

New Trends in Auger Pressure Grouted Piles

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Abstract: There have been several interesting new trends developing over the past few years for auger pressure grouted (APG) piles. These new trends are mainly focused on (1) new installation techniques and equipment, and (2) new quality control and quality assurance procedures. The new installation techniques involve the addition of displacement piles (no spoils) and partial displacement piles (some spoils) that utilize many of the same procedures as traditional APG piles. These new pile types are more applicable where soft to firm clay and loose to medium dense sand soil conditions are present. The new quality control and quality assurance measures available include (1) automated pile installation monitoring equipment, (2) non-destructive integrity testing and (3) grout maturity strength testing procedures.

Introduction

Auger Pressure Grouted (APG) piles continue to see significant growth in the market due to their unique combination of speed of installation and high capacity that results in one of the most cost effective deep foundation systems available. APG piles were first introduced in the 1940's, and are also known by a variety of names including auger cast and continuous flight auger piles. In the 1990's the Deep Foundations Institute came up with the generic term Augered Cast-In-Place (ACIP) piles to describe this type of deep foundation system.

Engineers in the past have had two main concerns with using APG piles on a widespread basis. The first area of concern had been where soft or loose soils conditions exist at a site and there is a potential for necking or removal of excessive soils when using a continuous flight auger to install the piles. The second area of concern had been associated with a perceived lack of quality control and quality assurance procedures for the pile installation process overall. In the past few years there have been several important new processes that have essentially eliminated both of these concerns.

Pile Types and Soil Conditions

The pile types used in practice today range from non soil displacement APG piles (and the low headroom application) to partial soil displacement and full soil displacement Auger Pressure Grouted Displacement (APGD) piles. The soil conditions at a specific site dictate which pile type will be most appropriate.

APG Piles. The APG pile is the traditional, industry standard pile that is installed using a hollow stem continuous flight auger to pump fluid grout under pressure during auger withdrawal to form the pile. APG piles are constructed by rotating a hollow stem, continuous flight auger into the ground to the desired tip elevation. When the required depth is reached, a high strength, fluid grout is pumped under pressure through the hollow stem of the auger exiting through the tip (or bit). A pre-established amount of grout is pumped prior to lifting the auger to build up a "grout head" around the outside of the auger. The auger is then withdrawn in a controlled manner slowly rotating clockwise as the pumping continues to both maintain the head of grout and avoid any intrusion of water or soil into the grout column.

The upper portion of the pile is then screened of any debris that may have fallen in while the spoils are removed from the pile location. Reinforcing steel is then placed through the fluid grout column, and the pile top elevation is established by either dipping out or adding fluid grout to the pile.

Pumping fluid grout under pressure (as opposed to pumping or tremieing concrete) results in a higher pile capacity, reduces quality control questions, allows for fast reinforcing steel

installation, and results in a overall quicker total installation time. This same basic process is used for all the pile types described in this paper.

APG piles can be installed with diameters ranging from 12-inches to 24-inches in 2-inch increments, plus 30-inch and 36-inch. The lengths of APG piles up to 24-inch-diameter can extend up to 130 ft. The lengths of 30-inch and 36-inch diameter piles can extend up to 100 ft.

LHR APG Piles. The low headroom (LHR) APG pile is a special application of the APG pile installation method that allows for pile installation in areas where there are overhead or lateral space constraints. Auger sections are added as the pile is drilled and removed as the pile is grouted. The lengths of the auger sections can be varied depending on the specific overhead limitations. LHR APG piles can be installed with diameters ranging from 10-inch to 24-inch in 2-inch increments. The lengths of LHR APG piles can extend up to 80 ft.

APGD Piles. APGD piles utilize a Berkel patented system that laterally displaces all the soil within the pile diameter to the area surrounding the pile. The lateral displacement action improves the load carrying capacity of the pile and virtually eliminates the need for spoils removal. The full displacement APGD piles can be installed with 12-inch, 14-inch, 16-inch and 18-inch diameters with lengths up to 80 ft. The partial APGD pile is a Berkel designed system that displaces a portion of the soil within the pile diameter to the area surrounding the pile. The partial lateral displacement action improves the load carrying capacity of the pile and reduces the amount of spoils generated. The partial displacement APGD piles can be installed with 12-inch, 14-inch, 16-inch, 18-inch and 20-inch diameters with lengths up to 55 ft.

Applicable Soil Conditions. The following table summarizes in general the most applicable soil conditions for each pile type. This information is meant to provide general guidelines only and would not necessarily preclude any of the pile types from being used for specific conditions. Please note that APG piles can be installed in any of these soil conditions but full displacement APGD piles cannot be installed in stiff clay/dense sand profiles.

To reduce the potential for ground loss, excessive depressurizing of the soils and the associated quality related issues, priority should first be given to full APGD, then to partial APGD, and then to APG piles when selecting the most appropriate pile type for the specific soil conditions.

| Pile Type | Main Soil Condition | Soil Layer/Pile Diameter Limitations |
|--------------|---|--|
| APG | Medium dense to very dense sand ; soft to hard clay ; soft rock | If a loose sand layer is present diameters should be limited to 24-inch; if the loose sand is more than 20 ft thick the diameter should be limited to 16-inch. |
| Partial APGD | Loose to dense sand with blow counts less than 50 | For any diameter stiff, firm and soft clay layers should not exceed 15 ft, 20 ft and 30 ft thick, respectively |
| Full APGD | Loose to medium dense sand with blow counts less than 25 | For any diameter stiff, firm and soft clay layers should not exceed 5 ft, 10 and 20 ft thick respectively; dense sand layers should not exceed 10 ft |

Note: Thin soil layers (or seams) less than 3 ft thick are not significant enough to factor into the selection of the most applicable pile type.

Drill Rig Types and Equipment Specifications

The types of equipment used to install the piles are a very important factor in the installation process. Usually, the selection of the specific equipment to install the piles is left completely up to the contractor, which is then sometimes reviewed in the submittal process. However, not enough attention is typically given to the selection and approval of adequately sized equipment for the particular application in practice.

In general, APG pile drill rigs cannot typically add crowd (or a down force) to the auger while drilling. The only down force is simply the weight of gearbox and auger. This is the case whether the leads are fixed (pinned) to the crane boom or hanging (swinging) from the boom tip. However, the drill rigs used for APGD piles must be able to produce both a large down force and a high gearbox torque. Therefore, a traditional lattice boom crawler crane supporting a gearbox and leads cannot be used for these piles. APGD piles must be installed using hydraulic fixed mast rigs specifically built for these types of drilling applications. There is a wide range of equipment commercially available, and much of it would be considered too small or undersized for most applications. The types of drill rigs used by Berkel and their main specifications are summarized below.

| Pile Type | Gearbox Torque | Crowd/Gearbox Weight | Drill Rig Horsepower |
|----------------|---------------------------|----------------------|----------------------|
| Typical APG | 36,000 ft-lbs | 5,000 lbs (wt) | 350 hp |
| Large/Deep APG | 88,000 ft-lbs | 10,000 lbs (wt) | 750 hp |
| LHR APG | 21,000 ft-lbs | 3,000 lbs (wt) | 200 hp |
| Partial APGD | 150,000 to 180,000 ft-lbs | 15 to 20 tons | 250 hp |
| Full APGD | 150,000 to 180,000 ft-lbs | 15 to 20 tons | 250 hp |

Quality Control and Quality Assurance

Several new trends for quality control and quality assurance of APG piles have emerged in the last few years. These new technologies can effectively supplement existing quality control procedures. In the past, quality control of APG piles has been performed manually; that is, by a person. This “inspector” is typically an engineer or technician working for the project’s geotechnical engineering firm or testing laboratory. These manual QC procedures were developed over many years and were published as industry standards by the Deep Foundations Institute in the 1990’s.

It is important to understand that these new technologies do not replace the inspector, they simply provide: (1) accurate and automatic records of key aspects of the pile installation process and (2) additional quality assurance tests and data for verification.

Automated Monitoring Equipment. Automated monitoring equipment (AME) has been developed in recent years that will automatically monitor and record key aspects of the pile installation process. Typical systems will measure: (1) time, depth and hydraulic pressure during drilling, and (2) time, depth, grout volume, and grout pressure during grouting. The systems will provide a real time graph for the operator to watch during installation, a hard copy print-out of the data, and a digital record that can be stored on a computer.

Drilling resistance for APG piles is a new concept developed as a result of the increased use of AME on the drill rigs. In the past this equipment has mainly focused on recording the volume of grout pumped as the auger is withdrawn from the drilled hole. The equipment has always had the capability to monitor key aspects of the drilling of the pile also. The data collected from the drilling of the pile was typically not used because it was not presented in a format that would be of any use. Drilling resistance is a direct measure of how hard it is to drill through the subsurface materials. Plots of drilling resistance versus depth can be developed to both quantify and compare the subsurface stratigraphy along the length of a pile and between different piles. In applicable subsurface conditions, this can provide a readily apparent and quantifiable means to infer where bearing materials were encountered or where harder zones were drilled.

The grout volume is measured with an in-line magnetic flowmeter and is reported to be accurate within 2 percent. Since the flowmeter measures volume directly it does not depend on or need to know the pump calibration. Time is measured to the nearest second and depth is measured to the nearest tenth of a foot (0.03 m). This results in a remarkably precise and accurate record on the pile installation compared to the manual techniques.

Nondestructive Integrity Testing. Even though piles installed in accordance with the specifications would be considered acceptable, there are times when additional testing is considered beneficial. This is especially true in new markets where the past use of APG piles has been limited. The designer may want to have some additional quality assurance that the methods described in the specifications do indeed result in a good quality, continuous pile that does not contain defects such as necking, soil inclusions or poor quality grout.

Nondestructive testing (NDT) of the structural integrity of the pile can be performed using sonic methods. These tests are performed after the grout has sufficiently cured. The main NDT methods used in practice for ACIP piles can be divided into two groups: (1) surface reflection, and (2) direct transmission.

Surface reflection methods (or pulse echo) involve striking the top of the pile with a hammer to generate a stress wave that is partially or completely reflected by changes in the pile. The reflections are monitored with an accelerometer at the top of the pile and, with a few assumptions, the depth to this reflection can be estimated. This method is not recommended for piles with a length to diameter ratio of more than 30. The reliability of this method is further reduced when there are multiple changes in the cross-sectional area of the pile.

Unfortunately for this method, APG piles typically have a length to diameter ratio of greater than 30. Also, the process of pumping grout under pressure through various soil layers produces piles with multiple changes in cross-section (bulges in softer layers). These unique properties of APG piles limit the usefulness of surface reflection techniques.

Sonic integrity logging is a direct transmission technique that was developed to overcome both the length to diameter and multiple changes in cross section limitations. Singlehole sonic logging (SSL) is typically used for APG pile applications. In this method, a pair of ultrasonic source and receiver probes is lowered down a single access pipe in the center of the pile. The travel time and signal strength of an ultrasonic pulse that travels between the probes (through the pile) is measured along the full length of the pile. Changes in travel time or signal strength identify the depth where a soil inclusion or poor quality grout is present.

SSL is considered to be much more reliable than surface reflection methods. Typically only 10 to 20 percent of the piles on a project are selected for SSL, and it is usually performed at the very beginning of the project to verify the pile installation procedures are resulting in good quality piles. NDT should only be used to supplement detailed installation records and soils information, not as a stand alone, pass/fail type of test.

Grout Maturity Method. The rate of strength gain for grout is essential information when determining the load carrying capacity of a recently placed pile. New technology in maturity meters allows for embedded components to be used in lieu of external recording devices, making the use of these instruments more feasible on job sites. This nondestructive means of determining in-place grout strength is referred to as the maturity method. The maturity method provides real-time grout strength information with the use of embedded sensors and a portable handheld reader. The sensors record time and temperature during hydration and curing to determine the rate of strength gain as compared to a specific mix design. The method has a published standard, as described in ASTM C 1074.

Grout maturity testing consists of implanting a time/temperature sensor in the actual pile and then using a readout gauge to obtain an empirical maturity reading. Having previously established a calibration curve for the specific grout mix, the maturity reading can then be correlated to an actual compressive strength. Any number of maturity (or strength) readings can be obtained from each sensor starting the day after the pile is installed, since the sensors are not

destroyed during testing. Only one strength reading can be obtained with a grout cube since it is destroyed during testing. Although this wouldn't completely replace traditional cube strength testing, this new method would certainly reduce the amount of cube testing required on APG pile projects.

Summary and Conclusions

Several new trends in APG piles have emerged in recent years. These trends mainly involve the development of new pile types and increased quality control techniques. Specific conclusions about these new trends are summarized below.

1. In addition to traditional non displacement APG piles, full and partial displacement piles can now be better utilized in soft soil conditions.
2. To reduce the potential for ground loss, excessive depressurizing of the soils and associated quality related issues, priority should first be given to full APGD, then to partial APGD, and then to APG piles when selecting the most appropriate pile type for the specific soil conditions.
3. Pumping fluid grout under pressure (as opposed to pumping or tremieing concrete) will provide for a higher pile capacity, reduce quality control questions, allow for fast reinforcing steel installation, and result in a overall quicker total installation time.
4. Automated monitoring equipment (AME) for all applications (except for limited headroom) can now be used to provide real time monitoring of key aspects of the installation for the operator and inspector, and provide a digital record of the installation.
5. Nondestructive testing (NDT) of the structural integrity of the pile can be performed using sonic methods. Singlehole sonic logging (SSL) is considered to be much more reliable than surface reflection methods. NDT should only be used to supplement detailed installation records and soils information, not as a stand alone, pass/fail type of test.
6. The grout maturity method provides for better quality control and quality assurance of the grout used on APG pile projects, and can be used to supplement and reduce the amount of traditional grout strength testing needed.