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PRACTICAL CONSIDERATIONS IN THE SELECTION AND USE OF CONTINUOUS FLIGHT AUGER AND DRILLED DISPLACEMENT PILES

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ABSTRACT: The use of continuous flight auger (CFA) and drilled displacement (DD) piles in the U.S. market has increased significantly in recent years. This paper describes some of the advantages and limitations of these drilling systems compared to other deep foundation systems. Geotechnical and project considerations are described which favor the use of CFA and DD piling. In addition, conditions are discussed which may be problematic for this type of construction or which may limit the practicality and competitive advantages of CFA and DD piles.

INTRODUCTION

Continuous flight auger (CFA) piles, also known as augered cast-in-place (ACIP) or augercast piles, is a deep foundation technology which has enjoyed a significant increase in use in recent years. The speed and economy of this type of construction can provide great advantages to engineers for many types of projects and ground conditions. In unfavorable conditions or with the wrong type of construction equipment and control, these foundations can be a nightmare of quality control problems. Drilled displacement (DD) piles are constructed in a similar way and with similar equipment, and have their own advantages and limitations for engineers to consider. This paper provides an overview of the practical considerations for engineers who may consider the use and design of these types of foundations relative to more conventional deep foundation alternatives.

DESCRIPTION AND BASIC MECHANISMS

Continuous flight auger (CFA) piles are drilled foundations in which the pile is drilled to depth in one continuous process using a continuous flight auger. The concrete or grout is then placed by pumping the concrete/grout mix through the hollow center of the auger pipe to the base while withdrawing the augers from the hole. Reinforcement is then placed into the fluid concrete/grout filled hole to complete the pile. The basic concept is

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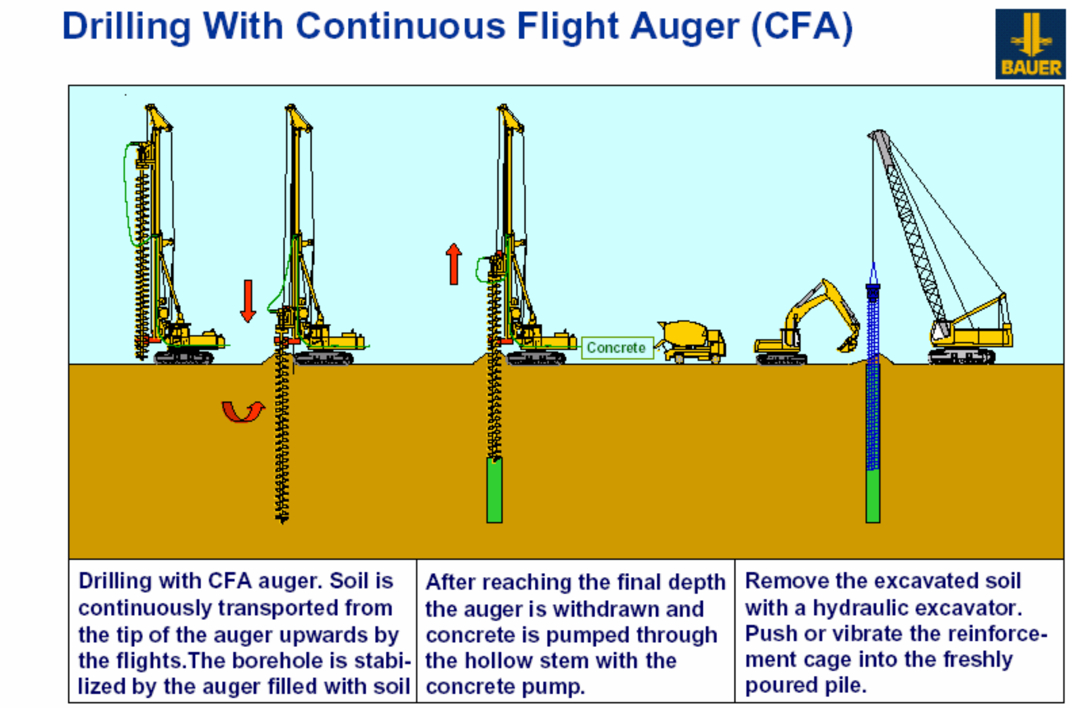

Figure 1 Schematic of CFA Pile Construction

that the flights of the auger are filled with soil as the auger is drilled into the ground, and this soil provides sufficient lateral support to maintain the stability of the hole. The grout or concrete mix is placed as the auger is removed, so that the hole is never left open or unsupported. This sequence of construction is illustrated graphically on Figure 1.

CFA piles are typically installed with diameters ranging from 0.3 to 1.0 m (12 to 40 inch) and lengths of up to 30 m (100 ft.), although longer piles have occasionally been used. U. S. practice has typically tended toward the smaller range of piles of 0.3 m to 0.45 m (12 to 18 inch) compared to that of Europe or Asia, primarily because smaller rigs have typically been used for commercial practice with these piles in the U.S. In common practice, the reinforcement is most often confined to the upper 10 to 15 m or so of the pile for ease of installation and also due to the fact that relatively little bending stresses are transferred to such depth below the ground surface.

The key component of the CFA pile system contributing to the speed and economy of these piles is that the pile is drilled in one smooth process with the continuous auger, thus reducing the time required to drill the hole. While advancing the auger to the required depth, it is essential that the auger flights be filled with soil in order that the stability of the hole is maintained. If the augers turn rapidly with respect to the rate of penetration into the ground, then the continuous auger acts as a sort of “Archimedes pump” and conveys soil to the surface. As illustrated on Figure 2, this action can result in reduction of horizontal stress around the pile and previously installed piles nearby, lateral movement of soil towards the hole, and ground subsidence at the surface. Figure 2 (a) represents an auger with rapid penetration, so that the flights are filled from the digging edge at the base of the auger with no lateral feed. Figure 2 (b) illustrates an auger with slow penetration and insufficient base feed to keep the auger flights full; the auger feeds from the side with attendant decompression of the ground.

As the auger cuts the soil at the base of the tool, material is loaded onto the flights of the auger. The volume of soil through which the auger has penetrated will tend to "bulk" and take up a larger volume after cutting than the in-situ volume. Some volume is taken by the auger itself. Thus it is necessary that some soil is conveyed up the auger during drilling. The trick is to convey only so much soil as is necessary to offset the auger volume and bulking, and no more. This control of the rate of penetration will avoid decompression of the ground, loosening of the in-situ soil, and ground subsidence.

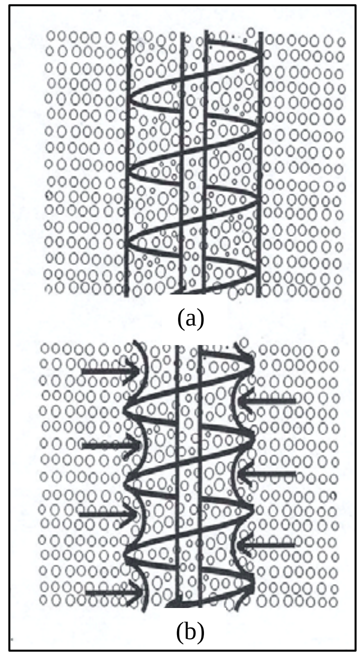

Figure 2 Effect of Over-excavation with CFA Piles (after Fleming, 1995)

It can be difficult to maintain the proper rate of penetration if the rig does not have adequate torque and down force to turn the augers and maintain penetration speed. Even if a rig is used with a large torque capacity for the majority of the soil, difficulties can arise when drilling through a weak stratum to penetrate a strong soil or rock; if the rig cannot penetrate the strong soil stratum at the proper rate, the augers can "mine" the overlying weak soil to the surface and cause subsidence. Insufficient penetration rate has been demonstrated to significantly and adversely affect pile performance (Mandolini, et al, 2002) by loosening the soil around the pile.

One solution to the difficulty in properly balancing soil removal with penetration rate has been to use auger tools that actually displace soil laterally during drilling. These types of piles are more commonly described as "Drilled Displacement" piles. Drilled displacement piles include a variety of patented systems, all of which include a larger center pipe within the augers and often some type of bulge or

Figure 3 Intermediate (Partial) and Full Drilled Displacement Piles

plug within the auger string which forces the soil laterally as it passes. The drilled displacement piles generally require rigs with greater torque than CFA, but the process ensures that soil mining is avoided. In addition, the soil around the pile tends to be densified and the lateral stresses at the pile/soil wall increased, thus leading to soil improvement and increased pile capacity for a given length. The downside is the greater demand for torque and down force from the rig and the limited ability to install piles to great depth.

It may be noted that CFA piles have been installed in many locations and geologic formations without any consideration of the rate of penetration or soil mining, and without apparent detrimental effects. Residual soil profiles, weak limerock formations, cemented sands and stiff clays are soil types that favor easy construction. Where soils are stable due to cohesion, cementation, and/or low groundwater levels, and pile lengths are relatively short, it may be feasible to neglect some of these considerations of drilling rate and soil mining. In such instances, the continuous auger is essentially being used to construct a small open-hole drilled shaft or bored pile.

When the drilling stage is complete and the auger has penetrated to the required depth, the grouting/concreting stage is immediately begun. Grout or concrete is pumped under pressure through a line to the top of the rig and delivered to the base of the auger via the hollow center of the auger string. Upon achieving pile tip elevation, the auger is lifted a short distance and concrete or grout is pumped under pressure to expel the plug at the base of the internal pipe and commence the flow. The concrete or grout is pumped continuously under pressure while the auger is lifted smoothly and in one continuous operation. After the auger has cleared the ground surface and a concrete or grout – filled hole is left, any remaining soil cuttings are removed from the area of the top of the pile and the top of the pile cleared of debris and contamination. The reinforcement cage is lowered into the fluid concrete or grout to the required depth and tied off at the ground surface to maintain the proper rebar elevation.

CONDITIONS AFFECTING SELECTION AND USE OF CFA PILES

Continuous flight auger piles generally work best in relatively uniform soil conditions where the optimal rate of penetration can be established and maintained efficiently. The author's experiences and observations of industry practice suggest that the following types of soil conditions generally favor the use of CFA piles:

- Medium to stiff clay soils where side shear can provide the needed capacity within a depth of around 25 m (80 feet).
- Cemented sands or weak limestone, so long as the materials do not contain layers which are too strong to be drilled using continuous flight augers; in cemented materials, it is not so critical that the cuttings on the auger maintain stability of the hole. In addition, CFA piles can often produce excellent side shearing resistance in cemented materials because of the rough sidewall (visible in CFA walls) and good bond achieved with cast-in-place grout or concrete.
- Residual soils, particularly silty or clayey soils, which have a small amount of cohesion. Installation can be fast and economical.
- Medium dense to dense silty sands or well graded sands, even containing gravel, and especially if the groundwater is fairly deep.

In addition to the geotechnical conditions cited above, the types of projects for which CFA piles should be considered include:

Figure 4 Railway Embankment to be Supported on CFA Piles

- Projects where speed of installation is important. CFA piles can be installed very quickly, provided the rig has a good working platform on which to move around the site and the geotechnical conditions are otherwise favorable. Production rates can be on the order of 300 to 450 m per day (1000 to 1500 feet per day) on projects with good site access, pile diameters in the 300 to 450 mm range (12 to 18 inch), and pile lengths of less than 20 m. On projects with lots of piles where high production rates are important, CFA piles can have advantages over drilled shafts or some types of driven piles.
- Projects where large numbers of piles are required. The favorable costs for CFA piles reflect the high productivity on projects where this efficiency can be used to advantage. Where simple and favorable soil conditions exist, prices for CFA piles are often a few dollars per 30 cm (foot) less than prestressed concrete piles of similar size and axial capacity. Productivity advantages can often be realized on large commercial building projects or pile supported embankments.
- Low headroom conditions where piles are needed. Low headroom equipment can be used effectively with CFA piles and is often more cost effective than high strength micropiles if the ground conditions are favorable for CFA pile installation.
- Secant or tangent pile walls of 10 m height or less. Where CFA piles of less than 1 m diameter can be used for a wall, and where geotechnical conditions are otherwise favorable, CFA piles can be a viable alternative to drilled shafts or slurry walls. For this application, it is important to utilize heavy drilling equipment which can maintain good vertical alignment, but the CFA drilling technique has been used successfully on many such projects with both anchored

Figure 5 Low Headroom CFA Pile Application

earth retention and cantilever walls. Most such applications are constructed as design-build contracts.

CFA piles can be problematic in the following types of soil conditions:

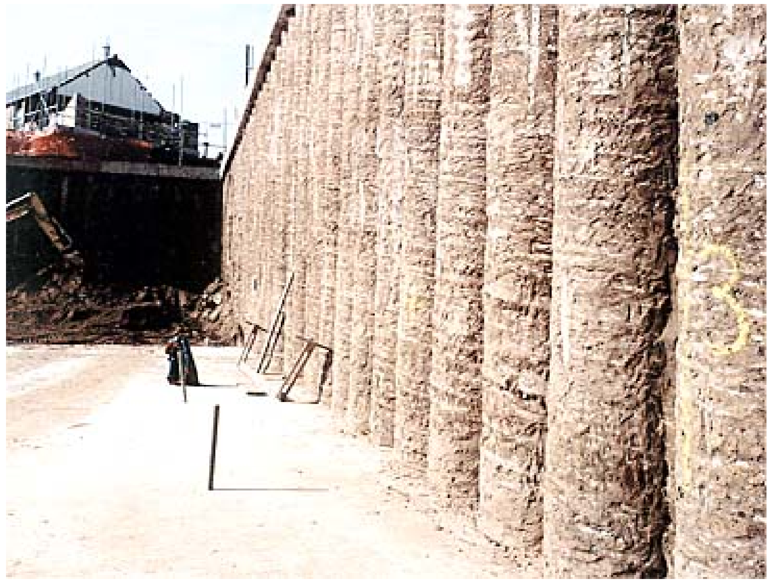

Figure 6 CFA Secant Pile Wall

- Very soft soils; in such materials, CFA piles can suffer from problems with stability of the ground which can produce necks or structural defects in the pile. Even with oversupply of concrete or grout (which costs money and makes the piles less economical), the result is a bulge in the very soft zones that can result in defects within the pile because it is difficult to reliably control the volume per unit length of pile during withdrawal of the auger. Bulges can also increase downdrag forces on the pile.
- Clean sands with shallow groundwater, particularly if the sands are loose. Under such conditions, control of the rate of penetration during drilling is extremely critical. Drilled displacement piles are likely to be more reliable.
- Geologic formations that contain voids, pockets of water or very soft soils, or flowing water. Limestone with solution cavities is a common source of such difficulties.
- A profile in which there is need to penetrate a hard bearing stratum that is overlain by soft soil or loose granular soil. The problem occurs when the hard stratum is encountered and the rate of penetration is slowed because of the difficult drilling; the overburden soils are then flighted by side loading of the auger above the hard stratum. Decompression of the ground above the hard stratum and ground subsidence can result. The author has observed substantial reductions in standard penetration test blowcounts on projects in which borings were made before and after CFA pile installation through medium dense sand into stiff clay. Van Weel (1988) has reported reductions in CPT resistance after CFA pile installation through sands. Note that this condition can result from a stiff clay below a waterbearing sand, even if the stiff clay can be drilled without great difficulty. The rate of penetration required for the stiff clay is lower than that for the sand, and the sand will tend to be flighted during drilling of the clay. Even with a sand stratum sandwiched between a surface clay and a deeper clay, the sand will tend to be flighted. In such a case the cone of depression caused by over-removal of the sand may not be visible at the surface, but could result in a

void beneath the upper clay and/or loosening of the sand and overconsumption of concrete or grout. These conditions favor the use of driven piles, or drilled shafts in which penetration through the overlying sands can be controlled with casing or slurry.

- A bearing stratum composed of clean, dense, water-bearing sand underlying a stiff clay stratum. In this case, the slower rate of penetration dictated by the clay will result in loosening of the sand stratum below, and excessive flighting of the sand from the stratum that is intended as the primary bearing formation. The water pressure in a confined aquifer contributes to this problem. The result is that the pile will not support the load at the tip or in the deeper sand as intended, but will almost solely rely upon side shear in the clay. Better that the pile should either terminate in clay with an appropriate design capacity, or else use driven or base-grouted piles into the sand.

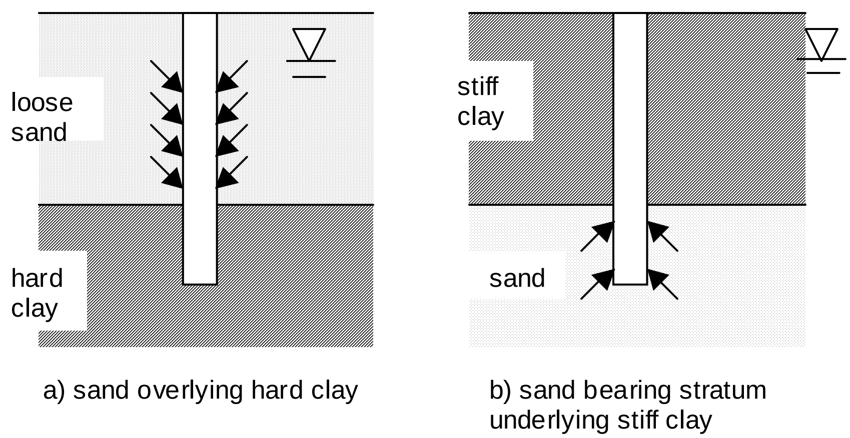

Figure 7 Difficult Conditions for CFA Piles

- Highly variable ground conditions, in which one of the cases noted above may be encountered at some locations across the site.
- A bearing stratum that is too hard to penetrate, such as rock. This condition would favor the use of drilled shafts or driven piles, or alteration of the design so that penetration of the rock is not necessary.
- Any ground conditions requiring excessively long piles. CFA piles longer than 30 to 35 m (100 to 115 feet) would require unusual equipment for this technique; although there have been isolated circumstances in which CFA piles longer than 30 m have been used, CFA piles of such length are uncommon and may require equipment with unusually high torque, high lifting capacity and tall leads.
- Ground conditions with deep scour or liquefiable sand layers. In these circumstances where total or near-total loss of lateral support may occur to significant depths, the piles may be subject to high bending stresses at great depth. CFA piles are most efficient in relatively smaller diameters, and placement of a

rebar cage to great depth can be difficult. If ground conditions exist where loss of support may occur, this condition tends to favor the use of larger diameter drilled shafts or large driven piles.

In summary, CFA piles are most effective when geotechnical and project conditions are relatively simple and the productivity advantages of this type of construction can be utilized for speed and economy. CFA piles are least effective when variable and unstable geotechnical conditions make control of construction difficult.

CONDITIONS AFFECTING SELECTION AND USE OF DRILLED DISPLACEMENT PILES

Drilled displacement (DD) piles have appeared on the scene in a significant magnitude within the last 10 years in U.S. In Europe, these are commonly referred to as "screw piles" and a much greater variety of patented systems are available. Screw piles in European practice appear to have been greatly increasing market share in the last decade, generally at the expense of both conventional CFA and driven piling.

According to Nesmith (2002), the ideal soil profile for a typical drilled displacement pile system would be clean, angular, well-graded sand, loose near the surface, with a gradual, uniform increase in density with depth. Drilled displacement piles increase the horizontal stress in the ground and densify sandy soils around the pile during installation. In so doing, this technique achieves a measure of ground improvement around the pile. This improvement leads to high unit values of side shear in granular soils, especially in loose to medium sands. Where groups of displacement piles are installed, significant improvements in capacity can be observed as a result of soil compaction and increased lateral stress in the ground (Brown and Drew, 2000; Van Impe and Peiffer, 1997). Drilled displacement piles are less subject to the problems of soil flighting as described previously for CFA piles and mixed soil profiles with loose granular soils interbedded with clays are less of a concern. In general, drilled displacement piles will achieve a given load carrying capacity at a shorter length than for a CFA pile of similar diameter.

The key feature that affects the selection and use of these piles is the effect of displacing the soil laterally rather than excavating to soil to the surface. There are techniques in use that remove some partial volume of soil (less than the full volume represented by the pile, as for CFA), and others which fully displace the soil around the pile without any spoil removal (see figures 3 and 8). In either case, the depth to which piles can be constructed is limited by the torque, crowd, and lifting capacity of the rig. Nesmith (2002) suggests that the practical limit for installation of drilled displacement piles is reached at cone tip resistances of around 14 to 19 MPa (150 to 200 tsf), although thin layers

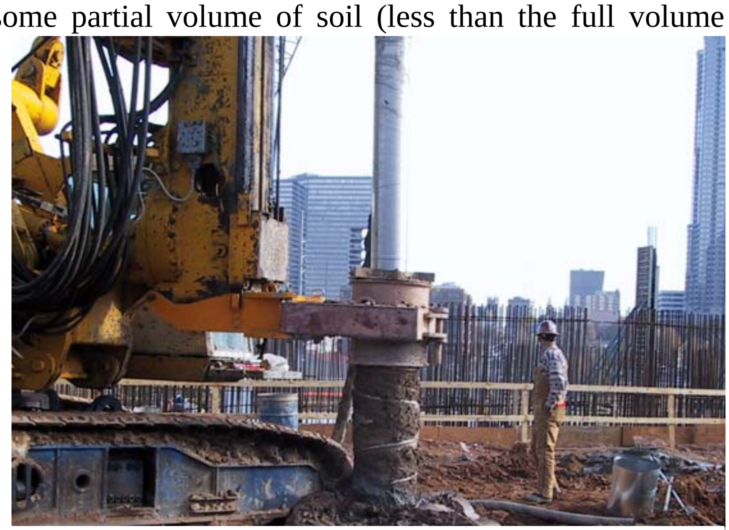

Figure 8 Drilled Displacement Pile Installation

(less than 2 m thickness) can often be penetrated. These limits will likely increase in the years to come as more powerful equipment becomes readily available.

Geotechnical and project conditions that generally favor the consideration and use of drilled displacement piles include the following:

- Soil conditions comprised of sandy soils where soil improvement can be realized using the displacement pile technique.
- In areas where contaminated ground exists or it is desirable from another standpoint to limit the spoil removed from the site.
- At sites where a weak layer is underlain by medium dense sands at a moderate depth (less than about 20 to 25 m), and installation of conventional CFA piles could be problematic due to concerns about soil mining.
- In areas where there exist concerns about damage to neighboring structures from pile driving vibrations or loss of ground from conventional CFA piles.

Geotechnical and project considerations that could be impractical or problematic for drilled displacement piles include:

- Sites composed primarily of plastic or saturated fine grained soils for which little or no improvement results from the displacement process and the extensive remolding associated with this construction can be detrimental to the soil structure and shear strength.
- Sites where dense strata or rock lenses are underlain by soft or compressible soils, so that the practical depth limit for installation of DD piles is exceeded by other geotechnical considerations (such as settlement).
- Sites where deep deposits of saturated fine grained materials are present and the pile spacing must be relatively close (generally 3 to 5 diameters or less). These conditions can impact production and performance because the freshly constructed piles can be affected by installation of subsequent piles as the drilling produces lateral soil movements and excess pore pressures that can contribute to concrete bleeding.
- Because of the high torque and crowd required to install these piles, the diameters are usually limited to around 450 mm or so, and thus the piles are not generally capable of supporting large bending stresses. DD piles are most often used as bearing piles and not for secant or tangent pile walls as are CFA or drilled shafts.

In summary, drilled displacement piles are most effective when geotechnical and project conditions are such that the improvement benefits of the displacement system can be used to advantage and where other limitations of the CFA system can be overcome using the displacement drilling technique.

SUMMARY

This paper has provided an overview of the construction and use of continuous flight auger and drilled displacement piles, with the objective of identifying applications and geotechnical conditions favorable for the efficient and economical use of these piling systems. Likewise, geotechnical conditions are described which can be problematic from the standpoint of construction, quality control, or efficient use of these piling systems. The conditions favoring the use of CFA piles are generally soil profiles that are relatively simple and for which the productivity advantages of this type of construction can be utilized for speed and economy. CFA piles are least effective when variable and unstable geotechnical conditions make control of construction difficult. Drilled displacement piles are most effective when geotechnical and project conditions are such that the improvement benefits of the displacement system can be used to advantage and where other limitations of the CFA system can be overcome using the displacement drilling technique.

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