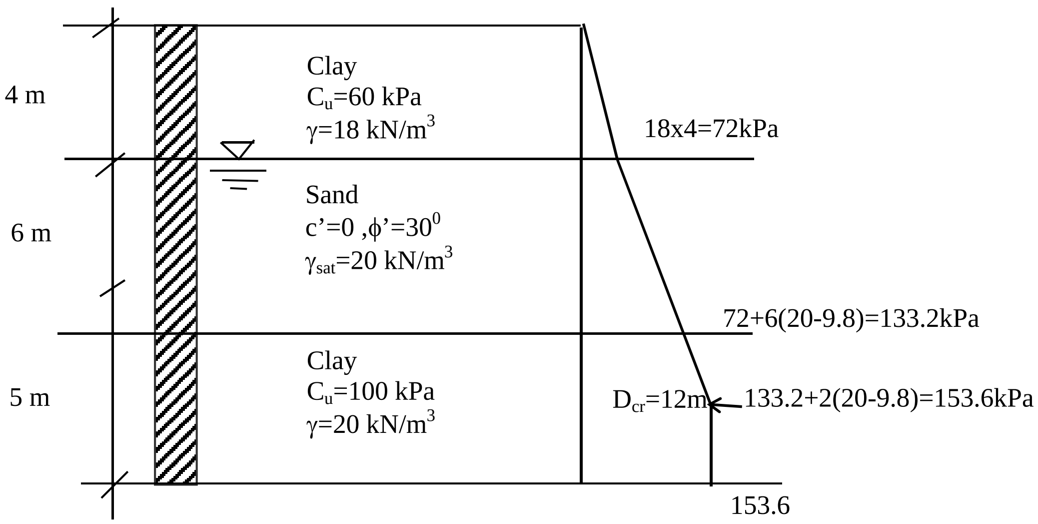
# CE 366 – PILE FOUNDATIONS

## Q1) ULTIMATE BEARING CAPACITY OF SINGLE PILES

**Question**

Determine the ultimate bearing capacity of the 800mm diameter concrete, bored pile given in the figure below. Assume $D_{cr}$ = 15*diameter; and the pile-friction angle =0.75$\phi'$

$D_{cr}$=15*0.8=12m




**Solution**

Ultimate capacity of pile:

$Q_{ult}=Q_p+Q_s$

- $Q_p= N_c.c_u.A_p= 9c_uA_p =9x100x[\pi x(0.8)^2/4]$ = <u>452 kN</u>

  $N_c$ : Fig 4.6, pp 73 of Lecture Notes

- $Q_s = Q_{s1} + Q_{s2} + Q_{s3}$
- where $Q_{s1}$ (0 < z < 4m), $Q_{s2}$ ( 4 < z < 10m), and $Q_{s3}$ (10 < z < 15m),

$Q_{s1}= \alpha.c_u.A_s$ = 0.8x60x($\pi$x0.8x4) = <u>483kN</u>

  $\alpha$ : pp 215 of Lecture Notes

$Q_{s2}= K_s.\sigma_{vo}'.\tan\delta.A_s$ ; where

  $K_s$ = 0.5 (pp 215 of Lecture Notes), $\delta$=0.75, $\phi'$ =22.5$^0$

  $A_s$ = p.L = ($\pi$x0.8)x6 =15.08 $m^2$

$Q_{s2}$=0.5x[(72+133.2)/2]xtan(22.5)x15.08 =<u>320 kN</u>

$Q_{s3}= \alpha.c_u. A_s$ =0.58x100x($\pi$x0.8x5) = <u>729kN</u>

$Q_{ult}$=452+(483+320+729)=**1984 kN**

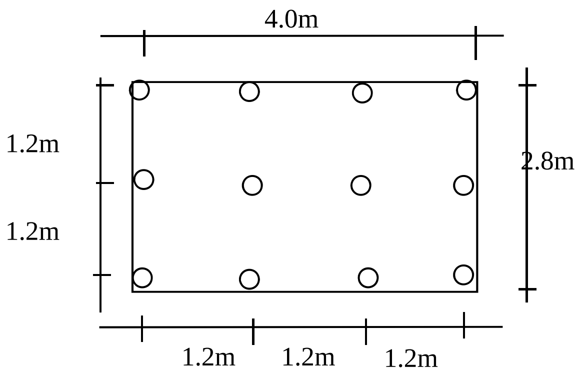
# Q2) PILE GROUP CAPACITY

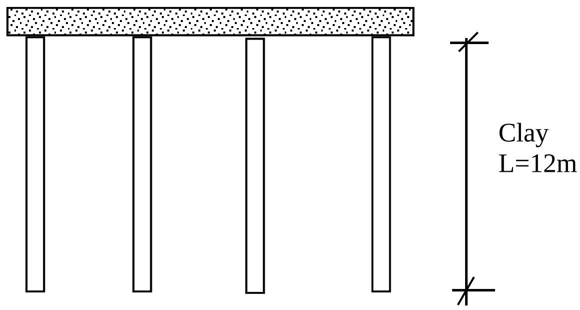
## Question

Find the allowable bearing capacity of a single pile in the group of piles given below, by using: (Diameter : 0.4m, $C_u$=50kPa, $\gamma$=18kN/m$^3$, and use F.S.=2.5)

a) Converse-Labarre Formula

b) Terzaghi-Peck Method




## Solution

a)

$Q_{ult}=Q_p+Q_s$

- $Q_p=9c_uA_p=9\text{x}50\text{x}\pi\text{x}(0.4)^2/4 = 56.5$ kN
- $Q_s=\alpha.c_u.A_s=0.84\text{x}50\text{x}\pi\text{x}0.4\text{x}12 = 633$kN

$Q_{ult}$ = 56.5+633 = 689.5 kN

$Q_{all}$ = 689.5 / 2.5 ≅ **275.8 kN**

**Converse-Labarre(Group action reduction)**

$$E = 1-\theta\left[\frac{(n-1)m+(m-1)n}{90mn}\right]$$

m= # of rows=3

n= # of piles in a row=4

$\theta$ = arctan(D/s)=arctan(0.4/1.2)=18.4$^0$

D=diameter

s=spacing(center to center)

$$E = 1 - 18.4\left[\frac{(4-1)3+(3-1)4}{90x3x4}\right] = 0.71$$

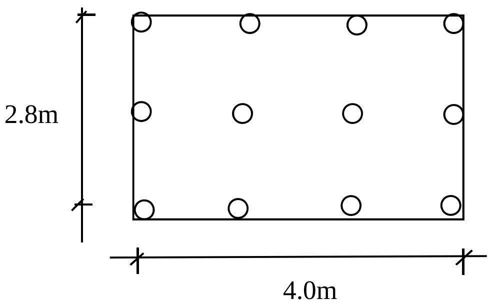
$(Q_{all})_{\text{single pile in the group}} = 275.8x0.71 =$ **195.8 kN**

**b)**

**<u>Terzaghi_Peck Group Reduction Method:</u>**

$(Q_g)_{ult} = \overbrace{pD_f c_u}^{\text{Skin fric.}} + \overbrace{A(q_{ult})_{net}}^{\text{Tip resist.}}$ ; $(q_{ult})_{net} = q_{nf} = c_u N_c$

$= pD_f c_u + Aq_{ult} - AD_f \gamma$




$p = 2(2.8+4.0) = 13.6m$

$A = 2.8x4 = 11.2m^2$

$Q_g = 13.6x12x50 + 11.2(50x8.6) = 12976kN$

$(Q_{ult})_{\text{for single pile}} = 12976/12 = 1081$ kN

$(Q_{all})_{\text{for single pile}} = 1081/2.5 = 432.5$ kN > 275.8 kN

> 195.8 kN

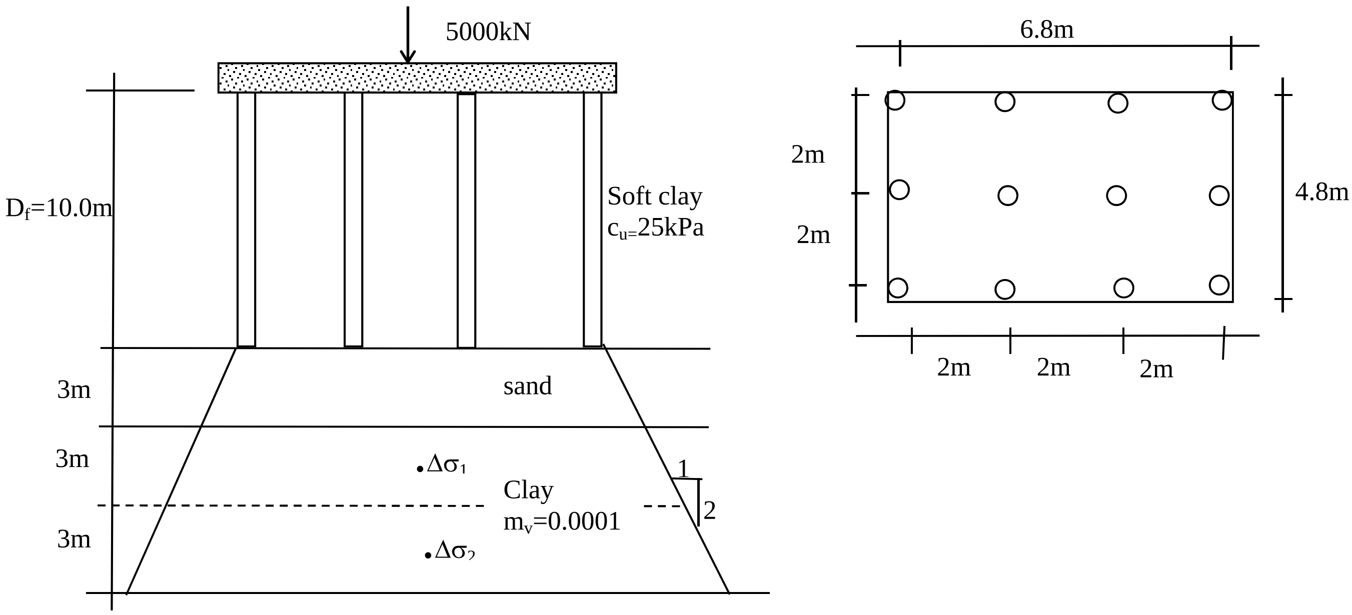
Bearing capacity is not controlled by $Q_{group}$; therefore:

$(q_{all})_{\text{single pile}} =$ **<u>195.8 kN</u>**

# Q3) SETTLEMENT OF PILE GROUPS

**Question**

Calculate the consolidation settlement of the 12 pile group consisting of 10 m long end bearing piles. Piles are 80 cm in diameter and spaced at 2m center to center in either direction. Pile group carries a vertical load of 5000 kN including the weight of the pile cap. Use 2:1(V:H) pressure distribution and divide the layer into two equal layers.




**Solution**

Stress distribution begins at the bottom of the pile group in stiff clay media. In the case of soft clay the distribution should be started at depth of 2/3 of L where L is the length of the pile.

$s = H \times m_v \times \Delta\sigma$

$\Delta\sigma_1 = 5000/((6.8+4.5)x(4.8+4.5)) = 47.6\ kN/m^2$

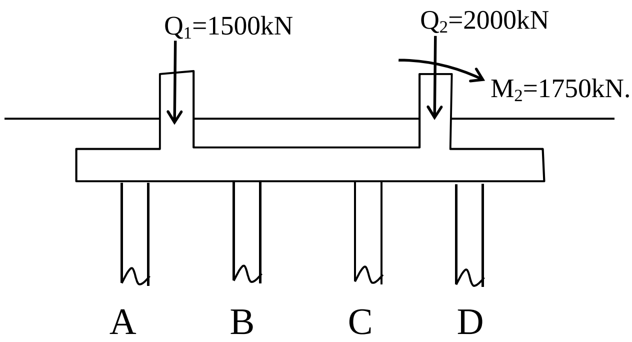
$\Delta\sigma_2 = 5000/((6.8+7.5)x(4.8+7.5)) = 28.4\ kN/m^2$

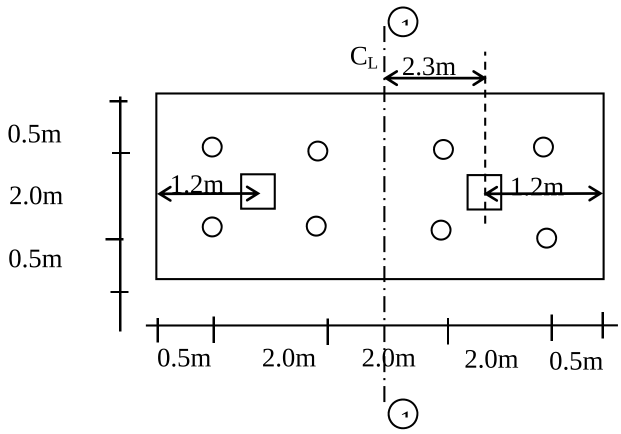
s=3x0.0001x(47.6+28.4)=0.0228m=**2.28cm**

# Q4) LOAD ON PILES

**Question**

Find the maximum and minimum vertical load in the pile group given below




**Solution**

$\Sigma Q$=3500kN

$$e = \frac{2000 * 2.3 + 1750 - 1500 * 2.3}{3500} = 0.83m$$

M=$\Sigma$Qxe=3500x0.83=2900kN.m

$I_{1-1}$=2x(2x$1^2$+2x$3^2$)=40pile-$m^4$

due to piles

$Q_i$=$\Sigma$Q /n ± Mx$d_i$ /I

$Q_D$=3500/8+2900x3.0 /40 = **<u>655 kN(max)</u>**

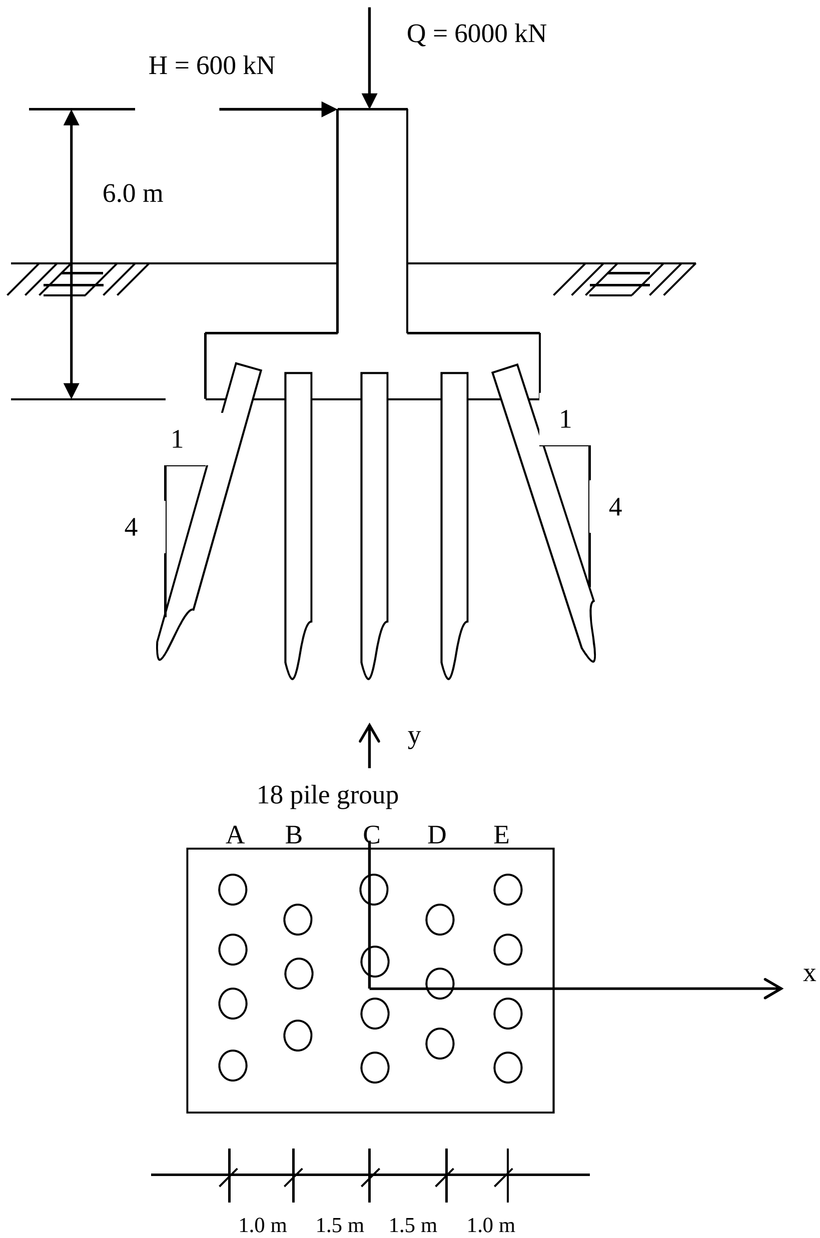
$Q_A$=3500/8-2900x3.0 /40 = **<u>220 kN(min)</u>**

# Q5) BATTER PILES

## Question

One of the legs of a steel structure rests on a concrete pedestal footing which is supported by a group of 18 piles. Outside rows are formed from batter piles (1 to 4) as shown below. Each pile is permitted to resist an horizontal force of 25 kN.

a) Calculate axial loads on all piles.
b) Could the unbalanced horizontal force be overcome?
c) If the allowable bearing value of single pile is equal to 600 kN, state whether or not this pile foundation is safe.



**Solution**

a)

- $M = 6 * 600 = 3600 kN - m$
- $I = 2 * \left(3 * 1.5^2 + 4 * 2.5^2\right) = 63.5 pile - m^2$

- Vertical Component of pile loads:

$$Q_i = \frac{Q}{n} \pm \frac{M}{I} * x_i$$

$$Q_A = \frac{6000}{18} - \frac{3600}{63.5} * 2.5 = 192 kN$$

$$Q_B = \frac{6000}{18} - \frac{3600}{63.5} * 1.5 = 248 kN$$

$$Q_C = \frac{6000}{18} = 333 kN$$

$$Q_D = \frac{6000}{18} + \frac{3600}{63.5} * 1.5 = 418 kN$$

$$Q_E = \frac{6000}{18} + \frac{3600}{63.5} * 2.5 = 475 kN$$

- Axial loads:

$$\tan\alpha = \frac{1}{4} \rightarrow \cos\alpha = 0.970$$

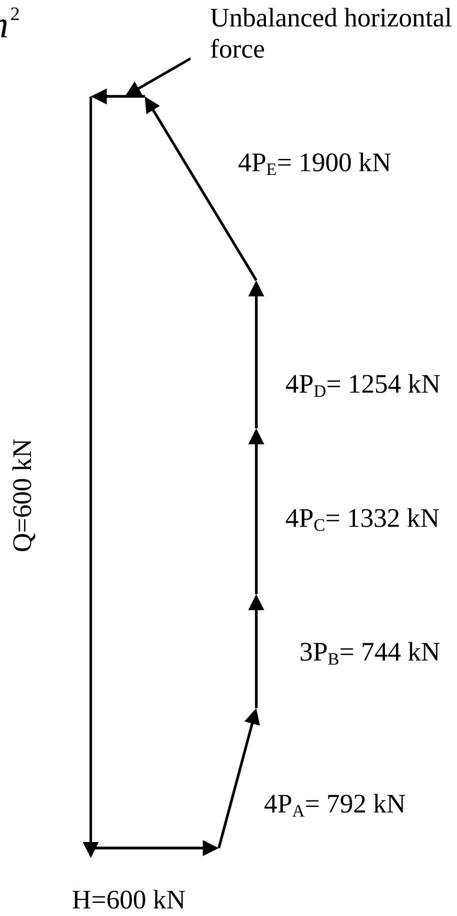
$$P_A = \frac{Q_A}{\cos\alpha} = \frac{192}{0.970} = 198$$

$$P_B = Q_B = 248 kN$$

$$P_C = Q_C = 333 kN$$

$$P_D = Q_D = 418 kN$$

$$P_E = \frac{Q_E}{\cos\alpha} = \frac{475}{0.970} = 490 kN$$




NOT SCALED

b)

- Unbalanced horizontal force:

$$H_u = 600 + 4 * 192 * \frac{1}{4} - 4 * 475 * \frac{1}{4} = 317 kN$$

c)

- Available horizontal resistance:

$H_r = 18 * 25 = 450 kN$. Since $H_u < H_r$ $\therefore$ Unbalanced force is overcome.

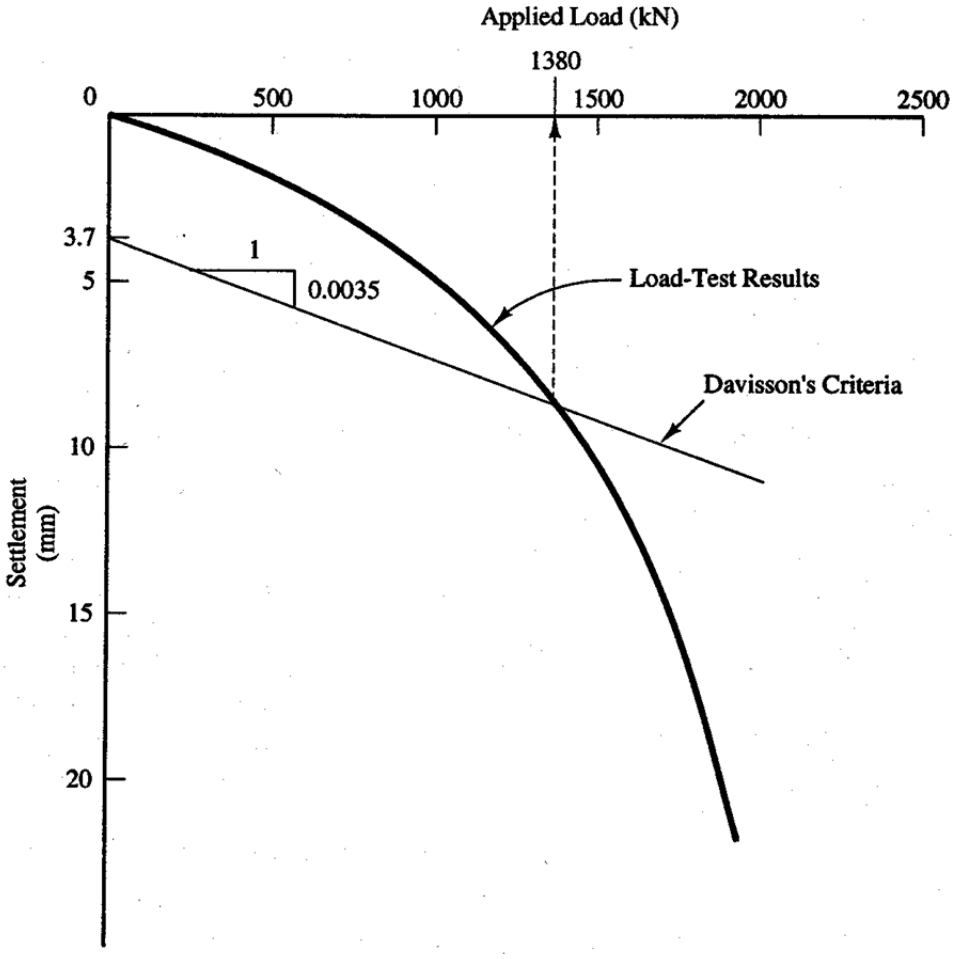
- Maximum axial load:

$P_{max} = 490 kN < P_{all} = 600 kN$ **(Foundation is safe)**.

# Q6) INTERPRETATION OF PILE LOAD TEST

## Question

The load-settlement data shown in the figure were obtained from a full-scale load test on a 400 mm square, 17 m long concrete pile (28-day compressive strength of concrete, $f_c' = 40$ MPa). Use Davisson's method to compute the ultimate downward load capacity.




## Solution

Davisson's method defines the ultimate capacity as that which occurs at a settlement of $0.012B_r + 0.1B/B_r + PL/(AE)$. The last term in this formula is the elastic compression of a pile that has no skin friction.

B= Diameter of the pile $\quad$ $B_r$= Reference width = 300 mm

P= Applied load $\quad$ L= Length of the pile

A= Cross-section area of the pile

E= Modulus of elasticity of the pile

200,000 MPa for steel

11,000 MPa for timber

$15{,}200\sigma_r\,(f_c^{'}/\sigma_r)^{0.5}$ for concrete where reference stress, $\sigma_r = 0.1$ MPa

$E = 15{,}200\sigma_r\,(f_c^{'}/\sigma_r)^{0.5} = (15{,}200)(100\text{ kPa})(40\text{ MPa} / 0.10\text{ MPa})^{0.5}$

$= 30.4 * 10^6$ kPa

$$\text{Settlement} = 0.012B_r + \frac{0.10B}{B_r} + \frac{PL}{AE}$$

$$= 0.012*300 + \frac{0.10(400)}{300} + \frac{P(17{,}000)}{400^2(30.4*10^6)(1*10^{-6}m^2/mm^2)}$$

$$= 3.7mm + 0.0035P$$

Plotting this line on the load-displacement curve produces **$P_{ult}$ =1380 kN**

# Q7) PILE DRIVING ENERGY CORRECTION

**Question**

400 mm square concrete piles are to be driven to depth of 12.5. m. What should be the stroke of a 1.5 ton rammer, due to the Danish Formula, if the amount of penetration should be about 5 mm/blow for the safe working load of 2000 kN on the pile? ($E_{conc} = 30*10^6$ kN/m$^2$)

**Solution**

$$A_{pile} = 0.4^2 = 0.16\,m^2$$

$$Q = \sqrt{\frac{W_r * H}{s + 0.5*c_2}}, c_2 = \sqrt{\frac{2\cdot Wr\cdot H\cdot L}{A\cdot E}}$$

$$c_2 = \sqrt{\frac{2\cdot(1.5\cdot 9.8)\cdot H\cdot 12.5}{0.16\cdot 30\cdot 10^6}} = \sqrt{\frac{H}{13100}}$$

$$Q = 2000 = \frac{14.7\cdot H}{0.005 + 0.5\cdot\sqrt{\frac{H}{13100}}} \Rightarrow$$

$$H = 1.4\,m$$

where

Wr: weight of rammer

H: stroke

L: Length of bored pile

s: average set

A: Area

E: Modulus of elasticity