DeepEX 2014 – Circular Shaft

Deep Excavation LLC
Software program: DeepEX 2014
Document version: 1.0
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www.deepexcavation.com
A. Project description

In this example we will design a 12.53m deep circular shaft excavation formed by unreinforced secant piles. Tables 1 and 2 present the soil properties and the stratigraphy respectively. Table 3 presents the external loads. Table 4 presents the wall properties. The general ground elevation is 4.43 m and the general water elevation is 3 m. Figures 1 and 2 present a top view and an idealized section of the excavation.

### Table 1: Soil properties

<table>
<thead>
<tr>
<th>Name</th>
<th>Soil Type</th>
<th>Φ' (deg)</th>
<th>c' (kPa)</th>
<th>S_u (kPa)</th>
<th>V_t (KN/m³)</th>
<th>V_dry (KN/m³)</th>
<th>K_x (m/sec)</th>
<th>K_z (m/sec)</th>
<th>E_loc (kPa)</th>
<th>E_ur (kPa)</th>
<th>q_skin_u (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>Sand</td>
<td>30</td>
<td>0</td>
<td>-</td>
<td>20</td>
<td>19</td>
<td>0.0001</td>
<td>0.0001</td>
<td>15000</td>
<td>45000</td>
<td>49.7</td>
</tr>
</tbody>
</table>

A friction angle of Φ' = 30 deg is required for producing Ko = 0.5.

### Table 2: Stratigraphy (Boreholes)

<table>
<thead>
<tr>
<th>Soil Layer Name</th>
<th>Top Elevation (m)</th>
<th>OCR</th>
<th>Ko</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>4.43</td>
<td>1</td>
<td>0.5</td>
</tr>
</tbody>
</table>

### Table 3: External loads

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Position</th>
<th>(X₀, Z₀)</th>
<th>(X₁, Z₁)</th>
<th>Q₀ (kPa)</th>
<th>Q₁ (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Surcharge</td>
<td>On the ground</td>
<td>(0.6, 4.43)</td>
<td>(7.5, 4.43)</td>
<td>25</td>
<td>25</td>
</tr>
</tbody>
</table>

### Table 4: Wall properties

<table>
<thead>
<tr>
<th>Type</th>
<th>Secant pile wall (unreinforced concrete piles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>C16/20</td>
</tr>
<tr>
<td>Top Elevation (m)</td>
<td>4.43</td>
</tr>
<tr>
<td>Height (m)</td>
<td>13.53</td>
</tr>
<tr>
<td>Thickness (m)</td>
<td>0.6</td>
</tr>
<tr>
<td>Hor. Spacing (m)</td>
<td>1.08</td>
</tr>
<tr>
<td>N of rebars</td>
<td>0</td>
</tr>
</tbody>
</table>
B. Modeling with DeepEX

First, we define the general project parameters by following the next steps. These parameters should be modified in construction stage 0.

1. **General ground and water elevation:** The general ground and water table elevation in DeepEX can be defined in the General tab of DeepEX software. By pressing the button "Move Model Elev"., the actual elevations dialog appears (Figure 3). Here we can define the general ground elevation at 4.43 m. In addition, in the General tab of DeepEX 2014 we can choose to change the water elevation on the both sides of the wall at elevation 3 m (Figure 4).
2. **Soil properties:** The soil properties in DeepEX can be defined in the General tab of DeepEX software. By pressing the button ![Edit Soil Type Data](Image), the soil properties form appears (Figure 5). Here we can add, delete and modify available soils by changing their type, the general properties like unit weights, strength parameters and permeability, modify the elastoplastic parameters and modify the bond resistance for tiebacks. A soil can be used in a boring more than one time. A number of estimation tools that help the user estimate values are also included.

![Figure 5: Edit soil properties dialog.](Image)

3. **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 6). 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.
4. **Model Dimension / limits – circular shaft**: In DeepEX we can choose to move model dimensions and limits in order to create a nice view of the model. In the same dialog we can choose to create a circular shaft. By pressing on the button in the general tab, the model limits dialog appears (Figure 7). In this dialog we choose to have a circular shaft. Next, we set the right limit at 8 m and the left limit at -2.65 m (the radius of the circular shaft).

![Model limits dialog](image-url)
5. **Wall sections:** The wall sections can be defined in the General tab. By pressing the button, the Edit wall properties dialog appears (Figure 8). Here we can choose the wall type, dimensions, sections, and edit the rebar options for concrete walls. In this example we will use secant pile walls without reinforcement, with Width \( d = 0.6 \text{ m} \), and a horizontal spacing \( S = 1.084 \text{ m} \) and concrete material: C16/20. We can add new materials by pressing the button “Edit” at the structural materials area in this dialog. This causes the Structural Materials dialog to appear (Figure 9).

![Figure 8: Edit wall properties dialog.](image)

![Figure 9: Edit structural materials dialog.](image)
6. **Walls:** By double-clicking on the wall in the model area (within the main software), the Edit wall data dialog appears (Figure 10). Here we can define the wall section, the elevation of the top of the wall and the wall height. In this example, we set the top of the wall elevation at 4.43 m and the wall depth at 13.53 m. The xWall coordinate is set to 0 (this point is on the left side of the wall). By setting the left model limit at -2.63 m in step 4 above, we created a circular shaft with a radius of 2.63 m. Here we can modify the shaft radius if we wish so (always starting from the left model limit). In this example we will use xWall = 0, as the internal radius of the model is 2.63 m.

![Figure 10: Wall data dialog.](image)

DeepEX requires that an excavation is modelled by including all construction stages. After the model is designed, the software calculates each construction stage, examines if the model is stable, and evaluates all construction stages, since the last stage may not always be the most critical. In DeepEX we can easily choose to “Add Stage” from the General tab. Next, we provide the steps in each construction stage, in order to simulate the project in DeepEX.

- **Stage 0 (Figure 11)**
  1. Define general ground and water elevations
  2. Define the soil properties
  3. Define the soil layers (stratigraphy)
  4. Define model limits and project type (circular shaft)
  5. Define the wall section and wall properties
• **Stage 1 (Figure 12)**
  1. Excavate on the left side of the wall to Elevation -8.1.
  2. Change the water elevation on the left side of the wall at Elevation -9.1. These parameters can be modified in the General tab of DeepEX.

In the first 2 stages (Stage 0 and Stage 1) we will use a simplified flow for the water analysis. We can add a new stage in the model and choose to use hydrostatic water pressures (Figure 14).

• **Stage 2 (Figure 16)**
  1. We choose to use hydrostatic water pressures from the Analysis tab of DeepEX (Figure 13). Please note that this change should be applied ONLY in this stage in the current example.
  2. We add the strip surcharge on the left side of the wall. 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. Figure 14 below presents the available options. After drawing the load on the model, the Edit surcharge dialog appears (Figure 15).
  3. We change the water table on the left side of the wall at elevation -8.1, and on the right side of the wall at elevation 4.43.
Figure 13: Use hydrostatic pressures and choose to seal excavation in Stage 2.

Figure 14: Load options.
DeepEX provides us the option to seal excavation. We can select this option from the analysis tab of DeepEX (see Figure 13 above). In this case, we should add a field surcharge on the bottom of the excavation on the right side of the wall in order to keep the sealing in place because of the vertical water pressures. The magnitude of this field surcharge should be:

\[ q = H \times dw \times FS \]

- \( q \) = the field surcharge magnitude
- \( H \) = the excavation depth (below the water surface), \( H = 12.53 \) m
- \( dw \) = the water strength, \( dw = 10 \) kPa
- \( FS \) = safety factor, \( FS = 1.1 \)

So, \( q = 137.83 \) kPa.

In order to use this option, we add a new stage to the model.

**Figure 15:** Edit distributed load dialog.

**Figure 16:** Model, Stage 2.
• **Stage 3 (Figure 17)**

1. Select option to seal excavation.
2. Add a strip field surcharge on the left side of the wall with a magnitude of $q=137.83$ kPa.  
   Note: The option “Treat as field surcharge should be checked in the “Edit distributed load” dialog that appears since we draw the load.

![Figure 17: Model, Stage 3.](image)

Next, we have to define the general analysis mode as follows:

In the Analysis tab of DeepEX we choose to perform a Beam on elastoplastic foundations (Non-linear) analysis (Figure 18). This type of analysis should be used in circular shaft calculations.

![Figure 18: Analysis mode.](image)

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. We can also easily rename the design sections. To do so, we have to right-click on the design section name in the design sections area on the left side of DeepEX interface (Figure 19).

In this example, we will rename this section to “Service” because we will not assign any additional code safety factors or multipliers in this section. Next, we choose to “Add as new design section”.

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This example will be analyzed according to Eurocode 7 – Design approach 1. This will cause a multiplier of 1.35 to be applied on the water and soil loads and a multiplier of 1.5 to be applied on the live loads, according to the design recommendations. On the new design section that is created as a copy of the previous one, we visit the Analysis tab of DeepEX. Here, by pressing in the arrow next to the button “Single”, we choose to use the EUR 2007-DA1/1 load case (Figure 20). In addition, we can edit the design sections name. We will rename this design section to EC7: DA1.

DeepEX provides the ability to have linked design sections. In our example this is useful, because keeping them linked allows us to perform changes only at the first DS: Service, and these changes automatically pass to the linked DS: EC7: DA1. We can choose to link DS: EC7: DA1 with DS: Service at the Analysis tab of DeepEX (Figure 21). Note: the action should take place when we are at DS: EC7: DA1.
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C. Results in DeepEX

Since the model is ready, we can choose to calculate the design sections, pressing on the button ![All design sections](image).

After the analysis is succeeded, the Summary table appears, with critical results for each design section and each construction stage. Figures 22 to 25 present some graphical results from the results tab of DeepEX.

**Figure 22:** Hoop force diagram (Stage 2, DS: Service and DS: EC7: DA1 respectively).

**Figure 23:** Combined wall check ratio, DS: EC7: DA1, Stage 3.
Figure 24: Effective horizontal soil pressures, DS: EC7: DA1, Stages 1 and 3 respectively.

Figure 25: Water pressures, DS: EC7: DA1, Stage 2.