

May 2001

FOUNDATION

DRILLING

ADSC: THE INTERNATIONAL ASSOCIATION OF FOUNDATION DRILLING

Deep Excavation
in Seattle

Seminar **SOLD OUT**
in Toronto

UMASS NDT
Wrap Up

Roping Recruits
in Texas



NDT Prediction Symposium at UMASS/NGES

The following article was co-authored by Magued Iskander, Polytechnic University, Douglas Roy, GZA Geoenvironmental, and Carl Ealy, FHWA. During the past eight years, the ADSC has been a prime mover in developing numerous NDT (NDE) test programs. The goal is to provide a reliable test of anticipated drilled shaft performance. It has been pointed out repeatedly that the best QA program is dependent on good QC, this means quality construction performed by experienced contractors augmented by real-time, on-site inspection. QC backed up by NDT analysis, when indicated as necessary, provides the most comprehensive QA. (Editor)

Summary

This paper presents the results of a blind prediction symposium of construction defects in drilled shafts. Six drilled shafts were constructed, at the National Geotechnical Experimentation Site in Amherst, Massachusetts. Several types of defects were integrated into the shafts including necking, voids, caving, and soft bottoms. Nine organizations participated in a blind defect prediction symposium, using a variety of NDT techniques including both down-hole techniques such as cross-hole sonic logging, single-hole sonic logging, and cross-hole tomography and surface techniques such as pulse echo and sonic mobility. Most participants found defects that were larger than 10% of the cross sectional area. However, false-positives and inability to locate smaller defects and multiple defects in the same shaft were encountered.

In recent years, the use of drilled

shafts foundations has been increasing. One reason for this growth has been the ability to routinely test

In recent years, the use of drilled shafts foundations has been increasing. One reason for this growth has been the ability to routinely test drilled shafts using Non Destructive Testing (NDT) methods.

drilled shafts using Non Destructive Testing (NDT) methods. Presently,

several NDT techniques are widely used including Cross-hole sonic logging (CSL), Pulse Echo Testing, and Sonic Mobility. These techniques help owners and engineers confirm that drilled shafts are unimpaired by construction defects. This is important for two reasons. First, drilled shaft foundations lack the redundancy of driven pile foundations, which typically utilize a larger number of lower capacity piles. Second, in the United States drilled shafts are often constructed with the aid of polymer or bentonite slurry to keep the hole open. This technique does not easily allow for inspecting the integrity of the shaft prior to and during concrete placement.

An effort to further study the accuracy of the NDT techniques commonly used by the consulting community and state highway departments was organized in the form of a blind Class-A prediction symposium. This effort took place in the form of a full-scale field test conducted at the



Built-in anomalies designed to replicate construction defects including necking, caving, and voids.



(continued on page 26)

National Geotechnical Experimentation Site (NGES) at The University of Massachusetts – Amherst in March–April, 2000. Six drilled shafts were constructed, some with built-in defects, for this project. Leading NDT testing firms and universities were invited to participate, and nine organizations took part in this program. This paper presents the results of this effort.

Integrity Testing Methods for Drilled Shafts

Down-Hole Techniques

Down-hole techniques require placement of a number of metal or PVC access tubes in the shaft prior to concrete placement. Down-hole techniques are based on measuring the wave velocity between a pair of hydrophone probes, one emitting an ultrasonic pulse and the second is a receiver. The tubes are filled with water to provide for coupling between the probes and the shaft. The wave velocity depends on the density and modulus of concrete. Presence of voids, soil inclusions, or poor quality concrete is manifested as a reduction in the wave velocity. Most state highway departments specify that testing be performed in 10 days or fewer of concrete placement, for PVC tubes, or 45 days or fewer for steel tubes to avoid problems associated with tube debonding. The most commonly used down-hole methods are:

- *Crosshole Sonic Logging (CSL)* is the most commonly used down-hole technique in the United States. The test is performed by lowering two probes to the bottom of two access tubes. Wave velocity is typically recorded every 50 mm (2 in) as the probes are withdrawn out of the holes. CSL tests are typically performed between all perimeter tubes to evaluate the concrete conditions at the outer edges of the shaft, and between major diagonal tubes, to evaluate concrete conditions at the

inner part of the shaft. Offset source and receivers are also used to better characterize the nature and location of defects.

- *Singlehole Sonic Logging (SSL)* is similar to CSL, but uses the same access tube for both the source and receiver. The technique is best suited for small diameter drilled shafts, minipiles, or auger-cast piles. It can also be used to further investigate a defect identified using CSL.

- *Crosshole Tomography (CT)* uses similar equipment to CSL, but with multiple sources and receivers. Tomography is an analytical technique which uses the travel time between multiple sources and receivers, in an iterative process, to generate a two dimensional image of the defect. When a defect is identified using CSL, CT tests can be used to better characterize the defect.

CSL is effective in locating defects between tube pairs, determining defect depths, but not the exact location of the defect between tube pairs. Also, CSL cannot locate diameter increases, or provide information about the condition of the shaft below the bottom. CT is better than CSL in identifying the location and shape of defects. However, CT is time consuming, and has not gained wide popularity.

Surface Techniques

Surface techniques are more commonly used in Europe. In the United States, they are primarily used when difficulties occur during the construction of drilled shafts where access tubes for CSL have not been planned. Nearly all surface techniques depend on the application of a stress wave at the top of the shaft using a hand held hammer, and signal analysis of the reflected waves. Waves travel along the depth of the shaft and reflect back to the surface when they encounter an impedance change, which could be caused by changes in the material or cross sec-

tion of the shaft. The force applied to the shaft is measured using a force transducer mounted in the hammer, and the reflected waves are typically measured using an accelerometer glued at the top of the shaft. The methods differ from one another, in the way the force and acceleration time histories are processed. The most commonly used methods in the United States are:

- *Acoustic Wave Reflection, Pulse Echo, or Sonic Echo* is based on observing the time taken for waves to reflect back from the tip of the shaft. Defects that exist along the length of the shaft will cause secondary reflections that could also be detected knowing the compression wave velocity of concrete.

- *Impulse Response or Sonic Mobility* is based on transforming the force and acceleration time records to the frequency domain. Shaft length, diameter, stiffness, and depth of defects can be theoretically deduced from the measurements.

Surface techniques are subject to a number of limitations, including: (i) the strength of the echo depends on the surrounding soil; (ii) signal to noise ratio decreases as the length-to-diameter ratio exceeds 20-30; (iii) size and lateral location of the defect cannot be determined, (iv) defects near the bottom of the shaft are difficult to detect, (v) defects can hide below other defects located above them, and (vi) unplanned diameter changes, such as bulbs which are typically acceptable, are indistinguishable from necking defects.

Gamma-Gamma Testing

Gamma-gamma testing involves lowering a probe containing a source of ionized radiation at one end, and a gamma-ray detector at the other end. The rate at which gamma-ray photons are reflected from the surrounding material is related to concrete density. The probe can penetrate

(continued on page 28)

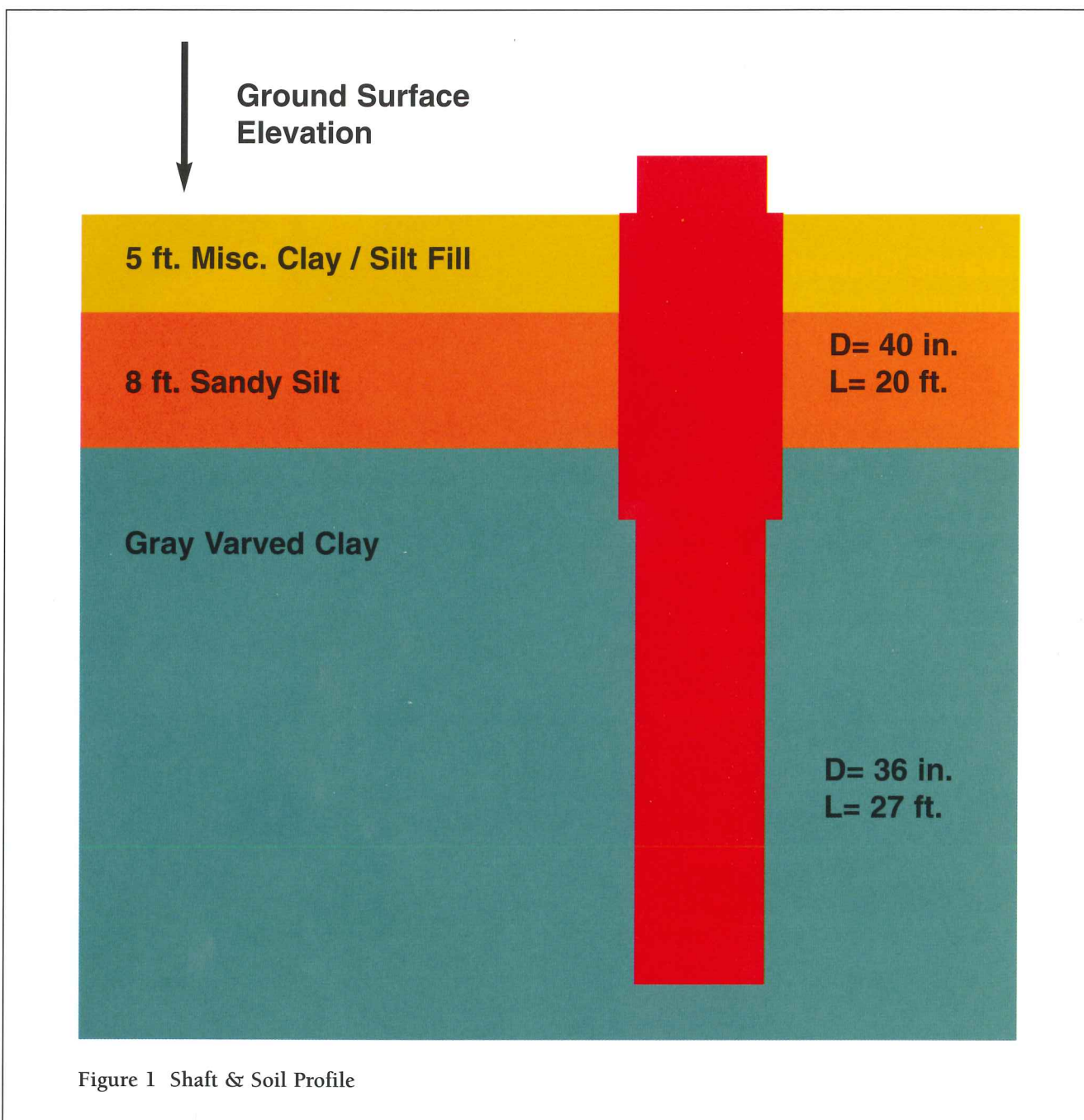


Figure 1 Shaft & Soil Profile

approximately 100 mm (4 in) of concrete surrounding the access tube. Voids and areas of poor quality concrete can be detected as a reduction in the rate of reflected gamma-rays.

Gamma-gamma testing is subject to a number of limitations, including: (i) access tubes cannot be made of steel, which prevents radiation from penetrating concrete; and (ii) access tubes should remain at a con-

stant distance from the steel cage in order to prevent steel from affecting the readings. One advantage of gamma-gamma testing over other methods is that it can provide information related to the quality of the concrete cover, since radiation can penetrate, outside the cage into the concrete cover.

Shaft Construction

Six drilled shafts were installed at

the UMASS-NGES using a Soilmec R-515 hydraulic rotary drill rig, and a Champion 36 rock auger. The subsurface conditions are shown in Figure 1. To facilitate construction, a 900 mm (36 in) diameter hole was augured to a depth of approximately 6 m (20 ft). A 1 m (40 in) outer diameter temporary casing was inserted in the augured hole. Next, a 900 mm (36 in) diameter hole was

(continued on page 29)

Table 1: Shaft Details

Shaft 1	Shaft 2	Shaft 3	Shaft 4	Shaft 5	Shaft 6
Engineered Defects	Unplanned Defect	Engineered Defects	Engineered Defects	Engineered Defects	No Engineered Defects
4 NDT pipes	4 NDT pipes	3 NDT pipes	4 NDT pipes	4 NDT pipes	4 NDT pipes
Concrete placed by tremie	Concrete placed by tremie	Concrete placed by free fall	Concrete placed by tremie	Concrete placed by free fall	Concrete placed by tremie

augured through the casing to a final depth of 14.3 m (47 ft) below grade. Below the casing, shafts were drilled open hole without the use of slurry. The hole remained open for several hours without the accumulation of more than 50 mm (2 in) of water prior to pouring concrete. The shaft bottoms were sounded prior to concrete placement.

Concrete having a 28-day compressive strength of 35 MN/m² (4,000 psi) was placed using both free fall and tremie methods as indicated in Table 1. The mix design consisted of 10 mm (3/8 in) aggregates (maximum), sand, Type II cement, and water (6.7:6:2.6:1 by weight). Plasticizers (REO1000), Retardant (100XR) and an air entrainment agent were added to improve the mix properties. The resulting mix was plastic and flowable, having a slump of 180 to 230 mm (7 to 9 in). Twelve test cylinders were collected from every shaft, and all tested cylinders exceeded the design strength.

Reinforcement, placed prior to concrete placement, consisted of 10 #9 bars (28.5 mm, 1.125 in) and #4 (12.5 mm, 0.5 in) stirrups, located 45 cm (18 in) on center. All reinforcement was full length. Four-50 mm (2 in) ID black iron pipes were installed for cross-hole sonic logging in all test shafts except one, where only three pipes were installed, to

study the effect of tube placement on NDT results (Table 1).

Description of Built-In Defects

Planned Defects

The objective of this study was to investigate the reliability of NDT methods in detecting large construction defects, which could influence the structural or geotechnical capacity of a drilled shaft. Accordingly, very small or very thin defects were not included.

Several types of defects were integrated into the shafts including necking, voids, caving, and soft bottoms. The defects were made of a variety of materials including 3.8 to 38 l (1 to 10 gallon) plastic pails, fiberglass and wood insulation, 23 to 33 cm (9 to 13 in) cardboard construction tubing, flexible PVC drain pipe, gasoline containers, and military water jugs. Some anomalies were filled with in-situ soils to replicate inclusions on side walls, others were left empty to simulate slurry pockets. Defects were rigidly attached to the rebar cage, using steel straps.

Defects were attached inside of the rebar cage. In some cases voids were extended outside the cage, to the outer perimeter of the shaft, using light-weight fiberglass insulation wrapped inside heavy PVC bags.

When insulation was used, the dimensions of the defects were effective, which include the thickness of the insulation. Inside the cage, we were forced to position all defects under each other in order to leave enough room for the tremie pipe used in pouring concrete.

At the planning stages, it was believed that slurry would be needed to maintain hole stability during

The objective of this study was to investigate the reliability of NDT methods in detecting large construction defects, which could influence the structural or geotechnical capacity of a drilled shaft.

construction. Some of the defects were designed with small holes that would permit slurry to fill the defect, but prevent concrete from displacing it. We observed all defects while concrete was poured, and believe that all of them survived until the point that they were covered with concrete. Obviously, we cannot be sure if one or more of the voids imploded due to the weight of the concrete. As a result, voids were placed in the

(continued on page 30)



Several NDT methods were used by the predictors to locate defects.

use of steel tubes eliminates the possibility of using gamma-gamma testing. Four teams used down-hole techniques (Teams 2, 4, 5, and 7), two teams used surface techniques (Teams 1 and 3), and two teams used both techniques (Team 6 and 8).

The performance of the eight participating teams was evaluated by comparing the predictions to the locations of the as built defects. Additionally in drawing conclusions, predictions of various teams were compared to one another in order to account for shifting of defects during concrete placement.

upper portions of the shafts, and soil filled inclusions were placed in the lower portions of the shafts to minimize the possibility of implosion.

Several necks were built into the shafts using 100 mm (4 in) corrugated flexible plastic tubing. The tubes were wrapped inside the reinforcing cage at specified locations, and cut section of the tubes were wrapped at the same location outside the cage.

A cleaning bucket was not used to clean the bottom of any of the shafts. Technically, all shafts had a soft bottom. Nevertheless, shafts appeared to be relatively clean prior to pouring concrete.

Un-Planned Defects

During the construction of Shaft 2, the contractor reported that the hole was squeezing. After the design depth of 14 m (47 ft) was reached, the construction crew spent approximately one hour pouring Shaft 4. Upon returning to Shaft 2, the measured depth of the hole was 1.2 m (4 ft) shorter. At that point, the cage was lowered into the hole, and concrete was tremied into the hole. Shaft 2 cage was the only cage that sank into the soil under its own weight, and had to be hung in its place using a timber support.



Blind Defect Detection Program

Nine organizations replied to a nationally advertised blind defect prediction program; two of these organizations worked as one team. The respondents represented some of the best known firms and universities in the field.

Black iron tubes were used for CSL to reduce false detection due to debonding, thus enhancing the likelihood that the shafts can be used in the future to verify the performance of NDT systems. As discussed earlier,

Performance of Down-hole Techniques

Down-hole techniques were able to identify the lengths and lateral locations of defects within the shaft. Participants were generally able to locate all defects exceeding 10% of the cross sectional area. Defects smaller than 5% of the cross sectional area were typically undetectable. The method was also able to locate necks that extended inside the reinforcing cage, but was unable to

(continued on page 31)

locate exterior necks, which did not extend into the cage.

Soil inclusions were more difficult to detect than voids. However, soft bottoms were detected, when access tubes extended through them.

The technique is somewhat dependent on operator skill. Some participants reported poor quality concrete, where no defects were planned. It is believed that these reports are false positives, particularly considering that poor quality concrete was reported by various participants at different locations.

The technique is highly dependent on the skill of the operator, and improved performance of surface techniques in this study may be attributed to the skill and experience of the participants.

Performance of Surface Techniques

Surface techniques performed surprisingly better than reported in previous studies. Surface techniques were able to identify several defects in each shaft, with some defects as small as 6% of the cross sectional area! The technique is highly dependent on the skill of the operator, and improved performance of surface techniques in this study may be attributed to the skill and experience of the participants.

Surface techniques are typically limited in their ability to locate multiple defects situated under one another. Nevertheless, some participants were typically able to locate three defects in the same shaft. The test shafts contained up to six defects per shaft, and none of the participants was able to locate all defects.

Some smaller voids occupying 6% of the cross section area were surprisingly easier to detect than larger soil inclusions occupying 17% of the cross sectional area. This could have been influenced, in part, by the fact that soil inclusions were located deeper in the shafts than voids, for the reasons discussed earlier.

Surface techniques were unable to reliably locate soft bottoms, except when the soft bottom caused the shaft to be 10% shorter than its design length. The technique was unable to identify the lengths and lateral locations of defects within the shaft, and tended to identify most defects as necks. One participant identified two bulbs, however it is not possible to confirm presence of bulbs using the available information.

Effect of Method of Concrete Placement

A secondary objective of this study was to investigate the effect of method of concrete placement on the presence of defects. Three shafts were tremied using a 125-mm (5 in) pipe, and three shafts were constructed by free-falling concrete in a dry hole. Based on the results of the eight participating NDT testers, there appears to be no difference between tremied and free-fallen

Based on the results of the eight participating NDT testers, there appears to be no difference between tremied and free-fallen shafts.

shafts. Some predictors reported false positives, which could be attributed to poor quality concrete. However, false positives were reported in both tremied and free-fallen shafts, at approximately the same rate.

The concrete mix used in this study contained small aggregates and plasticizers, which resulted in a plastic and flowable mix having a slump of 180 to 230 mm (7 to 9 in). No segregation was observed during free-falling of concrete. Mix design and absence of accumulated ground water are critical elements in ensuring the integrity of free-fallen concrete shafts.

Conclusions

The results of a blind prediction symposium of construction defects in six drilled shafts were presented. Eight teams participated, using a variety of NDT techniques including both down-hole techniques such as cross hole sonic logging (CSL) and surface techniques such as pulse echo, and sonic mobility methods.

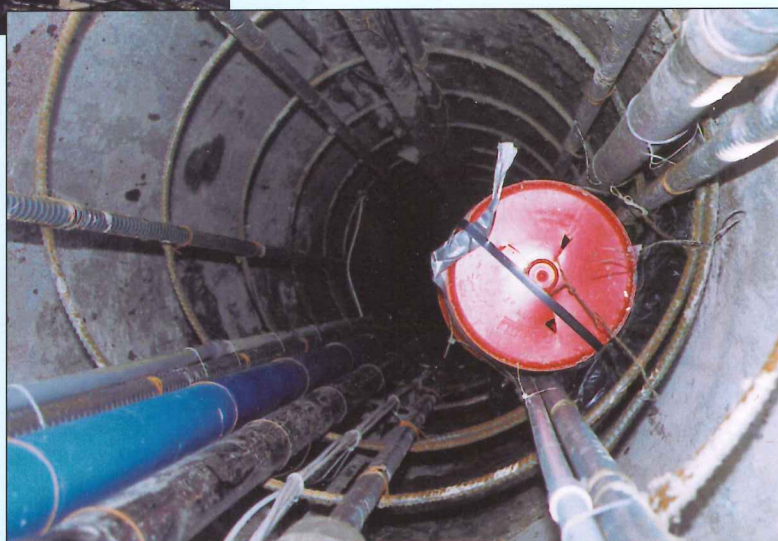
- Down-hole methods (CSL, CT) were generally able to identify defects exceeding 10% of the cross sectional area. The methods were able to identify the lengths and lateral locations of defects within the shaft.
- Surface techniques (Pulse echo, Impulse response) performed surprisingly better than reported in previous studies, with some identified defects as small as 6% of the cross sectional area. Participants were typically able to locate up to three defects in the same shaft.
- Large soil inclusions were more difficult to detect than smaller voids.
- Soft bottoms are difficult to detect using all techniques.
- All techniques are dependent on equipment and operator skill. Some participants reported some false positives, particularly when using down-hole techniques.
- There appears to be no difference between shafts where concrete was tremied or free-fallen, as long as the concrete mix is plastic and flowable.

(continued on page 32)



Cage to be placed in Test Shaft.

Downhole view of "defect."



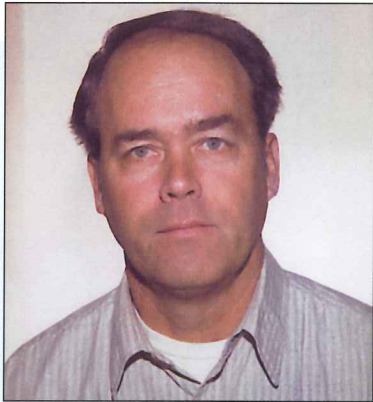
Rig leads cage for placement.

Who Made This All Possible

This work could not have been performed without the generosity and dedication of a large number of individuals. Jim Maxwell, president and owner of Hub Foundation Company provided the test shafts, at no cost to the project. We are very grateful to the NDT testers who participated in this program at their own expense. We are also very grateful to the Federal Highway Administration, not only for its financial sponsorship of the work, but also for the active roles of Carl Ealy and Al DiMillio in bringing this work to fruition. We are grateful to Scot Litke and the rest of the ADSC staff for introducing us to Hub Founda-

tions, and for shepherding the project. Members of the ASCE Geo-Institute Deep Foundations Committee helped conceive this project. In particular, we are grateful to Mike O'Neill, Len Cob, Mohamed Hussein, and Dan Brown for their advice. We are also grateful to UMASS faculty and students for their assistance, particularly Alan Lutenegger, Carlton Ho, Shawn Kelley, and Bob Mokowa. Special thanks to Grey Mullen, of USF and Pierre Gouvin of Slope Indicator Company for their assistance and advice. Credit is also due to Gil Peel of American Equipment and Fabrication Corporation for providing a substitute Soil Mec drill rig, when one became necessary.

(continued on page 34)



Jim Maxwell, President of Hub Foundations was on site taking care of construction details.

What is a defect?

Better predictions defined both the size and location of defects. However, we were disappointed that many participants hedged their bets when referring to defects. For example, many participants tended to refer to any anomaly as "poor quality concrete." One participant referred to defects as "minor signal delays." How is a contractor supposed to interpret that?!

References

A list of references that could be useful to contractors, owners, and engineers involved in NDT testing is available by contacting the ADSC office. Most papers are available for purchase from Linda Hall Library


(<http://www.lhl.lib.mo.us/>). FHWA reports are available from The National Technical Information Service (<http://www.ntis.gov/>) and ADSC.

NDT Participants

- Branagan & Associates, Inc.
- Construction Technologies Laboratory, Inc.
- Prof. Richard Finno, Northwestern University
- Prof. Sarah Gassman, University of South Carolina
- Geoscience Testing and Research, Inc.
- Goble Rausche Likins and Associates, Inc.
- GZA Geotechnical, Inc.
- Olson Engineering, Inc.
- STS Consultants, Inc.

The Authors

Magued Iskander, Ph.D., PE is Assistant Professor and Coordinator of The Geotechnical Engineering Program at Polytechnic University (formerly Brooklyn Polytechnic Institute), 6 Metrotech Center, Brooklyn, New York 11201. Douglas Roy, PE is Office Manager at GZA Geoenvironmental of New York, 2 Penn Plaza, New York, New York 10121 and Graduate Research Assistant at Polytechnic University. Carl Ealy, Highway Research Engineer, FHWA, 6300 Georgetown Pike, McLean, Virginia 22101. The authors can be contacted via their e-mail at Iskander@poly.edu or droy@gza.com, and by phone at (718) 260-3016 or fax at (718) 260-3433. ■




Pile Driving Analyzer[®]

Measures...

- Hammer performance
- Driving stresses
- Pile integrity • Bearing capacity

The PDA economically tests many piles for improved quality assurance and is in use on over 4000 sites yearly. It conforms to ASTM D4945, measuring force and velocity with sensors that are quickly and easily attached to driven piles or drilled shafts. The PDA routinely computes the pile bearing capacity replacing expensive static load testing and provides information on pile integrity, driving stresses, and hammer performance.



Pile Dynamics, Inc.

Quality Assurance through Dynamic Testing

4535 Renaissance Parkway • Cleveland, Ohio 44128 USA
Telephone: (216) 831-6131 • Fax: (216) 831-0916
www.pile.com • e-mail: info@pile.com

Since 1972 • Representatives Worldwide