PILE FOUNDATION.

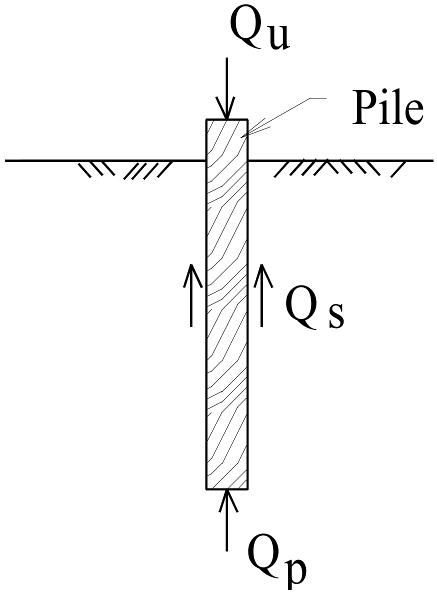
One or more of the followings:

(a)Transfer load to stratum of adequate capacity

(b)Resist lateral loads.

(c)[1]Transfer loads through a scour zone to bearing stratum

(d)Anchor structures subjected to hydrostatic uplift or overturning



$$Q_u = Q_p + Q_s$$

[1] *Check setlements of pile groups*

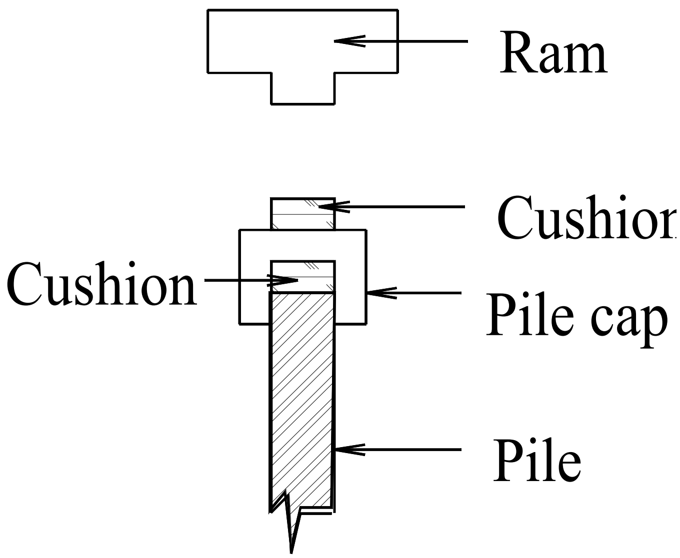
Do not use piles if:

Driving may cause damage to adjacent structures, soil may heave excessively, or in boulder fields.

Pile Installation

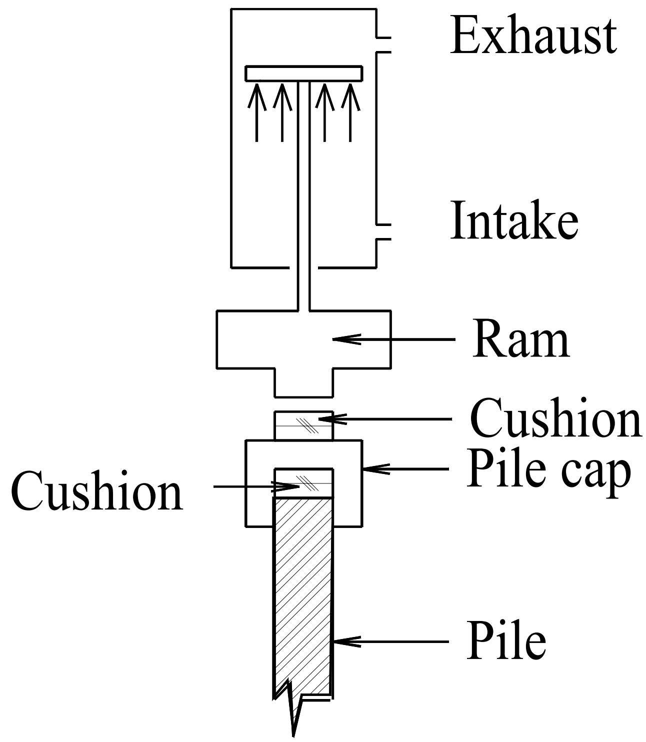
Hammers

Drop hammer[1]



Drop hammer

[1] *Very noisy, simple to operate and maintain , 5-10 blows / minute, slow driving, very large drop, not suited for end bearing piles, used on Franki piles*



Single acting hammer

Double acting[1]:

Differential acting[2]

Diesel[3]

Vibratory[4]

Jacking

Predrilling or Jetting

---

[1] *Uses pressure for up stroke and down stroke. Design limits prevent it to deliver as much energy as single acting, but greater speed, used mostly for sheet piles*

[2] *Has two pistons with different diameters, allowing it to have heavy ram as for single acting and greater speed as double acting*

[3] *Difficult to drive in soft ground, develops max energy in hard driving*

[4] *Rotating eccentric loads cause vertical vibrations, most effective in sand*

PILE TYPE

- Timber
- Concrete
- Steel

Timber piles

Butt dia 12" to 20", tip 5" to 10". Length 30-60'

Bark always removed.

Concrete piles

Pre-cast

- Reinforce and prestressed

Cast in place

- With or without casing[1]
- More common than precast.

Steel Piles

- Steel H-Pile
- Unspliced 140', spliced > 230', load 40 to 120 tons.

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[1] *more economical but more risk in their installation .*

PILES CLASSIFICATION

1. Material (wood, steel, etc.).

2. Method of installation[1]

3. Effect on surrounding soils during installation[2].

Pile load capacity prediction

- Full-scale load test
- Static formulae
- Dynamic method

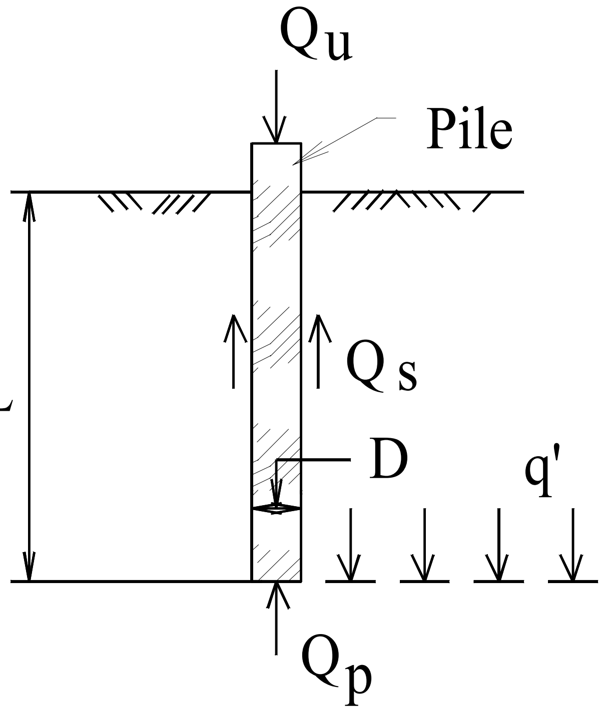
[1] *(driven: blow of a hammer, vibrations, pressure from a jack, etc.; jetted, augured, screwing, etc.).*
[2] *displacement, non-displacement*

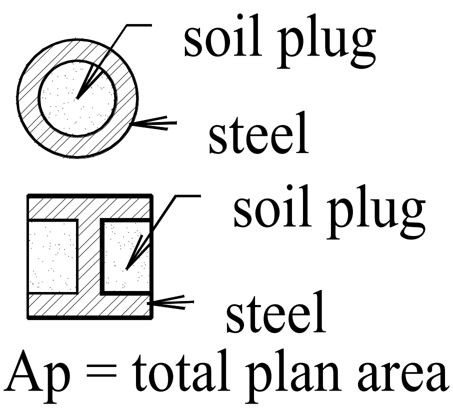
Pile shape effect and pile selection

Shape characteristics	Pile type	placement effect
Displacement	Closed ended steel	Increase lateral ground stress
	Precast concrete	Densifies granular soils, weakens clays[1]
Tapered	Timber, monotube, thin-walled shell	High capacity for short length in granular soils
Non-displacement	Steel H	Minimal disturbance to soil
	Open ended steel pipe	Not suitable for friction piles in granular soils, often show low driving resistance, field varification difficult resulting in excessive pile length

[1] *Seup time for large groups upto 6-months*

Load Transfer





$$Q_u = Q_p + Q_s$$

Settlement for full load transfer

- $Q_p \rightarrow 0.1D$ (driven), 0.25 D (bored)
- $Q_s \rightarrow 0.2'' - 0.3''$

End or Point Resistance

$q_{ult} = cN^*_c + q'_o N^*_q + \gamma D N^*_\gamma$

D = pile diameter or width

q'_o = effective overburden stress at pile tip

N^*_c, N^*_q, N^*_γ are the b.c. factors which include shape and depth factors

Since pile dia is small $\gamma D N^*_\gamma \approx 0$

$$Q_p = A_p (cN^*_c + q'_o N^*_q)$$

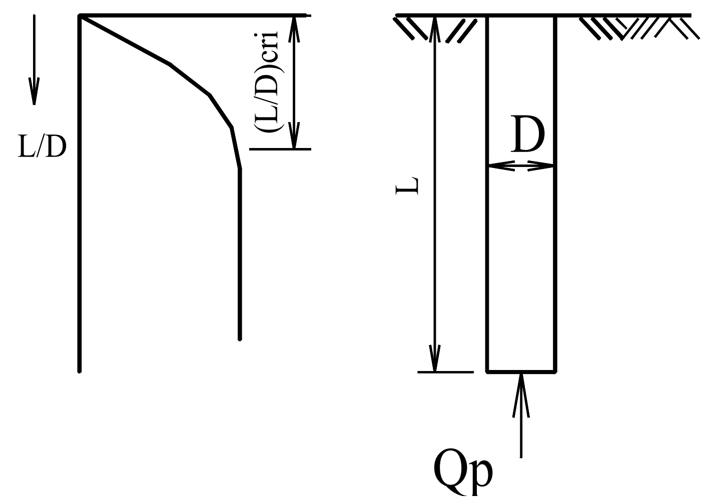
A_p = pile tip area

Meyerhof's Method

Point resistance increases with depth reaching a maximum value at L_b/D critical.

$(L_b/D)_{crit}$ varies with ϕ and c. Fig 9.12

L_b = embedment length in bearing soil



For values of N^*_c, N^*_q see Fig 9.13

Piles in Sand[1]

$$Q_p = A_p \cdot q_o^{'} \cdot N_q^{*} \le A_p \cdot q_l$$

where $q_l(\text{tsf}) = 0.5N_q^{*} \cdot \tan\phi$

ϕ in terms of 'N' or D_r

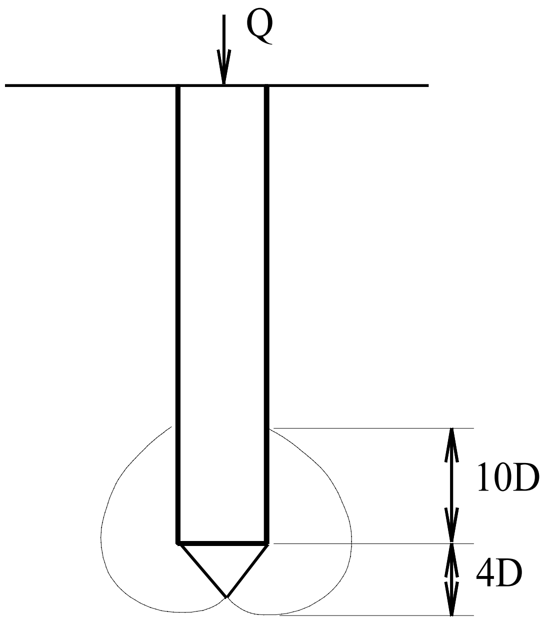
$$\phi = \sqrt{20N} + 15^o$$

$$\phi = 28^o + 15D_r$$

Point resistance from SPT

$$q_p\ (\text{tsf}) = \frac{0.4 \cdot N \cdot L}{D} \le 4 \cdot N$$

N = avg value for 10D above and 4D below pile tip



[1]*For a given initial ϕ unit point resistance for bored piles =1/3 to 1/2 of driven piles, and bulbous piles driven with great impact energy have upto about twice the unit resistance of driven piles of constant section*

Example 1

A pile with L = 65', x-section = 18"×18" is embedded in sand with $\phi = 30°$, $\gamma = 118.3$ pcf. Estimate point bearing resistance.

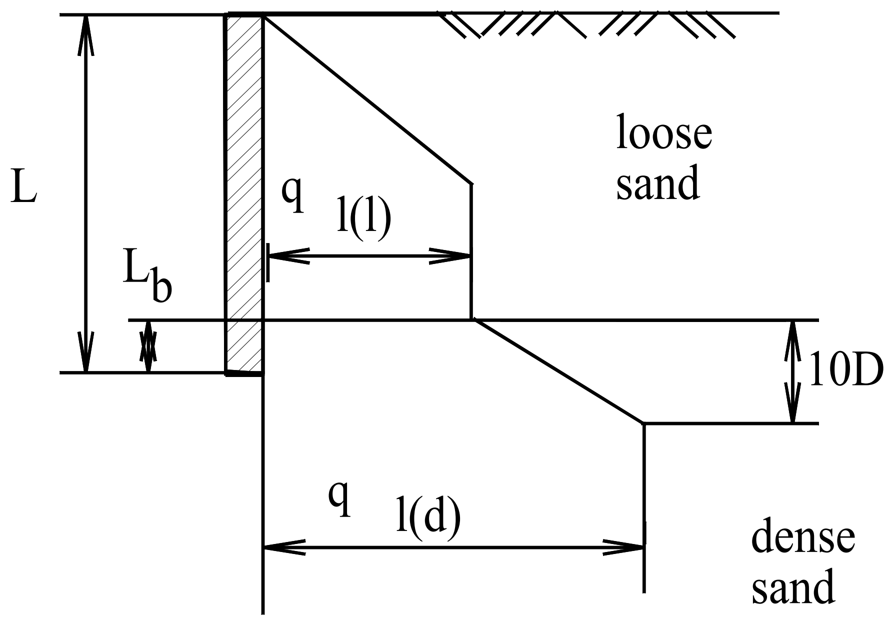
Solution (Meyerhof)

$$Q_p = A_p \cdot q_o' \cdot N_q^* \le A_p \cdot q_l$$

$$Q_p = 1.5 \times 1.5 \times 118.3 \times 65 \times 55 \div 2000 = 476 \text{ tons}$$

$$Q_p = A_p \cdot q_l = 1.5 \times 1.5 \times 0.5 \times 55 \times \tan 30 = 36 \text{ tons}$$

Upper weak lower firm soil



$$q_p = q_{l(l)} + \frac{L_b}{10D}\left(q_{l(d)} - q_{l(l)}\right) \le q_{l(d)}$$

$q_{l(l)}$ = limiting point resistance in loose sand

$q_{l(d)}$ = limiting point resistance in dense sand

Piles in Saturated Clay

If embedded length ≥ 5D, $N_c^* = 9$

$$Q_p = 9 \cdot c_u \cdot A_p$$

Example 2

Timber piles, 25' log with 10" point diameter, were driven through a silty sand with $\phi = 25°$ into undrelying dense sandy gravel with $\phi = 40°$. Penetration into the sandy gravel was 3'. Determine point bearing capacity of a pile.

Solution

q_l (silty sand) = $0.5N_q^* \tan\phi = 0.5\times25 \tan 25 = 5.82$ tsf

q_l (sandy gravel) = $0.5\times350\times \tan 40 = 146.8$ tsf

$$q_p = 5.82 + \frac{36}{10\times10}(146.8 - 5.82) = 56.6\text{tsf} < 146.8$$

$$Q_p = \left(\frac{10}{12\times2}\right)^2 \times\pi\times 56.6 = 30.9 \text{ tons}$$

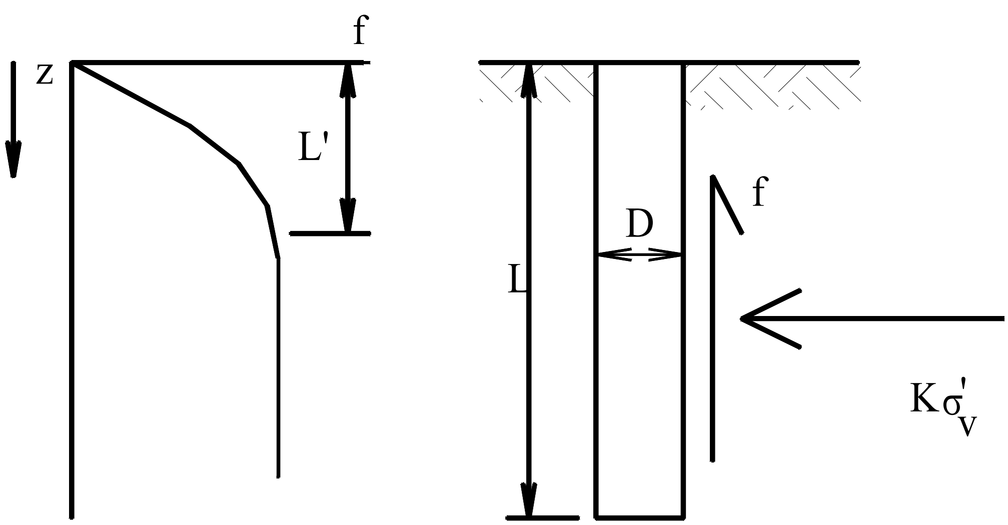
Shaft Resistance

It is due to skin friction and adhesion

$Q_s = \Sigma f \cdot A_s$

A_S = area of shaft surface

f = unit shaft resistance



$$f = K\sigma_o' \tan\delta + c_a$$

δ = soil-pile friction angle
c_a = is adhesion
K = earth pressure coefficient[1]

[1] *which is difficult to evaluate between at-rest and passive state*

Shaft Resistance in Sand

Since $c_a = 0$

$$f = K \cdot \sigma_o' \cdot \tan\delta$$

Like tip resistance a critical depth is reached after which 'f' does not increase. Use $(L'/D)_{critical} = 15$

Values of K

Pile type	K
Bored or jetted	$K_o = 1 - \sin\phi$
low disp. driven	K_o to 1.4 K_o
high disp. driven	K_o to 1.8 K_o or 0.5 +0.008 D_r[1]

[1] *Dr = relative density (%)*

Pile material	δ
steel	20°
concrete	0.75 ϕ
wood	0.67ϕ

$$Q_s = \Sigma p \cdot f \cdot \Delta L$$

p = perimeter

ΔL = incremental pile length for constant p and f.

SPT - basis for shaft resistance in sand

Meyerhof

$$f_{avg}(tsf) = \frac{\overline{N}}{50}$$ high disp. driven piles

$$f_{avg}(tsf) = \frac{\overline{N}}{100}$$ small disp. driven (H-pile)

$$f_{avg}(tsf) = 1.5 \cdot \frac{\overline{N}}{50}$$ pile tapered $> 1\%$

$\overline{N}$ = avg 'N' within embedded pile length

Skin Resistance in Clay[1]

λ Method[2]

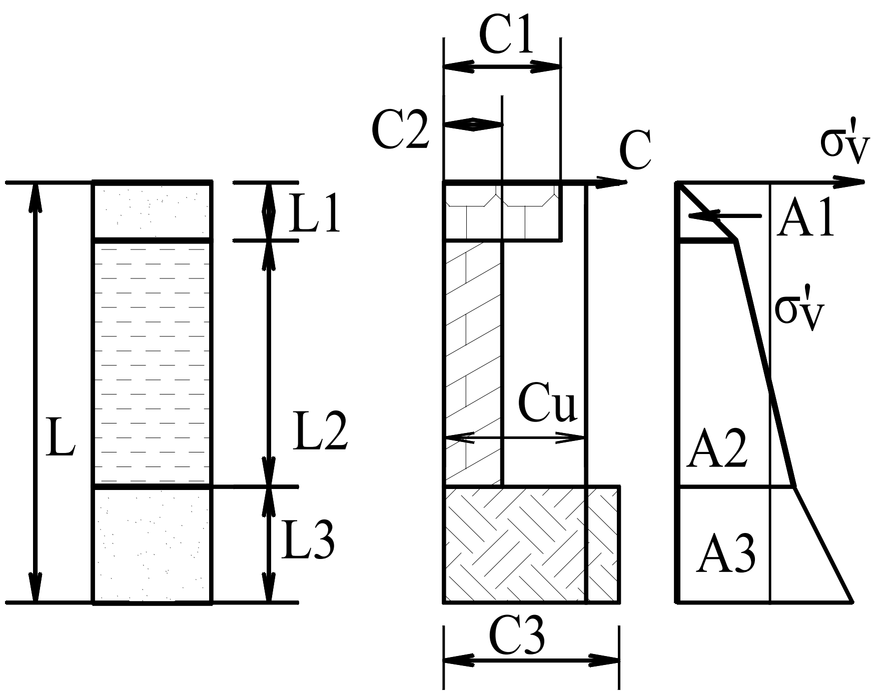
$$f_{av} = \lambda\left(\bar{\sigma}'_v + 2c_u\right)$$

$\bar{\sigma}'_v$ = mean effective vertical stress on pile length

λ- given in Fig. 8.17

$$Q_s = p \cdot f_{av} \cdot L$$

For layered soils use mean values of c_u and σ.



$$c_u = \frac{c_{u(1)}L_1 + c_{u(2)}L_2 + \ldots}{L}$$

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[1] *some problems 1. increase in pore water pressure 2. Low initial capacity 3. enlarged hole near ground surface-water may get in and soften clay. 4.ground and pile heaving. 5. Drag down effect from soft upper soils*

[2] *Short pile were driven in stiff clay OCR>1 but the long piles penetrated lower soft clay as well*

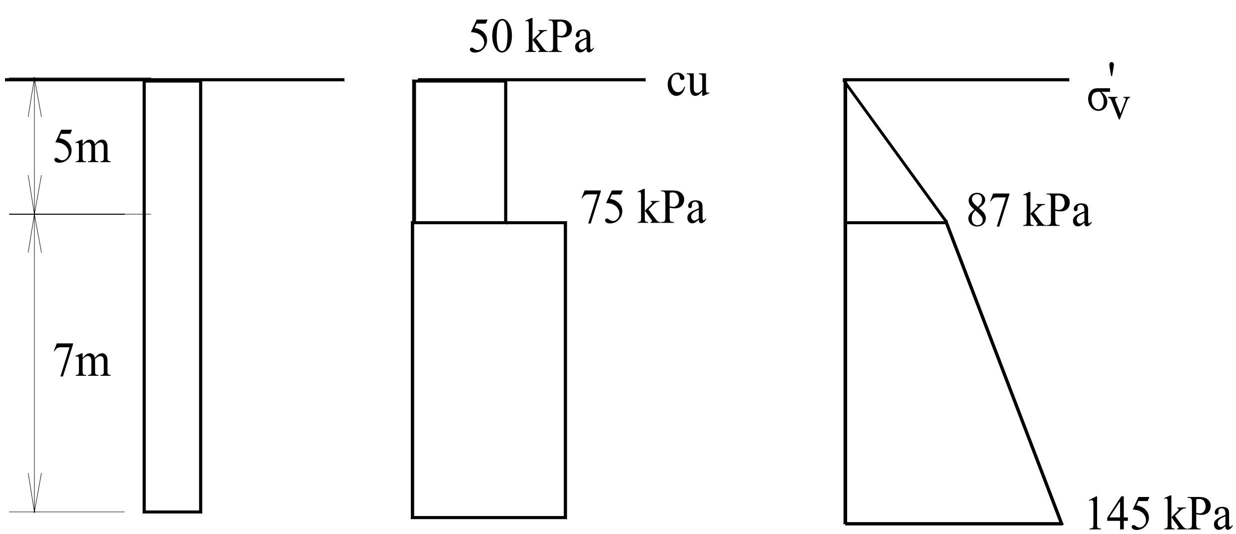
$$\overline{\sigma}_v^{'} = \frac{A_1 + A_2 + A_3 + ...}{L}$$

A_1, A_2, ... are areas of the effective stress diagrams

Example 3

A 12 m prestressed concrete pile 450 mm square is installed in a clay with water table at 5 m depth. Upper clay layer is 5 m thick, with $\gamma = 17.4$ kN/m^3 and $c_u = 50$ kPa. Lower clay has $\gamma = 18.1$ kN/m^3, $c_u = 75$ kPa. Determine pile capacity using λ - method.

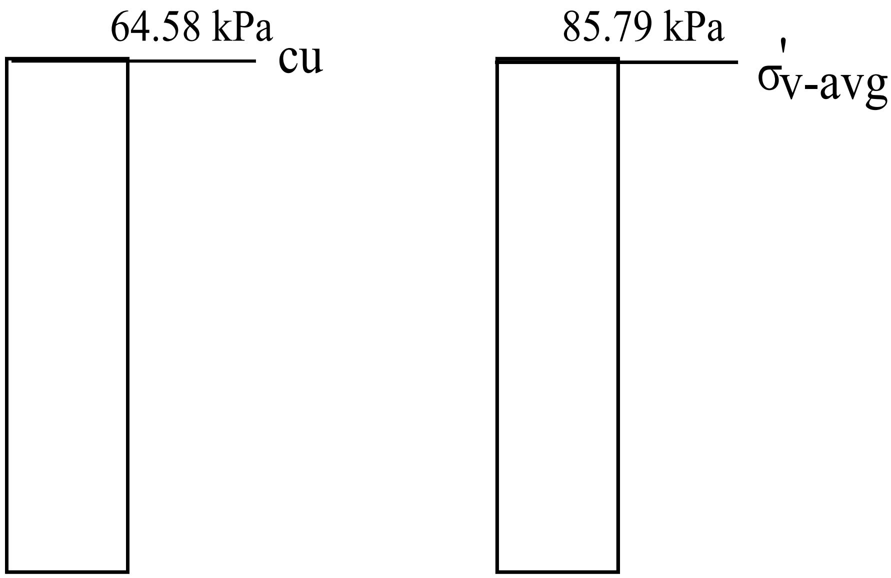
Solution: (λ - method)



$\sigma_5' = 17.4 \times 5 = 87$ kPa, $\quad \sigma_{12}' = 87 + (18.1 - 9.81) \times 7 = 145$ kPa

$$c_u = \frac{50 \times 5 + 75 \times 7}{12} = 64.58\text{kPa}$$

$$\sigma_v' = \frac{0.5 \times 87 \times 5 + 7 \times \frac{87 + 145}{2}}{12} = 85.79\text{kPa}$$



[1]$\lambda = 0.24$

$f_{avg} = 0.24(85.79+2\times64.58) = 51.6$ kPa

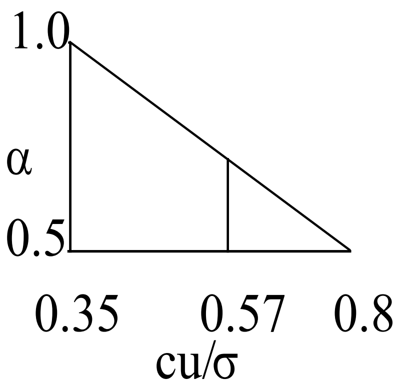
$Q_s = 4\times0.45\times51.6\times12 = 1114$ kN

[1] *Fig 9.17*

Example 4. Redo Example 3 using α - method

$$f = F \cdot \alpha \cdot c_u$$

Upper clay, $\frac{c_u}{\sigma_o'} = \frac{50}{87} = 0.57$



$$\alpha = 0.5 + \frac{1-0.5}{0.8-0.35}(0.8-0.57) = 0.756$$

L/D = 12/0.45 = 26.7, F = 1

Lower clay

$$\frac{c_u}{\sigma_o'} = \frac{75}{145} = 0.517$$

α = 0.814,

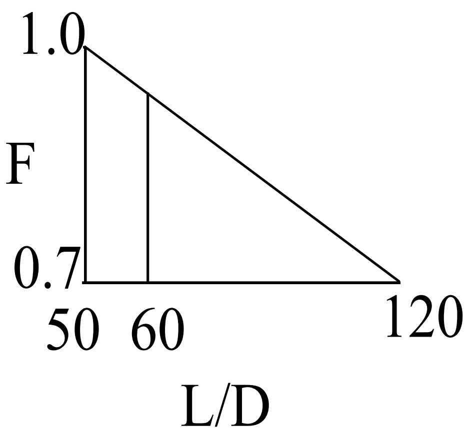
$f_1 = 1\times0.756\times50 = 37.8$ kPa

$f_2 = 1\times0.814\times75 = 61.05$ kPa

$Q_s = 4\times0.45\times5\times37.8 + 4\times0.45\times7\times61.05 = 1109$ kN

Example 5. Redo the Example 3 assuming 200 mm pipe

L/D = 12/0.2 = 60



$$F = 0.7 + \frac{(1-0.7)(120-60)}{120-50} = 0.95$$

$f_1 = 0.95\times0.756\times50 = 35.9$ kPa

$f_2 = 0.95\times0.814\times75 = 58.0$ kPa

$Q_s = \pi(0.2) \times (5\times35.9 + 7\times58.0) = 368$ kN

Example 6

Draw number of blows per inch versus R_u for the following conditions using EN formula, modified Engineering News formula, and Janbu formula. Steel HP10×57, coefficient of restitution (n) = 0.8, efficiency (E) = 0.85, Vulcan 08 hammer. C = 0.1". [1]Use two pile lengths 20' and 80'. Elastic modulus = 29×10^3 ksi

Solution

Hammer energy 26 k-ft, Ram weight 8 kips. Area of steel = 16.8 in^2.

$$C_d = 0.75 + 0.15\frac{57\times 20}{8000} = 0.771$$

Assume S = 0.1"

$$\lambda = \frac{.85\times 20\times 12\times 26}{16.8\times 29\times 10^3\times (0.1)^2} = 13.06$$

$$K_u = 0.771\left(1+\sqrt{1+\frac{13.06}{0.771}}\right) = 40.382$$

R_u (20 ft for S=0.1") = 657 kips

R_u (80 ft for S=0.1") = 354 kips

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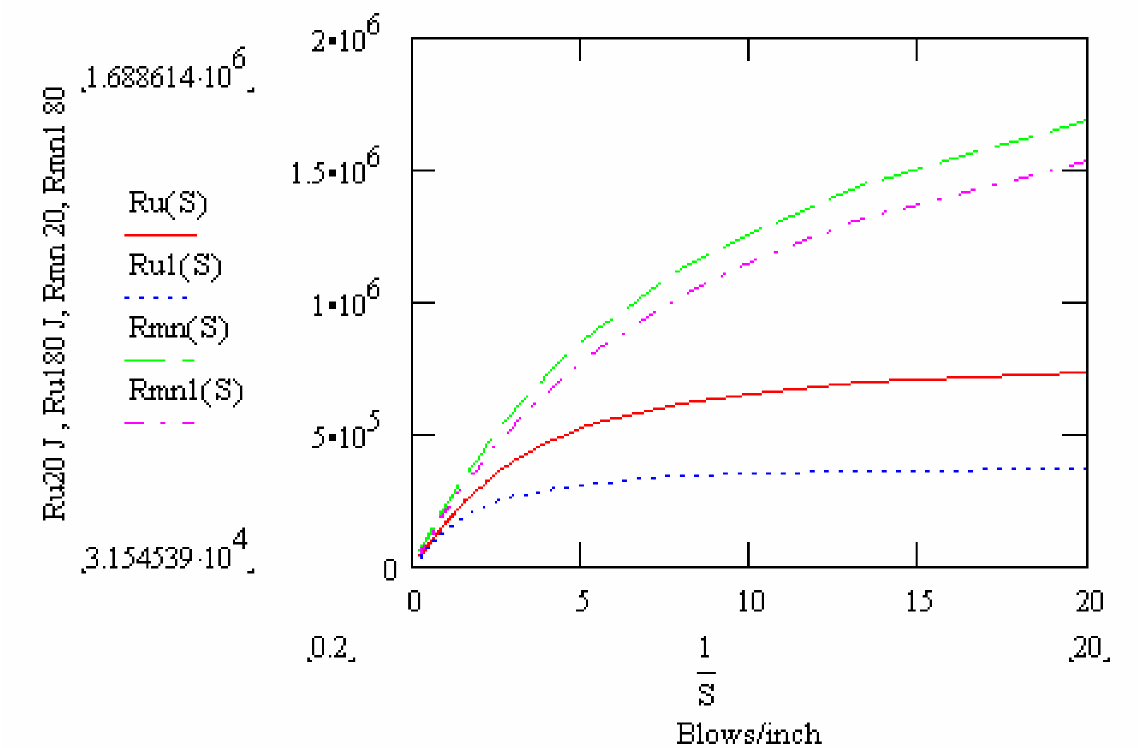
[1] *For plotting graphs assume several R_u and compute set*

Bearing Graph



Ru - Janbu 20', Ru1 - Janbu 80', Rmn = Modified EN 20', Rmn1 = Modified EN 80'

From Modified Engineering New Formula, the following results will be obtained.

R_u (20 ft for S=0.1") = 1266 kips

R_u (80 ft for S=0.1") = 1153 kips

Practical applications

Design

- Using laboratory and field soil data determine Q_u based on static formulae

Test pile

- Drive test piles using same equipment as proposed for production piles.
- If possible use pile driving analyser (PDA) incorporating strain and acceleration data on test pile. Prepare bearing graph.
- Make records of pile driving and correlate with boring logs to ensure that piles have penetrated the bearing soils.
- Load test the pile/s.
- If possible load to failure to establish actual factor safety.
- For small jobs load tests are not justifiable.
- When piles rest on sound bedrock load tests may not be necessary.
- Based on load test adjust design capacity, increase penetration depth, alter driving criteria as necessary.

Construction stage

- Record driving resistance for full depth of penetration
- Driving record must correspond to bearing graph of test pile.

- If not additional penetration into bearing material or greater driving resistance may be necessary.

Wave Equation

- Hammer, cushions, pile cap, and pile are modeled as discrete elements.
- Each element has a mass and there are springs between element of appropriate stiffness
- Soil-pile interface modeled as spring-dash pot. Springs model resistance to driving as a function of displacement and dash pots as function of velocity.

Computations

- Ram of mass M_1 with velocity v_1 travels a distance $v_1 \times \Delta t$ compresses spring K_1 with the same amount.
- Force in K_1 actuates M_2 from which displacements are computed.
- Process is continued for all masses for successive time intervals until pile tip stops moving.
- Software - TTI and WEAP (Wave Equation Analysis of Pile)

Pile Driving Analyser

- Two strain transducers and two accelerometers mounted near pile head
- A pile driving analyser (PDA)

PDA monitors strain and acceleration and yields:

- Force in pile - from strain, E and pile x-sectopm
- Particle velocity - from integration of acceleration
- Pile set - from integration of velocity

CAPWAP(Case Pile Wave Analysis Program):

Hammer and accessories - replaced by force-time and velocity-time time data from PDA, thus eliminating deficiencies of wave equation.