# INTERACTION BETWEEN A SQUARE PILE RAFT EMBEBED INTO THE SUBSOIL FOUNDATION

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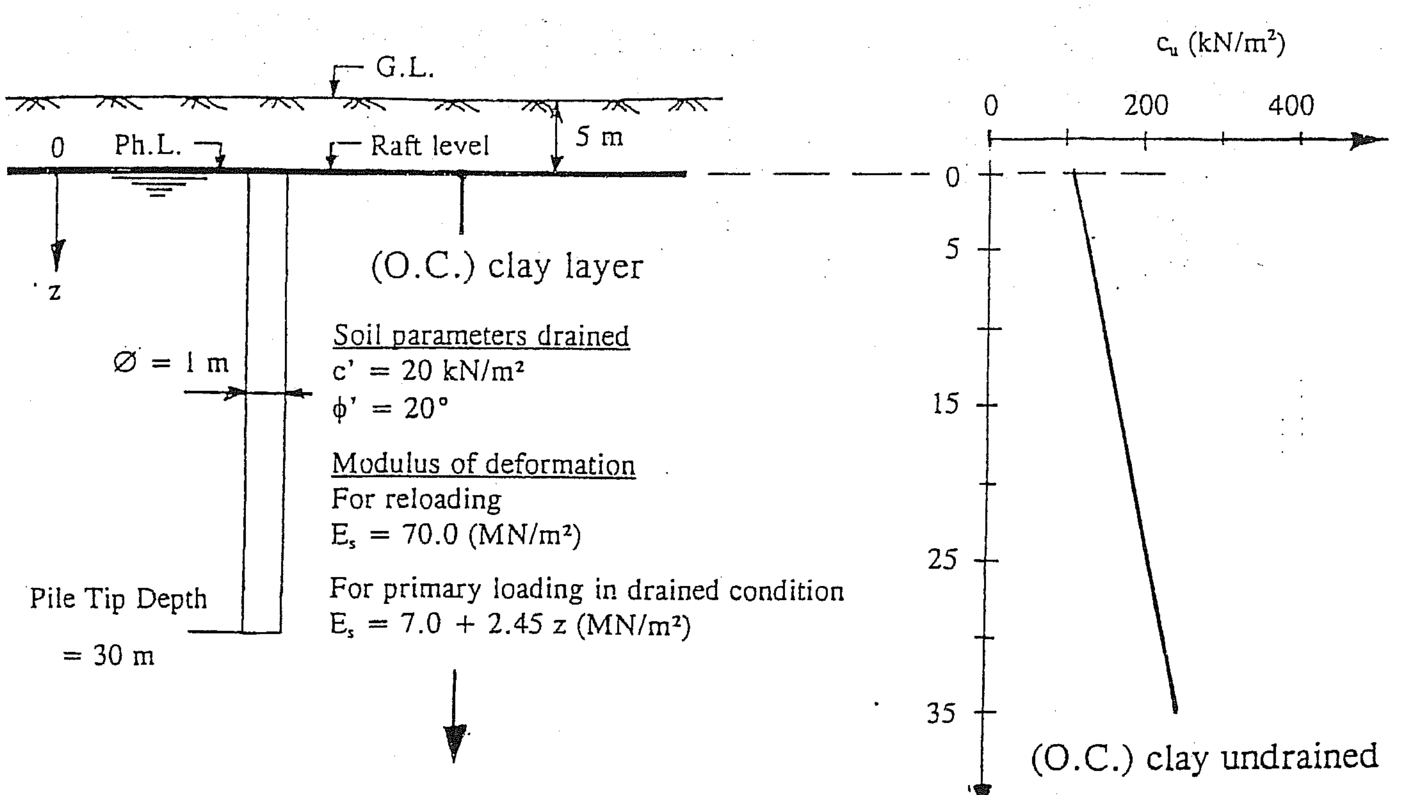
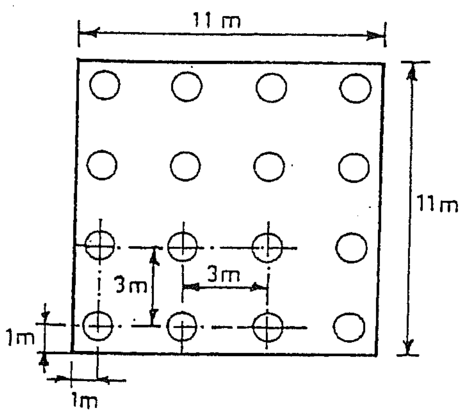
Copia del original enviado al TC-18 como resolución del ejemplo académico.




Square piled raft




A CASE STUDY PRESENTED BY
Dr. VAN IMPE TO ALL MEMBERS
OF ITC - 18 MAY 1998

Square piled raft

raft

| | | |
|---|---|---|
| - level of soil-raft interaction | : | at Phr. level (at 5 m depth) |
| - thickness of raft in concrete | : | 2 m |
| - area of raft | : | 11 m x 11 m |
| - total load ; (uniformly spread) on top of the raft | : | 80 MN |

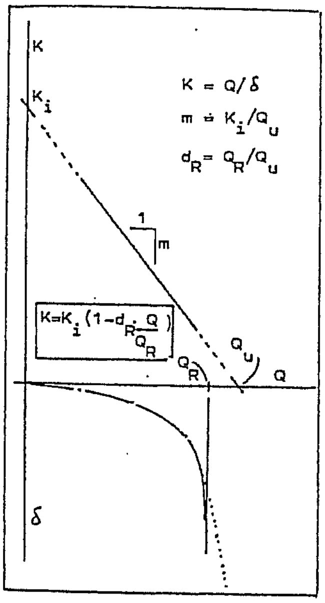
piles

- 16 reinforced concrete, 'ideally' bored piles

| | | |
|---|---|---|
| - $E_{concrete}$ | : | 35000 Mpa |
| - Ø = 1 m | : | 1 m |
| - pile tip at depth of | : | 30 m |
| - pile interdistance (axis to axis) | : | 3m |

INTERACTION BETWEEN A SQUARE PILED RAFT EMBEDED INTO THE SUBSOIL FOUNDATION

1.- Settlement of a rigid cap (C) into the ground, as an indidual footing, can be evaluate by this expression: $\delta_C = 1 / \left[ K_{Ci} ( 1/Q_C - d_{RC}/Q_{CR} ) \right]$ in which $\delta_C$: rigid cap settlement; $K_{Ci}$: equivalent "constant" spring at the origin; $Q_C$: central load transmited by the cap, which is considered as an isolated base; $Q_{CR}$: load bearing capacity of cap at "failure"; $d_{RC}$: $Q_{CR}/Q_{Cu}$ being $Q_{Cu}$ the "ultimate" load when the lineal relation between K = Q/δ and Q is accomplished ( $K = K_i - m.Q$ ) .




2.- For an individual rigid pile, the settlement $\delta_o$ can be estimated by $\delta_o = 1 / \left[ K_{Pi} ( 1/Q_P - d_{RP}/Q_{PR} ) \right]$ .

3.- A group of piles (G) under a rigid cap (C) with approximately square form, compared with a single pile, settle according to these empirical formulas

$\delta/\delta_o = \left[ 2B(m)/B(m)+B_o(m) \right]^n$ ▦ $\delta/\delta_o = r/ 1 + \alpha (r-1)$

($B_o$: sigle pile diameter ; B : width of group ; $r = B/B_o$ ) .

- ▦ pile group through soft soils resting into very dense sands or gravelly sands — $n=2$ ; $\alpha = 0,2$
- ▦ Idem for medium dense sands or grav. sands — $n=3$ ; $\alpha = 0,1$
- ▦ Idem a group of piles working prevailingly by friction — $n=4$ ; $\alpha = 0,05$

4.- The load $Q_T$ transmited by the cap resting on piles, produce a settlement $\delta_T = \delta_C = \delta_G$ . To this value, the cap and the group of piles take loads whose total sum is $Q_C + Q_G = Q_T$ . This expression can be writen

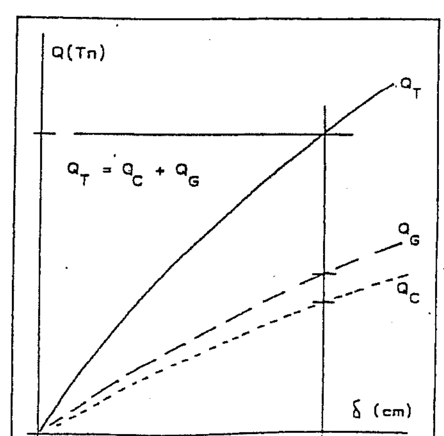
$$\frac{K_{Ci}}{\frac{1}{\delta} + K_{Ci} \cdot d_{RC}/Q_{CR}} + \frac{K_{Gi}}{\frac{1}{\delta} + K_{Gi} \cdot d_{RG}/Q_{GR}} = Q_T \quad \text{that became} \quad a\delta^2 + b\delta + c = 0$$

wherein $a = K_{Ci} . K_{Gi} \left[ ( d_{RC}/Q_{CR} + d_{RG}/Q_{GR} ) - d_{RC}/Q_{CR} . d_{RG}/Q_{GR} . Q_T \right]$

$b = K_{Ci} + K_{Gi} - ( K_{Ci} . d_{RC}/Q_{CR} + K_{Gi} . d_{RG}/Q_{GR} ) \, Q_T$ ▦ $c = - Q_T$

Solving the equation, the global foundation settlement can be estimated and the respective fraction of the total load on the global foundation $Q_T$ , in this case $Q_C$ and $Q_G$ , can be evaluated.

5.- The problem is solved appling the equality $Q_C + Q_G = Q_T$ . Dividing by δ , we have $K_C + K_G = K_T$ and for $Q = 0$ , $K_{Ci} + K_{Gi} = K_{Ti}$ The value of $K_T$ can be calculated with $K_T = K_{Ti} ( 1 - d_{RT} . Q_T / Q_{TR} )$ $K_T = Q_T / \delta_T$ . From $\delta_T$ we have the values of $Q_C$ and $Q_G$ . When "cap and group m values" are very different, the matching should be made from the $m_T$ value.




NOTE: The results of this semiempirical approach could be into ± 30% of the true values.

A CASE STUDY PRESENTED BY Dr. W.F. VAN IMPE (Second case, dated 05.05.98)

CAP square $\bar{B}$=11m ; A=$\bar{B}^2$=121m$^2$ ; $t_C$=2m ; $D_f$=5m ⁞ Piles $B_o$=1m ; d=3$B_o$=3m ; n=16 $L_P$=30m ; B=3d+1=10m ; Reinforced concrete "ideally" bored piles ⁞ Total load above cap: 80 MN = 8000 Tn ; Concrete: 35000MPa = 350x10$^4$Tn/m$^2$ = $E_b$ ⁞ Subsoil : (O.C.) clay undrained $c_u$ = 110 + 3,93 z (kN/m$^2$) ; z(m) starting from $D_f$ = 5m

<u>CAP</u> (as isolated footing): C $c_u$=110+3,93x2/3x11=140kN/m$^2$=14 Tn/m2;$q_u$=28Tn/m$^2$; $E_i \cong 300 q_u \pm$ 30% ; $E_i$=300x28=8400Tn/m2 ; $k_i$=1,1x1,5x8400/11=1260Tn/m$^3$; I=11x2$^3$/12 = 7,33m$^4$ ; $\mathcal{L}_i$=10(4x350x7,33/1260x11)$^{0.25}$=9,3m ; $\mathcal{L}_i \sim$ B ∴~rigid cap
$K_i$=$k_i$A=1260x121=1525Tn/cm ; $Q_{CR}$=$p_r$A=(c$N_c$.$s_c$$d_c$+$\bar{q}$)A~13100Tn ; subsoil:stiff to very stiff $d_{RC}$~0,85 ; $Q_{Cu}$=13100/0,85=15412Tn ; $m_C$=$K_i$/$Q_{Cu}$=1525/15412~0,1 cm$^{-1}$
$Q_C$ = $K_{Ci}$/(1/$\delta_C$ + $m_C$) = 1525/( 1/$\delta_C$ + 0,1) $Q_C$(Tn) ; $\delta$ (cm)

<u>PILE</u> <u>Friction</u> $Q_F$=π$B_o$L$f_s$=π x1mx30mx10Tn/m2=942Tn ; $\delta_{RF}$~10$^{-3}$L ± 30%
$\delta_{RF}$~3cm ; $K_{RF}$=942/3=314Tn/cm ; $d_{RF}$~0,75 ; $K_{iF}$=$K_{RF}$/(1-$d_R$)=1256Tn/cm ; $Q_{uF}$=942/0,7 =1256Tn ; m=$K_{iF}$/$Q_{uF}$=1 ; $Q_F$(Tn) = 1256/ (1/δ ) + 1 ; (cm)
<u>Point</u> $Q_{RP}$=c$N_c$+$\bar{q}$ ; $c_u$ = 110+3,93x30=22,8 Tn/m2 ; $\bar{q}$ = 9+0,75x30=31,5Tn/m2 ;
$Q_{RP}$=(22,8x15+31,5) π/4=293Tn ; $E_i \cong$300x2x22,8 = 13680Tn/m2 ; $K_{iP}$=$k_i$$A_P$= =(1,5x1,5x13680/1 xπ1$^2$/4)/100=242 Tn/cm ; $d_{RP}$=0,85 ; $Q_{uP}$=293/0,85=345 Tn ;
m = 242/345 = 0,7

$\delta_G = \beta \cdot \delta_P$ ; $\beta$ = 9

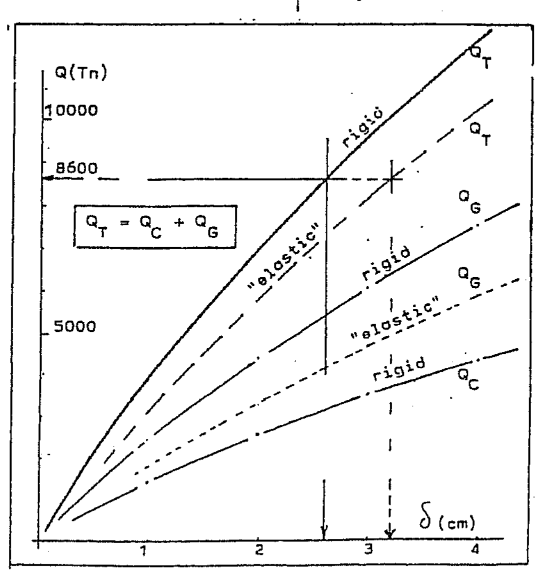
| $\delta_T$ (cm) | $\delta_P$ (cm) | $Q_P$ (Tn) | $Q_G$ (16$Q_P$) (Tn) | $Q_C$ (Tn) | $Q_T$ (Tn) |
|---|---|---|---|---|---|
| 1 | 1/9 | 151 | 2415 | 1386 | 3801 |
| 2 | 2/9 | 276 | 4412 | 2542 | 6954 |
| 2,6 | 2.6/9 | 341 | 5453 | 3147 | 8600 |
| 3 | 3/9 | 381 | 6091 | 3519 | 9610 |
| 4 | 4/9 | 470 | 7523 | 4357 | 11880 |

| δ (cm) | $Q_P$ (Tn) | $Q_F$ (Tn) | $Q_T$ (Tn) | δ +Δδ (cm) | K=$Q_T$/δ (Tn/cm) |
|---|---|---|---|---|---|
| 0,1 | 22,6 | 114,2 | 136,8 | 0,15 | 913 |
| 0,25 | 51,5 | 251 | 303 | 0,36 | 841 |
| 0,5 | 89,6 | 419 | 508 | 0,685 | 742 |
| 1 | 142 | 626 | 770 | 1,28 | 602 |
| 2 | 201 | 837 | 1039 | 2,38 | 437 |
| 3 | 234 | 942 | 1176 | 3,43 | 343 |
| 5 | 268 | 1047 | 1315 | 5,48 | 240 |

"elastic ": $K_{iP}$=1050Tn/cm ; $d_{RP}$=0,772
m = 0,614 cm$^{-1}$
"rigid ": $K_{iP}$=1500Tn/cm;$d_{RP}$=0,772;m=0,94

Parameters for an individual pile:
$Q_{RP}$ = 942+293 = 1235 Tn ; $K_{iP}$ = 1256+242 = = 1500 Tn/cm ; $Q_{uP}$ = 1256+345 = 1600 Tn ;
m = 1500/1600 = 0,94 cm$^{-1}$
$Q_P$ (Tn) = 1500 / (1/δ ) + 0,94 ; δ (cm)

<u>GROUP OF PILES</u> (G) weight of cap = 600 Tn
$Q_T$=8000+600=8600Tn ; $Q_P$=8600/16 = 540 Tn
$\delta_o$=1/($K_{iP}$/$Q_P$ - m)=1/ (1500/540)-0,94 ≅ 0,55cm
$\delta/\delta_o$=(2B/ B+$B_o$)$^4$= 2x10/910+1) $^4$ = 11
δ $\delta_o$= r/ 1+α(r-1) = 10/(1 + 0,05x9) = 7
average $\delta/\delta_o$ = β = ½(11+7) = 9
$K_{Gi}$= 16$K_{Pi}$/9 = 2667 Tn/cm ; $d_{RG}$ = 0,77
$Q_{GR}$ = 16x1235 = 19760Tn;m=2667/(19760/0,77)=0,1
a=336;b=2436;c=-8600 $\delta_T$= 2,6 cm




Then, for rigid piles, $Q_T$=8600Tn and $\delta_T$ = 2,6 cm . The calculation is presented in the upper table.
If we consider the elasticity of piles Δ = P.L'/$E_b$.$A_P$ ; the respective values are included in the lower table. The general prediction can be seen in the last figure. ⁞ "Rigid" piles: load taken by cap, 37%; by group, 63%. "Elastic" piles: 43% and 57% respectively.