Secant pile wall with tieback supports
(SI units)
A. Project description

In this example we will design a 9m deep excavation with a secant pile wall supported by two rows of tiebacks. Figure 1 presents the project model. Tables 1 and 2 present the soil properties and the stratigraphy respectively. Table 3 presents the external loads. Tables 4 and 5 present the wall and support properties respectively. The general ground elevation is at El. +0m and the ground water elevation is at El. -3m.

![Figure 1: Project model.](image)

<table>
<thead>
<tr>
<th>Soil Layer</th>
<th>Soil Type</th>
<th>Design parameter</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>φ' (deg)</td>
<td>C' (kPa)</td>
<td>γ (kN/m3)</td>
<td>γdry (kN/m3)</td>
</tr>
<tr>
<td>F</td>
<td>Fill</td>
<td>25</td>
<td>0</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td>S1</td>
<td>Sand</td>
<td>32</td>
<td>4</td>
<td>19.5</td>
<td>19.5</td>
</tr>
<tr>
<td>S2</td>
<td>Sand</td>
<td>34</td>
<td>10</td>
<td>21</td>
<td>21</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Soil Layer</th>
<th>Elevation (m)</th>
<th>OCR</th>
<th>Ko</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>-0</td>
<td>1</td>
<td>0.577</td>
</tr>
<tr>
<td>S1</td>
<td>-2</td>
<td>1</td>
<td>0.47</td>
</tr>
<tr>
<td>S2</td>
<td>-7</td>
<td>1</td>
<td>0.441</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Load</th>
<th>Load Type</th>
<th>Start Point</th>
<th>End Point</th>
<th>Load Magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load 1</td>
<td>Strip Surcharge</td>
<td>(-15.5,0)</td>
<td>(-0.5,0)</td>
<td>25 kPa</td>
</tr>
</tbody>
</table>
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### Table 4: Wall parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secant pile Diameter</td>
<td>0.6 m</td>
</tr>
<tr>
<td>Secant pile spacing</td>
<td>1 m</td>
</tr>
<tr>
<td>Wall depth</td>
<td>13 m</td>
</tr>
<tr>
<td>Steel pile section</td>
<td>HA 500A</td>
</tr>
<tr>
<td>Steel</td>
<td>Fe510</td>
</tr>
</tbody>
</table>

### Table 5: Support parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Tieback 1</th>
<th>Tieback 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tieback elevation on wall</td>
<td>-3 m</td>
<td>-6 m</td>
</tr>
<tr>
<td>Tieback spacing</td>
<td>3 m</td>
<td>3 m</td>
</tr>
<tr>
<td>Angle</td>
<td>20 deg</td>
<td>20 deg</td>
</tr>
<tr>
<td>Free length</td>
<td>7 m</td>
<td>7 m</td>
</tr>
<tr>
<td>Fixed length</td>
<td>11 m</td>
<td>11 m</td>
</tr>
<tr>
<td>Support section</td>
<td>4 Strands x 0.525in</td>
<td>4 Strands x 0.525in</td>
</tr>
</tbody>
</table>
B. Modeling with DeepEX

B1. Use of DeepEX

- **Soil properties:** The soil properties in DeepEX can be defined in the General tab of DeepEX software. By pressing the button ![Edit Soil Properties](image), the soil properties form appears (Figure 2). Here we can add, delete and modify available soils by changing their type, their general properties like unit weights, strength parameters and permeability, modify the elastoplastic parameters or the ultimate bond resistance for tiebacks. A soil can be used in a boring more than once. A number of estimation tools that help estimate values are available.

![Edit Soil Properties Dialog](image)

**Figure 2:** Edit soil properties dialog.
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**Borings (Soil layers):** The stratigraphy in DeepEX can be defined in the General tab of DeepEX software. By pressing the button ![Edit Boring](image), the soil layer dialog appears (Figure 3). In this dialog we can edit the borings available for use in the project. In each boring the user can add soil layers. To do this, we can type the new soil layer’s elevation, choose the soil type from the list of soil types and define the new layers OCR and Ko. In addition, by clicking on Edit button, we can modify the selected soil’s properties. The coordinates X and Y refer to the plan location of the boring and do not affect analysis results.

![Edit soil layers dialog.](image)

**Figure 3:** Edit soil layers dialog.
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- **Wall sections**: The wall sections in DeepEX can be defined in the General tab of DeepEX software.

  By pressing the button ![Edit Wall sections](image), the Edit wall properties dialog appears (Figure 4). Here we can choose the wall type and dimensions, choose the wall sections and edit the rebar options for concrete walls.

  ![Figure 4: Edit wall properties dialog.](image)

- **Walls**: By double-clicking on the wall in the model area of DeepEX, the Edit wall data dialog appears (Figure 5). Here we can define which wall section is used, the top of wall elevation, the wall height and the number of wall nodes for the limit equilibrium analysis.

  ![Figure 5: Wall data dialog](image)
- **Supports:** We can add supports in the model from the General tab of DeepEX. By selecting an option from the drop down menu, a support or other related support entities can be drawn on the model. The following options are available:

![Support options](image)

**Figure 6:** Support options.

After drawing the support on the model, the Edit support data dialog appears (i.e. for tieback supports, Figure 7).

![Edit support data dialog](image)

**Figure 7:** Edit support data dialog.
- **Loads:** We can add supports in the model from the General tab of DeepEX. The drop down menu contains tool buttons for adding external loads (surcharges) and some related surcharge options. The following options are available:

![Figure 8: Load options.](image)

After drawing the load on the model, the Edit surcharge dialog appears (i.e. for strip surcharges, Figure 9).

![Figure 9: Edit distributed load dialog.](image)
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- **Surface options:** We can modify the surface options in order to create inclined soil surfaces in the General tab of DeepEX. By clicking on the button, we can edit the surface options. These options are presented in the table below. In addition, we can change the elevation next to the wall.

![Surface Options](image)

**Figure 10: Surface options.**

- **Water elevation:** In this area we can define the water elevations next to the wall.

![Water Elevation](image)

**Figure 11: Water elevation – settings.**

- With the draw custom water surface tool, we can draw a non-horizontal groundwater table. To do this, select this option and then start clicking the left mouse button from left to right (press enter to complete). To delete the custom water line, move on top in the model and press delete.
- The draw a U line tool is used to draw a line of constant pore pressure in the model. This line is only used in slope stability analysis.
- The define user water pressures tool launches the dialog for defining custom values of water pressures next to the walls. Please note that in the non-linear engine, two consecutive zero values of water pressure still count in increasing the total vertical stress by $\gamma_w$ (see theory manual).
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- By clicking on the button \( \text{Button} \), the Ground water table dialog shows up.

![Ground Water Table](image1.png)

**Figure 12:** Ground water table.

In this dialog we can click on the option “Maintain at subgrade” so that the water elevation will follow in Elevation the excavation surface.

- **Structural code:** In the Design tab of DeepEX, we can define the structural code by pressing on the button \( \text{Code} \). Figure 13 below presents the available options. In this example we will use Eurocode 2 and 3 settings with a safety factor of 1.5.

![Design Codes](image2.png)

**Figure 13:** Design codes.
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B2. Example simulation

In DeepEX 2015 we can design our projects using construction stages. After the model is designed, the software calculates each construction stage, reassuring that the model is stable, since the last stage is not always the critical one. Next, we provide the steps in each construction stage, in order to simulate the project in DeepEX.

- **Stage 0 (Figure 14)**
  1. Define the soil properties
  2. Define the soil layers (stratigraphy)
  3. Define the wall section and wall properties
  4. Apply the load on the left side of the wall

![Figure 14: Model, Stage 0.](image)

- **Stage 1 (Figure 15)**
  1. Excavate on the right side of the wall to El. -3.5m.
In DeepEX we can design several design sections in the same model. We can add new design sections as new or as copies of the existing ones, doing several modifications in the model, or just defining different standards, calculation or analysis methods.

- **Stage 2 (Figure 16)**
  1. Install first tieback row at El. -3m.

- **Stage 3 (Figure 17)**
  1. Excavate on the right side of the wall to El. -6.5m.
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- **Stage 4 (Figure 18)**
  1. Install first tieback row at El. -6m.

  ![Figure 18: Model, Stage 4.](image)

- **Stage 5 (Figure 19)**
  1. Excavate on the right side of the wall to El. -9m.

  ![Figure 19: Model, Stage 5.](image)
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Next, we will define the general design and analysis options. In the Analysis tab of DeepEX we define to use wall friction as a percentage of the soil friction angle, defining a value of 50% (Figure 20).

![Figure 20: Wall friction.](image)

For the beam analysis for this example we will use the California Trenching and Shoring Manual 2011 (Figure 21), accepting all the proposed options and defining the CALTRANS parameters.

![Figure 21: Beam analysis method.](image)

Finally, we define the driving and resisting pressures methods. In this example, we will use Active pressures for the driving side for the first two stages, and for the other stages we will use FHWA Apparent pressures.
C. Analysis in DeepEX - Optimization

First, we will analyze this example with the Limit Equilibrium Analysis method, in order to calculate the supports Prestress and optimize the wall length. We select the analysis method in the Analysis tab of DeepEX (Figure 22). In the Design tab of DeepEX we click on the option “Optimize wall embedment for safety factors” (Figure 23).

Since the model is ready, we can choose to calculate the design section, pressing on the button .

After the analysis is succeeded, the Summary table appears. Table 6 below includes some critical checks and values for each construction stage. STR ratios on the wall are in essence load to design capacity stress checks. These values should be kept below one for a good design.

Table 6: DeepEX critical results/stage

<table>
<thead>
<tr>
<th>Stage</th>
<th>Calculation Result</th>
<th>Wall Displacement (cm)</th>
<th>Settle (cm)</th>
<th>Wall Moment (kN-m)</th>
<th>Wall Shear (kN)</th>
<th>Wall Shear (kN-m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage 0</td>
<td>Calculated</td>
<td>0</td>
<td>N/A</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Stage 2</td>
<td>Calculated</td>
<td>0.3</td>
<td>1.04</td>
<td>226.25</td>
<td>226.25</td>
<td>266.53</td>
</tr>
<tr>
<td>Stage 3</td>
<td>Calculated</td>
<td>0.1</td>
<td>1.15</td>
<td>74.79</td>
<td>74.79</td>
<td>59.83</td>
</tr>
<tr>
<td>Stage 4</td>
<td>Calculated</td>
<td>0.022</td>
<td>2.56</td>
<td>121.4</td>
<td>121.4</td>
<td>128.25</td>
</tr>
<tr>
<td>Stage 5</td>
<td>Calculated</td>
<td>0.14</td>
<td>2.14</td>
<td>81.63</td>
<td>81.63</td>
<td>85.84</td>
</tr>
<tr>
<td>Stage 5</td>
<td>Calculated</td>
<td>0.23</td>
<td>2.9</td>
<td>142.23</td>
<td>142.23</td>
<td>147.64</td>
</tr>
</tbody>
</table>
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After the optimization, the wall length is 42.35 ft. The optimization length though in this example is affected by the flange size since a driven steel beam is used. If the beam is changed, the optimized length would be approximately the same since the program uses an iterative optimization routine.

In the Limit-Equilibrium analysis, wall embedment safety factors of 1.3 to 1.5 or greater are typically required when the wall is braced. For cantilever walls, the wall embedment safety factor should generally be greater than 1.5 when the free earth method is used. The program computes three wall embedment safety factors, one on horizontal force balance for wall embedment (FSpas), one on rotational moments taken about the lowest support level (FSrot), and one based on the available wall embedment length (FSembed). FSembed is determined by first finding the most critical value from FSpas and FSrot and then describing the safety factor as the ratio of the available wall embedment by the required wall embedment for FS=1.0.

- **Tieback prestress**

By taking the mouse over the tieback supports, we can see the support reaction for each construction stage appearing right over the command line of DeepEX (Figure 24). By checking all stages, we see that the maximum tieback tension for each support is:

- 641 KN kips for Tieback 1, appearing in stage 5
- 627.2 KN for Tieback 2, appearing in stage 5

We usually desire to use a prestress for the tiebacks with a magnitude of 80% of the support tension (see above). In this example we will use a prestress magnitude of 400 KN for each tieback. The prestress is applied to each tieback ONLY in the tieback installation stage. To apply the prestress load, we double-click on the tieback in the installation stage (Figure 25).

![Figure 24: Tieback reaction.](image-url)
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Figure 25: Tieback Prestress.

- **Wall Embedment safety factors**

By clicking on the button [Wall Embed FS] in the Results tab of DeepEX, we can see the wall embedment safety factors (Figure 26).

![Wall Embedment Safety Factors](image)

Figure 26: Safety factors.

After we run the analysis again, we can see that the safety factor is increased to 1.518, which is acceptable.

- **Support checks**

By pressing the button [STR] in the results we can see the stress checks for each support at the current stage. The GEO ratio represents the geotechnical capacity stress ratio (for pulling out the tieback from the ground), while the STR ratio represents the structural stress check on the tieback steel. The stress checks can be seen in Figure 27. If the “ENV” button is selected, the critical stress checks from all stages will be displayed. As it can be seen, both supports are overstressed. Tieback 1 is the most critical.
• **Optimizing the excavation**

Once the analysis is completed, we can start optimizing the design using the optimization tools.

The button, will optimize the whole design section. After we press the button, the program offers us a choice of the 10 most efficient structural sections for the piles. Afterwards, the program optimizes the number of strands. The optimization can be performed only after the analysis is completed. Once the analysis is complete, we might need to confirm that the new stress checks are adequate, especially if a non-linear analysis is performed. After a section is optimized, we should always double check displacements to make sure that they are within tolerable limits.

During the optimization, some dialogs appear, where we should select from the available options. For the wall steel section we can select a section IPE A400 (Figure 28).
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Figure 28: Wall structural section optimization. The tieback section changed to 6-strand with \( \text{AS} = 6.42 \text{cm}^2 \) strand diameter (Figure 29). In addition, the tieback fixed lengths were modified.

Figure 29: Optimized parameters.
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After the calculation of the optimized model is completed, we are informed that the support ratio of the first tieback is 1.01. The model should need a second iteration. In addition, we can try to reduce the tieback spacing.

Non-linear Analysis

We can choose to add a second design section in the same model, by right-clicking on the “Base model” in the design sections area (Figure 30). In this design section, we choose to use Elastoplastic (non-linear) analysis, in the analysis tab of DeepEX.

The new design section can be linked to the base model, so that all changes in the base model will pass directly to the linked section. We can link the section by pressing on the button in the Analysis tab of DeepEX. In the dialog that appears we select the base design section. As well as, we choose the option “Do not link analysis type” in order to be able to run different analysis type in each design section (Figure 31).
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We choose to analyze all sections. Figures 32 to 35 present some graphical results from the results tab of DeepEX.

**Figure 32:** Wall moment diagram, Stage 3.

**Figure 33:** Wall shear diagram, Stage 5.

**Figure 34:** Wall deflection, Stage 4.
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**Figure 35:** Effective horizontal soil pressures, Stage 2.