**Tire Plant** **Augur Cast Piles In Karst**

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A project to expand a Nankang NS2 tire plant site in north Georgia occurred in the and of Appalachia, kinvolves a, that was constructed in five phases.

The initial project included adding manufacturing and warehouse buildings with two basic purposes: serving as a plant/warehouse or as mixing towers where rubber is formed and softened. The new plant/warehouse would consist of one-story concrete tilt up panels that could bear loads of 150 kips (667 kN) for steel columns, and 3 to 4 kips per linear foot (klf) (43.7 to 58.4 kN per linear meter) for continuous wall footings. A total of four mixing towers were constructed at this site. Each mixing tower had 2,000 kip (8,896 kN) columns with a cast-in-place concrete frame.

The Phase 1 and 2 geotechnical exploration was performed by previous consultants. The initial two phases also consisted of developing one mixing tower, the plant, and a warehouse building. The foundations for all four mixing towers were initially designed on drilled shafts. The plant and warehouse foundations were instead shallow spread footings designed with a maximum allowable bearing capacity of 3,000 pounds psf (143.6 kN per square meter).

Midway through Phase 1 and 2, while the first mixing tower construction was underway, the top-of-rock elevation dropped off; suitable bearing for the shafts could not be found within 100 ft (30.5 m) of the ground surface. Micropiles were then substituted for the drilled shafts to complete the foundation of the single tower developed. The micropiles were drilled to bearing in competent rock at depths of 200 to 300 ft (61.0 to 91.4 m) below the ground surface. Due to a major cost overrun and project delays, a lawsuit ensued.

**Phase 3**

A new design-build team was selected for Phase 3 and ECS Southeast provided geotechnical services as a subcontractor for that team. A major concern of the new team was the karst geology and support of one Phase 3 mixing tower immediately adjacent to the troubled mixing tower that had previously been constructed. The new team’s geotechnical subcontractor had experience with sinkholes and karst, and was selected with the goal of devising a plan that avoided micropiles under this Phase 3 mixing tower to reduce overall foundation costs.

Extensive subsurface exploration was conducted using Standard Penetration Test (SPT) borings and air-track soundings to define the upper rock surface for the new mixing tower. Exploration in the mixing tower footprint was performed at most planned column locations. Widely spaced SPT borings also were completed in low-rise warehouse areas.

Typical karst conditions were found that consisted of soft internally eroded soils overlaying the upper rock surface, and a highly variable depth to rock.

Several intermediate foundation options were discussed with a specialty foundation contractor. Micropiles, or at least some version of cased pile into rock, were recommended by that contractor. In the experience of ECS, though, auger cast piles (ACP) drilled to refusal would best adjust to highly variable conditions and pinnacled rock. Excess grout from ACP piles would provide an indirect benefit of grouting Karst under the building footprint. ACP piles would also allow for quality assurance (QA) testing and provide feedback on subsurface variability during installation.

While ACP piles were more cost-effective, with a potential savings of about $2 million dollars over micropiles, this option was not immediately accepted because the Japanese client had had a previous poor experience with ACP piles in the Pacific Rim. Additionally, our client had Japanese engineers reviewing the planned design. As a matter of practice, engineers in Japan are trained that ACP piles are friction piles with no end bearing resistance.

To build our client’s confidence, we suggested installing five test piles in the very small mixing tower area and loading them to three times the design load. Ultimately, 18 in (45.7 cm) diameter ACP piles with a design axial load capacity of 150 tons (136.1 m tons) were selected as the preferred option.

***Pile load testing***

A load test was performed on five ACP piles, using the ASTM D1143, Quick Load Test Method.

**Test Pile Results and Actual Pile Tip-Top of Rock Comparison**

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| Test Pile Number | Maximum Applied Test Load (tons [m tons]) | Creep at Maximum Load | Actual Test Pile Length (ft [m]) | Depth to Top of Rock\* (ft [m]) | Estimated Thickness of Rock Below Pile Tip\* (ft [m]) |
| Initial Load Cycle (in [cm]) | Rapid Reload Cycle (in [cm]) |
| 6023 | 450 (408) | 0.049 (0.12) | Apparent breakage at full depth | 39 (11.9) | 41 (12.5) | 7 (2.1) |
| 6027 | 450 (408) | 0.042 (0.11) | 0.002 (0.005) | 65 (19.8 m) | 70 (21.3) | 19 (5.7) |
| 6049 | 382.5(347) | Test stopped for safety reasons | No reload attempted | 44’ (13.4 meters) | 42 (12.8) | 7 (2.1) |
| 6073 | 450 (408) | 0.014 (0.036) | 0.017(0.043) | 66 (20.1 m) | 50 (15.2) | 3 (0.9) |
| 6079 | 450 (408) | 0.081 (0.21) | 0.042(0.11) | 44.5 (13.6 m) | 45 (13.7 m) | 2 (0.6) |

\*Estimated from air-track drilling at nearby column location.

During static load testing of test pile 6049, signs of instability were observed and the testing was terminated early. To confirm that test pile 6049 did not start to fail into the underlying rock, one SPT boring with 10 ft (3.05 m) of rock coring was drilled. The boring determined that the pile was sitting on a 6 ft (1.83 m) thick rock seam overlaying a 2 ft (0.61 m) thick void, which are common in karst geology. In addition, to check the interface between the pile tip and pinnacled/inclined rock, our client requested full-depth coring of 6049.

***Lessons learned***

During Phase 3 installation of the probe, reaction and test piles, the following lessons were learned:

1. Subsurface exploration into karst can reveal difficult drilling conditions due to highly inclined/pinnacled rock. Be prepared to lose some exploratory drilling equipment such as augers and rods.
2. By using innovation, you may be able to turn a foundation system’s inherent weakness into a benefit, such as the need for additional grouting with drilling some piles in karst.
3. Expect high grout takes initially to “treat” the underlying karst conditions, and to redrill and regrout individual piles several times until grout stops flowing from the hole into the Karst. threesix
4. Supporting an ACP pile on thin rock seams of 2 to 3 ft (0.61 to 0.91 m) thick is practical.
5. Any piles that require redrilling will take significant grout. For this project, actual grout takes of redrilled piles were typically 300% to 1,200% of the theoretical volume. As production progressed, grout takes lessened because early piles tended to seal the upper rock surface, reducing the number of open passageways into lower voids in the rock.
6. As with exploratory drilling, expect to lose some augers during ACP installation into karst. Some piles may even need to be abandoned if an auger shears off from sudden contact with pinnacled rock.

As a QA measure, we recommended piles be reviewed if, during pile installation, refusal occurred at depths less than 80 % of depth to rock in air-track borings or at a depth of less than 30 ft (9.1 meters) below the existing grade. The individual pile should be assessed relative to the adjacent piles in the same pile cap. It should be determined if that pile needs to be downgraded in design capacity and an extra pile added. The capacity of any tension piles should be revisited carefully.

Strain gauges were installed in test piles for Phase 3. That testing found the upper soil profile had significant skin friction capacity, or up to 56 % of axial load capacity. Only about 44 % of total capacity came from end bearing. For piles that were 44 to 66 ft (13.4 to 20.1 m) long, there did not appear to be much change in end bearing percentage. Deeper piles, greater than 65 ft (19.8 m) long, developed more skin friction due to penetration through dense soils and thin rock layers above refusal.

From the strain gauge results during Phase 3 pile load tests, recommended skin friction values were determined, as follows.

**Recommended Allowable Skin Friction at NS2 Tires**

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| SPT N-Values | Allowable Skin Friction  |
| 3 or less | None |
| 4 to 10 | 300 –500 psf (143.6 –23.9 kN/m2) |
| 10 to 35 | 500–1,100 psf (23.9 –52.7 kN/m2) |
| 35 to 50 | 1,100–1,500 psf (52.7–71.8 kN/m2) |
| Soft or Weathered Limestone | 1,700 psf (81.4 kN/m2) |

**Phase 4**

During Phase 4, shallower rock was found than in the part of the site worked on in Phase 3. Shallow pinnacled rock was found at depths ranging from 5 to 10 ft (1.5 to 3.0 m) below the existing grade near the equipment pits. Subsurface exploration also revealed a highly variable depth to top of rock at the Phase 4 mixing tower.

***ACP karst installation***

High grout loss (greater than150% grout take) is expected when installing ACP piles in karst geology. When significant grout loss occurs and freshly cast piles will not maintain grout head at the surface, the following procedures are recommended:

1. Remove steel cage and reinforcing steel center bar, if applicable.
2. Allow fresh grout to remain in the augered hole for a few hours.
3. After a few hours, attempt to reinstall pile using the general procedure. If high grout loss still occurs, fresh grout remains in augered hole until end of day, and low-strength flowable fill is placed into a hole before the hole is allowed to set overnight.
4. The following day, reattempt installing the pile using the general procedure. If high grout loss occurs again and freshly cast piles will not maintain grout head at the surface, let fresh grout remain in the hole for several hours or overnight.
5. Repeat the above steps until the pile is constructed by the general procedure.

***Grouting and sinkhole remediation***

During Phase 4 plant construction, distress was observed at several equipment pit areas following a very heavy rainfall. The distress consisted of cracking of non-structural mud slabs in the equipment pit. Low-slump pressure grouting was performed at multiple points in the equipment pit to remediate the apparent ground relaxations caused by karst/incipient sinkhole formation.

To better grasp the extent of karst and potential voids, an electrical resistivity (ER) survey was performed. High grout takes under the equipment pit mud slabs confirmed that very soft or raveled soil conditions were present, and those conditions were associated with karst and ongoing internal soil erosion. These conditions were thus found to be localized.

During excavations for utilities and such close to the equipment pit areas, several voids were exposed. These exposed voids were initially filled with flowable fill and surveyed for possible future remediation with pressure grout.

***Lessons learned***

The following lessons were learned during Phase 4 grouting:

1. Clients may be reluctant to spend money to protect against an unknown risk such as karst. This case study demonstrates, though, that construction over karst geology can involve an unknown magnitude of risk due to the high variability of subsurface conditions.
2. Low mobility grouting allows more control of the area and depth being remediated. At this site, the deepest injection pipes took most of the grout. When highly variable lengths and pressure grout takes occur during a project, extra grout injection points should be added to properly treat the area.
3. Pressure grout take should be tracked as total cubic yards and cubic yards per linear foot. Tracking grout take per foot treated tends to normalize the results, leading to a better understanding of conditions.

**Phase 5**

Phase 5 construction included additional equipment pits and a warehouse addition. Although the equipment pits were lightly loaded, they were critical to operations. To mitigate the risk of ground relaxations and damage similar to Phase 4, a decision was made to support the Phase 5 equipment pits on ACP piles. Their installation at these equipment pits went smoothly, with few redrills and only moderate grout takes. A small diameter sinkhole appeared later between two of the new equipment pits. Grouting at that sinkhole remediated the slab on grade area.

***Lessons learned***

The following lessons were learned during Phase 5 construction:

1. Unexpected conditions may occur during construction over karst geology, regardless of mitigation steps taken. As an example, ACP piles were installed without issue at the equipment pits, but a sinkhole later formed less than 5 ft (1.5 meters) from a previously installed pile, requiring remedial repair measures.
2. Moderate- to high-pressure grout takes can occur during sinkhole repair, even in an area adjacent to a previous ACP installation.

**Conclusion**

Construction over karst geology is challenging. Due to highly variable subsurface and rock conditions, expect the unexpected. For instance, expect to remediate with pressure grout in areas that show signs of ground relaxations, voids or sinkhole formation.

Some clients may want consultants to prove opinions and illustrate that quality is built into the **project through testing protocols**. A trusting client still allows geotechnical engineers to push the envelope and truly become better consultants. In this project and in general, the use of ACP piles as a foundation system in karst was messy. However, high grout takes can be, and were, effective in treating underlying karst conditions; use of ACP piles can also save money overall.

In the case of the Georgia tire plant, average grout takes in ACP piles declined by roughly 50% from Phase 3 to Phase 5. Though much higher than anticipated, the actual grout volumes for these phases were 147,684 ft3,66,672 ft3, and 29,205 ft3, respectively (or 4,181 m3, 1,887 m3, and 826 m3, respectively) . This was in part due to site-specific experience and generally better soil conditions in later phases.

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**ACKNOWLEDGEMENTS**

Berkel & Company Contractors served as the specialty foundation contractor that installed piles in challenging karst conditions. We would also like to thank KBD Group for their support and understanding during design and construction of Phases 3 to 5 of this project.

**ABOUT THE AUTHORS**

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**LIST OF FIGURES (sent separately)**

**TOP of article image options:**

-NS2 Aerial 012519\_187- is this the completed site? (credit: KBD Group)

-NS2 Aerial 121118-5 – this image would be very helpful for understanding project development, can you describe what is being added in to the building footprint and what action is happening?

- NS2 Aerial Photo1---081618: what stage is this image in, and what new structures can be pointed out?

-- NS2 Aerial\_0519: same stage, new structure questions here.

Plant Phases: please provide caption, including compass directions, and what green, red and yellowish/orange areas signify. We will try to use this image no matter what to help orient readers.

ER at Equipment Pit: electrical resistivity (ER) survey of equipment pits, with X color indicating XXX and Y color indicating ZZZZ.

Fig. 1 – Aerial of plant site showing Phase 5 construction

Fig. 2 – Soil cross section showing areas of raveled soils related to karst

Fig. 3 – Boring log at Test Pile 6049 showing void beneath pile tip

Fig. 4 – Rock core at Test Pile 6049 showing interface between ACP and pinnacled rock

Fig. 5 – Pinnacled rock at Carbon Black pit near mixing tower in Phase 4

Fig. 6 – Top-of-rock contour map for Phase 4 mixing tower

Fig. 7 – Grout take at Phase 4 equipment pits

Fig. 8 – A void discovered during excavation