Question 1

For a cantilever pile wall shown in Figure 1, assess the performance of the system and answer the following questions.

i. Estimate the net resulting horizontal thrust by using Rankine’s Earth Pressure Theory and limit equilibrium method using Slide software.

ii. Estimate the minimum depth \( d \) to achieve a FS=1.5 against a global rotational failure.

iii. Now model the problem by using RocScience RS2 software. Complete the excavation in 3 sets of 2m excavation stages. Assume a socket depth of 9m. Draw the axial force, shear and moment diagrams for each excavation stages. Similarly draw horizontal & vertical displacement profiles.

iv. Check if 16 Φ20 reinforcement with concrete cover of 7.5 cm is suitable to resist the estimated maximum moments.

v. Check if Φ16/ 20 cm spiral reinforcement fulfills the shear demand.

vi. After the completion of the design, a piezometer was installed at 13 m depth which recorded pore water pressure of 100 kPa. Discuss how this data may change your assessment.
Question 1.1

Estimate the net resulting horizontal thrust by using Rankine’s Earth Pressure Theory and limit equilibrium method using Slide software.

If we were to calculate the net resulting horizontal thrust by using Rankine’s Earth Pressure Theory:

$$K_a = \frac{1 - \sin \phi'}{1 + \sin \phi'} = \frac{1 - \sin(27)}{1 + \sin(27)} = 0.376$$

Tension crack, $$z_0 = 2c' \sqrt{K_a / K_{u_{wet}}} = \frac{2 \times 5 \times \sqrt{0.376}}{0.376 \times 18.5} = 0.88 \text{m}$$

$$p_a = 0.376 \times 18.5 \times (6 - 0.88) - 2 \times 5 \times \sqrt{0.376} = 29.48 \text{ kN/m}$$

$$P_x = \frac{29.48 \times (6 - 0.88)}{2} = 75.47 \text{ kN/m}$$

In order to estimate the net resulting horizontal thrust by using Slide software, back analysis is performed. For this analysis, Janbu Simplified limit equilibrium method is used.

[Image: Figure 2 - Back Analysis Result in Slide Software]
Net Resulting Horizontal Thrust (Using Slide Back Analysis) = 68.8822kN/m

**Question 1.2**

- Estimate the minimum depth \( d \) to achieve a FS=1.5 against a global rotational failure.

To estimate the minimum depth \( d \) to achieve the described criteria, free-earth method for cantilever walls is used [3]. Calculations are made using the following Excel tables. At the end, you will get a third degree equation which is composed on moment equilibrium to the lower part of socket part, point O. in excel, by trial and error once you write the forces and moments arms in a correct way according to unknown \( X \) (socket depth in the silty sand layer), it takes very short to achieve \( D_0 \)

Estimated \( d_0 \) is checked in order to achieve moment equilibrium at Point O.

Disturbing moments:

\[
111 \times 0.375 \times 6 \times 0.5 \times (2 + 5 + X) = 874.125 + 124.875X \\
111 \times 0.390 \times 5 \times (2.5 + X) = 541.125 + 216.45X \\
(158.5-111) \times 0.390 \times 5 \times 0.5 \times ((5/3) + X) = 77.187 + 46.31X \\
158.5 \times 0.237 \times X \times (X/2) = 18.782 X^2 \\
[(158.5+10X)-158.5] \times 0.237 \times X \times 0.5 \times (X/3) = 0.395 X^3
\]

Resisting Moments

\[
47.5 \times 3.56 \times 5 \times 0.5 \times ((5/3) + X) = 704.58 + 422.75X \\
47.5 \times 4.20 \times X \times (X/2) = 99.75 X^2 \\
[(47.5+10X)-47.5] \times 4.20 \times X \times 0.5 \times (X/3) = 7 X^3
\]

Where \( X \) is the amount of penetrated depth in silty sand layer.

At the equilibrium, net moment should be zero. Therefore equation becomes ➔

Assignment 4: The Performance of a Cantilever Pile Wall with RocScience RS2 Software
6.605 \times 10^3 + 80.97 \times 10^2 + 35.12 \times 10 - 787.86 = 0 \Rightarrow X = 2.65 \text{ m (in silty sand layer)}

It means a total of \(d = 5+\frac{2.65}{10} = 7.65\) m penetration depth needed to satisfy moment eq.

In free-end method, calculated \(d\) is increased %20, then checked if corresponding \(R\) value (horizontal forces difference above point \(O\) – moment equilibrium point) is smaller than those net passive resistance which is obtained from this increased %20 portion of socket length.

Active force on wall above \(O\) = 124.87 + 216.45 + 46.31 + 99.55 + 8.32 = 495.5 Kn/m
Passive force on wall above \(O\) = 422.75 + 528.66 + 147.47 = 1098.88 Kn/m

By using the force equilibrium, \(R\) is estimated as 1098.88 - 495.5 = 603.38 Kn/m
\(D_{\text{final}} = 1.2 \times 7.65 = 9.20\) m

At point \(O\), vertical stress on passive side below point \(O\) = 158.5 + 2.65 \times 10 = 185 Kpa
At tip of socket, vertical stress on active side below point \(O\) = 47.5 + 2.65 \times 10 = 74 Kpa

At tip of socket, vertical stress on passive side below point \(O\) = 158.5 + 4.2 \times 10 = 200.5 Kpa
At tip of socket, vertical stress on active side below point \(O\) = 47.5 + 4.2 \times 10 = 89.5 Kpa

Extra resistance due to %20 increase =
\[(185+200.5) \times 4.20 \times 0.5 \times (9.2-7.65) - (74+89.5) \times 0.237 \times 0.5 \times (9.2-7.65) = 1224.7\, \text{Kn/m}\]

\[
FS = \frac{\text{extra resistance due to } 20\%}{R} = \frac{1224.7}{603.38} = 2.02
\]

It is calculated above that a 9.2-7.65=1.55m increase in the depth \(d_0\) would result in an approximately \(FS = 2.02\). It means even a smaller increment would satisfy \(FS=1.5\)

To find the optimum value, iterative solution may be applied.

\(d_0 = 9.2\) m but can be smaller for a global rotational failure with \(FS=1.5\)

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Question 1.3

➢ Now model the problem by using RocScience RS2 software. Complete the excavation in 3 sets of 2m excavation stages. Assume a socket depth of 9m. Draw the axial force, shear and moment diagrams for each excavation stages. Similarly draw horizontal & vertical displacement profiles.

For this question, the cantilever pile wall is modelled in RS2 software using the following properties:

<table>
<thead>
<tr>
<th>Liner Name</th>
<th>Color</th>
<th>Type</th>
<th>Young's Modulus (kPa)</th>
<th>Poisson's Ratio</th>
<th>Material Type</th>
<th>Peak Compressive Strength (kPa)</th>
<th>Res. Compressive Strength (kPa)</th>
<th>Peak Tensile Strength (kPa)</th>
<th>Res. Tensile Strength (kPa)</th>
<th>Thickness (m)</th>
<th>Unit Weight (kN/m3)</th>
<th>Beam Element Formulation</th>
<th>Stage Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liner 1</td>
<td></td>
<td>Standard Beam</td>
<td>3e+007</td>
<td>0.2</td>
<td>Elastic</td>
<td>35000</td>
<td>5000</td>
<td>5000</td>
<td>0</td>
<td>0.8</td>
<td>20</td>
<td>Timoshenko</td>
<td>No</td>
</tr>
</tbody>
</table>

Model geometry and the generated mesh for the question;
Moreover,

- The model is staged in 4 stages. First one being without any excavation and the following three stages being 2m excavation stages.

- The cantilever pile wall model used is an elastic standard beam that has no reinforcement in. This has no non-neglectable effect over the force/shear/moment diagrams, but it should effect the horizontal & vertical displacement profiles.

- For the definition of soil material, effective Poisson ratio (v) is used.

Moment/Shear/Axial Force diagrams and Vertical & Horizontal Displacement profiles for each stage is as follows;

**Stage 1**

- Horizontal Displacement
  - Maximum Value 0.002973m
  - Minimum Value -0.002925m

- Vertical Displacement
  - Maximum Value 0m
  - Minimum Value -0.0084674m

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Stage 2

- Horizontal Displacement
  - Maximum Value 0.0081512m
  - Minimum Value -0.0030820m

- Vertical Displacement
  - Maximum Value 0.0450910m
  - Minimum Value -0.0040839m
Stage 3

- Horizontal Displacement
  - Maximum Value 0.0244610m
  - Minimum Value -0.0012434m

- Vertical Displacement
  - Maximum Value 0.0727060m
  - Minimum Value -0.0054501m
Assignment 4: The Performance of a Cantilever Pile Wall with RocScience RS2 Software
The following questions will be analysed using the maximum values obtained from all four stages of this analysis.
Question 1.4

- Check if 16 Φ20 reinforcement with concrete cover of 7.5 cm is suitable to resist the estimated maximum moments.

For the analysis of the reinforced concrete cantilever pile wall, the pile wall is modelled as a column for this question. In the analysis, methods described in A. Topçu’s textbook “Reinforced Concrete”[1] and U. Ersoy’s charts[2] for cylindrical columns are used.

Estimated concrete & reinforcement specifications are:
- Concrete: C30/37 – $f_{cd} = 20\text{MPa}$
- Reinforcement: B420C – $f_{yd} = 365.22\text{MPa}$

The chart used for this analysis,

![Figure 3 - Chart 8-53][2]

Assignment 4: The Performance of a Cantilever Pile Wall with RocScience RS2 Software
Design Moment \( M_d = 319.872 \text{ kNm} \)
\( \text{Design Axial Force} = 64 \text{ kN} \)

Area of Concrete = \( \frac{800^2 \pi}{4} = 502654.8246 \text{ mm}^2 \)

\[
\frac{d}{h} = \frac{65}{80} = 0.8125 \Rightarrow \text{Chart 8-53 is selected.}
\]

\[
\frac{N_d}{A_f cd} = \frac{64000}{502654.8246 \cdot 20} = 0.0064 \quad \frac{M_d}{A_f h cd} = \frac{319.872 \times 10^6}{502654.8246 \times 800 \times 20} = 0.04
\]

\[
\rho m = 0.08 \rightarrow \text{Read from the Chart 8-53} \quad \rho \times \frac{f_{yd}}{f_{cd}} = \rho \times \frac{365.22}{20} = 0.08 \Rightarrow \rho = 0.0044
\]

\[
A_{st} = 0.0044 \times 502654.8246 = 2202.091 \text{ mm}^2 \rightarrow \text{Required reinforcement area}
\]

\[
16\phi 20 \rightarrow A_{st} = 5026.55 \text{ mm}^2 \geq 2202.091 \text{ mm}^2 \rightarrow \text{Checked.}
\]

\[
0.01 \leq \rho = \frac{5026.55}{502654.8246} = 0.01 \leq 0.04 \rightarrow \text{Checked}
\]

**Reinforcement is suitable to resist the estimated maximum moments.**
Question 1.5

- Check if Φ16/20 cm spiral reinforcement fulfills the shear demand.

For the analysis of the spiral reinforcement a beam model is used in order to check the fulfilment of the shear demand. A. Topçu’s textbook “Reinforced Concrete” [1] is used for this analysis also.

- Design Shear Force = 150.2 kN
- Design Axial Force = 228.22 kN

Area of Concrete = \( \frac{800^2 \pi}{4} = 502654.8246 \text{mm}^2 \)

Max. Shear Force = \( V_{\text{max}} = 0.22 \times f_{cd} \times A_c = 0.22 \times 20 \times 502654.8246 = 2211.681 \text{kN} \)

Critical Shear Force = \( V_{cr} = 0.65 \times f_{cd} \times A_c \times (1+ \left( \frac{\gamma = -0.3 \times N_d}{A_c} \right)) = 361.245 \text{kN} \)

\( V_d \leq V_{cr} \leq V_{\text{max}} \rightarrow \) Shear demand can single-handedly fulfilled by concrete cross-section only.

**If the shear demand can single-handedly fulfilled by concrete only, then it is safe to say that Φ16/20 cm spiral reinforcement would also fulfil the shear demand.**
Question 1.6

- After the completion of the design, a piezometer was installed at 13 m depth which recorded pore water pressure of 100 kPa. Discuss how this data may change your assessment.

Normally, the expected pore water pressure at 13m depth is around 80 kPa. This could be seen in the figure below.

If the pore pressure is 100kPa at that depth, this would indicate a 25% increase in pore pressure at that depth. This would approximately mean a 25% increase in the axial, shear forces and moments for the cantilever pile wall. According to the calculations in 1.5 and 1.4 structurally, pile wall would still fulfil those extra forces. That being said, with the increase in the pore water pressure, excavation behind the wall could be subjected to base heave but boiling or seepage into the excavation is not expected due to cohesive soil both under and around the excavation.

References