Completed excavation

Hybrid Shoring Design for an Urban High-Rise Tower

Construction is underway on a 40-story high-rise apartment building development at 815 Pine Street — a tight urban site in downtown Seattle, Wash. With five levels of below-grade parking, the maximum depth of excavation was 62 ft (19 m) below the ground surface. Soil conditions were favorable and consisted of surficial fill and glacially consolidated silt, sand and gravel, with cemented zones and limited groundwater. The soils were generally intact, hard or very dense, and had a reliable record of laboratory information and performance data from nearby sites.

Unique development restrictions existed on all four sides of the site, located at the southwest corner of 9th Avenue and Pine Street in Seattle. On the north side of the site, a cut-and-cover transit tunnel was located below Pine Street extending to a depth of 41 ft (12.5 m) below site grades and was located approximately 15 ft (4.6 m) away from the site property line. On the west side, separated from the 815 Pine building by a 16 ft (4.9 m) wide alley, was the 23-story 801 Tower building, which was constructed in the 1970s with three below-grade levels and a spread foundation extending approximately 40 ft (12.2 m) below alley level. The Washington State Convention Center was located immediately adjacent to the south site boundary. Eighth Avenue, located to the east of the site, was relatively narrow thus limiting the available length of tieback anchors. Subgrade utilities including electric duct banks, electric vaults and sewer lines were present in the right-of-ways near the excavation, as is typical of urban sites.

Due to the site constraints, traditional shoring solutions were not possible. The presence of the 801 Tower basement and the cut-and-cover transit tunnel precluded the use of conventional soldier pile and tieback shoring on the north and west walls, as the existing structures were an obstruction to tieback anchors. On 9th Avenue, tieback anchors and soldier piles could not be designed with standard unbonded zone designs because of the narrow right-of-way. On the south wall, the planned excavation would expose nearly the full drilled shaft foundation supporting the convention center. To address the unique site shoring constraints, the project team employed a series of innovative solutions to enable the project to be constructed using conventional shoring elements without internal bracing.
The solution (and preferred alternative to expensive internal bracing) was an extensively modeled and monitored hybrid shoring system combining elements of both a soil nail wall and a soldier pile and tieback wall. GeoEngineers, Inc. and KPFF Consulting Engineers designed a similar shoring system for the nearby Olive 8 development, which was the first project to use this hybrid approach. For 815 Pine, the soldier piles consisted of W24x162 rolled sections installed in 3 ft (0.9 m) diameter predrilled shafts backfilled with concrete. The soldier piles were installed at a center-to-center spacing of 8 ft (2.4 m). Soil nails consisting of #10 threadbar grouted in 6 in (152 mm) diameter holes were installed between the soldier piles starting from just below the utilities and extending to a depth of 35 ft (10.7 m) below surface grades. The nails were spaced 3 ft (0.9 m) vertically and 4 ft (1.2 m) horizontally and were 15 ft (4.6 m) long and installed on a 15 degree angle.

Below the soil nails were tieback anchors inclined 25 to 31 degrees extending below the 801 Tower and Pine Street Stub Tunnel foundations to support the lower soil and surcharge loads from the foundations above. The soil strength and stiffness values were selected based on experience, laboratory tests completed at the site and nearby sites in similar soils, and published correlations. The model was also calibrated to the site conditions using recent load and deflection measurements from a nearby site in similar soils. Finally, the team conducted a parametric study to assess the effects of changes in the input soil properties and to optimize the design of the structural elements.

Numerical modeling is a powerful tool for evaluating the sensitivity of the shoring system to the various input parameters.
Construction Procedures

Shoring installation was completed by Malcolm Drilling Company, Inc. between September and December 2012. Construction began with the soldier pile installation. Given the nature of the consolidated silt soils and lack of significant groundwater, an open hole drilling method was selected. Malcolm utilized a Bauer BG-20 top drive drill rig to install the piles along the right-of-ways. The competent soils allowed them to drill and install between 600 and 650 ft (183 and 198 m) of soldier pile per day. Once the perimeter piles were installed, 18 ft (5.5 m) of shoring and excavation was required to expose the foundations for the convention center. Malcolm mobilized a Watson 2500 drill rig to assist the BG-20 installing the underpinning piles along the convention center. Malcolm began each underpinning pile by slant drilling with the BG-20 to the tip of shaft and followed with the Watson to ream the back of the shaft for the pile installation. This 2-rig combination allowed Malcolm to leverage the BG-20’s speed and torque capacities in conjunction with the Watson’s flexibility.

Following soldier pile installation, Malcolm continued installation of the shoring system consisting of soil nails and tiebacks for lateral support and wood lagging and temporary shotcrete for excavation support. The soil nails and tiebacks were installed in 6 in (152 mm) diameter holes utilizing a Davey 725 Drill.

Aside from the underpinning piles, one of the biggest challenges was removing the soil from the site. The footprint of the excavation was small at approximately 13,000 sq ft (1,208 sq m), and considering the 62 ft (19 m) depth, the site could not easily be excavated from the surface. To increase efficiency, two soil conveyors were placed inside the excavation to transfer the material into the staged dump trucks. Although the two conveyors added to the site congestion, close coordination between Malcolm and the earthwork contractor, JR Hayes & Sons, resulted in minimal impacts.

Monitoring and Performance

In addition to optical survey monitoring of the wall and surrounding site features required by the City of Seattle, the instrumentation program consisted of four inclinometers: two on the west wall and one each on the north and east walls.

Underpinning shoring was installed below the convention center grade beams and adjacent to the existing drilled shafts, both to maximize the usable space in the 815 Pine basement and to control deflections of the convention center. Soldier piles supported the loads from the convention center perimeter foundations in compression, and the tiebacks resisted the earth pressure, building slab and internal footing surcharge loads. Less than 0.5 in (13 mm) of lateral or vertical deflection was recorded by the optical survey, and no cracking was observed on the exposed convention center wall or the internal floor slab.

The soldier piles and the hybrid shoring wall initially deflected in a typical cantilever shape in the upper region. In the zone of soil nailing, the deflections were smaller, suggesting that the nails had the desired effect of reinforcing the soil and causing it to behave as a block. When the excavation reached a depth of approximately 30 ft (9.1 m), an increase in deflection was observed as the excavation progressed below the depth where preloaded struts from Pine Street Stub Tunnel cut-and-cover excavation were
The success of the shoring system was strongly influenced by a collaborative relationship between the geotechnical engineer, structural engineer and shoring contractor. This relationship allowed for constructability experience from the shoring contractor to be incorporated into the design. Additionally, key factors influencing the performance of the shoring system were discussed as a team prior to construction—this collaboration also attributed to the success of the shoring system.

Acknowledgments
The owner and developer of the 815 Pine project was Holland Partners. The general contractor for the project was Holland Construction and its shoring subcontractor was Malcolm Drilling. KPFF Consulting Engineers was the shoring designer and GeoEngineers, Inc. was the geotechnical engineer.

Conclusions
The hybrid shoring system successfully retained the soil, utilities and building surcharge loads. In favorable ground conditions, the hybrid shoring approach is a viable alternative that can save considerable construction costs compared to internally-braced shoring systems. Measured deflections on the hybrid walls were less than the 1 in (25 mm) requirement from the City of Seattle, and were close to the deflections predicted by the model. The soil parameter selection for the numerical modeling for this project was supplemented by local experience, tieback stressing data in similar soils and calibration of the numerical model for the nearby Olive 8 project, which employed a similar hybrid shoring system.

Finite element modeling of complex soil structure interaction situations can be completed reliably. An important step to success is carefully calibrating the model to the specific site soil parameters. Additionally, numerical modeling is powerful in evaluating the sensitivity of the shoring system to the various input parameters.

Underpinning of the drilled shaft-supported convention center building was successfully completed by transferring the drilled shaft loads into slant-drilled underpinning soldier piles. A structural connection consisting of large diameter steel bridge pins and a reinforced concrete cap assembly was effective in transferring the drilled shaft loads into the underpinning soldier piles.

Inclinometer results along the north wall