FEATURE STORY

GORDIE HOWE INTERNATIONAL BRIDGE PART 2

DRILLING DOWN —in— MOTOWN

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Vacaville, California, is a city of about 100,000 residents and is located southwest of the state capitol of Sacramento. This community is approximately 2,350 miles from the U.S. side of the Gordie Howe International Bridge project and has nothing to do with traffic across the U.S.-Canada border. Without Vacaville, however, construction of the foundations under the Detroit side of the bridge might have been more costly, and execution could have been much more complicated.

How was this California city instrumental in the successful completion of bridge foundations thousands of miles away? In 2007, ADSC Contractor Member Malcolm Drilling, of San Francisco, California, had to figure out how to complete a seismic rehabilitation of an existing bridge there in difficult conditions. It was a relatively small project with big implications 12 years later. Because what happened in Vacaville didn't stay in Vacaville.

THE PROJECT

The Gordie Howe International Bridge project is an ongoing effort to improve cross-border traffic between Windsor, Ontario, and Detroit, Michigan. Currently, the Ambassador Bridge, an aging, privately-owned structure, is the primary avenue by which 25% of all commercial traffic crosses the U.S.-Canadian border. The bridge will be cable-stayed and will have the longest main span (0.53 mile) of any cable-stayed bridge in North America. Three lanes will travel in each direction, and new Ports of Entry will be built on each side of the Detroit River.

No piers will be constructed in the river in order to maintain clear access through the busy shipping channel in the upper portion of the Detroit River. Heavy shipping traffic travels between Lake St. Clair to the north and Lake Erie to the south as part of the vast Great Lakes St. Lawrence Seaway system. Billions of tons of grain, gypsum, steel and other materials are transported through this network every year, and maintaining open channels is vital.

Early design activities led to the determination that drilled shafts would be the most suitable foundation type to carry the very large loads generated by the bridge superstructure and associated traffic loads. Malcolm Drilling was selected to construct the U.S. foundations, while ADSC Contractor Member GFL Environmental, Inc., of Vaughan, Ontario, was charged with building the Canadian foundations.

Malcolm's contract included three separate sections of the project: the main bridge tower piers, piers for the back spans and improved support for sheet pile walls adjacent to the bridge tower piers. Malcolm was responsible for minor earthwork, drilling, concrete placement and reinforcing steel cage construction and placement.

GEOLOGY AND LOCAL CONDITIONS

According to information published by Michigan State University, the Michigan basin is underlain by deposits of limestone, shale, sandstone, gypsum, anhydrite and halite (rock salt). The salts were deposited when Michigan was part of a warm inland sea during the Silurian geologic period. Great coral reefs surrounded the basin area, blocking flow of freshwater into the zone. Sea water gradually evaporated, leaving heavy salt deposits. Those deposits were then covered with other rock layers during subsequent glacial activity. The salt deposits in the Detroit-Windsor area are among the largest in the world.

Salt has been mined throughout the Detroit-Windsor area for over 100 years. In addition to deep brine wells, conventional room-and-pillar mines were excavated on both sides of the river. Like most mines advanced prior to modern regulations, large portions of the mines in the vicinity of the U.S. bridge foundations were unmapped or poorly mapped. Development of a sinkhole that swallowed part of an industrial plant on the Windsor side of the river in the 1950s indicated that subsidence was possible over the local salt mines.

Above the rock surface are deposits of glacial till 50 to 60 feet thick. The till consists of clays and silts at shallower depths transitioning into sands and gravels. The deepest till strata have been compressed to create a hardpan. Calcium carbonate materials in this layer have reacted with groundwater over time to develop light cementation in the hardpan. The result is a confining layer over the rock surface, separating groundwater conditions in the till from groundwater conditions in the rock. Artesian pressures of about 17.2 feet are present in the rock in the project area.

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Despite the fact that glacial till was deposited over the rock in the area, till is not present at the ground surface. Instead, uncontrolled fill from the past 300 years makes up the upper 20 to 30 feet of the stratigraphy. This material contains everything from silty sands to historic flotsam and jetsam from the river to pockets of dumped debris from over a hundred years of surrounding industrial operations.

In addition to the complicated subsurface conditions at the site, unusual river characteristics have affected construction of the bridge foundations and were incorporated into design elements. The Detroit River can fluctuate several feet over a few hours or more "as a result of transient meteorological conditions," according to the Detroit District of the U.S. Army Corps of Engineers. Strong east-west winds across Lake Erie account for the changes, the most extreme of which ever recorded was a change of 8 feet within 5 hours. The slope across the water surface of Lake Erie once was recorded to be 14.5 feet from one side to the other. Working in such conditions is like working in a tidal region without the regularity.

The confining nature of the hardpan has limited solution weathering in the limestone so that karst conditions are not prevalent in the project area. Most of the limestone deposits are characterized by fractures and microfractures. However, millions of microorganisms were present in the materials that evolved into this limestone, and the oxygen-poor environment led to the production of hydrogen sulfide gas as the microorganisms decayed. This gas is present in many of the fractures in the limestone in the Detroit area.

Hydrogen sulfide is the gas that produces a "rotten eggs" smell in sewers on dry days. Exposure to the gas is deadly; in confined spaces, hydrogen sulfide has already suffocated vital systems in the body by the time a worker smells it.

Cold temperatures also often cause ice formation on both Lake St. Clair and Lake Erie. When temperatures rise above freezing, ice sheets can drift downriver. During periods of time when Lake Erie has been iced over, ice sheets floating downstream can become blocked at the mouth of the Detroit River, resulting in a jam of ice sheets up the river.

To compound the natural complications, the active industrial setting presents additional challenges. The project site is located immediately adjacent to a very active Lafarge cement production facility. And although production had been curbed at the U.S. Steel plant on neighboring Zug Island, railroad tracks cross the project site, bringing in occasional trains and requiring construction of two crossings for construction equipment. The sheet pile retaining wall on the east side of the construction site also has remained in use during construction, as barges frequently tied up there to transport materials to Lafarge. It's important to note that not only did Malcolm have to avoid damaging the wall and work around traffic around it, but renovation of the support for this wall was part of their contract.

EXPLORATION AND DESIGN

Obviously, a robust geotechnical exploration program was needed to sort out and characterize the many elements that could affect construction and performance of the U.S. foundations. NTH Consultants, Inc. had been retained in 2005 by The Corradino Group, working for the Michigan Department of Transportation (MDOT), to perform geotechnical explorations for the bridge project. NTH completed an extensive program of exploratory borings to determine if past salt mining would present support risks for the new bridge and associated structures. Initial evaluations of existing data had indicated that brine wells, not room-and-pillar mines, were more likely to be located within the Detroit-side project footprint. Borings were advanced as deep as 1,750 feet below the ground surface in the area of two proposed bridge alignments. The borings were used in part to confirm that subsurface mine and subsidence voids were not located where foundation elements would be constructed.

The salt mining was explored using a combination of deep borings, wherein thousands of soil and rock samples were retrieved, and geophysical testing in the completed borings. Cross-well seismic imagery was used to attempt to identify voids and anomalies in the subsurface. Sonic profiling, natural gamma studies, and numerous other methods were used to give the best possible data for siting of the bridge and approaches. This allowed the owner to select a final alignment with the lowest possible risk of complications from the old mines.

The Gordie Howe International Bridge project was procured as a Public Private Partnership (P3). Bridging North America (BNA) was selected as the design-build entity, and AECOM was hired to perform design of the bridge superstructure and foundations.

Once the final alignment was chosen, NTH was retained again to conduct additional exploratory activities to facilitate design of the Detroit bridge foundations and support for associated structures. Additional borings were advanced, and necessary sampling and testing were conducted. The geotechnical team was well aware that issues with the old salt mines weren't the only factors that could pose problems for support and construction of the bridge system foundation elements; the artesian conditions, fracturing in the limestone, strength of the limestone, and hydrogen sulfide on the rock all were considered.

After reviewing all of the geotechnical data and evaluating the traffic needs, the design team came up with a plan including two primary bridge tower piers adjacent to the sheet pile retaining wall along the west side of the Detroit River. Each pier would be supported by six 3m-diameter drilled shafts. The shafts were planned to extend to top of rock about 90 feet below grade and socket 7 meters into limestone.

Six back span piers also were designed to be supported by drilled shafts 3 meters in diameter. These piers would be socketed 4.8 meters into rock to resist uplift from the superstructure. The back span piers were located about 1,000 feet to the west of the main bridge piers.

The sheet pile retaining wall along the Detroit River had been constructed many years ago of two rows of sheet piles: one row along the riverfront and a second row west of the river connected by tiebacks. Project designers were concerned about the lateral loads generated by construction activities and the new bridge system. According to Noah Miner, Chief Engineer for Malcolm's Midwest District, the concrete fluid pressure from a new retaining wall between the piers could have been sufficient to compromise the wall system. Therefore, the design team devised a reinforcing system consisting of 14 2m-diameter drilled shafts socketed 4 meters into rock. These shafts were sited 20 feet from the edge of the river; at the north pier, two of the wall shafts were located immediately adjacent to the bridge pier.

Each element of the final design was heavily suffused with aesthetic concepts, in addition to the necessary engineering principles. Public input shaped the plan into the final product, making the bridge a partnership between BNA and the community.

THE VACAVILLE PROCESS

When Malcolm Drilling was retained to install the foundation elements, every aspect of the project played to their strengths. Drilling through old fill? Check. Large diameter shafts? Check. Handling of large reinforcing steel cages? Check. Drilling in groundwater next to the river? Check. Advancing large diameter shafts deep into hard rock with aggressive artesian pressures 20 feet from where large barges are docking and the river tends to rise several feet over a few hours AT RANDOM? Wait. This might be a little tricky.

Veterans in Malcolm's ranks, however, recalled a squirrelly project back in 2007. Groundwater conditions and soil types necessitated formulation of a drilled shaft construction process that would allow installation of the shafts in conditions that normally would require permanent casing but would let Malcolm remove most of their casing. Voila! The Vacaville Process was resurrected and elevated to legendary status. What worked in California surely would work in Michigan – geology doesn't take sides.

Malcolm General Superintendent Clinton McFarlane was responsible for making sure the process achieved the desired goal: retaining the structural integrity of the shafts while enabling removal of most of the steel casing. McFarlane has worked for Malcolm for 22 years and was well-suited to make the magic happen.

As devised, each shaft would begin with a 1-in thick steel starter casing about 45 feet long affixed with a 3-ft cutting shoe. A Leffer casing oscillator would advance casing into the subgrade, and a hammer grab would be used to remove spoils. At a depth of about 20 feet, polymer slurry would be introduced into the shaft to equalize pressure from groundwater in the glacial till. Casing would be oscillated to a point about 10 feet above rock, where additional casing would be placed at the top of the shaft in order to increase the head of polymer slurry in the hole to counteract artesian pressures in the rock once they were encountered. Casing would continue to be advanced to top of rock, where it would be screwed in to rock about 6 inches to 1 foot to prevent water intrusion into the shaft from the till layers. Coring would take place using a Bauer BG50 drill rig to complete the rock sockets. The socket would be cleaned, the reinforcing steel cage would be placed, and concrete placement would begin. A tremie would be placed in the hole and concrete would be discharged, maintaining embedment of the tremie head in the concrete. As the casing slowly was extracted, Malcolm staff would keep watch for the joint at the top of the original casing. This joint would be used as the marker

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at which point the extraction process would be stopped and the remaining casing would be left in the ground.

The end result of the process would be a drilled shaft constructed per design with only about 45 feet of casing left in the ground. The design did not involve the use of casing for structural purposes, so no foundation capability would be lost, and money would be saved.

TESTING THE THEORY

The first opportunity to see if the Vacaville Process would translate to the Gordie Howe Bridge project came in June 2019 when the project team decided that a test shaft should be constructed. ADSC Associate Member Loadtest, Inc., of Gainesville, Florida, was hired to conduct the loading dictated by AECOM and record the corresponding data to confirm that in-situ conditions would provide the support as specified in the design.

Bill Ryan represented Loadtest on the project. He stated that his company had been involved with the proposed Gordie Howe International Bridge project since 2012 when various design-build teams started evaluating possible plans for the structure. By 2019, he was well aware of subsurface conditions in the area and possible construction complications.

Construction of the test shaft took about one week. Four 34-in-diameter Osterberg cells (O-cells) were tied into the reinforcing steel cage near the bottom of the shaft. The cells had nominal strength capacities of 6,000 kips and were placed 90 degrees apart with a central opening of about 12 inches for tremie concrete placement.

The test was set up as a "Chicago-style punch out test." The diameter of the bearing plate was 89.1 inches, so that the plate was smaller than the shaft diameter.

No significant problems took place during test shaft construction, and data confirmed that the shafts could provide the desired foundation performance. Ryan stated that testing was fortunately event-free. "Detroit is really nice in June," he said with a laugh. "It was good timing."

PUTTING THE PLAN INTO ACTION

A few tweaks to the plan took place after the load test, and production shaft construction didn't start right away. Minor design revisions were made, and Malcolm began work on a portion of the retaining wall shafts in early September 2019.

Although the Vacaville Process had proved to be effective getting the shafts in the ground, that didn't mean the process as a whole was easy. Reinforcing steel cages weighed 145,000 pounds and required two cranes to complete a safe pick. Jim Glider, Project Manager for Malcolm stated, "I've never used a 200-ton crane to backstop a cage pick." Miner echoed his sentiments, "It's like conducting an orchestra when you're pouring concrete and holding a 145,000-lb cage with 20 concrete trucks lined up at the site. It's a dance."

McFarlane also stressed that the real difficulties involved in the project were related to working so far above the top of the hole once the extra casing was placed to deal with the artesian conditions. "The difficulties came from doing everything at height. It's hard enough managing a

145,000-pound cage and dealing with concrete and polymer, but once you get down to the last 40 feet of the hole, you're doing it up in the air above the additional casing."

Hydrogen sulfide was encountered in the limestone in at least one of the shafts, with corresponding problems. According to Glider, the polymer level dropped about 1 foot overnight, and Miner stated that the pH of the solution was affected. But the problems were corrected relatively quickly, and the nature of the operation meant that workers were not exposed to the gas.

Cleaning each shaft took between 10 and 30 hours after coring was complete to achieve the sediment tolerances allowed by the project specifications. "After we had cleaned each hole to acceptable levels, we had exchanged as much as four shaft volumes worth of polymer," said McFarlane.

Construction of the shafts behind the sheet pile retaining wall involved even more logistical dance moves. Barge deliveries to Lafarge continued throughout construction, and bollard replacement was required to take place around these occurrences. Malcolm installed 2m-diameter shafts to top of rock, then excavated rock sockets 4 meters deep.

> ***"It's hard enough managing a 145,000-pound cage and dealing with concrete and polymer, but once you get down to the last 40 feet of the hole, you're doing it up in the air above the additional casing."***

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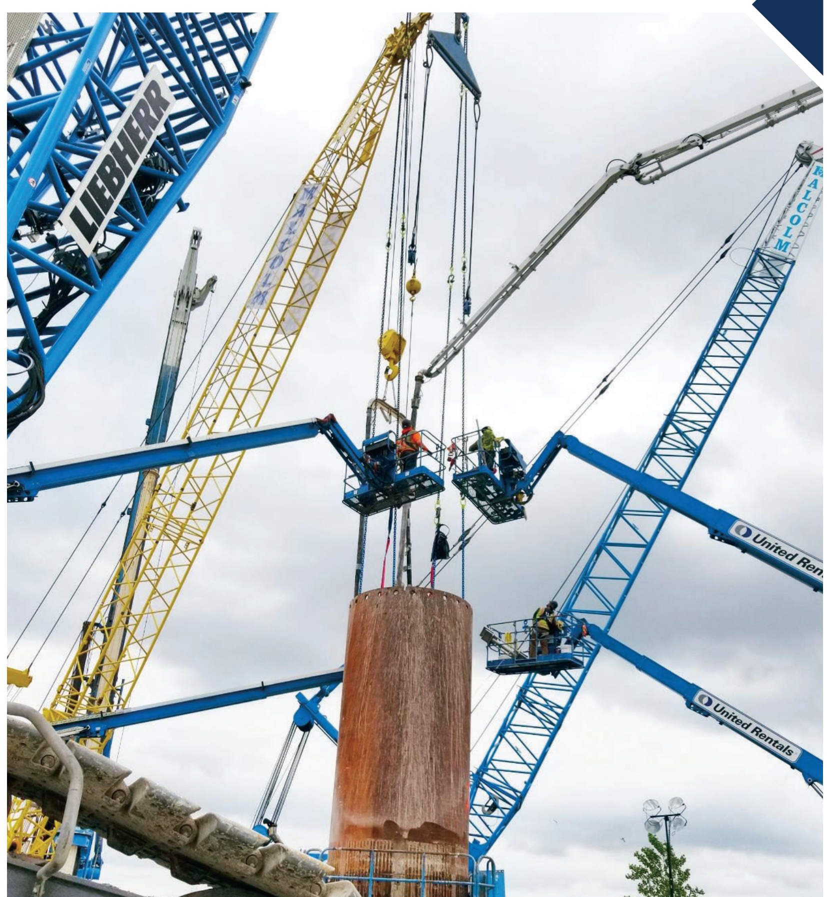
Each main tower pier shaft took approximately 4 to 5 days to complete, and the smaller shafts took about 2/3 as much time. Quality assurance testing took place within about 2 weeks of installation of each shaft. Work took place throughout the winter of 2019, continuing into early 2020. By the beginning of March 2020, only tower pier shafts remained to be built.

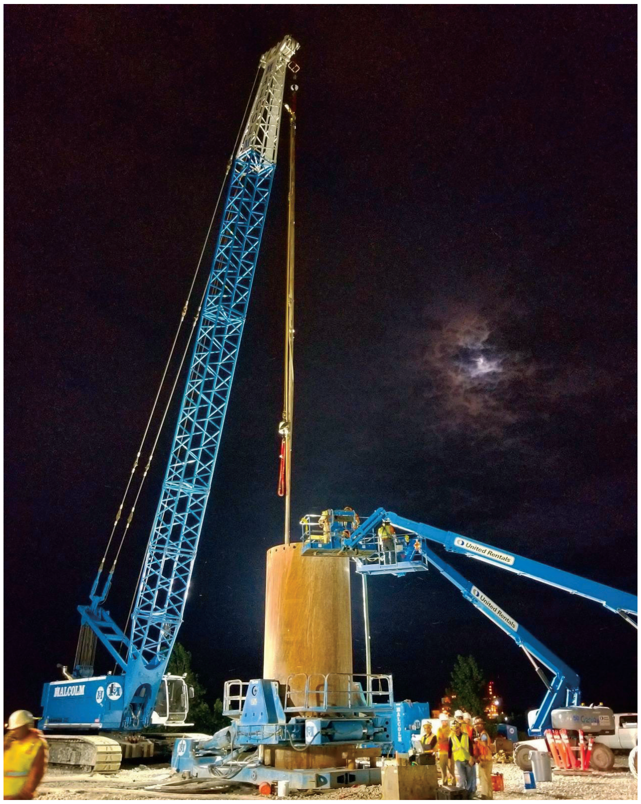
"We were almost finished when most of the country shut down due to COVID-19," said Glider. "We spent about two weeks in March unsure of whether or not regular concrete delivery could be guaranteed in the coming weeks. But it all worked out, and we finished production drilling March 26, 2020."

Malcolm de-mobilized from the site in June 2020 after several months of miscellaneous sitework. Thirty three shafts were constructed for the project – 18 3m-diameter production shafts for the tower piers and back span piers, one 3m-diameter test shaft, and 14 2m-diameter retaining wall shafts.

TESTING AND MORE TESTING

In addition to load testing performed on the test shaft to confirm performance and viability, non-destructive test methods were incorporated into each shaft. Cross-hole sonic logging (CSL) and thermal integrity profile (TIP) testing were conducted by Loadtest to demonstrate suitable concrete placement in the shafts by showing consistent cross-sectional area.





In general, test data showed the results that would be expected from tremie-placed concrete operations inside steel casing. However, a few of the TIP tests indicated areas of anomalous concrete density. CSL testing in the same areas did not agree with the questionable TIP test results. Evaluation by Loadtest and the project team concluded that the casing left in place likely was acting as a heat sink, affecting readings. This phenomenon has been observed on other project sites. Ryan also believed the temperature readings were affected by gradients in the fluctuating groundwater levels around the shafts. Coring was performed in at least one shaft to confirm that the CSL results were accurate; the positive test results indicated that additional testing and analysis were not necessary, and the structural integrity of the shafts were sound.

THE NEIGHBORHOOD

Detroit is known for its hard winters, but the project team got lucky with a "mild" winter during foundation construction. Ice sheets still floated down the Detroit River frequently, and a 12-inch snow event kept local employees from the jobsite. Jim Glider also remarked on one day when some workers spent most of their shift in a man basket above the site while snow blew horizontally. Mild, indeed.

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Winterization of all equipment still was needed to keep construction moving along on schedule. Twenty four-hour shifts ensured that time wasn't wasted thawing equipment and materials. According to McFarlane, the most difficulties occurred when pumping off water that accumulated in and around foundation construction operations. "Everything wanted to freeze," he said.

Snow wasn't the only material lighting up the sky either. Zug Island, the industrial site located just to the southwest of the bridge project, is home to U.S. Steel. Blue flames typically light up the sky above the island, and the skeletal steel silhouettes that dot the landscape are suggestive of an apocalyptic scenario. "It's like something out of Mad Max," said Noah Miner.

> ***"It's like something out of Mad Max."***

The "neighborhood" also rained good fortune in the form of outstanding local operators and laborers. McFarlane praised the work ethic and skillsets of all of the employees he got from the local union halls. "All of the operators were well above average with regard to their expertise," he said. "Tim Struthers in particular was absolutely stellar. I've hired operators from halls all over the world, and he's probably the best I've ever hired."

KEEPING SCORE

By all accounts, Malcolm's project was a success. Josh Perry, Construction Manager for the US side of the BNA project said, "Considering all the complexities of the project, it is very clear to me that Bridging North America made the right choice when choosing Malcolm Drilling to be our partner and perform the complex drilled shaft work in challenging local conditions while remaining compliant with our comprehensive P3 Project Agreement. Bridging North America and the Windsor-Detroit Bridge Authority can confidently continue to construct the Gordie Howe International Bridge on top of the deep foundations that were constructed by Malcolm Drilling with precision and a focus on quality." Malcolm couldn't ask for a more ringing endorsement from a happy client.

For the project as a whole, a consistent theme was encountered when speaking with people about foundations for the Gordie Howe International Bridge project. That theme was the idea of competition between the U.S. and the Canadian sides of this giant endeavor. Locals interviewed for this series, including newspaper editors, residents, and business owners, repeatedly expressed opinions about who was "ahead." Bill Ryan, who is working on both sides of the river, commented that "There seems to be a spirit of competition between Malcolm and GFL over who started first, who is getting done quicker, and every other small detail." During the current pandemic, when so many people are desperate for sports, "Foundation Wars" might draw even more than just the nerd and construction crowd.

As an added bonus, the two teams are led by ADSC Presidents. Former ADSC President Al Rasband is President of Malcolm Drilling and was called in to sort out some sticky questions a few times when Malcolm was sorting out how to execute the U.S.-side project. Current ADSC President Mauro Scanga, of GFL, has been hard at work on the Ontario side, where… well, that would be giving away the next issue's story. Look for the January issue of Foundation Drilling to read the last installment of this saga. Was this like a hockey game, all handshakes at the beginning then punches thrown two minutes into play? Or was the competition felt a bit more by the locals? In a field where real success is marked by nothing moving when it's not supposed to, the millions of travelers who will cross this bridge when it's finished hope that the end result is a tie.