1. For the construction of underground **Metro Railway**, a **14 m deep** and **10 m wide** opening with braced excavation system as shown in **Fig. 1** is proposed in cohesive soil strata. The excavation is proposed to be made with **500 mm thick** diaphragm walls with struts located at **2.5 m, 6.5 m** and **10.5 m** below ground level.

![Fig. 1](image-url)

The subsoil condition is given below,

<table>
<thead>
<tr>
<th>Depth</th>
<th>Description</th>
<th>Soil parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 4 m</td>
<td>Brownish gray silty clay</td>
<td>$\gamma = 1.8 \text{ t/m}^3$, $c_u = 4 \text{ t/m}^2$</td>
</tr>
<tr>
<td>4 – 11 m</td>
<td>Soft gray organic silty clay</td>
<td>$\gamma = 1.7 \text{ t/m}^3$, $c_u = 2.5 \text{ t/m}^2$</td>
</tr>
<tr>
<td>11 – 16 m</td>
<td>Bush gray silty clay</td>
<td>$\gamma = 1.9 \text{ t/m}^3$, $c_u = 6 \text{ t/m}^2$</td>
</tr>
<tr>
<td>16 – 25 m</td>
<td>Brown silty clay</td>
<td>$\gamma = 1.9 \text{ t/m}^3$, $c_u = 8 \text{ t/m}^2$</td>
</tr>
<tr>
<td>&gt; 25 m</td>
<td>Dense sand</td>
<td>$\gamma = 2.0 \text{ t/m}^3$, $N &gt; 40$</td>
</tr>
</tbody>
</table>

(Ground water table is **4 m** below ground level)

(a) Calculate the factor of safety of the braced cut against bottom heave in a stratified cohesive soil as detailed above.
(b) Design the suitable depth of penetration for the diaphragm wall.

(c) Check and comment whether adequate factor of safety against clay bursting is available or not. If not, what measures one can adopt to prevent clay bursting?

(d) Draw the apparent earth pressure diagram on the wall and estimate the maximum loads on each strut. Assume that struts are placed @ 3 m c/c longitudinally.

(e) Determine the maximum bending moment on the diaphragm wall.

(f) Determine the maximum bending moment on the inbuilt wales/runner beam.

(g) Estimate the maximum ground displacement and the extent of ground displacement due to above braced excavation.

********* END *********
Let $D_p = 4.5 \text{ m}$

$$D = (85 - 14 - 4.5) = 6.5 \text{ m}$$

$$\frac{B}{\sqrt{2}} = 7.07 \text{ m}$$

$\Rightarrow D_i = \text{Smaller of } D \text{ and } \frac{B}{\sqrt{2}} = 6.5 \text{ m}$

$$F_S = \frac{C_u A N_c + \gamma D_p + \frac{\delta_c u H}{D_i}}{\gamma (H + D_p)}$$

$$= \frac{8 \times 6 + (1.9 \times 5.5) + \left[ \frac{(4 \times 4) + (1 \times 2.5) + (3 \times 6)}{5.5} \right]}{(1.8 \times 4 + 1.7 \times 7 + 1.9 \times 5 + 2.5 \times 1.9)}$$

$$= 1.86 < 2$$

Let $D_p = 5.5 \text{ m}$

$$D = (85 - 14 - 5.5) = 5.5 \text{ m}$$

$$\frac{B}{\sqrt{2}} = 7.07 \text{ m}$$

$\Rightarrow D_i = 5.5 \text{ m}$

$$F_S = \frac{8 \times 6 + (1.9 \times 5.5) + \left[ \frac{(4 \times 4) + (1 \times 2.5) + (3 \times 6)}{5.5} \right]}{(1.8 \times 4 + 1.7 \times 7 + 1.9 \times 5 + 2.5 \times 1.9)}$$

$$= 1.92$$
Let \( D_f = 6.5 \text{ m} \)

\[
D = 4.5 \text{ m}
\]

\[
\therefore D_1 = 4.5 \text{ m}
\]

\[
F_S = \frac{(8 \times 6) + (1.9 \times 6.5) + \left[ \left( \frac{4 \times 4}{} + (7 \times 2.5) + (3 \times 6) \right) \right]}{4.5 + 5.9 + 1.9 \times 4.5} = 1.93 < 2
\]

Let \( F_0.8 = 2 \)

\[
2 = 48 + (1.9 \times D_f) + \left[ \frac{16 + 11.5 + 18}{11 - D_f} \right]
\]

\[
(1.2 + 11.9 + 3.5 + 1.9 \times D_f)
\]

\[
2(52.6 + 1.9 \times D_f) = 528 - 48D_f + 20.9D_f - 19D_f^2 + 515
\]

\[
\frac{11 - D_f}{11 - D_f}
\]

\[
(1.9D_f^2 - 11.7D_f - 49.1) = 0
\]

\[
\therefore D_f = 9.04 \text{ m}
\]

Taking \( D_f = 9.1 \text{ m} \)

\[
F_S = \frac{48 + (1.9 \times 9.1) + 27.11}{45.89} = 2.03 > 2
\]

Hence Safe.
(c) **P.S.**

Clay crushing

\[ \frac{\gamma_{th} + 3\gamma_{w}h}{B} \]

\[ = \frac{9.1 \times 1.9 + \frac{2 \times 8 \times 9.1}{10}}{17 \times 19.1} \]

\[ = 1.67 > 1.3 \quad \text{(Safe)} \]

(d) Clay is soft to medium \((S_n > 4)\)

\[ P_a = \gamma_{th} \left[ 1 - m \frac{\Delta c}{\gamma_{th}} \right] \]

\[ = \gamma_{th} - 4 \Delta c \]

\[ = \frac{(4 \times 1.8 + 7 \times 17 + 3 \times 19)}{17} \]

\[ = 24.8 - (4 \times 3.68) \]

\[ = 10.08 \approx 10.1 \text{ kPa} \]
\( \Sigma M_B = 0 \)

\[ R_A x 4 = \frac{1}{2} \times 10.1 \times 3.5 \times 3 \times (3 + \frac{2.5}{3}) + 3 \times 10.1 \times 3 \frac{2}{3} \times 2 \]

\[ 4R_A = 357.29 \]

\[ R_A = 89.32 \text{ kN} \]

\( \Sigma H = 0 \)

\[ R_A + R_B = \left( \frac{1}{2} \times 10.1 \times 3.5 \times 3 \right) + (3 \times 10.1 \times 3) \]

\[ R_B = 54.6 \text{ kN} \]

\( \Sigma M_B = 0 \)

\[ R_C x 4 = 10.1 \times 7.5 \times 3 \times 7.5 \frac{2}{3} \]

\[ R_C = 213.0 \text{ kN} \]

\( \Sigma H = 0 \)

\[ R_B + R_C = 10.1 \times 7.5 \times 3 \]

\[ R_B = 227.25 - 213 = 14.25 \text{ kN} \]

\[ R_A = 89.32 \text{ kN} \]

\[ R_B = 54.6 + 14.25 = 68.85 \text{ kN} \]

\[ R_C = 213 \text{ kN} \]
(c) Maximum moment in diaphragm wall = \( \frac{pA^2}{10} \)

\[ = \frac{10.1 \times (4)^2}{10} \]

\[ = 16.16 \text{ kN.m/m length} \]

(d) Maximum moment in wall

At A, \( M_{\text{max}} = \frac{PA \times S^2}{8} \)

\[ = \frac{89.32 \times 3}{8} \]

\[ = 33.5 \text{ kN.m/m} \]

B, \( M_{\text{max}} = \frac{68.95 \times 3}{8} \)

\[ = 25.82 \text{ kN.m/m} \]

C, \( M_{\text{max}} = \frac{213 \times 3}{8} \)

\[ = 79.9 \text{ kN.m/m} \]

(e) According to Mara and Clough (1989) graph, it, range of variation of \( \frac{h_{\text{max}}}{H} \)

with F.O.S against basal shear

For F.O.S = 0.03

\[ \frac{h_{\text{max}}}{H} = 0.2 \% \]

\[ \therefore h_{\text{max}} = \frac{0.2}{100} \times 14 = 0.028 \text{ m} \]

\[ \sigma_{\text{max}} = 0.5 \times h_{\text{max}} \]

\[ = 0.014 \times 14 = 0.038 \text{ m} \]

According to Peck 1969,

for \( \sigma_{\text{max}} = 0.2 \% \), \( \frac{h}{H} \)

\[ \text{Dist. from base wall} = 2.1 \text{ to 4} \]

\[ \text{Dist. from base wall} = 0.1 \times 14 = 2.4 \text{ m} \]