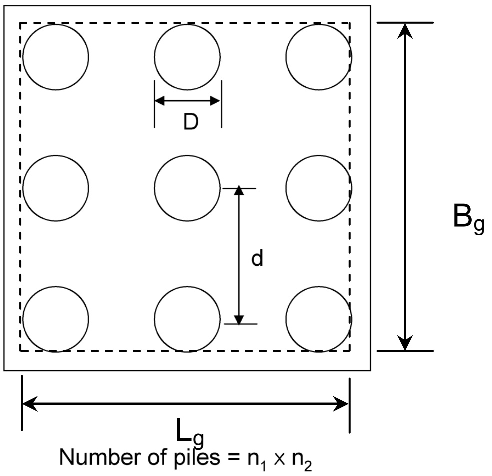
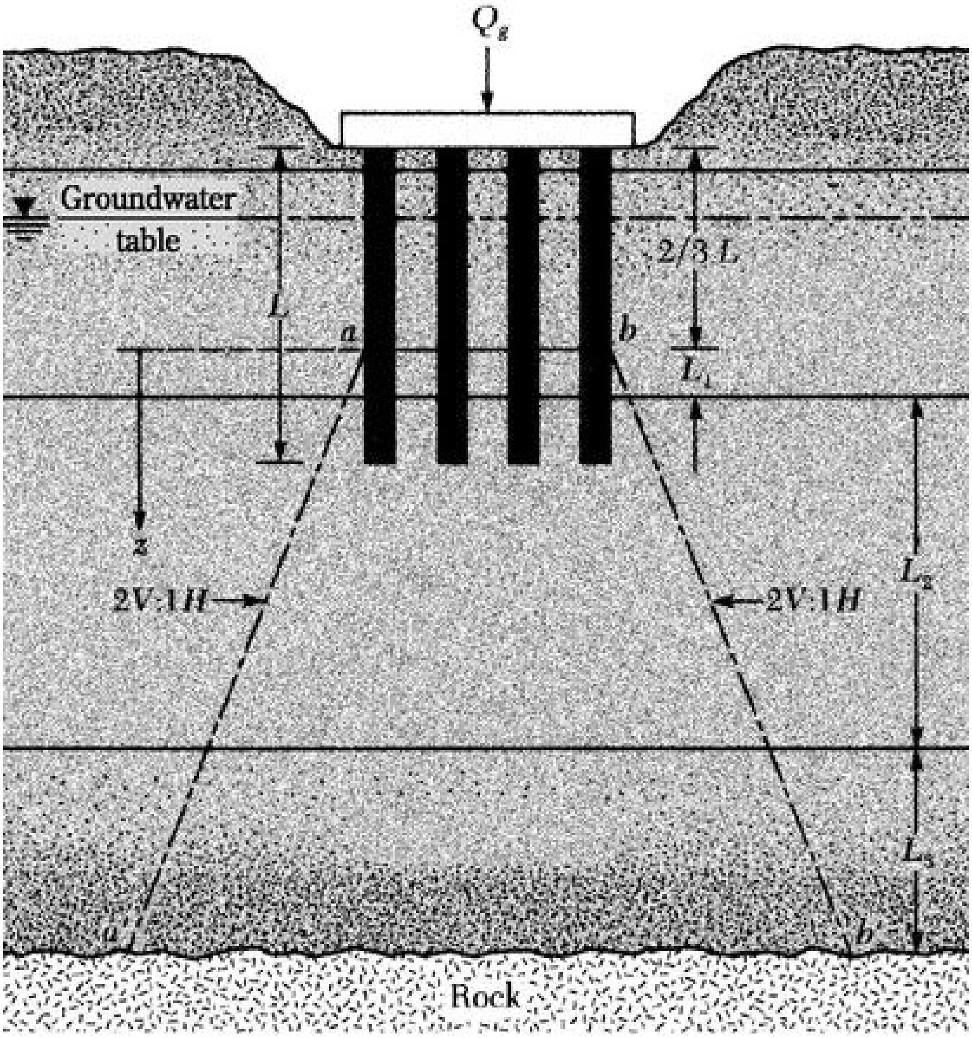
ii) Settlements of group piles

① Imaginary Raft Footing Method



- Replace pile group with an imaginary raft footing.
  - Friction pile ⇒ at a depth of 2/3L
  - End bearing pile ⇒ at pile tip

- $\Delta p(z) \Rightarrow$ can be determined by 2:1 method (or 30^o frustum)
- Can determine elastic and consolidation settlement.
- Add elastic compression of pile.



$$\Delta p(z) = \frac{Q_g}{(B_g + z)(L_g + z)}$$

② Empirical recommendations for elastic settlement of pile group

- Based on S_o = settlement of single pile

- <u>Empirical Recommendations</u>

a) Skempton ; $S_{g(e)} = S_o(\frac{4B_g + 9}{B_g + 12})^2$

where B_g = width of the pile group section in feet

b) Meyerhof (including the geometry of pile group)

$$S_{g(e)} = S_o(\frac{SR(5 - SR/3)}{(1 + 1/r)^2})$$

where $SR = \frac{pile\ spacing}{pile\ diameter} = \frac{d}{D}$

and r = no. of rows for a square group (or average no. of rows and columns for a rectangular group)

- Using SPT results, elastic settlement on sand and gravel by Meyerhof,

$$S_{g(e)}(in) = \frac{2q\sqrt{B_g}I}{N_{cor}}$$

where $q = Q_g/(L_g B_g)$ (in US tons/ and ft)

$N_{cor}(= N_{60}) \equiv$ average corrected SPT *N* value within seat of settlement ($\approx B_g$ deep below the tip of the piles)

$I \equiv$ Influence factor $= 1 - L/(8B_g) \geq 0.5$

L = length of embedment of piles (ft)

Similarly using CPT (Meyerhof)

$$S_{g(e)} = \frac{qB_g I}{2q_c}$$

where all symbols have consistent units.

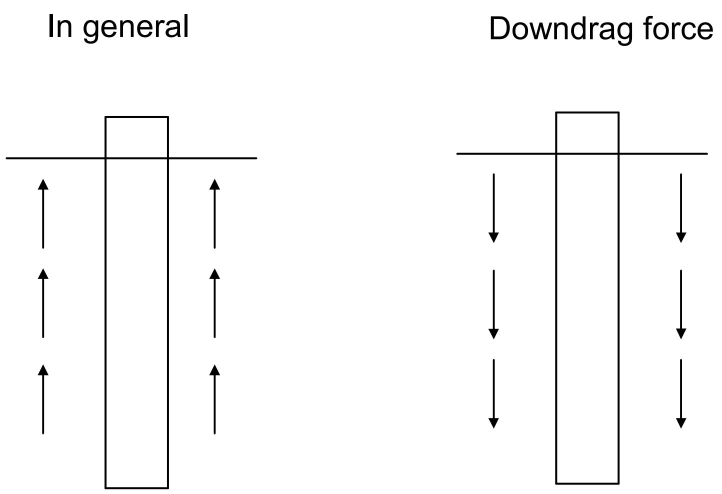
c) Vesic,

$$S_{g(e)} = S_o \sqrt{\frac{B_g}{D}}$$

where D = width or diameter of each pile in the group

12) Negative Skin Friction

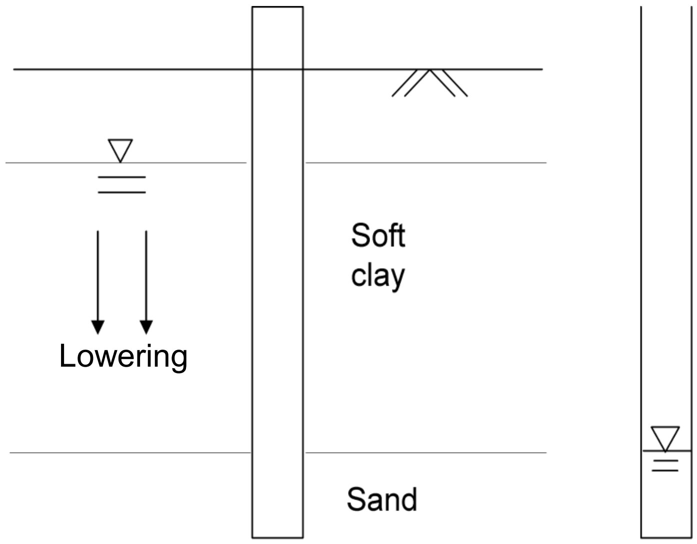
- Side friction resistance



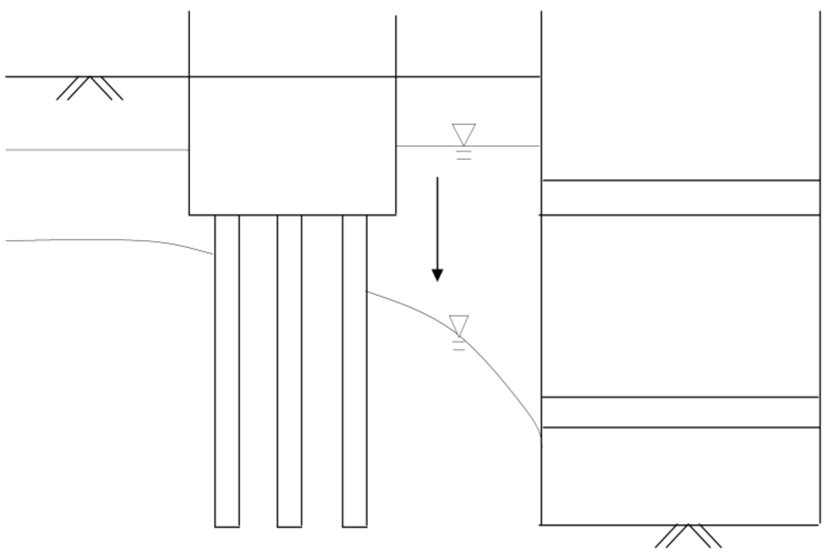
- Downdrag force develops when relative downward movements of soil to the pile occur due to consolidation of surrounding soils.
  ⇒ Observations show that relative displacements of 0.6(in) is needed to generate full downdrag force.

- Downdrag movement caused by any increase in effective stress;
  - Dewatering.
  - Surface loads after installation of piles.
    - Granular soil fill over clay
      ⇐ consolidation of clay layer by fill load
    - Clay fill over granular soil
      ⇐ self-consolidation of clay fill
  - Dissipation of excess pore water pressure after pile driving.

ex)



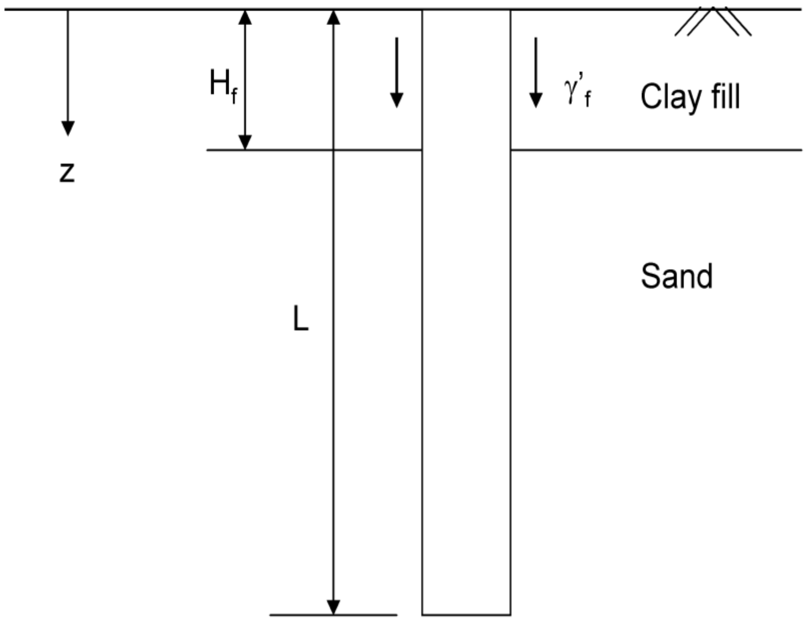
⇒ Lower water level to the sand.
⇒ Cause consolidation settlements by vertical effective stress.



At excavation site, construction dewatering causes downdrag forces.

● <u>Estimation of downdrag</u> (similar to β method)

i) Clay fill over granular soils



- The unit negative skin friction on the pile is

$$f_n = K'\sigma_v' \tan\delta \ (= N_s'\sigma_v')$$

where $K' \equiv$ earth pressure coefficient

$$= K_0 = 1 - \sin\phi$$

$$\sigma_v' = \gamma_f' z$$

$\delta =$ soil-pile friction angle $\approx (0.5 - 0.7)\phi$

- Hence the total downward drag force, Q_n on a pil e is

$$Q_n = \int_0^{H_f} \{pK'\gamma_f' \tan\delta \cdot z\} dz$$

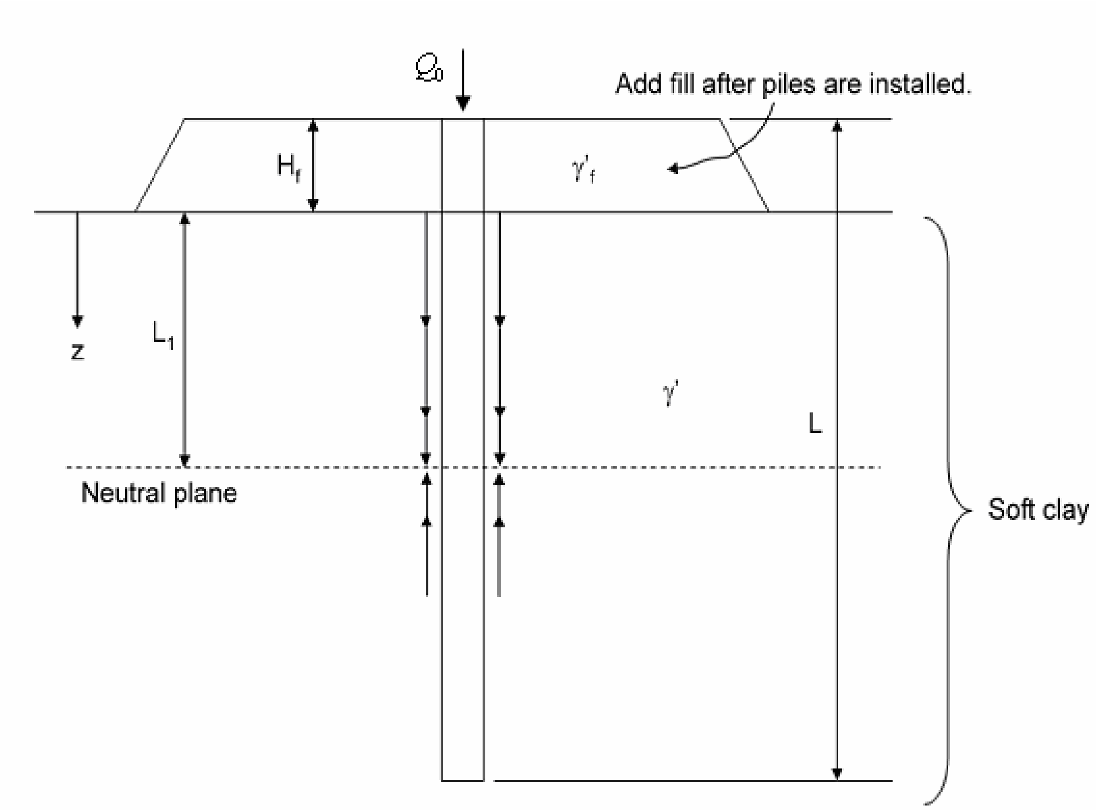
$$= \frac{1}{2} pK'\gamma_f' H_f^2 \tan\delta$$

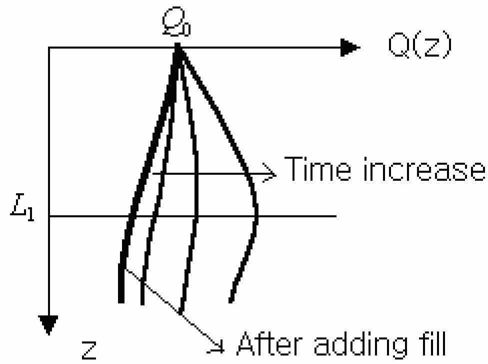
where p = perimeter of pile.

H_f = height of fill.

ii) Granular soil fill over clay

● The negative skin friction on the pile exists from z=0 to z=L_1 as shown below.





- Neutral depth L_1 : up to L_1, the negative skin friction is activated.

$$L_1 = \frac{(L-H_f)}{L_1}\left[\frac{L-H_f}{2} + \frac{\gamma'_f H_f}{\gamma'}\right] - \frac{2\gamma'_f H_f}{\gamma'}$$

For end bearing piles, the neutral depth may be assumed to be located at pile tip (L_1=L-H_f).

$$Q_n = \int_0^{L_1} pf_n dz = \int_0^{L_1} pK'(\gamma'_f H_f + \gamma' z)\tan\delta dz$$

$$= (pK'\gamma' H_f \tan\delta)L_1 + \frac{1}{2}L_1^2 pK'\gamma'\tan\delta$$

- Applying loads = $Q_{pile\,cap} + Q_n$
- Resistance = $Q_s + Q_p$ (Q_s not for fully embedded length of pile but only for length where upward frictional resistance is mobilized.)
- $Q_{allow} = \frac{Q_s + Q_p}{FS} \geq Q_{pile\ cap} + Q_n$

- To reduce downdrag
  1. Predrilled hole, then install pile (reduce K).
  2. Coat the pile with bitumen(reducing δ).

13) Drilled Piers and Caissons

i) Drilled Piers (Drilled Shafts)

- Cast-in-place pile with D>75cm

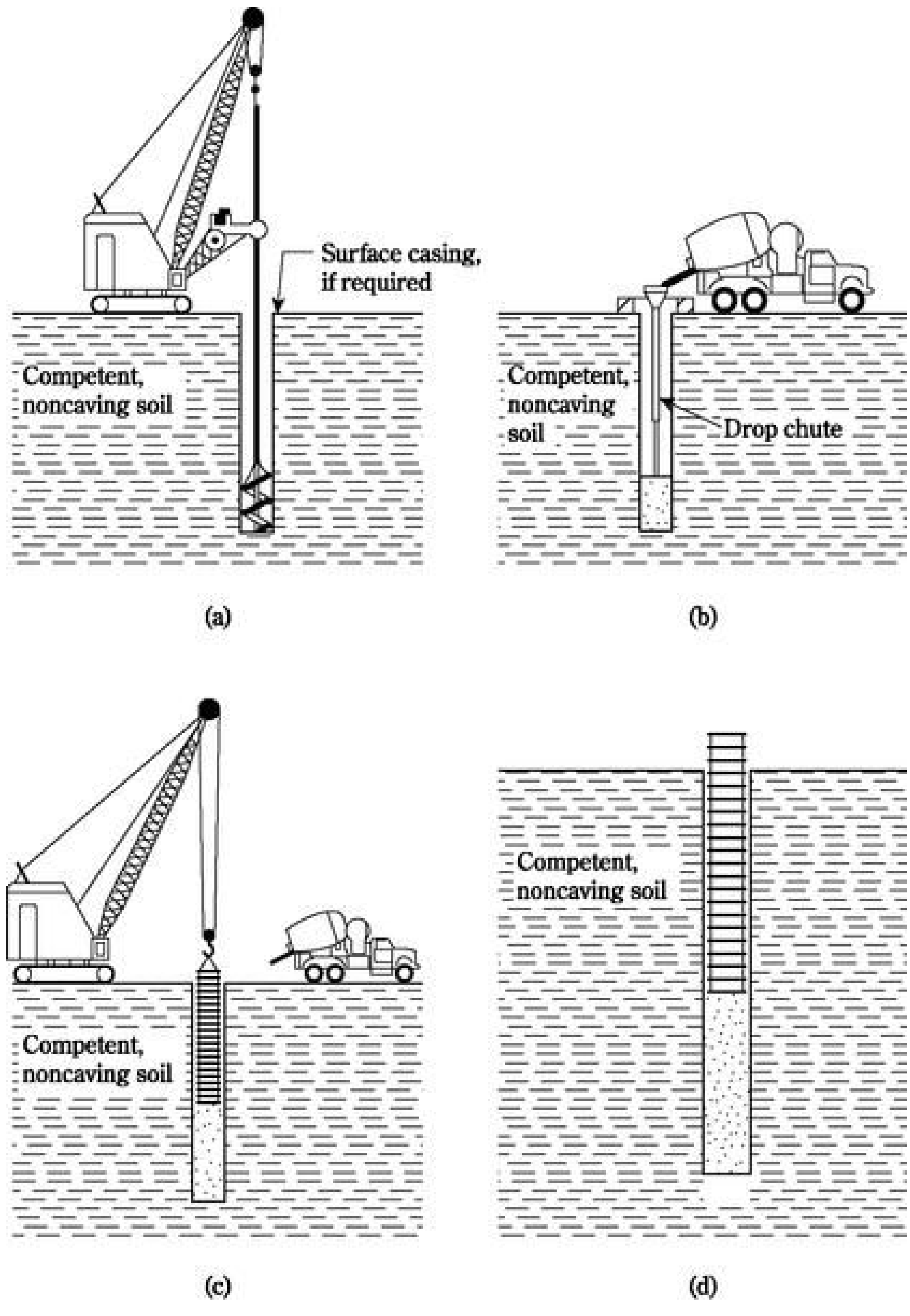
- Advantages
  1.
  2.
  3.
  4.
  5.

  6.

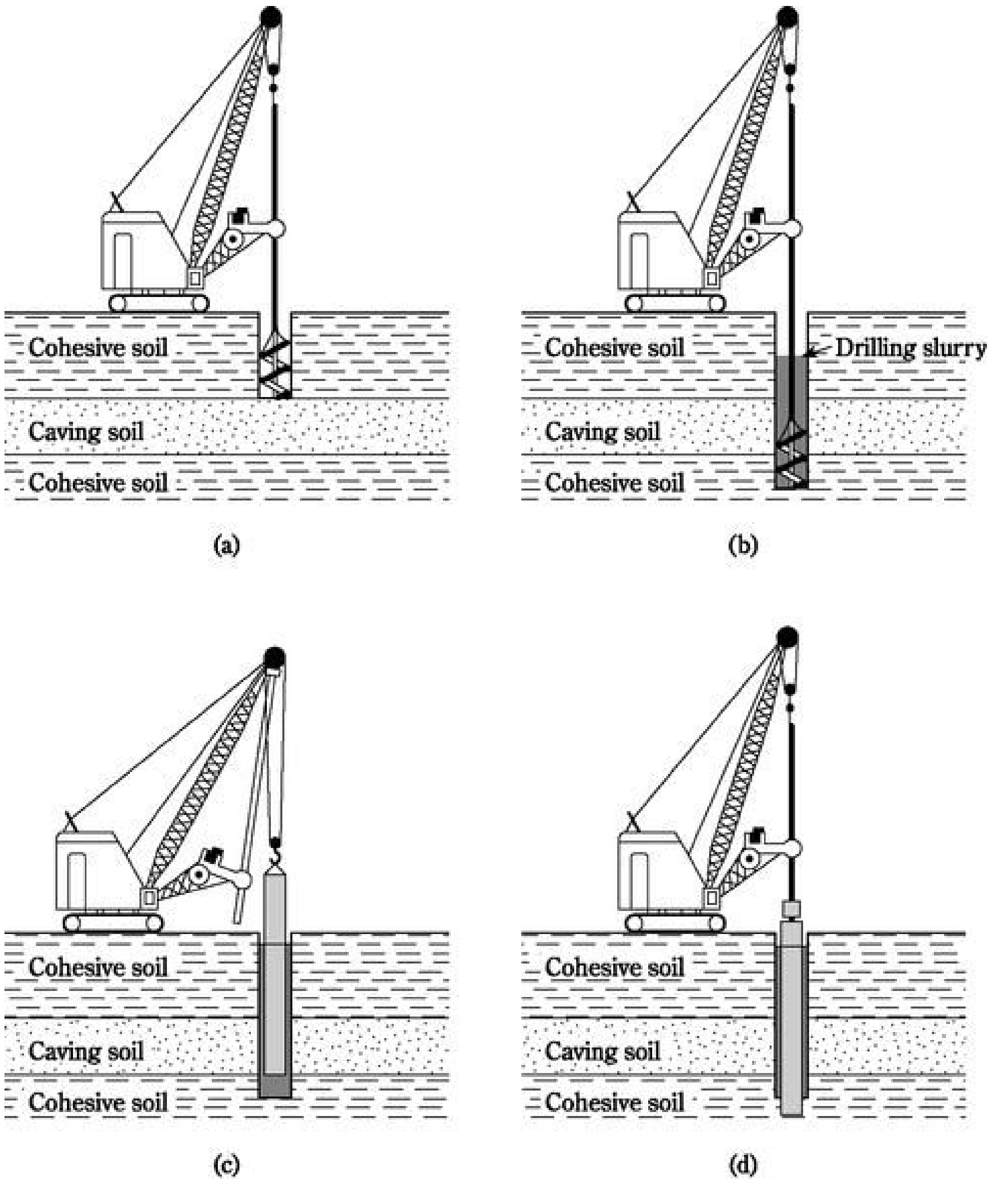
- Disadvantage
  1.

  2.

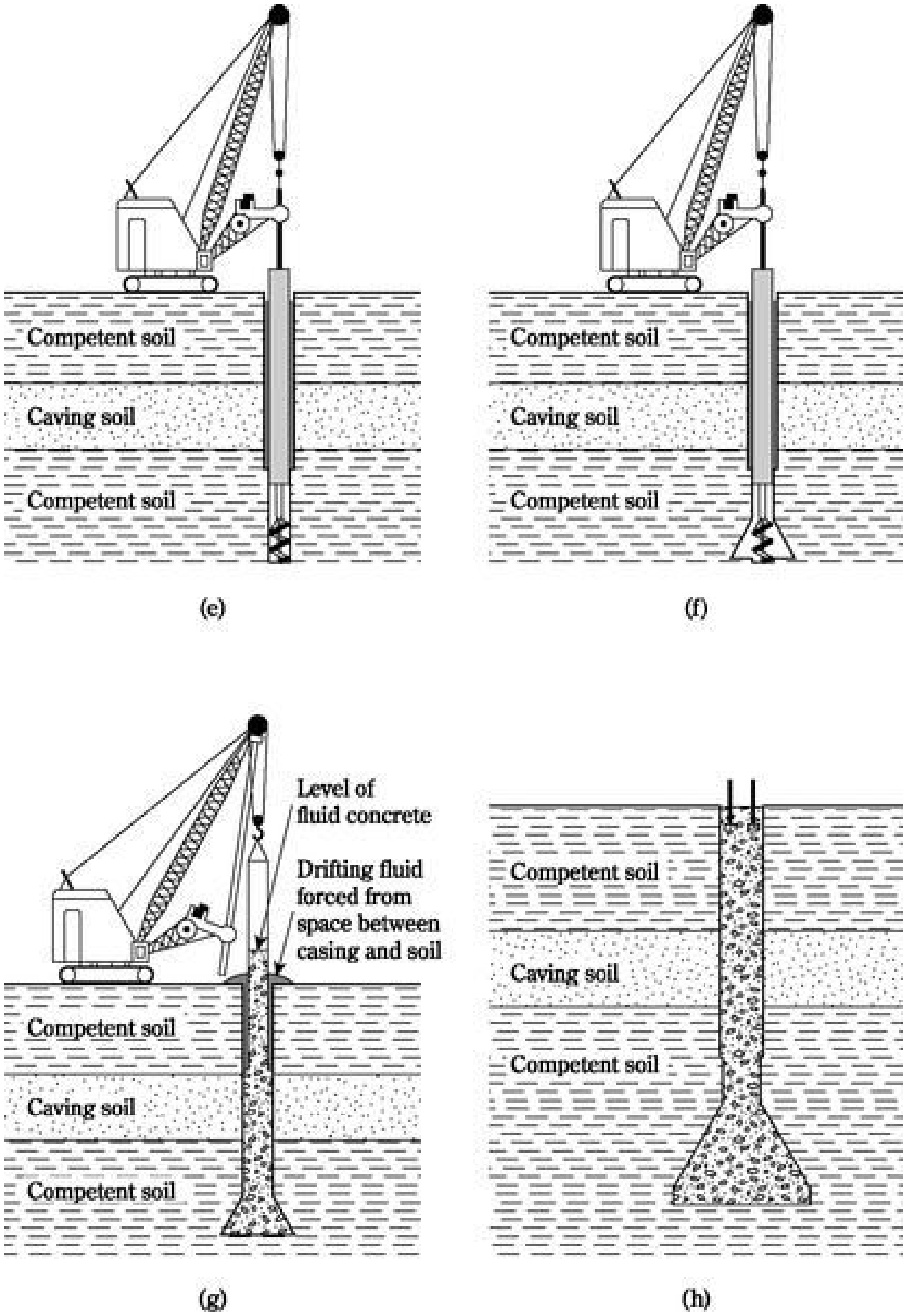
- Construction Procedures
  1. Dry method of construction (Stiff soils above the water table).
     - a) initial drilling
     - b) starting concrete pour
     - c) placing rebar cage
     - d) completing shaft



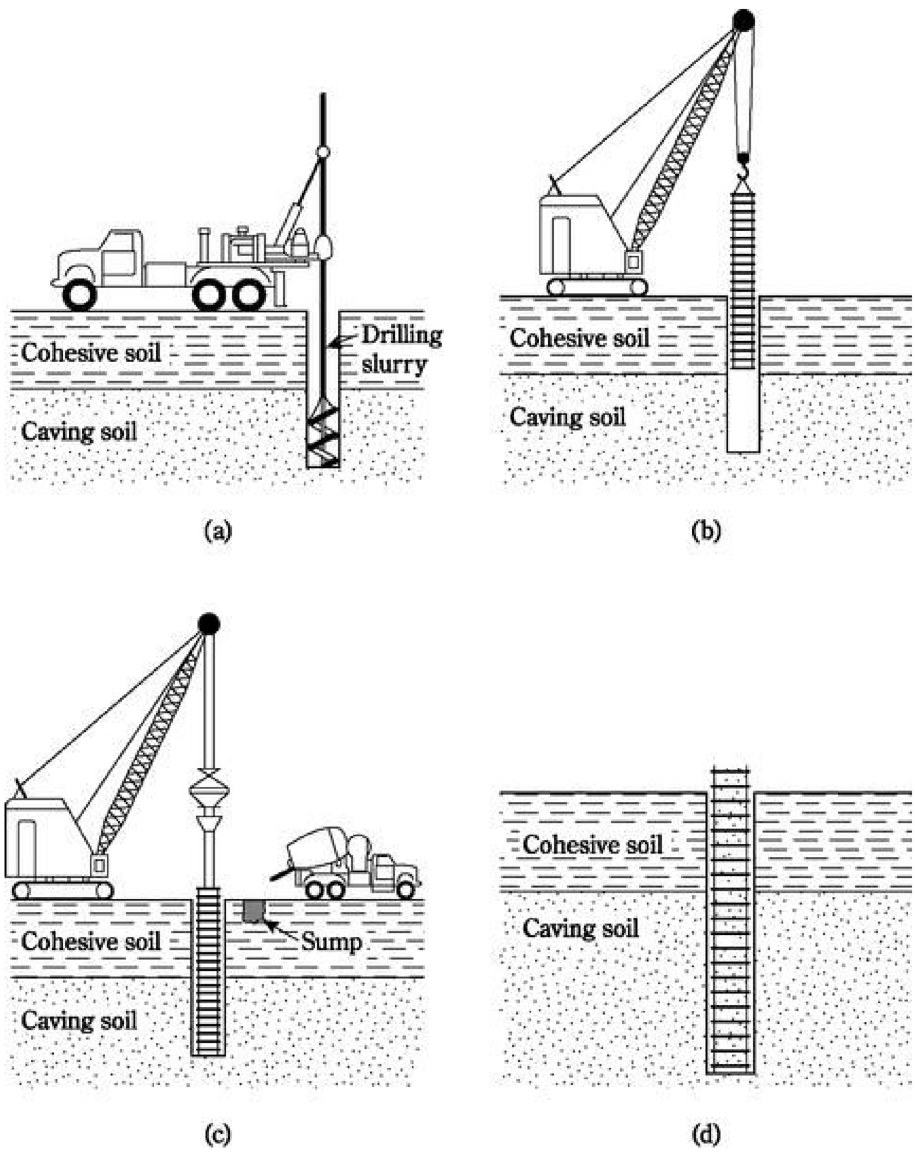
2. Casing method of construction
   - a) initial drilling
   - b) drilling with slurry
   - c) introducing casing
   - d) casing is sealed and slurry is being removed from interior of casing



e) drilling below casing
f) underreaming
g) pouring concrete and placing rebar (removing casing)
h) completing shaft
* Note : Either all casing or partial casing can be used.



3. Wet method of construction.
    a) drilling to full depth with slurry and removing slurry
    b) placing rebar cage
    c) pouring concrete
    d) completing shaft



- Analytical approach to predict capacity
  : Same procedures as driven piles
  (but different values of f_s are used)

<u>ii) Caissons</u>

- Substructure element used at wet construction sites such as rivers, lakes and docks

- Types of Caissons
  1) Open caissons
     -
     -
     -
     -

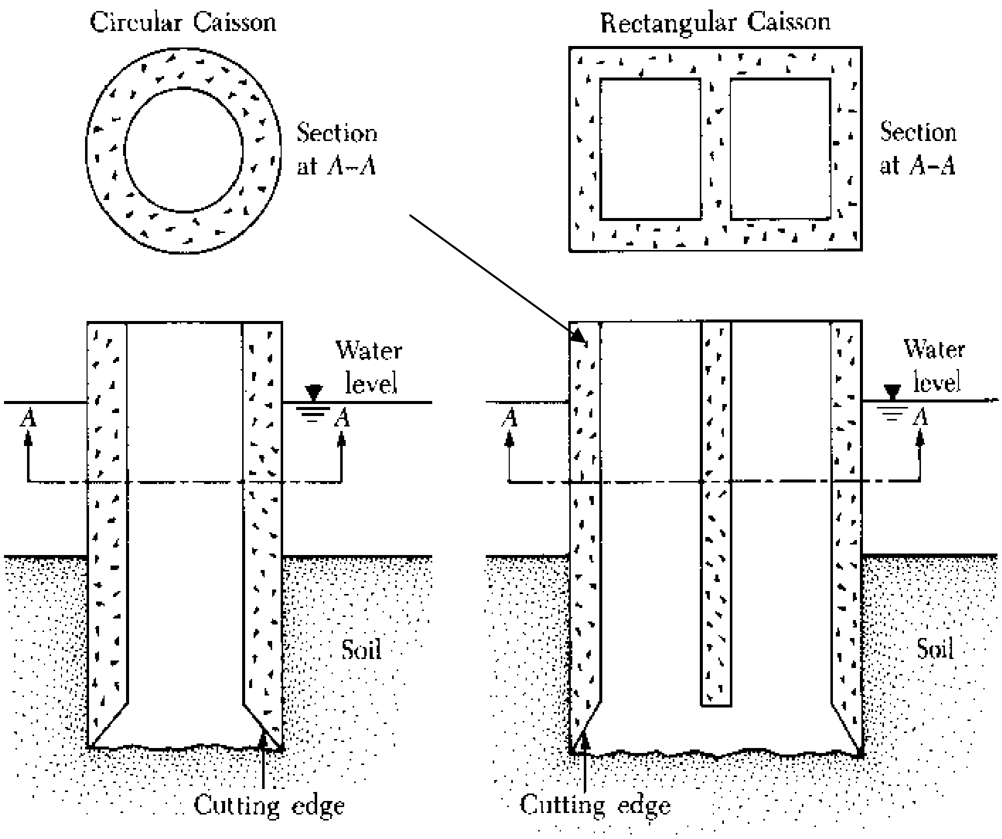
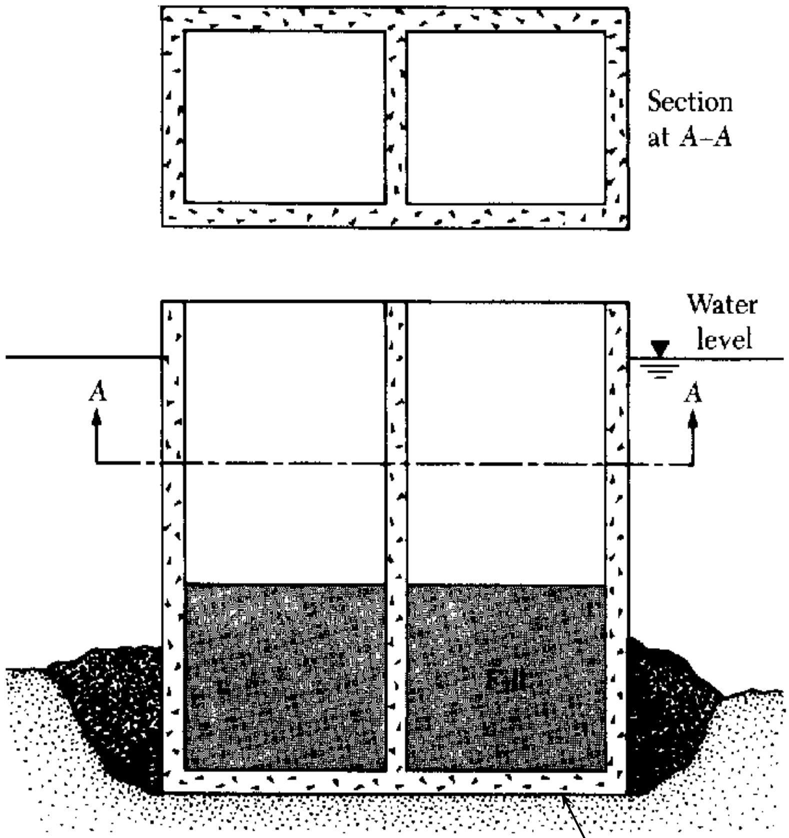


FIGURE 10.30 Open caisson

2) Box caissons
   -
   -



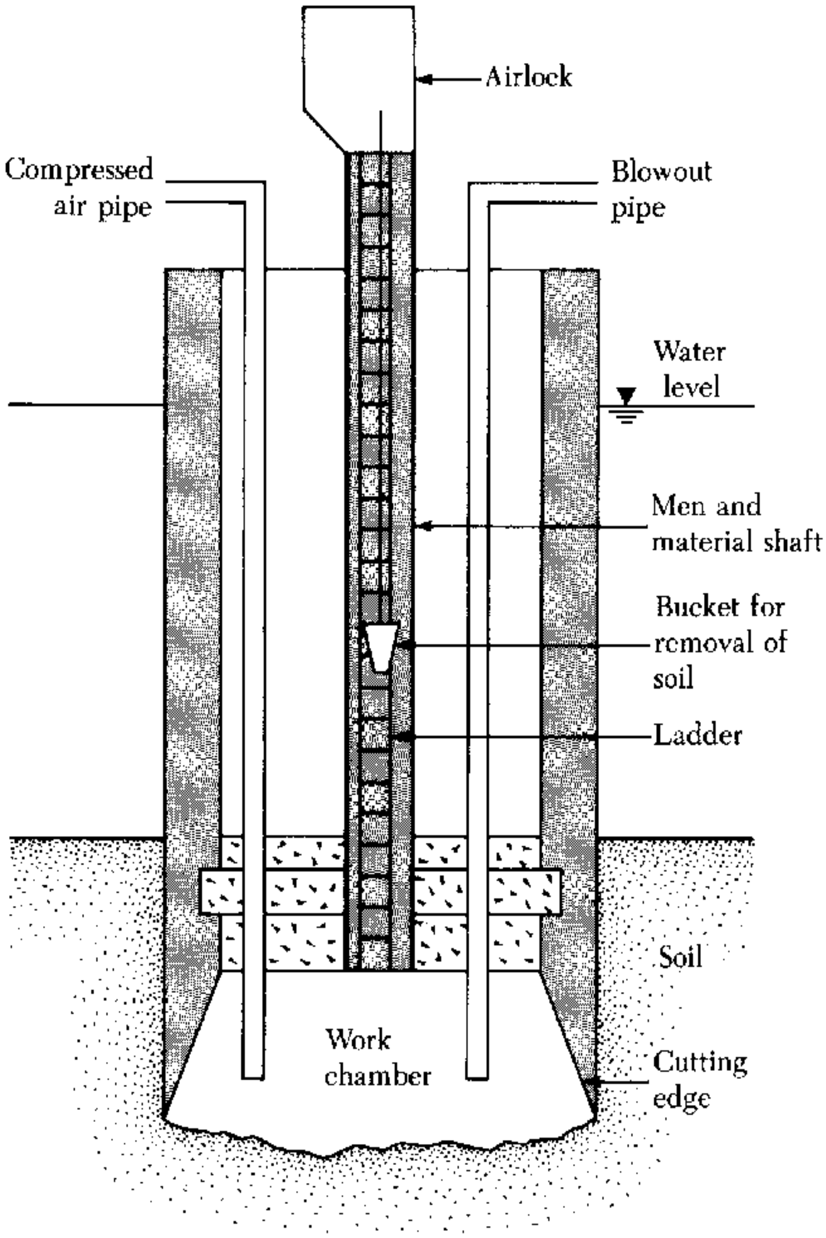
▼ **FIGURE 10.31** Box caisson

Should be leveled

3) Pneumatic caissons

-

-



▼ **FIGURE 10.32** Pneumatic caisson