PERFORMANCE SPECIFICATIONS FOR DRILLED PILES

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Deep foundation contracting for transportation projects in the United States has typically followed the design-bid-build model in which contractors bid on a specific work product according to relatively inflexible prescriptive specifications. With continuous flight auger piling and the many types of proprietary drilled displacement auger piling, there appear to be advantages to contracting this work according to a different model. This paper provides a discussion of the use of a performance specification for this work in which the contractor has greater freedom to choose the most appropriate foundation system and also greater responsibility for the performance of the completed foundation. With public agencies subject to open bidding, this type of contractual arrangement presents opportunities to encourage innovation. There are also challenges for implementation in public works projects, notably the selection of qualified contractors and the verification of performance requirements on production foundations.

INTRODUCTION

Continuous flight auger (CFA) piling have a history of use in the U.S. commercial market, but have been used infrequently on public works transportation projects. This under-utilization of a viable technology is at least partly the result of perceived difficulties in quality control on the part of transportation agencies. In addition, the proprietary systems used for the installation of drilled displacement (DD) piles are not easily incorporated into traditional design-bid-build delivery systems for public works projects.

This paper outlines a process for utilizing a performance-based specification for drilled foundation piling in which the contractor is responsible for the final determination of pile length. The approach requires that the contractor provide the quality control and performance measurement parameters necessary to ensure that the owner is provided with the foundation capacity that is required for the job. The key for the owner is that the specifications require measurements that provide a reliable indication of performance. With reliable performance indicators, this approach can allow contractors to exercise ingenuity and seek the most cost-effective and timely solutions to achieve the project requirements. The procedures outlined in this paper are incorporated into Federal Highway Administration guidelines for the use of CFA and DD piling on U.S. transportation projects.

DRILLED PILES IN U.S. PRACTICE

Most CFA piling installed in the U.S. for the last 30 years have utilized crane-mounted drilling equipment with a sand-cement grout pumped through the hollow stem of the auger as shown in Fig. 1. These crane-mounted rigs have no means of applying downcrowd onto the auger, and therefore have limited ability to control the rate of penetration and the potential for soil mining, i.e., removal of excess soil during drilling. Piles installed in this manner are typically described as “augercast” piles, “augered pressure grouted (APG)” piles, or “augered cast-in-place (ACIP)” piles.

Recent years have seen a trend toward new drilling technologies replacing the old. More American contractors have obtained the equipment and expertise to install continuous flight auger piling using European type hydraulic equipment, and these more powerful drilling systems have generated increased use of alternative types of drilled piles. These include conventional CFA (Fig. 2), drilled displacement (DD) piles (Fig. 3) intended to install a cast-in-place pile with full

Figure 1 Crane Attachment for ACIP Pile

Figure 2 Hydraulic CFA Rig

Figure 3 Partial or Intermediate Displacement Pile Rig

Figure 4 Full Displacement Pile Rig

displacement and no spoil, and partial or intermediate drilled displacement (IDD) piles (Fig. 4) which may displace some soil but not act as a full displacement pile. Many contractors and equipment builders have patented various components of the drilling system, most typically some part of the tooling.

Another new technology which is gaining increasing acceptance is the use of on-board computer monitoring of drilling installation parameters as a function of depth, including drilling speed, applied torque, grout or concrete pressure, and delivered volume. Such systems offer the potential for improved verification of the quality of the constructed pile.

U.S. public transportation agencies often wish to utilize the economy and efficiency of drilled piles in appropriate circumstances, but these myriad of different and proprietary systems are difficult to incorporate into the conventional design-bid-build project delivery used on most transportation works. The result is that most project designers stick with driven or bored piles with prescriptive specifications controlling every aspect of the work. The open bidding process is very effective in achieving the lowest possible unit cost, but may not achieve the greatest overall economy if many alternatives are excluded.

Preparation and enforcement of contract documents are important critical steps in the introduction of new technologies. Performance based contract specifications offer the potential to encourage the use of new technology, and public agencies have utilized this approach in recent years for micropile construction. In order to encourage local transportation agencies to exploit new technologies to achieve improvements in speed, economy, and reliability, the Federal Highway Administration (FHWA) of the U.S. Department of Transportation is working to develop a performance based guide specification for CFA and drilled displacement piles.

PERFORMANCE vs PRESCRIPTIVE SPECIFICATIONS

The use of prescriptive contract specifications has a long history for driven and bored piles in the U.S. transportation industry. Public agencies are required by law to use open bidding for selection of contractors in order to avoid any possibility of favoritism (political or otherwise) in the selection process. The result is that transportation projects typically utilize an extensive set of rigorous specifications covering all aspects of design and construction. These range from the AASHTO (American Association of State Highway and Transportation Officials) design specifications, to individual state design and construction specifications to project-specific special provisions. Contractors may have some options for construction methodology, e.g., the use of casing or drilling slurry with bored piles, but the specific requirements associated with each type of construction methodology are tightly controlled by the specifications.

Advantages and Limitations of Prescriptive Specifications for Piling

The current practice of using prescriptive specifications for bored and driven piles has many perceived advantages. With conventional design-bid-build, the designer assumes all the risks of performance (i.e., load resistance) but also exercises direct control over the selection of pile quantities. Construction of a quality product is thought to be assured by the rigorous specifications and inspection. The competitive bidding process obtains the lowest possible unit cost for the pile as designed. This system has worked well in many respects for these mature technologies, as failures are extremely rare and contractors have great incentive to control prices.

However, with emerging or rapidly developing technologies, the use of prescriptive specifications has significant limitations. The designer has little incentive to assume performance risk with innovative systems with which he or she has little experience. The open bidding process generally precludes the designer from specifying a single proprietary pile system, and there is little incentive for the designer to attempt to provide a wide range of alternates. Likewise, contractors have little incentive to improve the product or to produce a quality product to any level above the absolute minimum standard established by the specifications and the owner-specified quality assurance system. The development of rigorous specifications for design and construction is a time-consuming process which cannot respond to rapidly changing technologies in a timely manner without extraordinary effort. Although performance failures have been rare, claims and delays are all too frequent.

A Performance-Based Guide Specification for Piling for Public Agencies

As a part of the development of Geotechnical Engineering Circular No. 8 for the U.S. Department of Transportation, Federal Highway Administration (FHWA), a guide specification has been developed for use by U.S. public transportation agencies and any other interested parties. This specification provides for an owner-controlled design wherein the owner (public agency) provides preliminary plans that show the pile design loadings, footing/cap design, and pile layout for each footing/cap location. The owner also provides related design criteria and requirements, subsurface data, site limitations, construction material and testing specifications, and required contractor submittals and review requirements. The pre-qualified CFA pile contractor designs the individual piles and pile cap connections and selects the CFA construction process and equipment.

During the pre-bidding process, the pre-qualified CFA pile contractors prepare a preliminary CFA pile design and a firm cost proposal based on the owner's preliminary plans and specifications. If the CFA pile portion of the project is to be subcontracted, general contractors will receive bids from the list of pre-qualified CFA pile contractors and include the best offer and name of the selected CFA pile subcontractor in their bid submittal. Once the contract is awarded, the selected CFA pile contractor prepares detailed CFA pile design calculations and working drawings and submits them to the Engineer for review.

Advantages and Limitations of Performance Specifications for Piling

Performance based specifications offer some advantages for new technologies, and in the U.S. transportation industry, micropiles have enjoyed successful implementation in this market by using performance specifications. With new technologies, designers may be encouraged to accept innovation because the

risks associated with performance are assumed by the contractor. Rather than using rigorous prescriptive specifications, a rigorous testing program is used to verify performance. Rather than using the lowest unit cost for a specified pile type to obtain competitive bids, contractors are provided with incentive to offer the most competitive pile system to achieve speed and economy. This more flexible system encourages innovation and is well suited to rapidly changing technologies. In the U.S. transportation construction market, drilled piles (including CFA, DD, IDD) are an emerging technology which can offer benefits to owner agencies from this alternate procurement method.

There are difficulties and limitations with performance specifications. Although the designer does not directly assume the risk of performance, the end result is dependent upon a clear and concise expression of the designers expectations of performance. The level of testing and monitoring to assure performance must be defined in order to provide the quality assurance necessary to protect the owners interests. Because a greater burden is placed onto the contractor, it is even more important that a qualified and experienced contractor be chosen; pre-qualification of contractors is an issue with which many public agencies struggle. If contractors propose new and innovative piling systems, the design and inspection team will have a challenge to familiarize themselves with the features of the system so that verification of performance can be assured.

REQUIREMENTS OF PERFORMANCE SPECIFICATIONS

Performance specifications include some important features that are general to any good specification for piling works and some requirements that are specific to CFA, IDD, and DD piling.

General Requirements

Some of the general requirements of a good performance specification for foundation piling include:

- well defined provisions for prequalification of subcontractors,
- clearly defined performance requirements,
- high quality geotechnical information,
- requirements for contractor submittals,
- testing requirements for verification of performance.
- mandatory preconstruction meeting

Contractor prequalification is a critical issue because of the increased responsibility for the foundation performance to be placed on the contractor under this type of contract. Prequalification requirements focus on the documented experience of the contractor and jobsite supervisor as well as the licensed design engineer (who may be either an employee or a separate consultant partnering with the contractor). Enforcement of this provision is important, as inexperienced and unqualified contractors can lead to delays, inferior work, potential claims, and increased costs.

Another factor that project owners/designers must consider is that the performance expectations must be clearly conveyed through the contract documents. The performance requirements include axial and/or lateral load resistance and limiting displacements for service load conditions. If reinforcement and/or flexural capacity for bending are part of the owner design, minimum tip elevations and minimum reinforcement lengths may be specified. It is worth noting that some types of drilled displacement piles may enhance lateral load performance and there may be provisions to include this performance characteristic in the contractor design component. However, the design of the connection to the pile cap requires that the pile cap details be clearly indicated on the contract documents.

Performance requirements are inherently tied to geotechnical conditions, and it is critical that high quality geotechnical information must be included in the contract documents. Reliable geotechnical information is also necessary in order to minimize the risk of claims and disputes. For routine projects, it is not practical or efficient for contractors to obtain their own geotechnical information for preliminary design. There are often constraints of time, permits, right-of-way, and practical efficiencies of allocating scarce resources for multiple contractors to be duplicating the site investigation efforts in order to bid a job.

Contractor submittals after the contract has been awarded must include complete design calculations and working drawings for review and approval by the project engineer. These submittals should be signed and sealed by the contractor's design engineer, who had been previously pre-qualified to perform this work. Working drawings must include all the information necessary for the construction and

quality control of the piling. A pile installation plan must be submitted to document the equipment, step-by-step description of the installation procedures, sequence, mix designs, equipment and procedures for monitoring critical parameters during construction, and protection of nearby structures. A conformance testing plan should also be submitted along with the pile installation plan, and this plan should describe both the pre-production load testing program and the post-installation testing to verify capacity and/or pile integrity.

General testing requirements for verification of performance must be spelled out in the specifications. In general, the total number of load tests on any specific project may depend on such factors as the size of the project, the soil conditions and variability, the required load resistance, sensitivity of the structure, and site access conditions. However, the minimum load testing requirements for the specific project should be specified. The contract documents should include an item for additional tests above the specified minimum number so that the project engineer has a means to direct that additional testing be performed without change orders. It is important to note that the pre-production tests are used not only to demonstrate the performance of the test pile, but also to establish installation criteria for the production piles.

A final general requirement is to include a mandatory preconstruction meeting. Such a meeting can help to establish communication, bring attention to any special concerns, and help to minimize the risk of misunderstandings later.

Specific Requirements for Drilled Piles

Besides the general requirements for performance-based specifications outlined above, there are some items specific to drilled piles that should be included. These include specific items pertaining to automated monitoring of installation and concreting operations, to integrity and verification testing, and to the correlation of these control parameters to those established during construction of pre-production test piles.

Automated Monitoring

The use of automated monitoring equipment is a key element of quality assurance for drilled piles. In fact, the availability of this QA/QC technology is a major factor in the acceptance of continuous flight auger piles for public works projects, given that many public agencies have had reservations about their ability to adequately verify the performance characteristics of production piles. Some of the required components of an automated monitoring system include:

Figure 5 Automated Monitoring for QC/QA

- rate of penetration of the tool during drilling,
- torque and down pressure from the rig,
- concrete (or grout) volume during extraction of the tool,
- concrete pressure during pumping.

The rate of penetration of the tool may be a critical parameter for performance, depending upon the type of pile to be installed and the geotechnical conditions. The torque and down pressure from the rig are generally recorded along with the rate of penetration as an indication of the effort extended during installation. The axial capacity of conventional CFA piles in non-cohesive soil can be quite sensitive to penetration rate, and ground subsidence can occur if excessive soil flighting is permitted during installation. For partial or intermediate displacement piles, the amount of lateral soil displacement affects capacity and will be related to the rate of penetration. In these conditions, the penetration rate during drilling must be tied to the production control parameters for QA/QC.

However, the axial capacity of a displacement-type pile is generally insensitive to the rate of penetration of the tool, since the resulting soil improvement around the pile is produced by the shape of the tool and flighting of soil does not occur in any case. In cohesive or cemented soils, the capacity of a conventional CFA pile may be relatively insensitive to the rate of penetration, since these non-caving

soils tend to stand without flighting even if the tool is over-rotated. Examples include the cemented limerock soils in Miami and weathered shales in Texas. In these conditions, the emphasis on penetration rate during drilling may be relaxed as a production control parameter for QA/QC.

Volume and pressure of concrete or grout during casing are critical parameters for QA/QC to ensure that a pile of good structural integrity is achieved. Only with an automated monitoring system that records these controls as an incremental function of length along the pile can the owner be assured that the pile is cast correctly. These systems also provide the real time feedback that allows the operator to control the process with precision. The FHWA guide specification requires the use of these systems on all CFA projects for bridges and other critical transportation structures.

Integrity and Verification Testing

A performance-based specification must include testing to provide the owner with assurance that the performance requirements are achieved. With CFA piles, there are two major components to the testing requirements: 1) integrity testing for assurance that the pile is structurally sound and 2) verification testing for assurance that the pile has the required geotechnical capacity.

Several types of integrity tests have been used for CFA piles, but the most widely used and economical test method is the sonic echo test. Sonic echo is performed by striking the pile top and observing the echo trace returned to an instrument from the pile toe or any changes in impedance along the pile; this technique is well documented in the technical literature and represents a relatively mature technology. The advantages are the speed and economy of this test method compared to alternatives (which might include one or more access tubes within the pile). A limiting factor is the attenuation of the signal with long slender piles and the fact that any irregularities in geometry will complicate the return signal and make a defect in the pile more difficult to detect.

Defects in terms of structural integrity are potentially the most serious when they occur near the top of the pile, and a defect near the top would be most easily detected using sonic echo. Additionally, the uppermost few meters are often the most vulnerable to construction related defects because of the potential for instability at the top of the hole, the lack of

Figure 6 Proof Testing of Production Piles with Statnamic (Rapid Load Test) Device at a project in Florida

pressure in the fluid concrete or grout, and the potential for contaminants to fall into the fluid concrete or grout during rebar placement. Sonic echo testing of each pile during the test pile program and early in the production pile schedule can help to identify any problems in the construction techniques being used at the project site and allow correction before a large number of defective piles are constructed. A typical performance specification should require some minimum percentage of piles to be tested, perhaps even 100% for a difficult project.

Verification load testing on production piles can now be readily accomplished using dynamic (DLT) or rapid (RLT) loading techniques (as illustrated on Figure 6). With the advent of relatively mobile testing equipment, a significant number of production piles can be selected by the engineer or owner's representative for verification testing. These load testing technologies provide a good indication of load resistance, particularly if "calibrated" against conventional static load tests during the pre-production pile load testing program.

Pre-production Pile Load Testing

A pre-production pile load testing program is critical for performance based contracting of CFA piles. The load test program not only is used to verify the contractor's design methodology, but also to establish control parameters for construction based on the automated monitoring program. The control parameters (penetration rate and/or torque and downcrowd if appropriate, concrete volume and pressure and over-consumption ratio of concrete or grout) set by the contractor and measured during construction of the test piles are, within some allowable range, the target requirements for production piling. Without the link between the control parameters and measured performance, it would be quite easy for the rig operator to very carefully install the load test piles with an eye toward optimizing capacity, only to see a later change in emphasis toward optimizing production after the test pile program is over. By establishing control parameters based on the load test piles, a consistency can be established that will provide assurance to the owner that the performance criteria are met.

CHALLENGES FOR IMPLEMENTATION

While the advantages of performance specifications for CFA piles are apparent, there are significant challenges to implementation of this approach. These challenges include enforcement of pre-qualification requirements, owner/engineer review of contractor submittals in a timely manner, recruitment and training of inspectors for CFA pile construction.

Prequalification of subcontractors can be a challenge for public agencies because of the history and public demand for open bidding in the U.S. The public agency must devote the time and energy to establish appropriate requirements for contractors and to set up a review process that will be recognized as fair and impartial. Several state departments of transportation have successfully established prequalification of subcontractors for micropile and other specialty construction works, so there are precedents to follow in this regard.

For a performance based design, the contractor must make a submittal with calculations, drawings, and a description of the construction plan. CFA piles have been relatively uncommon in construction of transportation works, and therefore many engineers within public transportation agencies have relatively little experience with these piles. In addition, new techniques and equipment are rapidly emerging in the industry. There is a distinct need for education and training of engineers in order that critical evaluation of proposed designs can be achieved in a timely manner.

Besides the need for education and training of design engineers, the inspectors and technical support staff require recruitment and training. Training for construction inspection is needed across all types of deep foundation works, but the additional testing requirements and the different approach represented by performance based specifications for CFA piles add to the challenge.

Perhaps it could be concluded that the biggest challenge for implementation is at the national level, for the FHWA to implement education and training programs to address the challenges facing the individual state a local agencies!

Summary and Conclusions

CFA and drilled displacement piles represent a potentially useful technology for transportation works due to the speed and economy of these piling systems. The wide variety of different piling systems can be utilized via a performance based approach to contracting for these foundations. A number of features characteristic of performance specifications are described in this paper, with particular emphasis on the need for QA/QC using automated monitoring systems and the need for an appropriate testing program to assure the owners that the performance criteria are met. There are challenges for implementation of this approach relating to prequalification of contractors and education and training of engineers and technical staff. However, the adoption of a performance based specification offers the promise of encouraging contractors to be innovative and focused on performance aspects of their foundation installations.

References

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