PILE FOUNDATION

Pile: Small diameter shaft is driven or bored into ground.

Piers & Wells: Large diameter shaft is constructed by excavation and then it is sunk to required depth.

Classification of Pile

- **Material**
  - Timber
  - Steel
  - Concrete
  - Composite
- **Mode of load Transfer**
  - End Bearing
  - Friction
  - Combined
- **Function or action**
  - Load Bearing
  - Tension or uplift
  - Compaction
  - Fender Piles
  - Sheet Piles
  - Batter Piles
- **Installation Method**
  - Driven
  - Bored, cast in situ
  - [redacted]
  -
- **Displacement of soil**
  - Displacement Pile
  - Non-Displacement Pile

End Bearing Piles: Develop most of their load Bearing capacity at the toe of the pile, taking support on strong soil or rock.
Used in stiff clay or dense sand. (at base) → Hard soil is at base

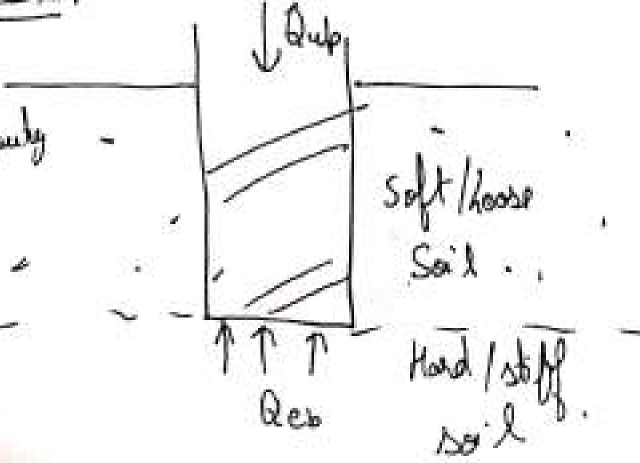
Friction Pile: It is a type of pile that utilizes the frictional resistance force between the pile surface and adjacent soil to transfer the superstructure load.
Used in Soft Soil & Clay.

~~Combined Pile~~

Q_{up} → Ultimate load carrying capacity of pile

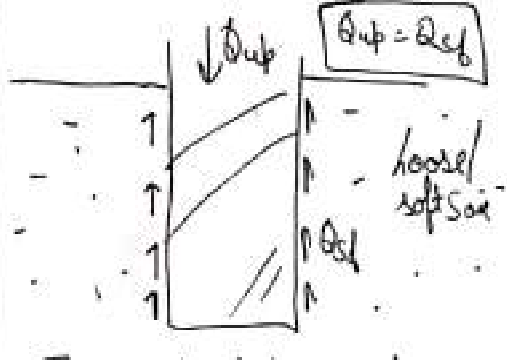
$Q_{up} = Q_{eb}$

End Bearing:



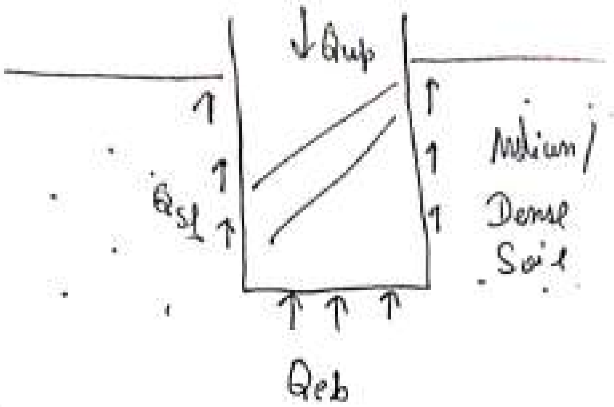
Friction Pile / Hanging:

$Q_{up} = Q_{sf}$



These extend to great depth.

Combined Pile: If Piles are driven in medium to stiff soil, then load carrying capacity is due to combined effect of end bearing action & skin friction both.



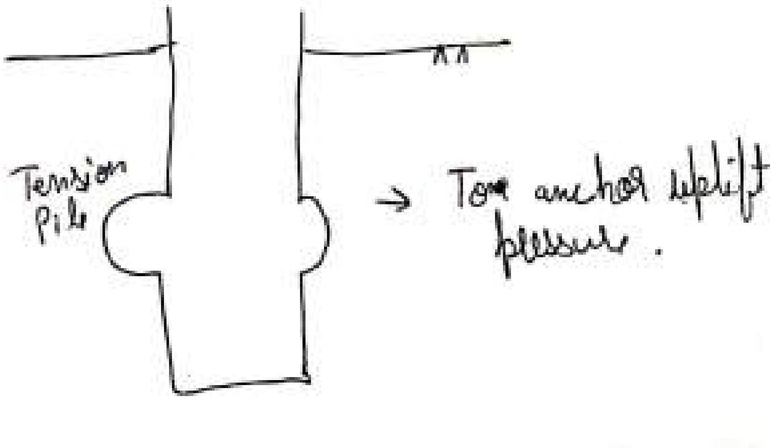
$$Q_{up} = Q_{eb} + Q_{sf}$$

On Basis of function or action:

1) **Load Bearing Pile:** It transmits the load of building through a layer of soil to stronger layer of soil.

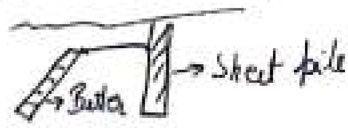
2) **Compaction Pile:** These are driven in loose sand in order to increase its density & bearing capacity.
   ↳ to compact a surface to inc. bearing capacity
   → It is drawn near the seas or river to avoid the process of liquefaction.

3) **Tension / Uplift Pile:** These type of piles are used to anchor the structure subjected to uplift pressure caused by swelling of soil such as in black soil.



4) Fender Pile: used to anchor the structure subjected to tidal wave caused by siesmic activities
→ Used in water front structures.

5) Batter Pile: These piles are driven in inclined ~~distra~~ direction to prevent horizontal ~~trus~~ thrust.
→ Used in Water front structures



6) Sheet piles: It is used to retain the earth mass & also used below the hydraulic structure to minimize piping failure.

Installation Mtd:

1) Driven pile: Pile driver is a device used to drive piles into soil.

2) Bored piles: are piles where the removal of soil froms hole for a reinforced concrete pile which is poured in situ.

On Basis of Displacement of Soil.

① Displacement Piles: The piles which displaces the soil and causes disturbance while driving are called displacement pile.

② Non-displacement Piles: When it does not displace or does not disturb the ~~so~~ adjacent soil it is called non-displacement piles.

Ultimate load Carrying Capacity of pile : (Q_{up})

→ It is the total load which can be applied on piles without shear failure.

→ Ultimate load carrying capacity is sum of end bearing resistance and surface friction/skin friction

$$Q_{up} = Q_{eb} + Q_{sf}$$

Allowable or Safe load of piles : (Q_{ap} / Q_{safe})

→ It is the max safe load which can be allowed on the pile without risk of shear failure.

$$Q_{ap} / Q_{safe} = \frac{Q_{up}}{F.O.S}$$

$$Q_{safe} = \frac{Q_{eb} + Q_{sf}}{F.O.S}$$

F.O.S = 2.5 to 3

Q_{eb} → end bearing load

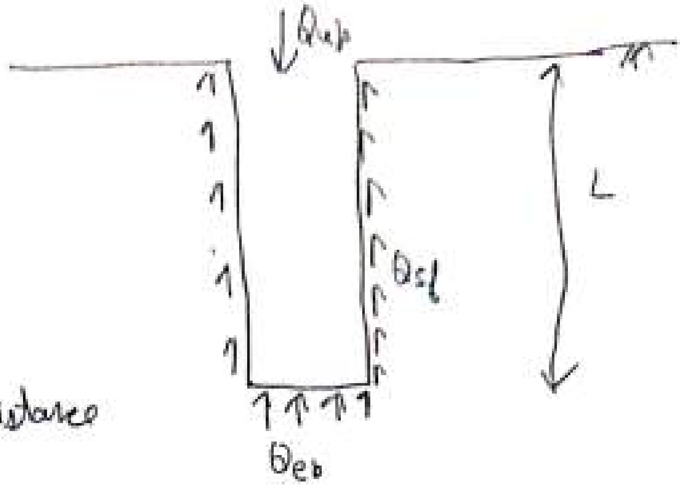
Q_{sf} → surface friction load / skin friction load

Method of determination of Pile load Capacity :

- Static / Analytical Method
- Dynamic Method (for dense sand)
- Field Method
  - Pile Load Test
  - Cyclic Pile load test
  - Standard Penetration ~~Tess~~ Test
  - Cone Penetration Test.

Note: Cyclic Pile load test gives end bearing resistance & skin friction resistance separately.

I) Static / Analytical Method:



$Q_{up} = Q_{eb} + Q_{sf}$

$Q_{eb} = q_b \cdot A_b$

$Q_{sf} = q_s \cdot A_s$

$q_b \rightarrow$ ~~unit point~~ end bearing resistance
$A_b \rightarrow$ Area of base
$q_s \rightarrow$ Unit skin friction resistance
$A_s \rightarrow$ Surface area of pile

	Circular	Square
A_b (base Area)	$\frac{\pi}{4} D^2$	B^2
A_s (skin surface area)	$\pi D L$	$4BL$

$$\boxed{Q_{up} = q_b A_b + q_s A_s}$$

Case 1 : For Clay (C- soil):

q_b = End Bearing resistance
= Ultimate bearing capacity at base

As per Meyerhoff : $\boxed{q_b = 9C}$ → for clay soil

C → Unit Cohesion

q_s = side resistance

$\boxed{q_s = \alpha \bar{C}}$ $\bar{C}$ = avg. Cohesion along length of Pile

α = adhesion factor b/w pile & soil.

$\alpha = (0.6 \text{ to } 0.9) \rightarrow$ for soft Clay
$\alpha = (0.4 \text{ to } 0.6) \rightarrow$ Medium Clay
$\alpha = (0.2 \text{ to } 0.4) \rightarrow$ Stiff Clay

∴ <u>Ultimate load Carrying Capacity of Pile in Clay</u>:

$$Q_{up} = Q_{eb} + Q_{sf}$$
$$Q_{up} = q_b A_b + q_s A_s$$
$$\boxed{Q_{up} = 9 C A_b + \alpha \bar{\tau} A_s} \; **$$

<u>Note</u>: For very long pile ($L \geq 25 m$) the above Mtd is very Conservative. For such piles, unit skin friction also depends upon <u>effective</u> overburden pressure.

∴ Avg. unit friction can be represented by:

$$\boxed{q_s = \lambda(\bar{\sigma}_v + 2\bar{\tau})}$$

λ = friction Capacity factor
$\bar{\sigma}_v$ = Mean eff. stress

$$\boxed{Q_{up} = 9 C A_b + \lambda(\bar{\sigma}_v + 2\bar{\tau}) A_s} \; **$$

<u>Case 2</u>: <u>For Sand (For ϕ soil)</u>

As per Meyerhoff ⇒ $q_u = \cancel{C N_c}^{0} + \gamma D_f N_q + 0.5 B \gamma N_\gamma$

& $\gamma D_f N_q >> 0.5 B \gamma N_\gamma$
↳ as $B << D_f$

∴ $q_u = \gamma D_f N_q$ where D_f = Depth of footing = L

$$\boxed{q_u = \gamma L N_q}$$

q_b = end bearing resistance
= ultimate bearing capacity at base

$$\boxed{q_b = \gamma L N_q}$$

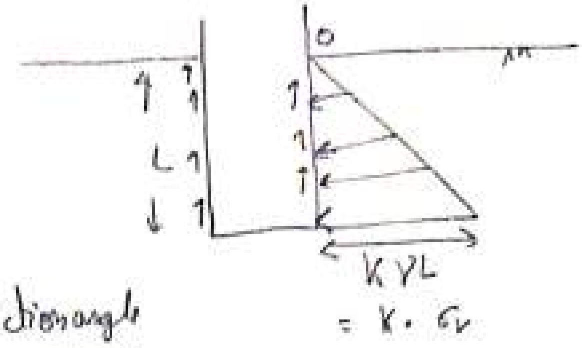
N_q : Meyerhoff. Bearing Capacity factor

q_s = skin friction resistance (for sand

$$q_s = \mu \,(\text{avg. earth press.})$$

$$= \mu \left(\frac{0 + K\sigma_v}{2} \right) \qquad \sigma_v = \gamma L$$

$$= \frac{\mu K \cdot \gamma L}{2} \qquad \mu = \text{friction angle}$$



$$q_s = \left(\frac{K\gamma L}{2} \right) \tan\delta \qquad \boxed{\mu = \tan\delta}$$

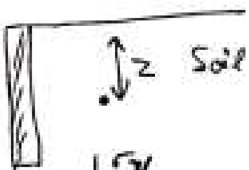
K = earth press. coeff.
L = Length of pile
δ = Friction angle b/w pile & soil

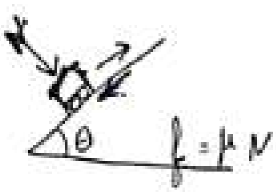
$$\boxed{q_s = \frac{1}{2} K \cdot \gamma L \tan\delta}$$

Ultimate load Capacity for sand :

$$Q_{up} = q_b A_b + q_s A_s$$

$$\boxed{Q_{up} = (\gamma L N_q) \cdot A_b + \left(\frac{1}{2} K \gamma L \tan\delta \right) A_s} \; **$$





$\mu = \tan\theta$

N = Normal

At pt. Z ⇒ σ_v, σ_H $\quad K = \frac{\sigma_v}{\sigma_H}$

$$\sigma_H = \sigma_v \cdot K$$
$$= \gamma \cdot Z \cdot K$$
$$= \gamma \cdot L \cdot K \rightarrow \text{for L depth}$$

2) Dynamic Method:

→ This analysis is based on the assumption that the dynamic resistance to drive the pile is equal to the ultimate load capacity using static method.

→ In this the ~~kinem~~ Kinetic energy / Potential energy of hammer is equal to work done by pile.

$$\text{Energy Imparted} = W \times H$$

a) Engineering News Formula:

$$Q_{up} = \frac{WH}{S+C}$$

$$\boxed{Q_{allowable} = \frac{WH}{F.O.S(S+C)}}^{*}$$

(in kN) → For drop hammer or Single acting steam hammer

W = ~~load~~ ~~on~~ Wt. of hammer in kN

H = Ht. of free fall of hammer in cm

S = Settlement per blow of hammer in cm

Settlement is taken as avg. value of last 5 blow for drop hammer

or it is equal to last 20 blows of steam hammer

C = Emperical Factor

= 2.5 cm → For drop Hammer

= 0.25 cm for single acting steam hammer

$\boxed{F.O.S = 6}$

(b) Hiley's Formula:

$$Q_{up} = \eta_h \cdot \eta_b \left(\frac{WH}{S + \frac{C}{2}} \right)$$

Safe load carrying Capacity of soil:

$$Q_{safe} / Q_{ap} = \frac{Q_{up}}{3} = \frac{Q_{ub}}{3}$$

F.O.S = 3

W = Wt. of hammer in kN
H = Height of free fall in cm
S = Final set per blow in cm
C = Total elastic compression per blow
i.e of soil + ~~pad~~ pile

η_h = efficiency of hammer
η_h = 1 → drop hammer
η_h = 0.75 to 0.85 → Single acting steam hammer
η_h = 0.7 to 0.8 → double acting steam hammer
η_b = efficiency of hammer blow

Q. Determine the safe load for pile of 30 cm dia driven into a medium dense sand ($\gamma = 21 kN/m^3$, $K = 1.0$, $\tan\delta = 0.70$) Depth of pile = 3.6 m. Take F.O.S = 2.5 ; $N_q = 66$

⇒ Vertical press = $3.6 \times 21 = 75.6 kN/m^2$

$$Q_{up} = (\gamma L N_q) A_b + \left(\frac{1}{2} K \gamma L \tan\delta\right) A_s$$

$$= 21 \times 3.6 \times 60 \times \frac{\pi}{4} \times (0.3)^2 + \left(\frac{1}{2} \times 1 \times 21 \times 3.6 \times 0.70\right) \pi \times 0.3 \times 3.6$$

$$Q_{up} = 1282.52 + 87.77$$

$$= 1372.296 kN$$

$$Q_a = \frac{1372.296}{2.5} = 548.92 kN$$

Q. A 30 cm dia concrete pile is driven into homogenous consolidated clay deposit ($C_u = 40 kN/m^2$, $\alpha = 0.7$). If the embedded length is 10 m, estimate safe load (F.OS = 2.5)

⇒ $$Q_u = 9 C A_b + \alpha \bar{C} A_s$$

$$= (9 \times 40) \frac{\pi}{4} (0.3)^2 + 0.7 \times 40 (\pi \times 0.3) 10$$

$$= 289.2 kN$$

$$Q_a = \frac{Q_u}{2.5} = \frac{289.2}{2.5} = 115.7 kN$$