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The bearing capacity of screwed piles in cohesive layers

La capacité portante des pieux vissés dans les sols cohérents

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SYNOPSIS

Two pile loading tests up to failure were performed on continuous screwed concrete piles of the Atlas-type, in a uniform tertiary clay layer. The type of pile mentioned and its related screwing method is described by Imbo (1984). From the results of the test loading an analysis is made concerning the total point and shaft bearing capacity in respect also with the cone penetration results. Some considerations are made about the influence of the time interval between performing and test loading of the piles.

INTRODUCTION

The Atlas-type pile is a concrete auger pile, cast in place while screwing out a thickwalled steel tube equiped at its bottom with an hollow exchangeable auger. This augered end with helical shape also bears a helical flange. At the bottom the casing is closed off by a non-retrievable cast-iron drilling tip (Fig.1a). Screwing in the steel tubes this tip grips, while screwing out it loses its grip and is left behind allowing to cast the concrete, (Fig. 1b).
Two of such screw piles were made, as test piles, near Kortrijk-Belgium in a quite uniform thick tertiary eocene clay layer (Ieper-clay). At the location of the two test piles (Fig. 2) a number of static cone penetration tests (CPT) were performed. Their results are shown in Fig. 3. Some of these test results were obtained before bringing in, others after performing the piles. No appreciable differences in CPT-results could be measured with respect to this time factor.
The two identical test piles were installed on April 6, 1984. The loading up to failure for test pile P1 was made on May 8 ; for test pile P2 on July 7, 1984. At the mentioned loading dates (30 days, respectively 90 days after performing the piles, small differences in test results also were expected from the point of view of reconsolidation of the clay surrounding the pile shaft.
Each loading and unloading step of the loading program was kept constant for one hour. The shaft diameter (Fig. 1), due to the special way of casting the concrete while screwing out the steel tube equals at least its diameter of D_s = 360 mm. The full shaft and base diameter, due to the flanges at the screw in this case was D_b = 460 mm.

THE TEST LOADING RESULTS

The loading program on each pile can be deduced from Fig. 4 and Fig. 5.
For the test pile P1, failure occurred as a continuous and rather quick penetration at the loading level of about Q = 1560 kN (Fig. 5a). Following outer load had to be decreased immediately as to maintain and later on to decrease the penetrating rate of the pile into the soil.
The failure at test pile P2 was introduced at Q =

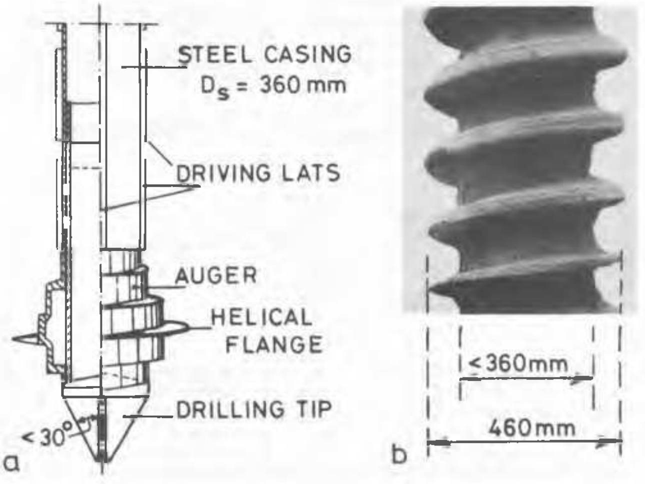

Fig.1 The Atlas-pile type

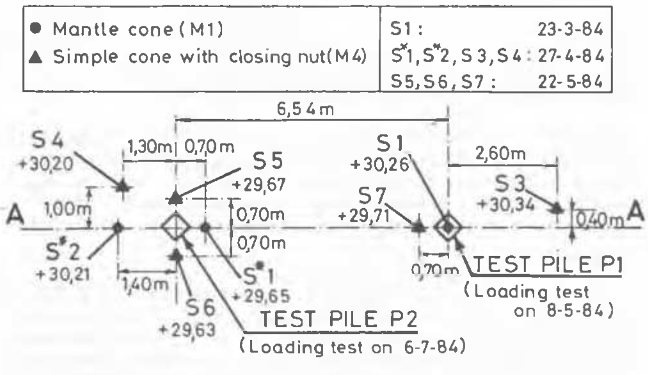

Fig.2 Location of test piles and CPT

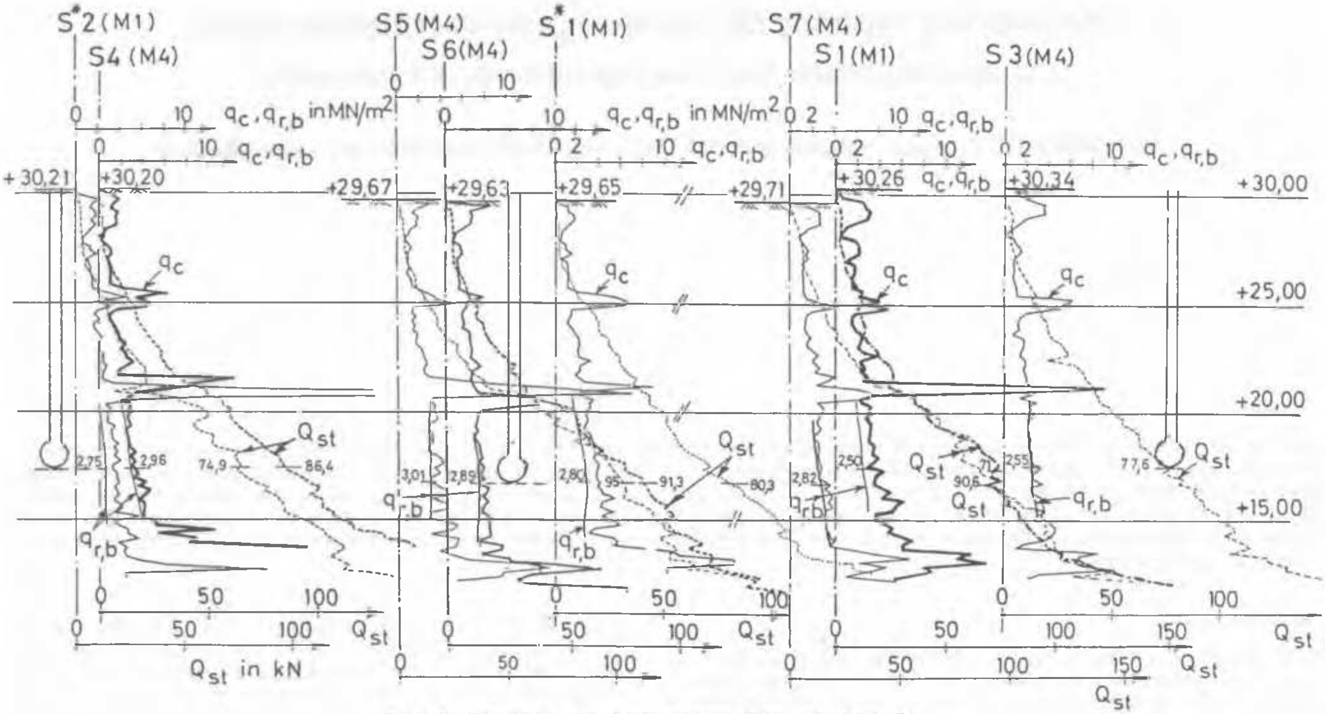

Fig.3 Results of CPT along A-A of Fig.2

1700 kN although continuous penetration at a rate of about 30 mm/hour only was obtained at a constant total load of 1765 kN, which so was considered as the rupture load.

Out of this loading-settlement results, the failure criteria of Van der Veen (1953) and Christiaens (1970) as described by De Beer (1967) are used.

For the first mentioned criterion an appropriate straight line on Fig. 6 is indicating the failure load Q_r. From Fig. 6 for the test pile P1 the Van der Veen's value becomes $Q_r^{(L)} = 1580$ kN ; for the test pile P2 it rises up to be $Q_r^{(L)} =$ 1755 kN.

The application of the Christiaen's criterion, describing the failure load at the intersection point Y of two best fitting straight lines in a semi-logaritmic load settlement diagram, (Fig. 7), brings the $Q_r^{(L)}$-values up to $Q_r^{(L)} = 1550$ kN for pile P1 and $Q_r^{(L)} = 1680$ kN for P2. In Table I such failure loads are gathered.

ANALYSIS OF THE PILE BEARING CAPACITY

a) Using De Beer's method (1971) for driven piles, taking into account the scale effect of pile base diameter versus cone diameter, out of each mentioned CPT-result the ultimate unit point bearing capacity $q_{r,b}$ is deduced from the cone resistance values q_c.

The CPT-results obtained from mantle cone tests although beforehand were adapted, because with this extended cone type some resistance measured at levels above its point in fact also is included in the cone resistance measurement. In

TABLE I

Assumed total failure load $Q_r^{(L)}$ from test results

Test pile	Observed	Van der Veen criterion	Christiaens criterion
P1	1560 kN	1580 kN	1550 kN
P2	1765 kN	1755 kN	1680 kN

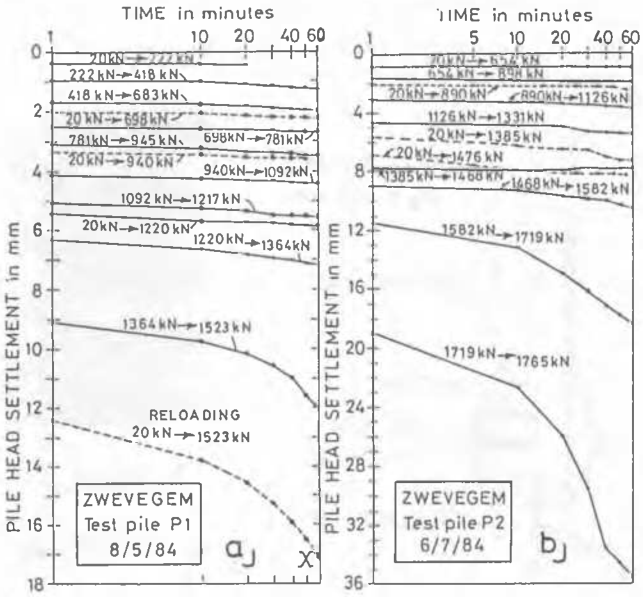

Fig.4 Time-settlement results

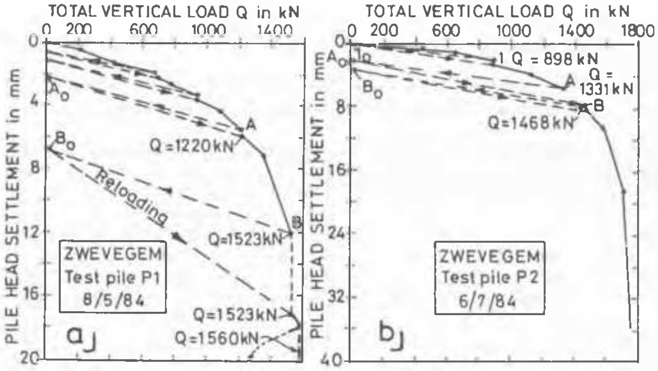

Fig.5 Vertical load versus pile head settlement

comparison with the simple cone with closing nut therefore a decrease has to be taken into account. For clays and values of the cone resistance q_c (Fig. 3) of 2 $MN/m^2 < q_c <$ 4 MN/m^2 such dncrease Δq_c here is described proportionally as : 0,4 $MN/m^2 < \Delta q_c <$ 0,8 MN/m^2.

On Fig. 3, each of the corresponding $q_{r,b}$-curves is drawn, allowing to obtain the $q_{r,b,o}$-value at the pile tip level, corresponding to each of the CPT-results. At the same level, $Q_{s,t,o}$ is the cumulated lateral resistance measured on the cone penetration tubes (d_s = 0,036 m).

In Table II, for all CPT-results (adapted for the extended mantle cone results), the values of $q_{r,b,o}$; $Q_{s,t,o}$; $Q^{(c)}_{r,b}$; $F^{(c)}_{p,c}$ and $Q^{(c)}_r$ are given, in which

$$Q^{(c)}_{r,b} = q_{r,b,o} \cdot \frac{\pi D_b^2}{4} \text{ ; ultimate point bearing} \tag{1}$$

$$F^{(c)}_{p,s} = Q_{s,t,o} \cdot \frac{Ds}{ds} \text{ ; ultimate shaft bearing} \tag{2}$$

and

$$Q^{(c)}_r = Q^{(c)}_{r,b} + F^{(c)}_{p,c} \tag{3}$$

TABLE II

Results of calculated bearing capacities out of CPT

CPT	$q_{r,b,o}$ $(\frac{MN}{m^2})$	$Q_{s,t,o}$ (kN)	$Q^{(c)}_{r,b}$ (kN)	$F^{(c)}_{p,s}$ (kN)	$Q^{(c)}_r$ (kN)
(adapted)S1	2,50	71	415,5	907,2	1322,7
S3	2,55	77,6	424,0	991,6	1415,6
S7	2,82	90,6	469,3	1157,7	1627
(adapted)S*1	2,80	80,3	465,3	1026,1	1491,4
(adapted)S*2	2,75	74,9	457,0	957,1	1414,1
S4	2,96	86,4	491,9	1104,0	1595,9
S5	3,01	95,0	500,2	1213,9	1714,1
S6	2,89	91,3	480,3	1166,6	1646,9

Out of the data in Table II, some maximum and minimum values are derived in Table III in order to get an estimation of the allowable bearing capacity.

From the Table III-data, (on next page), allowable bearing capacities P_n were calculated as :

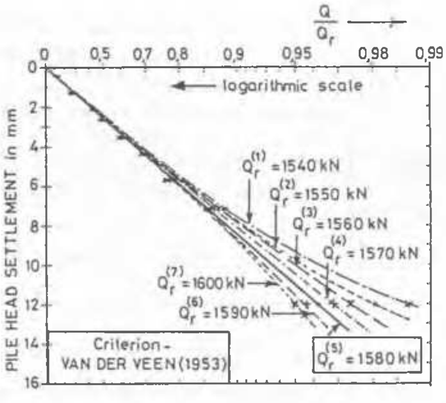

Fig.6 Failure load from Van der Veen-criterion

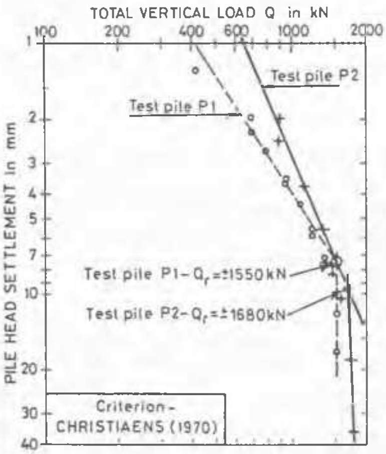

Fig.7 Failure load from Christiaens-criterion

$$P_n = \frac{1}{n_1} \cdot \left(\frac{Q^*_{r,b,max}}{n_2} + \frac{F^*_{p,s,max}}{n_3} \right) \tag{4}$$

or, with n_1 = 1,4 :

P_n for test pile P1 becomes : P1 = 730,9 kN

P_n for test pile P2 becomes : P2 = 944,8 kN

b) The devision into point and shaft bearing capacity can be made using Van Weele's method (Van Weele, 1957).

In Table IV the data, out of the test loading results, needed in this respect, are gathered.

The ultimate shaft bearing capacity $F^{(L)}_{p,s}$ then is calculated (Van Impe, 1984) as :

$$F^{(L)}_{p,s} = \frac{Q_A \cdot \frac{\Delta V}{\Delta Q} - V_A}{\frac{\Delta V}{\Delta Q} - (1-n) \cdot \frac{\ell}{E\Omega}} \tag{5}$$

where

$$n = \frac{\int_0^\ell Q_{s,t,x} \cdot dx}{\ell \cdot Q_{s,t,o}} \tag{6}$$

ℓ = 13 m

E = 28,5 kN/mm^2

Ω = 0,1159 m^2

Out of the CPT-results ; CPT-S1 for test pile P1

TABLE III

Derived values from table II

CPT nr	Test pile nr	Values from CPT at or around the test pile				Values from CPT-overall spreading					
		$Q^{(*)}_{r,b,max}$ (kN)	$Q^{(*)}_{r,b,min}$ (kN)	$F^{(*)}_{p,s,max}$ (kN)	$F^{(*)}_{p,s,min}$ (kN)	$Q^{(o)}_{r,b,max}$ (kN)	$Q^{(o)}_{r,b,min}$ (kN)	$F^{(o)}_{p,s,max}$ (kN)	$F^{(o)}_{p,s,min}$ (kN)	$n_2 = \frac{Q^{(o)}_{r,b,max}}{Q^{(o)}_{r,b,min}}$	$n_3 = \frac{F^{(o)}_{p,s,max}}{F^{(o)}_{p,s,min}}$
S1, S3, S7	P1	415,5		907,2		500,2 for P1 and for P2	415,5 for P1 and for P2	1213,9 for P1 and for P2	907,2 for P1 and for P2	1,20 for P1 and for P2	1,34 for P1 and for P2
S^*1, S^*2, S4, S5, S6	P2	500,2	457,0	1213,9	957,1						

TABLE IV

Data from Fig.3a,b-pile loading tests

Pile nr	Total measured settle-ment of pile head (mm)	Measured plastic settlement of the pile head (mm)	Elastic uprising $V_x = s_x - s_{x_o}$ (mm)	Pile load (kN)	$Q = Q_B - Q_A$ (kN)	$V = V_B - V_A$ (mm)
P1	$s_A = 5{,}555$ $s_B = 12{,}058$	$s_{A_o} = 2{,}140$ $s_{B_o} = 6{,}785$	$V_A = 3{,}415$ $V_B = 5{,}273$	$Q_A = 1217$ $Q_B = 1523$	306	1,858
P2	$s_A = 5{,}493$ $s_B = 7{,}793$	$s_{A_o} = 2{,}113$ $s_{B_o} = 3{,}163$	$V_A = 3{,}380$ $V_B = 4{,}630$	$Q_A = 1331$ $Q_B = 1468$	137	1,250

and CPT-S6, for test pile P2, one gets :

$$n_{(P1)} = 0{,}306 \quad \text{and} \quad n_{(P2)} = 0{,}333$$

From equation (5) and Table IV, it can be derived :

for pile P1 : $F^{(L)}_{p,s} = 1190$ kN

for pile P2 : $F^{(L)}_{p,s} = 1350$ kN

The ultimate point bearing capacities $Q^{(L)}_{r,b}$ out of the loading test results, then become :

test pile P1 : $Q^{(L)}_{r,b} = Q^{(L)}_{r} - F^{(L)}_{p,s} = 1560 - 1190 = 370$ kN

test pile P2 : $Q^{(L)}_{r,b} = 1765 - 1350 = 415$ kN.

Following this calculating method the increase of the rupture load by about 11% is almost entirely due to the ultimate shaft bearing uprising. Comparing of these results with all from surrounding CPT-results calculated values (in Table II), leads to table V-results.

Although at start a much higher failure load to be measured in the testing of P2 (versus P1) was expected, (being in accordance with the assumption of some reconsolidation of the clay layer) out of the ratio $Q^{(L)}_r/Q^{(c)}_r$ in Table V it was discovered this is not the case. In this case no influence of any reconsolidation on the béaring capacity was deduced. This probably can be attributed on the one hand to the fact that the time interval of 60 days between the two loading tests in this case was rather small ; on the other hand it is thought the effect of the plastic remoulding and disturbing of the soil while screwing in the flanges at the tip, was neutralized by the noticed dragging out of some clay around the driving lats, screwing out the steel tubes.

From equation (5) and Van Weele's method the bearing capacity share of the pile shaft $\left(\frac{F^{(L)}_{p,s}}{Q^{(L)}_r}\right)$ in this case of pile loading tests seems to exceed the predicted ratio $\left(\frac{F^{(c)}_{p,s}}{Q^{(c)}_r}\right)$ by about 10%.

TABLE V

CPT nr	Pile nr	out of CPT-results around pile: $Q^{(c)}_r$ (kN)	$F^{(c)}_{p,s}$ (kN)	$\frac{F^{(c)}_{p,s}}{Q^{(c)}_r}$ (%)	out of pile loading tests: $Q^{(L)}_r$ (kN)	$F^{(L)}_{p,s}$ (kN)	$\frac{F^{(L)}_{p,s}}{Q^{(L)}_r}$ (%)	$\frac{Q^{(L)}_r}{Q^{(c)}_r}$
S1 S3 S7	P1	1322,7 1415,6 1627	907,2 991,6 1157,7	68,6 70,0 71,1	1560	1190	76,3	1,18 1,10 0,96
S^*1 S^*2 S4 S5 S6	P2	1491,4 1414,1 1595,9 1714,1 1646,9	1026,1 957,1 1104,0 1213,9 1166,6	68,8 67,7 69,2 70,8 70,8	1765	1350	76,5	1,18 1,25 1,11 1,03 1,07

CONCLUSION

For the Atlas pile of Fig. 1b, the total bearing capacity, as a first approximation, can be predicted from CPT-results using a calculation method developed for driven piles, after correcting measured CPT-cone resistances when using extended mantle cone. Loading test results in this case are showing failure loads exceeding about 10% the mentioned predicted values.

The calculated predictions for $F_{p,s}^{(c)}$ starting from the total lateral friction $Q_{s,t,o}$ in CPT-results, are underestimating the real shaft bearing capacity $F_{p,s}^{(L)}$ of this type of screw pile. Out of the test results of measured rupture load and using equation (5), it looks (Table V) as the share of the shaft bearing in total failure load with this Atlas-pile is about 10 % higher than predicted from CPT-results.
No influence was detected of some reconsolidation effect on the bearing capacity in a time interval of 60 days between the two loading tests.

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