Shaft works on Toronto's Coxwell Bypass Tunnel

Shaft Complexities

A healthy demand for shaft design and construction in North America is being driven mostly by CSO projects. NATJ looks at the market and explains why shafts are so much more than simply points of tunnel access.

Going back to the early aughts, contractors on the City of Portland's West and East Side Combined Sewer Overflow (CSO) tunnel projects needed to build multiple deep shafts through difficult and potentially unstable soils.

The largest, the pump station shaft, had a 137ft (42m) diameter with an excavated depth of 163ft (50m). Bencor, now part of Keller, deployed hydromill technology to excavate many of these shafts.

For Giancarlo Santarelli, director of Bencor at the time and now with Keller, he highlights a tremendous increase in the use of hydromills for diaphragm wall construction following those Portland shafts. "That opened up a new chapter for us, especially for all the CSO work in the United States. There's very good market for it."

The US Environmental Protection Agency estimates about 850 billion gallons of untreated wastewater and stormwater are released from CSO each year, across 750 cities, and in 1994 it set out requirements for municipalities to reduce the country's 9,300 CSO outfalls.

These CSO-related tunnel projects have been credited for driving changes in shaft design and construction. With clients building deep rock tunnel systems, shafts are being used for facilitating the tunneling process as well as housing permanent facilities long after construction is completed.

There are numerous projects over the last two decades where hydromill technology has enabled deeper shafts, and therefore deeper tunnels. "We can go to depths of up to 400ft, which was not achievable before with a system using a regular clam shell on diaphragm walls, or going with secant piles where there are limitations with depth and hard rock," Santarelli says.

Jewels Stover, project manager with Nicholson agrees and explains, "by using diaphragm walls, we're able to take the shafts deeper. We can also reduce the need for combined systems secants with ribs and liner plates. The same diaphragm wall technique is becoming more and more viable also for smaller diameter shafts and not only for really large diameters, which has been a big misconception in the industry."

Shaft complexities

CSO and other water management projects are expected to continue to drive demand for shafts. However, there can be a tendency on projects for owners or other parts of the team to underestimate the complexity of the shafts. They may be too focused on the tunneling work or oversimplifying the loading—not thinking about the crane that will be working 3m from the shaft.

"On a lot of these major projects the tunnel itself is the major component of the project, and might end up being the most costly part, however the planning and design of shafts tend to be more complicated and challenging," says Mark Stephani, principal geotechnical and tunneling engineer, HNTB.

For CSO projects—where it's necessary to locate drop shafts where they properly intercept the flows, while also configuring shafts to achieve hydraulic performance—there are additional design challenges or limited options for shaft locations. That's not to mention numerous other factors like ventilation, odour control and durability.

There are five shafts on Toronto's Coxwell Bypass Tunnel project, which is being built to reduce CSOs. All of these are at least 20m in diameter and more than 50m deep through both soil and rock. "We weren't able to use conventional precast elements or pre-stressing because we are in a river valley and there is a really high flood loading on top of them," explains Tyler Lahti, manager for structures and tunnels with R.V. Anderson Associates Limited, which is doing the design in association with Black & Veatch.

This was particularly significant on one of the shafts, for which the design had to account for 3.5m of hydrostatic loading acting on the precast concrete roof from a regional flood load case. The design team's solution comprised custom precast concrete slabs or "planks" across the structure, with a structurally bonded cast in place concrete topping, to create a composite concrete roof slab. The contractor is a joint venture of Jay Dee, Michels and C&M McNally.

"It's going to allow them to build something similar to what would have been a cast in place concrete slab but without any formwork," Lahti says. "It was a big cost saver because if they had to do it conventionally they'd need to have really sophisticated forms that hang from the walls, or scaffold the whole thing."

Sensitive sites

Work sites in urban areas with tighter constraints is driving demand for more complex shafts, as well as changes to construction.

The industry can expect to see more cases of initial support being used as part of the final lining, says Mike Wongkaew, associate vice president and national tunnel practice lead – Northwest for HNTB. "It requires careful consideration of the detailing of the waterproofing and making sure the quality of initial supports meets the same goal of permanent structure," he says.

He's also seen a trend for unreinforced concrete for initial support, adding "essentially it takes advantage of the geometry of shafts and compression rings in the wall, and I think we are seeing more of that because people now have three-dimensional tools to analyse the structures and they are more comfortable understanding the behaviour of the shaft."

Daniel Garcia, senior structural engineer at WSP, says to also expect more changes to materials in the future—especially with the growing trend for initial support structures that are incorporated in the permanent structure system. "We expect the wider use of higher strength and high-performance concrete in order to make our initial support structures watertight and also more cost and schedule efficient."

CSO shafts in confined spaces on the First Street Tunnel

He adds that currently clients typically prefer separate support systems, but he expects to see more combined systems in the future. "They reduce the excavation area required, minimize the cost of materials, and reduce the number of truck journeys required to remove soil and deliver concrete."

More work sites in urban areas also means more attention to impact of construction on third parties, and adoption of techniques to minimize disruption.

For the First Street Tunnel, part of the District of Columbia Water and Sewer Authority's (DC Water) CSO mitigation work, the contractor needed to excavate three shafts of approximately 23ft (7m) internal diameter with depths of 160ft (49m). These were located in a quiet, residential neighbourhood and dewatering wouldn't be an option due to concerns about settlement. The Skanska/Jay Dee joint venture chose groundfreezing.

Working in such a sensitive environment the freeze system could not be located adjacent to the shafts as is normally done and instead ran through a utility trench up to the main job site, as much as 800m away. Instrumentation is increasingly important, says Joe Sopko, director of ground freezing with Keller North America.

"We are able to work in areas where we couldn't before because of the advancements in instrumentation and monitoring," he says.

"The First Street Tunnel—that would have been very tough to convince the contractor and the owner that freezing was technically feasible. But in the last 20 years the freezing equipment has gotten so much more powerful, quiet and so much more reliable. An even bigger change is the quality of crews. The equipment is a lot more sophisticated so the crews are much better trained, and we're able to put pipes in more accurately and safely."

Likewise, with increased concern for contaminates, compared to 20 or 30 years ago, this may rule out dewatering on a project because it could mobilize the contaminate, and ground freezing becomes the better solution. Bill Levy, a senior manager with Aecom who has spent much of his career working for various owners including DC Water, explains all this CSO work in urban environments, like the First Street Tunnel, will make more demand for ground freezing, in part to reduce the impacts of pollutants like dust and noise.

Overall, quality assurance and quality control is key to successfully implementing these projects in urban environments. "That's what makes CSO a little different," he says. "You typically have a lot of surface work sites where you're tying your tunnel into an existing sewer system. Then you've got the deep side—the shaft and any adits—and together that makes a big footprint and you have a complex choreography on tight work sites."

Another solution is the use of mechanised shaft sinking machines that can construct a lining while mining a shaft. Herrenknecht's Vertical Shaft Sinking Machine (VSM) is one example and it has been deployed on projects worldwide including a sewer in Hawaii.

The equipment works well on smaller job sites and the impact on the environment is significantly lower, says Peter Schmäh, member of the executive board, Utility Tunnelling for Herrenknecht. In most cases, a secondary lining is not required reducing the thickness of shaft walls and the amount of excavation needed. It also avoids the need to lower the groundwater level.

"VSM is somehow still a niche, however under certain conditions it is an interesting alternative to conventional methods," Schmäh says.

For Singapore's Deep Tunnel Sewerage System Phase 2 project a VSM is sinking access shafts to a depth of 53m.

With schedule an imperative on most major projects the industry is looking for ways to save time and money, like the VSM, says David Smith, geotechnical and tunneling practice leader at WSP in New York City. "On the right size project and with the right number of shafts you can potentially get the investment costs back with rapid excavation of those shafts. Techniques such as that or other forms of caisson shaft sinking are increasingly looked at, though haven't much yet been adopted, but I think we will see that."

Storage shafts

Stormwater mitigation work does not always require an entire deep tunnel rock system. Increasingly there have been projects looking at the use of deep and large shafts for storage where previously a client might have been looking at tunnels or large above-ground tanks, reports Luca Barison, vice president of preconstruction for Nicholson.

"These are all underground, so they are built using the same techniques that we use for traditional shafts for tunneling, like diaphragm walls," he explains.

This large tank strategy is being used in Minnesota where Interstate 35 West cuts through south Minneapolis and has long been prone to flooding. The Minnesota Department of Transportation (MNDot) began developing a refurbishment project for the sewers running below a 2.5-mile stretch of the interstate. However, due to both challenging ground conditions and limited underground space, MNDot separated out work near a single cross street into its own flood mitigation project to create a stormwater storage facility.

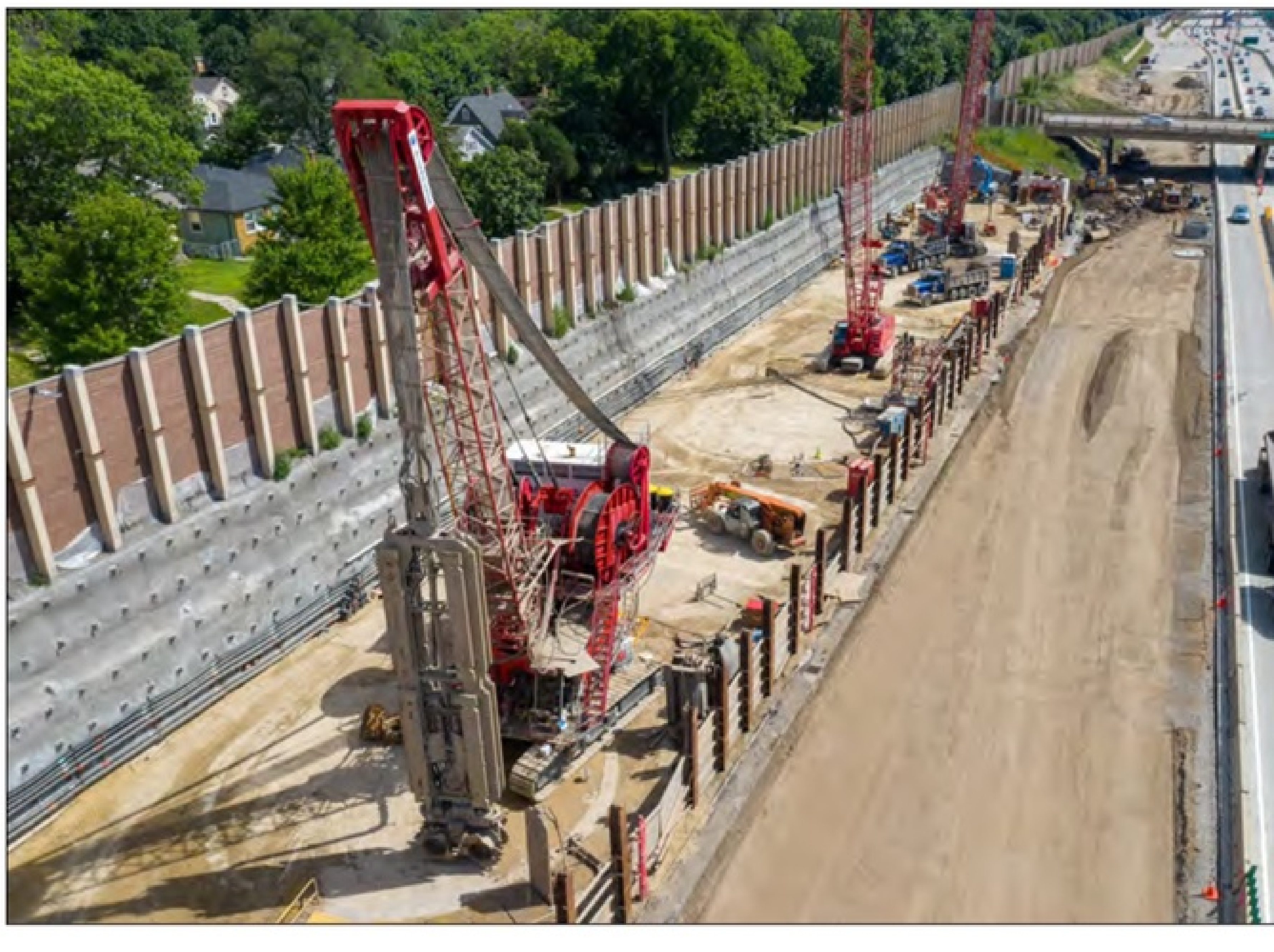
For this, the agency chose a Construction Manager General Contractor (CMGC) delivery approach and awarded the contract to a joint venture of Kramer and Nicholson. Barr Engineering led the design with Brierly Associates and TKDA Engineering. An approach like the CMGC can feel like an added step in the design stage, explains Mike Haggerty, vice president and senior geotechnical engineer with Barr Engineering. But it can pay off later in the project "ideally bringing constructability into the design, additionally the contractor can work with the owner to identify risk and how that affects costs."

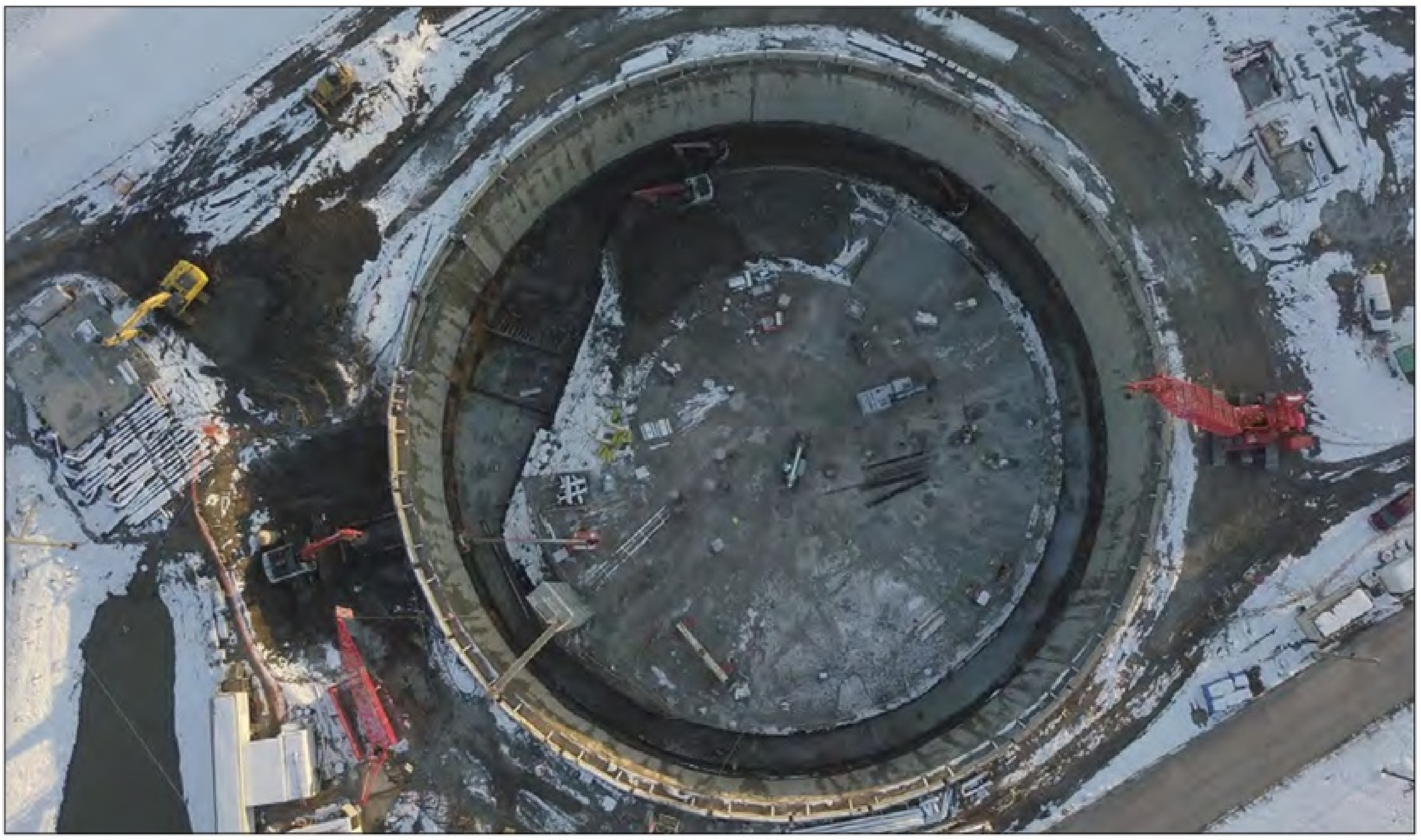
Risk mitigation has played a major part in the stormwater storage facility. Concerns included a high groundwater table with glacial outwash and alluvium-type ground conditions, as well as the proximity of a residential neighbourhood on either side of the freeway. They selected a solution comprising six underground tanks built using diaphragm walls—essentially six shafts—for a storage volume of 4.8 million gallons. These are being excavated via clamshell and hydromill from the freeway shoulder.

"There are potentially highly conductive ground water materials and it's a really tight space," Haggerty explains, "it allows the existing adjacent downtown to crosstown project to go on uninhibited. We did not want to impact the schedule of that project."

The diaphragm walls are approximately 4ft (1.2m) wide, with an 18-inch-thick cast-in-place concrete liner, with an inside finished diameter of 42ft, explains Joe Welna, senior civil engineering with Barr Engineering. The finished tanks will be 85ft (36m) deep from the ground surface and the diaphragm walls extend down 109ft (33m) below ground. "That was to get the benefit of a cut-off,

Interstate 35 West makes shaft sinking challenging in Minnesota





Birdseye view of the Louisville mega-shaft

by extending down deeper into more favourable ground conditions," he says.

The six shafts or "cells" are connected together and to the existing stormwater sewer pipe in the median. In a flood-level precipitation event the flow will spill into the shafts, which fill equally. Once the storm clears, the existing infrastructure has pumps in the last cell to return the water to the mainline system. "It was a novel application of a more traditional technology," Haggerty says.

Engage early

Alongside this growing demand for complex shafts, there has also been an increase in early contractor involvement in the design phase—a change that foundation specialty construction firms would like to see continue to grow. For Aecom's Levy, he's also a proponent of more innovative project delivery approaches. "In my mind this is where we should have been decades ago—collaborating with contractors pre bid," he says.

From the contractor's perspective, this is the best approach, Barison says, because there is a complete and transparent understanding of what the risk is and how best to manage and mitigate it. "We believe the best opportunity that any owner has to tap into the knowledge that we, as specialty foundation contractors, have is at the early part of the project. This is the stage where we can positively influence the design and constructability of the project."

This is the case for a very large diameter shaft for a stormwater storage basin on a recent project in Louisville, Kentucky. The design of the shaft was the contractor's responsibility. The initial approach in proposals to various general contractors bidding the project was the use of sheet piles for the temporary support of excavation of the shaft with a double side permanent concrete liner wall, a very typical system used in the area, according to the Nicholson team.

The general contractor, Dugan & Meyers, was concerned about using the sheet pile system with the shaft's proximity to a nearby river and levee. They contacted Nicholson during the procurement process who provided a design for a diaphragm wall, which could be used as the support of excavation.

Nicholson's Stover explains, "this allowed our client the ability to eliminate the double-sided form, dowel the permanent concrete liner directly into the diaphragm wall, making it part of the permanent structure, and utilized its deadweight as part of the structural design."

Eliminating the double-sided form allowed Nicholson to reduce the diameter of the diaphragm wall shaft to a final 239ft (72.5m) internal diameter.

Additionally, the original drawings had called for over-excavating the hard shale at the bottom of the shaft before pouring a thick and heavily-reinforced concrete base slab to withstand the uplift forces. Instead, Nicholson's team proposed a tie-down rock anchor solution.

"That approach effectively eliminated the need for rock blasting as was planned in the original construction approach and any of the subsequent excavation of the blasted rock. It also reduced the required thickness of the base slab," Stover says. "With our early involvement, not only were we able to help them optimise the design and construction of the shaft, but it opened the door to where our expertise ultimately helped them save schedule and money in a phase of the project that we wouldn't have considered if we were just looking at a traditional plans and specs approach."

Looking forward

With new challenges and new opportunities for shaft construction in tunneling Jim Morrison, vice president, technical director with Cowi, and David Klug of David Klug Associates, have established a Tunneling and Underground technical committee as part of the Deep Foundations Institute (DFI).

"DFI is historically an organization of deep foundation contractors and they are very good at supporting technical committee activities. They've had technical committees for all of the technology used in shafts—a slurry wall committee, one for secant piles," Morrison explains. "With the new committee we want to pull all of that together, and to collaborate with those other committees on how that technology can be amplified in the tunneling world."

One of their goals is to put together a state of practice type technical paper specific to shaft construction in the tunneling industry. Readers who'd like to contribute or find out more can contact Jim by email JSMN@cowi.com.