Application of the ground anchor facility in Plaxis 3D Foundation

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Introduction
The ground anchor in Plaxis 3D Foundation consists of two different parts. The first part represents the free anchor length and the second part the grout body. The free length is modelled as a node-to-node anchor, which represents the connection between the grout body and e.g. a diaphragm wall, and the grout body consists of embedded beam elements, which are line elements with a special interface to model the grout-soil interaction. For the definition of the ground anchor eight input values are required (Fig. 1).

The soil-interaction is defined with the two separate values for skin resistance along the grout body. Thus it is possible to define a constant, linear or trapezoidal distribution of skin resistance. The maximum interaction force between the soil and the grout body is directly applied in the “interface” of the embedded beam.

It is pointed out that this represents the skin resistance at failure (i.e. when the pull out force is reached) and that the skin traction distribution below full mobilisation is influenced by the specified limiting distribution. In reality mobilisation will start at the top of the grout body and only close to the pull out force (failure) the skin traction at the bottom should be mobilised. In the embedded pile the mobilisation follows the predefined shape from the beginning (also at the bottom). However, tests have shown that this does not have a noticeable influence on the global behaviour of an anchored structure under working load conditions.

Another important point is, that for forces close to the theoretical pull out force numerical failure may occur due to plasticity in the soil adjacent to the grout body. Although this is of course possible in reality, in the model it may be artificial and caused by the fact that the grout body is a line element. To overcome this problem in ultimate limit state conditions it is necessary to work with an enlarged diameter of the grout body. This virtual diameter of the grout body is defined as follows:

$$D_{\text{virtual}} = f \times D_{\text{real}}$$

In this equation f is the factor for the enlargement, and a value of f in the range of 2 – 4 is suggested. This does not affect the pull out force (this is an input due the input of the limiting skin resistance and the length of the grout body) and has minor effect on the behaviour under working load conditions. It follows, and the user must be aware of this, that when using this option in Plaxis 3D Foundation the maximum pull out force is an INPUT and cannot be OBTAINED from the analysis.

Deep excavation with prestressed ground anchors
In order to demonstrate the application of the ground anchors in Plaxis 3D Foundation, some results from a practical example, namely a deep excavation in Berlin sand, are presented. This example was chosen for testing the ground anchor facility under working load conditions because a 2D reference solution was available. The model dimensions and material sets for the soil layers have been taken from the 2D reference solution (Fig. 2).

The diaphragm wall has been modelled as a continuum element (Fig. 3), with linear elastic material behaviour and a stiffness $E_{\text{ref}}=3.0 \times 10^7$ kN/m. The hydraulic cut off does not act as a structural element, the properties are the same as for the soil (sand 20 – 40m).
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Continuation

To obtain the current porewater distribution inside the excavation the porewater pressure was defined after each groundwater lowering (with user defined pore pressure distribution). The ground anchors have different spacing and prestress forces in the different layers and therefore the anchor rods have different properties. The properties of the ground anchors are the same in all rows (Table 1).

<table>
<thead>
<tr>
<th>Properties of the nodeshield anchor:</th>
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</tr>
</thead>
<tbody>
<tr>
<td>anchor row 1</td>
<td>anchor row 2</td>
<td>anchor row 3</td>
<td></td>
</tr>
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<td>stresses (kN/m²)</td>
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<td>prestress force (kN)</td>
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</tr>
<tr>
<td>spacing (m)</td>
<td>spacing (m)</td>
<td>spacing (m)</td>
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</tr>
<tr>
<td>2,30m</td>
<td>1,35m</td>
<td>1,35m</td>
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Table 1: Ground anchor properties

Aim of the test was to see if the embedded pile model (employed for the grout body) works well in working load conditions and therefore the skin resistance in the grout body has been defined about two times the expected axial load in the node-to-node anchor. In the different calculations the material model, the shape of the limiting skin resistance and the enlargement of the grout body have been varied (Table 2).

<table>
<thead>
<tr>
<th>Properties of the grout body</th>
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<td>grout body</td>
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Table 2. Soil parameters for the HS-model

Table 3. Soil parameters for the MC-model

Table 4. Variations in the different calculations

In calculation 5 the stiffness of the grout body has been changed according to the ratio of the real diameter (0.125m) to the fictitious enlarged diameter (0.125*f=0.5m).

Results

It follows from Figure 4 that neither the variation of the predefined limiting skin resistance of the grout body nor the f-factor for the enlargement of the grout diameter have a significant influence on the axial forces predicted under working load conditions. However the distribution of the mobilised skin traction along the grout body is not what one would expect in reality (Fig. 5). If the Mohr Coulomb model is employed the results are slightly different (Fig 6).

Figure 4: Axial forces in the first anchor row (calculation 1, 2, 3, 4, 5)

Figure 5: Mobilised skin friction and axial force – first anchor row (after excavation, calculation 1)

With respect to the horizontal displacements there is a trend that wall deflection with a linear predefined shape of the skin friction is slightly higher than the one with constant skin traction distribution. It is also notable that by increasing the f-factors for the virtual grout body diameter displacements in horizontal direction become smaller. The differences are in the order of 10%. With the MC-Model the highest deformations in horizontal direction are located around the grout body (Fig. 7), whereas with the HS-Model this is not the case. This effect also occurs with the assignment of a high f-factor. The settlements behind the diaphragm wall are in the range of 11mm (almost the same for the different variations) with the HS model, but with the MC model there is a heave of more than 14mm, an effect which is well known.
Conclusions

A deep excavation supported by a diaphragm wall and three rows of anchors has been analysed utilizing Plaxis 3D Foundation with the ground anchor option. The results from the 3D calculation with the HS-model compare well to the 2D reference solution (both with respect to anchor forces and displacements) and as a consequence from the parametric study it can be concluded that it is not necessary to artificially increase the diameter of the grout body for working load conditions.

Concerning the distribution of the skin friction along the grout body, it is obvious that the mobilisation is not realistic. The reason is, that also at working load conditions the distribution of the skin friction is strongly influenced by the distribution in the failure state, which is an input. Due to the fact that the limiting skin friction is an input the grout body length has no or minor influence on the result and therefore the length cannot be determined from the analysis.

Compared to the HS-model, the MC-model predicts significantly larger deformations around the grout body. The virtual enlargement of the grout body diameter (f-factor) does not change the results significantly for working load conditions.

However for ultimate limit state calculations the f-factor becomes important, because in these calculations a premature failure (i.e. a failure below the theoretical pull out force) may occur when f=1.0. To overcome this problem it is essential to work with a virtual grout body enlargement.

It follows from this study that the ground anchor concept in Plaxis 3D Foundation is efficient for working load conditions, but for ultimate limit state analysis assumptions such as the f-factor, mesh coarseness and stiffness parameters of the soil (adjacent to the grout body) may have a significant influence on the result. It is emphasized again the maximum pull out force is an input to the analysis and not a result.