When is Enough Enough? SR 33 Micropiles for Bridge Stabilization

Allen Cadden[1] and Kerry Petrasic[2]

ABSTRACT

Micropiles were used for the foundation of a pair of new highway bridges, in Eastern Pennsylvania, where sinkhole activities resulted in near collapse of the original bridge. Emergency Repair Funding Rules required it to be replaced at the same location. Due to the very challenging karstic geology, micropiles were selected for the new foundation. A variety of dramatic events occurred during installation of the foundation, not the least of which was micropiles installed to more than 100 m deep. As the bridges neared completion, movements were observed again and emergency action was taken. This paper reviews the general history of the project and focus on the need for critical evaluation of foundation installation data beyond quality control (QC) testing.

Introduction

Quality is the buzzword for the construction industry in the new millennium. The contractors or engineers develop quality control plans; the engineers or owners can create quality assurance plans. Many projects go beyond this to require a quality systems manager to oversee the entire program. Paper work is created, everyone is held accountable for each step of the program. However, experience in the foundation construction industry has been that all the documentation and checks and balance procedures can and often do miss the big picture. What are we really trying to accomplish? And, what is the ground telling us?

We have all heard of the record pile lengths, or unusual grout volumes injected into an anchor. Neat stories, but did anyone stop and ask why? Should we keep driving or drilling? Will pumping that next bag of grout make the anchor any better? Often, we are missing the bigger picture. The ground is trying to tell us something, and we are just plowing ahead with the installation program as defined in the construction documents.

If all of the piles on a site refuse at 15m and the current one being driven is already at 20 or 25m deep, shouldn't we stop and ask why? It is very likely that this unusually long pile will not behave well as part of the foundation system so we are wasting a lot of time and money. This is a story of similar woe. When is enough enough? When is the ground telling us to stop, look harder at the site, and rethink what we are doing?

History

[1] Principal, Schnabel Engineering North, LLC, 510 East Gay Street, West Chester, PA 19380, (610) 696-6066, (610) 696-7771 fax, acadden@schnabel-eng.com

[2] Chief Geotechnical Engineer, Pennsylvania Department of Transportation, 118 State Street, Harrisburg, PA 17120, (717) 787-4319, (717) 705-5750 fax, kpetrasic@state.pa.us

Eastern Pennsylvania has many areas underlain by karstic limestone. This material is highly variable due to solutioning of the carbonate minerals in the rock mass. Often, the remaining conditions consist of pinnacles of hard rock, voided areas and zones of very soft wet soils that are remnant of the solutioning and subsurface erosion process.

PA Rt. 33 is a four lane highway that runs through such an area. Separated by a grass median, these two limited access roads cross the Bushkill Creek about 15 km north of Easton, Pennsylvania. The original separated bridges were constructed in 1970 utilizing spread footings for the center piers and driven steel H-piles for the abutments.

A large limestone quarry is located about two kilometers to the west of this area. Early estimates of the dewatering for this operation indicated that water was being drawn from a depth of about 80m and discharged about 1 to 2 $x10^5$ m^3 per day into the Bushkill Creek. Sinkhole activity in the area is extensive. Numerous documented depressions and sinks have been mapped as shown on Figure 1. Large sinkholes have resulted in the condemnation of homes and complete collapse of a smaller bridge immediately east of the Rt. 33 location.

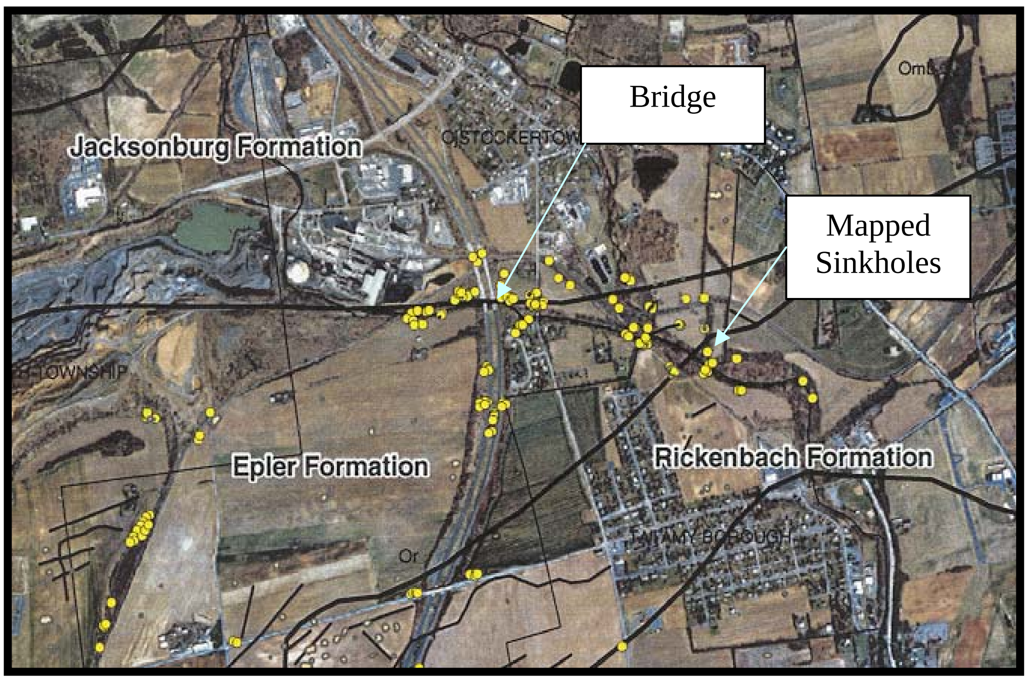

Figure 1. Site location, geologic conditions, and sinkhole mapping.

In 2004, on-going settlement of the Rt. 33 bridge became excessive and the northbound bridge was closed. Measurements estimate that the abutments moved more than about 250 to 350 mm during the life of the structure and the center pier about 735 mm. Emergency repair design was initiated and a single span precast concrete beam structure was designed and built to eliminate the center piers in the creek.

Construction began on the northbound bridge in the spring of 2004. With completion of the northbound span in late 2004, the southbound bridge reconstruction began. By the end of 2004 and winter of 2005, following a series of sinkholes forming to the east of the structures, movement was again observed in the northbound bridge.

FOUNDATION CONSTRUCTION

Micropiles were selected to support the new bridge abutments. This choice was based on the ability to penetrate the difficult karstic conditions consisting of interbedded soil and rock. Drilling was performed with duplex methods utilizing a down hole hammer. The first abutment (south side of northbound bridge) went well. Average length of piles was on the order of 23 m with few piles exceeding about 33 m. Given the site history, this would be considered well-behaved karstic conditions. Although massive rock was not encountered immediately in every pile, the design 3 m bond length was developed with few surprises.

When construction moved to the northern abutment, it was another story all together. Pile lengths ranged from 35 to 70 m. Sinkholes developed during this work. Similar problems continued as the work proceeded to the two southbound bridge abutments. Pile lengths of nearly 110 m were built. Tables 1 and 2 provide a summary of the pile lengths and number of piles that were abandoned during construction for a variety of reasons including binding, breakage of drill strings, and loss of down hole hammers. Figures 2 and 3 depict the pile installation data in plan and 3-dimensional form to give a more detailed indication of the conditions encountered and final construction as completed.

Table 1. Summary of Pile Installation (Petrasic, 2005)

Abutment	Pile Length (m)				Number of Piles	
	Min	Max	Avg	Total	As Built	Abandoned
NB-1 (South)	12	32	21	741	36	--
NB-2 (North)	33	87	61	183	30	13
SB-1 (South)	20	94	61	1,655	27	13
SB-2 (North)	33	106	67	1,877	28	4
Total				6,104	121	30
Abandoned Piles			63	1,759	30/121 = 25% of Installed Piles	
Grand Total				7,864 meters		

Table 2. Summary of Pile Lengths (Petrasic, 2005)

Abutment	No. of Holes within each Depth Range					
	<30m	30-61m	61-76m	76-91	>91m	# Abandoned
NB-1	32 (91%)	3 (9%)	Zero	Zero	Zero	Zero
NB-2	Zero	14 (47%)	10 (33%)	6 (20%)	Zero	13
SB-1	3 (11%)	2 (7%)	15 (56%)	6 (22%)	1 (4%)	13
SB-2	Zero	15 (54%)	Zero	8 (29%)	5 (17%)	4
Total	35 (29% of total)	34 (28%)	25 (21%)	20 (17%)	6 (5%)	30

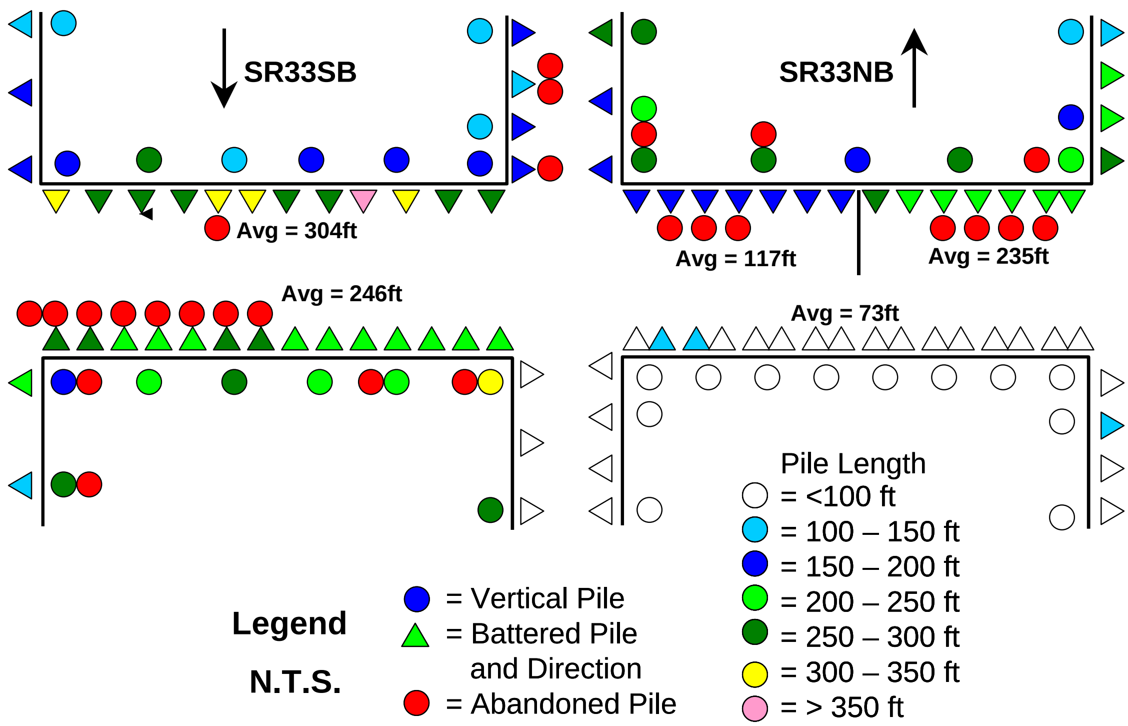

Figure 2. Summary of pile installation (Petrasic, 2005).

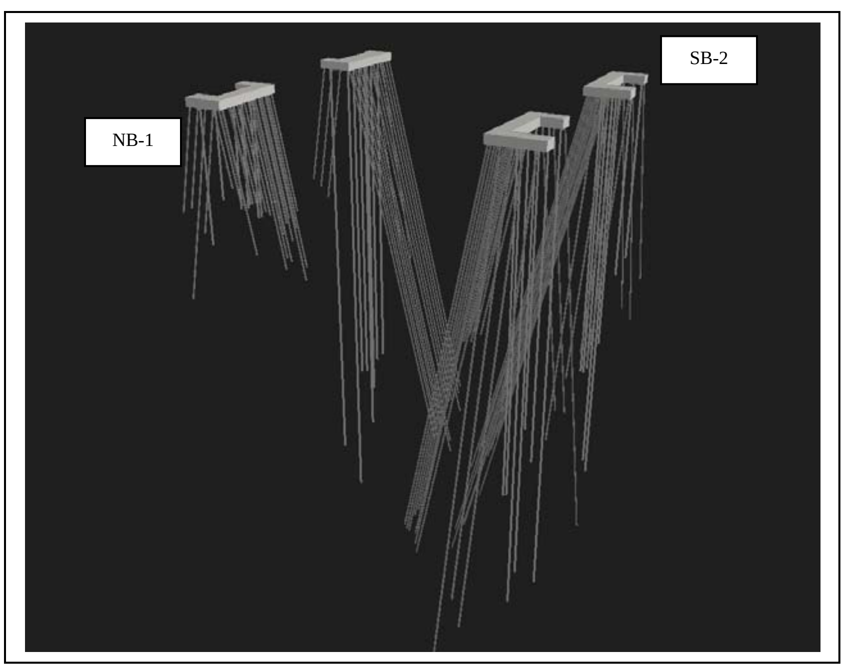

Figure 3. Three -dimensional view of micropile installation if holes are straight.

Forensic Investigation

Movements observed in the bridge structure, as well as the approaches, raised concern with the Pennsylvania Department of Transportation. Immediate investigation, as well as measures to stabilize the structure was initiated. Structural repairs included: repair of approach slabs, and connection of the deck beams to the abutment. Geotechnical investigation also ensued. Twelve test borings were drilled with Sonic techniques between the two bridges to gain a better understanding of the conditions. Eight of these were vertical and four were angled at 12.5 degrees to extend under the creek in a similar fashion as the battered micropiles installed for the abutments. Although 13 other test borings, seismic refraction and resistivity surveys were completed prior to reconstruction of the new bridge, it was believed site conditions were not fully understood as evidenced by continued movements. As such, this new exploration sought to perform a more extensive characterization of the site and evaluate the conditions in which the piles were constructed.

These new sonic borings extended to nearly 165 m in the vicinity of the creek but were limited to 50 m further away. Figure 4 depicts the test boring locations. The goal of this program was to explore well beyond fractured rock zones to develop a better understanding of the geologic conditions. Significant fracture zones were found at depths of about 10 to 150 m similar to the drilling records for the piles.

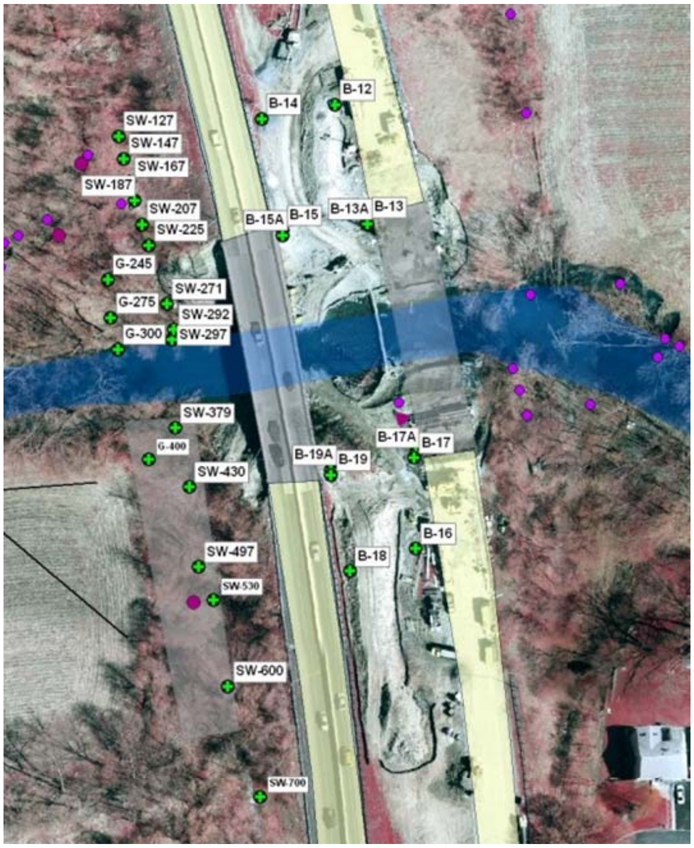

Figure 4. Test boring location plan

Deviation measurements were made on these borings to facilitate interpretation of the data. As can be seen in Figure 5, with depths of up to 110 m in some locations, the alignment of these borings is highly irregular. This deviation is most pronounced on the angled holes as would be expected. Inclusion of this information in the data evaluation was critical, and may be a further indication that the actual conditions of the deep micropiles may be far from intended.

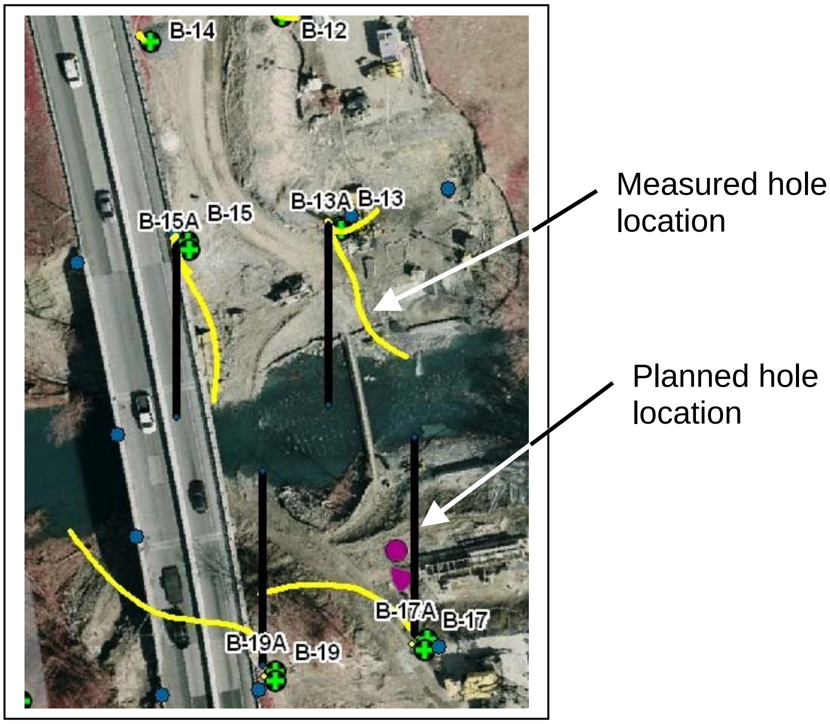

Figure 5. Deviation measurements in angled test borings

A second series of borings was completed on the western side of the highway (quarry side). These borings were located at closer spacing, and extended laterally, well beyond the creek, to define the limits of the problematic rock conditions. The linear array extended to 50 m north of the creek and about 110 m south of the creek. Again, borings near the creek extended to more than 160 m.

The boreholes were each cased to collect further data. Most of the holes included perforated casing to allow groundwater logging for temperature, pH, conductivity, and dissolved oxygen. Others included additional instrumentation. Instrumentation included inclinometer casing and copper electrodes attached to the casing at 5 m intervals. The electrodes allowed electrical resistivity tomography to be completed in between the bridges, as well as 2-D resistivity profiles between the holes and the ground surface.

A self potential survey, as well as further 2-D resistivity traverses were also completed west of the roadway to enhance the understanding of regional conditions.

Figures 6 through 8 provide a general depiction of the geophysical, temperature logging, and test boring results.

The results of testing completed by the Pennsylvania Geologic Survey on a low flow day revealed that the quarry is discharging nearly 83,000 m3 per day of groundwater into the creek about 1500m upstream of the bridge. Sinkhole activities in the area of the Rt. 33 bridge result in the loss of nearly 61,000 m3 (about 73% of the volume as measured by the PA Geologic Survey) from the creek. The forensic studies have shown that there is a zone of karstic rock extending about 125 m deep may be funneling a large portion of this water back towards the quarry. This has set up a recirculating system with soil being washed out of a zone nearly 75 m wide at the bridge.

Given these conditions, the micropiles embedded at depths of up to 110 m are likely “along for a ride” in an unstable geologic condition that was not realized at the time the bridge was redesigned and replaced.

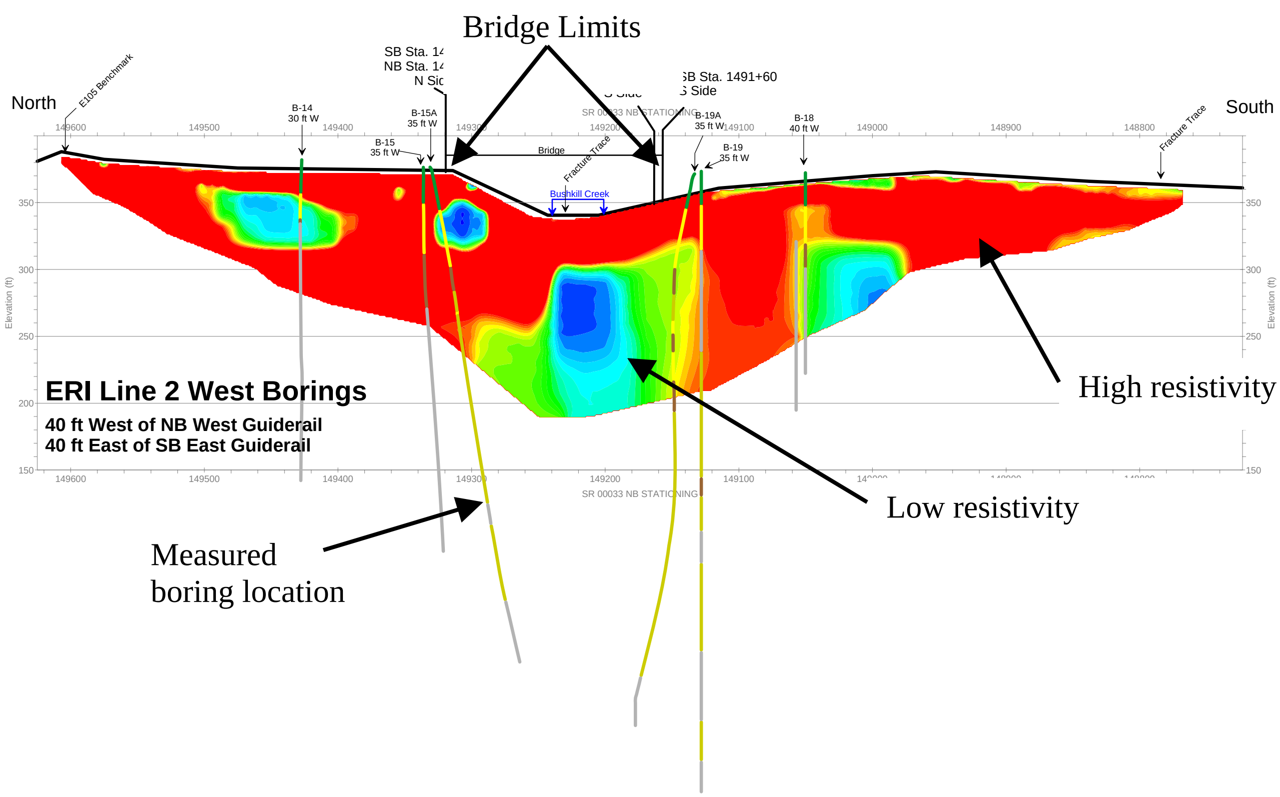

Figure 6. Typical two-dimensional resistivity section.

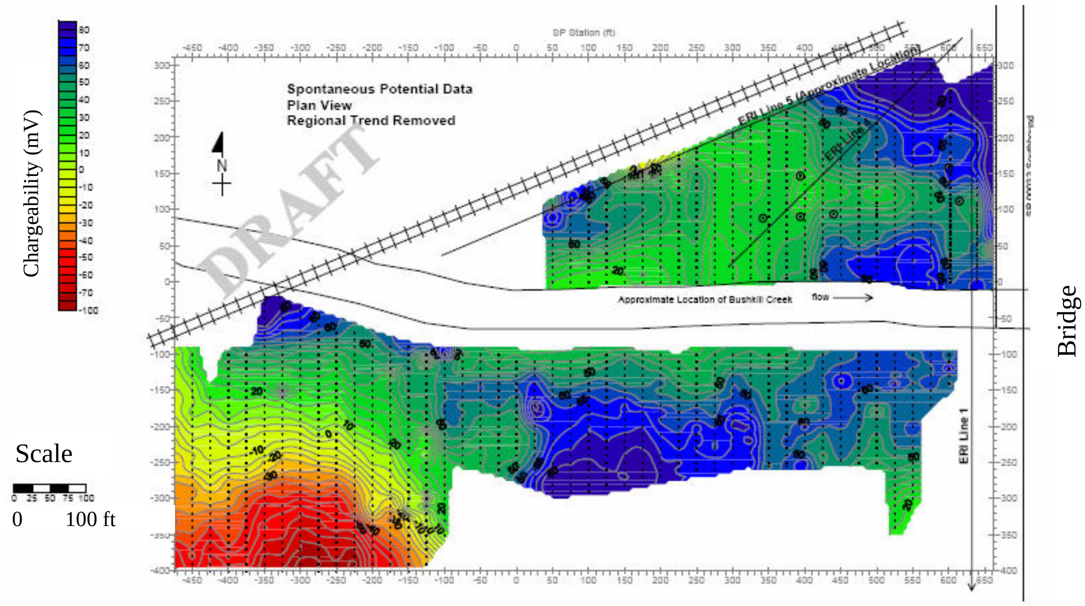

Figure 7. Spontaneous potential survey west of the bridge.

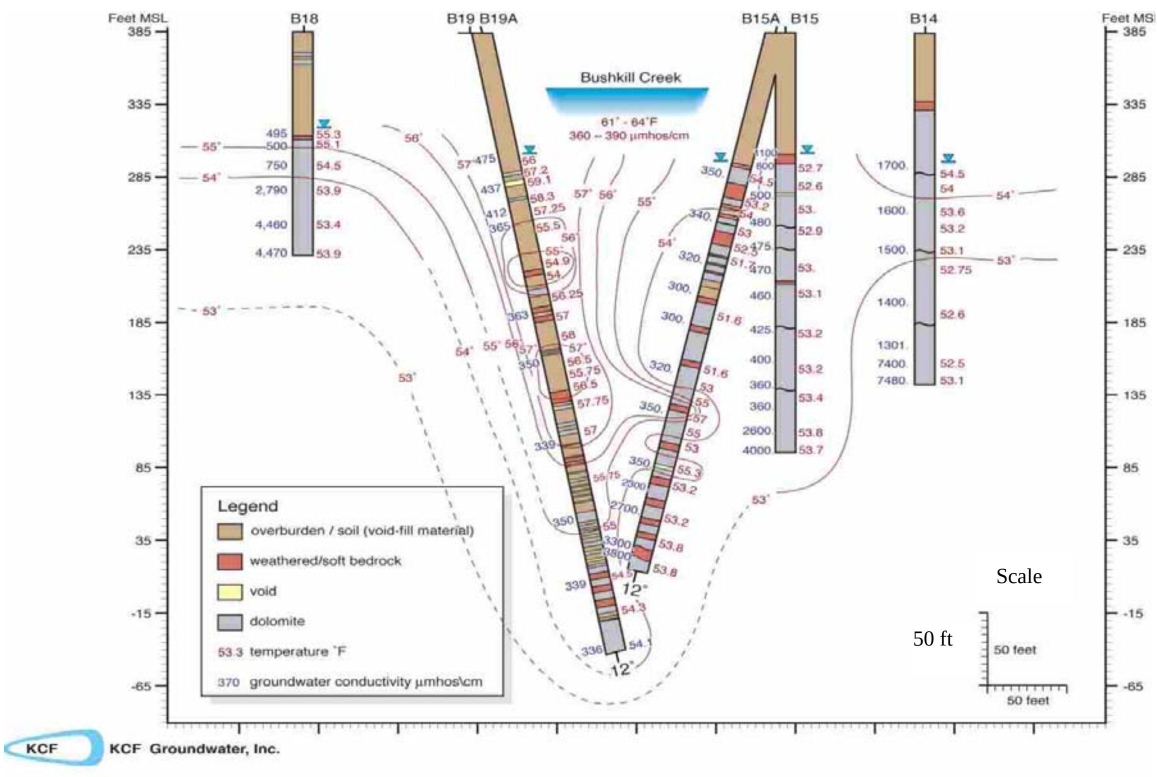

Figure 8. Typical temperature profile of groundwater-note depressed contours in area of flow (Lolcama, 2005)

LESSONS LEARNED

The geologic conditions of some sites can be highly irregular. In general, we hope for the best when developing our exploration plans. Without significant indication of bad conditions, we again assume that our exploration provides reasonable insight into the ground and develops a foundation system to meet the conditions revealed. In reality, we cannot afford the time or expense to do extremely detailed exploration on most projects so we have to rely on judgment.

Where emergency conditions exist or fast track schedules press a projects construction time frame, we often extend this wishful thinking and try to deal with it in the field. Far too often, however, we do not have the proper people with good observation skills, an understanding of the design and geologic conditions that will affect it, or the time to collect and evaluate the information at hand, on-site during construction. Cadden et al. (2005) outlines the level of services that must be provided on projects so that all stakeholders remain involved and informed throughout the project and timely decisions can be made when needed.

Although the piles on this project passed load tests, held grout, and encountered what seemed to be reasonable rock during drilling, the data were telling a bigger story that was not recognized. As with many projects where a few anomalous foundations are taken deeper because we can, this project did not recognize that the ground was inherently not stable. Furthermore, given the slenderness of the elements, the installation methods and the problematic conditions observed, hindsight would tell us that the as built conditions are probably far from what was expected by the designers.

Were micropiles the best solution based on the design information at the time construction began? Most likely. As the data came in, do we still think they are the best foundation beneath this bridge? That may be a bit questionable. The key though is that we must learn to question these issues at the time of construction, not wait until a structure is in place and we are making emergency repairs.

When anomalous conditions are encountered, these naturally affect the installation schedule, as well as the cost of the element. We see these issues every day and can deal with them through standard contracts. What we also have to recognize is that these anomalies affect the stiffness of the foundation and may also impact the structure. They are often indication of problem conditions in the ground that may impact more than just the element being installed. A further concern is that we may be pushing the capacity of the equipment doing the installation and risking unnecessary damage or reduced quality control of the foundation elements being constructed.

Maybe it is better in some cases to say enough is enough; step back and evaluate the situation. The solution may be to redesign the foundations in this area, change the foundation system all together, or may even mean a decision to collect more data. Whatever it is, it is most likely that the solution would be better than forcing an extremely irregular foundation element into the ground just because we can. In the long run, that element will not perform well, will cost us extra time in installation, money for materials and labor, and possibly, result in damage to the final structure.

CONCLUSIONS

Whether driven piles, drilled shafts, micropiles, anchors or even undercutting for shallow foundations or embankment fill placement, sound engineering judgment is necessary on every project. The site conditions must be determined in advance to the best of our ability, using all tools at hand including: drilling, mapping, historic information and common sense. Then, we must recognize that each foundation element is another bit of data and should be used to refine our understanding.

We need to remember the words of Karl Terzaghi as they teach us about the observational method. We have to spend the time necessary to understand the systems. It is quite amazing how we are able to find the time and money to do extensive investigation after the failures, yet we don't take the initiative to insist on a reasonable level of investigation and quality control services during the initial work.

In this case, warning signs such as sinkholes and problems during drilling were addressed, but the overall system was not understood. Construction schedules, political pressures, and stakeholder needs all conspired to push this project along; even though the evidence was mounting that the system was questionable. The designers did not expect 110 m micropiles during design, yet the project went on.

REFERENCES

Bruce, Donald, Project File Information, 2005

Lolcama, Jim, Project File Information, 2005.

Cadden, A., Bruce D., and Bean, J., "The Field Inspection and Documentation of Micropile Works," Geo3 Conference, ADSC, November 2005.

Petrasic, Kerry W., "PA State Route 33 over Bushkill Creek: Structure Failure and Replacement in an Active Sinkhole Environment," ASCE Central Pennsylvania Geotechnical Seminar, February 2005