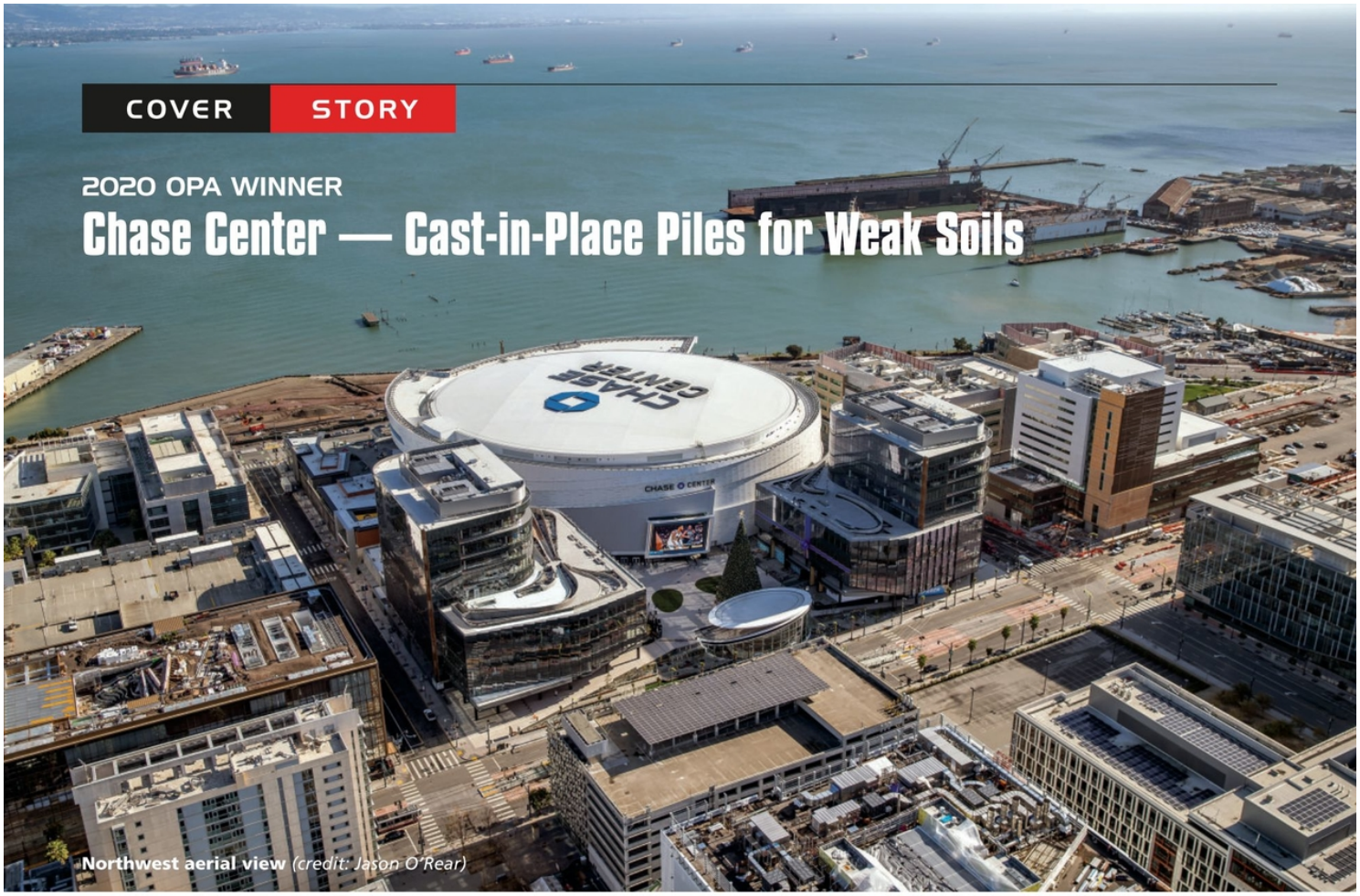
COVER STORY

2020 OPA WINNER

Chase Center — Cast-in-Place Piles for Weak Soils



Northwest aerial view *(credit: Jason O'Rear)*

Chase Center opened in the San Francisco Bay Area in fall 2019 to provide the home court of the Golden State Warriors. The 18,000 seats at the world-class sports and entertainment center also are used for concerts by the likes of Metallica, Eric Clapton and Janet Jackson. In addition, specialty stores and restaurants occupy the facility on four city blocks in the Mission Bay district, which evolved long ago from its shallow bay origin.

What's above ground at Chase emerged after a 30 ft (9.1 m) excavation that was unprecedented in Mission Bay for its depth and size. The 2-plus years of construction involving Langan Engineering and Environmental Services and colleagues addressed poor ground conditions that presented challenges for designing foundations, supporting the excavation, dewatering and maintaining a stable subgrade.

Subsurface Conditions

Site challenges stemmed from the area's origin as a shallow bay, which was reclaimed from about 1860 to 1910 by importing thousands of cubic yards of sand, rocks and dirt — much of it debris from San Francisco's 1906 earthquake. Today, the subsurface consists mainly of fill, Bay Mud, Colma Formation sand, Old Bay Clay and Franciscan Complex bedrock, and has a significantly variable profile across the site.

The site fill extends 9 to 32 ft (2.7 to 9.8 m) as a thick, heterogeneous composition of loose to very dense sands and gravels, soft to stiff clay, brick, rubble and rock — ranging from cobbles to boulders. The thicker fill encountered adjacent to thinner fill was indicative of a mud wave. Such waves can occur when heavy fill loads have been placed atop weaker Bay Mud, causing a bearing-capacity failure. As the Bay Mud fails, the fill sinks into the soil and Bay Mud pushes up around the failure zone, causing the thick-and-thin fill profile. At the same time, the mud mixes with fill, creating zones that include soft clay.

Bay Mud, a second layer about 2.5 to 45 ft (0.7 to 13.8 m) thick, is a very soft to medium-stiff weak compressible marine clay. In contrast, the Colma Formation that forms the fourth layer is a medium-dense to very dense sand with varying fines content. Below the Colma Formation is an overconsolidated, stiff to hard marine layer known as Old Bay Clay, approximately 6 to 21 ft (1.8 to 6.4 m) thick. Bedrock, consisting of serpentinite, greenstone, shale and claystone of the Franciscan Complex, occurs from 33 to 130 ft (10 to 39.6 m) deep. The bedrock is crushed to intensely fractured, soft to moderate hard, and friable to weak, with deep to moderate weathering.

Groundwater, which is shallow, was typically encountered 6 to 12 ft (1.8 to 3.7 m) below the surface. With the site so close to San Francisco Bay, the groundwater is influenced by tidal action, creating additional construction difficulties.

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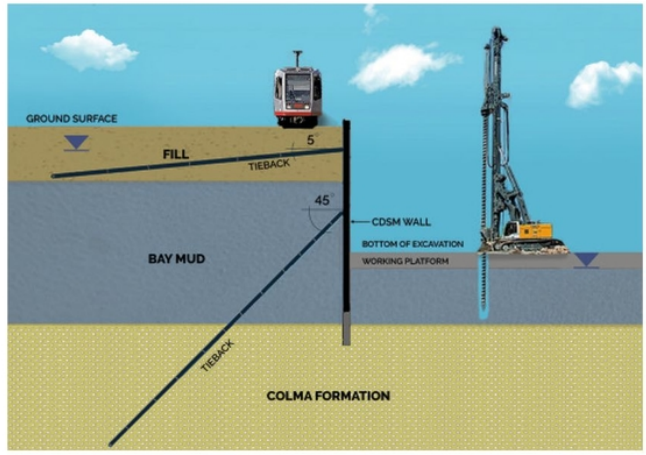
Construction Challenges

In addition to poor subsurface conditions, construction constraints from the neighborhood included light-rail trains running along Third Street on the west side of the site and a UCSF Medical Center hospital kitty-corner from the site. Also, the neighborhood is a biotech hub with nearby buildings that contain sensitive equipment. Therefore, noise and vibrations were restricted to typical construction levels.

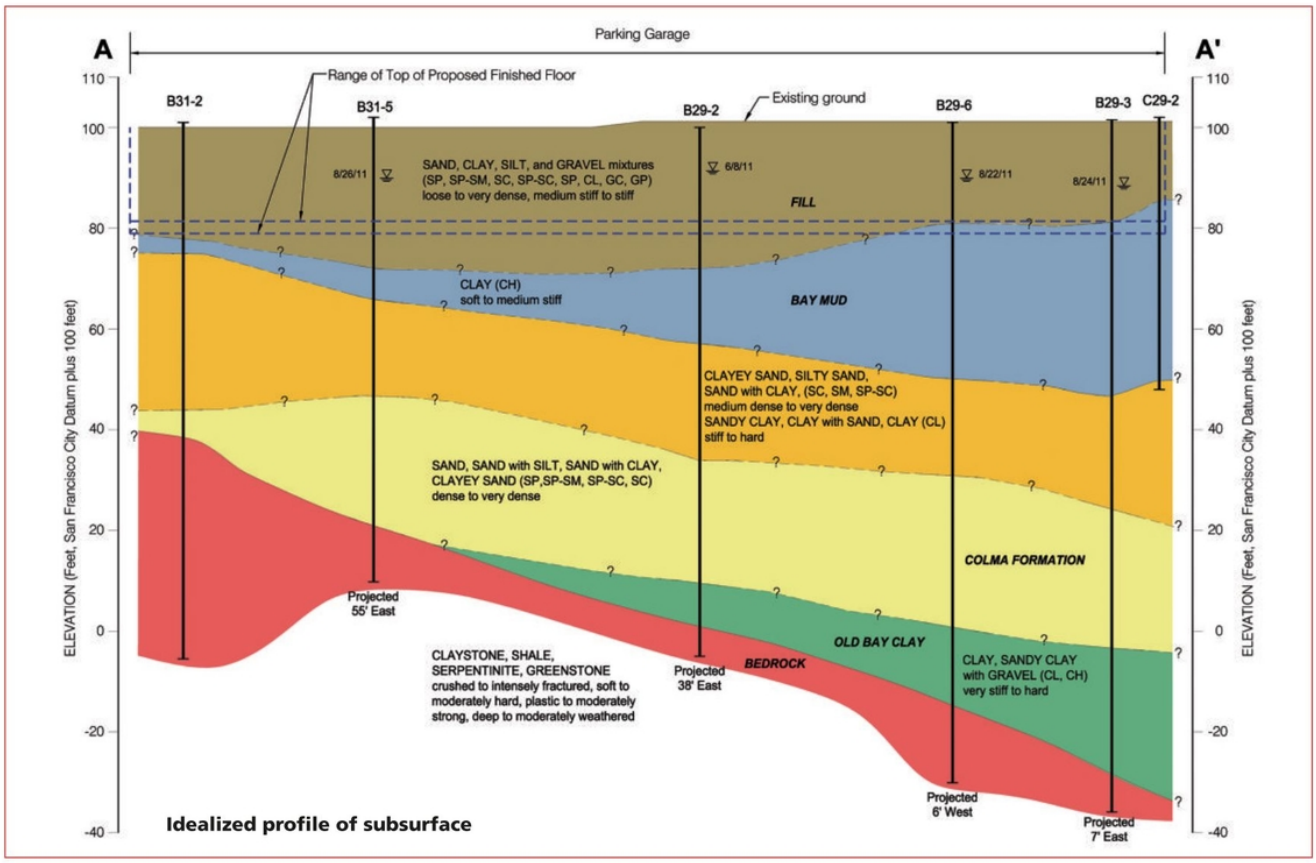
Because of the variable subsurface fill, soft clay and shallow groundwater, the structure needed deep foundations that extended into bedrock to gain adequate capacity. Most feasible was a cast-in-place deep foundation system that could be cased to maintain the shaft openings in loose fill and soft clay. In addition, the foundation contractor, Malcolm Drilling, had to adjust foundation lengths on the fly to account for hardness and variations in the depth to bedrock.

Augered cast-in-place (ACIP) piles were the most feasible and economical foundation type; but where loads of the arena core were high and significant uplift resistance was required, foundations had to reach far enough into rock to develop sufficient compression or uplift capacity. Achieving the uplift capacity was particularly difficult where bedrock was shallow and the overburden inadequate to provide much uplift resistance without a significant rock socket. As a result, Malcolm proposed a 'hybrid' foundation solution in which drilled shafts with rock sockets were used about one quarter of the time, when ACIP piles could not develop adequate capacity. This value-engineered solution not only addressed uplift capacity efficiently, but also ensured meeting a tight construction schedule despite potential ground condition difficulties.



Excavation support from tied-back cutoff wall

The 30 ft (9.1 m) deep excavation — the deepest yet in Mission Bay — extended into weak Bay Mud, requiring a shoring system designed to provide adequate support. The shoring also had to provide groundwater cutoff to maintain a dry excavation and prevent the groundwater level outside the site from dropping. Because of the compressible Bay Mud, lowering the groundwater beyond the site's limits could have caused settlement of nearby improvements—including the light-rail tracks. The excavation was supported using a tied-back, cement deep soil-mixed (CDSM) cutoff wall. Low resistance of the fill and Bay Mud, however, made it difficult to adequately restrain the shoring.



Idealized profile of subsurface

Throughout the majority of the site, the excavation bottomed in the Bay Mud, which could not support the excavation equipment, including the rigs used to install ACIP piles and drilled shafts. So, a working platform was installed.

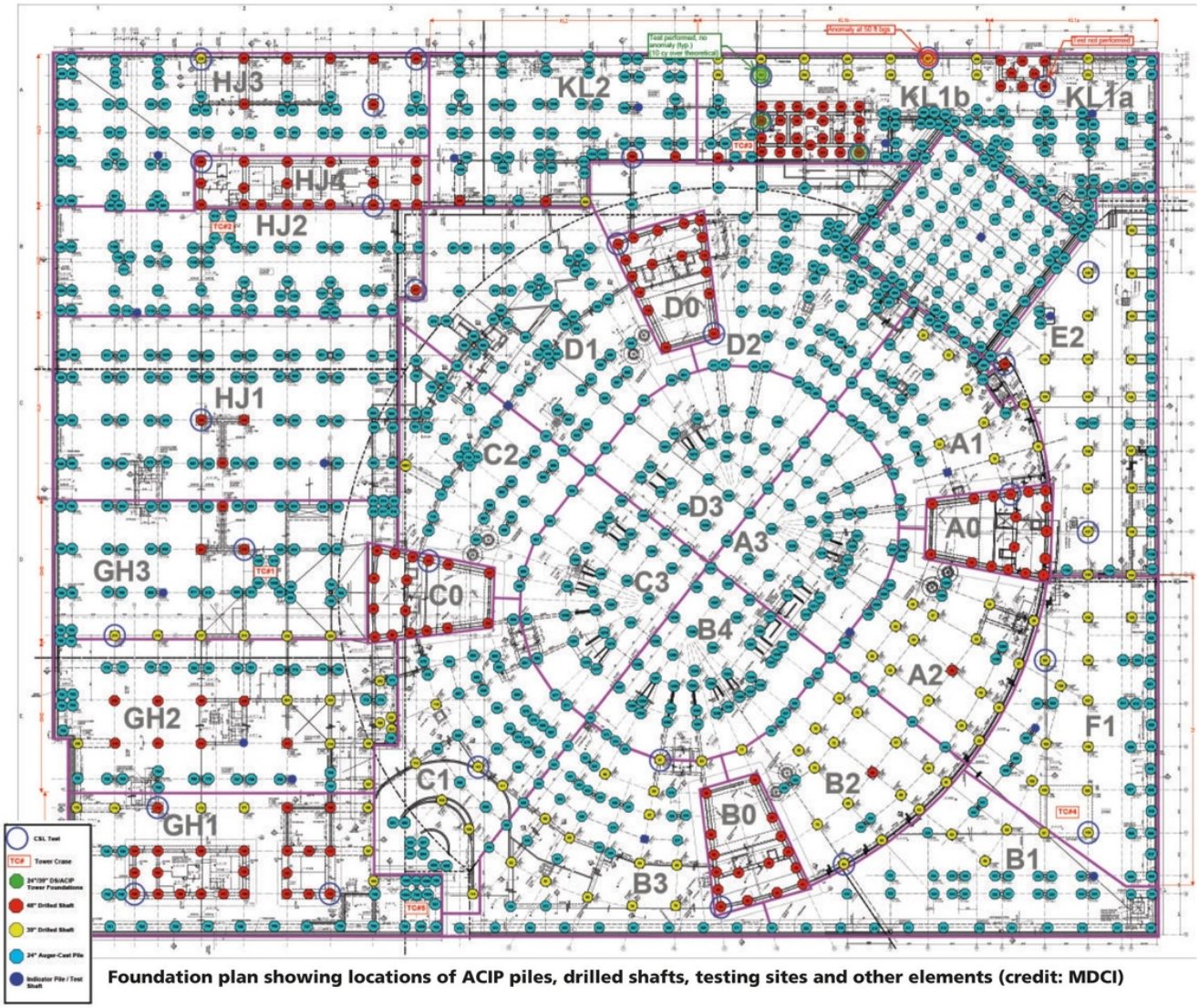
As with most sports facilities, opening day was a non-negotiable completion date: the Golden State Warriors had its first home basketball game set for October 24, 2019. Therefore, geotechnical issues had to be overcome within 33 months of groundbreaking to meet the tight schedule.

Because of the complexity of the project, an extraordinary number of brainstorming sessions and regular meetings were held to problem solve with the owner, owner's representative, design team, general contractor joint venture, and specialty shoring and foundation subcontractors.

One of 10 ACIP dynamic load tests

Deep Foundation Testing

For the deep foundations, drilled shafts were used at the heavy arena cores and where ACIP piles could not provide uplift resistance in shallow bedrock. More than 1,000 ACIP piles were also used. To start, an indicator pile and a load test program were used to confirm constructability and capacity of both foundation types. This test program was designed to provide enough data to make decisions when installing production piles in the variable subsurface conditions throughout the site — while keeping cost in mind. Indicator piles were installed in production locations so they could be used for structural support. Some of the test piles, however, were placed in nonproduction locations so they could be tested to failure, and were not reused.



Foundation plan showing locations of ACIP piles, drilled shafts, testing sites and other elements (credit: MDCI)

One drilled shaft was installed and tested using bidirectional load test methods, with pairs of strain gauges included to provide data in each soil stratum. This test shaft was 48 in (122 cm) in diameter in soil and 42 in (106.7 cm) in diameter in rock, with a 58 ft (17.7 m) long rock socket. Sonic caliper testing and crosshole sonic logging were performed. The shaft was loaded to 3,377 kips (1,532 m ton/megagram), at which load the pile deflected 0.65 in (1.7 cm) upward and 0.2 in (0.5 cm) downward. No downward failure was observed. Strain gauges embedded in the shaft were used to determine frictional resistance in the various soil layers and in bedrock.

Twenty-five indicator ACIP piles were installed to evaluate the ability of the equipment to install at least 10 ft (3 m) into bedrock. The ACIP load test program consisted of 3 static compression, 3 static uplift and 10 dynamic load tests, all of which confirmed that the planned 10 ft (3 m) of rock embedment was enough to support the design loads.

Design and Construction

Based on test results, the foundations for production consisted of:

- 1,019 ACIP piles with 10 ft (3 m) of embedment in bedrock and allowable axial compression capacities of 350 to 900 kips (159 to 408 m ton/ megagram) applied in eight zones based on the thickness of various soil layers and the depth-to-bedrock capacity. Pile lengths are 50 to 145 ft (44 m).

Installing drilled shafts and ACIP piles

- 314 drilled shafts that are 39 to 48 in (99 to 121.0 cm) in diameter in soil and 36 to 42 in (91.4 to 106.7 cm) in diameter in rock, with 12 to 65 ft (3.7 to 19.8 m) long rock sockets and allowable axial compression capacities of 750 to 3,000 kips (340 to 1,361 m ton/megagram) applied in 12 capacity zones, based on soil layer thickness, the depth to bedrock, and the rock-socket length. Drilled shaft lengths are 45 to 170 ft (13.7 to 51.8 m).

The foundations were constructed over about four months using as many as four foundation rigs working simultaneously each day. Because of the extreme variation in subsurface conditions, the total length of piles and embedment in bedrock had to be identified case by case during construction. Langan developed a decision matrix for each field representative to determine, in real time, the required length and rock embedment to achieve the required capacity. The team knew that foundation lengths could not be planned in advance, and Malcolm Drilling was able to adjust cage length on the spot as pile lengths were determined.

Support of Excavation

The design and construction of the tied-back CDSM cutoff wall was constrained by shallow groundwater, poor fill and weak Bay Mud. And, because of the variable soil conditions throughout the site, lateral earth pressures were developed for design of the various shoring systems in zones around the site, allowing the shoring to be designed for specific conditions in each zone.

The perimeter shoring included 3,200 lft (0.98 lkm) of CDSM wall. Over two-and-a-half months, the CDSM panels were installed using a triple-axis soil-mix rig. The panels terminate in Bay Mud, stiff clay or bedrock, depending on the depth of excavation and soil conditions required in each part of the site to create groundwater cutoff. A total of 730 soldier piles were installed from 25 to 75 ft (7.6 to 22.9 m) of depth. Also, because of the various sizes of debris found in the fill, extensive predrilling and pretrenching were performed before the CDSM panels were installed.

Because Bay Mud could only provide low resistance, the lateral restraint system was designed to avoid relying on the mud. The system consisted of tiebacks installed at a very shallow angle (10 degrees) to remain in the fill, and tiebacks installed at a very steep angle (up to 45 degrees) to dive through the Bay Mud and into the dense sand of the Colma Formation — and sometimes into bedrock. A total of 1,200 tiebacks were installed, with lengths of up to 100 ft (30.5 m).

Depending on the depth of excavation and soil conditions behind the wall, as many as three rows of tiebacks were installed. Up to three rounds of post-grouting were performed in tiebacks installed into the loose fill. Where the fill included soft clay (likely from historical mud waves), additional tiebacks were needed to develop sufficient restraint. Installation of tiebacks in the fill was difficult during rising tides when significant groundwater intrusion shot through the drilled hole, like a fire hose! To mitigate this problem when possible, the schedule was adjusted to install tiebacks that were near the bay during ebb tides.

Working Platform

Wet and weak fill and Bay Mud were exposed throughout most of the bottom of excavation, where construction equipment would apply pressures as high as 4,500 to 6,000 psf (215 to 287 kPa). Recognizing that a stable and dry bottom was critical for the success of deep foundation construction, a working platform was designed and constructed using a decision matrix, depending on the anticipated loads and actual site conditions. The working platform consisted of layers of Tensar TriAx TX130S Geogrid and 3 to 4 ft (0.9 to 1.2 m) of cement-treated fill or 3 to 6 ft (0.9 to 1.8 m) of lime-treated Bay Mud. This working platform also served to resist hydrostatic seepage during construction and helped maintain a mostly dry bottom of excavation.


Installing a deeper, steeply angled tieback

Construction Coordination

The management and coordination during several stages of construction was logistically complex because of several operations taking place simultaneously at the site each day, including tieback installation and testing, excavation, deep-foundation installation, and basement and core construction. Up to four ACIP and drilled-shaft rigs with support cranes and other equipment were installing deep foundations, while three tieback rigs worked their way around the perimeter. As many as seven field inspectors were on site observing the geotechnical aspects of the foundation and shoring installation and testing.

Conclusions

Chase Center design and construction was successful despite time constraints and complicated site conditions because of the collaboration and commitment of the entire project team. Even through challenges, the project team's innovation through partnership allowed the on-schedule completion of the state-of-the-art facility. Site challenges included:

- Developing foundations to provide adequate compression and tension support, especially where bedrock is shallow and the arena core loads would be high. A combination of large-diameter drilled shafts and ACIP piles was used for foundation support.
- Overcoming poor soils with a support-of-excavation system involving a laterally restrained CDSM cutoff wall along the entire perimeter. The perimeter shoring system included tiebacks in the fill, Bay Mud, and deeper dense sand of the Colma Formation and bedrock.
- Overcoming groundwater intrusion issues. The CDSM cutoff wall also cut off groundwater into the excavation. The CDSM panels extended into the low permeability Bay Mud to cut off groundwater.
- Overcoming the low bearing capacity of Bay Mud at the bottom of excavation. A stabilized working platform was constructed to support deep foundation equipment and to resist hydrostatic seepage during construction.

Acknowledgements

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