Managing the Installation of Augered Cast-In-Place Piles

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Installation of augered cast-in-place (ACIP) piles, which are uncased as the auger is removed and the pile is grouted, will always be accompanied by ground displacements. Managing the installation to minimize ground displacements can be of special importance in urban areas where nearby structures or buried utilities might be affected adversely. Experience with ACIP installations in New York City and southern Florida has led to the development of recommended procedures to reduce soil loss during installation and the associated ground displacements. Rationales for recommended rates of auger insertion, auger rotation during grouting, grout pressures, and pile spacing are provided. Observations confirm that soil loss during installation is less when ACIP piles are installed in cohesive soils instead of other materials. To help engineers to manage the installation of ACIP piles, information is provided in some detail.

Augered cast-in-place (ACIP) piles, known in Europe as continuous flight auger piles (and by several other names in the United States) are low-vibration, low-displacement, and frequently low-cost deep-foundation elements commonly used to support loads between 40 tons (0.36 MN) and 80 tons (0.71 MN). ACIP piles, which are cast in diameters ranging from 12 in. (300 mm) to 20 in. (500 mm), have been used in southern Florida to support building loads of as much as 110 tons (0.98 MN), and some people reported their reaching higher capacities. ACIP piles are commonly believed to afford a particular advantage in loose-sand environments, where the energy associated with driving conventional displacement piles is likely to cause sand densification and the settlement of nearby structures or facilities.

In this paper ACIP piles are characterized as low-displacement, deep-foundation elements to contrast them with driven piles, which displace their volume as they are installed. We emphasize that the installation of every deep-foundation element has the potential to cause some soil displacement. The displacements may be either positive, flowing outward when driven piles are installed, or negative, flowing inward when an augered or washed hole is created and then filled with grout or concrete to form a pile. Displacements inevitably result from the installation of ACIP piles; managing the displacements is a primary focus of this paper because the displacements from new installations can structurally harm existing structures, buried sewers or pipelines in proximity to the site.

Most building codes explicitly permit the use of ACIP piles. Recently, the limitations on their length included in many codes have been reduced significantly, as long as a professional and knowledgeable geotechnical engineer is involved with the construction (*1*). However, one exception is the New York City Building Code, adopted in 1968; it still does not permit the use of piles that are not fully cased throughout the installation process (except for the compacted concrete foundation or Franki pile), not without petition to and approval by the building department. This restriction reportedly was included in the code because of the failure of certain uncased piles before the code was written.

Today knowledgeable geotechnical engineers agree that the safe installation of ACIP piles requires both an experienced contractor, one who is dedicated to providing a quality product, who will have experienced personnel install the piles, and an engineering-inspection force that understands the potential problems associated with pile installation and how the contractor can best avoid them.

Recommendations for managing the installation of ACIP piles are provided that are the outgrowth of the authors' experiences with installations in New York City and southern Florida.

ISSUES TO CONSIDER

ACIP piles are formed by rotating into the ground a hollow-stem, continuous-flight auger to a predetermined depth and by continuously injecting grout under pressure through the hollow stem as the auger is withdrawn. Soil is brought to the surface by the auger as it penetrates into the ground. Control of the volume of material excavated by the auger is frequently critical in urban areas where ground displacements can result from excessive excavation and cause damage to nearby facilities.

One issue relates to the volume changes that occur as grout is injected and the auger is withdrawn to form the pile. The relationship between the volume of grout injected, the rate of auger withdrawal, and the additional volume of soil brought to the surface as the auger is slowly rotated during withdrawal must be considered.

Other considerations include what grout pressures to use during installation, how to space piles to avoid damaging members already installed, the quality of grout at the head of the pile, and whether to use reinforcing steel to provide resistance to lateral loads.

Volume Changes During Augering Down

Ninety-foot-long (27.4 m) ACIP piles, 16 in. (400 mm) in diameter, with a 75-ton (0.67 MN) capacity were installed in lower Manhattan (New York City) within 4 ft (1.2 m) of two nineteenth-century buildings founded on rubble-stone foundations. One of these buildings is designated as a public landmark. Details of this case history have been published elsewhere (*2–4*), so only selected information is repeated.

As a consequence of installing the first 19 (of a total of 230 ACIP piles) within 4 ft (1.2 m) to 15 ft (4.6 m) of the landmark

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building, settlement of up to 1.5 in. (38 mm) was observed. Most of this settlement was attributed to the loss of soil that resulted from redrilling after equipment failure. The bottom plug of the hollow-stem auger was too small for the bung hole and imploded twice before the problem was diagnosed, filling the auger with sand and requiring auger removal and redrilling. The implosion problem was exacerbated by the need to auger through rubble fill. Consequently, a protective guard was designed and constructed by the contractor and the plug shape and size altered. Redrilling was also required at other times because of premature grout setup and clogs in the grout-injection system as well as a malfunctioning grout pump.

During this initial period of pile installation, a study was made of the volume of soil excavated by the auger and how to reduce the loss of ground. It was observed that at an auger installation rate of between 11 ft/min (3.35 m/min) and 13 ft/min (4 m/min) (fast rotation), between 8 yd^3 (6 m^3) and 12 yd^3 (9 m^3) of soil was brought to the surface by the auger; the "neat" or theoretical volume of the pile is about 5 yd^3 (3.8 m^3). The ratio of actual volume of injected grout to the neat volume of the pile ranged between 1.8 and 2.4.

An experimental testing program was undertaken to reduce the volume of soil removed by the augers. The program was able to

- Slow the rate of auger rotation and increase, to the extent possible, the down-pressure so that the auger penetrated at an average vertical rate between 6 ft/min (1.8 m/min) and 7.5 ft/min (2.3 m/min). Time for auger installation almost doubled to between 12 min and 15 min.
- Lower the volume of soil removed to between 5 yd^3 (3.8 m^3) and 6 yd^3 (4.6 m^3) by modifying the procedure.
- Lower the ratio of the actual volume of injected grout to the pile's neat volume to between 1.4 and 1.8.

The ideal would be to screw the auger into the ground and to excavate only the volume of the auger and stem, if that were possible. For installation procedures to approximate the ideal, however, contractors would need to use equipment capable of delivering high torque and rotating slowly as the auger penetrates the ground. Lacy and Moskowitz (*5*) found, on a project in Newark, New Jersey, about 5 mi (8 km) west of lower Manhattan, that when rotation rates were limited to two or fewer revolutions of the auger per advance into the ground equal to the length of one pitch of the flight, the volume of grout required to form each pile was reduced to about 60 percent above the nominal volume of the hole drilled by the auger. (See also their paper in this Record.) The same average ratio was achieved for ACIP piles in lower Manhattan.

Typical specifications in the United States for ACIP piles require a minimum ratio of actual to neat volume of 1.4 to account for normal oversizing of the pile as the auger wobbles during insertion, and to provide comfort to the engineer that the area of the pile at all cross sections is equal to or greater than the design area. It appears, however, that in the United Kingdom, where ACIP piles are common, most installations are in cohesive materials, and concrete is pumped routinely instead of grout, ratios of actual to neat volume in excess of 1.2 are considered excessive (Greenwood, 1993, unpublished data). Experience in the United States with ACIP piles in cohesive soils also indicates that ratios of about 1.25 are sufficient; such ratios may be all that can be achieved without the auger being lifted by grout-injection pressure.

Managing Volume Changes During Grout Injection

As grout injection begins, the auger is withdrawn about 1 ft (0.3 m) and a high grout pressure is developed at the toe by injecting 10 to 20 pulses of a grout pump, delivering between $^1/_3$ ft^3 (9 L) and $^1/_2$ ft^3 (14 L) per stroke. The pile then is redrilled to the original depth and the auger withdrawn slowly at a rate compatible with the volume of grout injected. Grout injection for each 5-ft-long (1.5-m) section is measured and recorded. No individual 5-ft (1.5-m) section may have less that 115 percent of the neat volume of the pile injected. The final volume of grout injected must equal at least 140 percent of the neat volume of piles cast in other than cohesive materials. The minimum acceptable volume of grout injected depends on the material and amount of lost ground.

Many building codes (*1*) permit no rotation of the auger as it is withdrawn and grout is injected. This "dead pull," which avoids loss of ground during the pile casting, is generally not possible for piles more than 30-ft (9-m) long, because of equipment limitations. It is probably not desirable to execute a dead pull on long piles. Large suction (negative) pressures can develop, potentially collapsing the hole and producing a neck in the pile, if the pull rate were, at any time, to exceed the rate of grout injection. Therefore, a very slow rate of positive (clockwise) rotation accompanies auger withdrawal, increasing the volume of the pile to be filled with grout. Grout pressures and grout injection rates should be sufficiently high to control the negative consequences of this increase in lost ground.

Grout pressures during grout injection are not well understood. Pressures are measured at the grout pump instead of at the point of injection. Grout pump pressures vary; typically they range between 75 psi (500 kPa) and 150 psi (1,000 kPa). In one case, 250 psi (1,700 kPa) of pressure was used in lower Manhattan, when observations during a field-testing program suggested that high pressures at the grout pump reduced ground displacements.

Pressure losses in the grout lines that run from the grout pump to the highest point on the auger are unknown, however. Therefore, the actual pressure at the point of injection is uncertain. However, it is important for several reasons:

- Inadequate pressure can lead to a reduction in the cross-sectional area of the pile (necking).
- Excess pressure can result in grout loss by hydrofracture and the potential to damage recently cast, nearby piles by the upward movement of the ground.
- Sufficient pressure is necessary to cause an upward flow of groundwater around the auger, followed by a flow of grout, when the auger is still 25 ft (7.5 m) to 30 ft (9 m) in the ground.

Once grout flow has appeared at the ground surface, the auger can be removed without rotation. The fact that a satisfactory rate of grout injection is being maintained can be verified by observing a continuous flow of grout at the surface, in addition to continuously measuring the volume of grout pumped. Grout should fill the auger flights as they are withdrawn.

Significant loss of ground can occur when piles are cast if sufficient grout is not available to complete the casting of a pile, and it must be reaugered and regrouted. This is a frequent problem in congested urban areas where grout delivery can be delayed by traffic. Such a problem occurred in Minneapolis, Minnesota, when a crane operator, inexperienced with the installation of ACIP piles in the loose river sands, decided to auger several holes while waiting for grout delivery. A portion of the adjacent building settled 1 in. (25 mm) because of the loss of ground. As a safeguard, the policy for the lower Manhattan installation was that no pile could be drilled until sufficient grout was on-site to complete the pile.

Spacing of Piles

It is common practice to design piles for center-to-center spacings of 2- to 3-pile diameters. The 16 in. (400 mm) ACIP piles in lower Manhattan were spaced 3 ft (0.9 m) on centers. When injection pressures were increased to 250 psi (1,700 kPa), the original specification that piles installed on any day could not be less than 6 ft (1.8 m) apart was increased to 9 ft (2.7 m) apart. Piles could be installed 6 ft (1.8 m) apart after curing for at least 24 hrs.

These modifications were made in response to the fear that upward ground movement from hydrofracture could heave and pull apart unreinforced, weak piles. Survey measurements of 19 piles during the period of installation indicated no heave or settlement related to the installation process.

Quality of Grout at Pile Head

The slow rotation of the auger as it is withdrawn, its slight wobble as it is raised, and the continuous upward flow of grout to the ground surface combine to produce the broad top of the pile, often weakened by the mixing of grout and soil near the ground surface. It is, therefore, advantageous to install an 18 in. (460 mm) to 36 in. (915 mm) section of metal shell at the top as soon as the casting of the pile is completed and to ''clean the grout''. Clip-on sections of metal shell and a ''pile screen'' to clean the grout within the shell are available for this purpose. When a metal shell was not used properly at a site in Brooklyn, New York, and cleaning was not done, the grout strength at the pile head was reduced by the mixing with soil from the specified 4,000 psi (27.6 MPa) to 2,500 psi (17 MPa) or less. The low-strength concrete was removed before casting the pile cap, and the cap deepened to engage grout of adequate strength.

Weakened grout at the pile head has also been reported when excessive ''bleeding'' of grout occurs at the top and when upward water flow from the ground washes out the cement and segregates the grout components.

Comparative tests of the Brooklyn and lower Manhattan installations show that reasonably reliable indications of the strength of the grout at the pile head can be obtained using a concrete rebound hammer (Schmidt hammer). The use of the Schmidt hammer to provide an initial indication of the adequacy of the grout strength is recommended.

Reinforcing Steel

ACIP piles can be reinforced to resist lateral forces and to increase axial compression or tension capacity. The most common reinforcement is a single steel bar introduced into the pile immediately after casting and penetrates to the bottom of the pile. Centralizers are required to be certain that the bar remains within the pile section. Less common is introducing the bar through the hollow stem as grouting begins. A bar that is at or near the center of the pile has only a modest effect on the bending resistance but can provide significant tension capacity if adequate bond strength is available.

Bending strength can be provided readily by introducing a reinforcing cage or a steel member like a lightweight H section or a pipe into the pile just after grouting has been completed and before the grout has set. These sections also require centralizers to ensure that they remain within the grout section as they are pushed into place. In general, there has been limited success pushing steel sections or cages to depths greater than 20 ft (6 m). Ordinarily this depth is sufficient to reinforce the pile against horizontal forces applied at the ground surface, but a shorter depth limits the usefulness of the ACIP pile for use in cantilever retaining structures that are more than 10 ft (3 m) to 15 ft (4.5 m) high.

CONCLUDING COMMENTS

That surface displacements inevitably result from ACIP pile installations in granular soils is now well documented. Displacements of the landmark structure in lower Manhattan of 2 in. (50 mm) to 3 in. (75 mm) primarily resulted from equipment failure and pile redrilling. It is estimated from the available data that trouble-free pile installation would have produced between 0.5 in. (13 mm) and 0.8 in. (20 mm) of building displacement. It was surprising to observe that about half the estimated trouble-free displacement occurred during a 10-week period after pile installation was completed. The cause of this ''secondary compression'' of granular soils is unknown. Also well documented is the fact that careful management of the installation process by contractors and engineers can limit the magnitude of displacements.

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