

Atlas Screw Pile: A Vibration-Free, Full Displacement, Cast-In-Place Pile

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Developed in Belgium about 35 years ago, the Atlas screw pile has been used widely during the last decade in Europe and elsewhere. The Atlas screw pile can be defined as a vibration-free, cast-in-place concrete pile with double lateral ground displacement (during penetration as well as during extraction of the casing). The pile's high level of acceptance is related to the reliability of its equipment, the low level of noise pollution and lack of vibration during its construction, and availability of a computerized data-acquisition system to monitor its execution parameters, as well as its excellent bearing performance. Hydraulic rigs allow for production rates in the range of 100 to 150 m per day with a 2-person crew. Standard screw pile diameters range from 45 to 70 cm. Allowable bearing capacity typically is between 1,000 and 2,000 kN in compression and up to 1,000 kN in tension. The pile's method of construction characteristics, range of application, design, performance, and its quality control are described. Piles can be constructed in nearly all soil types in which traditional rammed cast-in-place piles are used. The lateral soil displacement effect, with the virtual absence of any significant spoil, as well as the particular helical screw shape of the concreted pile contribute to its high bearing resistance and stiff settlement behavior.

Since its development in Belgium about 35 years ago, the concrete Atlas screw pile has been introduced successfully in many European countries and in Australia. The pile is fabricated by screwing into the ground a temporary, closed casing with an auger-shaped displacement head at its bottom and by filling the created void with concrete during the extraction of the casing. In effect, the pile is a cast-in-place pile with double lateral soil displacement—occurring once during the penetration and once during the extraction of the casing. The pile is characterized by a particular helical shape over its full shaft length, as shown in Figure 1.

Although the Atlas screw pile sometimes is classified as an auger pile, a clear distinction should be made between two classes of auger piles (Figure 2). First, auger piles of the drilled type, such as continuous flight auger piles, are constructed using an auger with continuous flight on a central stem. An example, with relevant soil extraction, is shown in Figure 2(a). Second, (single) auger piles of the screwed type, such as the Atlas screw pile, essentially displace the soil laterally and produce virtually no spoil, as shown in Figure 2(b).

It is obvious that the load behavior of auger piles may be quite different depending on whether they are installed by drilling or screwing with drilled piles. There is the detrimental effect of soil decompression because of excessive upward soil displacement during drilling or extraction of the continuous auger. With screwed piles, on the other hand, there is the beneficial effect of soil compaction and an increase in lateral stresses around the pile shaft caused by substantial lateral soil displacement during pile installation.

PILING EQUIPMENT

Atlas screw piles are installed by a hydraulic rig built for that purpose. Most rigs allow for vertical piles only. However, with a BTS-50 rig, it is feasible to make batter piles up to an inclination of one third (approximately 20 degrees).

The general configuration of the actual rigs in the BT-40 series is shown in Figure 3. The heart of the rig consists of a drilling table and two hydraulic rams to penetrate and extract the casing. The 2-speed drilling table transmits a rotational movement of the casing at high speed (12 to 16 rpm) or low speed (6 to 8 rpm). The pressure rams can function either separately or in combination. In the former case, one ram exerts a crowd force on the casing, while the inactive ram returns to its initial position to take over when the first ram ends its course. In this way, a continuous rotational and translational movement of the casing is obtained. Both rams also can work together to double the total thrust force. In that case the rotating movement is not continuous. The combined power operation is applied, for example, when hard soil layers have to be penetrated, or at the onset of reversed screwing in order to obtain an enlarged base or a more characteristic helical shape. For the actual machine generation, the torque of the drilling table is a maximum 450 kNm; the maximum crowd force of both rams together is of 240 kN, whereas the maximum extraction force is of 800 kN.

The rig further comprises the following:

- Main framework, which houses the central engine, the pumps, the steering equipment, and the four outriggers for stabilization and leveling of the rig;
- Crane jib with a lifting capacity of 10 kN and a maximum reach of 16 m, used to place the reinforcing cage and to lift the skips to introduce the concrete into the casing;
- Underframe, provided with caterpillar tracks, can spin around.

Another substantial feature of the screw-piling equipment is the casing, which is composed of the following (see Figures 3 and 4):

- Hopper on which the concrete skips are placed.
- Mandrel, consisting of several thick-walled, steel tube segments, joined together by concealed joints. Only one type of casing, all with an external diameter of 324 mm, is used for the various standard pile diameters. On the outside of the mandrel, steel driving laths are welded to transmit the rotational and translational movement from the drilling table and the pressure rams to the casing.

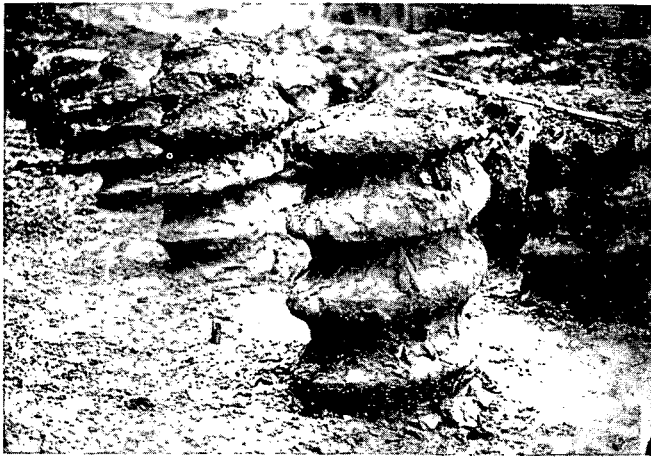


FIGURE 1 Exposed Atlas screw pile.

- Hollow dismountable head, consisting of a cast-iron helical body with a minimum diameter D_c , which ensures the lateral displacement of the soil, and a helical flange with an outer diameter D_f , which is welded on this body at the point where the diameter is greatest.

- Sacrificial tip equipped with two one-way carriers; the joint between the tip and the displacement head is sealed to make the casing watertight.

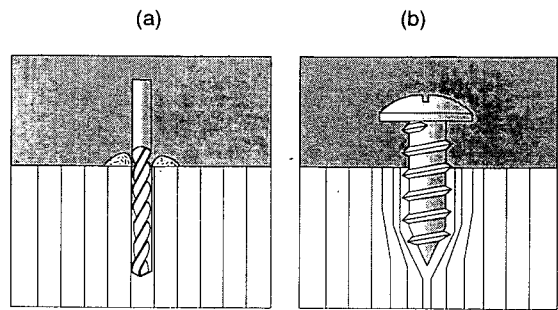


FIGURE 2 Drilling (a) and screwing (b).

PILE INSTALLATION PROCEDURE

The pile installation sequence is shown in Figure 5. On the site where a screw pile is to be constructed, a rig is placed in the correct operational position by means of four leveling supports, whereby the axis of the casing is placed along the theoretical line of the pile axis. The sacrificial tip is placed under the displacement head and the joint between them sealed with a waterproof-plastic kit.

The combined action of the rotating drilling table and both pressure rams takes the casing down in a continuous clockwise, helical, penetrating movement, causing the first lateral displacement of the surrounding soil. The operation is vibration free and also relatively noise free. Simultaneously the drilling parameters

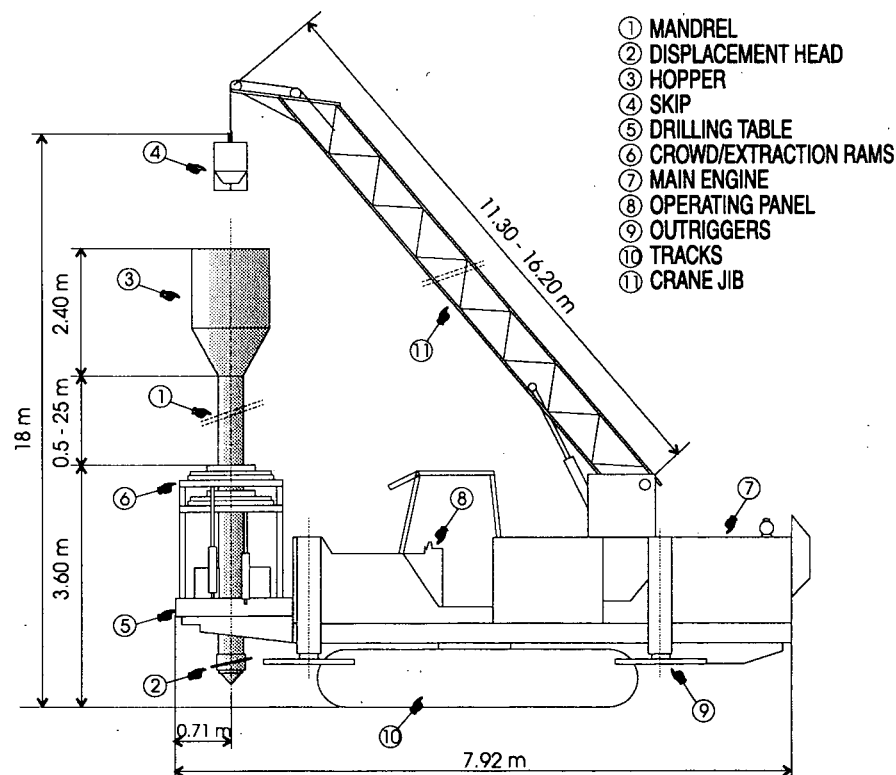


FIGURE 3 The Atlas BT-40 screw pile rig.

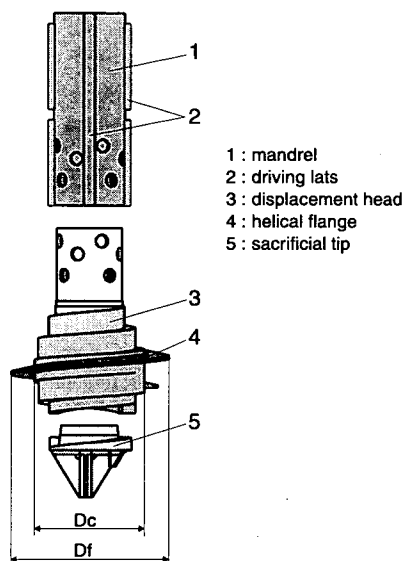


FIGURE 4 Detail of the displacement head and sacrificial tip.

are measured and recorded by a computerized data-acquisition system.

When the required founding depth is reached, a full-length reinforcing cage is placed into the hollow mandrel, and concrete is skipped into the hopper in sufficient quantity to completely fill the pile. To form the pile, the casing is then rotated in the reverse

direction and extracted. The initial backward rotation forces off the sacrificial tip, which remains in position in the soil. As the enlarged displacement head is recovered, lateral soil displacement occurs a second time, during the extraction. The concrete immediately fills the void created by the displacement head. Care is taken that the hydrostatic concrete pressure at the bottom of the casing at all times is kept considerably higher than the combined soil and water pressure acting at that point. In this way the danger of shaft constriction is avoided.

After concreting, and when important bending moments have to be taken up (for pile walls, for example), a second reinforcing cage can be installed in the fresh concrete by static pushing or by using a small vibratory device. Guidance by the first cage guarantees the centering of the additional cage.

CHARACTERISTICS OF THE ATLAS PILE

Concrete

Van Impe's research on the behavior of auger piles (1) shows that the method of casting and the quality of the concrete—water/cement (W/C) ratio and workability—influence the arching effect of the fresh concrete in the casing in an important way and thus affect the real concrete pressure at the outlet. The concrete used should be as plastic as possible without having an excessively high water content, as that would reduce the concrete's strength, and increase the risk of leaching out of the cement. Concrete with a good grain-size distribution—made of low-sized, rounded

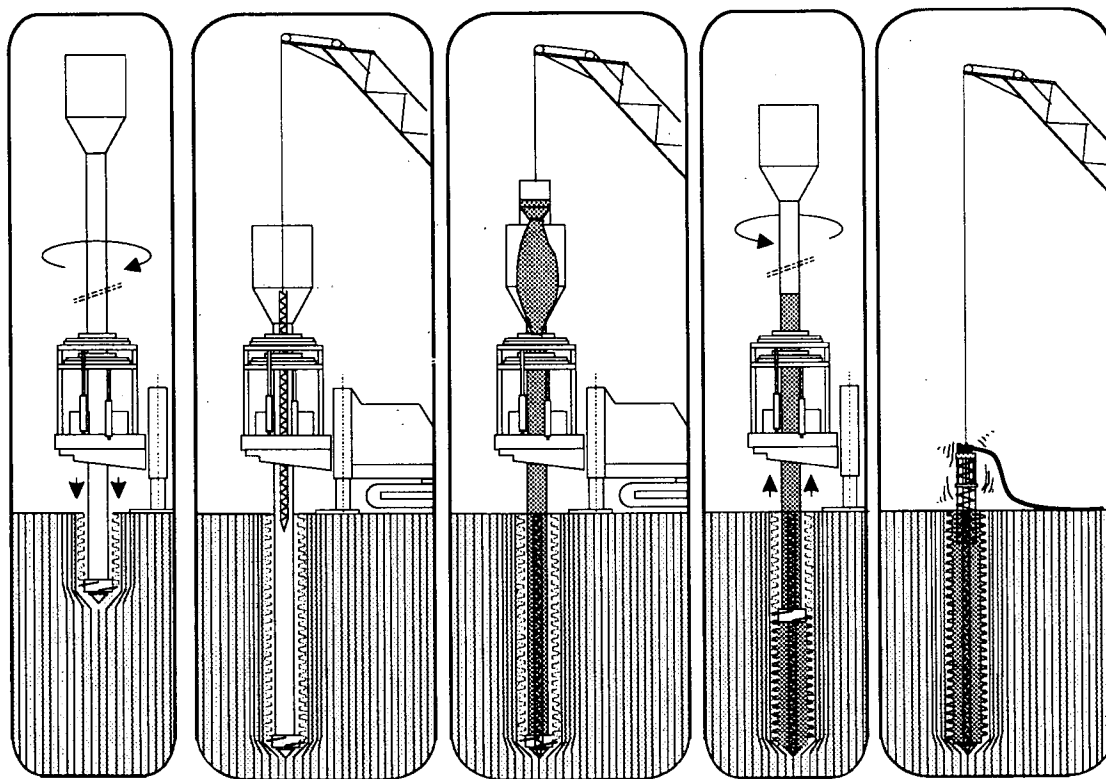


FIGURE 5 Installation sequence for Atlas pile; (from left to right) screwing in, introduction of central reinforcing cage, filling of casing hopper with concrete, screwing out and concreting, and introduction of additional reinforcing cage.

gravel, not too fine sand, a suitable cement type, and eventually an appropriate plasticizer—is of utmost importance to successful construction of a pile.

The following mixture is often used:

- 350 kg cement HK40;
- 1250 kg (approx. 800 l) rounded gravel $\frac{1}{4}$ mm;
- 625 kg (approx. 400 l) sand $\frac{2}{5}$ mm;
- Water/cement (W/C) ratio: 0.5 to 0.8;
- Consistency: slump > 175 mm.

If only a top reinforcing cage has to be installed, somewhat coarser crushed gravel $\frac{1}{2}$ mm can be used.

As an illustration, the average compressive strength of cubes of 200 mm, $f_{cm,cub200}$, is estimated for two W/C ratios on the basis of the empirical relation derived by Lambotte-Van Nieuwenburg (1):

$$f_{cm,cub200} = (0.47 \times f_{cm})/(W/C)$$

where f_{cm} is the standardized compressive strength of the cement mortar, defined at a W/C ratio of 0.45 (± 45 N/mm²).

For concrete with a relatively high W/C ratio of 0.7 to be very workable, its estimated mean compressive strength attains

$$f_{cm,cub200} = (0.47 \times 45)/0.7 = 30 \text{ N/mm}^2$$

When using super-plasticizers, similar workability can be obtained, however, with a much lower W/C ratio, 0.45, for example, in which case the mean compressive strength can be increased to a value of the order of

$$f_{cm,cub200} = (0.47 \times 45)/0.45 = 47 \text{ N/mm}^2$$

In terms of its compressive strength, the concrete used for Atlas piles belongs to one of the European standardized strength classes C20/25, C25/30, or C30/37, where the first number equals the characteristic strength $f_{ck,cil}$ (N/mm²), determined on cylinders ϕ 150 mm and H 300 mm after 28 days, and the second number equals the characteristic strength $f_{ck,cub150}$ (N/mm²), determined on cubes 150 mm after 28 days.

Characteristic values are summarized in Table 1 using the following relations:

$$f_{ck} = f_{cm} - 1.64 s$$

where s = standard deviation \cong 15 percent of f_{cm}

$$f_{c,cub200} = f_{c,cub150}/1.05$$

In Europe, concrete with the required mix, workability, and strength in most cases is available through companies certified to sell ready-mixed concrete. In this way, detailed quality-control procedures and supervision by the authorities guarantee the product's conformity and quality.

TABLE 1 Compressive Strength Values

Strength class	C20/25	C25/30	C30/37
$f_{ck,cil}$ N/mm ²	20	25	30
$f_{ck,cub150}$ N/mm ²	25	30	37
$f_{ck,cub200}$ N/mm ²	23.8	28.6	35.2
$f_{cm,cub200}$ N/mm ²	31.6	37.9	46.7

Reinforcement

As standard reinforcement 4 or 5 longitudinal bars ϕ 14 to 16 mm are used. The quality of the steel is generally BE50 (yield stress of 500 N/mm² at 0.2 percent elongation). The longitudinal bars are connected to each other by a helical wire ϕ 5 or 6 mm with a pitch of 20 cm. This forms a reinforcing cage with a diameter of 15 to 20 cm that is centered in the mandrel before concreting. If only a top cage is required, installation is done after concreting. In order to take up important bending moments from lateral loads, a second cage of larger diameter can be positioned in the top section of the pile after concreting.

Pile Geometry

Vertical piles may be installed to depths of 22 m by most rigs; exceptionally, piles can extend as much as 25 m. With the most powerful rig (BTS-50), vertical piles up to 28 m and piles inclined over one third (approximately 20 degrees) up to 25 m in depth are feasible.

The typical helical pile shape and shaft cross sections are defined by the displacement head dimensions D_c and D_f as well as by the relationship between rotation and translation speed during extraction. The value D_c is normally considered the minimum diameter for a pile shaft, considering the structural design of a pile. The nominal base and shaft diameter to be introduced in the design for bearing capacity are related to the diameter D_f of the steel flange on the displacement head (see section on Design). A survey of characteristic displacement-head dimensions is summarized in Table 2. The table also provides the maximum allowable structural pile load Q_n , assuming an allowable concrete stress σ'_{cb} of 7.5 MPa and a full-length standard reinforcement of 5 ϕ 16 mm (steel quality BE50).

APPLICABILITY

Soil Types

It is possible to construct Atlas screw piles in nearly all soil types (sands, clays, silts, chalk, and marls) in which traditionally rammed piles embedded in the soil are feasible (2). Penetration of 2 to 3 m in very dense sand or gravel usually poses few problems. In clay soils, it is possible to construct deeper piles with this system than is possible with traditional driving methods. Clay is more easily displaced by static penetration than by dynamic impact. Finally, screwing out the displacement head and the mandrel's continuous movement pose fewer problems than does pull-

TABLE 2 Characteristic Values for Atlas Piles

Head N°	D_c	D_f	$Q_n^{(*)}$
(-)	(cm)	(cm)	(kN)
1	31	45	671
2	36	50	869
3	41	55	1,095
4	46	60	1,352
5	51	65	1,637
6	56	70	1,953

(*) on basis of an allowable concrete stress of 7.5 MPa.

ing out a casing for a cast-in-place rammed pile. Occasionally, preboring using a continuous flight auger is done to facilitate penetration through resistant soil layers or backfill on top.

As is true for all cast-in-place piles without permanent casing, care and workmanship are needed in penetrating the very low-resistance layers, for example, sands close to critical density, soft clays, and peats. In these cases an appropriate concrete mix (one with a lower volume weight) can be used to avoid excessive concrete consumption and post-setting by the lateral yielding of fresh concrete in weak ground layers. The presence of large boulders, on the other hand, may impede penetration.

Site and Environmental Aspects

The Atlas pile is appropriate if vibration-free, quiet installation is required (as in urban areas, when operating adjacent to schools, laboratories, or historical buildings). In contaminated soils, the screwed displacement pile has the advantage of producing virtually no spoil, which is a safety risk to people and requires expensive disposal.

Piles can be installed 0.8 m from existing surface structures. Special precautions have to be taken however when working close to fragile structures, in order to avoid possible damage from the soil-displacement effect. Preboring through the top layers and filling the bore with loose sand is often an effective safeguard.

Particular Applications

On several job sites in Belgium, the Atlas pile has been used successfully for the construction of soil-retaining walls. Details on this application have been reported by De Cock and Lhoest (3). Piles may have either a temporary or a permanent lateral soil-retaining function combined with a vertical bearing function in such cases. Generally, a discontinuous pile wall is constructed, with the spacing of the piles, axis to axis, 2 to 3 times the pile diameter. Retaining heights of 6 to 8 m are common. In many cases one or two rows of ground anchors are provided. Outlines of the usual construction phases of a discontinuous pile wall are given in Figure 6.

Atlas piles have been used several times for slope stabilization as well. The increase in mean shear characteristics of the pile-soil system along the potential sliding surface, in combination with passive soil resistance on the piles, improves stability, protecting against deep sliding or allowing an increase in the average slope angle, thereby reducing the volume of earth works and area of expropriated land.

Due to the high shaft resistance that can develop with its use, the Atlas pile is also appropriate as a tension pile.

BEHAVIOR OF ATLAS SCREW PILE

Unlike the less powerful pile-screw machines and other auger-pile techniques, Atlas machines are able to displace soil laterally. They use a recoverable displacement head, and soil displacement not only occurs during penetration but also during extraction. Double soil displacement is characteristic of the Atlas technique and is critically important in view of the screw pile's shape and behavior. By displacing soil laterally, and in a volume equal to the pile's

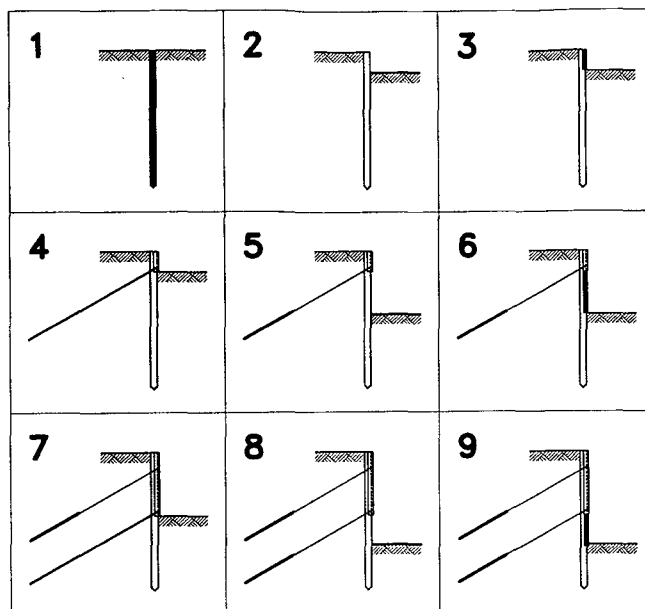


FIGURE 6 Installation phases for anchored discontinuous pile wall.

volume, soil density and lateral stresses surrounding the pile will increase, depending upon soil type, its initial density, and stress state.

A selection of representative static load tests on Atlas piles in both granular and cohesive soils is given in Figure 7. See work by Van Impe for a detailed analysis of these tests (1). Double soil displacement, which typically occurs with the Atlas screw pile, varies somewhat, depending on soil characteristics.

Displacement in Granular Soils

In granular, loose to medium-dense soils, an important increase in density and thus in shear characteristics may result from the displacement effect. Comparative model tests on different steel-screwed auger piles (having a shape and relative geometry comparable to the Atlas pile) and rammed or jacked tubular piles have been performed in sand by G. Petrasovits of the Technical University of Budapest, Hungary. From these tests it was concluded that for the screwed pile

- No relevant change in soil density was found in the layers underneath the pile base, in contrast to the additional compaction experienced with rammed piles or the eventual decompaction experienced with bored piles;

- Soil essentially moved horizontally along the whole pile;
- Soil between the threads was compacted, the initial dry-bulk density γ_d of 16 kN/m³ being increased to 17.5 kN/m³, corresponding to a reduction in void ratio e from 0.67 to 0.51;

- The extent of the compacted zone near the pile was higher for greater initial soil densities.

Densification of sands near the pile shaft also has been revealed in situ. Figure 8, for example, shows the results of a static cone

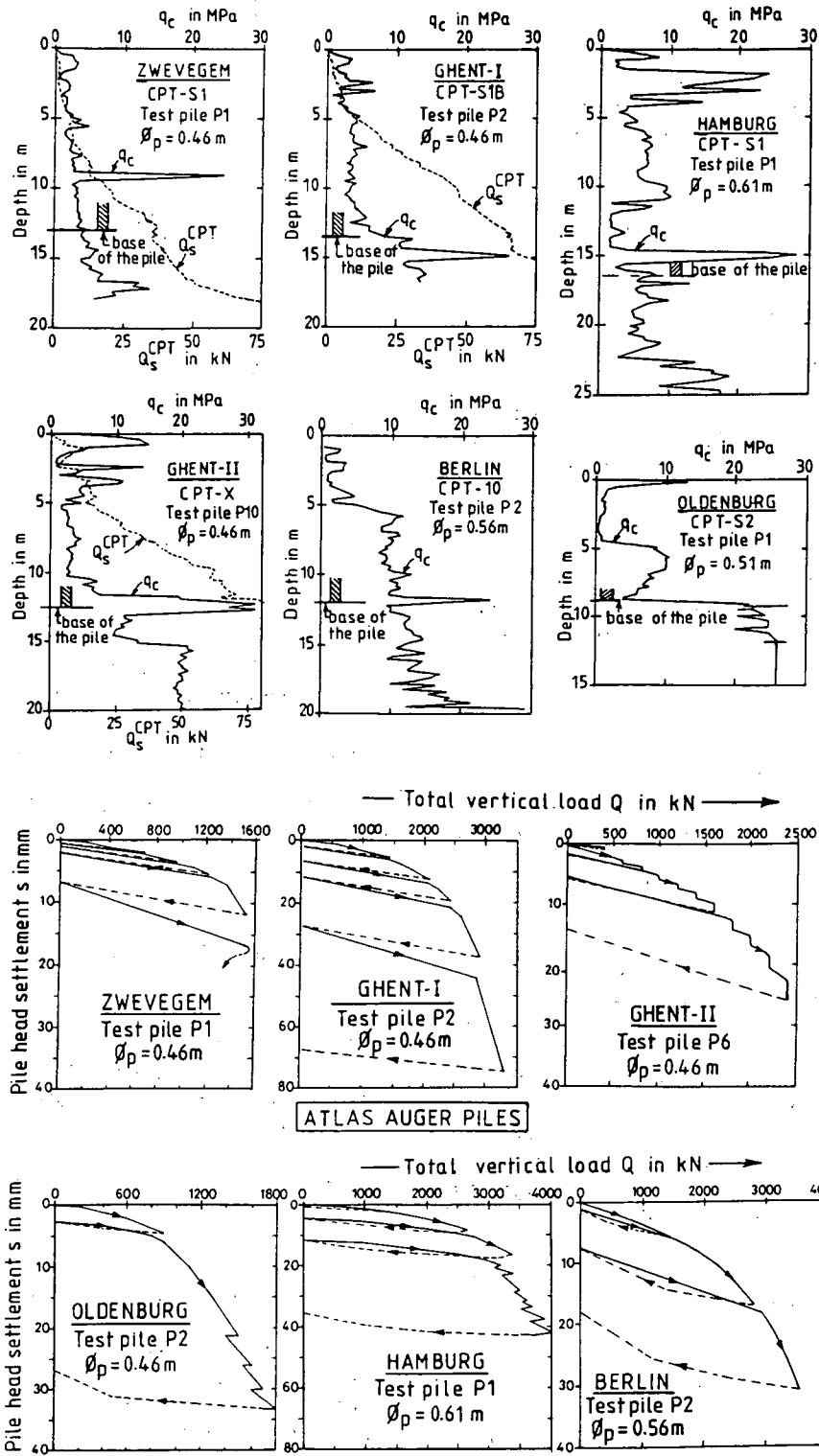


FIGURE 7 Examples of CPT and pile load settlement results in Atlas pile research.

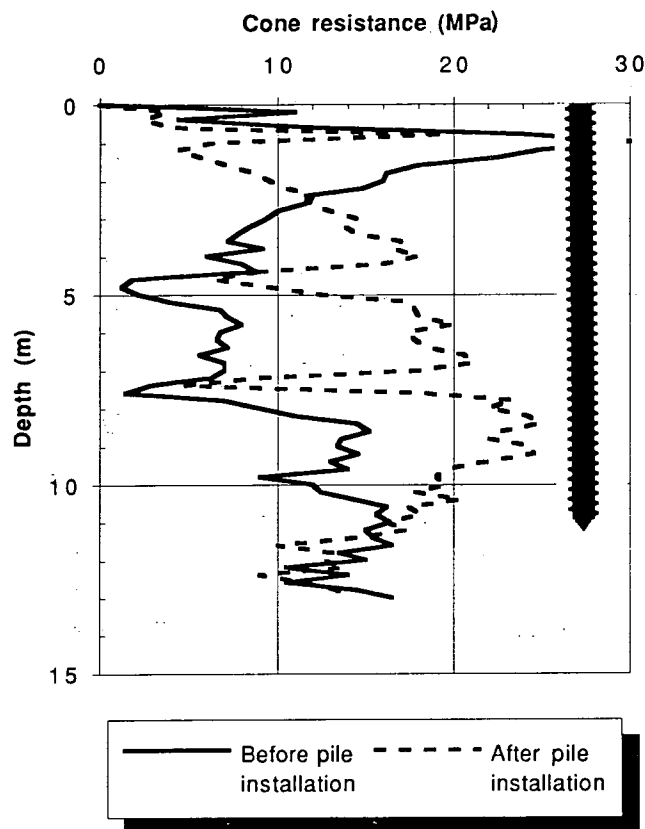


FIGURE 8 CPTs on axis of screw pile before installation and 0.5 m from edge of pile after installation, (Southport Lincs, United Kingdom).

penetration test executed before and after piling works on a job at Southport Lincs, in the United Kingdom (4).

In sum, the above-mentioned phenomena will affect pile performance in granular soils in such a way that the ultimate shaft resistance and base resistance of Atlas piles at least are comparable to those of rammed concrete piles. Furthermore, the settlement of end-bearing Atlas piles may be somewhat greater than the settlement of equivalent rammed piles but much less than it would be for comparable drilled piles.

Displacement in Fine-Grained Soils

Soils with a pronounced silt or clay character are less compactible by short-duration forces. In fine-grained soils, the lateral soil displacement by pile installation will essentially result in an increase of locked stresses around the pile shaft.

The stress state during and after installation of Atlas piles has been analyzed in situ at a test site in Koekelare, Belgium (5)(6). The research program, conducted in 1992, involved the collaboration of Franki Foundations, Belgium, and the University of Ghent. Underneath the silty and clayey top layers (5 to 6 m below), the subsoil consists of stiff, tertiary, overconsolidated clay [Figure 9(a)]. Soil stress analysis was performed with a Dilatometer Test (DMT) with the Marchetti dilatometer blade before and after pile execution at a distance of 1.5 times the pile diameter to

the pile axis. Comparison of the data for the Atlas piles (diameter 51/65 cm) indicated an average increase in horizontal stress index K_a of about 29 percent and an increase in undrained shear strength, c_u , of 24 percent [Figures 9(a) and 9(b)]. Note that the measurements were made at a distance of about 65 cm from the outer surface of the shaft. Moreover, the clay layer geologically is already highly overconsolidated.

At a test site in Zwevegem, Belgium, one with the same type of tertiary clay, the soil entrapped in between the concrete flanges of the piles was closely investigated (1). The investigation indicated significant remolding and compaction of the clay located between the flanges. On inspection, this enclosed soil was found to consist of very thin, successive lenses of soil squeezed together in thin, vertical spiral seams. The shear parameters of the soil between the flanges ($\phi' = 25$ degrees; $c' = 24.3$ kPa) as defined by triaxial tests were remarkably higher than those of the surrounding natural soil.

In conclusion, all measurements and observations demonstrated the lack of any relevant loss of stress nearby the pile shaft with the installation of an Atlas screw pile and showed improved shear characteristics in the surrounding soil. Again, in the case of silty and clayey soils, the result is a very high shaft resistance on Atlas piles comparable to the shaft resistance on a Franki pile with rammed dry concrete, and even higher resistance than that on rammed cast-in-place piles with vibrated shafts, rammed precast piles, or jacked piles. Second, the end-bearing behavior of Atlas screw piles is quite similar to that of rammed piles.

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DESIGN

In Germany, pile design often is based on preliminary load tests at a particular job site, in accordance with the DIN codes. In other countries, such as Belgium, France, the Netherlands, and United Kingdom, the design of pile-bearing capacity is based on calculation, using semi-empirical methods of deduction from currently used in situ soil tests. Before detailing these methods, for completeness, the pile design method based on the theory of plasticity and often used in the United States is mentioned briefly.

Method Based on the Theory of Plasticity

The bearing capacity of single piles subjected to vertical loads may be calculated from the effective shear parameters (angle of friction, ϕ' ; cohesion, c' ; or adhesion, a) and the effective stresses. The equations for the ultimate unit-base resistance q_{bu} and the ultimate unit shaft resistance q_{su} usually are presented thus:

$$q_{bu} \text{ (for all soil types)} = c'N_c \zeta_c + q_0N_q \zeta_q$$

$$q_{bu} \text{ (for cohesive soils, } \phi' = 0) = c_uN_c'$$

where

c and $\phi' =$ effective shear parameters;

$q_0 =$ effective vertical stress at the pile base level;

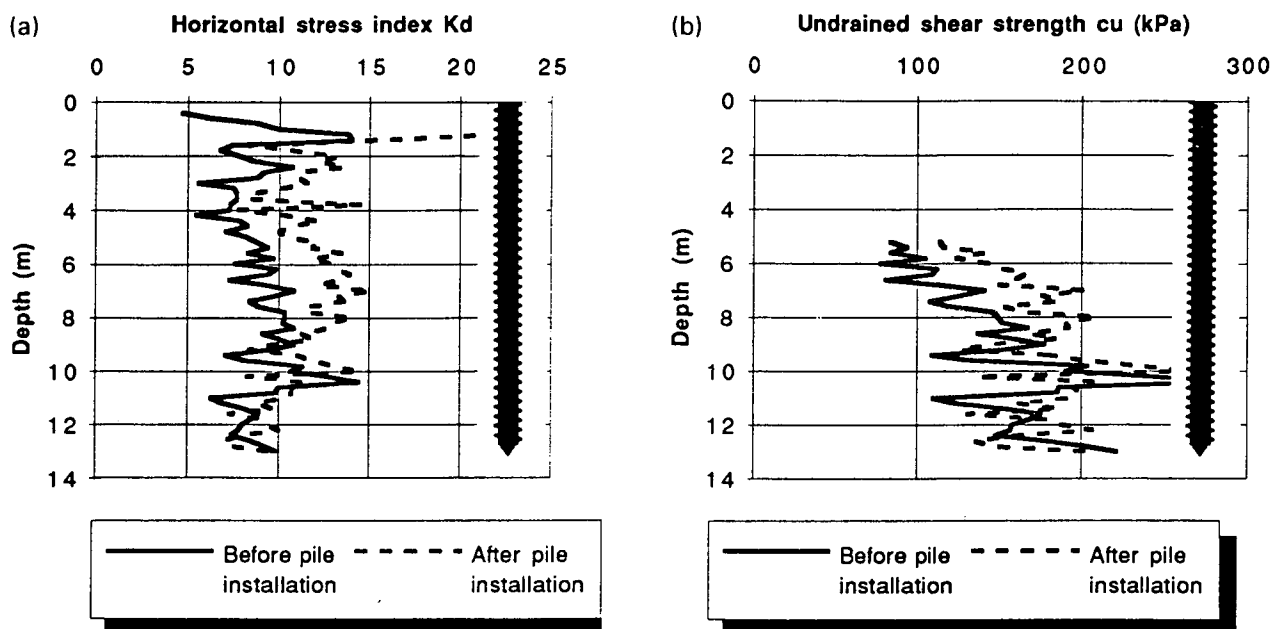


FIGURE 9 DMTs on axis of screw pile before installation and 0.6 m from edge of pile after installation (Koekelare).

N_c and N_q = dimensionless bearing-capacity factors and a function of ϕ' , defined by Meyerhoff (7);

ζ_c and ζ_q = shape factors and a function of ϕ' ;

c_u = undrained shear strength at the pile-base level; and

N'_c = dimensionless bearing-capacity factor, varying between 9 (for pile diameter < 0.5 m) and 6 (for pile diameter > 1.0 m).

$$q_{s,z} \text{ (for noncohesive soils)} = K_s \tan \delta' \sigma'_z$$

$$q_{s,z} \text{ (for cohesive soils, } \phi' = 0) = \alpha c_u$$

where K_s equals $\sigma'_{zh}/\sigma'_{zv}$, a function of ϕ' and the pile-installation method, and $\tan \delta'$ is the coefficient of friction pile-soil (= 0.7 to 1.0 $\times \tan \phi'$).

For the Atlas pile, the parameters and empirical coefficients used for concrete-displacement piles may be applied. Therefore, the following values are proposed for the coefficients mentioned above:

N_c and N_q = as for rammed piles,

$K_s = 1.5 K_0$ for normally consolidated (NC) soils,

$K_s = 1.0 K_0$ for over-consolidated (OC) soils,

$\tan \delta' = \tan \phi'$, and

$\alpha = 1.0$.

(PMT), or standard penetration tests (SPT), using semi-empirical relations. In general, the empirical coefficients to be introduced for end bearing and skin friction on different pile types in different soil conditions are based on the results of large numbers of representative static load tests. The accuracy and validity of extrapolation from these coefficients depend on the relevance of the test conditions, the number of data available, and the scatter of results.

Bustamante and Gianselli's analysis of 23 loading tests on concrete Atlas piles was reported in a paper (8) that provides practical guidelines and methods given for designing Atlas piles on the basis of the three types of in situ soil tests, the CPT, PMT and SPT mentioned above. In summarizing the proposed design method the authors used somewhat different symbols from the ones used in Bustamante's papers in order to conform with European rules.

Note that in the example that follows the empirical coefficients related to the CPT are valid when using a mechanical Dutch mantle cone (cone type M1). For electrical cones, these approximative relations can be taken into account:

$$q_c \text{ mechanical} = \beta \times q_c \text{ electrical},$$

where β is 1.3 to 1.5 for cohesive soils and 1.0 to 1.2 for saturated sands.

Deduction Methods for In Situ Soil Tests

The bearing capacity of single piles in both cohesive and non-cohesive soils can be derived from the results of in situ soil tests, such as static cone penetration tests (CPT), pressuremeter tests

Nominal Pile Dimensions

The nominal diameter of the pile base D_b and of the pile shaft D_s to be introduced in the calculation of the cross section of the pile tip A_b and the surface area of the pile shaft A_s depend on the

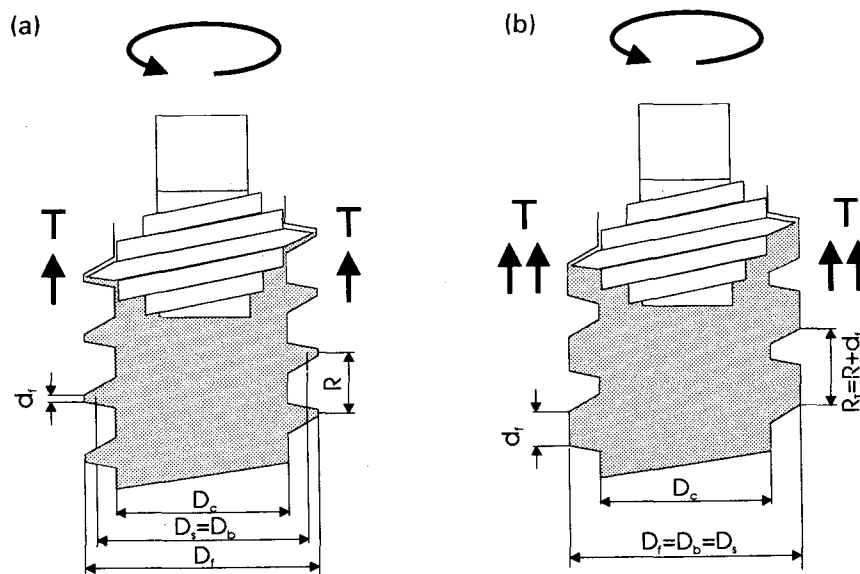


FIGURE 10 Cross section and nominal diameters of Atlas pile (a) with thin flanges, (b) with thick flanges.

maximum diameter of the displacement head, D_f , that is used. Bustamante proposed these rules:

- When the extraction procedure allows the realization of sufficiently thick flanges, as in Figure 10(b), it is generally the case with the powerful BT-40 and BT-50 rigs that

$$D_b = D_s = 1.0 \times D_f$$

- When the thickness of the flanges is small, as in Figure 10(a)

$$D_b = D_s = 0.9 \times D_f$$

Base Resistance

The ultimate total base resistance Q_{bu} is expressed as:

$$Q_{bu} = A_b K \alpha$$

where

- A_b = the nominal area of the pile base;
- K = the bearing factor depending on pile type, soil type, and soil test; and
- α = the equivalent unit-base resistance factor, based on soil test data

In practice

$$A_b = (\pi \times D_b^2)/4$$

The bearing factors K_p (for PMTs), K_C (for CPTs), or K_N (for SPTs)—tests for the concrete Atlas pile in various soil types—are given in Table 3. Whereas K_p and K_C are dimensionless, the factor K_N is expressed in terms of stress.

The equivalent unit-base resistance factor α , which characterizes the relevant soil density and shear strength in the vicinity of the pile tip, is derived from the soil-test results; and α corresponds to p_{le} , q_{ce} , or N_e , which are defined as representative average values of the limit pressures p , the cone resistances q_c , or the N values over a height a above and below the pile tip. In general a is equal to $\min \{1.0 \text{ m}; 1.5 \times \text{pile diameter}\}$.

Shaft Resistance

The ultimate shaft resistance Q_{su} is obtained from the summation of the shaft resistance over the i shaft-bearing layers:

$$Q_{su} = \sum A_{s,i} \times q_{su,i}$$

where $A_{s,i}$ is lateral pile area in layer i ($H_i \times \pi \times D_s$) and $q_{su,i}$ is ultimate unit skin friction in layer i .

For the unit skin friction q_{su} , both the chart in Figure 11 and Table 4 are used. First the curve to be considered is deduced from Table 4, depending on soil type and soil resistance. Figure 11 then allows us to define q_{su} as a function of the p , q_c , or N values.

TABLE 3 End Bearing Factors for Concrete Atlas Piles (7)

Type of soil (-)	K_p (-)	K_C (-)	K_N (MN/m ²)
Clay	1.6 - 1.8	0.55 - 0.65	0.9 - 1.2
Sands	3.6 - 4.2	0.5 - 0.75	1.8 - 2.1
Gravels (1)	≥ 3.6	≥ 0.5	undetermined
Chalk	≥ 2.4	≥ 0.6	≥ 2.6
Marls	≥ 2.4	≥ 0.7	≥ 1.2

(1) CPT and SPT results remaining always questionable for gravels.

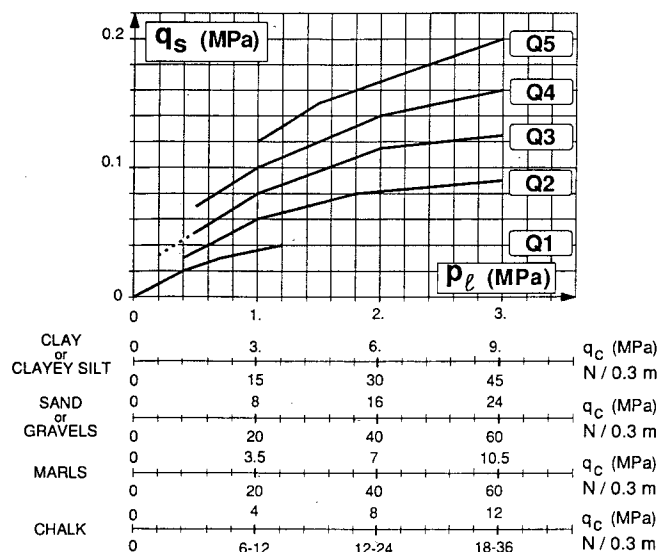


FIGURE 11 Design curves for the choice of unit skin friction q_{su} (7).

Specific Design Method on Basis of CPT: Belgian Practice

The design of displacement-type auger piles, such as the Atlas pile, is described in detail by Van Impe (1).

In the authors' considerations of ultimate pile capacity, the ultimate values refer to the conventional rupture load corresponding to the load that causes a relative pile base settlement s_r of 10 percent D_b , where D_b is pile-base diameter. In addition, the empirical factors used are related to the CPT with electrical cone.

Base Resistance

The ultimate unit-base resistance q_{bu} in Belgium is usually obtained from CPT results as

$$q_{bu} = \alpha_b \times \epsilon_b \times q_{bu}^*$$

where

q_{bu}^* = the ultimate unit-base resistance derived directly from the CPT in the natural soil conditions (before piling works);

α_b = an installation factor for the related type of pile and soil;

ϵ_b = a scale factor for soil discontinuities, such as fissuring.

Methods for q_{bu}^* derivation are discussed by De Beer (8) and Van Impe et al. (9). These methods take into account the resistance of the influencing soil layers beyond and below the pile base over a height depending on a piles diameter.

For cast-in-place auger piles of the displacement type, an α_b factor = 1.0, as is used for rammed piles, has been found to be realistic for both sands and clays.

In the Belgian Boom clay, which is a tertiary, overconsolidated clay, at ϵ_b factor related to the fissuring of the clay has been found to be approximately equal to

$$\epsilon_b = 1 - 0.01 (D/d - 1)$$

where D is diameter of the pile and d diameter of the sounding rod = 0.036 m.

For non-fissured soils, ϵ_b can equal 1.0.

Shaft Resistance

Shaft resistance on basis of q_c values can be calculated. More or less similarly to Bustamante, Van Impe (1,9) relates the unit-shaft resistance q_{su} to the cone resistance q_c by a coefficient η_p :

$$q_{su} = \eta_p \times q_c$$

Some proposed values of η_p for the displacement auger pile are summarized in Table 5. Again, these values correspond fairly well with the values found for rammed piles, as relevant soil decompressions are avoided by the pile installation method.

Shaft resistance on basis of total CPT skin friction can be determined also. The easiest way for evaluating the total shaft resistance Q_{su} on a pile remains related to the value of the total skin friction F_s measured by the CPT:

$$Q_{su} = \xi_f \times F_s \times \frac{D_s}{d}, \text{ where, for the Atlas pile, } \xi_f \geq 1.25.$$

TABLE 4 Curves To Be Considered for q_s in Function of Soil Type and Soil Resistance (7)

Soil type (-)	pl (MPa)	qc (MPa)	Curve to be taken (-)
Clay or clayey silt or sandy clay	< 0.3	< 1.0	Q1
	> 0.5	> 1.5	Q3
	≥ 1.0	≥ 3.0	Q4
sand or gravel	< 0.3	< 1.0	Q1
	> 0.5	> 3.5	Q4
	> 1.2	> 8.0	Q5
chalk	> 0.5	> 1.5	Q4
	> 1.2	> 4.5	Q5
marls	< 1.2	< 4.0	Q4
	≥ 1.5	≥ 5.0	Q5

TABLE 5 Proposed Values on the Coefficient η_p for Displacement Auger Piles

Soil type (-)	qc value (MPa)	Coefficient η_p (-)	Max. q_{su} (kPa)
Clay	Soft to medium	< 1.0	1/20
	Medium to stiff	1.0 - 4.0	1/40
	Stiff to hard	> 4.0	1/80
Silt	Loose	≤ 5.0	1/50
	Dense	> 5.0	1/100
Sand	Loose	≤ 15.0	1/100
	Dense	> 15.0	1/200

Calculated and Measured Bearing Capacities Compared

Applying the design method described by Van Impe to the cases given in Figure 7, the calculated, ultimate bearing capacity is compared in Table 6 to the in situ conventional rupture load values (I). A fairly good, and somewhat conservative, correlation is found.

QUALITY CONTROL: ATKWAP MONITORING SYSTEM

Computerization has made its way to the job site and piling rigs are beginning to be equipped with data-acquisition systems that record relevant execution parameters. A specific data-acquisition system, ATKWAP, has been developed for the Atlas rigs.

Description of the ATKWAP System

The ATKWAP system is composed of a central computer and data-logging system, and a separate operating box installed near the machine operator. The operating box mainly consists of a small printer unit and touch screen, which can be used by the operator to input the required pile data and displays real-time information during pile installation. Hydraulic pressures, penetration depth, and the number of rotations are continuously measured during the screwing in and extraction of the casing. The data are stored in the central computer and displayed in real-time on the computer screen. In the meantime, a graph of the actual torque as a function of depth and a table of the number of revolutions per meter-depth interval are issued.

The flow chart on Figure 12 gives an overview of the main-screen menus to be handled by the operator. Additional help screens to guide the operator's introduction of the required information are represented by short darts to the right or left of the main-screen displays.

The following parameters are measured and stored during the entire piling process:

- Rotational torque M transmitted to the casing by the drilling table (kNm);

- Vertical thrust N exerted on the casing by the two pressure rams (kN);
- Depth of penetration (m); and
- Number of revolutions from the drilling head and the casing (R).

With these parameters and a time factor, variable parameters can be deduced as a function of depth:

- Torque M (kNm);
- Total vertical thrust N (kN);
- Rotational speed of penetration (rev/min); and
- Vertical speed of penetration (cm/sec).

Sample ATKWAP data are given in Figure 13(a) and (b). The soil stratigraphy successively consists of sandy hydraulic fill, soft alluvial clay, medium-dense to dense quaternary sand, sandy clay, and dense to very dense tertiary sand.

Practical Uses for the ATKWAP System

The ATKWAP system is a practical tool for an operator, giving real-time information on the installation process, guiding the correct operation and manipulation of the machine, and indicating the soil conditions at each pile location. Development of the system would increase its value for the operator (for example, if it were to display the pre-installed pile layout on the screen).

The ATKWAP system may be linked with a reporting system and automatically transfer collected data to generate daily or weekly job reports, reducing time-consuming administrative work for the superintendent. Data from the site can be incorporated in financial reports as well. If statistically analyzed, the data provide the management team useful information on the overall operation team within a short time.

Detailed and automated registration of most relevant execution parameters enables thorough supervision of work performed and provides documentation for a client, supervisor, and contractor's project engineer.

Finally, a data-acquisition system constitutes an important and powerful tool for pile design. To the extent that pile parameters

TABLE 6 Comparison Between CPT Predicted and Measured Conventional Ultimate Bearing Capacity for Auger Piles in Various Soil Conditions (I)

Test site (-)	Pile (-)	Predicted values			Measured value	
		Q_{su} (kN)	Q_{bu} (kN)	Q_{tu} (kN)	Q_{ru} (kN)	Q_{ru}/Q_{tu} (-)
Zwevegem	P1	424.7	949.4	1374.1	1560	1.14
	P2	479.0	1098.9	1577.9	1765	1.12
Ghent-I	P1	834.9	1662.4	2497.3	2763	1.11
	P2	879.7	1690.1	2569.8	3000	1.16
Ghent-II	P6	1617.0	1280.0	2900.0	2800.0	0.97
Oldenburg	P1	1269.2	542.3	1811.5	>(1710)	>(0.94)
Hamburg	P1	965.1	2562.0	3527.1	3710	1.05
Berlin	P1	2290.0	1350.0	3640.0	3700	1.02
	P2	2560.0	1740.0	4300.0	4400	1.02

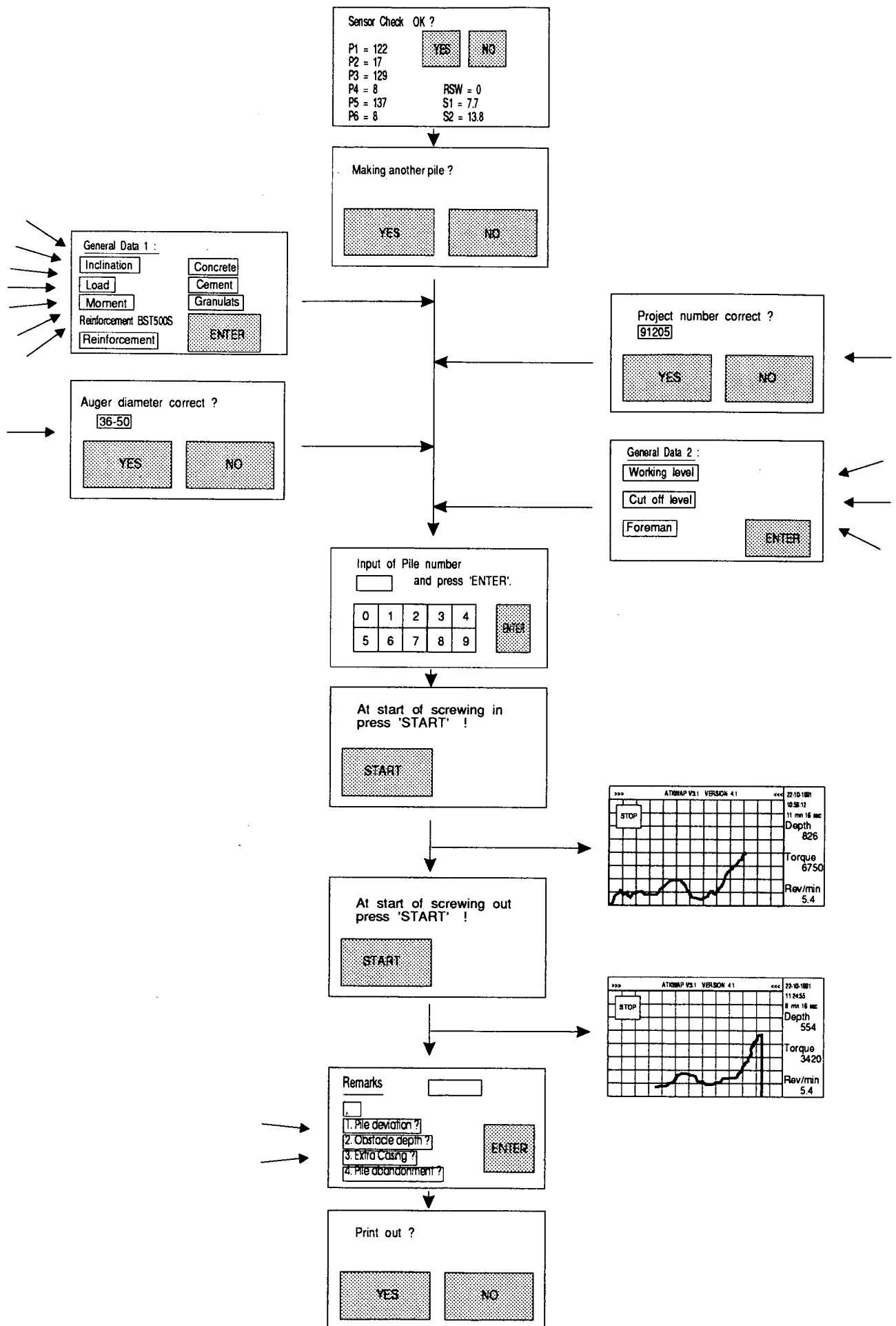


FIGURE 12 Mean operator instruction menus for data acquisition of installation parameters with ATKWAP system.

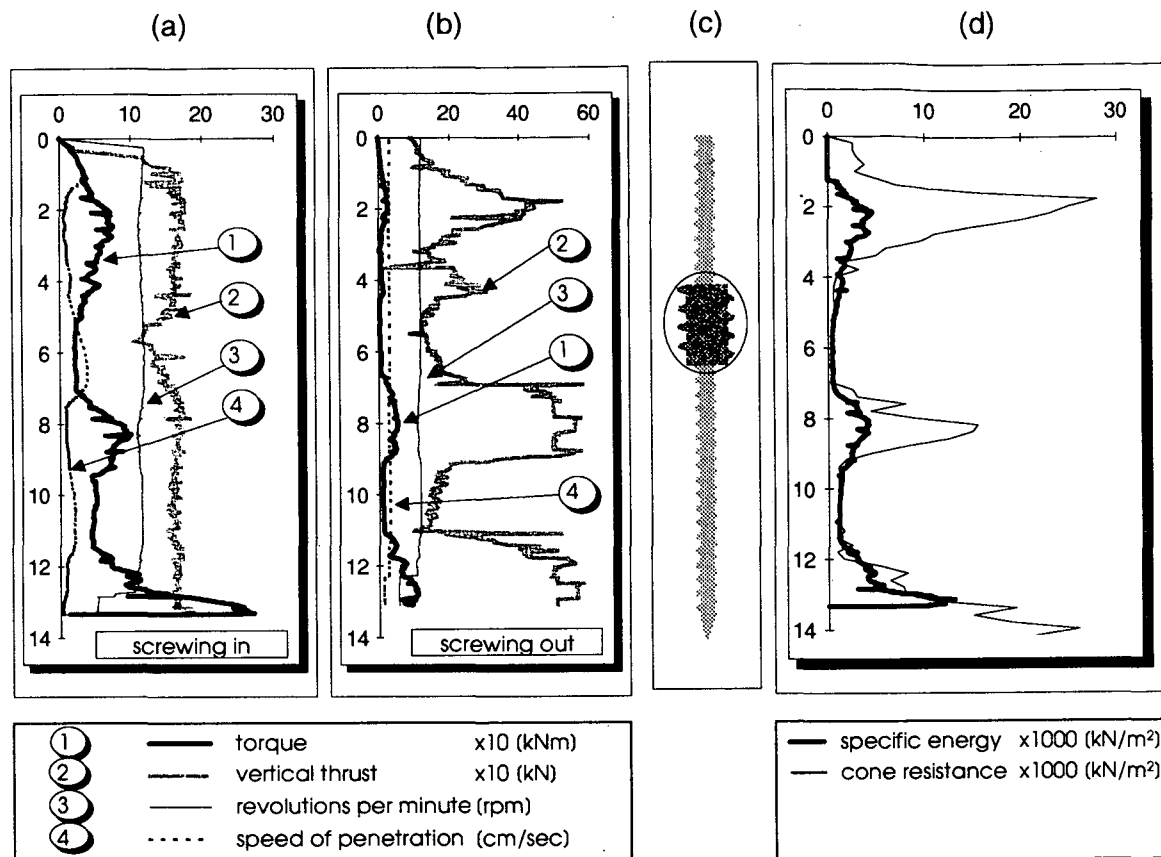


FIGURE 13 Example of ATKWAP installation parameters and deduced values; (a) ATKWAP parameters for screwing in, (b) ATKWAP parameters for screwing out, (c) deduced theoretical pile shape; (d) comparison of deduced specific installation energy and q_c values before pile installation.

reveal information on actual piles' geometry and the soil conditions affecting a particular pile, before and after installation, an engineer has a more or less complete answer to a pile's quality and expected performance.

For example, on the basis of the measured vertical and rotational speed of a pile casing during extraction, the pile's theoretical shape or geometry, its depth and the thickness of its flanges, can be delineated [Figure 13(c)]. If the concrete flow as a function of depth is known, an even more precise image of the pile shape can be obtained. (In the future, the data-acquisition system will no longer require manual registration.)

Analysis of Specific Installation Energy

One expects the energy required to penetrate a casing to be directly related to soil characteristics (nature and resistance). When the Atlas pile was first developed, rotational torque, which was read out on a manometer, depended to a large extent on the resistance of the soil at the level of the displacement head. It also was found that, when correcting the registered torque by a factor τ equal to the real penetration per revolution over the pitch of the auger, an even closer correlation between this so-called corrected torque and the soil conditions was obtained.

A more fundamental analysis of the installation process takes into account not only torque, but also vertical thrust, penetration

speeds, and displacement-head geometry. Van Impe et al. proposed to define an overall installation parameter that has a physical sense, that is, the specific installation energy (10) defined as

$$E_s = \frac{A \times N \times v + B \times n \times M}{\Omega \times v}$$

where

E_s = specific installation energy (kJ/m^3 or kNm/m^3);

A and B = machine-installation parameters, depending on displacement-head geometry and soil parameters;

N = vertical thrust (kN);

M = rotational torque (kNm);

v = vertical penetration speed (m/min);

n = rotational speed (revolutions/min); and

Ω = area of the outer projection of the displacement head

The ATKWAP system automatically calculates the specific energy for given values for the parameters A and B . The E_s graph is given in Figure 13(d) together with the q_c diagram of a relevant CPT in the vicinity of the considered pile. One can observe remarkable and useful similarities between the specific energy diagram and the cone resistances. The correlation, proven to be valid in all cases, confirms the practical use of the data-acquisition system for active design. In practice, piles are executed at the begin-

ning of the job near the locations of the relevant soil tests that have been the base for the theoretical pile design. This allows for calibration of pile-installation parameters and for definition of the minimum values that have to be achieved for these parameters for other piles at the site. When discordance is revealed (for example, due to changes in local soil conditions), one is able to make appropriate adjustments.

In the future, it should be possible to deduce the degree of ground improvement during the pile installation from the ATKWAP parameters and to make quantitative predictions regarding pile-bearing capacity.

CONCLUSIONS

With the advent of the powerful BT-40 and BT-50 rigs, the Atlas screw pile has been developed into a high-quality foundation system that not only offers solutions to technical problems relating to deep foundation but also meets ever more stringent environmental demands. Soil tests before and after screw-pile installation demonstrate the beneficial effect of these piles' installation on shear parameters or stress state of surrounding soil. This effect results in high base and shaft resistances that are comparable to those of common rammed piles. Additionally, practical design rules for the bearing capacity on basis of CPT, PMT, or SPT tests enable sound prediction of pile performance in various types of loose soils. Supervising pile installation and controlling for soil conditions surrounding a pile are aided by the continuous recording of relevant execution parameters. Further research on interpreting specific installation energy should reveal additional quantitative information on pile quality and expected performance.

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