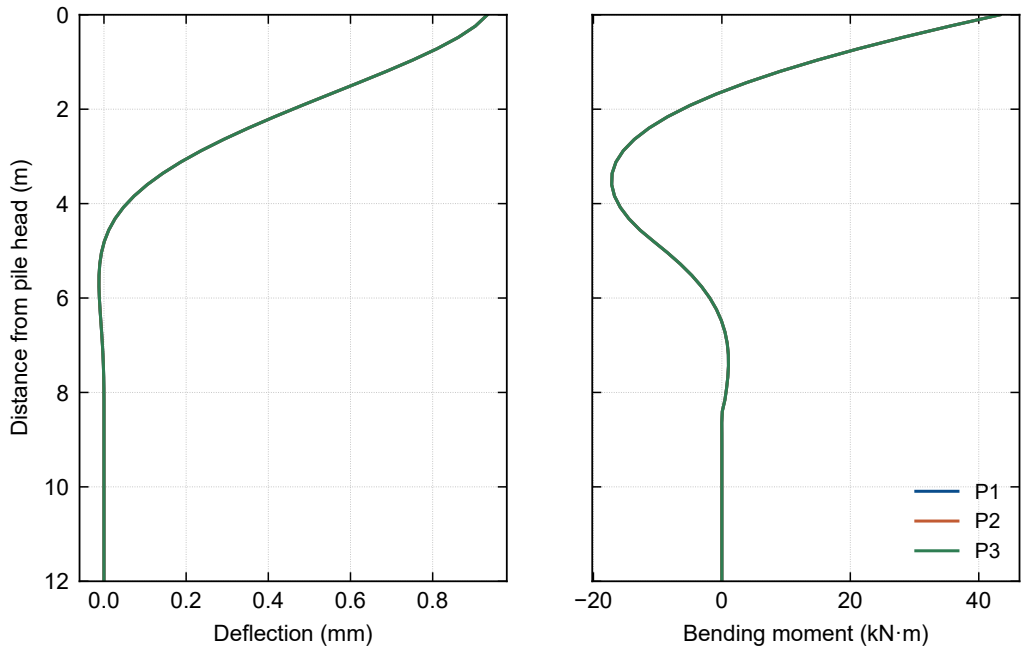



**Figure 16.2 —** Deflection and bending moment along piles P1 to P3

## 16.2 Example 2: jetty bents with battered piles

A jetty deck on bents is loaded horizontally across the bents, for example by a berthing ship. Battered piles carry much of the horizontal load by axial force, which makes the foundation stiffer.

### 16.2.1 Model

1. **File ▸ New Model…**, template **Trestle / Bent (jetty)** with its defaults: four bents at 6 m, four piles per bent at 3 m, the outer pile pair of each bent battered at 9.46° (1:6) away from the bent, piles 24 m long, and a deck (cap) over all bents. The bents lie along Y and their piles across X. The pile heads and the deck are at +4.0 m, the seabed (ground surface) is at 0.0 m and the water at +3.0 m, so the piles stand free through the water before they enter the soil.
2. The deck is rigid and the pile heads are fixed.
3. **Analyze ▸ Analysis Options…**: **Include axial load variation along the piles** is ticked, so that the axial force along each pile comes from its t-z analysis and can be drawn.
4. Load on the deck in the pattern SDL: $F_x$ = 800 kN across the bents and $F_z$ = −3000 kN from the surfacing, services and equipment on the deck. The deck is the cap itself, so its own weight comes from the self weight multiplier of DEAD and is not typed.
5. For comparison the same model is built with all piles vertical (outer batter 0).

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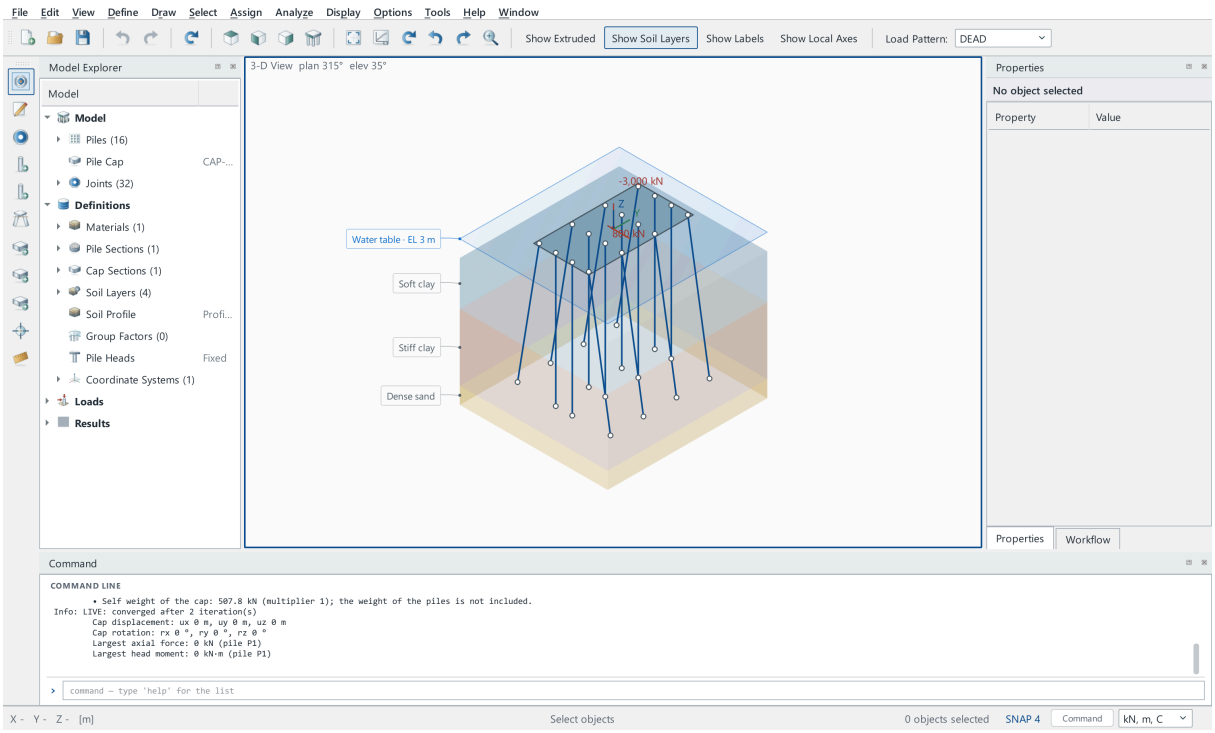



**Figure 16.3 —** Example 2 — the jetty model with its load on the deck

### 16.2.2 Results

With the battered piles the deck moves 8.644 mm in X; with all piles vertical it moves 13.454 mm, so that the batter reduces the horizontal movement by 36 %. Table 16.2 lists the head forces of the piles of the first bent.

**Table 16.2 — Head forces of the first bent (piles P1 to P4, from −X to +X)**

| Pile | Axial, battered (kN) | Axial, vertical (kN) | Shear, battered (kN) | Shear, vertical (kN) | Moment, battered (kN·m) | Moment, vertical (kN·m) |
|---|---|---|---|---|---|---|
| P1 | 325.6 | 395.0 | 40.7 | 50.1 | 158.6 | 193.7 |
| P2 | 644.0 | 446.6 | 39.8 | 50.0 | 155.7 | 193.7 |
| P3 | 355.5 | 498.3 | 40.1 | 50.0 | 156.0 | 193.8 |
| P4 | 576.9 | 550.0 | 39.2 | 49.9 | 153.2 | 193.7 |

With vertical piles the axial forces vary linearly across the bent, from the rotation of the deck, and every pile takes the same shear. With battered piles the pile battered in the direction of the load (P4) gains compression and the pile battered against it (P1) loses compression: the horizontal load is partly carried as a pair of axial forces, and the shears and moments of the vertical piles decrease. The batter here is mild; steeper batters carry more of the load axially.

**Display ▸ Results in Canvas ▸ Show Contour Plot…** with **N · axial force along pile** colours each pile along its length by its axial force (Figure 16.4): the force is largest at the head and decreases with depth as the shaft friction carries it into the soil. The same component in **Force Diagrams in Canvas…** draws it as a diagram on every pile.

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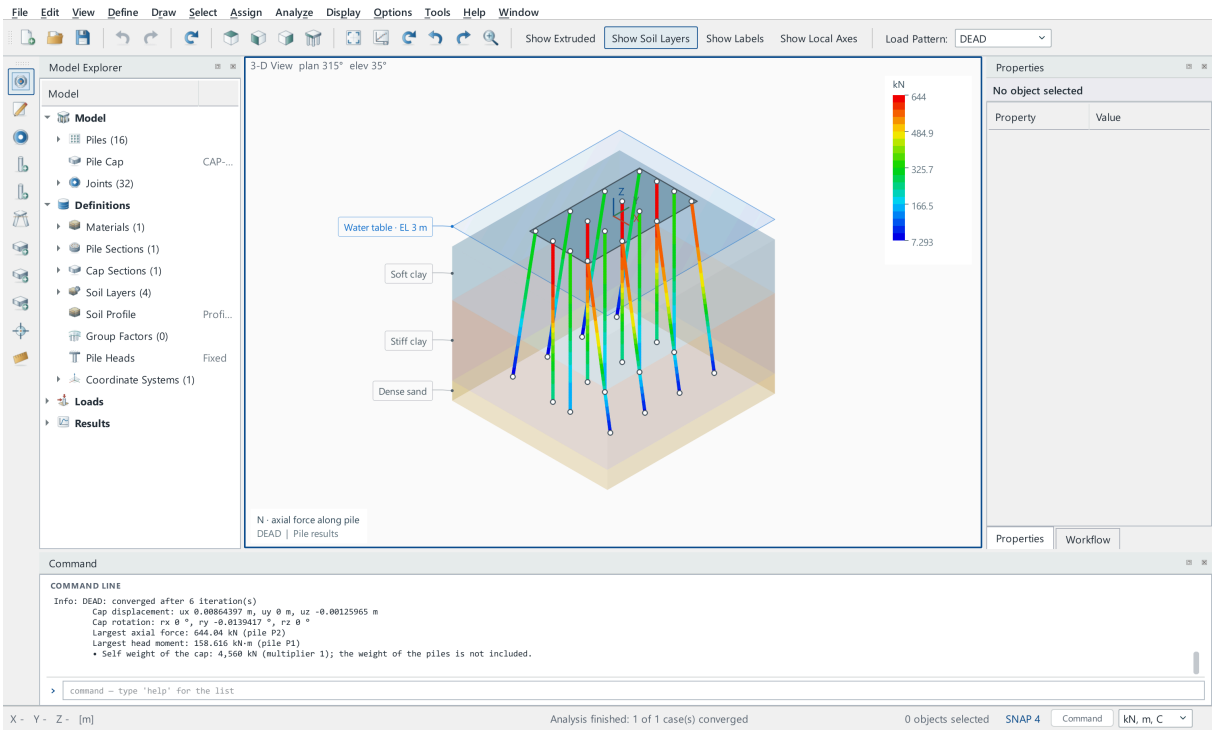



**Figure 16.4 —** Example 2 — axial force along the piles, battered piles

## 16.3 Example 3: rigid and flexible caps under two columns

A cap that is thin compared with the spacing of the piles bends under load, and the piles near the loads receive more than their share. This example carries two columns on a square group and compares a rigid cap with flexible caps of decreasing thickness.

### 16.3.1 Model

1. Template **Rectangular Pile Group**: 3 × 3 piles at 2.4 m, otherwise as in example 1. The cap is 5.8 m square.
2. Two columns stand on the middle line of the cap, 2.4 m apart, each halfway between two piles. Each column is a reference point (**Draw ▸ Draw Reference Point**, then the exact position in the Properties panel): *C1* at $X = -1.2$ m and *C2* at $X = +1.2$ m, $Y = 0$.
3. Each column carries $F_z = -2700$ kN in the pattern SDL: the reference point is picked in the Model Explorer, and **Assign ▸ Cap Loads ▸ Point Forces / Moments…** applies the force at **Selected points / pile-head joints**. The pattern DEAD carries the self weight of the cap; the load case DEAD applies both.
4. First the cap is rigid. Then **Rigid cap** is unticked in the cap section (**Define ▸ Section Properties ▸ Cap Sections…**); the plate mesh is generated at once, 168 plates. Along X the plates are a little narrower, so that a node falls under each column as well as under every pile head. The analysis is repeated with the cap section 1.0, 0.5 and 0.3 m thick; the mesh follows each change of thickness by itself.

### 16.3.2 Results

**Table 16.3 — Axial forces in the piles under two columns**

| Cap | Corner pile P1 (kN) | Edge pile P2 (kN) | Centre pile P5 (kN) | Settlement (mm) |
|---|---|---|---|---|
| Rigid | 689.7 | 689.7 | 689.7 | −1.36 |
| Flexible, 1.0 m | 573.7 | 687.3 | 929.0 | −1.92 |
| Flexible, 0.5 m | 265.3 | 595.9 | 1543.8 | −3.36 |
| Flexible, 0.3 m | 106.6 | 456.6 | 2081.1 | −5.11 |

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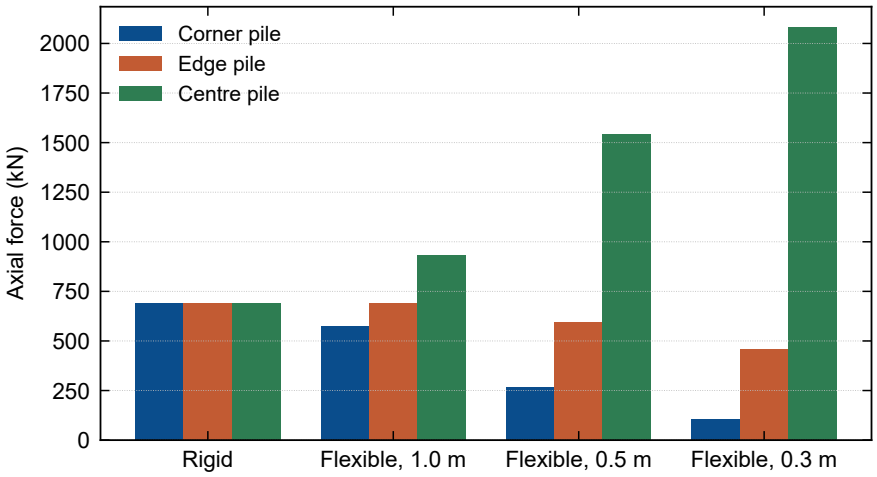



**Figure 16.5 —** Axial forces of corner, edge and centre piles for a rigid cap and for flexible caps

The rigid cap moves as one block: the two columns are placed symmetrically, so the nine piles share the column loads and the weight of the cap equally. A flexible cap of the same thickness already gives the centre pile, between the two columns, more than the corner piles; as the cap becomes thinner the load concentrates in the line of piles under the columns and the corner piles carry little. The settlement reported for a flexible cap is that of the cap reference point at its centre. In each case the sum of the axial forces equals the column loads plus the weight of the cap. A rigid cap is a good model only when the cap is stiff compared with the piles; the flexible cap shows when it is not.

The bending of a thin cap also turns the pile heads, so the piles carry head moments without any horizontal load: see **Display ▸ Show Tables ▸ Pile Head Results**, columns *Moment-2* and *Moment-3*.

The contours of the plate moments (**Display ▸ Results in Canvas ▸ Show Contour Plot…**, *M*11 or *M*22), best read in plan (**View ▸ XY**), show where the cap bends most: under the two columns, with moments of the other sign over the piles beside them (Figure 16.6).

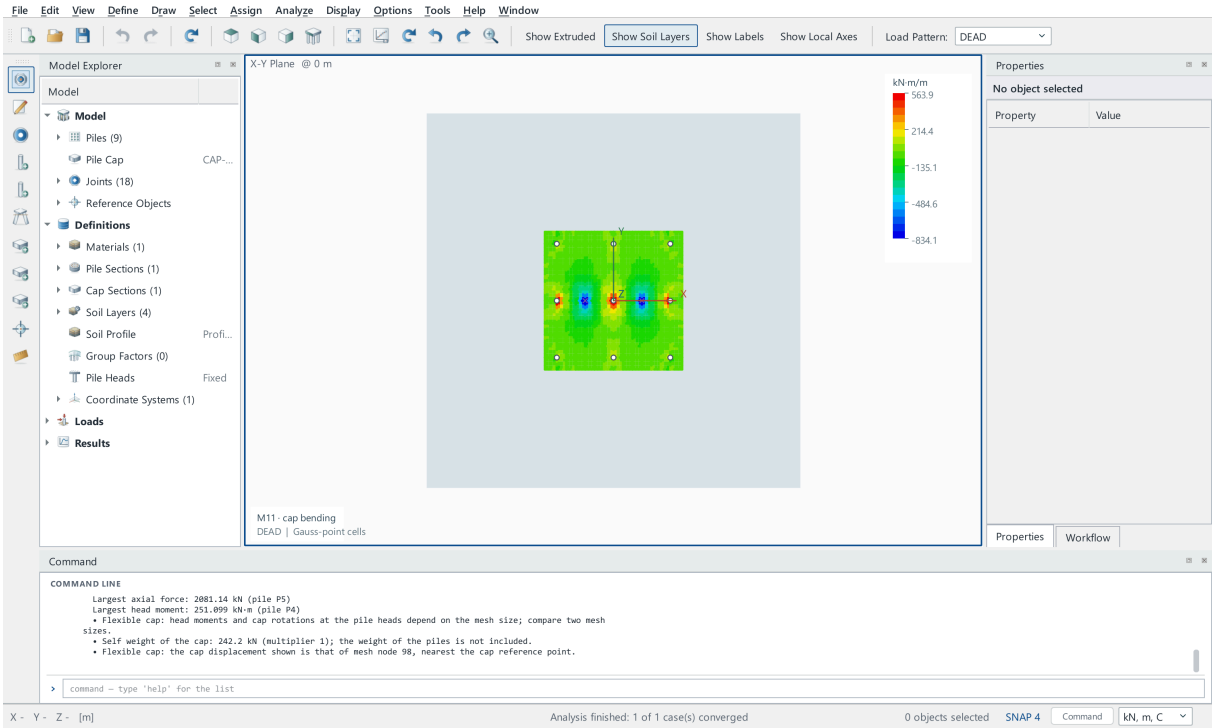



**Figure 16.6 —** Example 3 — plate moment *M*11 of the 0.3 m cap under the two columns, in plan

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## 16.4 Example 4: group effect of closely spaced piles

The group of Example 1 (3 × 3 piles of 0.6 m diameter at 1.8 m, three diameters) carries $F_x$ = 900 kN and $F_z$ = −2 700 kN at the cap. It is analysed three times: without group reduction; with a set of the method *AASHTO LRFD Table 10.7.2.4-1*, load direction 0° (**Define** ▸ **Soil** ▸ **Lateral Group Effect (p-y)…**, **Compute from spacing**), which gives the p-multipliers 0.8, 0.4 and 0.3 to the leading, second and third rows at $s/D$ = 3; and with a set of the method *Closely-spaced piles*, which computes a factor for every pile from the positions of the others. The set is selected for the model in **Analyze** ▸ **Set Analysis Options…**.

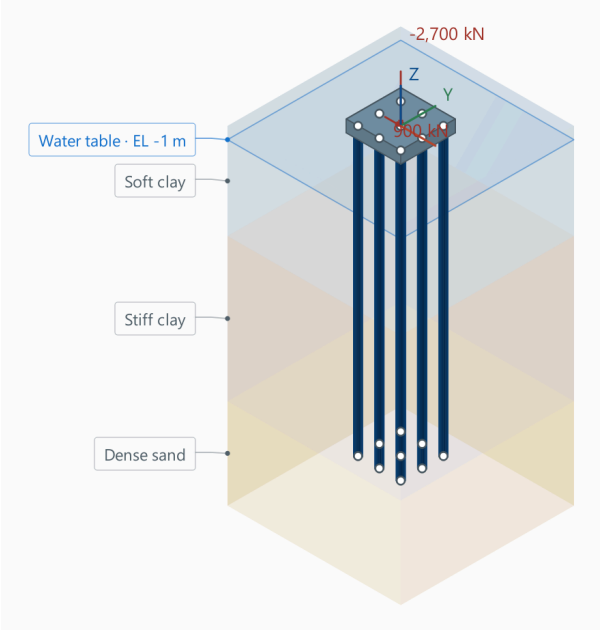



**Figure 16.7 —** Example 4 — the model in the 3D view

**Table 16.4 — Example 4 — cap displacement and mean pile-head shear of each row**

| Group effect | Cap Ux (mm) | Leading row (kN) | Second row (kN) | Third row (kN) | Largest head moment (kN·m) |
|---|---|---|---|---|---|
| None | 6.30 | 100 | 100 | 100 | 191 |
| AASHTO, by rows | 14.98 | 139 | 88 | 74 | 325 |
| Closely-spaced piles | 10.79 | 120 | 90 | 90 | 265 |

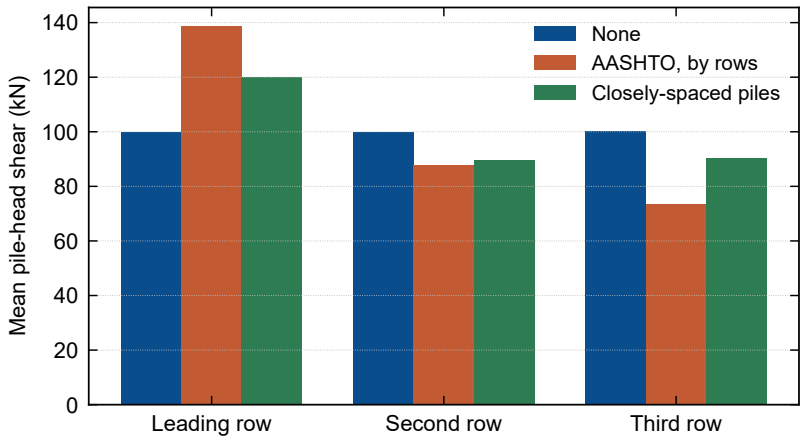



**Figure 16.8 —** Example 4 — mean pile-head shear of each row

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Without reduction the three rows share the load equally. The group factors make the soil softer, so the cap moves more, and they make the rows unequal: the leading row, which pushes into undisturbed soil, takes the largest share, and the pile moments grow accordingly. The two methods differ in degree: the row table of AASHTO applies a single factor to a whole row, while the method of closely-spaced piles also distinguishes the corner and the middle piles of a row and follows the direction in which the cap actually moves. In every case the shears add up to the applied 900 kN. Group factors should be used whenever the spacing is less than about five diameters in the direction of loading.

## 16.5 Example 5: connection of the pile heads

Examples 5 to 11 each start again from the group and load of Example 4 ($F_x$ = 900 kN, $F_z$ = −2 700 kN) without group reduction and with fixed pile heads, and change only what they describe; a model carried on from the previous example keeps its group effect, head connection or extra load.

The same group and load are analysed with three pile-head connections (**Assign ▸ Pile ▸ Project Default Pile-Head Connection…**): fixed, pinned, and elastic with rotational springs of 20,000 kN·m/rad in both planes.

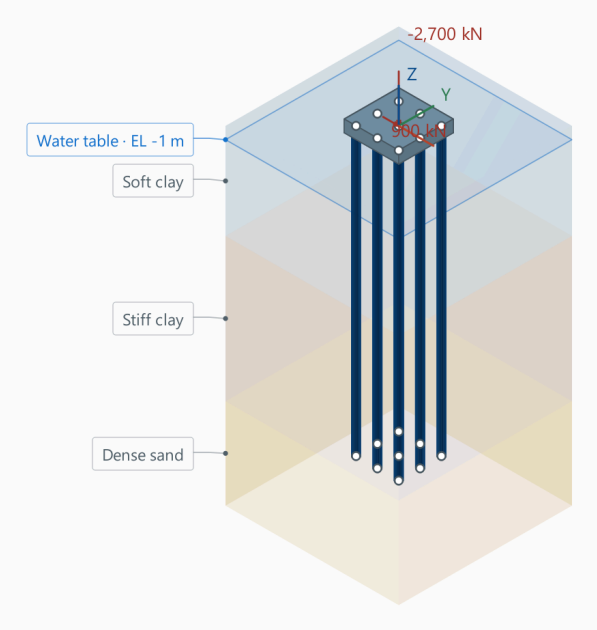



**Figure 16.9 —** Example 5 — the model in the 3D view

**Table 16.5 — Example 5 — effect of the head connection**

| Connection | Cap Ux (mm) | Head moment (kN·m) | Largest moment (kN·m) | at depth (m) |
|---|---|---|---|---|
| Fixed | 6.30 | 191 | 191 | 0.0 |
| Elastic | 15.74 | 72 | 139 | 4.1 |
| Pinned | 22.27 | 0 | 194 | 3.6 |

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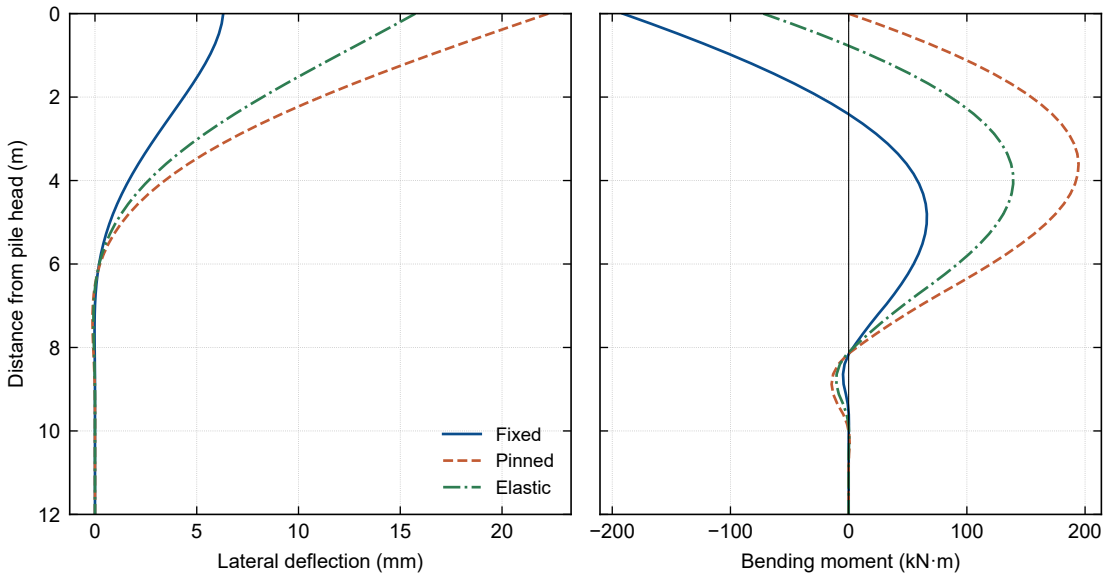



**Figure 16.10 —** Example 5 — deflection and moment of the centre pile for the three connections

A fixed head restrains the rotation of the pile, so the largest moment is at the head and the cap moves least. A pinned head carries no moment: the pile rotates freely at the cap, the cap moves several times more, and the largest moment moves down into the soil, where it is of similar size. The elastic connection lies between the two. The connection of real piles is rarely fully fixed; a range of connections should be analysed when the cap detail is uncertain, and the pile designed for the largest head moment and the largest moment in the soil that result.

### 16.5.1 A prescribed settlement

A load case can prescribe a movement of the cap instead of a force. How much vertical load settles this group by 10 mm, while the frame above keeps the cap level? In **Define ▸ Load Cases…** the case DEAD is copied (**Add Copy…**, name *SETTLE*); its loads stay, so the 900 kN horizontal load still acts. In **Specified Displacements…** the box *Prescribe cap degrees of freedom in this load case* is ticked, Uz is set to *Displacement*, −0.01 m, and Ry to *Displacement*, 0: a prescribed zero holds that rotation. The other degrees of freedom stay force controlled. A case like this cannot be part of a combination, because its load at a prescribed degree of freedom is an outcome of the analysis (Section 11.3).

After the run, **Display ▸ Show Tables…**, table *Cap Reactions*, has one row for each case that prescribes a movement: 10 mm of settlement takes 27,076.9 kN down at the cap, and holding the cap level against the horizontal load takes a moment of −1,835.4 kN·m. At this level of settlement the group gives about 2,708 kN per millimetre, ten times the column load of 2 700 kN for the 10 mm.

## 16.6 Example 6: stiffness of the foundation for the structural model

The load case of the group is given $F_x$ = 900 kN, $F_z$ = −2 700 kN and $M_y$ = 600 kN·m, and **Foundation Stiffness…** is requested in the load case with the method *Based on nonlinear soil response* at five levels, 0.2 to 1.0 of the case load. Each loaded degree of freedom of the cap is pushed alone at each level and the stiffness is the inverse of the secant flexibility. Only the loaded degrees of freedom (Ux, Uz and Ry here) can be swept.

**Table 16.6 — Example 6 — diagonal terms of the foundation stiffness**

| Level | K11, Ux (kN/m) | K33, Uz (kN/m) | K55, Ry (kN·m/rad) | K15, Ux–Ry (kN/rad) |
|---|---|---|---|---|
| 0.2 | 552,763 | 4,601,049 | 11,285,922 | −290,679 |
| 0.4 | 315,535 | 4,601,049 | 11,039,203 | −204,286 |
| 0.6 | 224,447 | 4,601,049 | 10,918,646 | −147,737 |
| 0.8 | 176,587 | 4,601,049 | 10,826,963 | −134,337 |

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| Level | K11, Ux (kN/m) | K33, Uz (kN/m) | K55, Ry (kN·m/rad) | K15, Ux–Ry (kN/rad) |
|---|---|---|---|---|
| 1.0 | 146,699 | 4,601,049 | 10,768,534 | −113,345 |

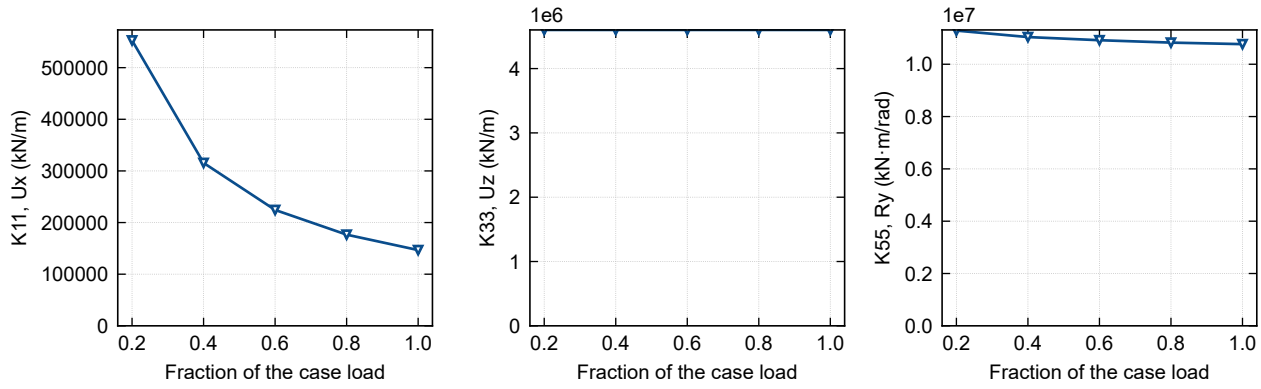



**Figure 16.11 —** Example 6 — diagonal stiffness terms against the load level

The horizontal stiffness falls steeply with the load, because the p-y curves of the soft clay near the surface are strongly nonlinear: at the full load it is about a quarter of its value at 0.2 of the load. The vertical stiffness does not change over this range, because the axial load of each pile stays well below its capacity, and the rotational stiffness, which comes mostly from the axial response of the outer piles, changes little. The coupling term K15 between horizontal translation and rotation is not small and should be kept in the structural model. The matrix of the level that matches the load of the structural analysis is copied from **Show Cap Response…**, tab Foundation (**Copy**); the analysis is iterated until the loads and the stiffness agree (Technical Reference, “Foundation stiffness and pushover”).

## 16.7 Example 7: pushover of the group

The load case is changed to the analysis type *Pushover* with the load factors 0.25, 0.5, 0.75, 1, 1.5, 2, 2.5 and 3 (**Pushover…** in the load case), and *Hold Uz / Fz constant*, so that the vertical load stays at 2 700 kN while the horizontal load grows from 225 to 2,700 kN.

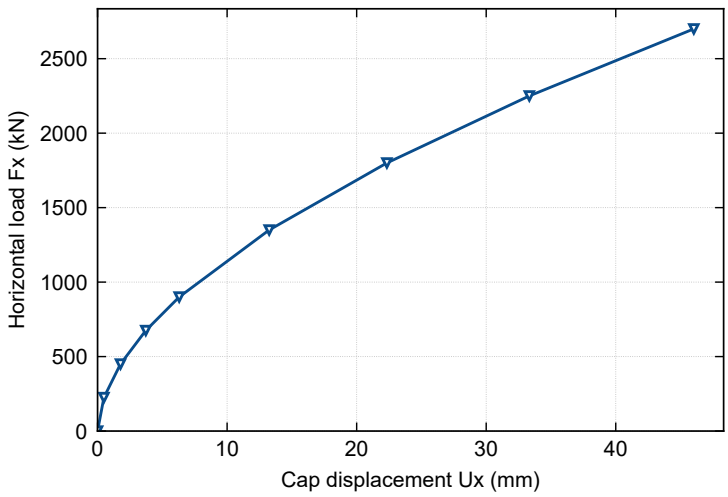



**Figure 16.12 —** Example 7 — horizontal load against cap displacement

At the design load of 900 kN the cap moves 6.3 mm; at twice that load it moves 22.3 mm and at three times 46.0 mm. The curve shows how quickly the group softens beyond the design load and is used to judge the reserve of the foundation, for example for an accidental load or an earthquake. Every step starts from the previous one; the path is shown in **Show Cap Response…**, tab Pushover, and in **Special Plots…**.

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## 16.8 Example 8: piles in moving soil

Next to an embankment or in a lateral spread the soil moves past the piles. The group carries only its vertical load of 2 700 kN, and a free-field soil movement is assigned to every pile (**Assign ▸ Free-field Soil Movement…**): 100 mm in X at the ground surface, decreasing linearly to zero at 8 m depth.

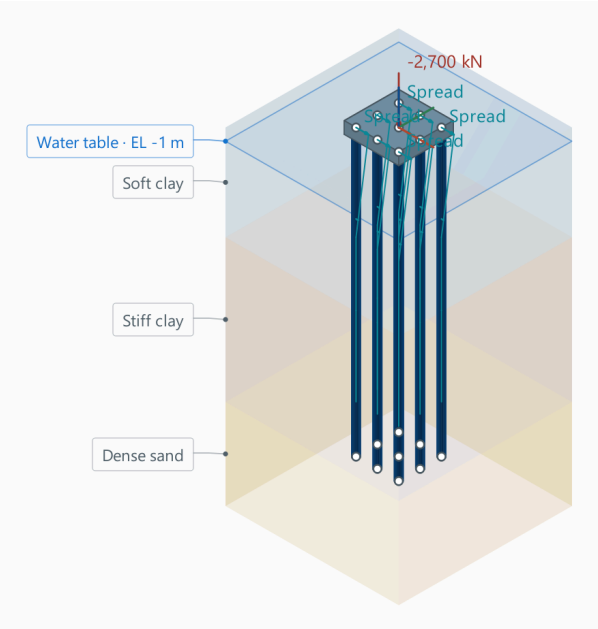



**Figure 16.13 —** Example 8 — the model in the 3D view; the profile of the soil movement is plotted in Figure 16.14

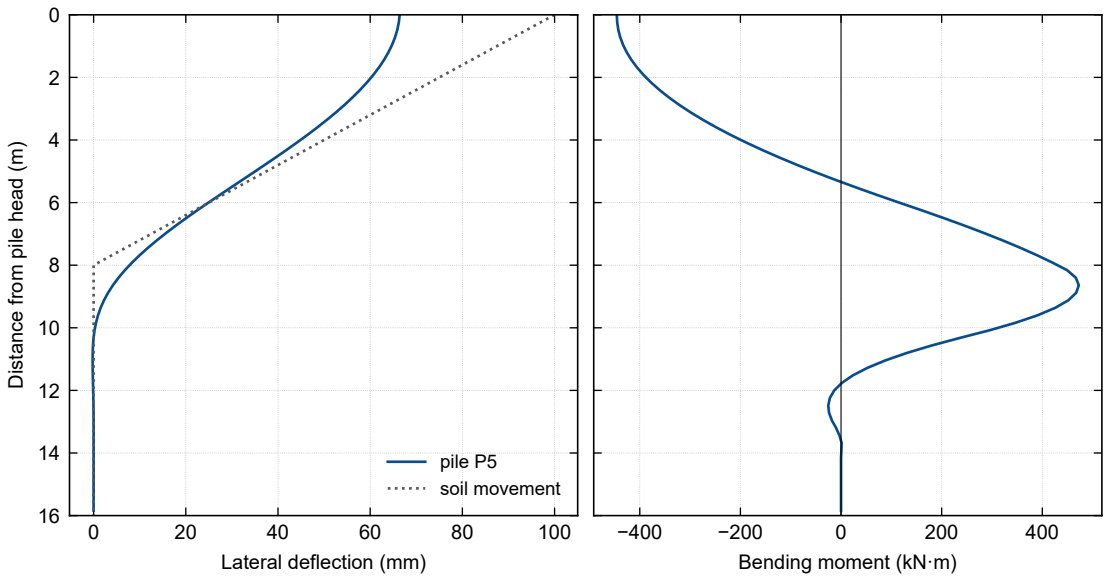



**Figure 16.14 —** Example 8 — soil movement, deflection and moment of the centre pile

Although no horizontal load acts on the cap, the moving soil drags the group: the cap moves 66.4 mm. The sum of the pile-head shears is zero, as it must be with no horizontal load on the cap; the moving soil loads the upper part of each pile and the stable soil below holds the lower part. The largest moment, 474 kN·m at 8.6 m below the head, occurs just below the moving zone, where the soil changes from driving the pile to resisting it, and the head moment is 448 kN·m. These moments are larger than those of the 900 kN cap load of Example 4: soil movement is often the governing action for piles near embankments.

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## 16.9 Example 9: embedded pile cap

The pile heads are placed at elevation −1.5 m, so that the 1 m thick cap lies in the soil, and the group carries $F_x$ = 900 kN and $F_z$ = −2 700 kN. The analysis is made without and with the soil resistance on the cap (**Assign ▸ Cap ▸ Embedment & Soil Resistance…**, model *From the soil layer data*, method *Applying an equivalent lateral load*).

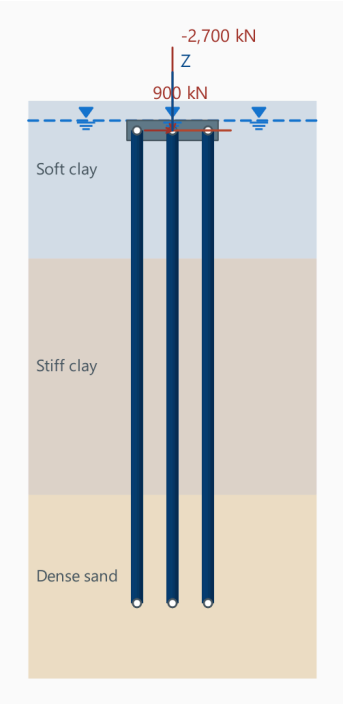



**Figure 16.15 —** Example 9 — the model in the X-Z elevation

**Table 16.7 — Example 9 — effect of the soil resistance on the cap**

| Cap resistance | Cap Ux (mm) | Sum of pile shears (kN) | Resistance on the cap (kN) |
|---|---|---|---|
| Off | 4.44 | 900 | 0 |
| On | 4.00 | 852 | 48 |

The soil in front of the cap takes 48 kN, and the piles carry the rest; the shears and the resistance add up to the applied load. The effect is modest here because the soil around the cap is soft clay; in stiff soil or compacted fill it can be much larger. The resistance should be counted only where the soil is certain to stay in contact with the cap.

## 16.10 Example 10: torsion from the position of a load

A ship that berths against a dolphin does not only push it. Its hull also rubs along the fender, and that friction acts at the edge of the cap, so it twists the dolphin. Nothing has to be typed for the twist: it comes from where the load acts.

### 16.10.1 Model

1. Template **Radial Batter Group**: eight steel pipes of 914 × 16 mm (Steel 355, elastic) on a ring of 2.5 m radius, battered 10° outward, 30 m long, heads at +4 m, and a round cap with an edge offset of 0.9 m. The same ring can be built from one battered pile with **Edit ▸ Replicate**, tab Radial, 45° per copy, seven copies (each copy turns its batter with it), and **Draw ▸ Quick Draw Cap** with the cap shape Circle in **Set Default Draw Properties**.
2. The seabed of Example 19: soft clay from 0 to −6 m over medium sand, water at +3 m.
3. Pattern SDL: $F_z$ = −1,500 kN at the middle of the cap, the fender frame and the walkway on the dolphin.
4. A reference point *Fender* on the edge of the cap at (3.4, 0, +4) m. Pattern BERTH (type BERTHING), at the selected point: $F_x$ = −600 kN towards the centre, and the friction of the hull, 0.2 times the push, $F_y$ = 120 kN along the fender.

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5. Combination *D+B* = DEAD + BERTH, Linear Add.

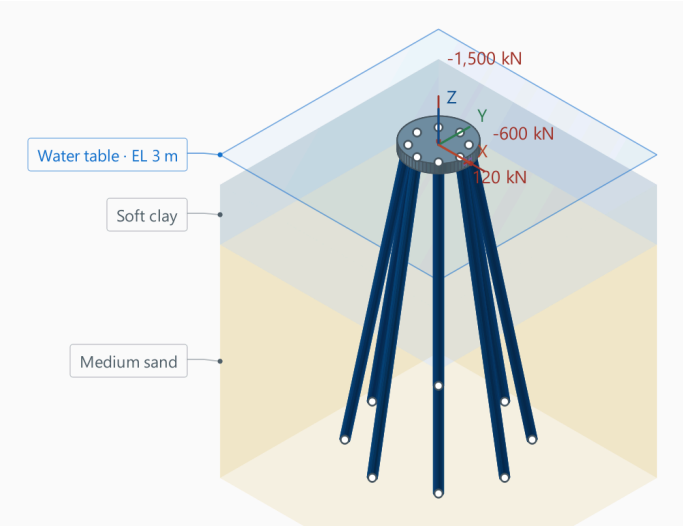



**Figure 16.16 —** Example 10 — the ring of battered piles under a round cap

### 16.10.2 Results

The push points at the centre of the ring and does not twist the cap; the friction acts 3.4 m from it, a torque of 408 kN·m from the position alone. Under D+B the cap turns 0.016° about Z. The battered ring takes the push along its piles: P5, on the far side and leaning away from the ship, is pressed with 510.4 kN, and P1, at the fender, with 87.2 kN. The piles also twist: P1 carries 12.6 kN·m of torsion at its head, and the eight heads together 101 kN·m. The rest of the torque is carried by the pile shears around the ring, times its radius. The torsional response of a pile comes from its torque–rotation curve (**Show Soil Curves…**, tab T-R; Technical Reference, “Torsional response”).

## 16.11 Example 11: effect of scour

The group of Example 4, without group reduction, is analysed with no scour and with 2 m of soil removed by scour (**Define ▸ Soil ▸ Soil Profile…**, *Scour depth*).

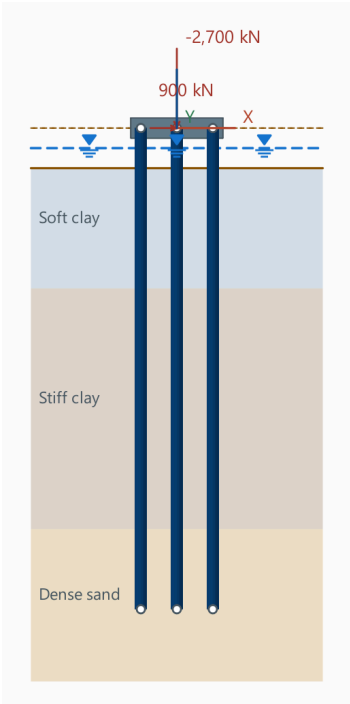



**Figure 16.17 —** Example 11 — the model in the X-Z elevation; the scour depth is a property of the soil profile

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**Table 16.8 — Example 11 — effect of 2 m of scour**

| Scour depth | Cap Ux (mm) | Largest moment (kN·m) |
|---|---|---|
| 0 | 6.30 | 191 |
| 2 m | 17.53 | 309 |

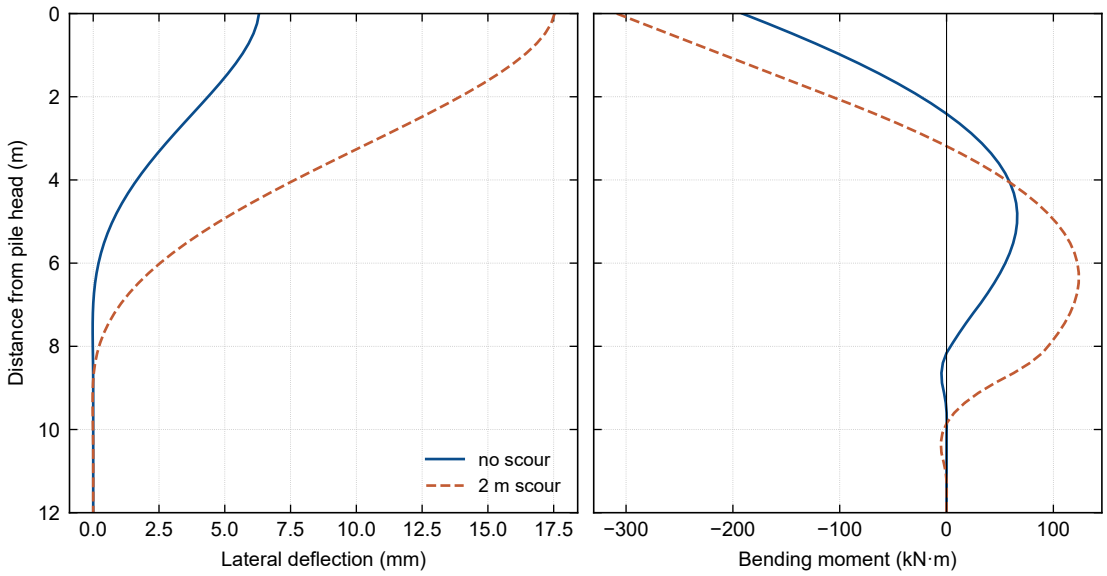



**Figure 16.18 —** Example 11 — deflection and moment of the centre pile with and without scour

Removing the top 2 m of soil, the part that resists the lateral load most, almost triples the displacement and increases the moments by more than half. Scour of the soil near the surface, by water, excavation or erosion, must be included where it can occur.

### 16.11.1 An impact on one pile

With 4 m of scour the piles stand free at the top, in a river. A drifting barge can strike one of them, and that load goes on one pile at its own elevation, not on the cap: a pattern *IMPACT* (type OTHER), pile P1 selected, **Assign ▸ Pile Loads ▸ Point Force Along Pile…**, $F_x$ = 400 kN at elevation −1.5 m, and the combination *D+I* = DEAD + IMPACT.

Under D+I the struck pile P1 has a head shear of −218.3 kN: it pushes the cap, instead of the cap pushing it, while its neighbour P2 takes 154.4 kN from the cap. The head moment of P1 drops to 230.4 kN·m against 664.5 kN·m in P2, and its largest moment, 558.2 kN·m, is no longer at the head but at the impact, 1.5 m below it (**Show Forces Along Piles…**, case D+I, pile P1). A pile that can be struck is designed for that point as well as for its head.

## 16.12 Example 12: cracking of a concrete pile

The group is built with bored piles of 0.8 m diameter at 2.4 m spacing, with 16 bars of US #8 in a reinforcing steel *Rebar 420* added in **Define ▸ Section Properties ▸ Materials…** ($f_y$ = 420 MPa, $E$ = 200 GPa; the other entries of the round concrete section keep their defaults), and loaded with $F_z$ = −2 700 kN at the middle of the cap and a horizontal load from 300 to 1 500 kN in X that comes through a bearing on the edge of the cap: a reference point *Bearing* at (0, 2.4) m, over the last row of piles, and the force applied at the selected point. Pushed off the middle line, the cap twists as well as slides. The section is first elastic with the gross *EI* of the concrete, then nonlinear, with moment–curvature curves at the thrusts 0, 1 000 and 2 000 kN.

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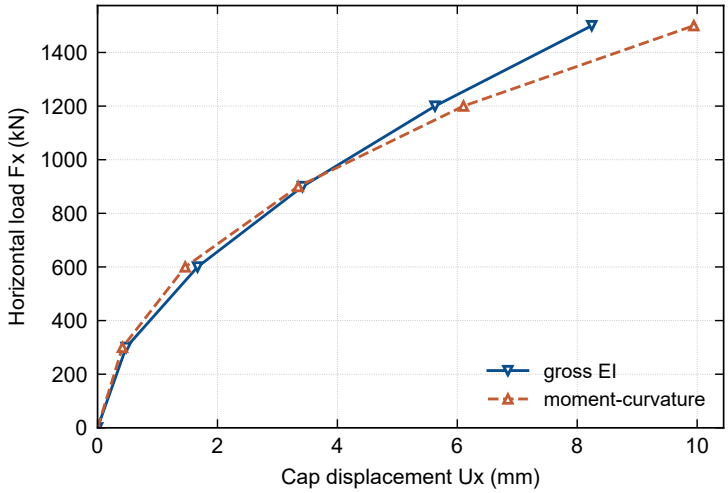



**Figure 16.19 —** Example 12 — elastic and nonlinear sections

At small loads the nonlinear section is slightly stiffer than the gross concrete section, because the reinforcement adds to the stiffness of the uncracked section: at 300 kN the cap moves 0.41 mm against 0.48 mm. Once the head moments exceed the cracking moment the section softens, and at 1 500 kN the cap moves 9.94 mm against 8.24 mm. The cracked piles also attract less moment at the head (542 against 683 kN·m). Because of the twist the piles do not share alike: with the gross section at 1 500 kN, P8 in the row under the bearing has a head moment of 682.7 kN·m and P2 in the far row 217.4 kN·m. For reinforced-concrete piles under significant lateral load the nonlinear section should be used, both for the displacements and for the distribution of the moments.

## 16.13 Example 13: moment–curvature of a bored pile

The nonlinear section of Example 12, a bored pile of 0.8 m diameter with 16 bars of US #8 (25.4 mm, steel *Rebar 420*) in concrete of 30 MPa, is examined in **Pile Section Data**, tab Nonlinear, with the thrusts 0, 2 000 and 4 000 kN entered manually; **Show moment-curvature…** draws the curves (Figure 16.20).

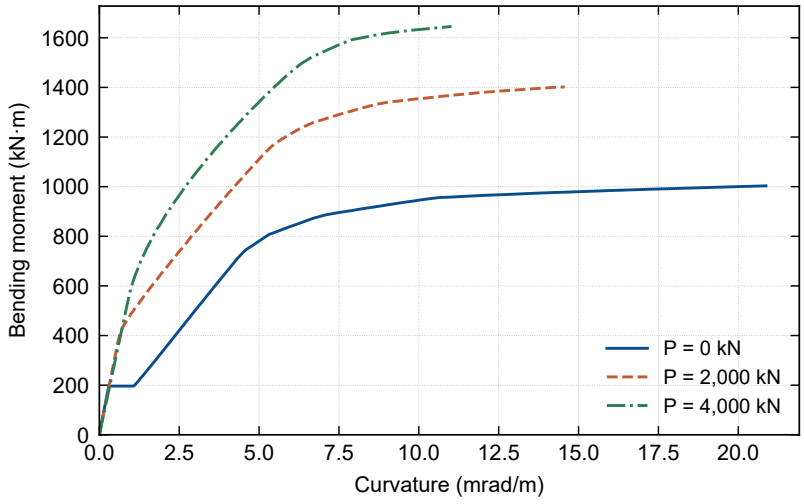



**Figure 16.20 —** Example 13 — moment–curvature of the bored pile at three thrusts

**Table 16.9 — Example 13 — peak moment and initial stiffness**

| Axial thrust (kN) | Peak moment (kN·m) | Curvature at the peak (rad/m) | Initial *EI* (kN·m²) |
|---:|---:|---:|---:|
| 0 | 1,003 | 0.0209 | 682,132 |
| 2,000 | 1,402 | 0.0146 | 646,284 |

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| Axial thrust (kN) | Peak moment (kN·m) | Curvature at the peak (rad/m) | Initial *EI* (kN·m²) |
|---:|---:|---:|---:|
| 4,000 | 1,645 | 0.0110 | 605,946 |

Axial compression delays the cracking of the concrete and holds the tension reinforcement in a more effective position, so the peak moment rises with the thrust over this range, while the curvature at the peak, and with it the ductility, falls. The initial stiffness is that of the uncracked transformed section; it decreases slightly as the thrust grows, by about a tenth between 0 and 4 000 kN, because the concrete becomes softer at higher compressive stress. Because the curve of each node is interpolated between the thrusts of the list, the list must span the axial forces of the piles; a pile in tension needs a negative thrust in the list.

## 16.14 Example 14: prestressed concrete pile

A square prestressed pile of 400 mm side with chamfered corners, eight 1/2″ strands of grade 250 ksi, a prestress force of 1 000 kN before losses and a loss of 15 % is examined at the thrusts 0, 1 000 and 2 000 kN (Figure 16.21).

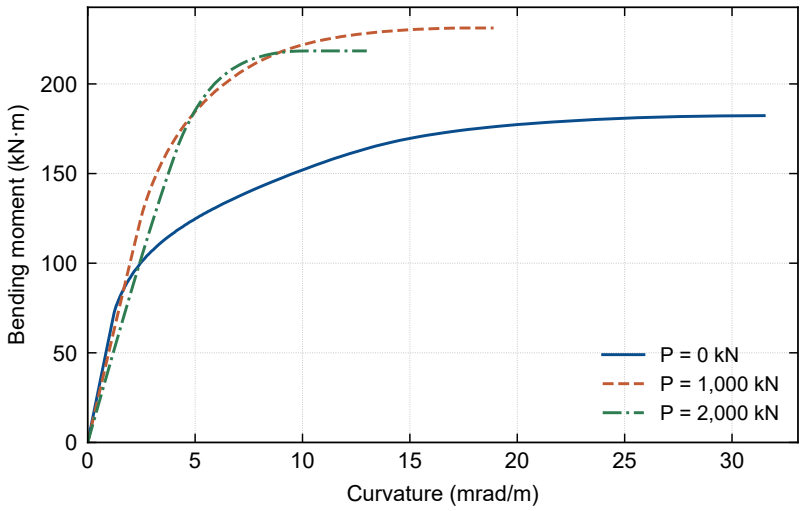



**Figure 16.21 —** Example 14 — moment–curvature of the prestressed pile

**Table 16.10 — Example 14 — peak moment of the prestressed pile**

| Axial thrust (kN) | Peak moment (kN·m) | Curvature at the peak (rad/m) |
|---:|---:|---:|
| 0 | 182 | 0.0315 |
| 1,000 | 231 | 0.0173 |
| 2,000 | 218 | 0.0106 |

The prestress already compresses the section, so a moderate external thrust raises the capacity, but a larger thrust brings the concrete closer to crushing and the capacity falls again: at 2 000 kN the peak moment is lower than at 1 000 kN. A prestressed pile therefore has a narrow band of axial force in which its bending capacity is greatest, and the list of thrusts should include the extremes of the axial forces in the piles.

## 16.15 Example 15: steel pipe pile and a check by hand

A steel pipe of 508 mm outside diameter and 12 mm wall, yield strength 345 MPa, is examined without axial load (Figure 16.22). The plastic moment of a pipe follows from its plastic section modulus

$$Z = \frac{D^3 - (D - 2t)^3}{6}, \qquad M_p = F_y Z \tag{16.1}$$

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which gives $Z$ = 2,953×10$^{-6}$ m$^3$ and $M_p$ = 1,019 kN·m. The moment–curvature curve of Solgroup reaches 1,009 kN·m, 99.1 % of the plastic moment: the curve ends at a finite curvature, where the outermost fibres have strained far into the plastic range but the fibres near the neutral axis are still elastic, so the full plastic moment is approached but not reached. The agreement checks the input of the section; a large difference would point to a wrong yield strength or wall thickness.

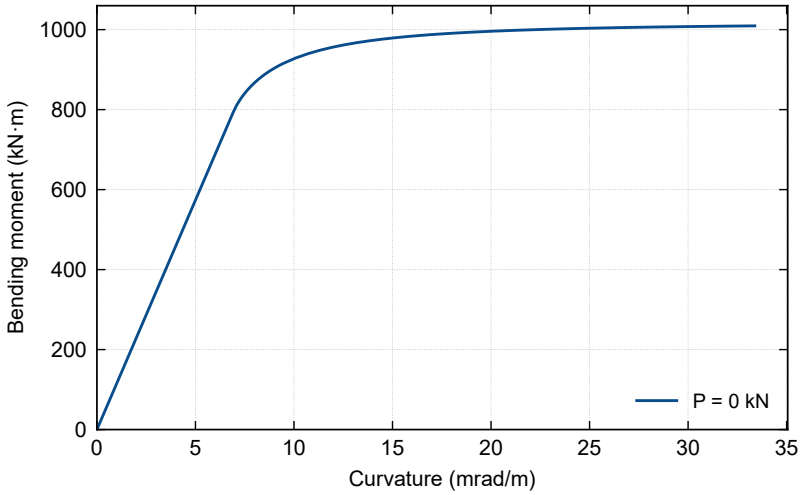



**Figure 16.22 —** Example 15 — moment–curvature of the steel pipe

## 16.16 Example 16: unsymmetrical group of bored piles

Four bored piles of 1.0 m diameter and 20 m length carry a column. The piles are drawn by hand on a grid (**Draw ▸ Quick Draw Pile**), or entered with **File ▸ New Model…**, template *Custom from Table*; the section is an elastic circular section of 1.0 m, and the cap is generated around the piles (**Draw ▸ Quick Draw Cap**) with an edge offset of 0.8 m. Two layouts are compared: a square of 3.0 m side, and a trapezoid in which the fourth pile is moved 3.0 m further in X, to (4.5, 1.5) (**Edit ▸ Move**), after which the cap is drawn again.

The column stands at the centre of the square, (0, 0). It is marked by a reference point, *Column*, and its load is applied at that point (**Selected points / pile-head joints**), in the pattern SDL: $F_x$ = 500 kN, $F_y$ = 300 kN and $F_z$ = −6 000 kN. A pipe support is bolted to the head of P2 only: a joint load on the joint *P2 · Head* (**Assign ▸ Joint Loads ▸ Point Forces / Moments…**), $F_y$ = 40 kN and $F_z$ = −150 kN.

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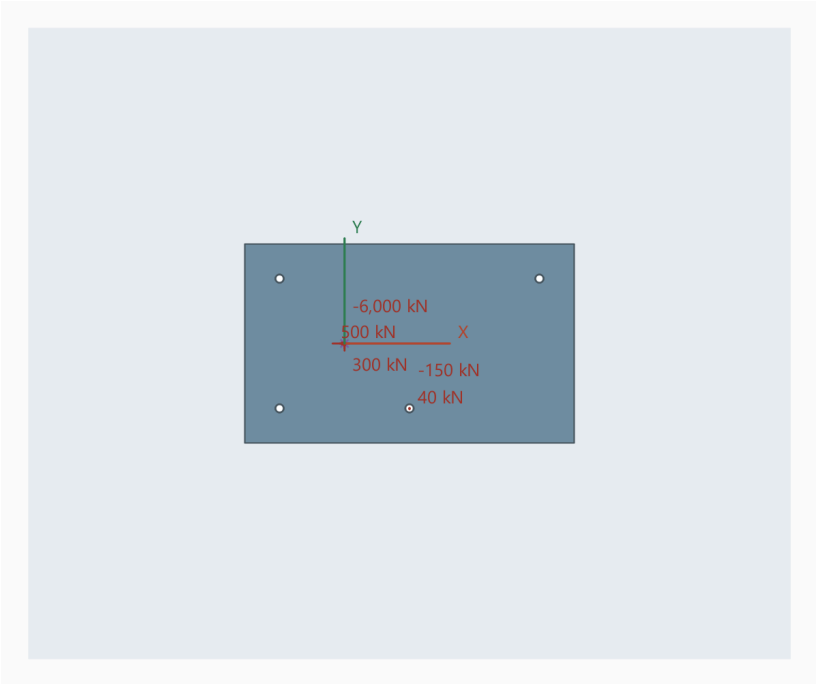



**Figure 16.23 —** Example 16 — the model in the plan, with the column load at its reference point and the pipe load on the head of P2

For the square the column lies at the centroid of the piles. When P4 is moved and the cap is drawn again, the middle of the cap moves to X = 1.50 m, but the column load stays where the column is, on its reference point at X = 0: a load applied with nothing selected would have moved with the middle of the cap. The centroid of the piles is now at X = 0.75 m, so the vertical load bends the group about the Y axis and $F_y$ twists it.

**Table 16.11 — Example 16 — cap movement and pile-head forces of the trapezoidal group**

| Pile | X (m) | Y (m) | Axial force (kN) | Resultant shear (kN) | Resultant head moment (kN·m) |
|---|---|---|---|---|---|
| P1 | −1.5 | −1.5 | 1,832 | 151.6 | 413 |
| P2 | 1.5 | −1.5 | 1,470 | 146.4 | 398 |
| P3 | −1.5 | 1.5 | 2,185 | 158.7 | 440 |
| P4 | 4.5 | 1.5 | 1,502 | 150.2 | 415 |

The cap of the trapezoid moves 2.06 mm in X and 1.81 mm in Y and turns −0.098 mrad about Z. Because the column stays near P1 and P3, the outlying pile P4, now far from it, carries only 1,502 kN against 2,008 kN in the square, and P3, at the other end of its row and close to the column, takes the most, 2,185 kN. The twist adds to the shear of the piles on one side and subtracts from the other. Even the square group has unequal axial forces under a load with no moment: the fixed heads carry bending moments, which the cap balances by adding compression to the piles at the front and taking it from those at the back, and P2 carries the pipe as well.

Put a column load where the column is. With nothing selected a cap load goes to the middle of the cap, and that middle moves every time the cap is drawn again.

## 16.17 Example 17: strength increasing with depth

Five piles of 0.6 m diameter and 24 m length stand in a diamond, one at the centre and four at 2.0 m from it on the X and Y axes, and carry $F_x$ = 400 kN and $F_z$ = −2 500 kN. The upper 16 m are soft clay whose undrained shear strength grows from about 20 kPa near the surface to 50 kPa at 16 m; stiff clay follows below. The soil is described in two ways in **Define ▸ Soil ▸ Soil Layers…** and **Soil Profiles…**:

- four sublayers of 4 m, soft clay with $c_u$ = 20, 30, 40 and 50 kPa;
- a single layer of 16 m with the average strength, $c_u$ = 35 kPa.

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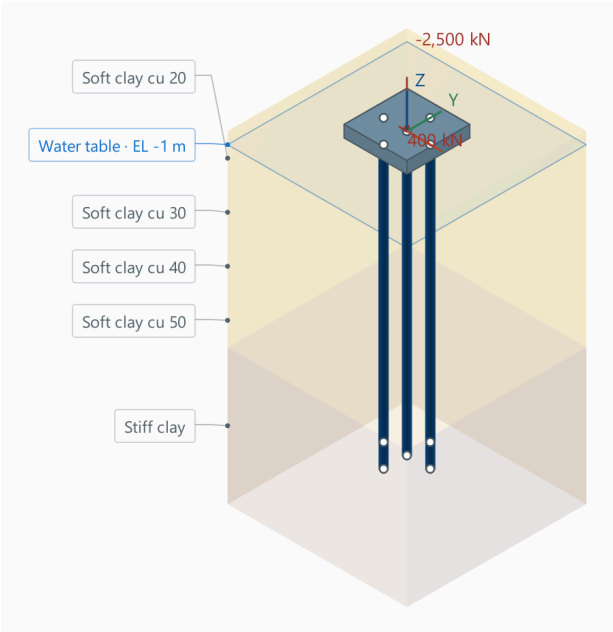



**Figure 16.24 —** Example 17 — the model in the 3D view

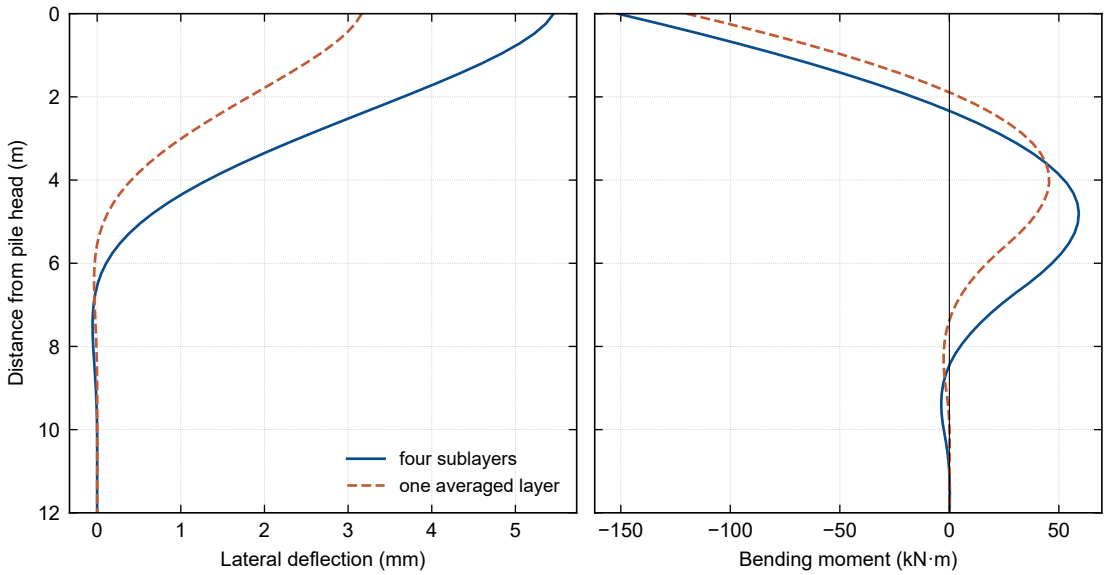



**Figure 16.25 —** Example 17 — deflection and moment of the centre pile for the two descriptions of the soft clay

**Table 16.12 — Example 17 — response of the diamond group**

| Soft clay | Cap Ux (mm) | Cap Ry (mrad) | Largest moment (kN·m) | Front pile axial (kN) | Rear pile axial (kN) |
|---|---|---|---|---|---|
| Four sublayers | 5.46 | 0.274 | 151 | 814 | 436 |
| One averaged layer | 3.16 | 0.231 | 120 | 782 | 483 |

The averaged layer moves the cap only 3.16 mm against 5.46 mm, and gives a head moment of 120 instead of 151 kN·m. The lateral response of a pile is governed by the soil within a few diameters of the ground surface, here the upper 3 to 5 m, where the real strength is well below the average of the layer. The axial forces barely change, because the vertical load is carried along the whole length. Divide a layer whose strength varies with depth into sublayers that follow the variation, at least over the upper ten diameters.

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## 16.18 Example 18: ring of piles loaded in two directions

Eight piles on a ring of 3.0 m radius (template *Circular (Single Ring)*, start angle 0°, so that pile P1 lies on the X axis) carry a vertical load of 8 000 kN, a horizontal load of 600 kN and an overturning moment of 2 400 kN·m about the horizontal axis perpendicular to the load. The horizontal load and the moment are applied first along X (0°) and then at 22.5° from X, which points between two piles; the components are entered as $F_x$, $F_y$, $M_x$ and $M_y$ of one cap load.

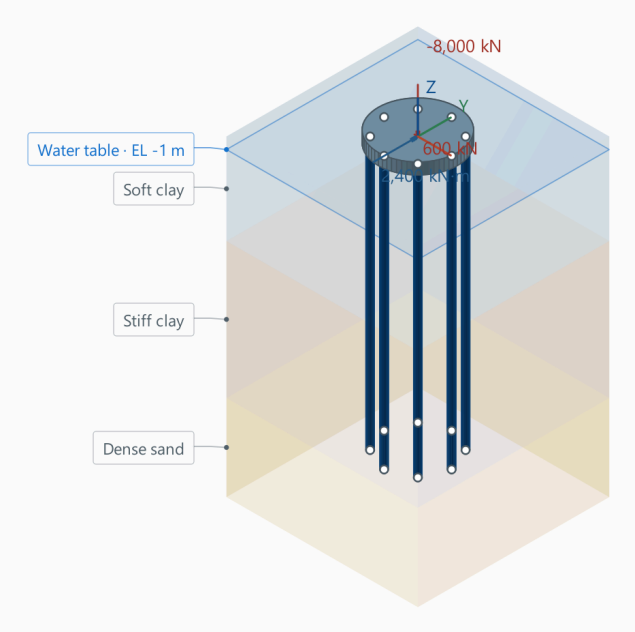



**Figure 16.26 —** Example 18 — the model in the 3D view

**Table 16.13 — Example 18 — ring of eight piles**

| Direction of load | Horizontal cap movement (mm) | Largest axial force (kN) | Smallest axial force (kN) | Largest shear (kN) | Largest head moment (kN·m) |
|---|---|---|---|---|---|
| 0° (towards P1) | 4.02 | 1,401 | 830 | 75.2 | 129 |
| 22.5° (between P1 and P2) | 4.02 | 1,380 | 851 | 75.2 | 129 |

The ring is laterally isotropic: the cap moves the same 4.02 mm in either direction, and the shears and head moments do not change. The axial forces do. The increase of the axial force can be checked by hand. The moment of inertia of the ring about any horizontal axis through its centre is $I = \Sigma r^2 = nR^2/2 = 36$ m$^2$, and the moment that the axial forces must carry is the applied moment plus the eight head moments, which the fixed heads transfer to the cap ($\Sigma M_{\text{head}} = 1{,}030$ kN·m):

$$\Delta N = \frac{(M + \Sigma M_{head})\, R \cos\alpha}{I} \tag{16.2}$$

with α the angle between the load and the nearest pile. For 0° this gives 285.8 kN, for 22.5° 264.1 kN; the program gives 1,401.4 − 1 000 and 1,379.6 − 1 000 kN. The direction that points at a pile governs the axial design of a ring; for a ring with few piles the difference grows, and both directions should be analysed.

## 16.19 Example 19: breasting dolphin with battered piles

A breasting dolphin stands on six steel pipe piles of 914 mm diameter and 16 mm wall (steel of 355 MPa, an elastic section of shape *Steel pipe*) in two rows of three, 3.0 m apart in X and 2.5 m in Y. The pile heads are 4.0 m above the seabed; 6 m of soft clay overlie medium sand (the layers *Soft clay* and *Medium sand* of the jetty tutorial, Section 7.3), with the water 3 m above the seabed. A berthing load of 600 kN acts in +X with a dead load of 1 500 kN. Three arrangements are compared, the batter being set with **Assign ▸ Pile ▸ Batter…**:

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- all six piles vertical;
- the front row (on the side towards which the load pushes) battered 10°, with its tips outward in +X;
- both rows battered 10° outward, the rear row with its tips in −X.

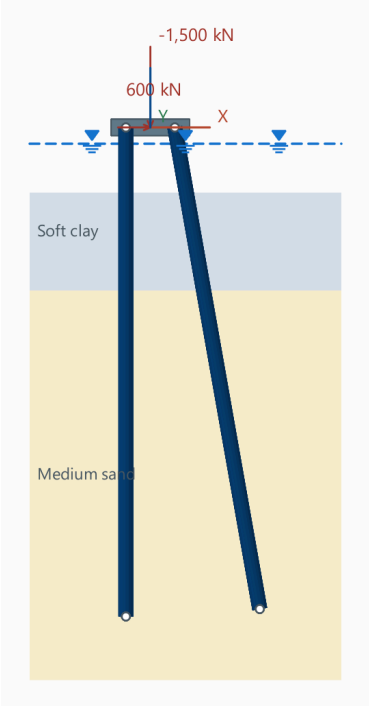



**Figure 16.27 —** Example 19 — the model in the X-Z elevation, with the front row battered

**Table 16.14 — Example 19 — dolphin under the berthing load**

| Piles | Cap Ux (mm) | Front row axial (kN) | Rear row axial (kN) | Sum of shears (kN) | Largest head moment (kN·m) |
|---|---|---|---|---|---|
| All vertical | 11.03 | 662 | 99 | 600 | 422 |
| Front row battered | 3.64 | 545 | 233 | 318 | 226 |
| Both rows battered | 3.94 | 596 | 176 | 387 | 301 |

With vertical piles the whole berthing load is carried in bending: the six shears add up to 600 kN, the cap moves 11.0 mm and the rear row is lifted (99 kN, a negative axial force is tension). Battering the front row lets its axial force carry part of the load: three piles of 545 kN at 10° give 3 × 545 × sin 10° = 284 kN in X, so the shears, which in a battered pile act perpendicular to its axis, carry the remainder. The displacement falls to 3.6 mm and the moments by more than a third. Battering the rear row as well reduces the displacement further, to 3.9 mm, but the moments rise again: under the small dead load the rear piles stay in compression (176 kN), and a compressed pile whose tip points away from the load pushes the cap the same way as the load. A rear batter pays only when the rear piles go into tension; check it with the smallest vertical load that can act with the berthing load.

## 16.20 Example 20: jetty on a sloping seabed

A jetty deck stands on six rows of two steel pipe piles (812 × 16 mm, 40 m long, heads at +3.0 m), 5.0 m apart in X and 6.0 m in Y, elastic sections of shape Steel pipe in the steel of Example 19. The seabed slopes from −2 m under the landward row to −12 m under the seaward row. One soil profile describes the layers of Example 19 by their elevations, soft clay from −2 to −8 m over medium sand, with the water at +1 m; the sloping seabed is entered with **Sloping…** in *Soil Profile Data* (Section 9.6.1): template **Inclined plane**, slope angle 21.8° (2 m in 5 m), upper ground elevation −2 m, starting at row 1. Every pile takes the seabed where its axis meets it, −2, −4, …, −12 m from row 1 to

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row 6. The soil above the seabed of a pile is not counted, and the layers below keep their elevations. For comparison the seabed is also taken flat at the mean level of −7 m, assigned to every pile with **Assign ▸ Pile ▸ Ground Surface Elevation Override…**. The deck carries $F_x$ = 1 200 kN and $F_z$ = −9 000 kN.

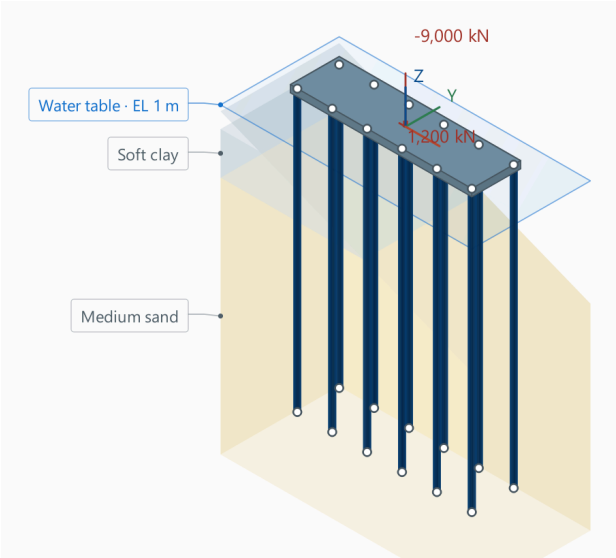



**Figure 16.28 —** Example 20 — the model in the 3D view, with the sloping seabed

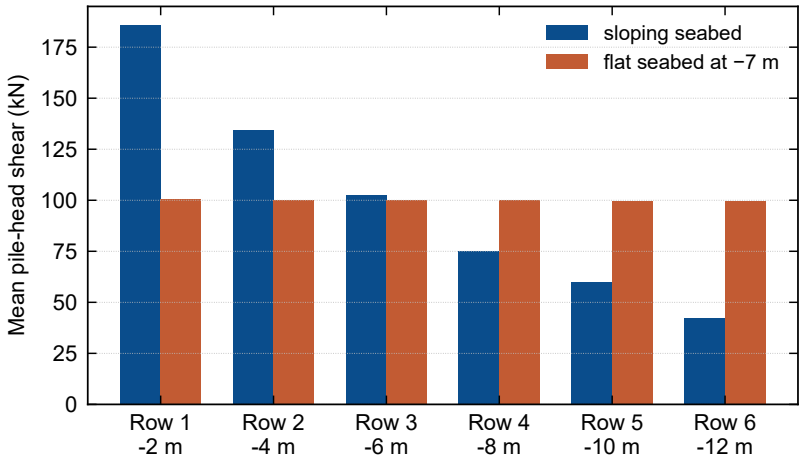



**Figure 16.29 —** Example 20 — mean pile-head shear of each row on the sloping and on a flat seabed

**Table 16.15 — Example 20 — pile-head forces of each row on the sloping seabed**

| Row | Seabed (m) | Shear (kN) | Head moment (kN·m) | Axial force (kN) |
|---|---|---|---|---|
| 1 (landward) | −2 | 186 | 1,030 | 992 |
| 2 | −4 | 134 | 851 | 1048 |
| 3 | −6 | 103 | 721 | 1094 |
| 4 | −8 | 75 | 590 | 1133 |
| 5 | −10 | 60 | 512 | 1186 |
| 6 (seaward) | −12 | 42 | 408 | 1230 |

On the flat seabed every row takes about the same shear, 100 kN. On the slope the short landward piles are much stiffer and attract the load: row 1 takes 186 kN, more than four times the 42 kN of row 6, and its head moment of 1,030 kN·m exceeds the 732 kN·m of the flat model by about two fifths. The total movement of the deck changes

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little (38.6 against 41.0 mm), so a check of the deck displacement alone would not reveal the difference: a sloping seabed must be modelled pile by pile.

### 16.20.1 Waves on every row, and the stiffness of the sand

The sloping model is given a scour of 1.5 m (**Define ▸ Soil ▸ Soil Profile…**) and two further checks. Waves load the piles themselves: a pattern *WAVE* (type WAVE), all piles selected, **Assign ▸ Pile Loads ▸ Distributed Lateral Load…**, Global X, from the water surface at +1 m to −2 m, above even the shallowest seabed, 4 kN/m at the top and 1 kN/m at the bottom, the same 7.5 kN on each of the twelve piles. The deck shares the 90 kN out by stiffness: the short, stiff first row takes 9.8 kN at its head, more than its own wave, while the long sixth row has −5.4 kN: the deck holds it back and hands its wave to the stiff rows. The head moments are 68.7 and 5.0 kN·m.

The *k* of the sand comes from a table, and a cone test might show a softer sand. The soil profile can override *k* for one layer without a new layer: column *k override* of the sand row, 12,200 kN/m$^3$, half the table value. It is read only by layers whose p-y curves take a *k*, as this sand does. Under the case DEAD the deck then moves 49.7 mm against 49.4 mm, and the first row bends with 1,103.7 against 1,101.1 kN·m: hardly any change. The *k* only sets how steeply the sand curves start; at this load they are already far along, so the strength of the sand governs, not its first slope.

## 16.21 Example 21: rectangular section bending about both axes

A rectangular concrete pile of 400 × 500 mm (*Rectangular concrete*, **Width (axis 2), b** = 0.40 m and **Depth (axis 3), h** = 0.50 m) has 10 bars of US #8 in the pattern *Rectangular*, three bars on each short face and four on each long face, concrete of 30 MPa and reinforcement of 420 MPa. A rectangular section bends differently in its two planes; Solgroup computes the curve for the second plane from the same section turned through 90°, so the section is entered only once (Figure 16.30).

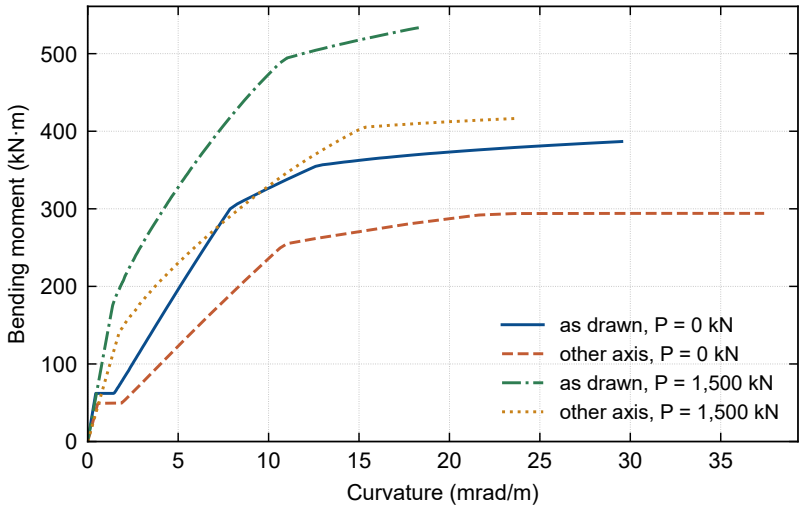



**Figure 16.30 —** Example 21 — moment–curvature of the rectangular section in its two planes, without axial load and at 1 500 kN

**Table 16.16 — Example 21 — peak moment and initial stiffness in the two planes**

| Axial thrust (kN) | Plane | Peak moment (kN·m) | Curvature at the peak (rad/m) | Initial *EI* (kN·m²) |
|---:|---|---:|---:|---:|
| 0 | bending with $I_{33}$ (depth 0.50 m) | 387 | 0.0295 | 142,542 |
| 0 | bending with $I_{22}$ (depth 0.40 m) | 294 | 0.0276 | 90,596 |
| 1 500 | bending with $I_{33}$ | 534 | 0.0185 | 128,363 |
| 1 500 | bending with $I_{22}$ | 416 | 0.0236 | 81,470 |

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The gross moments of inertia are $bh^3/12 = 4.167\times10^{-3}$ and $2.667\times10^{-3}$ m$^4$, a ratio of 1.56; the initial stiffnesses of the two curves without axial load stand in nearly the same ratio, which checks the orientation of the section. The bars do not scale the same way, so the ratio of the peak moments is smaller, $387/294 \approx 1.3$. When a rectangular pile is rotated in plan, use **Assign ▸ Pile ▸ Local Axes…** to turn its local axes rather than swapping width and depth.

## 16.22 Example 22: bored pile with a permanent casing

The bored pile of Example 13 (0.8 m diameter, 16 bars of US #8) is compared with the same pile left in a steel casing of 12 mm wall (*Round concrete with permanent casing*, casing steel of 355 MPa), both at an axial thrust of 1 000 kN (Figure 16.31).

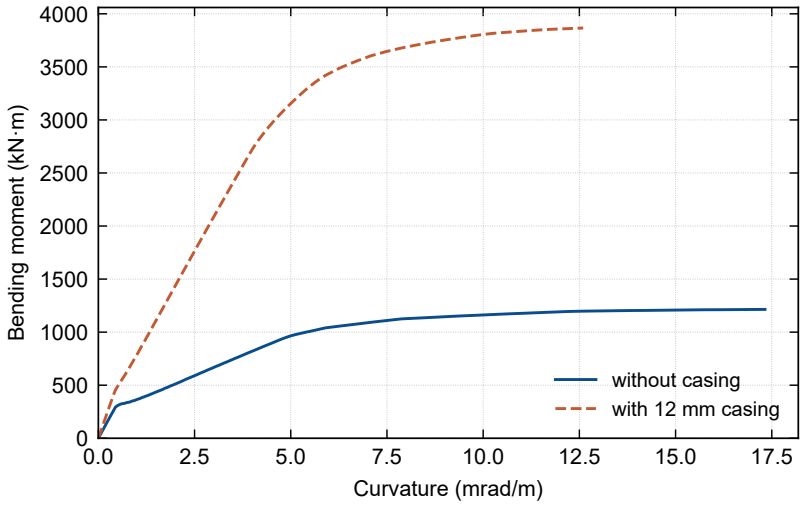



**Figure 16.31 —** Example 22 — moment–curvature with and without the casing

The casing triples the bending capacity, from 1,214 to 3,866 kN·m, and raises the initial stiffness 1.57 times. A rough check is the plastic moment of the casing alone, $F_y(D^3 - (D - 2t)^3)/6 = 2{,}645$ kN·m, added to the capacity of the uncased pile: the sum, 3,860 kN·m, is close to the curve. Over the length where the casing is not left in place, use the uncased section with **Assign ▸ Pile ▸ Section along Length…**.

## 16.23 Example 23: unsymmetrical reinforcement

A square concrete section of 500 mm, in the concrete and reinforcement of Example 21, has four bars of US #10 along one face and two bars of US #6 at the corners of the opposite face, entered with the pattern *Manual*: bar centres 75 mm from the faces, in the table X and Y from the section centre, the four #10 at X = −0.175, −0.0583, 0.0583 and 0.175 m with Y = −0.175 m, the two #6 at X = ±0.175 m with Y = +0.175 m. Its positive and negative bending capacities differ, and the program computes a separate branch for each direction (Figure 16.32). Such a section can be analysed only with **Allow non-symmetric nonlinear sections** ticked in **Analyze ▸ Set Analysis Options…**; without it, Check Model stops the run and names the section.

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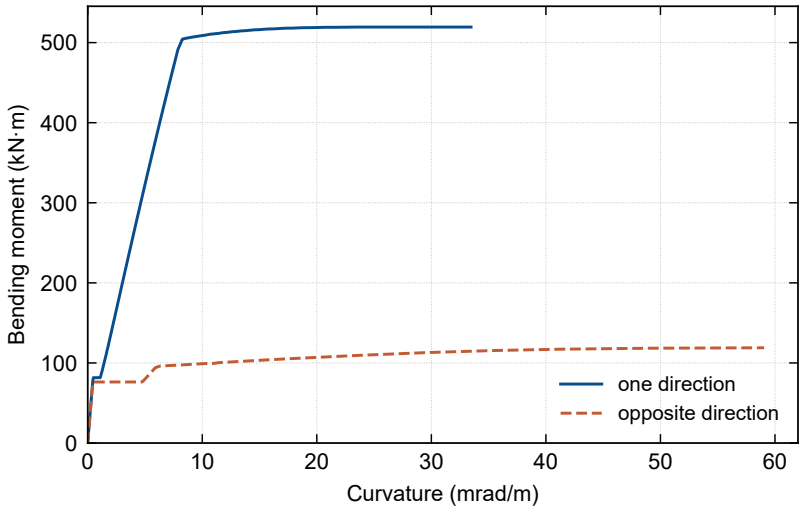



**Figure 16.32 —** Example 23 — moment–curvature of the unsymmetrically reinforced section in the two directions of bending

With the four large bars in tension the section carries 519 kN·m; with the two small bars in tension only 119 kN·m, 4.4 times smaller. The initial stiffness is the same in both directions (179,028 kN·m$^2$), since the uncracked section does not depend on which face is in tension. In the opposite direction the curve flattens as soon as the concrete cracks: the two small bars can hardly carry the cracking moment, the behaviour of a face with less than the minimum reinforcement. A pile with such a section must be oriented with **Local Axes…** so that its strong face meets the governing load, and both directions of the load should be analysed.

## 16.24 Example 24: editing the model in a spreadsheet

Large changes are often quicker in a spreadsheet than in the dialogs. The model of Example 1 is written with **File ▸ Export ▸ Model Tables (Excel)…** to one workbook of 25 sheets, one per table of **Show Tables**, with the units of the display in the column headings: the input tables (Materials, Pile Sections, Section Reinforcement, Cap Sections, Piles, Joints, Assignments, Soil Layers, Soil Profiles, Lateral Reduction Sets, Group Effect Factors, Load Patterns, Joint Loads, Load Cases, Load Combinations) and the result tables.

In the workbook three changes are made:

1. in the sheet *Piles*, whose columns are ID, Label, X (m), Y (m), Z Head (m), Z Tip (m), Length (m), Batter from Vert (°), Batter Ratio 1:m and Azimuth (°), the length of all nine piles is changed from 24 to 30 m;
2. a tenth row is added with the ID P99;
3. in the sheet *Joint Loads* the force Fx of the cap load of pattern SDL is changed from 300 to 600 kN.

The workbook is saved and read back with **File ▸ Import ▸ Model Tables (CSV / Excel)…**. The program reports:

```
Materials: 0 value(s) updated, 1 row(s) matched
Pile Sections: 0 value(s) updated, 1 row(s) matched
Cap Sections: 0 value(s) updated, 1 row(s) matched
Piles: 9 value(s) updated, 9 row(s) matched
   not found: P99
Assignments: 0 value(s) updated, 9 row(s) matched
Soil Layers: 0 value(s) updated, 3 row(s) matched
Load Patterns: 0 value(s) updated, 3 row(s) matched
Joint Loads: 1 value(s) updated, 1 row(s) matched
```

The rows are matched by their key column, not by their order, so a sheet sorted in the spreadsheet still lands on the right objects (Table 16.17). A row whose key is not in the model is reported as *not found* and ignored: the import changes existing objects but does not create new ones, so the pile P99 is not added. New piles are drawn or generated in the program, and their properties then edited in the workbook. Columns that cannot be edited in Show Tables,

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such as Z Tip, and the columns of the result tables, are ignored without failing the import; a value that is not accepted, for example a negative length, is listed below the table with its line in the file. Sheets that are read only in Show Tables (Section Reinforcement, Soil Profiles, Load Cases and the result tables) and empty sheets are passed over without a line in the report. The whole import is one step of **Edit ▸ Undo**.

**Table 16.17 — Key columns by which the rows of each model table are matched**

| Table | Key column(s) | Table | Key column(s) |
|---|---|---|---|
| Materials | Name | Soil Layers | Name |
| Pile Sections | Name | Lateral Reduction Sets | Set, Depth |
| Cap Sections | Name | Group Effect Factors | Set, Row |
| Piles | ID | Load Patterns | Name |
| Joints | ID | Joint Loads | Target, Pattern |
| Assignments | Pile | Load Combinations | Name |

After the import the model is analysed again. With the doubled horizontal load the cap moves 3.13 mm instead of 0.93 mm and the largest head moment rises from 43 to 111 kN·m, more than in proportion to the load because the soil response is nonlinear; the longer piles change the lateral response little, since the upper part of a long pile governs it.

## 16.25 What to try next

- In example 1, select a lateral group-effect set by the AASHTO method in the analysis options, and compare the shear forces of the leading and trailing rows.
- Add a **Pushover** case to example 1 to follow the response of the group to several times its load.
- In example 2, compute the foundation stiffness of the deck (**Foundation Stiffness…** of the load case) with and without the battered piles.

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# 17 Troubleshooting

This chapter shows what Solgroup reports when a model cannot be analysed or an analysis does not converge, and how to find the cause. The messages quoted are those of Solgroup 1.0.8 for small variations of the group of Example 1. Two places hold the information: **Analyze ▸ Check Model** lists the findings about the input, and, after a run, the **Command** panel lists one entry per load case with the notes of the analysis. A click on a finding selects the objects it concerns.

## 17.1 Errors found by Check Model

Check Model runs before every analysis, and a model with an error is not analysed. Each finding has a level, a code and a message that names the objects concerned. Two common errors:

**Table 17.1 — Examples of errors found by Check Model**

| Code | Message | Cause and remedy |
|---|---|---|
| SEC-001 | *Pile P1 has no pile section assigned.* | The pile has no section, for example after the section it used was renamed in another file. Select the piles and assign a section with Assign ▸ Pile ▸ Section. |
| SOIL-019 | *The tip of pile P1 (7.00 m) is at or above the ground surface of its soil profile (0.00 m); the pile must reach into the soil.* | The pile does not reach the soil, for example because the pile heads were placed above the ground with too short a length, or the ground surface of the profile is wrong. Correct the length or the elevation of the piles, or the ground surface of the profile. |

Warnings and information do not stop the run but should be read. For example, *LOAD-007: Load pattern 'LIVE' carries no load* points to a pattern that was meant to be loaded; *LOAD-015* states that the self weight multiplier of a pattern has no effect. The complete list of findings is in Appendix A.

## 17.2 Bearing failure under vertical load

The vertical load of the group of Example 1 is raised to 60 000 kN, far beyond the axial capacity of nine 0.6 m piles 24 m long. The run does not converge, and the Command panel reports for the case:

```
DEAD: NOT converged
  The group stiffness matrix is singular
  • Possible bearing failure: the axial head displacement of some piles is beyond the upper end of
    their load-displacement curve.
  • To hold these piles at the end of their curve instead, switch on 'Extend L-D / T-R curves beyond
    their last point' in Analysis Options.
  • No resistance left (bearing), pile P1: the axial head displacement 0.14256 m is past the
    0.0653617 m end of its curve, so it carries no axial load at all.
  …
```

The axial load–displacement curve of each pile ends at the displacement at which its full capacity is mobilised. A pile pushed beyond that point carries no axial load, so the group loses its vertical stiffness and the equations become singular. The remedies are, in order: check the load and its units; check the side friction and the tip resistance of the soil layers; lengthen the piles or add piles. The option *Extend L-D / T-R curves beyond their last point* holds the axial force of such piles at its value at the end of the curve, so that the analysis can continue; the result then shows a group that is at its axial capacity, which must not be used as a design state.

## 17.3 Failure under a very large horizontal load

With a horizontal load of 20 000 kN on the same group, the run does not converge either. The piles cannot carry the horizontal load by bending, the cap rotates strongly, and the overturning pushes the piles on one side down and pulls the piles on the other side up:

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```
DEAD: NOT converged
  The group stiffness matrix is singular
  • Possible bearing failure: …
  • No resistance left (bearing), pile P2: the axial head displacement 0.132124 m is past the 0.0653617
m
    end of its curve, so it carries no axial load at all.
  …
  • Possible pull out failure: the axial head displacement of some piles is beyond the lower end of
    their load-displacement curve.
  • No resistance left (pull out), pile P1: …
```

A failure of this kind is a real failure of the foundation, not a numerical difficulty: the group cannot carry the load. The pushover of Example 7 shows how the displacement grows as the load approaches such a state.

## 17.4 An analysis that does not converge

Where the cause is not a failure of the soil or of a pile, a load case may still stop at the iteration limit. In that case:

1. Read the notes of the case in the Command panel; they name the piles whose iteration did not close and, where it applies, the reason.
2. Check the input that drives the nonlinearity: a nonlinear section whose thrust list does not span the axial forces of the piles, a p-y model with a parameter far outside its usual range, or a pile tip in a layer without a tip curve.
3. Apply the load in steps: set an *Initial step* and a *Minimum step* smaller than 1 in the Analysis control of the case (Table 11.2). A case that converges only for part of its load reports the fraction reached.
4. Raise the iteration limits (*Iterations, pile group* and *Iterations, single pile*) moderately; a case that needs many more iterations than the default is usually close to a failure.
5. Run a pushover with increasing load factors (Example 7) to find the load at which the response becomes unstable.

**NOTE** The results of a case that did not converge are its last iterate, not a solution. They are shown so that the cause can be found, and must not be used for design.

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# Appendix A Check Model messages

The table lists every finding of **Analyze ▸ Check Model**, by code. *Error* stops the run; *Warning* and *Info* do not, but should be read before the results are used. The sign ... marks the name of an object or a value that the message fills in. When a code has several variants of its message, the first three are shown.

| Code | Level | Message (… = name or value filled in) |
|---|---|---|
| AXIAL-002 | Error | Axial curve '… ' assigned to pile … is not in the catalog. |
| AXIAL-003 | Error | Torsional curve '… ' assigned to pile … is not in the catalog. |
| AXIAL-006 | Error | … |
| AXIAL-007 | Error | … |
| AXIAL-008 | Warning | The … curve '… ' needs at least two points; pile(s) … use the curve generated from the soil instead. |
| CAP-000 | Warning | The pile cap was deleted, but the analysis still ties all pile heads to one rigid cap. |
| CAP-001 | Error | The pile cap polygon has fewer than three vertices. |
| CAP-002 | Error | The pile cap has no cap section. |
| CAP-003 | Error | Cap section '… ' is not in the catalog. |
| CAP-004 | Warning | The pile cap does not cover pile heads … . They are still tied to the cap: a rigid cap ignores its outline (an embedded or flexible cap uses it). A pile on its own needs a separate model. |
| CAP-005 | Warning | The pile cap vertices are not coplanar. |
| CAP-006 | Warning | Head of pile … at elevation … does not match the cap elevation of … . |
| CAP-007 | Info | The cap is set to Flexible but carries no plate mesh yet; one is generated for the analysis from the cap outline and its section (Assign > Cap > Generate Flexible Cap Mesh keeps it in the model). |
| CAP-008 | Error | … flexible-cap plate(s) point at a node that is not in the mesh (first: element … ).<br>… flexible-cap beam(s) point at a node that is not in the mesh (first: beam … ). |
| CAP-009 | Error | Flexible-cap plates use plate section number(s) … , which the mesh does not define. |
| CAP-010 | Error | The cap is marked as embedded but no soil resistance model is chosen. |
| CAP-011 | Error | An embedded cap needs an equivalent diameter, or plan dimensions to take it from. |
| CAP-012 | Error | The user HFD curve needs both k50 and an ultimate resistance above zero. |
| CAP-013 | Error | The HFD curve needs a maximum deflection above zero. |
| CAP-015 | Error | The embedded part of the cap has its top (… , … ) at or below its bottom (… , … ). |
| CAP-016 | Error | The springs along the embedded cap need 1 to … increments. |
| CAP-017 | Error | The pile cap thickness is zero or negative. |
| CAP-018 | Error | … |
| CAP-019 | Error | Cap restraints (… ) are not used. Prescribe a zero displacement in the load case instead, then clear them (Assign > Cap > Clear Legacy Cap Restraints). |
| CAP-020 | Error | … pile head(s) are neither at a node nor inside a plate of the flexible-cap mesh (… ); regenerate the mesh after moving piles. |
| CAP-021 | Error | Plate section … needs a positive modulus and thickness. |
| CAP-022 | Warning | Plate section … has Poisson's ratio … , above 0.5, the limit for an isotropic material; the plate is analysed with it, but check the value. |
| CAP-023 | Info | … pile head(s) lie inside a flexible-cap plate rather than at a node (… ); the pile is tied to the plate's four nodes through its shape functions. |
| CAP-024 | Error | Plate section … has Poisson's ratio … ; the plate's bending and shear stiffness need a ratio between -1 and 1, so the flexible cap cannot be analysed. |
| CAP-025 | Warning | No pile head of the flexible cap carries torsion and the cap has no beams: a moment about the vertical axis cannot be carried, and the cap rotations about it are not meaningful. Fix one pile head, or add cap beams. |
| CAP-026 | Warning | The cap is embedded, but a flexible cap is analysed without the passive soil resistance on its sides yet; the embedded-cap settings are not used. |

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| Code | Level | Message (… = name or value filled in) |
|---|---|---|
| CAP-027 | Error | The flexible cap has no stored mesh, and the one generated from its outline with an element size of … would have up to … plates; at most … are allowed. Use a larger element size in the cap section. |
| CAP-028 | Warning | The pile heads are at different elevations (… to … ); a flexible cap ignores the differences (a rigid cap uses them). Put the heads at one elevation, or use a rigid cap. |
| CAP-029 | Error | Flexible-cap beams use pile section(s) … , which the catalog does not define; the analysis stops at them. |
| CAP-030 | Error | The flexible cap has no stored mesh and its cap section '… ' is not in the catalog, so its plates cannot be generated. Assign a cap section (Assign > Cap > Cap Section).<br>The flexible cap has no stored mesh and its cap section '… ' names no material, so its plates cannot be generated. Choose a material in Define > Section Properties > Cap Sections. |
| CAP-031 | Error | … flexible-cap node(s) are not connected to any pile (first: node … ). |
| CAP-032 | Error | … flexible-cap plate(s) are not a convex four-sided shape: the nodes are out of order around the plate, a corner points inward or two corners coincide (first: element … ). Its stiffness would be wrong. |
| CAP-033 | Error | … flexible-cap beam(s) have no flexible length: the two nodes are at the same place in plan, or the end zones cover the whole beam (first: beam … ). |
| CAP-034 | Warning | The flexible-cap mesh keeps the thickness and material it was generated with from cap section '… ', which has changed since: the analysis uses the mesh values. Regenerate the mesh (Assign > Cap > Generate Flexible Cap Mesh) to apply the cap section.<br>The flexible-cap mesh no longer matches the element size (… ), cap outline, piles or loads: the analysis uses the stored mesh. Regenerate the mesh (Assign > Cap > Generate Flexible Cap Mesh) to apply them.<br>The flexible cap uses the plates stored with its imported mesh (thickness … ); cap section '… ' (thickness … ) is not used by the analysis. Regenerate the mesh (Assign > Cap > Generate Flexible Cap Mesh) to use the cap section. |
| CASE-001 | Warning | Load case '… ' contains no load pattern. |
| CASE-002 | Error | Load case '… ' refers to load pattern '… ', which does not exist. |
| CASE-003 | Error | Initial condition '… ' of load case '… ' does not exist. |
| CASE-004 | Error | Load case '… ' has an unreasonable tolerance or iteration count. |
| CASE-005 | Warning | The model has no load case. |
| CASE-006 | Error | Load case '… ': the minimum step is larger than the initial step, so the solver can never reduce it. |
| CASE-007 | Error | Load case '… ' asks for absolute cap criteria but leaves both the displacement and the rotation at zero. |
| CASE-008 | Warning | Load case '… ' is cyclic with … cycle(s); it is still analysed with the cyclic p-y curves… , not the static ones. Check the number of cycles. |
| CASE-009 | Error | Load case '… ' prints the full pile length with a printing increment below one. |
| CASE-010 | Warning | Load case '… ' prints the full length of every pile but has every output variable switched off, so the table along the piles is empty. |
| CASE-011 | Error | Pushover of load case '… ' holds every component constant, so nothing is pushed; untick at least one. |
| CASE-012 | Error | Pushover of load case '… ' needs at least one load factor. |
| CASE-013 | Warning | Pushover of load case '… ' asks for a logarithmic ramp from or to zero; the factors fall back to arithmetic. |
| CASE-014 | Warning | Load case '… ' carries pushover settings but its analysis type is … . |
| CASE-015 | Error | Load case '… ' asks for a foundation stiffness matrix but lists no load level. |
| CASE-016 | Warning | Load case '… ' opens the specified-displacement table but every degree of freedom is still force controlled. |
| CASE-017 | Warning | Load case '… ' prescribes zero displacement for … ; that is a restraint, not a load. |
| CASE-018 | Warning | Load case '… ' asks for BOTH a foundation stiffness matrix and a pushover analysis; a load case runs only one of them, so it is run as the foundation stiffness analysis with the pushover left out. |
| CASE-019 | Warning | Load case '… ' lists … foundation stiffness levels; … the Load Case dialog accepts at most 10, so editing this load case there requires removing some. |
| CASE-020 | Warning | Pushover of load case '… ' lists … load factors; … the Load Case dialog accepts at most 25, so editing this load case there requires removing some. |

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| Code | Level | Message (… = name or value filled in) |
|---|---|---|
| CASE-023 | Error | Load case '… ': the foundation stiffness target is the … , but the loads give no … at the cap origin, so no equivalent stiffness can be found. Load that direction or choose another target. |
| CASE-024 | Warning | Load case '… ' is Linear Static; the analysis has no linear option, so it is solved with the same nonlinear soil-pile analysis as every load case. |
| CASE-025 | Warning | Load case '… ' is Nonlinear Staged; the analysis has no staged option, so it is solved in one nonlinear analysis at full load (load steps: Incremental / Pushover). |
| CASE-026 | Warning | Load case '… ' is of type Pushover but its incremental analysis is not set up (Define > Load Cases > Pushover), so it is solved as one nonlinear analysis. |
| CASE-027 | Warning | Load case '… ' continues from '… '; every load case starts from zero, so the initial condition is not used. |
| CASE-028 | Warning | 'Use EI from the previous iteration' is not used by the analysis (load case(s) … ). |
| CASE-029 | Warning | The specified displacements of load case(s) … carry their own point of application, but an embedded or flexible cap is analysed about the cap reference point, where they are prescribed instead. |
| CASE-030 | Warning | Load case '… ' asks for a foundation stiffness matrix but lists no nonzero load level, so the matrix is not computed; only the load case itself is solved… . |
| CASE-031 | Warning | Pushover of load case '… ' has no nonzero load factor, so the pushover analysis is not run; only the load case itself is solved. |
| CASE-032 | Error | Load case(s) … prescribe displacements of the pile cap, but the cap is analysed as a flexible cap, which has no single displacement to prescribe, so Run stops for them. Enter the load as forces, or set the cap behaviour to Rigid. |
| CASE-033 | Warning | Load case(s) … ask for a pushover or foundation stiffness analysis, which is not available for a flexible cap yet; only the load case itself is solved. |
| CASE-034 | Warning | Load case '… ': … |
| CASE-035 | Error | Pushover of load case '… ' asks for … load steps; at most … are allowed. Lower the number of steps or list the load factors. |
| CASE-036 | Warning | Load case '… ' asks for … , which a flexible cap does not compute yet; only the load case is solved. |
| CAT-001 | Error | The name '… ' is used by … entries of the … catalog; every name must be unique, because the model refers to objects by name and only one of the entries would be used. Rename the extra ones in Define. |
| CHK-000 | Error | Check Model could not finish its … checks (… : … ). Correct the values reported here, or re-enter the … data. |
| COMB-001 | Error | Combination '… ' is empty. |
| COMB-002 | Error | Combination '… ' refers to '… ', which is neither a load case nor a combination. |
| COMB-003 | Error | Circular reference between combinations: … |
| COMB-004 | Warning | Combination '… ' of type … contains nonlinear load cases (… ). Superposition of results is not valid for a nonlinear analysis. |
| COMB-005 | Error | Combination '… ' (row … ) uses load case '… ', which prescribes cap displacements/loads; such a case cannot be combined. Remove it from the combination. |
| COMB-007 | Error | Combination '… ' of type … cannot be analysed: a combination is either re-analysed with its factored loads (Linear Add) or picks extremes (Envelope). Change its type or remove it from Analyze > Set Load Cases to Run. |
| COMB-008 | Error | Combination '… ' has an unreasonable tolerance or iteration count. |
| COMB-009 | Error | Combination '… ': the minimum step is larger than the initial step, so the solver can never reduce it. |
| COMB-010 | Error | Combination '… ' asks for absolute cap criteria but leaves both the displacement and the rotation at zero. |
| COMB-011 | Warning | Combination '… ' is cyclic with … cycle(s); it is still analysed with the cyclic p-y curves… , not the static ones. Check the number of cycles. |
| COMB-012 | Warning | Load case '… ' holds pile-cap … at zero displacement and so does every other case of combination '… ' (row … ); the combination keeps that restraint. |
| COMB-013 | Warning | Combination '… ' does not apply the p-multiplier sets named by its load cases (… ) to every pile: pile(s) … keep their own set from an older project and the other piles use … . |

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| Code | Level | Message (… = name or value filled in) |
|---|---|---|
| COMB-014 | Error | Combination '… ' keeps the pile-cap restraint (… ) of its load cases, but the cap is analysed as a flexible cap, which has no single displacement to hold, so Run stops for it. Set the cap behaviour to Rigid. |
| COMB-015 | Warning | Combination '… ' has a … resistance factor of … ; no … demand/capacity ratio is computed for it.<br>Combination '… ' has a … resistance factor of … , above 1.0; its demand/capacity ratios are computed against that factor times the capacity. |
| COMB-016 | Warning | Combination '… ' enters a negative … ; it is read as zero, which means not entered. |
| COMB-017 | Warning | Combination '… ': … |
| GEO-000 | Error | The model has no piles. |
| GEO-001 | Error | Pile … has zero or negative length. |
| GEO-002 | Error | Pile … has no direction. |
| GEO-003 | Warning | Pile … batter is … ° from vertical, beyond the usual limit of … °. |
| GEO-004 | Error | Pile … points upward. |
| GEO-005 | Error | Pile heads … and … coincide within the merge tolerance of … . |
| GEO-006 | Warning | Piles … and … intersect each other. The analysis treats each pile on its own; check the geometry if the crossing was not intended. |
| GEO-007 | Warning | Minimum spacing is … = … D, below … D. Group effects are significant; check the p-multipliers. |
| GEO-008 | Warning | All piles are vertical and in a single line. This group has no overturning resistance across that line; consider battered piles. |
| GEO-009 | Error | The model needs at least two piles. |
| GEO-011 | Error | Pile … starts on the axis of pile … (divided pile), so it would hang from the cap as a separate pile. Join them (Edit > Join); to vary the section, use Assign > Pile > Section along Length. |
| GEO-012 | Warning | The embedment / cut-off elevation of pile(s) … is not used: the analysis takes each pile over its whole length, from the head at the cap to the tip. |
| GEO-013 | Error | A coordinate of … is more than … from the origin, beyond any site. Check the coordinates and their units. |
| HEAD-001 | Error | … is negative (… ). |
| HEAD-002 | Warning | … has translational or torsional springs; the analysis connects a pile to the cap with two rotational springs only, so those springs are not used. |
| HEAD-003 | Warning | … is Free; a pile under a cap is never free, so it is analysed as Pinned.<br>… has a Free plane; a pile under a cap is never free, so that plane is analysed as Pinned. |
| HEAD-004 | Error | … is Specified Rotation, which the analysis does not support; use Fixed, Pinned or Elastic (Assign > Pile > Project Default Pile-Head Connection, or Assign > Pile > Head Connection for single piles). |
| LOAD-001 | Error | A joint load refers to load pattern '… ', which does not exist. |
| LOAD-002 | Error | A joint load refers to joint '… ', which does not exist. |
| LOAD-003 | Error | A distributed load refers to pile '… ', which does not exist. |
| LOAD-004 | Error | A distributed load has an inverted elevation range. |
| LOAD-005 | Error | A pile point load refers to pile '… ', which does not exist. |
| LOAD-006 | Warning | Soil movement '… ' has fewer than two depths, so it is not applied; a movement profile needs at least two depths. |
| LOAD-007 | Warning | Load case '… ' carries no load: its load patterns are empty. |
| LOAD-008 | Warning | A distributed load on cap plates exists, but the cap has no plate mesh; the load is not applied. |
| LOAD-009 | Warning | A distributed load on cap plates names plate set '… '; plate sets are not supported yet, so the load is not applied. |
| LOAD-010 | Error | A distributed load on cap plates covers plates … ..... , none of which exists (the mesh has … ). |
| LOAD-011 | Warning | A distributed load on cap beams exists, but the flexible-cap mesh has no beam; the load is not applied. |
| LOAD-012 | Warning | A distributed load on cap beams names beam set '… '; beam sets are not supported yet, so the load is not applied. |
| LOAD-013 | Error | A distributed load on cap beams covers beams … ..... , none of which exists (the mesh has … ). |

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| Code | Level | Message (… = name or value filled in) |
|---|---|---|
| LOAD-014 | Error | A point load on pile … has an elevation outside the pile. |
| LOAD-015 | Info | The self weight multiplier of load pattern(s) … adds nothing: cap section '… ' has no material with a weight per unit volume. |
| LOAD-016 | Error | A point load on pile … has an axial component, but the pile's axial response comes from … , which cannot carry an interior axial force. Remove the axial component or use the pile's generated curves. |
| LOAD-017 | Error | A … refers to load pattern '… ', which does not exist, so it is not applied. |
| LOAD-018 | Warning | Soil movement '… ' is not assigned to any existing pile, so it is not applied.<br>Soil movement '… ' lists pile(s) … , which do not exist; they are ignored. |
| LOAD-019 | Error | A distributed load on pile … lies outside the pile. |
| LOAD-020 | Warning | A distributed load on pile … extends beyond the pile; the part outside is not applied. |
| LOAD-021 | Error | A point load on pile … lies too close to the pile head for the analysis mesh (it would need … segments; at most 4,000). Apply it at the head as a joint load, or move it further down the pile. |
| MAT-001 | Warning | Material '… ': … = … MPa is outside … -… MPa for … . Check the units of the value. |
| NUM-001 | Error | … has no value. Enter a valid value.<br>… more values are not finite numbers. |
| OPT-001 | Info | … is off (Analyze > Set Analysis Options), so the values assigned to pile(s) … are kept but not used. |
| OPT-002 | Error | The source dimension of the model (… ) must be 2 or 3 (a project file value; it has no screen). |
| PM-001 | Error | p-multiplier set '… ' … but is not in the catalog. |
| PM-002 | Warning | Set '… ' row … : … p-multiplier … is greater than 1.0.<br>Set '… ' pile … : … -direction p-multiplier … is greater than 1.0.<br>Set '… ', table row s/D … : the p-multiplier of the … (… ) is greater than 1.0. |
| PM-003 | Error | Set '… ' row … : … p-multiplier is negative.<br>Set '… ', table row s/D … : the p-multiplier of the … is negative.<br>Set '… ' pile … : … -direction p-multiplier is negative. |
| PM-004 | Warning | Set '… ' uses method … but its table is empty; fill it from the reference or choose AASHTO. |
| PM-006 | Error | Set '… ' row … : … y-multiplier is zero or negative; it must be positive.<br>Set '… ' pile … : … -direction y-multiplier is zero or negative; it must be positive. |
| PM-007 | Error | … pile(s) are assigned p-multiplier set '… ', which is not in the catalog. |
| PM-008 | Warning | Some piles still carry their own p-multiplier set from an older project; it takes precedence over the group effect of the model, which applies to every pile, except that one analysis applies only one closely-spaced or per-pile set (see PM-010). |
| PM-009 | Info | Set '… ' measures s/b with the diameter of the first pile (… , … ), but the piles have … diameters, so the factors depend on the pile order. Tick 'Use the average diameter of each pile pair' to avoid it. |
| PM-010 | Warning | One analysis applies only one closely-spaced or per-pile set: … . In load cases without their own set, set '… ' (of the first such pile) is applied to all these piles. Keep one such set. |
| PM-011 | Warning | Set '… ' has no entry for row … of the … pile rows along its load direction (… deg): pile(s) … are analysed with a p-multiplier and a y-multiplier of 1.0. |
| PM-012 | Warning | Set '… ' has a table row whose spacing ratio s/D is zero or negative.<br>Set '… ' lists the same spacing ratio s/D in more than one table row; the factors jump at that ratio instead of changing gradually.<br>Set '… ' lists row … more than once; only the last entry of each row is used. |
| RED-001 | Error | Pile … has an axial load reduction factor of zero or less. |
| RED-002 | Warning | Pile … has an axial load reduction factor above 1.0, which increases the load instead. |
| RED-003 | Error | Pile … refers to lateral reduction set '… ', which is not in the catalog. |
| RED-004 | Warning | Lateral reduction set '… ' has fewer than two depths, so it is not applied; a reduction set needs at least two depths. |
| RED-005 | Error | Lateral reduction set '… ' repeats a depth. |
| RED-006 | Error | Lateral reduction set '… ' has … at depth … . |
| RUN-001 | Error | The run list contains '… ', which does not exist. |
| SEC-001 | Error | Pile … has no pile section assigned. |
| SEC-002 | Error | Pile section '… ' assigned to pile … is not in the catalog. |

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| Code | Level | Message (… = name or value filled in) |
|---|---|---|
| SEC-003 | Error | Pile section '… ' has no material. |
| SEC-004 | Error | Material '… ' used by pile section '… ' is not in the catalog. |
| SEC-005 | Warning | Pile … is divided into only … increments; 50 is a reasonable minimum. |
| SEC-006 | Error | A section segment on pile … has an inverted elevation range. |
| SEC-007 | Error | Section '… ': the area is zero or negative.…<br>Section '… ': the area is zero or negative. Enter the area in the section's dimensions.<br>Pile section '… ' has a zero or negative area. |
| SEC-008 | Error | Pile section '… ' is nonlinear but has no reinforcement material, so its moment-curvature would use a default strength that is nowhere on screen. |
| SEC-009 | Error | Pile section '… ': … |
| SEC-011 | Error | Section '… ': the torsional stiffness GJ is zero or negative.…<br>… the torsional stiffness GJ is zero or negative. |
| SEC-012 | Error | Section '… ': the modulus of elasticity is zero or negative.… |
| SEC-013 | Error | Section '… ': the moment of inertia … is zero or negative.<br>… the moment of inertia … is zero or negative. |
| SEC-014 | Error | Section '… ': the equivalent diameter is zero or negative.…<br>Section '… ': the equivalent diameter is zero or negative.<br>… the equivalent diameter is zero or negative. |
| SEC-015 | Error | Sections along pile … do not cover the whole pile: the first section must … . |
| SEC-016 | Error | Section '… ': moment-curvature curve … (axial thrust … ) must start at zero moment and zero curvature. |
| SEC-018 | Warning | Section '… ' is nonlinear and tapered (only elastic sections taper): it uses its head values over the whole pile, with axial and torsional stiffness from the gross section instead of the automatic values. To vary it: Assign > Pile > Section along Length. |
| SEC-019 | Warning | The material override of pile(s) … is not used: the analysis takes the material of each pile's section. |
| SEC-020 | Warning | Section '… ' has no axial thrust levels for its M-φ curves, so the analysis rebuilds the curve at every axial force (slow, may not converge). Enter them in Define > Section Properties > Pile Sections. |
| SEC-021 | Error | Pile section '… ': … Its moment-curvature cannot be computed, so the analysis does not run rather than fall back to the gross stiffness. |
| SEC-022 | Error | Section '… ' uses a specified moment capacity, but its capacity about axis … is zero or negative. Enter a positive moment capacity for both axes. |
| SEC-023 | Warning | Pile section '… ' uses … , an option the section dialog no longer offers. It was kept from the file and still changes the moment-curvature curve, but the dialog does not show it. |
| SEC-024 | Error | Pile section '… ': … |
| SEC-025 | Error | Pile section '… ': … |
| SEC-026 | Warning | Pile section '… ' is a … shape but its material '… ' is … ; choose a … material (Define > Section Properties > Pile Sections > Material). |
| SEC-027 | Error | Pile section '… ': … Choose one of the listed cores in Define > Section Properties > Pile Sections. |
| SEC-028 | Error | Pile … is divided into … increments; the analysis handles at most … (Assign > Pile > Segmentation accepts 10 to 200). |
| SEC-029 | Warning | A row of the sections along pile(s) … lies inside another row, between … : the nodes there are analysed with the last row that starts above them ('… '), not with the row that spans them. Make each row start where the previous one ends. |
| SEC-030 | Error | A row of the sections along pile(s) … overrides the modulus of elasticity with a negative value (… ). Enter a positive modulus, or leave it empty to use the material's modulus. |
| SEC-031 | Error | A row of the sections along pile(s) … names section '… ', which is not in the catalog. The analysis stops at that row; choose an existing pile section for it. |
| SEC-032 | Error | Pile section '… ' names '… ' as its … material, which is not in the Materials catalog, so its moment-curvature would use strengths that are not on screen. Choose an existing material in Define > Section Properties > Pile Sections. |
| SEC-033 | Error | Section '… ': no moment-curvature curve can be computed at axial load… (… ); the section cannot carry that load. Remove the axial load from the section's list of axial loads, or change the section. |

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| Code | Level | Message (… = name or value filled in) |
|---|---|---|
| SEC-034 | Error | Sections along pile(s) … : … . |
| SEC-035 | Warning | Pile … is divided into … increments, more than the 200 the Segmentation form accepts; the analysis uses all of them. |
| SET-001 | Error | The unit system '… ' of this model is not one this version knows, so the calculation rules of the file's unit family cannot be chosen. Choose a unit system in Preferences. |
| SET-002 | Warning | The moment sign convention '… ' in Preferences is not one this version knows, so the moment diagrams use 'Tension on right'. Choose a convention in Preferences. |
| SOIL-001 | Error | The model has no soil profile (Define > Soil > Soil Profile). |
| SOIL-002 | Error | Soil profile '… ' assigned to pile … is not in the catalog. |
| SOIL-003 | Error | Soil profile '… ' has no layers. |
| SOIL-004 | Error | The tip of pile … (… ) is below the bottom of soil profile '… ' (… ); extend the profile to the pile tip. |
| SOIL-005 | Error | Profile '… ' has a gap with no layer between elevation … and … . |
| SOIL-006 | Error | Layers '… ' and '… ' in profile '… ' overlap. |
| SOIL-007 | Error | Layer '… ' used by profile '… ' is not in the Soil Layers catalog. |
| SOIL-009 | Error | Layer '… ' in profile '… ' has an inverted elevation range. |
| SOIL-011 | Error | Scour depth of profile '… ' is negative. |
| SOIL-012 | Error | Scour of profile '… ' removes the entire soil profile.<br>The lowest point of the sloping ground of profile '… '… is below the bottom of the profile. |
| SOIL-013 | Error | Layer '… ': the … unit weight is zero or negative. |
| SOIL-014 | Warning | Layer '… ': saturated unit weight is less than the unsaturated value. |
| SOIL-015 | Error | Layer '… ' uses user-defined p-y curves, but pile(s) … have no p-y set (tick User-defined p-y curves in Analyze > Set Analysis Options, then Assign > Pile > p-y Set). |
| SOIL-016 | Error | Layer '… ': the uniaxial compressive strength of the weak rock is zero or negative. Enter a positive strength. |
| SOIL-017 | Error | Layer '… ': the friction angle of the cemented silt is zero or negative. Enter a positive friction angle. |
| SOIL-018 | Error | The … of pile … is above the top of the soil profile (… ); lower it to the profile or below. |
| SOIL-019 | Error | The tip of pile … (… ) is at or above … (… ); the pile must reach into the soil. |
| SOIL-020 | Error | Layer '… ': the friction angle of the API sand is zero or negative. Enter a positive friction angle. |
| SOIL-021 | Warning | Pile(s) … use soil profile '… ' instead of the project profile '… ' (kept from an older version) and are analysed with it. To vary the ground per pile, use Assign > Pile > Ground Surface Elevation. |
| SOIL-022 | Warning | Soil profile '… ' has no layer; pile(s) … take their lateral resistance from their user-defined p-y set. Without a layer there is no generated axial curve either, so check the axial load-displacement curve of those piles. |
| SOIL-030 | Error | Layer '… ' (loess): … '… ' asks for … cycles of loading, but the loess model covers 1 to 10 cycles. Set the number of cycles to 10 or fewer. |
| SOIL-031 | Error | Layer '… ' (massive rock): Ei and Em are both zero or negative. Enter the intact-rock modulus Ei (Em then follows from Ei and GSI) or the rock-mass modulus Em. |
| SOIL-032 | Warning | Layer '… ' (loess) has a zero or negative cone tip resistance qc, so it gives no lateral resistance.<br>Layer '… ' (massive rock) has a zero or negative uniaxial compressive strength, so it gives no lateral resistance.<br>Layer '… ' (liquefied sand hybrid): (N1)60cs below 5 gives a zero residual strength, so the layer gives no lateral resistance (enter the residual strength to use option 2). |
| SOIL-033 | Error | Layer '… ' (Piedmont residual) has no valid field test selected (SPT, CPT, dilatometer or pressuremeter). |
| SOIL-034 | Warning | The … of pile(s) … reaches … below elevation 0, but the pile tip is at … , so every load case stops at Run. Extend the curves to the pile tip (Define > Soil > User p-y Curves).<br>The … of pile(s) … holds a single curve; a set needs two curves to interpolate between, so every load case stops at Run. Add a second curve deeper than the pile tip (Define > Soil > User p-y Curves). |
| SOIL-035 | Warning | Pile(s) … : … Until then every load case stops at Run. |
| SOIL-036 | Error | The ground surface of soil profile '… '… (… ), used by pile(s) … , is above the top of its first layer (… ); raise the layer or lower the ground surface so that no part of the ground is without a layer. |

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| Code | Level | Message (… = name or value filled in) |
|---|---|---|
| SOIL-037 | Error | Layer '… ' (… ): … cannot be negative. |
| SOIL-038 | Error | Layer '… ' (… ): … , so the layer cannot be analysed. |
| SOIL-039 | Warning | Layer '… ' (… ): … ; the analysis uses the value as entered. |
| SOIL-040 | Error | Pile(s) … are assigned p-y set '… ', which is not in the catalog; without it they take the p-y curves of their soil layers instead (Assign > Pile > p-y Set). |
| SOIL-041 | Error | The sloping ground of profile '… ' has a value that is not a finite number.<br>The sloping ground of profile '… ': each point must be farther along than the one before it. |
| SOIL-042 | Warning | The sloping ground of profile '… ' has a single point and is not used; add a second point or choose Flat. |

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