Construction of Drilled Displacement and Auger Cast In Place Piles

Walter I. Paniagua
Pilotec, S.A. de C.V., Mexico City

ABSTRACT: Auger cast in place piles and drilled displacement piles (in Europe known as continuous flight auger piles and screw piles, respectively), are extensively used in other countries for foundation elements requiring accelerated construction, or involving the rehabilitation of existing structures, become a natural alternative for rigid inclusions construction. Different types of drilled displacement piles and auger cast in place piles are described, with installation methods varying according to local experience. The general description includes the equipment used to install them, overall differences in the construction process between them, and the quality control processes typically used in some of them.

1 INTRODUCTION

It is a common place to admit that the most exciting developments in the early years of the new millennium, at least as far as piling is concerned, are in displacement auger piling systems (Heath, 2003). As is already an everyday practice in Europe, the construction industry must take on board the environmental constraints of the future. This technology is yet to be developed in emerging economy countries, in contrast with the Low Countries, where the technique was developed.

Is astonishing that over 90 % of the auger piles in that area are formed by displacement methods, while elsewhere over 90% are formed by non-displacement methods – primarily CFA in Europe, bored piles in America. Soil characteristics is not the root cause – there are bad soft soils everywhere, but the cost of disposal of spoil. Once it is established that spoil is not desirable (especially contaminated material), the rest follows, and the whole world will be there in the future.

Displacement auger piling is not without its problems. It is relatively simple to install conventional bored and CFA piles even when the site investigation may be less than adequate but to displace the ground and achieve the design capacity takes a little more care and effort.

The first screw pile, cast-iron or composite one´s (Fig. 1), are first recorded for used in 1833, by Alexander Mitchell, who used them to support lighthouses in England, as a mean of extending the capability of piles to carry higher compressive or uplift loads.

However, a distinction should be made between concrete/grout cast drilled displacement piles described in this paper an those where a single or multiple helix steel auger is screwed into the ground to form the pile, which installation and design differ greatly from the mentioned earlier. In Fig 2, the more commonly used terminology for auger piles is presented.

In this paper, a general description of the most common methods on displacement and CFA piles is presented, among its main advantages and drawbacks. The design methods for this piles are beyond the scope of this paper.

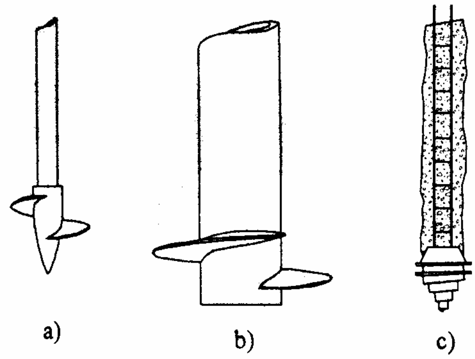


Figure 1. (Bustamante and Gianeselli, 1998) a) Early pattern of cast iron screw pile; b) Modern screw cylinder about 1 m diameter, open at the bottom (after Whitaker, 1970) c) Fundex pile.

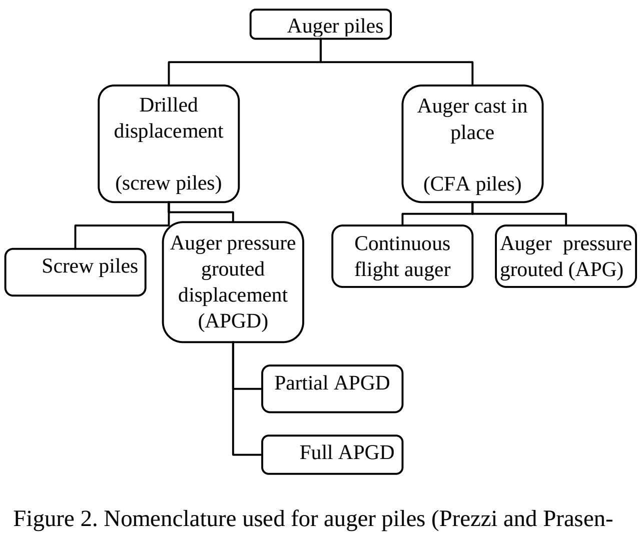


Figure 2. Nomenclature used for auger piles (Prezzi and Prasenjit, 2005)

2 DISPLACEMENT PILES

There have been patented methods of forming displacement auger piles since earlier XX century but it is only relatively recently that use of the first generation systems has become widespread.

The first generation piles (dating from the early sixties) were formed by rotating steel tubes into the ground leaving a large sacrificial tip at the base of the pile; typical in this category are Atlas piles. Others merely used a large diameter stem with vestigial flighting. This piles are based on the principle of soil excavation during penetration of the auger, resulting in rather slow pile installation rates but requiring only a limited overall torque of 50-100 kNm. Many piles have been formed in this way but there is a drawback to using such a blunt instrument: it takes time and power to form such piles.

The second generation of displacement auger piles emerged during the seventies as “single” lateral displacement type of screw piles, and addressed the aspect of penetration by placing flighting at the lower end of the auger. This helped penetration but had the effect of disturbing the soil adjacent to the pile. The larger the diameter of the flighting and the smaller the stem, the easier the penetration; the installation energy increasingly adapted up to torques of the order of 500 kNm, in combination with some downward vertical thrust. However, this can lead to greater disturbance which in certain ground can give very unusual pile sections and problems in assessing pile capacity.

At the beginning of the eighties, Van Impe went on to develop and patent the Omega piling system. This represents the start of the third generation systems where the efficiency of the auger comes into play - the third generation is typified by efficient screwing. Such augers represent a significant step forward but there are still improvements to be made.

It is a distinctive that the last generation of screw piles are installed by means of equipment of very high energy which allow:

i) To combine high torque (150 to 450 kNm) with additional vertical down and upward thrust (up to 250 kN),
ii) To use special designed screw-head in order to ensure as high penetration rate as possible,
iii) A strict limitation of the amount of excavated soil, among with low noise and vibration.
iv) It is also typical that under the influence of CFA technique, screw piles can be nowadays equipped with heavy large diameter reinforcement cages.

The installation procedure of the most common drilled displacement piles is described next. General characteristics of the systems included are presented in an appendix.

2.1 *First generation piles*

Atlas pile. In this pile, lateral displacement of soil occurs both during drilling and extraction of the auger. The drilling rig has two hydraulic rams that can work independently (one taking over from the other after its full stroke is achieved) to allow a continuous drilling operation. In the case of hard soils, the two hydraulic rams can work simultaneously. The rig can be operated at dual rotational speeds. This helps to control the drilling tool penetration rate in different soil types.

In the Atlas pile installation, a sacrificial tip (a lost pile shoe) is attached to a displacement body, which in turn, is attached to a steel casing or mandrel (Fig. 3). The displacement body consists of a cast-iron dismountable helical head with an enlarged helical flange. The joint between the displacement body and the sacrificial tip is made watertight. The combined action of the torque and the vertical thrust forces the casing down into the ground with a continuous, clockwise, helical penetrating movement. After the desired depth is reached, the steel shoe is detached from the casing. A steel reinforcing cage is inserted into the casing. High-slump concrete is then poured through a hopper placed on top of the casing to cast the pile shaft. As the casing and the displacement body are extracted by a vertical pulling force and counter-clockwise rotation, concrete completely fjlls the helical bore formed by the upward-moving displacement screw. This way. a screw-shaped shaft is formed. After concrete placement, it is possible to push into the pile a supplementary reinforcing cage (Bustamante and Gianeselli).

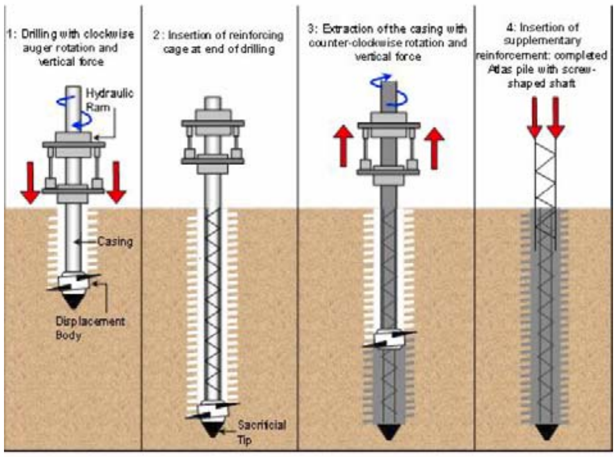


Figure 3. Installation of Atlas pile.

De Waal pile. The drilling tool used to install the De Waal pile consists of a sacrificial tip. a partial-flight auger and a displacement body (Fig. 4). The drilling tool is attached to a casing that has additional helices welded near the top. The partial flight auger is closed at the bottom with the sacrificial tip. To install the De Waal pile, the drilling tool is rotated clockwise to the required depth with a torque and a vertical force, the sacrificial tip is released and the reinforcement age is installed. Concrete is injected into the casing as the casing is extracted with clockwise rotation and a vertical force. Unlike the Atlas piles, in this case a nearly smooth shaft is created. The helices near the top of the casing produce an enlarged shaft near the pile head.

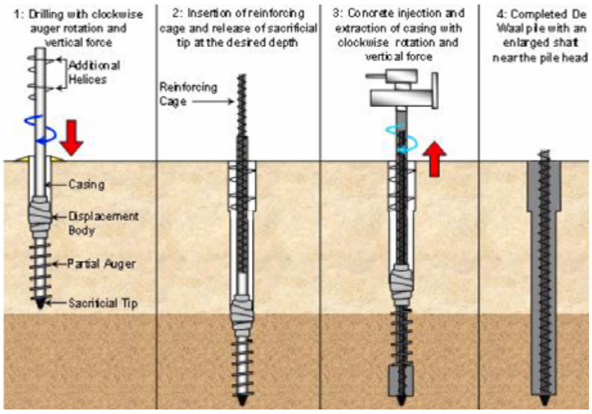


Figure 4. Installation of De Waal pile.

A simplification of the sacrificial tip of a similar system conducted to the Spire pile (Bustamante and Gianeselli, 1998).

Franki VB pile. The Franki VB (Verdrangungsbohr) pile is a term used in Germany for "displacement auger" pile. To install this pile, a large-stem auger is rotated and pushed into the ground. A sacrificial bottom plate is attached to the auger. Once the desired depth is reached, reinforcement, which can be anchored to the bottom plate, is installed. The casing is then filled with concrete. As the casing is withdrawn, more concrete is pumped into the casing to guarantee the quality of the shaft.

Fundex pile. In the Fundex pile installation, a casing with a conical tip attached to its end is rotated clockwise and pushed down into the soil (Fig. 5). The joint between the casing and the conical tip is made watertight. As the casing is drilled into the ground, soil is displaced laterally. In dense or hard layers, drilling can be combined with grout injection or water jetting through the conical tip. After the desired depth is reached, the sacrificial conical tip, which forms an enlarged pile base, is released. The reinforcement cage is then inserted into the casing and concrete is placed; in the meantime, the casing is extracted in an oscillating upward and downward motion with 180° clockwise and counter-clockwise rotations. This rotation produced a nearly smooth shaft.

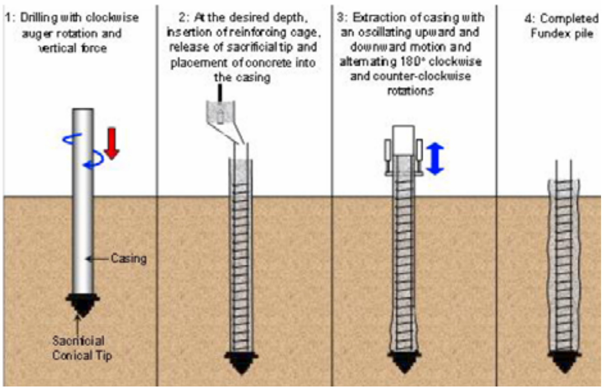


Figure 5. Installation of Fundex pile.

Olivier pile. The installation of the Olivier pile is similar to that of the Atlas pile (Fig. 6). A lost tip is attached to a partial-flight auger which, in turn, is attached to a casing. The casing, which is rotated clockwise continuously, penetrates into the ground by action of a torque and a vertical force. At the desired installation depth, the lost tip is released, and the reinforcing cage is inserted into the casing. Concrete is then placed inside the casing through a funnel. The casing and the partial-flight auger are extracted by counter-clockwise rotation. Similarly to the Atlas pile, the shaft of the Olivier pile is also in the shape of a screw.

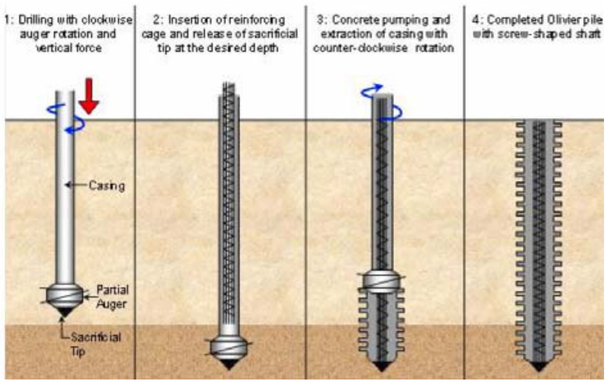


Figure 6. Installation of Olivier pile.

2.2 *Second generation piles*

Funderingstechnick pile. The screw injection pile is, basically, a steel tube pile encased in hardened cement grout. During installation the ground is wholly displaced, thereby increasing the bearing capacity. The steel tube is installed by screwing, whilst simultaneously injecting cement grout. During the installation the grout acts as a lubricant, which temporarily reduces driving resistance. When set the cement grout increases the strength and stiffnes of the pile, transfers part of the loading to the ground and gives corrosion protection to the steel tube. The steel tube is filled with either cement grout or concrete.

Pressodrill pile. The installation equipment consists of a crane that supports a leader on which a rotary head slides. A large hollow-stem auger. sealed at the base with a plate. is inserted into the ground by rotation and by a vertical force provided by the weight of the rotary head and the weight of the casing. After the installation depth is reached. reinforcement is lowered into the casing and locked to the bottom plate of the auger. The lower ends of the bars are bent towards the pile center. A hollow-steel mandrel, provided with side holes. is then lowered down through the auger to rest on the auger bottom plate. The mandrel and the auger are then fjlled with high- slump concrete. The top of the auger is equipped with a device that forces the mandrel to move downward and the auger to move upward. This upward force extracts the auger in successive stages. while the downward movement of the mandrel exerts a reaction force on the bottom plate. preloading the soil under the pile base. After withdrawal of the auger, the mandrel is removed from the ground.

SVB pile. The SVB pile (Schnecken-Verdrangungsbohrpfahl), is a drilled, partial-displacement pile. The drilling is done by a large-stem auger which also acts as a casing. Both a torque and a pull down force are used during drilling. The bottom of the casing is sealed off with a disposable plate (Fig. 7). When installing the casing, some of the soil is transported along the helices to the surface, while a certain amount of soil is displaced laterally. When the desired depth is reached, reinforcement is installed and concrete is pumped into the casing. The casing is extracted by a pull-out force and a torque, leaving the bottom plate in the ground. Since the casing is rotated clockwise during extraction, a nearly smooth shaft is formed (Geoforum).

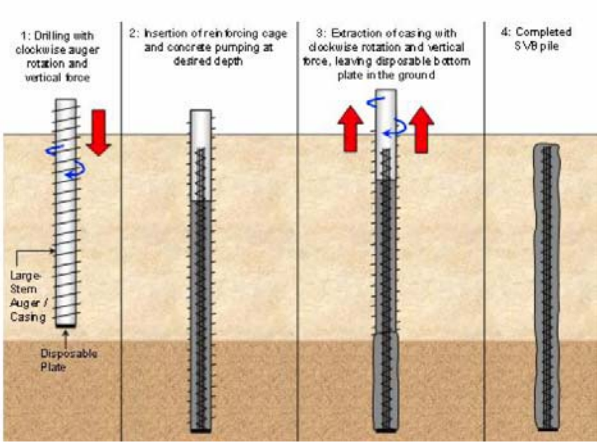


Figure 7. Installation of SVB pile.

SVV pile. The SW pile (STRABAG Vollverdrangungsbohrpfahl), is a drilled large- displacement pile (Fig. 8). The pile is installed using a patented casing that has a segment with an enlarged diameter and a drill head. The installation procedure of the SVV pile is similar to that of the SVB pile (Geoforum).

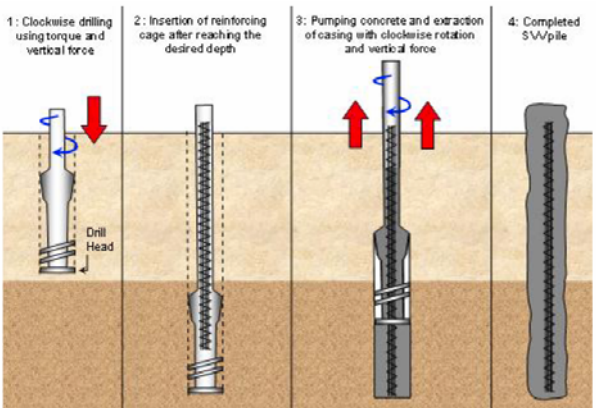


Figure 8. Installation of SVV pile.

Tubex pile. The Tubex pile, is a drilled displacement pile with a permanent casing that is left in the ground. The pile casing is fabricated from a tube by welding a special drill point to its base and helical flanges to its shaft. In order to install this pile, the casing is drilled into the ground until the desired depth is reached. The casing is then cut off at ground level, reinforcement is inserted into the casing and concrete is placed. This type of pile can be used in very unstable ground and is well suited for temporary foundations because it can be drilled out and removed from the ground. This type of pile can also be installed under limited headroom, and in that case is known as Tirex pile.

2.3 *Third generation piles*

APGD pile. The APGD pile technology, is a modification of the original APG piling system. Compared with APG piles, there is minimal spoil of soil at the ground surface during the installation of APGD piles. This is especially crucial for a contaminated site. During the installation (Fig. 9) of an APGD pile, the surrounding soil is displaced laterally as the drilling tool is advanced into the ground. There are two types of APGD piles: 1) auger pressure-grouted with partial soil displacement and 2) auger pressure- grouted with full soil displacement. The partial- displacement pile installation causes less lateral soil displacement around the pile shaft than the full- displacement one. In contrast to APG pile rigs, the APGD pile rigs are capable of producing both a torque and a downward crowd force, which facilitates the drilling operations. Once the desired depth is reached, high-strength grout is pumped under pressure through the drill stem and the drilling tool is withdrawn as it rotates clockwise. The reinforcement cage is inserted into the grout column to complete the pile installation process. Full- displacement piles can be 0.3 to 0.45 m in diameter and up to 24 m in length. These piles are used in loose to medium dense sands (NSPT < 25).

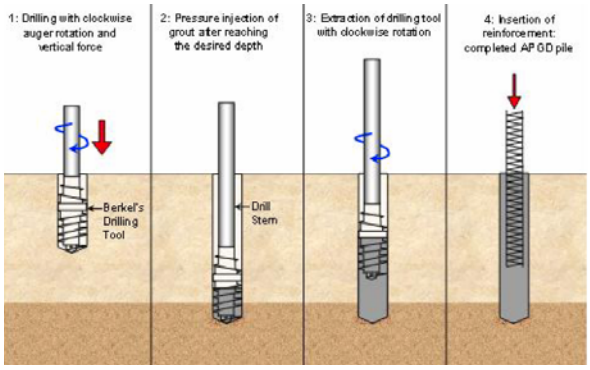


Figure 9. Installation of AGPD pile.

Bauer displacement pile. The tool for the partial displacement pile consists of a lower auger with a small hollow stem with large flights and an upper auger with a large hollow stem with small flights, Fig. 10. During drilling, the soil is transported by the bottom auger upwards; as the soil moves up, it displaces the surrounding soil laterally because there is less room available in the helical space of the upper auger which has a larger diameter. This pile installation method is effective when a loose stratum is underlain by a dense layer. After the design depth is reached, concrete is pumped through the hollow stem. and the auger is withdrawn. The reinforcing cage is either pushed in or inserted with the help of top vibrator. The Bauer pile can be up to about 30 m in length. Piles with a diameter of up to 0.6 m are possible with this technology.

The tool for the installation of the full displacement pile consists of a lower tip, a middle displacement part and an upper auger section with counter- rotating flights. The insta/1ation method is identical to that of the partial-displacement pile. However, the use of a Kel1y extension may increase the drilling depth by 6 to 8 m.

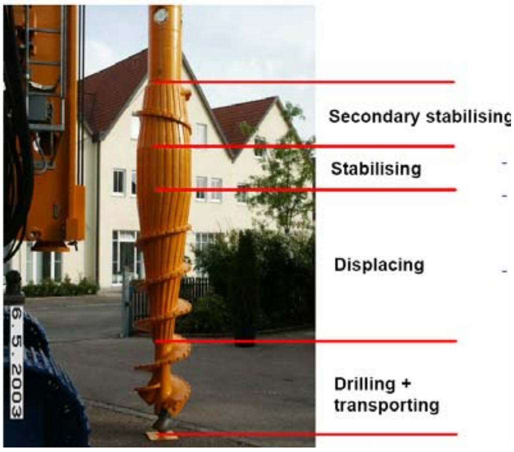


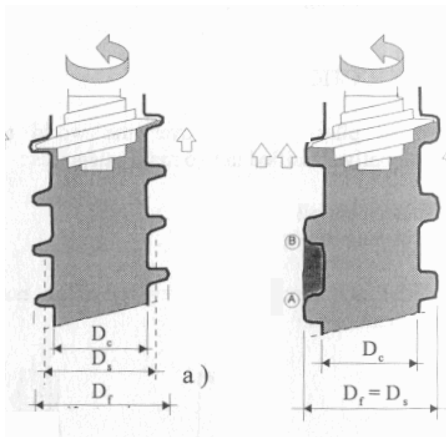
Figure 10. Elements of Bauer displacement pile tool.

Cementation screw pile. It is a development of the Atlas technique. In contrast, the new screw piling system has been developed specifically for use in cohesive strata and soft rocks. The construction process is similar to that for CFA piles. The tool is drilled into the ground to the required depth, or rig refusal. The tool is then extracted while concrete is pumped from the base of the tool. The concrete fills the profile left by the tool, forming a pile with a central shaft of 300mm diameter, and a helical protuberance of 600mm diameter. Cementation claims that the piles behave like standard 600mm diameter CFA piles in terms of geotechnical capacity. The relatively small central shaft diameter means that structural capacity is limited to 700kN. Screw piles require high-torque drilling rigs to wind the tool into the ground. During drilling, downward thrust is mostly generated by the screwing action of the tool itself, although the rig can assist with thrust through less cohesive superficial strata if required.

Cementation soil displacement piles. The tool is advanced using a combination of torque and downward thrust from the rig. The displacement action of the tool compresses the surrounding soil as the pile is formed. This enhances the shaft friction and also increases the end bearing resistance of the finished pile. Once the tool has reached the desired depth it is extracted as the pile is concreted under pressure via an opening in the tool tip. Both drilling and concreting processes are fully instrumented. The magnitude of the torque, in combination with an active vertical crowd force and the shape of the tool, are the key elements of the high displacement capacity of the system. Measuring the concrete feed pressure at the bottom of the tool assists the construction of a high quality concrete column.

Discrepile. This type of pile is sub-divided into two categories: *CDSP* **(**Cylindric Displacement Piles) and *SDSP* (Screw Displacement Piles). The method requires that drilling string and tool are rotated and driven into the ground, displacing the material while penetrating. Once the designed drilling depth is achieved, concrete is fed through the drilling string that is slowly withdrawn while the hole is filled. When required, a steel cage is lowered inside the drilling stem, before concreting starts, or it is driven later on in the fresh concrete. Special drilling rods and tool for displacement pile are used. Drilling string has a sturdy construction so to withstand the torque of the rig and a design that allows a smooth flow of fresh concrete. Tool is fitted with a temporary bit that helps the penetration and prevent soil from clogging the tool stem. Temporary bit is expelled by concrete pressure and is left in the hole. It is usual to monitor and record drilling and pumping parameters, such as drilling depth, torque, trust, rotation speed, penetration speed, lifting speed and volume of concrete.

Franki-Atlas pile. A modified Atlas pile with a thin-walled casing attached to the screw head is used in highly compressible soils, or in soils with large cavities or voids. The casing is left in the ground with the sacrificial tip. This type of pile is characterized by the thick flange of the helical head, Fig. 11.



a) with thin flanges b) with thick flanges

Figure 11. Franki-Atlas screw head

Omega pile. In this case, drilling is done by a displacement auger which is closed at the bottom with a sacrificial tip (Fig. 12). A casing is attached to the upper end of the displacement auger. Unlike other drilled displacement piles, concrete is injected under pressure into the casing even before the desire depth is reached. After reaching the required depth, the sacrificial tip is released, and the auger is slowly rotated clockwise and pulled up. The withdrawal of the auger with a clockwise rotation produces a nearly smooth shaft. The reinforcement cage is then vibrated into the fresh concrete.

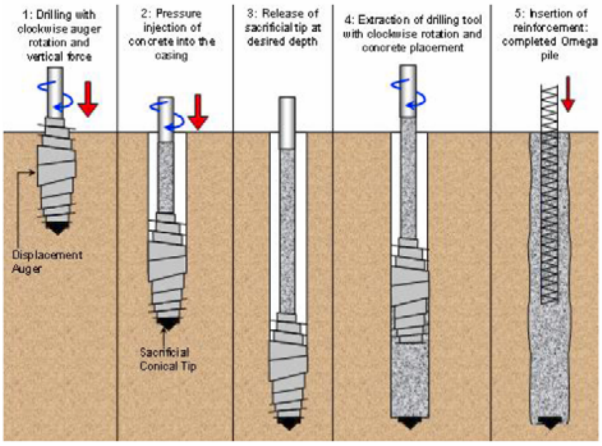


Figure 12. Installation of the Omega pile

T pile. Named after Threaded pile, improves the skin friction by adding a helical concrete thread that winds round the shaft of the pile. Devolopers of the system claim that the T.Pile pile has a bearing capacity 30 to 50% greater than a traditional smooth shaft pile of the same diameter. Conversely, for an equal bearing capacity, the T.Pile reduces by 20 to 40% the amount of concrete needed and the amount of spoil to be evacuated. There are three versions of the T.Pile: Screwsol is an improvement on the old pre-cast screw pile, SolThread improves on the traditional bored pile, and StarT.Pile on the Starsol piles.

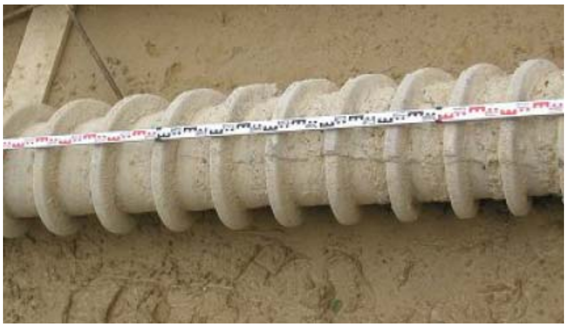


Figure 13. T. pile

TSD pile. The shape of the displacement auger itself is particular. The central stem increases in diameter from the tip upwards but the surface is angled to aid penetration and increase the efficiency of the auger. Conventional flighting of constant pitch is also used to aid penetration. The upper auger consists of a series of discontinuous reversed screw fins. The shape allows soil displacement to take place over a larger area, thus reducing wear during installation. As the auger first enters the ground, at the start of drilling, there is a minimal initial displacement of spoil to the surface. But as penetration continues all the subsequent spoil is laterally displaced within the bore. When the required depth is reached, concrete is pumped through the hollow stem as the auger is withdrawn. Reinforcement can be placed in the concrete as with other augered systems. Manufacturer craims that this pile has a larger penetration capability in both dense granular strata and stiff clays with reduced auger wear.

3 AUGER CAST IN PLACE PILES

The progress in auger piling technology was motivated in part by the development of ACIP piles. To install an ACIP pile, a plugged hollow-stem, continuous flight auger is drilled into the ground at a certain rate (Fig. 14). The plug prevents soil from entering the hollow stem of the auger during drilling. The rate of auger penetration during the pile installation is very important, as it has an impact on pile performance. During auger penetration, some soil is removed by the auger flights, and “bulking” of the soil adjacent to the auger occurs. Ideally, the rate of auger penetration should be such that there is minimal release of lateral stress due to soil removal. In reality, there is always some lateral displacement (Van Impe, 2004). Problems bay be encountered during ACIP installation when there is the need to penetrate a comparatively hard stratum underneath a soft clayey or loose sandy soil layer. If the penetration rate decreases when the auger tip enters the hard stratum, then the supply of soil into the auger flight from the auger tip drops. At the same time, there is more lateral feed of soil into the auger flights from the relatively soft/loose overlying layers. This may cause considerable loss of lateral confinement to adjacent piles and structures; also, ground subsidence may occur.

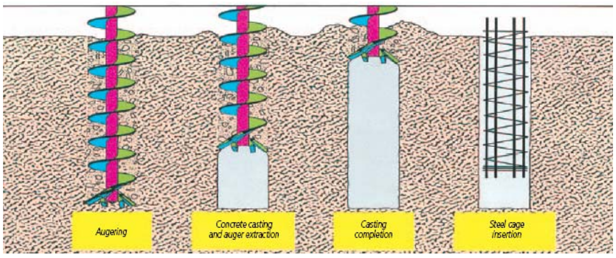


Figure 14. Installation of a auger cast in place pile.

According to Viggiani (1989), the critical penetration rate is given by:

$$v_{cr} = nl\left(1 - \frac{d_0^2}{d^2}\right) \qquad (1)$$

where:

n rate of auger rotation
d diameter of the auger
d_o outer diameter of the hollow stem of the auger
l pitch of the auger

If, for a given penetration rate v, the rate of auger rotation n is comparatively high, then v < vcr. Consequently, the horizontal stresses are reduced, and more soil is removed from the region around the auger than from the region below the auger tip.

After the desired depth is reached, concrete or grout is pumped into the hollow stem, and the auger is raised a small distance (about 0.3 m) to release the hollow stem plug and the lowered back to the original position. A certain amount of concrete or grout is the pumped to form a concrete or grout head on the auger flights. Subsequently, the auger is withdrawn, while concrete or grout is continuously pumped under pressure throughout the auger withdrawal process. Auger withdrawal is accomplished by initially rotating the auger clockwise to fill out with concrete or grout the lower flights of the auger and then by lifting it without rotation (CFA piles); alternatively, the aguer is rotated clockwise at los speeds (Berkel piles) at the same time it is lifted. After concrete placement is completed, the reinforcement cage is inserted or vibrated into the fresh concrete, and tied off at the surface. In some cases H steel profiles are used.

The rate of withdrawal of the auger is important as well; it needs to be synchronized with the concrete or grout pumping rate. The average cross-sectional area of the pile is equal to the ratio of the concrete pumping rate to the auger withdrawal. This ratio should be selected based on the pile diameter assumed in design. An erroneous selection of this ratio may lead to a different pile diameter. If it is too fast, the integrity of the pile is compromised; if is too slow, it will lead to excessive consumption of concrete.

Computer monitoring of the rate of auger penetration, the concrete pumping rate and the rate of auger withdrawal from the ground provides additional confidence on the integrity and performance of these piles. With the currently available equipment, CFE and APG piles can be installed in diameters ranging from 0.3 to 1.4 m and lengths reaching up to 40 m.

Starsol pile. This is a different type of ACIP pile; the basic difference is that in this case, the rotation head drives a hollow stem auger and a tremie pipe simultaneously into the ground. The auger and the tremie pipe are fitted with earth cutting tools at the base and rotate and drill together. After drilling is completed, the tremie pipe is clamped in position while the auger is raised slightly ro open two holes on the sides of the tip of the tremie pipe (Fig. 15). Concrete is then pumped through these holes under pressure, as the auger is raised slowly. Typical diameters are between 0.4 and 1.0 m, and maximum length is about 20 m.

4 INSTALLATION MONITORING

Depending on the equipment available, some or all of the following quantities can be measured or calculated during the installation of ACIP piles: the rate of auger rotation, the rate of auger penetration, the torque, the concrete pumping rate, and the auger extraction rate (Mandolini et al., 2002).

In the past, quality control (QC) of these piles was performed by field inspectors, based mainly on the industry standards and well practice (Brettmann, 2003). Currently, automated systems are attached to many pile rigs throughout the world. Even though these monitoring systems can provide valuable information on the quality of the piles, they are not meant to replace qualified field inspections. Automated QC monitoring techniques are based on measurements of either volume or pressure of the grout/concrete. Typical automated systems measure: i) time, depth and hydraulic pressure during drilling and ii) time, depth, grout/concrete volume or grout/concrete pressure during casting. Continuous, real time graphs of relevant data are available to the operator during the installation (this facilitates any real time adjustments that may be needed). These files can also be stored electronically for future reference.

Similar automated monitoring systems are available for the drilled displacement pile rigs as well. These can be used to continuously monitor the depth of penetration, the vertical force, the torque, and the rate of auger/casing penetration and rotation (Fig. 16). A specific energy term can be calculated which involves the variables mentioned above and other machine-specific installation parameters. The specific energy profile along the depth of the pile can be correlated with in-situ test results and used to visualize the effects of pile installation and to help predict pile load capacity.

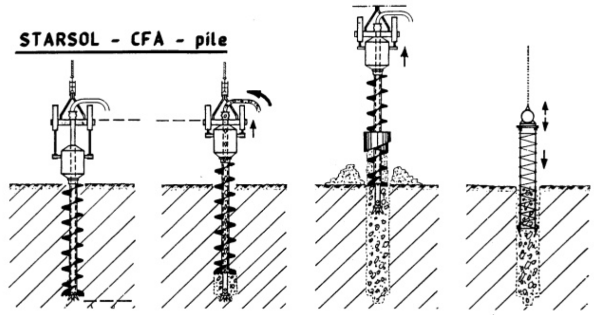


Figure 15. Execution sequence of a Starsol pile.

5 FINAL COMMENTS

Displacement (or screw) piles and auger cast in place (or continuous flight auger) piles, are used extensively in Europe, and are winning a market share in the US. This piles are becoming less expensive, faster to build and environmentally friendly (less spoil, noise and vibrations) than the typical bored piles. The techniques to perform this kind of piles vary according to the local practice and soil conditions to be found; however, most of this systems may be adapted to emerging economy countries.

The application of this methods to build rigid inclusions is immediate: feasibility of relatively small diameters, increase of friction capacity, possibility to avoid, or at least reduce, steel reinforcement, among others. Therefore, in emerging economies, technology transference or applied research is urgently needed in this area.

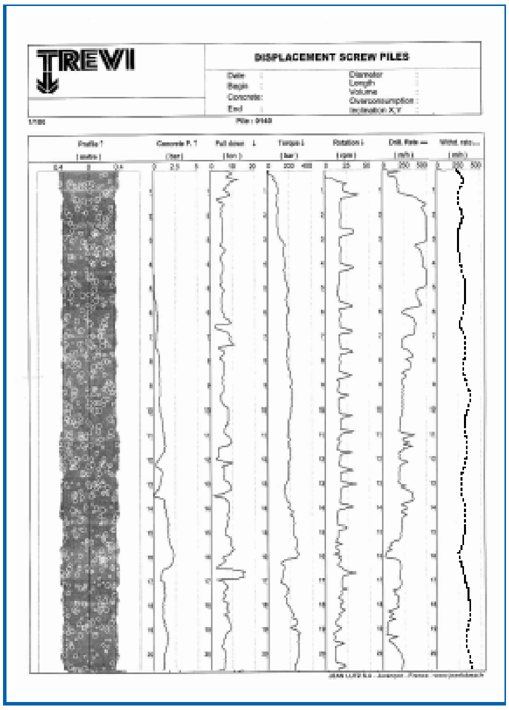


Figure 16. Log data from the construction of a Discrepile.

REFERENCES

Brettmann, T. 2003. Constructibility of augered cast in place piles. *Geo-strata, 8-11.*

Bustamante, M. and Gianeselli, L. 1998. Installation parameters and capacity of screwed piles. *Deep foundations on bored and auger piles, BAP III*, Balkema, Rotterdam.

Fenoux, G. and Buysere, G. 1988. Starsol Enbesol procedure. *Deep foundations on bored and auger piles*, Balkema, Rotterdam.

Geoforum – www.geoforum.com.

Heath, C. 2003. On the quest for piling's Holy Grail, *Foundation World Magazine, London.*

Mandolini, A, Ramondini A., Russo G. 2002. Full scale loading tests on instrumented CFA piles. *Proceedings of the International Deep Foundation Conference, Geotechnical Special Publication N° 116, ASCE.*

Prezzi, M. and Prasenjit, B. 2005. Overview of construction and design of auger cast in place and drilled displacement piles. *Deep Foundations Institute Conference Proceedings, Chicago.*

Van Impe, W. 2000. New screw pile technology: geotechnical design and performance. *3er Simposio Consultores – Constructores de Cimentaciones Profundas*, SMMS, México.

Viggianni, C. 1989. Influenza dei fattori tecnologici sul comportamento dei pali. *Atti, XVII Convegno Nazionale di Geotecnica*, Taormina, Italy.

Whitaker, T. 1970. The design of piled foundations, Pergamon Press, Oxford.

Appendix
General Data on Displacement Pile Systems

Pile / Technique	Country	Developer – Contractor*	Torque needed kNm	Diameter mm	Length m
First Generation					
Atlas	Belgium	Franki		460-660	
De Waal	USA	Morris Shea			
Franki VB	Germany				
Fundex	USA	American Pile Driving		450-670	25-35
Second Generation					
Screw injection	Neetherlands	Funderingstechnick		110-550	
SVB	Germany	Jebens		400-670	< 24
SVV	Germany	Jebens		440	< 20
Tubex	USA	American Pile Driving			
Third Generation					
APGD	USA	Berkel		350-460	< 23
Displacement	Germany	Bauer	250	600	22
Screw pile	UK	Cementation		300/600	
Soil displacement	UK	Cementation			
Discrepile	Italy	Trevi	> 200	300-750	25-30
Omega	Belgium	Socofonda			
T.	France	Soletanche-Bachy			
TSD	UK	May Gurney		300-600	25

Notes:

* Either the inventor of the system or the owner of the rights