DeepEX 2015 – Example: Diaphragm wall with tieback supports

Diaphragm wall with tieback supports
(SI units)

Deep Excavation LLC
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A. Project description

In this example we will design a diaphragm wall with 3 tieback rows, supporting a 12 m excavation. Figure 1 below 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 ground surface is at El. +0 m and the water table is at El. -16 m.

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

<table>
<thead>
<tr>
<th>Soil Layer</th>
<th>Soil Type</th>
<th>$\phi'$ (deg)</th>
<th>C'/Su (kPa)</th>
<th>$\gamma$ (KN/m3)</th>
<th>$\gamma_{dry}$ (KN/m3)</th>
<th>$E_{LOAD}$ (kPa)</th>
<th>$E_{RELOAD}$ (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>Fill</td>
<td>25</td>
<td>0</td>
<td>19</td>
<td>19</td>
<td>15000</td>
<td>45000</td>
</tr>
<tr>
<td>C</td>
<td>Clay</td>
<td>29</td>
<td>10</td>
<td>18</td>
<td>18</td>
<td>20000</td>
<td>60000</td>
</tr>
<tr>
<td>S2</td>
<td>Sand</td>
<td>34</td>
<td>0</td>
<td>20</td>
<td>20</td>
<td>30000</td>
<td>90000</td>
</tr>
</tbody>
</table>

Table 2: Stratigraphy.

<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>C</td>
<td>-2</td>
<td>1</td>
<td>0.515</td>
</tr>
<tr>
<td>S2</td>
<td>-9</td>
<td>1</td>
<td>0.441</td>
</tr>
</tbody>
</table>

Table 3: External loads.

<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>Diaphragm width</td>
<td>0.6 m</td>
</tr>
<tr>
<td>Concrete Fc</td>
<td>C20/25</td>
</tr>
<tr>
<td>Reinforcing steel grade</td>
<td>B450C</td>
</tr>
<tr>
<td>Long. reinforcement diameter</td>
<td>D25</td>
</tr>
<tr>
<td>Shear reinf. diameter</td>
<td>D10</td>
</tr>
</tbody>
</table>

**Table 5: Support parameters.**

<table>
<thead>
<tr>
<th>Tieback</th>
<th>Tieback elevation on wall</th>
<th>Tieback spacing</th>
<th>Angle</th>
<th>Free length</th>
<th>Fixed length</th>
<th>Support section</th>
<th>Prestress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tieback 1</td>
<td>-3 m</td>
<td>3 m</td>
<td>20 deg</td>
<td>7 m</td>
<td>12 m</td>
<td>4 Strands x 0.525in</td>
<td>320 kN</td>
</tr>
<tr>
<td>Tieback 2</td>
<td>-6 m</td>
<td>3 m</td>
<td>20 deg</td>
<td>7 m</td>
<td>12 m</td>
<td>4 Strands x 0.525in</td>
<td>320 kN</td>
</tr>
<tr>
<td>Tieback 3</td>
<td>-9 m</td>
<td>3 m</td>
<td>20 deg</td>
<td>7 m</td>
<td>12 m</td>
<td>4 Strands x 0.525in</td>
<td>320 kN</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 ``, 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.

![Figure 2: Edit soil properties dialog.](image)
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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.

![Figure 3: Edit soil layers dialog.](image)
Wall sections: The wall sections in DeepEX can be defined in the General tab of DeepEX software. By pressing the button , 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)
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- **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](image1)

**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](image2)

**Figure 7**: Edit support data dialog.
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- **Loads:** We can add loads 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 load can be drawn directly on the model. The following options are available:

![Load options](image)

*Figure 8: Load options.*

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

![Edit distributed load dialog](image)

*Figure 9: Edit distributed load dialog.*
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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 Figure 10 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 Settings](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 and drag to draw the line. Drawing the line starts 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, the Ground water table dialog shows up (Figure 12).

![Ground water table dialog](image)

**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. Figure 13 bellow presents the available options. In this example we will use Eurocode 2 and 3 settings with a safety factor of 1.5.

![Design codes](image)

**Figure 13:** Design codes.
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

\[\text{Figure 14: Model, Stage 0.}\]

- **Stage 1 (Figure 15)**
  1. Excavate on the right side of the wall to El. -3.5m.

\[\text{Figure 15: Model, Stage 1.}\]
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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.

![Figure 16: Model, Stage 2.](image1)

![Figure 17: Model, Stage 3.](image2)
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- Stage 4 (Figure 18)
  1. Install second tieback row at El. -6m.

- Stage 5 (Figure 19)
  1. Excavate on the right side of the wall to Elevation -9.5m.
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- **Stage 6 (Figure 20)**
  1. Install third tieback row at Elevation -9m.

![Figure 20: Model, Stage 6.](image)

- **Stage 7 (Figure 21)**
  1. Excavate on the right side of the wall to El. -12m.

![Figure 21: Model, Stage 7.](image)
C. Results in DeepEX

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

After the analysis is succeeded, the Summary table appears. Table 5 below includes some critical checks and values for each construction stage. Figures 22 to 25 present some graphical results from the results tab of DeepEX.

Table 6: DeepEX critical results/stage

<table>
<thead>
<tr>
<th>Calculation Result</th>
<th>Wall Displacement (cm)</th>
<th>Sattama (cm)</th>
<th>Wall Moment (kN.m)</th>
<th>Wall Moment (kN.m)</th>
<th>Wall Shear (kN)</th>
<th>Wall Shear (kN)</th>
<th>STR Comb Wall Ratio</th>
<th>STR Comb Wall Ratio</th>
<th>STR Comb Wall Ratio</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>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Stage 1</td>
<td>Calculated</td>
<td>0.77</td>
<td>0.26</td>
<td>122.25</td>
<td>5.03</td>
<td>5.03</td>
<td>0.08</td>
<td>0.08</td>
<td>0.08</td>
</tr>
<tr>
<td>Stage 2</td>
<td>Calculated</td>
<td>0.71</td>
<td>0.20</td>
<td>102.66</td>
<td>5.04</td>
<td>5.04</td>
<td>0.24</td>
<td>0.24</td>
<td>0.24</td>
</tr>
<tr>
<td>Stage 3</td>
<td>Calculated</td>
<td>0.87</td>
<td>0.61</td>
<td>86.89</td>
<td>6.97</td>
<td>6.97</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
</tr>
<tr>
<td>Stage 4</td>
<td>Calculated</td>
<td>0.89</td>
<td>0.52</td>
<td>85.08</td>
<td>6.05</td>
<td>6.05</td>
<td>0.15</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>Stage 5</td>
<td>Calculated</td>
<td>1.17</td>
<td>1.34</td>
<td>154.67</td>
<td>100.03</td>
<td>100.03</td>
<td>0.04</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>Stage 6</td>
<td>Calculated</td>
<td>1.21</td>
<td>1.33</td>
<td>145.67</td>
<td>85.59</td>
<td>85.59</td>
<td>0.34</td>
<td>0.34</td>
<td>0.34</td>
</tr>
<tr>
<td>Stage 7</td>
<td>Calculated</td>
<td>2.11</td>
<td>2.62</td>
<td>364.24</td>
<td>143.08</td>
<td>143.08</td>
<td>0.85</td>
<td>0.85</td>
<td>0.85</td>
</tr>
</tbody>
</table>

Figure 22: Wall moment diagram, Stage 3.
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**Figure 23:** Wall shear diagram, Stage 5.

**Figure 24:** Wall deflection, Stage 6.

**Figure 25:** Effective horizontal soil pressures, Stage 2.
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D. Optimization in DeepEX – Embedment safety factors – Prestress calculation

Optimization:
DeepEX 2015 offers useful optimization tools that can help user optimize the model really fast. The following options are available in the Optimize tab of DeepEX:

<table>
<thead>
<tr>
<th>Optimization tool</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALZ</td>
<td>Optimizes all design section items (wall sections – reinforcement, support sections, geotechnical optimization of ground anchors – autodesign fixed length)</td>
</tr>
<tr>
<td>STR</td>
<td>Structural optimization – autodesign of a support (support sections)</td>
</tr>
<tr>
<td>STR L</td>
<td>Structural optimization – autodesign of a wall (wall sections - reinforcement)</td>
</tr>
<tr>
<td>GEO</td>
<td>Geotechnical optimization of a ground anchor – autodesign of fixed length</td>
</tr>
</tbody>
</table>

In order to optimize a model or a specific item with the optimization tools of DeepEX, the model must be calculated. Either we select a tool from the toolbar in the Optimize tab of DeepEX and next we click on a specific item, or we choose to optimize all design section items. The software performs calculations and offers various options for structural sections to the user, also providing the stress check for each section.

Wall embedment safety factors:
By clicking on the button in the Results tab of DeepEX, we can see the wall embedment safety factors (Figure 26). 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. The wall length should be modified in order to achieve the required safety factors for each model.

![Figure 26: Safety factors.](image-url)
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**Prestress calculation:**
In DeepEX we can easily estimate the prestress magnitude of ground anchors (tiebacks). We should initially design the model and choose to analyze it with Limit Equilibrium method. 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 27). By checking all stages, we see that the maximum tieback tension for each support. We usually decide 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 100 kips 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 28).

**Figure 27: Tieback reaction.**

**Figure 28: Tieback Prestress.**