CMC rigid inclusion installation for new 5-story structure

FEATURE ARTICLE

Rigid Inclusions and Piles for Mixed-Use Redevelopment

The project site encompasses an entire city block in the heart of Pittsburgh's historical Strip District, which was an industrial site until approximately the 1950s, when it was converted to warehouse space.

The plan for the site was to demolish existing 2- and 5-story buildings, leaving only the 4-story building standing. The façade of this adjacent 4-story building (back left of photo) remained, with the interior becoming new retail and office space. Two new stairwells and elevators shafts were added within the existing 4-story structure to service the new office spaces. A new 5-story structure on the southwest portion of the site would consist of ground-level retail space with a 4-story parking garage. The soils had a compressible nature at the site, so Menard recommended ground improvement using controlled modulus column (CMC) rigid inclusions to support the 5 stories. Due to the low overhead conditions within the existing 4-story structure, Menard recommended Magnum design the helical piles to support the new stairwells, elevator shafts and below-grade ramp into the garage.

Boring Coverage

Performing soil borings on site was a challenge because of existing structures. During the bid phase, borings located approximately 600 ft (182.8 m) away at an adjacent site were used to approximate soil properties (see later boring map). During final design, a geotechnical investigation was performed, but was limited to the parking lot area, as the 2- and 5-story buildings had yet to be demolished. The closer borings were used to refine the ground improvement design; however, the majority of the site still did not have boring coverage.

Site Conditions

Due to the location in a historic industrial area near the Allegheny River, site conditions vary greatly within just a few feet. Generally, the soils consist of medium-dense to very dense fill from existing grade, at an elevation of 729 ft to 718 ft (222 m to 219 m), underlain by medium-stiff clay to an elevation of 704 ft (215 m), followed by a medium-dense to dense sand and gravel bearing layer. Groundwater was present at an elevation of 716 ft (218 m). The entire Strip District previously occurred at a lower elevation. After a historical flooding event, though, the entire Strip District became filled with rubble and other material, often including building

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foundations that had been buried in place. As a result, minor obstructions were encountered during the ground improvement installation and were removed as needed by the on-site earthwork contractor.

The basement slabs in the 4-story structure, which had a top elevation of 722 ft to 716 ft (220 m to 218 m), were cut out and the helical piles were to be installed from the exposed subgrade. Similar site soils were anticipated there as occurred with the soils encountered during the rigid inclusion installation for the new 5-story garage; that is, a similar bearing layer at an elevation of 704 ft (215 m) was anticipated. During the helical pile installation, vast amounts of cobbles were encountered and were removed from beneath two stairwells. In one of two stairwells built, cobble removal and water caused soil supporting the slab to slough off into the excavation, causing voids under the slab. For fear of damaging the integrity of the existing slab, excavation was stopped and micropiles were deemed necessary to complete the support of what was called stairwell D. The same soil properties were present for the ground improvement, helical pile and micropile design, the latter of which Nicholson oversaw as an added subcontractor.

Transformed 4-story building (left) and parking garage (right) (credit: McCaffery and Studio 67)

challenges that resulted in critical and beneficial collaboration with the structural engineer and general contractor. Menard worked with the structural engineer to provide support of the new garage, stairwells and elevator foundations, and supplied grade beams and guidance to other subcontractors on maintaining a proper distance from the existing foundations; the latter involved sharing modeling results to determine the appropriate support to handle the eccentric loading of the footings on the existing 4-story building.

A small alley, Mulberry Way, and a supporting retaining wall needed to remain in place because the alley is laden with utilities; so, the foundations of grade beams on top of the eccentrically loaded footings was designed along the length of the alley.

Soil	Blow Counts (N)	Unit Weight (γ)	Friction Angle (φ')	Young's Modulus (Ey)	Top of Layer Elevation
	bpf	pcf [kN/m^3]	deg [rad]	psf [kN/m^2]	ft [m]
New or Existing Fill	16	120 [18.9]	32 [0.56]	501,000 [23,988]	729 [222]
Medium Stiff Sandy Clay	6	100 [15.7]	27 [0.47]	940,000 [45,007]	718 [219]
Medium Dense Sand and Gravel	18	125 [19.6]	33 [0.58]	751,900 [36,001]	704 [215]

Soil properties used for design (Results derived from May 2019 ECS subsurface investigation)

Site Design Challenges

The open lot that was the former location of the 2-story building and its associated parking lot made for easier rigid inclusion installation of the planned 5-story garage. Right-of-way constraints caused structural design of the new 5-story garage could not cross into Mulberry Way. Due to the eccentric loading condition resulting from the garage foundations having to be confined within the property line and the face of the new 5-story garage being against the property line, a series

5-Story Load Test

To determine proper support of the new 5-story garage with street-level shops, a load test was conducted by Menard of an 18 in (46 cm) diameter, 36.1 ft (11 m) long CMC rigid inclusion, which was embedded in the medium-dense sand and gravel. To confirm the design assumptions regarding the load-carrying capacity of the CMCs at the loads given in the design calculations, the *Standard Test Methods for Deep Foundations Under Static Axial Compressive Load* was used (ASTM International, 2013). The performance criteria were 1.0 in (2.5 cm) of total deflection and 0.5 in (1.3 cm) of differential settlement for a design load of 103 kips (458 kN). The same 2013 standard was used to determine the axial capacity.

During the test, a maximum load of 388 kips (1,726 kN) was applied, exceeding the test load of 155 kips (690kN, or 1.5 times the design load). The deflection of the test column at the design load and the test load was approximately 0.05 (1.3 cm) and 0.07 in (0.2 cm), respectively. The measured deflection was less than the 1 in (2.5 cm) estimated during design for the CMC.

A test column instrumented with 5 strain gauges measured that 66 kips (294 kN) reached the tip of the CMC and

213 kips (948 kN) reached the top of the bearing layer when 388 kips (1,726 kN) was applied at the column head, resulting in 0.3 in (0.8 cm) of total deflection, consisting of 0.2 in (0.5 cm) of elastic deformation and 0.1 in (0.25 cm) of tip deflection. Ultimately, Menard installed 136 CMCs of 12 and 18 in (30 or 46 cm) diameter to be used for the garage, with an average rigid inclusion depth of 35 ft (11 m).

Typically, net settlement at ultimate load for helical piles is taken as 10% of the average helix diameter per ICC AC358 (2007); thus, piles would have been allowed a net settlement of 1.48 in (3.8 cm) in addition to elastic shortening of the pile shaft at ultimate load.

The helical piles were planned to support strip footings for stairwells, elevator shafts and an interior garage ramp, as well as providing temporary construction shoring. Installing piles within the existing building limited the equipment to a small skid steer, which also limited the pile size. The limited pile size increased the elastic shortening, which affected the total pile settlement and dictated that the pile length be kept to a minimum. Magnum Piering designed the helical piles to bear in the medium-dense sand with an anticipated installation length of 30 to 40 ft (9.1 to 12.1 m) below ground surface. Based on load testing, the installation criteria was revised to a length of 24 ft (7.3 m), or an installation torque of 12,500 ft-lbs (16,948 Nm).

Boring coverage (red pins) at and near the site, which includes 4-story building outline (red dashed line) (credit: https://earth.google.com/)

Helical Pile Load Test

Helical pile responses were similar even though the bearing layer had different torque values and the piles had different lengths. The 0.29 in (0.74 cm) of net deflection is the worst-case scenario and resulted in a 1.8 in (4.6 cm) horizontal offset at the top of the tower, relative to the base. The helical pile design vertical net deflection is 0.2 in (0.5 cm), which was projected by the structural engineer to result in a horizontal displacement at the top of the 80 ft (24.4 m) elevator shaft equal to 1.5 in (3.8 cm). Thus, the load per pile had to be reduced to 24 kips (107 kN), and additional piles were added.

Micropile Design Challenges

The micropile layout and design replaced the original 20 helical pile locations for stairway D. Nicholson designed the micropiles with 5.5 in (14 cm) diameter 80 ksi (552 MPa) mill secondary casing with a 5 ft (1.5 m) bond zone in rock. The micropiles were designed to be embedded in slightly weathered siltstone with compressive strengths ranging from 3,000 to 5,130 psi (20,684 to 35,370 kPa) to limit settlement. The design grout strength was 4,000 psi (27,579 kPa) and a #9 grade 75 ksi (517 MPa) all-thread bar was placed in the bond zone with a minimum 5 ft (1.5 m) overlap into the casing. Due to changes in bedrock elevation across the Strip District, the total length of the piles was determined in the field by the driller when they hit

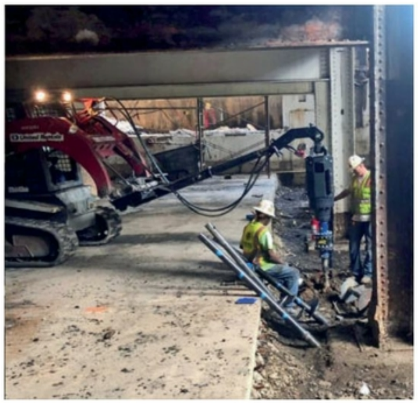
4-Story Design Challenges

Working in the basement of an abandoned 4-story building, the biggest challenge Magnum had was the low overhead clearance and tight working space between existing steel columns and temporary shoring. In addition, the interior piles had strict deflection criteria as they were used in conjunction with existing H-piles to support new 4-story stairwell and elevator shafts. The H-piles were considered rigid, and there was concern that the towers would cause significant horizontal offsets at the top relative to the base, should the piles have a net vertical settlement of more than 0.2 in (0.5 cm).

A total settlement criteria of not more than 1 in (2.5 cm) at two times the design load also had to be met. Total settlement is the result of both elastic pile shortening and soil deflection.

Test	Design Load, kips [kN]	Test Load, kips [kN]	Length of Pile, ft [m]	Torque at Bearing Layer, ft-lbs [Nm]	Deflection at Design Load, in [cm]	Deflection at Test Load, in [cm]	Elastic Deflection, in [cm]	Net Deflection at Design Load, in [cm]	Net Deflection at Test Load, in [cm]
Test 1	30 [133.5]	60 [267]	24.5 [7.5]	5,500 [7457]	0.39 [1]	0.84 [2.1]	0.10 [0.25]	0.29 [0.74]	0.74 [1.9]
Test 2	30 [133.5]	60 [267]	15 [4.6]	11,000 [14914]	0.39 [1]	0.84 [2.1]	0.10 [0.25]	0.29 [0.74]	0.74 [1.9]

Helical pile load test results



A skid steer with torque motor to install helical shaft

competent rock. The piles ended up being drilled 65 ft (19.8 m) from the ground surface.

The tight working space was the biggest challenge, and required temporary modifications to the drill mast during mobilization. At the time of micropile installation, the flooring above the stairway was cut out, which significantly helped with setting up the drill rig at the pile locations. The drill rig used had to be in the excavation to drill the piles, and the small area where the concrete slab was cut out made maneuvering the drill tedious.

CMC installation near 4-story building façade

Care had to be taken when cobbles and obstructions were encountered so that the drill casing did not kick out of alignment, which would have caused pile location tolerance issues. The down-hole hammer had no trouble getting past these obstructions, however.

Micropile Load Test

One maintained compression test was completed. It was a challenge to get the reaction piles and test pile aligned to have the correct spacing, while avoiding the production locations, and allowing a large enough area to support each end of the test beam. The final setup required approval to have the reaction and test pile spacing reduced to 6 ft (1.8 m). The ends of the beam then sat on the concrete slab on each end. The reaction anchors were prestressed so that the beam would not lift off the supported ends when the test was performed. The test was very successful and had less than 0.25 in (0.64 cm) of total deflection at the 200% test load (80-kip [356kN]); the net settlement was 0.03 in (0.08 cm).

Conclusion

Menard worked closely with the general contractor and structural engineer to successfully execute the ground improvement design and build the 5-story garage.

Menard, together with Magnum Piering (affiliated with Magnum Geo-Solutions), designed a helical pile system to support the 4-story stairwells, elevators and garage ramp. The subgrade was unexpected and had cobbles in some areas, and a weaker bearing stratum in others. The team quickly worked with the owners and determined the additional helical piles needed to meet the deflection criteria. Areas that were not penetrable with helical piles were switched to micropiles that were designed by Nicholson.

Approximately 62 helical piles were installed within stairwell A, the two central elevator shaft locations and the interior garage ramp, and 20 micropiles were installed in stairwell D.

The teamwork of the three companies and the owners led to cost-effective solutions to complete the project in a safe and timely manner.

Micropile installation within 4-story building

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