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.

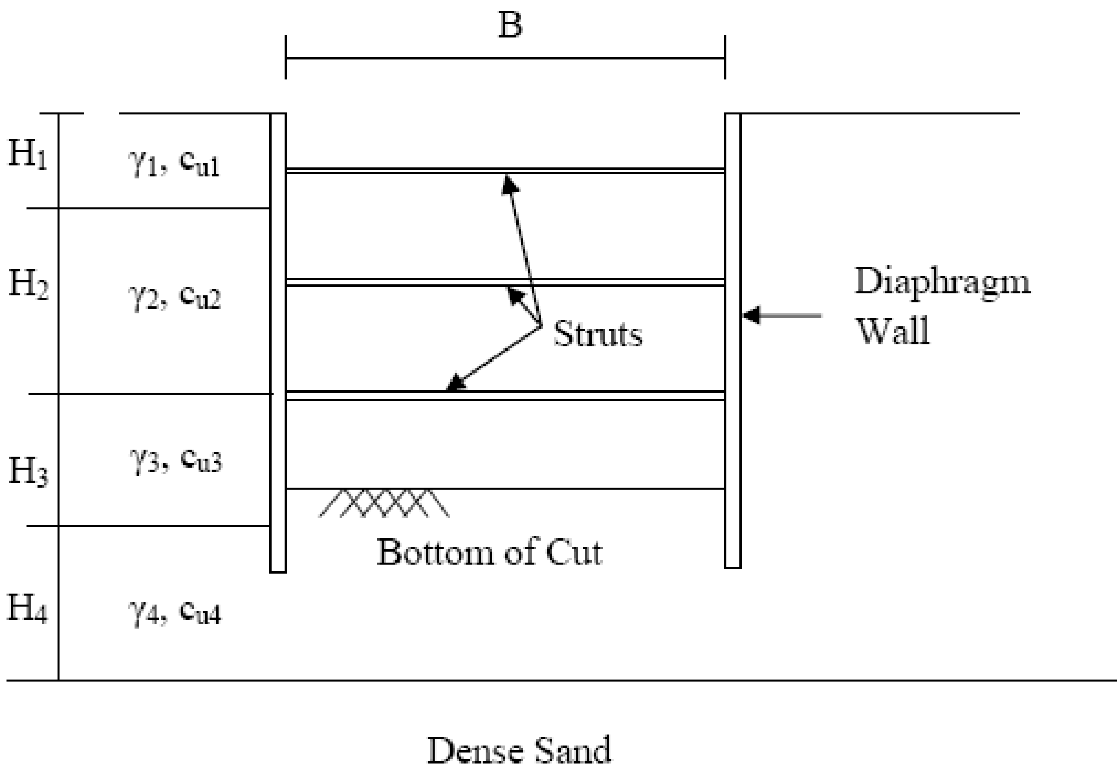


Fig. 1

The subsoil condition is given below,

Depth	Description	Soil parameter
0 – 4 m	**Brownish gray silty clay**	γ **= 1.8 t/m^3, c$_u$ = 4 t/m^2**
4 – 11 m	**Soft gray organic silty clay**	γ **= 1.7 t/m^3, c$_u$ = 2.5 t/m^2**
11 – 16 m	**Buish gray silty clay**	γ **= 1.9 t/m^3, c$_u$ = 6 t/m^2**
16 – 25 m	**Brown silty clay**	γ **= 1.9 t/m^3, c$_u$ = 8 t/m^2**
> 25 m	**Dense sand**	γ **= 2.0 t/m^3, N > 40**

(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 ********

Ans (a) Let $D_f = 4.5\,m$

$$D = (25 - 14 - 4.5) = 6.5\,m$$

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

$\Rightarrow D_1$ = Smaller of D and $\frac{B}{\sqrt{2}}$ = 6.5 m

$$F.S = \frac{C_{u4} N_c + \gamma D_f + \frac{\Sigma C_u H}{D_1}}{\gamma (H + D_f)}$$

$$= \frac{8 \times 6 + (1.9 \times 4.5) + \left[\frac{(4\times 4) + (7 \times 2.5) + (3 \times 6)}{6.5}\right]}{(1.8\times 4 + 1.7\times 7 + 1.9\times 5 + 2.5\times 1.9)}$$

$\Rightarrow 1.86 < 2$

Let $D_f = 5.5\,m$

$$D = (25 - 14 - 5.5) = 5.5\,m$$

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

$\therefore D_1 = 5.5\,m$

$$FS = \frac{8 \times 6 + (1.9 \times 5.5) + \left[\frac{(4\times 4) + (7\times 2.5) + (3\times 6)}{5.5}\right]}{(1.8\times 4 + 1.7\times 7 + 1.9\times 5 + 1.9\times 3.5)}$$

$= 1.92$

Let $D_f = 6.5\,m$

$D = 4.5\,m$

$\therefore D_1 = 4.5\,m$

$$FS = \frac{(8\times6) + (1.9\times6.5) + \left[\frac{(4\times4) + (7\times2.5) + (3\times6)}{4.5}\right]}{(1.8\times4 + 1.7\times7 + 1.9\times5 + 1.9\times4.5)} = 1.93 < 2$$

(b) Let F.O.S = 2

$$\therefore 2 = \frac{48 + (1.9\times D_f) + \left[\frac{16 + 17.5 + 18}{11 - D_f}\right]}{(7.2 + 11.9 + 9.5 + 1.9 D_f)}$$

$$\therefore 2(28.6 + 1.9 D_f) = \frac{528 - 48 D_f + 20.9 D_f - 1.9 D_f^2 + 515}{11 - D_f}$$

(or) $1.9 D_f^2 - 11.7 D_f - 49.7 = 0$

$\therefore$ $\boxed{D_f = 9.04\,m}$

Taking $D_f = 9.1\,m$

$$\therefore F.S = \frac{48 + (1.9\times9.1) + 27.11}{45.89} = 2.03 > 2$$

Hence safe.

(c) $F.S._{\text{Clay bursting}} = \dfrac{\gamma H_1 + \dfrac{2 c_u H_1}{B}}{\gamma_w h}$

$= \dfrac{9.1 \times 1.9 + \dfrac{2 \times 8 \times 9.1}{10}}{1 \times 19.1}$

$= 1.67 > 1.3$ (Safe)

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

$P_a = K \gamma H$

$= \left[1 - m \dfrac{4c}{\gamma H}\right] \times \gamma H$

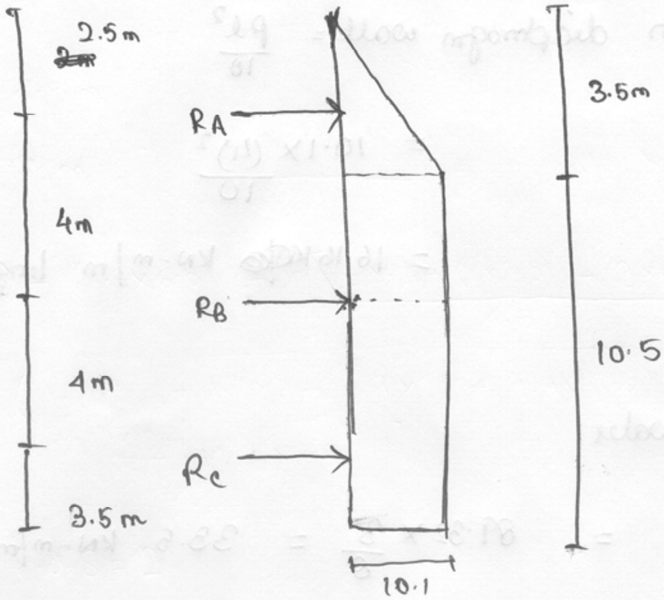
$= \gamma H - 4mC$

$= \dfrac{(4 \times 1.8 + 7 \times 1.7 + 3 \times 1.9)}{14} \times 14 \quad - \quad 4 \times 1 \times \dfrac{(4 \times 4 + 7 \times 2.5 + 3 \times 6)}{14}$

$= 24.8 - (4 \times 3.68)$

$= 10.08 \approx 10.1$ kPa

d)



$\sum M_B = 0$

$R_A \times 4 = \frac{1}{2} \times 10.1 \times 3.5 \times 3 \times \left(3 + \frac{3.5}{3}\right) + 3 \times 10.1 \times \frac{3}{2} \times 3$

$4R_A = 357.29$

$R_A = 89.32$ kN

$\sum H = 0$

$R_A + R_{B_1} = \left(\frac{1}{2} \times 10.1 \times 3.5 \times 3\right) + (3 \times 10.1 \times 3)$

$R_{B_1} = 54.6$ kN

$\sum M_B = 0$

$\therefore R_C \times 4 = 10.1 \times 7.5 \times 3 \times \frac{7.5}{2}$

$\therefore R_C = 213.0$ kN

$\sum H = 0$

$\therefore R_{B_2} + R_C = 10.1 \times 7.5 \times 3$

$R_{B_2} = 227.25 - 213 = 14.25$ kN

$\Rightarrow R_A = 89.32$ kN

$R_B = 54.6 + 14.25 = 68.85$ kN

$R_C = 213$ kN

(e) Maximum moment in diaphragm wall $= \frac{Pl^2}{10}$

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

$= 16.16$ kN-m/m length

(f) Maximum moment in wales

At A, $M_{max} = \frac{R_A S^2}{8} = 89.32 \times \frac{3}{8} = 33.5$ kN-m/m

B, $M_{max} = 68.85 \times \frac{3}{8} = 25.82$ kN-m/m

C, $M_{max} = 213 \times \frac{3}{8} = 79.9$ kN-m/m

(g) According to Mana and Clough (1981) graph. i.e, range of variation of $\frac{\delta_{H max}}{H}$ with F.O.S against basal heave

For F.OS = 2.03

$\frac{\delta_{H max}}{H} = 0.2\%$

$\therefore \delta_{H max} = \frac{0.2}{100} \times 14 = 0.028\,m$

$\delta_{v max} = 0.5\,\sigma_{h max}$ (to) $1.0\,\sigma_{h max}$

$= 0.014$ (to) $0.028\,m$

According to Peck 1969,

for $\frac{\delta_{v max}}{H} = 0.2\%$

$\frac{\text{Dist. from braced wall}}{H} = 2.1$ to 4

$\therefore$ Dist. from braced wall $= 0.1 \times 14 = 29.4\,m$