Artist's rendition – IMP entrance

The Keys to Success in Waikiki

For decades, the International Market Place (IMP) has been an icon in the heart of Waikiki in Honolulu, Hawaii. It was famous for Duke Kahanamoku's restaurant where people flocked to hear Don Ho sing in the '60s and '70s. Later, it was a bustling, open-air hub of small vendors who peddled everything from Hawaiian souvenirs and jewelry to food court meals and farmer's market produce. Small buildings and shacks that housed the businesses were located on a curved tract of land — just one block off the beach — that stretches from Kalakaua Avenue to Kuhio Avenue. The entrance to the complex is dominated by a huge, old (circa 1850) Banyan tree. This tract is owned by the Queen Emma Land Company. Queen Emma was a Hawaiian Queen from the 1800s. Revenue from the land has supported the Queen's Medical Center in Honolulu for decades.

The reimagined IMP is owned by Taubman Centers, of Bloomfield Hills, Mich., and CoastWood Capital Group of San Francisco, Calif. The IMP will offer a distinctive collection of upscale fashion and lifestyle retailers, including Hawaii's only Saks Fifth Avenue store, as well as ten sit-down restaurants, including concepts by award-winning chefs Michael Mina and Roy Yamaguchi. The mall features two large open-air courts, the first of which has the huge Banyan tree as its entryway centerpiece. The second open-air court, called Queen's Court, includes a stage and mature monkeypod trees and a few palm trees.

Foundation Selection

After a geotechnical exploration that was directed by SME, Plymouth, Mich., and performed by Geolabs, Honolulu, it was discovered that the historical site had hidden and challenging foundation conditions. The subsurface conditions included a very deep but now in-filled ancient river valley containing more than 180 ft (54.9 m) of lagoonal deposits consisting of normally consolidated plastic clayey silts and silty clays with blow counts mainly varying in N-value from 1 to 6. The silt was underlain by several soft coralline layers, some overconsolidated clays and various basalt layers. The static groundwater level on the site was at a depth of about 5 ft (1.5 m), closely matching sea level.

Although driven piles had previously been used as the preferred deep foundation support for adjacent structures, this area of town is now fully developed and local noise ordinances preclude their use. Augercast piles were initially considered, but when the general contractor dck/FWF, Pittsburgh, Pa., asked for bids for the augercast piles, several foundation contractors offered alternate systems. The practical installation depth of augercast piles was limited and due to the depth of the in-filled alluvial valley, this system could likely have left soft silt below the tips of the piles over much of the site.

AUTHORS Alison Savage, P.E., and Michael Terry, P.E., Hayward Baker Inc.

Additional geotechnical investigation and settlement modeling predicted that augercast pile settlements could exceed 12 in (305 mm), rendering that option untenable. Drilled shafts were also proposed and considered. Due to cost, schedule advantage and technical merit, a micropile option proposed by Hayward Baker was selected. A particular design consideration was elastic deflection. With a 300 kip (1,334 kN) working load and anticipated micropile depths that might exceed 235 ft (72 m), elastic deflections of 2 in (51 mm) were predicted. These anticipated deflections were modeled and accounted for by the structural engineer in the final design.

The structural engineering design for the IMP project, by Ludwig Structural Consultants, Seattle, Wash., required approximately 700 micropiles. Using a highly-efficient design, compression loads were resisted using 300 kip (1,334 kN) and 200 kip (890 kN) micropile elements. The micropile foundation elements consisted of flush-joint threaded 7-5/8 in (194 mm) and 5-1/2 in (140 mm) OD steel pipes, grade 80 ksi (551 MPa), with all-thread bar reinforced bond zones. The bond zone sockets were founded in dense soil or rock located beneath the lagoonal deposits. The bond zones were reinforced with 2-1/4 in (57 mm) or 2-1/2 in (64 mm) diameter all-thread bars, grade 150 ksi (1,034 MPa). The larger piles had nominal working load capacities of 300 kips (1,334 kN) in compression and 154 kips (685 kN) or 200 kips (890 kN) (where necessary) in tension and also 10 kips (44.5 kN) of lateral resistance. The smaller piles had working load capacities of 200 kips (890 kN) in compression and 75 kips (334 kN) (where necessary) in tension and 15 kips (67 kN) of lateral resistance. Micropiles with pipe joints in the upper 8 ft (2.4 m) of the pile required special reinforcement. Tension piles required full-length all-thread bars. A 1/8 in (3 mm) corrosion reduction in the steel pipe thickness was included in the micropile design as agreed with by the owner and structural engineer. Although no particularly aggressive soils were noted, the site was very close to the beach and salt water.

A working bond strength of 55 psi (380 kPa), with a factor of safety of two, was selected for the design. This resulted in a nominal bond zone length of 25 ft (7.6 m) for both types of piles; note that the smaller piles were installed in smaller drill holes. This bond length was derived from 'hard drilling' soils and rocks. It was noted that there were often softer zones intermixed in the profile. Hayward Baker used a proprietary Data Acquisition System (DAQ) to develop a 'Drilling Index,' which was used to identify and quantify the denser soils, capable of achieving the required design bond stress. Two drill rigs were outfitted with this equipment, and this information was discussed and shared with all of the drillers on the project. This in-situ testing resulted in real-time engineering decisions to extend many of the bond zones through soft soil pockets in the highly variable soil profile, resulting in some deeper and longer bond zones.


Aerial view of IMP site

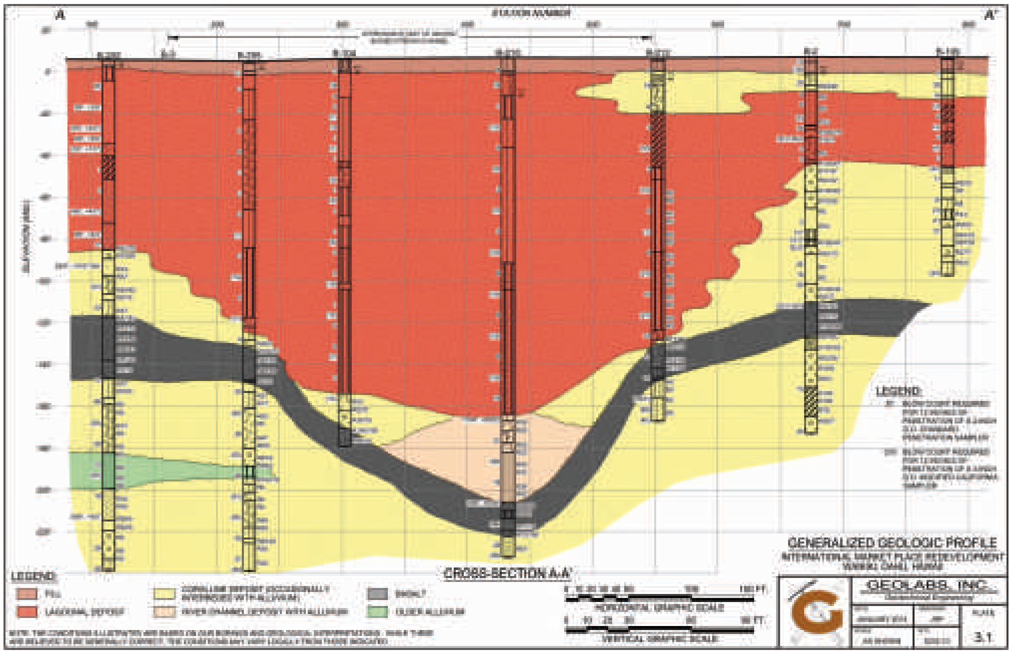
Load Testing Program

Due to the difficult drilling conditions and unknown nature of the cement grout bonding characteristics expected for the complex subsurface strata, an initial load testing program was included in the scope of work. The load tests were performed prior to full mobilization and were primarily located on the northern side of the site to coincide with the demolition and hazardous materials abatement schedule. Initially, six tension load tests were performed on isolated bond zones to confirm the design bond strength followed by two full-scale compression verification loads tests. The lengths of the tested piles ranged from 84 ft (25 m) to 204 ft (62 m) and they were positioned to analyze data from both within and outside the alluvial valley. Tension testing was selected for the majority of the initial test program and for the proof tests on production piles due to ease of test pile set up and reduced cost.

DAQ equipment was used during the installation of test program piles. The DAQ system was used for real-time monitoring to measure drilling parameters including depth, rotation speed, crowd pressure and flow rate. These parameters were then processed to create a depth-based drilling index and drill logs as a means to directly measure the quality of the bonding strata by drawing comparisons to test results and the adjacent boring logs.

The test program yielded good results that indicated ultimate bond strength capacities just in excess of design requirements. Some of the test piles showed acceptable but larger than expected deflections up to 3-1/4 in (83 mm) at design load.

Five percent of the production micropiles required proof testing according to the specification. The proof test piles were identified by the owner's representative. Full-length bars were installed at proof test pile locations during construction to allow for tension testing. Thirty-five proof test piles, tested to 1.33 over the design load, were all successfully verified by tension testing over the course of the project, in various areas of the site. Twenty-seven of



Generalized north-south geologic profile of the site

the 300 kip (1.334 kN) piles and eight of the 200 kip piles (890 kN) were tested. These piles varied in length from 133 ft (40.5 m) to 253 ft (77 m). The average deflection at design load for the proof tested piles was 1.22 in (31 mm). The use of tension testing provided a significant cost savings when compared to full-scale compression testing of the 35 piles.

Micropile Production for the Main Structures

Prior to preparing pile cap locations for micropile drilling, each site was investigated for historic 'iwi,' Hawaiian for 'bone' or human remains. The project team was aware of the presence of ancient Hawaiian burial sites near the large Banyan tree and possibly elsewhere on the site. All excavations were monitored and checked by a native Hawaiian cultural representative and then backfilled and marked as clear.

The production plan included the use of up to six drill rigs with one spare on site to meet the project schedule. A Casagrande C14 as well as Comacchio MC-22s and MC-28s were used to install the piles. The micropiles were installed by first flushing the outer casing into the ground using water. The starter pieces of casing had 'J' shaped carbide-tipped drill teeth welded to their end sections. Taking note of the typical depth to bond zone soils/rocks in the vicinity; the outer pipes were flushed to refusal or about 10 ft (3 m) above the bond zone materials. An inner string of drill rods was then added with roller bits and extended 1 ft (0.3 m) in front of the pipe casing. The remainder of the pile, and particularly the bond zone, was duplex drilled using this arrangement. Typically, 20 ft (6 m) tooling was used. Drill pipe and rods were added using a rod handler mounted on an excavator at each drill rig. After reaching design depth, the inner drill string was pulled and the interior all-thread bar was set to the bottom of the pile along with a flexible tremie pipe. The piles were pumped full of grout from the bottom up. Due to the great length of the micropiles, and the permeable nature of the coralline and basaltic rocks, average grout takes were on the order of 124 cu ft (3.5 cu m) per pile. An automated batching facility was set up on site. The grout mix was made using bulk Portland cement delivered and stored in silos. A water-cement ratio of 0.45 was used, along with a water reducer/superplasticizer. The design grout strength was 4,000 psi (27.5 MPa). Only two samples failed to reach this strength over the entire project. The potable water used was often very warm and when water temperatures above 95 degrees F (35 degrees C) were noted, some flash setting was observed. Adding ice to the mix or a water chiller was considered but geothermal cooling was utilized instead.

During drilling, several deeper soft soil zones were discovered. Due to this, some micropile lengths exceeded 300 ft (91 m) in one area. A total of 698 micropiles were installed for the project. Of this total, 485 micropiles with 300 kip (1,334 kN) capacity were installed, with 35 having a tension capacity of 154 kips (685 kN) and 10 piles requiring a 200 kip (890 kN) tensile capacity. Also 162 micropiles with a 200 kip (890 kN) capacity were installed. A total of 115,040 linear ft (35,064 m) of micropiles were installed on the project including approximately 85,700 cu ft (2,426 cu m) of Portland cement grout with an average pile length of 165 ft (50 m).

Production micropile drilling

Most of the piles were installed in unlimited headroom but some micropiles were installed in reduced headroom (20 ft [6 m]) beneath the Banyan Tree. At those locations, a Comacchio MC-602 drill rig was used in the lowest overhead conditions. In addition, the tree roots were carefully investigated and trimmed sparingly by a specialist.

Micropile installation logs were kept for every pile. The logs contained all of the pertinent information for the pile, including the driller's name and simple description of details observed during drilling. Logs include the date, pile number and location, the required installation elevations of the top of pile, the steel pipe and all-thread bar sizes and lengths, the grouting records including admixtures and material lengths used and any additional comments. The details of the installation log were independently recorded and verified by Geolabs and then translated to a digital database. All data and installation logs were provided weekly to the design and construction project team and discussed at weekly design meetings.

The DAQ system, which was calibrated during the test program, was used as a quality assurance measure throughout the project. The DAQ equipped drill rigs were predominantly the first to explore new areas of the site. They confirmed the depth and bond layer consistency based on the drilling index values. In cases where anomalous conditions were discovered by a non-DAQ equipped drill rig, the adjacent pile was installed with a DAQ equipped rig to better understand the subsurface conditions. The DAQ system allowed real-time decision making by the internal design team and quality assurance that the piles had been installed to the appropriate depth and bond length. This DAQ capability also created a more transparent relationship with the client who shared in the risk related to the variation in quantity of pile depths.

Trouble in Paradise

After approximately 80 percent of the project was completed, Hayward Baker's field team noted an unusual phenomenon regarding the grout within the cased portion of the micropile. Throughout the project it was not unusual, after completion of grouting to the top of the casing, to see some drop of the grout within the micropile permanent casing. As long as the grout did not drop below a threshold value, predetermined based on the cased length of the pile, the fall in grout level was not concerning. Typically the grout level within the pile was measured after installation and the pile was topped off with grout as soon as possible. However, there was an observed case where after completion and the initial grout drop measurements were taken, the grout level rose up significantly overnight.

After extensive additional study and discussions with the project team, artesian water pressure was ultimately blamed for the problem. The areas around Waikiki are surrounded by hills and mountains. Many lava tubes exist on the islands that could possibly connect with the higher ground. It was discovered later that the word "Waikiki" in the Hawaiian language comes from 'Wai,' meaning 'fresh water' and 'kiki,' meaning 'shooting up from the ground!'

Remediation of Suspect Micropiles

After this 'grout rise event' was noted, the installation records for each pile were examined by the internal design team and cross analyzed by the project team. Additional piles were identified using criteria related to grout level measurements, grout volumes and groundwater to grout head depth ratio. Each pile identified using this comprehensive analysis was drilled out and investigated, except a select few which were replaced without investigation per access restraints. The vast majority of the installed piles were without anomaly and without concern of being affected. Of the suspect piles identified, several were found to have bond zones with anomalous grout that were partially or completely washed out. After any required consolidation grouting, the reinforcing bars were reinstalled and the micropiles were tremie grouted. An additional 10,300 cu ft (291 cu m) of grout was installed during the remediation of the affected micropiles, including the required consolidation grouting.

Observing a micropile load test


Micropile drilling under the Banyan tree

Tremie grouting a micropile

At the time of this discovery, Hayward Baker had already begun scaling back resources on site due to the limited areas available for work around the other ongoing construction activities. The planned demobilization was halted and additional resources were quickly mobilized to the project site. This included additional personnel, an additional drill rig and ancillary equipment, and tooling to support seven operating drill rigs. The general contractor, dck-FWF, restructured the project schedule and other subcontractors to accommodate the necessary access for the remediation efforts. The final installation and remediation of the micropile foundations was completed in early January 2015, two months after discovery and one month after agreement on the remedial action plan was reached.

Keys to Success

The installation of the micropiles at IMP had significant difficulties and constraints: highly variable substrata, live trees protected in place, archeological concerns, working on an island, artesian ground water, complex critical path schedule, and the list goes on. These significant challenges were met by a diverse project team that worked cooperatively with the project's goals clearly in focus. The use of a design-assist concept with the foundation contractor provided a unique atmosphere of technical cooperation, to the benefit of the project. The project team members met weekly throughout the project to discuss the current and upcoming challenges.

The agreed goals and open communication created a partnering environment between the contractor, owner, consultants and specialty foundation contractor to ensure performance in safety, quality, financial control and schedule. According to Duke Ellington, "A problem is a chance for you to do your best."

Project Team Members

Owner: Taubman Centers, Inc.: – Jonathan LoPatin, Bryan El-Zoghby, AIA

General Contractor: dck-FWF – Frank Falciani

Owner's Consultant: Ehlert Consulting Services – George Ehlert, P.E.

Structural Engineer: Ludwig Structural Consulting – Adam Ludwig, P.E.

Geotechnical Engineers: SME – Tim Bedenis, P.E., Mark Kramer, P.E. and Geolabs, Inc. – Aaron Wong, P.E., Robin Lim, P.E.

Micropile Design-Build/Design Assist Contractor: Hayward Baker Inc.

Project Executives: Mike Terry, P.E., Ron Triplett

Project Manager: Alison Savage, P.E.

Design Engineers: Bob Scott, P.E., Lisheng Shao, Ph.D., P.E., G.E., John Wolosick, P.E., D.GE

Project Engineers: Jeff Fijalka, P.E., Will Makowski, EIT Ryan Thamm, EIT, Dylan Fisher, EIT

Operations: Milo Osmun, Thayne Harris

Superintendents: Tom Finn, Shane Lewis

Work progresses on the IMP site