ENCE 4610
Foundation Design and Analysis

Figure 4-6 Drilling into Rock through a Cased Hole

Lecture 19
Drilled Shafts and Auger Cast Piles
Axial Capacity

Static Geotechnical Capacity Analysis

Drilled Shafts

- Drilled Shafts do not compact the soils as driven piles do; they expand the soils, so soils can be looser around them, depending upon how long the hole remains open
- Analysis methods
  - Empirical Methods
  - Methods that deal with the additional uplift resistance of a belled toe (which we will deal with when we get to expansive soils)
  - It is also possible to use t-z software to analyze drilled shafts, as is the case with driven piles
- Method of Analysis
  - We use the O'Neill and Reese (1999) or "old" FHWA Drillled Shaft manual
  - Soils for drilled shafts are classified as follows:
    - Cohesive Soils (cohesion < 5 ksf)
    - Granular Soils (SPT < 50)
    - Intermediate Geomaterials (IGM)
      - Cohesive, cohesion > 5 ksf
      - Granular, SPT > 50
    - Rock, unconfined compressive strength > 100 ksf

Drilled Shafts in Clay Soils

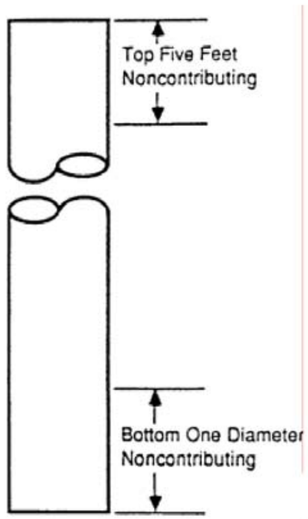
- Shaft Capacity
  - Use alpha method, compute as follows:

$\alpha = 0.55, c_u \leq 150 \text{ kPa or } 3 \text{ ksf}$

$\alpha = 0.45, c_u \geq 250 \text{ kPa or } 5 \text{ ksf}$

Linearly interpolate for intermediate values

  - Watch for excluded zones



- Toe Capacity

$$q'_b = N_c c_u$$

- q'_t = net unit toe-bearing pressure
- N^*_c = bearing capacity factor
  - 6.5 at c_u < 25 kPa (500 psf)
  - 8.0 at 25 kPa (500 psf) < c_u < 100 kPa (1000 psf)
  - 9.0 at c_u > 100 kPa (2000 psf)
- c_u = undrained shear strength between the toe and 2B below the toe

Ultimate Capacity of Drilled Shafts in Sand

- Sand Shaft Friction

$$f_{si} = \beta_i \sigma'_{oi}$$

$$\beta_i = K_{si} \tan \delta_i$$

$$\beta_i = \frac{N_{60}}{15}\left[\frac{3}{2} - \sqrt{\frac{z_i}{16.66}}\right], N_{60} < 15 \text{ BPF } (\mathrm{z_i} \text{ in meters})$$

$$\beta_i = \frac{N_{60}}{15}\left[\frac{3}{2} - \sqrt{\frac{z_i}{54.87}}\right], N_{60} < 15 \text{ BPF } (\mathrm{z_i} \text{ in feet})$$

$$\beta_i = \left[\frac{3}{2} - \sqrt{\frac{z_i}{16.66}}\right], N_{60} \geq 15 \text{ BPF } (\mathrm{z_i} \text{ in meters})$$

$$\beta_i = \left[\frac{3}{2} - \sqrt{\frac{z_i}{54.87}}\right], N_{60} \geq 15 \text{ BPF } (\mathrm{z_i} \text{ in feet})$$

$$\beta_i = 2 - \left(\frac{z_i}{12.55}\right)^{0.75}, N_{60} \geq 15 \text{ BPF, Gravelly Sands or Gravels } (\mathrm{z_i} \text{ in meters})$$

$$\beta_i = 2 - \left(\frac{z_i}{41.16}\right)^{0.75}, N_{60} \geq 15 \text{ BPF, Gravelly Sands or Gravels } (\mathrm{z_i} \text{ in feet})$$

- Toe Resistance

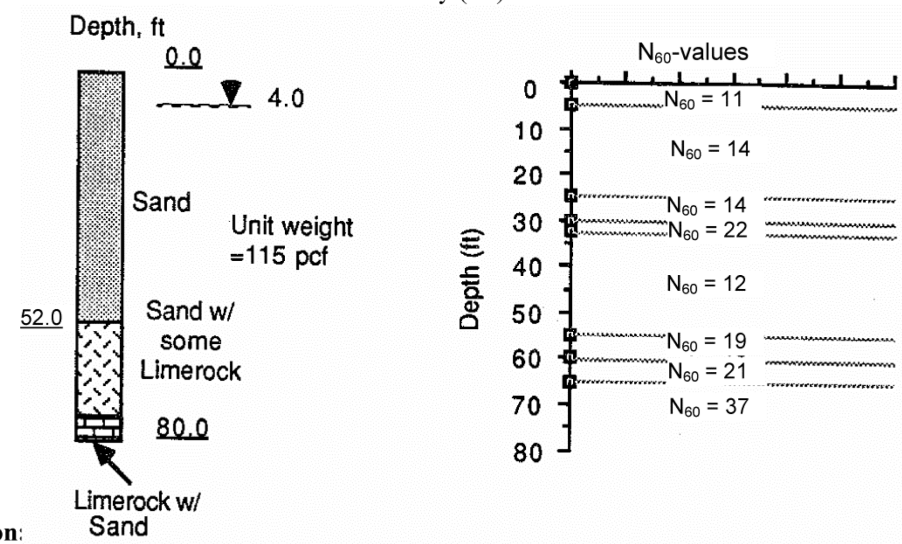
$$q_b = 1.2\, N_{60} \leq 60\, ksf \; (U.S.)$$

$$q_b = 57.5\, N_{60} \leq 2900\, kPa \; (SI)$$

  - Method based on SPT results

Drilled Shaft Design Example

Example 9-5: Size a shaft to resist 170 tons of vertical design load in the soil profile shown below. Assume a factor of safety (FS) of 2.5.



Solution:

The ultimate geotechnical axial load = (FS) (Design Load) = (2.5) (170 tons) = 425 tons. Assume a straight-sided drilled shaft with a diameter of 3-ft and a length of 60-ft. Thus, $\pi(D)$ = 9.42-ft

Use Equation 9-41 to determine ultimate skin resistance, $Q_s = \pi D \sum_{i=1}^{N} \gamma_i' z_i \beta_i \Delta z_i$

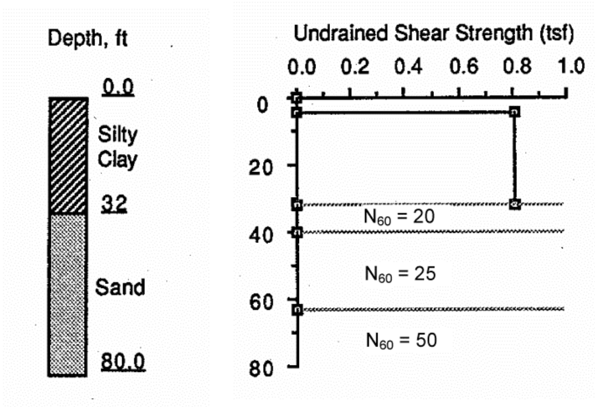
Depth Interval, Δz, ft	**Surface Area per depth interval, $\Delta z(\pi)(D)$, ft^2**	**Average effective vertical (overburden) stress, $p_o = \gamma' z_i$ tsf**	**β** $\beta_i = 1.5 - 0.135\sqrt{z_i}$ with $1.2 > \beta_i > 0.25$	**ΔQ_s Tons**
0 – 4	37.7	0.115	1.20	5.20
4 – 30	245.0	0.572	0.94	131.70
30 – 60	282.7	1.308	0.59	218.20
			Q_S	355.10

Base resistance (N_{60}=21 at 60-ft). Using Equation 9-45a $q_t = 1.2N_{60} = 25.2$ ksf = 12.6 tsf
$A_t = 7.07$ ft^2 Therefore, $Q_t = (7.07$ ft$^2)$ (12.6 tsf) = 89.1 tons

Thus, ultimate geotechnical axial resistance, Q_{ult} is given by:

$Q_u = 355.1 + 89.1 = 444.2$ tons $\approx$ 440 tons > 425 tons Okay.

Example 9-6: Determine the shaft length to resist 150 tons of vertical design load in the mixed (clay on sand) soil profile shown below. Assume a safety factor of 2.5. Assume a total unit weight of 125 pcf for clay and 115 pcf for sand. Water table is at a depth of 17-ft. Assume depth of zone of seasonal moisture change to be 5-ft. Once the shaft is sized for ultimate load, check the deformation under design load of 150 tons.



Solution:

For a factor of safety of 2.5, the ultimate axial load is computed to be (2.5)(150 tons) = 375 tons.

For a straight-sided shaft with a diameter of 3.0-ft and a depth of penetration of 50-ft, π(D) = 9.42-ft

Use Equation 9-36 and 9-41,

$$Q_s = \pi D \sum_{i=1}^{N} \alpha_i s_{ui} \Delta z_i$$

$$Q_s = \pi D \sum_{i=1}^{N} \gamma_i' z_i \beta_i \Delta z_i$$

Soil	Depth Interval, Δz, ft	Surface Area per depth interval, Δz(π)(D), ft^2	Shear Strength or Average effective vertical (overburden) stress, tsf	α or β	ΔQ_s Tons
Clay	0 – 5	--	--	0.00	0
Clay	5-32	254.5	0.80 (shear strength)	α = 0.55*	112.0
Sand	32-50	169.6	{(17 ft x 125 pcf) + (32ft -17 ft)(125 pcf-62.4 pcf) +9ft(115 pcf - 62.4 pcf)}/2,000 =3537.4 psf/2,000 = 1.769 tsf	β = 0.64**	192.0
				Q_S	304.0

* From Equation 9-37a

** From Equation 9-42, $\beta_i = 1.5 - 0.135\sqrt{z_i}$

At mid-depth of sand layer, z_i = 32 ft + (50 ft – 32 ft)/2 = 41 ft

At z_i = 41 ft, $\beta_i = 1.5 - 0.135\sqrt{41\,\text{ft}} \approx 0.64$

Base resistance (N_{60}=25 at 50 ft)

Use Equation 9-45a

$q_t = 1.2N_{60} = 1.2\,(25) = 30$ ksf = 15 tsf

$A_t = 7.07$ ft^2

Q_t = (7.07 ft^2) (15.0 tsf) = 106 tons

Total ultimate axial resistance, Q_{ult} is given by:

Q_u = 304.0 + 106.0 = 416.0 tons > 375 tons Okay.

Check of settlement under design load (150 tons)

Because most of the load in side resistance and all of the end bearing are derived from sand, Figures 9-52 and 9-53 will be used to estimate settlement. A settlement near the upper bound in both figures will be selected as a conservative estimate.

A settlement of 0.15 percent of the diameter is selected for the average settlement of the sides, or 0.06-inch. That would indicate that about 138 tons is carried in side resistance, and about 12 tons is carried in bearing, assuming that the shaft is essentially incompressible.

Comment: The settlement solution appears to be reasonable.

Drilled Shaft Design Example

Questions?