Standard Penetration Test

- used to determine insitu properties of soil
- specially suited for cohesionless soil.
- Borehole dia ৫৫ - 100 mm
- Hammer ৬৫ kg
- Drop height ৩ inch
- Total drive 18 inch → 6", 6", 6"
  ↳ 1st one neglected

Refusal:

1. A total of 50 blows during one of the three 6"
2. If more than 100 blows required (১৫" drive করতে total 100 blow এর বেশি লাগলে)
3. If no advance of sampler during application of 10 successive blows

   For automated system, advance less than 0.1 in/blow is considered refusal.

4. If a sampler cannot be driven 6 in due to handpan or very dense soil, it is written as blows/number of inches.

Factors affecting variation of SPT-N at a given depth of similar soil profiles:

1. hammer efficiency
2. borehole diameter
3. sampling method
4. Drill rod Length
5. Water table
6. Overburden pressure

Two types of hammer: 1. donut hammer
2. Safety hammer

SPT is conducted at every 1.5 depth or at the change of stratum.

Standardization of SPT value:

1. Correction for field procedure:

$$N_{60} = \frac{E_H C_B C_R C_S N}{0.60}$$

E_H = Hammer Efficiency (0.5 for BD)

C_B = Borehole diameter correction

C_R = Drill rod correction

C_S = Sampler correction

N = SPT at field

N_{60} = Correct SPT

2. Correction for overburden pressure:

$$C_N = 0.77 \log \frac{2000}{\sigma_o'}$$

$\sigma_o' > 0.25$ KN/m²

σ_o' = effective overburden pressure at depth of SPT

$$C_N = \sqrt{\frac{1}{\sigma_o'}}$$

σ_o' ⟶ tsf or kg/cm²

KN/m² ⟶ 98.1 divide ⟶ kg/cm²

Maximum value 2

C_N → Correction factor

Corrected SPT-N value

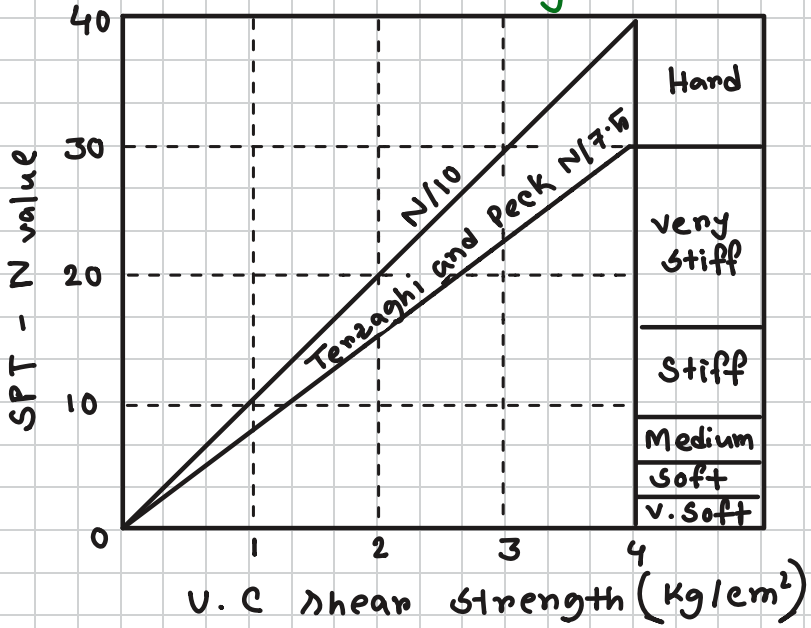
$$(N_1)_{60} = C_N \times N_{60}$$

Relation between SPT-N and angle of internal friction ϕ

$$\phi^\circ = 27 + 0.3N_{60} + 0.00054N_{60}^2$$ → More Accurate

$$\phi^\circ = \sqrt{N_{60}} + 15$$

SPT value and consistency of Cohesive soil



Relation between SPT and Unconfined compression Strength:

$q_u = 12.5\, N_{60}$ $PI \leq 30$

$q_u = 10\, N_{60}$ $PI > 30$

$q_u = 12.5\, N_{60}$

$q_u = 10\, N_{60}$

For Bangladesh.

$q_u = 14.3N$ $(LL \leq 35)$

$q_u = 16.9\, N$ $(35 \leq LL \leq 50)$

$q_u = 17.8\, N$ $(LL > 50)$

$q_u = 14.3N$

$q_u = 16.9\, N$

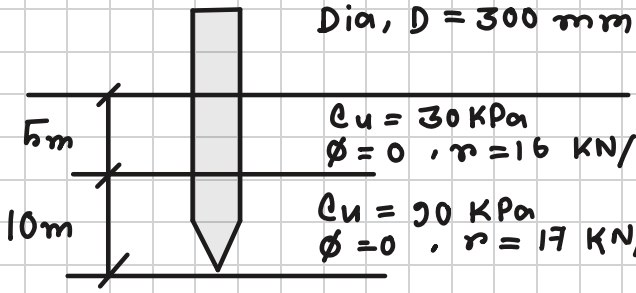
$q_u = 17.8\, N$

Bearing capacity of pile foundation:

$$q_{ult} = cN_c + \tfrac{1}{2} B\gamma N_\gamma + qN_q$$

$q = \gamma D_f$

$C_u = 20\ KPa \longrightarrow \alpha = 0.90$
$C_u = 100\ KPa \longrightarrow \alpha = 0.45$



$A_s = \pi d h$
$f_s = \alpha C_u$

$$Q_s = A_s f_s = A_{s1} f_{s1} + A_{s2} f_{s2}$$
$$= (\pi \times 0.3 \times 5) \times (0.85 \times 30) + (\pi \times 0.3 \times 10) \times (0.5 \times 90)$$
$$= 544.2$$

$$Q_b = A_b f_b = \left(\frac{\pi \times 0.3^2}{4}\right)(9 \times 120) = 76.3\ KN$$

$$Q_{ult} = 544.2 + 76.3 = 620.5\ KN$$

$f_s = \tau = \sigma \tan\phi + c$

$f_s = \sigma \tan\phi$

$f_s = \beta \times \sigma_v$ ⟶ cohesionless soil

→ Angle of wall friction

$\beta = \beta \times \sigma_v$

$\beta = K \tan\delta$

Math

Question 4

a. A 16 m thick layer of stiff clay overlies a deep dense sand. Series of standard penetration tests were undertaken and the clay stratum showed an average N-value of 21. From the tests on dense sand, the N-value at the interface has been interpolated as 48. A bored pile of 500 mm diameter is to be constructed down through the clay and just resting on to dense sand layer. Taking a factor of safety of 3, determine the allowable load that the pile can carry. 15

$\bar{N} = 21$ $N = 48$ $d = 500\ mm = 0.5\ m$ $FS = 3$

	End bearing (f_b)	Skin friction (f_s)
Sand	400N	$2\bar{N}$
Silt	300N	$2.67\ \bar{N}$
Clay	45N	$5\bar{N}$

$f_{s_{bore}} = \frac{1}{3} 5\bar{N} = \frac{1}{3} \times 5 \times 21 = 35\ KN/m^2$

$f_{b_{bore}} = \frac{1}{2} 400N = \frac{1}{2} 400 \times 48 = 9600\ KN/m^2$

$A_s = \pi DL = \pi \times 0.5 \times 16 = 25.12\ m^2$

$A_b = \frac{\pi}{4} D^2 = \frac{\pi}{4} \times 0.5^2 = 0.196\ m^2$

$\therefore Q_s = A_s f_s = 25.12 \times 35 = 879.2\ KN$

$\therefore Q_b = A_b f_b = 9600 \times 0.196 = 1881.6\ KN$

$\therefore Q_{ult} = Q_s + Q_b = 879.2 + 1881.6 = 2760.8\ KN$

$\therefore Q_a = \frac{Q_{ult}}{SF} = \frac{2760.8}{3} = 920.27\ KN$

b. A structure weighing 20000 KN is to be carried by a piled foundation. The soil profile indicates that the top 8 m is cohesive soil with C_u of 60 kPa ($\alpha = 0.70$). The bottom layer is stiff clay with C_u = 100 kPa ($\alpha = 0.45$) that extends to a great depth. Check whether nine 16 m long piles, as shown in Figure 1 can carry this load safely. The piles are to be placed 3 diameter apart, forming a 3.5 m square group. Assume a factor of safety of 3.0.

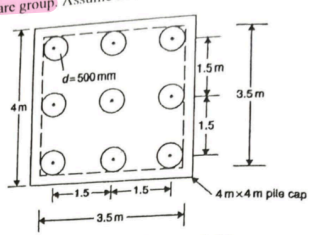
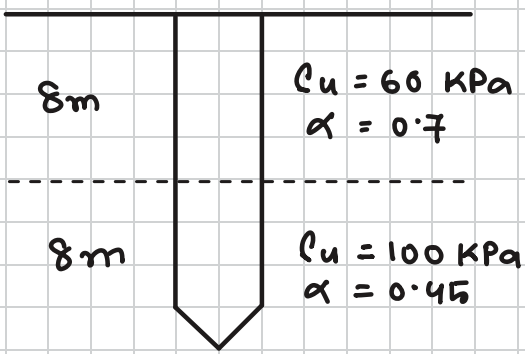


Figure 1 for Question 3 (b)



$Q_s = A_{s1} f_{s1} + A_{s2} f_{s2}$

$= 2(3.5 + 3.5) \times 8 \times 0.7 \times 60 + 2(3.5 + 3.5) \times 8 \times 0.45 \times 100$

$= 9744\ KN$

$Q_b = A_b \times f_b$

$= 3.5^2 \times 9 \times 100 = 11025\ KN/m^2$

$Q_{ult} = 9744 + 11025 = 20769\ KN$

$Q_a = \frac{20769}{3} = 6923\ KN$

$\therefore$ 9 piles can cannot carry the load of 2000 KN

b. A group of nine driven friction piles, 15m long and 400 mm in diameter is to be arranged in a square pattern in cohesive soil with an average unconfined compressive strength of 150 kN/m³. Work out 15

the spacing of piles for a group efficiency of 1.0. Neglect bearing at the tip of the piles. Assume block failure and an adhesion factor $\alpha = 0.60$.

$L = 15m \quad D = 0.4m$

$q_u = 150 KN/m^2$

$\therefore C_u = \frac{q_u}{2} = \frac{150}{2}$

$= 75 \ KN/m^2$

$$\eta_g = 1 - \left[\frac{(n_1-1)n_2 + (n_2-1)n_1}{90 n_1 n_2}\right] \times \theta$$

$$1 = 1 - \left[\frac{(3-1)3 + (3-1)3}{90 \times 3 \times 3}\right] \tan^{-1}\frac{0.4}{s}$$

$$\Rightarrow \tan^{-1}\left(\frac{0.4}{s}\right) = 0$$

$$\therefore \quad s = \infty$$

i.e. when $d/s << 1$, piles work as individual ones

$$Q_{ult} = 9 f_s A_s = 9 \times \alpha \times C_u \times \pi DL = 9 \times 0.6 \times 75 \times \pi \, 0.4 \times 15$$

$$= 7634.07 \ KN$$

Question 2

a. Based on subsoil investigation report of a nearby site, a preliminary design of footing foundation gives the dimensions as shown in Figure-1. It is decided that a fresh subsoil investigation would be done at the site. What should be the reasonable boring depth from the ground surface while considered a 2(vertical):1(horizontal) stress distribution?

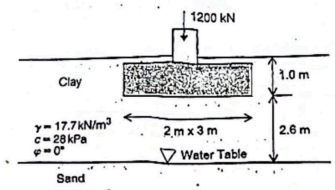


Figure 1 for Question No. 2(a)

$P = 1200\ KN$

$A = 3 \times 2 = 6\ m^2$

Depth of foundation,

$D_f = 1\ m$

$$q = \frac{1200}{6} - 17.7 \times 1$$

$$= 182.3\ KPa$$

1. Depth at 10% stress = depth at 10% area

i.e. $$\frac{182.3 \times 6}{(3+z_0)(2+z_0)} = 0.1 \times q = 18.23$$

$\therefore\ z_0 = 5.26\ m$

$\therefore$ total depth of boring $= 5.26 + 1 = 6.26\ m$

2. Effective vertical stress at depth of boring

$$\sigma_z' = 3.6 \times 17.7 + (17.7 - 9.81)(z_0 - 2.6)$$

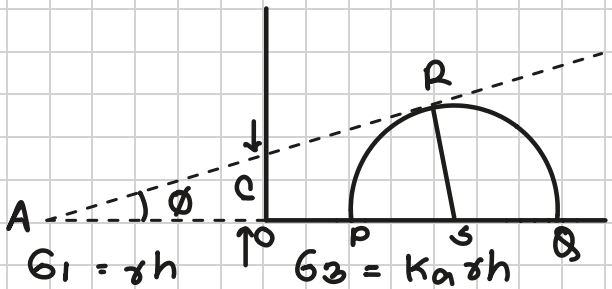
$\therefore$ Stress at depth of boring

$$\frac{182.3 \times 6}{(z_0+3)(z_0+2)} = 0.05\left\{3.6 \times 17.7 + (z_0 - 2.6)(17.7 - 9.81)\right\}$$

$\therefore\ z_0 = 10.63\ m$

$\therefore$ depth of boring $= 10.63 + 1 = 11.63\ m$

1. Rankine's Theory:



$\sigma_1 = \gamma h$ $\quad \sigma_3 = K_a \gamma h$

$\tan\phi = \frac{C}{AO}$

$\therefore AO = \frac{C}{\tan\phi}$

$$K_a = \frac{1-\sin\phi}{1+\sin\phi}$$

$$\sin\phi = \frac{RS}{AS} = \frac{RS}{AO+OS} = \frac{\frac{\sigma_1-\sigma_3}{2}}{\frac{C}{\tan\phi} + \frac{\sigma_1+\sigma_3}{2}}$$

$$\text{or, } \frac{C}{\tan\phi}\sin\phi + \frac{\sigma_1+\sigma_3}{2}\sin\phi = \frac{\sigma_1-\sigma_3}{2}$$

$$\text{or, } 2C\cos\phi + (\sigma_1+\sigma_3)\sin\phi = \sigma_1 - \sigma_3$$

$$\text{or, } 2C\cos\phi = \sigma_1(1-\sin\phi) - \sigma_3(1+\sin\phi)$$

$$\text{or, } \sigma_3(1+\sin\phi) = \sigma_1(1-\sin\phi) - 2C\cos\phi$$

$$\text{or, } \sigma_3 = \sigma_1 \frac{1-\sin\phi}{1+\sin\phi} - 2C\frac{\cos\phi}{1+\sin\phi}$$

$$= K_a\gamma h - 2C\frac{\sqrt{1-\sin^2\phi}}{1+\sin\phi}$$

$$= K_a\gamma h - 2C\sqrt{\frac{1-\sin\phi}{1+\sin\phi}} = K_a\gamma h - 2C\sqrt{K_a}$$

$$\therefore \sigma_3 = K_a\gamma h - 2C\sqrt{K_a}$$

Depth of tension crack,

$$\sigma_3 = 0$$

$$\text{or. } K_a \gamma h_c - 2c\sqrt{K_a} = 0$$

$$\text{or. } h_c = \frac{2c\sqrt{K_a}}{K_a \gamma} = \frac{2c}{\gamma\sqrt{K_a}}$$

$$K_a = \frac{1 - \sin\phi}{1 + \sin\phi} \longrightarrow \phi = 0^\circ \quad K_a = 1$$

$$\therefore \boxed{h_c = \frac{2c}{\gamma}}$$

unsupported height $= 2h_c$

$$= 2 \times \frac{2c}{\gamma} = \frac{4c}{\gamma}$$

Minimum Depth of boring :

2 criteria

1. Stress at depth of boring due to structure = 10% of stress under footing

2. Stres at depth of boring due to structure = π% of effective vertical stress at depth z_0

Question 2

a. Based on subsoil investigation report of a nearby site, a preliminary design of footing foundation gives the dimensions as shown in Figure-1. It is decided that a fresh subsoil investigation would be done at the site. What should be the reasonable boring depth from the ground surface while considered a 2(vertical):1(horizontal) stress distribution? 15

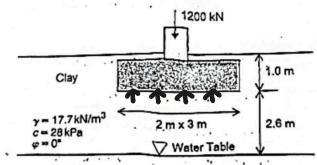


Figure 1 for Question No. 2(a)

Solution:

$$q = \frac{1200}{2\times 3} - \gamma h_{Bone}$$

$$= \frac{1200}{2\times 3} - 17.7\times 1$$

$$= 182.3 \text{ KPa}$$

$$\frac{182.3\times 6\times 6}{(3+z_0)(2+z_0)} = 0.1\times 182.3$$

$$\therefore z_0 = 5.26$$

$$\therefore \text{Total depth of boring} = 5.26 + 1 = 6.26 \approx 6.3\text{m}$$

Effective vertical stress at depth z_0

$$\sigma_z' = 1\times 17.7 + 2.6\times 17.7 + (z_0 - 2.6)\times(17.7 - 9.81)$$

$$= 63.72 + 7.89 z_0 - 20.514$$

$$= 43.2 + 7.89 z_0$$

Again,

$$\frac{182.3\times 6}{(3+z_0)(2+z_0)} = 0.05\,(43.2 + 7.89 z_0)$$

$$z_0 = 10.63\text{ m}$$

$$\therefore \text{total depth of boring} = 10.63 + 1 = 11.63\text{ m}$$

$$\therefore \text{Minimum depth} = 6.3\text{ m}$$

b. A five story office building is to be built in a deep, moderately uniform fine-grained soil deposit. The bedrock has a depth of over 75 m. The foundation level will be located at a depth of 1.5 m below ground surface. At the foundation level, the unfactored uniformly distributed load (q) from the building structure is 70 kpa. The building will be 50 m wide and 85 m long. Estimate the required number, spacing and location of exploratory boreholes. Appropriate values for any missing data may be assumed. 15

Since Multistoried building ($S=5$) on moderately uniform soil

minimum number of boring $= 5$

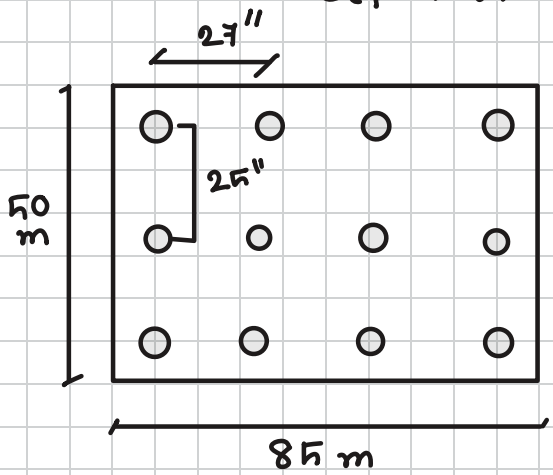
Spacing $= 30$ m

minimum depth of boring $= 3S^{0.7} + D$

$= 3 \times 5^{0.7} + 1.5$

$= 10.76$ m

≈ 11 m



Pile foundation:

80% load end bearing carry করে

- bearing pile

80% load or more skin friction carry করে

- friction pile

3 methods

α – method (for cohesive soil)

$f_s = \alpha C_u$

$f_b = 9 C_u$

β - method (for cohesionless soil)

$f_s = \beta \sigma_{vavg}$ $\quad \beta = K \tan\delta$

$f_b = q N_q$

λ method

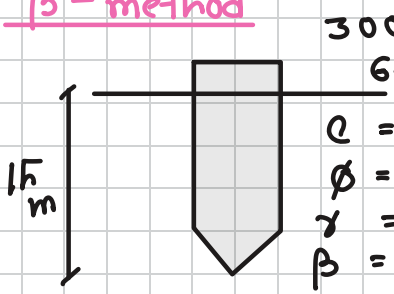
$f_s = \lambda (\sigma_{vavg} + 2C_{uavg})$

$f_b = 9 C_u \text{ , } q N_q \text{ , } (9C_u + q N_q)$

Pile load test করা থাকলে $FS = 2$

না করা হলে থাকলে $FS = 3$

β - method



$\sigma_v = \gamma L = 16 \times 15 = 240$

$$f_s = \beta \sigma_{v_{avg}} = 0.9 \times \frac{0 + 240}{2} = 108 \text{ KPa}$$

$$Q_s = f_s A_s = 108 \times \pi D L = 1526.81 \text{ KN}$$

$$f_b = q N_q = \gamma L \times 15 = 16 \times 15 \times 15 = 3600 \text{ KPa}$$

$$Q_b = f_b \times A_b = 3600 \times \pi \times (D/2)^2 = 254.47$$

$$\therefore Q_{u+} = 1526.81 + 254.47 = 1781.28$$

For bored pile

$f_s = 1/3\ f_s$ (driven pile)

$f_b = 1/2\ f_b$ (driven pile)

Bearing capacity from SPT-N value

	f_b	f_s
Sand	400N	$2\bar{N}$ (≤ 60 KPa)
Silt	300N	$2.67\bar{N}$
Clay	45N	$5\bar{N}$ (≤ 70 KPa)