7) Pile-Driving Formulas

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i) ENR formula (F.S. = 6.0)

$$Q_u = \frac{W_R h}{S + C}$$

W_R = weight of the ram
h = height of fall of the ram
S = penetration of pile per hammer blow
C = a constant $\Rightarrow$ depends on hammer blow
(C = 1 inch for drop hammer
C =0.1 inch for steam hammer)

ENR formula is not reliable and gives conservative values.
$\Rightarrow$ The modified ENR formula (F.S. = 4 ~ 6)

$$Q_u = \frac{EW_R h}{S + C} \frac{W_R + n^2 W_p}{W_R + W_p}$$

where E = Hammer efficiency (energy loss due to friction of guide wall and air)
C = 0.1 inch
W_p = weight of the pile
n = coefficient of restitution

Hammer Type	E	Pile material	n
Single and double acting hammer	0.7 - 0.85	Cast iron hammer and Concrete piles (without cap)	0.4 - 0.5
Diesel hammer	0.8 - 0.9	Wood cushion on steel piles	0.3 – 0.4
Drop hammer	0.7 - 0.9	Wooden piles	0.25 – 0.3

ii) Gates formula (F.S. = 3.0) ⇒ simple and relatively reliable

$$Q_u = 4.0\sqrt{EW_R h}\log\frac{25}{s} \quad \text{in cm and tons}$$

Notes

1.

$$\Rightarrow\ Q_{cu} = 9.36\sqrt{EW_R h}\log\frac{25}{s} - 83\,.$$

2.

3.

8) Point Bearing Capacity of Piles Resting on Rocks

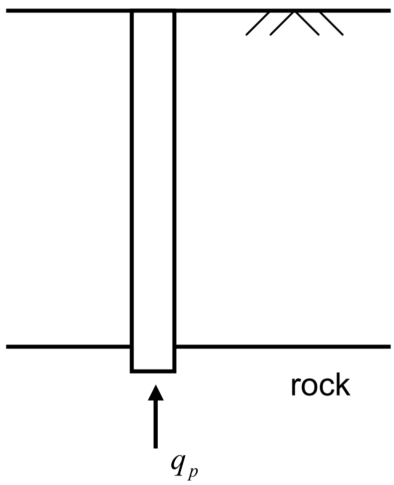
- Point bearing capacity (ultimate point resistance) of piles on rock(Goodman, 1980),

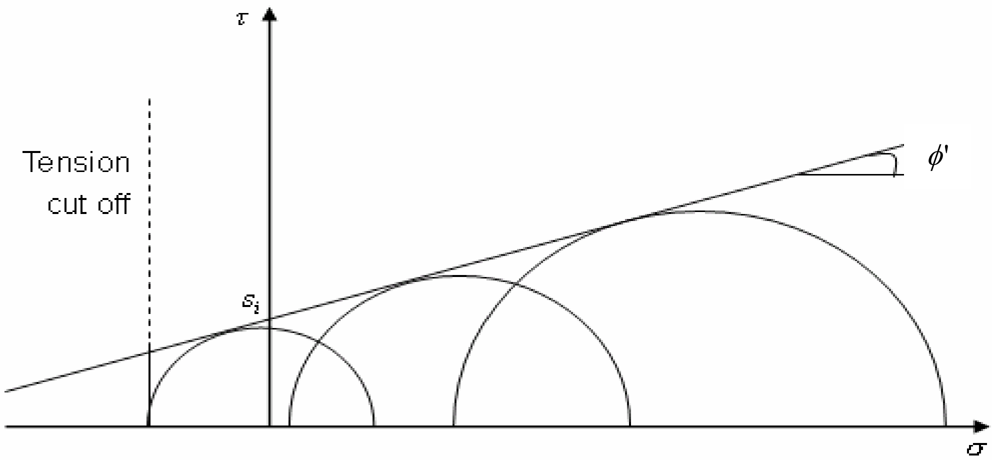
$$q_p = q_u (N_\phi + 1) \text{..........(1)}$$

q_u : unconfined compression strength of rock

$N_\phi = \tan^2(45 + \phi'/2)$

ϕ' : drained angle of friction





- Representative values of ϕ' and q_u

<Typical Unconfined Compressive Strength and Angle of Friction ϕ' of Rocks>

Type of rock	q_u		Angle of friction, ϕ' (deg)
	MN/m^2	lb/in^2	
Sandstone	70-140	10,000-20,000	27-45
Limestone	105-210	15,000-30,000	30-40
Shale	35-70	5,000-10,000	10-20
Granite	140-210	20,000-30,000	40-50
Marble	60-70	8,500-10,000	25-30

- Scale effect on q_u

  As the diameter of the specimen increases, q_u decreases.

  (Due to joints and fissures in rock mass)

  $\Rightarrow$ Diameter $\geq 1m$ $\rightarrow$ q_u remains approximately constant.

  Generally, $q_{u(design)} = \dfrac{q_{u(lab)}}{5}$

- So, allowable point bearing capacity is :

$$Q_{p(all)} = \frac{[q_{u(design)}(N_\phi + 1)]A_p}{F.S.} \qquad \text{(FS} \geq 3.0)$$

- Note : Bearing capacity from above equation cannot exceed the material strength of pile.

9) Elastic Settlements of Piles

The settlement of pile under a vertical load is caused by three factors;

$$S_e = S_{e(1)} + S_{e(2)} + S_{e(3)}$$

where S_e :

$S_{e(1)}$:

$S_{e(2)}$:

$S_{e(3)}$:

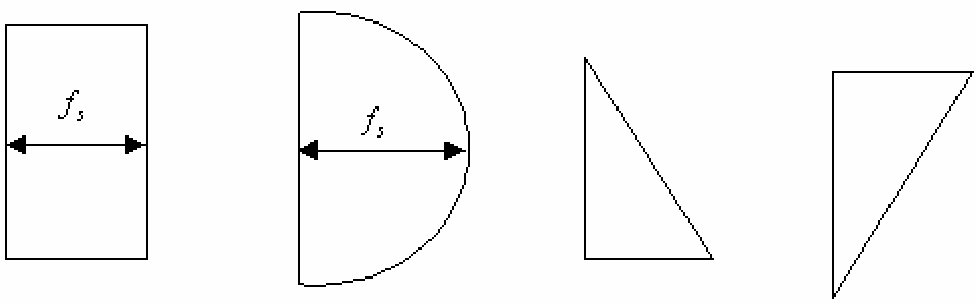
i) Determination of $S_{e(1)}$

$$S_{e(1)} = \frac{p'L}{A_p E_p} = \frac{(Q_{wp} + \xi Q_{ws})L}{A_p E_p}$$

where, Q_{wp} = load carried by the pile point under working load condition.

Q_{ws} = load carried by frictional(skin) resistance under working load condition

ξ = factor that depends on distribution of frictional resistance along the pile shaft.



$\xi = 0.5$ $\xi = 0.5$ $\xi = 0.67$ $\xi = 0.33$

ii) Determination of $S_{e(2)}$

(similar to that given for shallow foundation)

$$S_{e(2)} = \frac{q_{wp} D}{E_s}(1-\mu_s^2) I_{wp}$$

where D =width or diameter of pile, $q_{wp} = \frac{Q_{wp}}{A_p}$,

and $I_{wp} \approx 0.85$.

By Vesic, (semi-empirical method)

$$S_{e(2)} = \frac{Q_{wp} C_p}{D q_p}$$

where, q_p = ultimate point resistance

C_p = an empirical coefficient

<Typical values of C_p [from Eq.(11.75)]> (Vesic (1977))

Type of soil	Driven pile	Bored pile
Sand (dense to loose)	0.02-0.04	0.09-0.18
Clay (stiff to soft)	0.02-0.03	0.03-0.06
Silt (dense to loose)	0.03-0.05	0.09-0.12

iii) Determination of $S_{e(3)}$

$$S_{e(3)} = (\frac{Q_{ws}}{pL})\frac{D}{E_s}(1-\mu_s^2)I_{ws}$$

where *(Q_{ws}/pL)* ≡ average value of frictional resistance along the pile shaft

I_{ws} ≡ influence factor

$= 2 + 0.35\sqrt{L/D}$ (by Vesic)

By Vesic, (simple empirical relation)

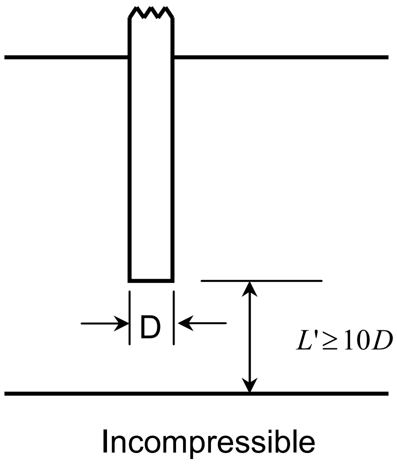
$$S_{e(3)} = \frac{Q_{ws}C_s}{Lq_p}$$

C_s ≡ an empirical coefficient

$= (0.93 + 0.16\sqrt{L/D})C_p$

Notes

1. Valid when



$$L'/D = 5. \Rightarrow S_{e(L'/D=5)} = 0.9 S_{e(L'/D \geq 10)}$$

$$L'/D = 1. \Rightarrow S_{e(L'/D=1)} = 0.1 S_{e(L'/D \geq 10)}$$

2. Short term movements (immediate elastic settlements) only;

   So if we have a compressible stratum of low permeability below pile tip, we must calculate consolidation settlements in that stratum and add them to the short-term settlements.