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TUNNELING & UNDERGROUND CONSTRUCTION

THE OFFICIAL PUBLICATION OF UCA OF SME   WWW.TUCMAGAZINE.COM   VOLUME 5 NO 4   DECEMBER 2011

Pearl River CSC storage

Large diameter microtunneling

Ultrafine cement grouts

Special Editorial Section from the publisher of *Mining Engineering*

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COVER STORY

COVER — A plan to build a new sewer and replace two aging lift stations in Lafayette, IN became much more complex during the planning stages when a major user indicated it would be increasing its flows to the system. At the same time, planners discovered major restrictions in the existing system. The solution to these challenges was a combined sewer overflow system tunnel. See story on page 55.

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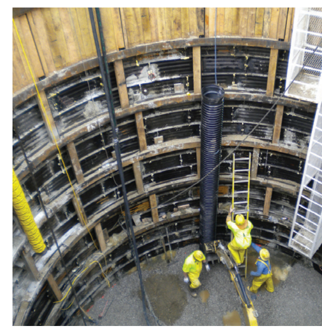
FEATURE ARTICLES



DEPARTMENTS

CHAIRMAN'S COLUMN

As the year draws to a close, it's time to focus on the future

It is hard to believe that another year will soon come to an end. I know that many people and businesses in our country have not done as well as they would have liked during this past year, but it seems that everyone I talk to in our industry has not changed their opinion that there is a lot of work out there in the underground market. Because of this, most people have kept very busy in their aspect of the business. That's a good thing.

With that in mind, I was pleased to read in the news recently that all the predictions of the world as we know it coming to an end in 2012 are not true. It seems that 2012 was the year that a gigantic fire ball from the sun would strike Earth — something about highly increased solar activity that occurs every 11 years or so. However, NASA scientists have looked into the details of this and are certain that it just won't happen in 2012. There is simply not enough energy there for a killer fireball to make it 93 million miles to Earth. This is also a good thing, in my opinion. So now there are no excuses to not get our business plans completed and start working on all of those goals and New Year's resolutions for 2012.

One of those goals we have set within the UCA is for improved education and training within our industry to address the shortage of people that will be available to take on the increased demand in the coming years.

I want to take this opportunity to share news about a developing program I recently learned about to address this very issue.

The Colorado School of Mines (CSM) in Golden, CO is launching the Center of Excellence in Underground Construction and Tunneling. I recently traveled to the school to learn more about this program and am very excited to see the start of what I think will be an excellent development in our industry. This center will be an interdisciplinary program to address the many different technical needs of the underground industry in education, training and technical research as a minimum.

But don't just take my word for it; check out the article by Mike Mooney in this issue of *T&UC* (page 71)to learn more. Programs such as these will not survive on their own. I encourage you to reach out to CSM, or any other school for that matter, to see what you can do to help develop or improve the training and development that exists for all aspects of our industry.

■

On Jan. 24, the UCA of SME will host the annual George A. Fox Conference at the Graduate Center, City University of New York.

This year, the conference will be a little different and take an international perspective. There will still be dicussions about some domestic projects, especially those on the East Coast, but attendees will also be treated to presentations about international projects such as the Gotthard Tunnel in Switzerland, a high-speed rail project in Spain and Crossrail, the largest infrastructure project in Europe. There will also be a much anticipated keynote address from In-Mo Lee, professor at Korea University. He will speak about challenges of tunneling and underground structures.

I hope to see you all at the George Fox Conference. Be well, and be safe. ■

Jeffrey Petersen,
UCA of SME Chairman

FEATURE ARTICLE

Challenges and triumphs of a large-diameter microtunnel relief interceptor sewer in Indianapolis

Jeremy Morris, James McKelvey, Todd Brown and Sandra Shafer

Jeremy Morris, is director, construction engineering with Christopher B. Burke Engineering, Ltd.; **Todd Brown**, member UCA of SME, is project manager with Bradshaw Construction Corp.; **James McKelvey**, member UCA of SME, is associate vice president and tunnel practice leader with Black & Veatch Corp. and **Sandra Shafer** is construction manager with Citizens Water (formerly the City of Indianapolis, Department of Public Work, e-mail jmorris@cbbel-in.com, tbrown@bradshawcc.com, mckelveyjg@bv.com or sandra.shafer@citizensenergygroup.com.

The city of Indianapolis has more than 25,000 homes currently on septic systems. Many of these systems do not function well because of their age and surrounding soil conditions. As Indianapolis has worked to eliminate septic systems and install sanitary sewers in large unsewered areas on the northwest side, capacity of the existing Belmont North Interceptor (BNI) became a concern. The BNI system currently services an area of approximately 80 km^2 (31 sq miles) located within the northwest quadrant of the city (Fig. 1).

Monitoring of the existing interceptor indicated portions of the system flowing half- to two-thirds full during dry weather conditions and surcharging during some wet weather conditions. Further analysis of the BNI based on growth projections coupled with increased sewershed yield resulting from the city's septic tank elimination program (STEP) indicated dry-weather flows could potentially triple over the next 20 years. Based on these modeling results and current wet weather capacity issues, the city determined further STEP projects could not be performed within the BNI service area until additional capacity within the interceptor was achieved.

FIG. 1

Belmont North Interceptor service area.

In addition to BNI improvements being critical to the STEP program, the city and U.S. Environmental Protection Agency (EPA) included a BNI relief sewer project in the federally mandated city-wide consent decree to increase sewer capacity, reduce combined sewer overflows (CSO) and eliminate wet weather sanitary sewer overflows (SSO). Indianapolis' consent decree currently consists of 31 consent decree control measures totaling

$1.3 billion in 2004 dollars. These CSO program projects are being completed per specified consent decree milestone schedule dates with the entire CSO requiring to be completed and in full operation by 2025 or the city could receive significant fines.

The Belmont North Relief Sewer Project is one of the first projects and, at the time, was the largest single project, to be constructed in terms of the city's consent decree.

Detailed engineering feasibility studies and preliminary engineering reports ultimately resulted in the design of a multi-phased relief sewer project to eliminate the BNI capacity issues. The Belmont North Relief Interceptor (BNRI) Project consists of four sections (Fig. 2):

BNRI Section 1 — Project includes construction of approximately 1,600 m (5,250 ft) of 1,800 mm (72 in.) diameter gravity relief sewer, 1,219 m (4,000 ft) using trenchless methods and the remaining 381 m (1,250 ft) using traditional opencut methods. The project also includes construction of nine significant cast-in-place sanitary sewer structures, two of which require construction while maintaining flow in active large diameter connection sewers.

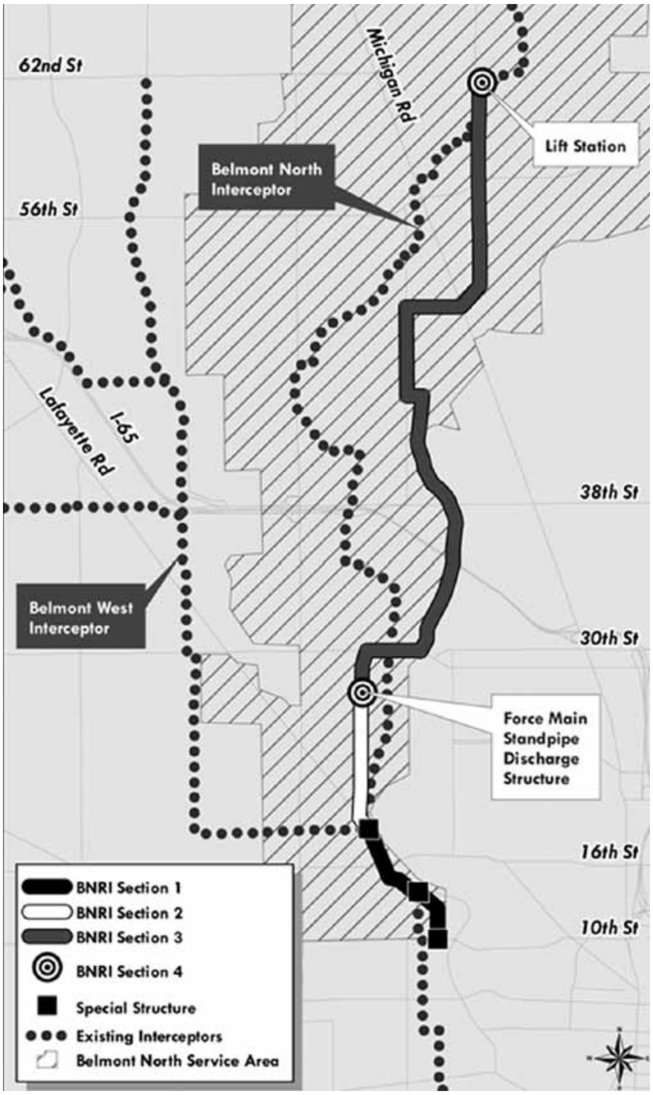
BNRI Section 2 — Project includes construction of approximately 1,525 m (5,000 ft) of 1,200-mm- (48-in.-) diameter gravity sewer installed using opencut excavation and limited trenchless installation. Project includes crossing and supporting/protecting critical water and gas utility transmission lines.

BNRI Section 3 — Project is comprised of approximately 8,534 m (28,000 ft) of 1,000-mm- (42-in.-) diameter sanitary force main installed using opencut excavation and limited trenchless installation. The project also includes approximately 1,980 m (6,500 ft) of 200-mm (8-in.) gravity sanitary sewer installation as part of the septic tank elimination program (STEP). The project starts at the Section 4 Standpipe and stretches north to Juan Solomon Park where it ends at the Section 4 lift station.

BNRI Section 4 — Project consists of the 144,000 m^3/d (38 million gal/day) Belmont North Lift Station (BNLS) and Belmont North Standpipe (BNS) discharge structure. The lift station design includes a wet well and dry well approximately 12 m (40 ft) deep, with a large control building for power, pump control and odor control equipment situated over the dry well. The lift station uses four high-horsepower, dry-pit submersible pumps to send waste water to the 1,000 mm (42 in.) Section 3 force main, which eventually discharges into the BNS at Coffin golf course. The Section 4 BNS accepts waste water flow from the Section 3 force main and transfers it into the Section 2, 1,200-mm- (48-in.-) diameter gravity sewer immediately downstream to the south.

FIG. 2

Belmont North Relief Interceptor project sections.



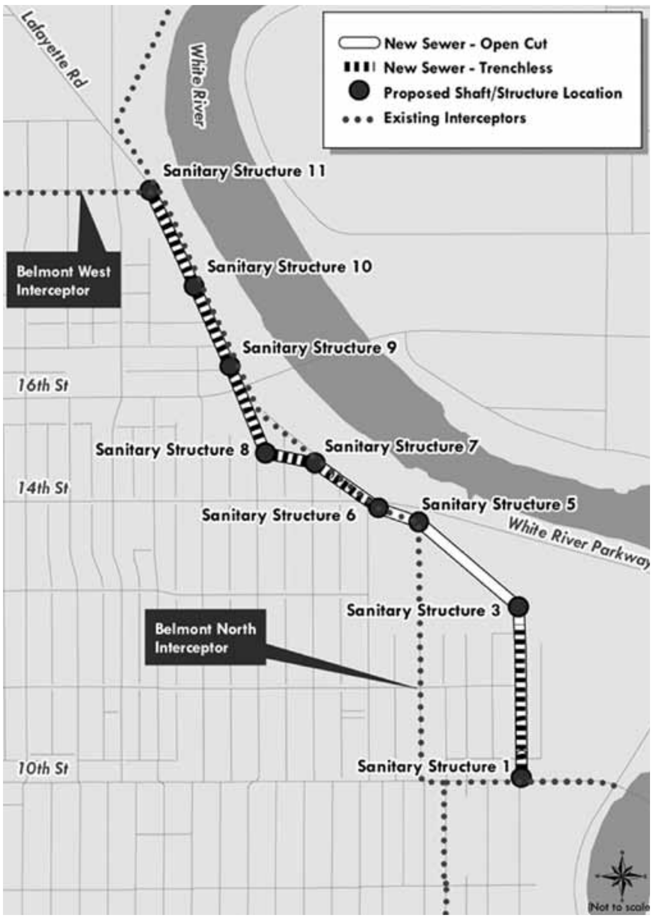
The remainder of this article focuses on the challenges and successes of the BNRI Section 1 project, the large diameter microtunnel relief sewer.

Planning and execution constraints

The Belmont North Relief Interceptor (BNRI) Section 1 project is the southern downstream end of the relief sewer system and consists of approximately 1,600 m (5,250 ft) of 1,800-mm- (72-in.-) diameter gravity sewer installed primarily using microtunneling methods. Right-of-way and city-owned property, coupled with feasible jacking and receiving shaft locations, resulted

FIG. 3

Belmont North Relief Interceptor Section 1 project alignment.



in six microtunnel boring machine (MTBM) drives and one traditional opencut section (Fig. 3).

BNRI Section 1 — project phasing

Arguably the most difficult challenge realized during design of the Section 1 project was critical project shafts and associated sewer connection structures could potentially result in the simultaneous closures of multiple major roadways within the same general vicinity of the city. City representatives determined traffic restrictions or closures of 10th St. and White River Parkway West Drive (WRPWD), two thoroughfares within the project limits, could not be permitted during the following three critical yearly community events as a matter of public safety:

- Indianapolis Mini-Marathon—May 2, 2009 and May 1, 2010;
- Indianapolis 500—Weekends of May 24, 2009 and May 30, 2010 (to include Friday, Saturday, Sunday and any additional rain days);
- Brickyard 400—Weekends of July 26, 2009 and July 25, 2010 (to include Friday, Saturday, Sunday and any additional rain days).

In addition, the city decided traffic restrictions at 10th St. could not be permitted to occur simultaneously with restrictions on WRPWD.

In order to effectively manage these significant traffic related construction restraints and ensure completion of the Section 1 project within the required time, the project was divided into four phases (Fig. 4). Each phase was assigned a substantial completion and final completion period (calendar days), each including liquidated damages, in an effort to ensure work would be prosecuted regularly and diligently, while still achieving the city's traffic control requirements. The following summarizes the contract specified project phasing, timeframes, liquidated damages and key work elements within each phase:

Phase 1: Overall project includes all other project phase and limits.

- 550 Calendar days to achieve substantial completion.
- Final completion of all work 90 days following substantial completion.
- $750/calendar day liquidated damages for delay in achieving substantial completion.
- $400/calendar day liquidated damages for delay in achieving final completion.

Phase 2: Work at the 10th St. and Miley Ave. intersection, including the shaft and structure for connection to the existing BNI, several other smaller sewer relocations/connections and all associated restoration work.

- 150 calendar days to achieve substantial completion.
- Substantial completion cannot extend beyond Phase 1 substantial completion.
- $500/calendar day liquidated damages for delay in achieving substantial completion.

Phase 3: Work in the vicinity of 19th St. and Lafayette Rd., including the shaft and structure for connection of the 1,000-mm (42-in.) Belmont West Interceptor, several other smaller sewer relocations/connections, and all associated restoration work.

- 180 calendar days to achieve substantial completion.
- Substantial completion cannot extend beyond Phase 1 substantial completion.
- $500/calendar day liquidated damages for delay in achieving substantial completion.

Phase 4: Work within White River Parkway West

Dr., including multiple shafts and connection structures for relief interceptor bends and all associated restoration work.

- 270 calendar days to achieve substantial completion.
- Substantial completion cannot extend beyond Phase 1 substantial completion.
- $500/calendar day liquidated damages for delay in achieving substantial completion.

Bidding approach

In the initial pre-bid assessment of any tunnel project, the first step taken by bidders is to compare the geotechnical reports provided and the engineer's specified means-and-methods with their company's equipment fleet and availability. In the case of BNRI Section 1, the geotechnical baseline report (GBR) demonstrated a complex variable geology containing soils from loose, wet sands to dense glacial till, all of which contained high concentrations of cobble and boulders; including one drive were all of the different conditions were expected to be encountered (Fig. 5).

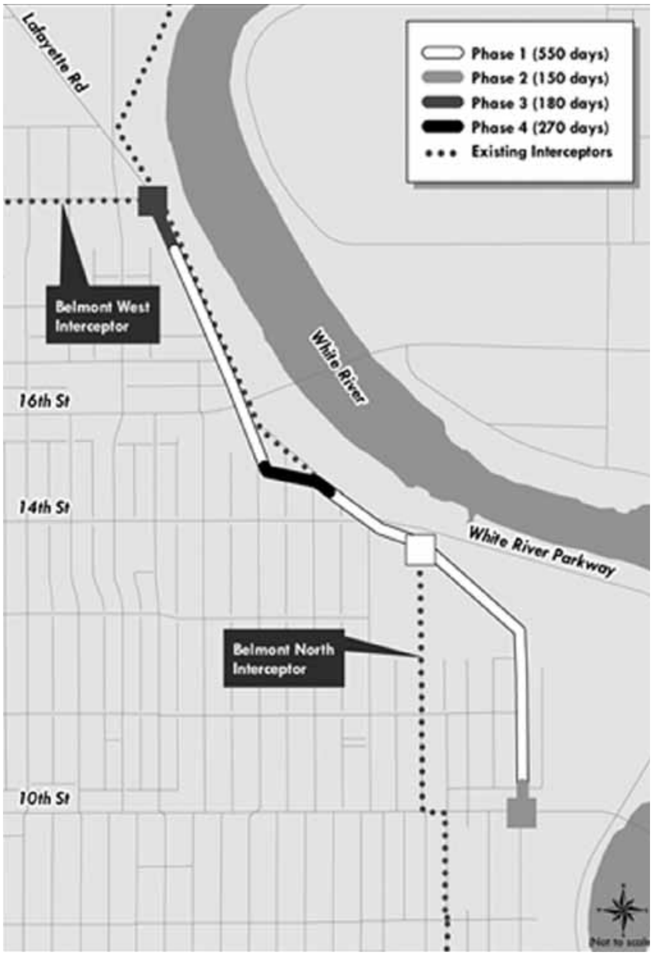
The Rasa DH-1900 MTBM owned by Bradshaw Construction Corp. was selected for use in this application because its size was a reasonable fit with the product pipe, and because of its power and weight. The 1,800-mm (72 -in.) interior diameter pipe size, on the larger end of the microtunnel pipe jacking spectrum, allowed the MTBM to have enough power and thrust to effectively cut the cobbles and boulders to a manageable size and to have room enough for an opening allowing manned access to the tunnel face that could be used in investigating and/or removing a boulder that was blocking the cutter head. Having successfully used the MTBM on previous projects, Bradshaw Construction was comfortable with the Rasa machine's ability to perform on the project. However, the specification that the project mobilization would serve as full payment for the MTBM rental added significant bidding risk if it did not perform, regardless of the cause. The potential boulder encounters made this risk a significant consideration.

Pipe selection was a less complicated operation, as to win a job, contractors typically have to use the least expensive product allowed by the specifications. And while both ASCE Type B and Type C joints were allowed for use, the only quotation available at bid time was the Type B. The quote from a local manufacturer, Independent Concrete Products, would allow Bradshaw Construction ready access to the construction process and availability of their engineers and technicians if the project required it.

Another bidding consideration was the restraints to the schedule due to the project's proximity to the Indianapolis Motor Speedway and the restrictions during events to be held there. As an 11-m- (35-ft-) deep tunnel access shaft cannot simply be "plated over" to allow safe access to traffic, the tunneling operation had to be condensed into phases within the total project duration. The potential of not meeting the phase durations also added bidding risk to the project.

FIG. 4

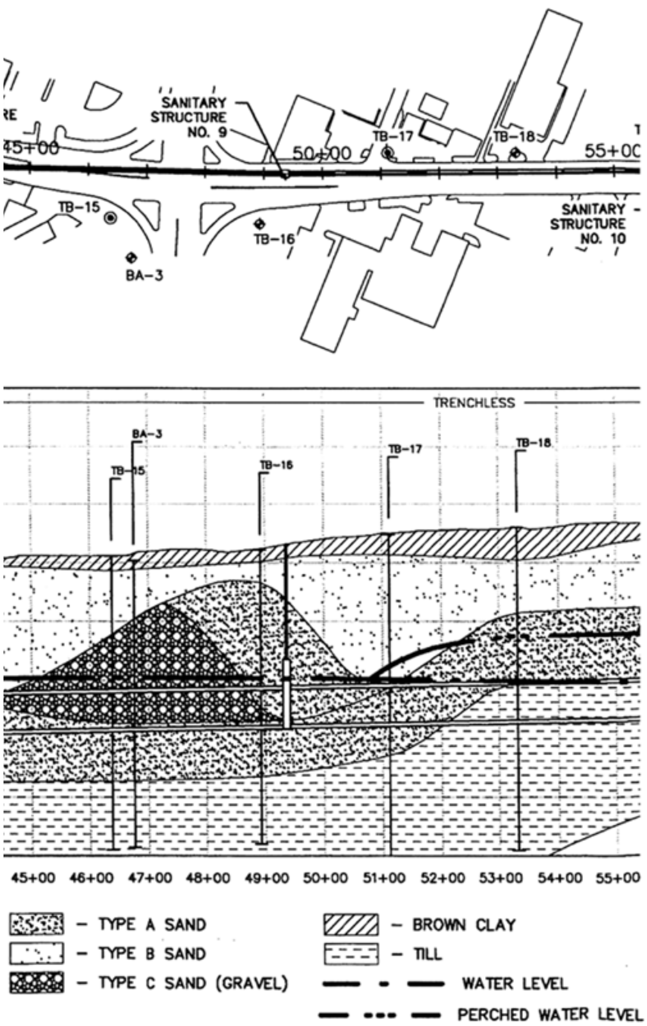
Belmont North Relief Interceptor Section 1 project phases.



Bid Alternates 1 and 2, as defined by the city, also had to be considered. Bid alternate No. 1, which eliminated Structure No. 2 and lengthened the tunnel north from Structure No. 1 by 76 m (250 ft) to Structure No. 3 was selected to bid by Bradshaw Construction. Not only would this change present a cost-savings to both the city of Indianapolis and Bradshaw Construction Corp., the pipe size and soil conditions would allow for the additional length to the tunnel drive with minimal additional risk. Bradshaw Construction did not elect to pursue bid alternate 2 as it would require the mobilization of a second TBM. The company did not feel that elimination of one of the three shafts on Lafayette Road would present savings in either cost to the city or gains to the overall project schedule.

FIG. 5

Belmont North Relief Interceptor Section 1 typical geotechnical profile.



Construction

Shaft sinking. The selection of support of excavation materials for shaft sinking was made considering the geotechnical information, cost effectiveness and versatility of the system. Steel sheeting was eliminated from consideration, as the boulder content in the soils from the GBR made driving sheeting very risky, if not impossible. A large boulder could stop the sheet from being driven to its correct depth, and even boulders that did not cause refusal of the sheet, would slow productions, and would have made sheeting an expensive option. The location of the ground water table also had to be considered in shaft support material selection. The typical ground water table throughout the project was located 3 m (10 ft) above the bottom of excavation and could be dewatered, but the sandy soil conditions required that the supports be installed in such a way that only small surface areas be exposed at any given time to limit soil raveling. Also, in many instances, the proximity of the shaft perimeter to existing overhead power lines would have either required the electric line to be de-energized (which the utility was unable to do) or the shafts to be moved. Relocating shafts was not an acceptable option because it would not maintain traffic lanes while keeping all work within the defined construction easements.

Gasketed liner plate and steel rib shaft supports solved these issues. Individual plates installed in a dewatered condition minimized ground loss and, in areas where boulders conflicted with the shaft perimeter, they were removed as needed with their voids filled during the grouting process. The segmental nature of liner plate shaft construction allowed the shaft supports to be assembled by hand in areas where a crane could not reach such as directly below power lines, eliminating the overhead conflict. Additionally, since the plates are individually installed when the soil is exposed, shaft penetrations can be made with only minor gaps between the shaft support and the existing utility, such as the existing 1,400 mm (54 in.) and 2,000 mm (78 in.) sewer at Structures No. 5 and No. 1, respectively. Also, in dealing with the installation of the shafts that contained existing sewers, there was no guessing game when it came to the exact location of the sewers. Once they were physically located within the shaft excavations, the penetration was constructed tightly around the sewer. The alternative of driving sheeting would have required the assumption of a location and, if that information was wrong, a sheet could be driven through the existing pipeline on one side while the gap on the other side is so large that stopping the soil from raveling into the shaft would be a challenge. In total, nine liner plate shafts were installed on the project with diameters ranging from 7.3 m (24 ft) to 12 m (40 ft) to an average depth of 10.3 m (34 ft) (Figs. 6 and 7).

The shaft for Structure No. 1 is a good example of the advantages of liner plate construction. Structure No. 1 was the connection point between the new 1,800 mm (72 in.) Belmont Relief Interceptor and the existing 2,000 mm (78 in.) Belmont Interceptor. On the south and west sides of the structure location were active overhead power lines. The line on the west side was a large transmission line that served as a one-way feed to a mill that could not be de-energized for any reason. The selection of a liner plate shaft was made to avoid this power line during construction. The shaft was designed with 10.7-m- (35-ft-) diameter inside clearance to allow the recovery of the MTBM, while the existing interceptor remained in service and to allow CIP structure construction to occur per plan giving the sewer location a ±1 m (±3 ft) tolerance. Bradshaw Construction felt that this tolerance was necessary because the existing sewer had been installed by tunnel more than 50 years ago and the nearest manhole in which the alignment could be verified was more than 150 m (500 ft) away.

As shaft excavation progressed, the existing sewer was encountered near its plan location. However, it was determined to be a 2,750-mm (108-in.) liner plate horseshoe tunnel with a cast-in-place concrete tunnel liner instead of the 2,000-mm (78-in.) reinforced concrete carrier pipe (RCP) expected. Only minor alteration to the shaft supports were required to complete the excavation, but the support of the sewer itself did require redesign. The initial intention was to remove the existing tunnel supports from the sewer and hang the 2,000-mm (78-in.) RCP from the surface using steel beams and cables. The cast-in-place liner did not allow for this support system, as its weight was estimated at more than twice that of the RCP. In order to make use of the same support materials that had already been purchased and was onsite, the pipe support was revised by pouring a concrete cradle under half of the exposed span. This cradle reduced the unsupported tunnel span enough that the current support beams could handle the weight. Since the shaft supports were one-time use liner plates, the delays associated with the change did not result in additional support of excavation costs to the city.

Microtunneling

The 1,193-m (3,913-ft) of microtunneling on the project was accomplished in six drives ranging in distance from 107 m (351 ft) to 346 m (1,136 ft) and was completed by pipe jacking of 1,800 mm (72 in.) RCP with an ASCE Type B joint behind a Rasa DH-1,900 MTBM. One of the most challenging aspects of the project's tunneling was the use of the same machine for different soil conditions. The southern three-quarters of the tunneling occurred in glacial sands below the ground water table with the north one-quarter in glacial till, all of which had the potential for cobbles and boulders. The transition between the two major soil types even occurred in the middle of the tunnel drive between structures No. 9 and No. 10. The Rasa MTBM owned by Bradshaw Construction had to be modified to handle all of these conditions. In conjunction with the engineers at Rasa, a mixed-face cutter wheel, equipped with nine disc cutters, was determined to be the appropriate cutter head for the job. Its tooling could be arranged to excavate both the sand and till, while the cutters would be able to crush boulders as they presented themselves. Equipping the cutter wheel in this manner was more than required for excavation of most soils, but it significantly reduced the risk that the MTBM would be required for its rescue should it encounter a boulder it could not cut with a lesser cutter wheel. A BNRI microtunneling summary is included in Table 1.

The MTBM and cutter wheel proved effective throughout the project, with average 12-hour shift advances of approximately 6 m (20 ft) in the glacial till and 14 m (46 ft) in the sands. Additionally, the authors believe that is was effective in crushing boulders. Many boulders ranging up to 1.8-m- (6-ft-) long were encountered in the shaft excavation at the level the MTBM mined through, and all six tunnels were completed without rescue and without finding a boulder being pushed ahead of the MTBM upon recovery. Large spikes in cutter head torque were seen in all drives during the course of the mining operations, some that even rolled the machine 10°- to 15°. The authors assume that these occurrences were boulder caused, and assume that they were crushed as they did not cause a stop to the tunnels. With microtunneling, there is no physical way of viewing the actual soil at the cutting face dur-

FIG. 6

Typical project shaft.

FIG. 7

Shaft with typical launch/receiving portal.

Table 1

Belmont North Relief Interceptor microtunneling summary.

Drive number	Drive length (M)	MTBM launch/ recovery date	Shifts per day	Maximum pipe in-stalled per shift	Maxium jacking forces (tonnes)	Number of IJS	Alignment tolerance achieved (mm)
No. 1	176	11/05/09-11/18/09	1	8	390	1	±33 V / ±48 H
No. 2	107	12/03/09-12/09/09	1	10	360	0	±46 V / ± 41 H
No. 3	198	12/29/09-01/14/10	1	8	740	1	± 43 V / ± 50 H
No. 4	195	02/04/10-02/22/10	1	9	320	1	± 25 V / ± 56 H
No. 5	171	03/09/10-04/02/10	1	4	360	1	± 38 V / ±15 H
No. 6	346	09/14/10-09/29/10	2	9	625	3	± 43 V / ±53 H

ing excavation because it is a closed machine and the spoils are recovered by a slurry separation system. The mining anomalies of torque spikes and sudden MTBM roll are the only direct evidence of the boulder presence (Figs. 8 and 9).

The mining, despite consistent production, was not without its own issues. One of the first challenges occurred in the first tunnel drive from Structure No. 6 to Structure No. 7, where shortly after the launch, the pipe spigot directly behind the MTBM was found to have broken. In this case, a steering correction less than 15 m (50 ft) from the launch shaft probably caused the damage, but broken pipe spigots are not uncommon in pipe jacking of RCP with Type B bell-and-spigot joints. In order to meet rebar cover requirements, the rebar cage cannot be extended through the entire pipe spigot making it the weakest point on the pipe. A steering correction or boulders in the soil wedging against the pipe, among other things, can cause a point load which can cause such a break. In this case, as the jacking forces were transmitted in the pipe bell only, the structural integrity of the pipe was still intact allowing mining to continue. Working together with the pipe manufacturer, an internal steel brace was installed to prevent further damage and limit ground water infiltration. Upon recovery, the broken joint was cut off of the pipe at its connection to the cast-in-place structure wall. To limit the potential for further spigot breaks, Bradshaw Construction design and constructed an additional steel trailing section to follow the MTBM through the ground. It was made 3-m- (10-ft-) long and at the same diam¬eter as the MTBM, which is larger than the 2.4-m- (8-ft-) long RCP pipes with a slightly smaller diameter. The theory is that the larger trailing section will better distribute any point loads and the pipes themselves can pass through its path with less resistance. Of the approximately 500 pipe joints installed less than 1 percent required repair, of which most were hairline cracks that passed a joint test prior to repair. All repairs were performed and guaranteed by the pipe manufacturer.

FIG. 8

Rasa DH-1900 MTBM.

Another issue occurred in the tunnel drive from Structure No. 8 to Structure No. 9. With 95 percent of the mining complete, the MTBM ceased being able to return excavated materials to the surface. Typically, this would indicate that the slurry circuit was blocked. Under that assumption, Bradshaw Construction Corp. proceeded to test all of the valves in circuit and inspect the lines for blockages, but could not find the problem. While testing the circuit, a sinkhole developed above the MTBM. This occurrence was especially perplexing in that it developed while no spoils had been excavated. What Bradshaw Construction found was that the blade of the valve used to bypass the slurry circuit behind the MTBM cutting face had sheared off. Externally, the valve looked like it was opening and closing normally and was indicating such to the MTBM operator in the surface control container. In reality the only thing rotating was the automated stem while slurry pressures left the bypass valve in a constant open position. The problem this posed was that when attempting to excavate material, the path of least resistance for the slurry was through the "closed" bypass valve and not through the cutting face, thus no excavation. We could only assume that the sinkhole developed through head vibration when the MTBM could not excavate and slurry pressure while trying to clear a non-existent blockage, consolidated the fines in the soil into the sands below causing the sinkhole. Luckily, all of this occurred once the MTBM had exited the lanes containing active traffic and beneath a concrete pavement layer nearly 300-mm- (12-in.-) thick. The nearly 30-m^3 (40-cu yd) void was filled using a low strength, cement-fly ash slurry material that, because it is self-leveling and highly flowable, was able to fill the void through a 300-mm- (12-in.-) diameter hole cored in the pavement.

As replacement parts for this type of machine are not typically off-the-shelf items, and this valve failure had never before occurred during Bradshaw Construction's microtunneling history, a direct part replacement was not an option. While a new valve was ordered and expedited for delivery, the tunnel drive still needed to be resumed faster than the part could be delivered. The farther out a pipe jacking tunnel has progressed, the higher the risk of the pipe freezing in place due to friction if it is not moved. And, in this case the MTBM was less than 7.5 m (25 ft) from the recovery shaft. The temporary fix was to install a standard 150-mm (6-in.) butterfly valve in place of the broken one. The challenge with this solution was that the valve stem did not match the machines automated system and had to be operated manually. The tunnel was completed with one operator driving the machine in the control container and another opening and closing the bypass valve by hand inside the MTBM. The replacement valve was installed prior to the MTBM's next launch (Fig. 10).

Active flow sewer tie-ins

Completion of the project required the tie-in of the relief sewer to the existing system at three locations: 2,000 mm (78 in.) at Structure No. 1, 1,400 mm (54 in.) at Structure No. 5 and 1,000 mm (42 in.) at Structure No. 11. While the 1,000 mm (42 in.) tie-in required the diversion of an existing sewer into the new interceptor and abandonment of its previous connection, the other two larger tie-ins were at junctions structures were the new and existing lines remained active. The connection points also occurred away from the existing manhole structures on straight sections of the existing pipelines. Bradshaw Construction Corp.'s initial assessment of the tie ins was to perform them with temporary flumes. A typical bypass pumping system was not seen as feasible in these locations because depth of the existing sewers,

FIG. 9

Cutter head tooling.

7.5 - 9 m (25 - 30 ft) below ground surface, would be at the extreme end of efficient suction pump capabili¬ties, meaning more pumps would be required to move the same amount of flow in a shallower pipe line. Secondarily, the access allowed by the contract staging areas did not provide the required room for pump setup upstream of the tie-in, easement for discharge piping, or a discharge location.

Once presented with the flume option reducing the 2,000 mm (78 in.) sewer at Structure No. 1 to a 1,500 mm (60 in.) flume and reducing the 1,400 mm (54 in.) at Structure No. 5 to 1,000 mm (42 in.), the city of Indianapolis's design engineer, Clark Dietz Engineers, verified that the diameter reduction would present a minimal increase to the system's hydraulic grade line in high flow conditions and approved using a flume.

The next hurdle was to design a flume system that would allow efficient, safe installation and removal while providing working access. This all had to occur within inside diameter of the existing sewer so the flow channels could be installed. The solution to this problem was presented by MacAllister Machinery and Plug-it Products. Their system was a hydraulically powered, telescoping flow-diverter equipped with inflatable

FIG. 10

MTBM breakthrough.

plugs on either end to match the existing pipelines, and flow-through openings to match the designed flume diameter.

Installation of the flumes was found to be less complicated than a bypass pumping setup. The walls of each structure were cast around the existing sewers while they were still active (Fig. 11). Once ready to install the flow channel, the existing pipe was saw-cut near the face of the walls and removed, leaving the interior of the structures to serve as a retention pool for the sewer flow until the flume could be installed (Fig. 12). At that point, the collapsed flume was lowered into the structure and extended so that the plugs on either end entered the existing sewer (Fig. 12). The plugs on either end were then inflated, returning all flow from the sewer into the flume. Lastly, the structure's interior was pumped out and the sewage washed away from the working area for construction of the flow channel and benchwalls (Fig. 13). After the channel was poured, removal simply consisted of deflating the plugs, collapsing the flume's hydraulic jacks and hoisting it out of the channel, activating the structure. The entire operation was confined to the shaft's staging area and structure's footprint as a working zone.

Schedule

Bradshaw Construction's preliminary construction schedule delivered within two days of the notice to proceed (NTP) elicited some discussion between the CM and contractor. While it accurately reflected the overall and specific execution constraints described, the main causes for concern were multiple critical paths and the proposal to complete Phase 4 followed by Phase 2 before the Indianapolis Mini Marathon on May 1, 2010. This was partly because the longest MTBM drive of 346 m (1,136 ft) was included in Phase 2. Consequently any delay to the scheduled completion of both of these phases would violate the contractual requirement that Phase 2 work could not be carried out during several iconic Indianapolis events, including the annual mini marathon, the Indianapolis 500 and the Brickyard 400 races.

Bradshaw Construction felt that this aggressive schedule was necessary to meet the project phase milestones. The period between the mini marathon and the Brickyard 400 (May 3 to July 26, 2010) was not enough time to complete the Phase 2 work, which included excavation of shaft, MTBM recovery, tie-in to the existing 2,000 mm (78 in.) interceptor and construction of Structure No. 1. Therefore the work would either have to be done before the 2010 Mini Marathon or after the 2010 Brickyard 400 race. Phase 3 schedule limitations at the staging area No. 9 at the furthest upstream end of the project could not be completed until after the downstream end of the sewer was activated. Performing the Phase 2 work after the shutdown period would have led to an incredible amount of work to be done in the last third of the contract duration while having virtually no critical path work completed during the preceding spring and summer.

During several rounds of reviews and discussions when the Primavera P3 cost loaded schedule was produced, Bradshaw Construction conceded that any delays would compromise timely completion of Phase 2 and assured the city and the CM that a contingency plan was put in place in the event that a late start on the drive from Sanitary Structure No. 3 to Sanitary Structure No. 1 would jeopardize completing Sanitary Structure No. 1 and therefore opening 10th St. before the mini marathon.

By the end of November 2009, it became clear that Phase 2 could not be completed before the mini marathon and a change in approach was needed. Bradshaw Construction submitted a revised construction schedule that postponed Phase 2 to the end of July 2010, after the Brickyard 400. Essentially, this involved microtunneling from Sanitary Structure No. 10 to Sanitary Structure No. 9 directly following the Phase 4 work that required the closure of White River Parkway West Dr. This would all be completed before the longest drive (Sanitary Structure No. 3 to Sanitary Structure No. 1) terminating at Miley Ave. and 10th St. Figure 3 illustrates the layout reflecting the drives and sanitary structures.

To increase the efficiency of this alternate schedule, Bradshaw Construction Corp. proposed to move Structure No. 11 south along the alignment. This change would allow the shaft to be installed and the tunnel from Structure No. 10 to No. 11 completed without closing the intersection of 19th St. and Lafayette Road which is what the Phase 3 work constraint detailed. As the upstream tie ins to Structure No. 11 had always occured outside the structure walls themselves, shortening the tunnel distance and lengthening the tie-ins presented a situation that would alleviate much of the post-Brickyard scope and allow the final tie-ins to be completed independently of the structure at the end of the project.

Disputes review board

Officials from the city of Indianapolis Department of Public Works were aware that they were embarking on a $1.3 billion CSO program that included approximately 40 km (25 miles) of tunnels as well as associated working and retrieval shafts, 30 drop shafts and several miles of large diameter consolidation and relief sewers to comply with their consent decree. Large tunnel contracts were new to the city, so managing these contracts had been foremost in the minds of the department, and strategies included appointing the Clean Stream Team as program managers and ensuring that consultants appointed for the underground design contracts were experienced in this field. Another strategy that was under consideration was the use of a dispute review board (DRB), particularly for underground construction elements of the program. While the Belmont North Relief Interceptor – Section 1 is a relatively small part of the overall program, it provided an ideal opportunity for the department to evaluate the benefits of a DRB without the added pressure of managing the main tunnel contracts, scheduled to be the largest construction contract in the history of the city, all at the same time.

The DRB was set up contractually with a conventional DRB three-party agreement, with the city and Bradshaw Construction each nominating a DRB member with the concurrence of the other party and these two members selected the DRB chairman. The DRB members were, respectively, Ed Cording, Don Hill and Dan Meyer, and the first DRB meeting was held on site five months after the notice to proceed was issued to Bradshaw Construction.

This meeting was clearly an information gathering exercise for all involved. As is usual, the DRB chairman posted a detailed agenda so that the DRB members could be swiftly and efficiently brought up to speed and to supplement the contract documents and documentation they had already received such as pre¬construction and progress meeting notes. Many city staff representatives were eager to learn about DRBs, and their numbers from the Department of Public Works and the Clean Stream Team surprised the DRB Members. Of course Bradshaw Construction Corp., Christopher B. Burke Engineering, Ltd., Clark Dietz Engineers, and Black & Veatch Corp. were also in attendance.

The main outcome of the meeting, in addition to routinely setting up a schedule for quarterly DRB meetings and site visits as well as outlining the procedures should a dispute arise were as follows:

- The informal nature of the regular meetings was emphasized; notes were not to be kept of these meetings.
- Dan Meyer made it clear that any DRB procedures required the agreement of both parties to the contract.
- The DRB strongly suggested that an agreed, contractual schedule be finalized as soon as possible to replace the working schedule that was being used to monitor the work.
- All DRB recommendations to try and resolve a dispute would be based strictly on the contract terms and conditions. In other words, the DRB were not going to try and broker an extra-contractual deal.

Notwithstanding the success of the initial DRB

FIG. 11

Structure walls cast around.

FIG. 12

Removal of existing sewer.

FIG. 13

Flowline and benchwall construction.

meeting, a certain amount of reluctance to accept the benefits of a DRB was still noticeable. This was not confined to Bradshaw Construction. The city, Clean Stream and Christopher B. Burke Engineering staff all jokingly discussed with Bradshaw Construction how removing the DRB would result in an immediate cost reduction of $50,000 (the allowance item for the DRB) on the project.

What must be recorded is that the DRB recommendation to finalize the contractual construction schedule did provide the impetus needed to get that task done. As time passed and the regular quarterly meetings and site inspections became routine, the benefits of having the DRB review notes of progress meetings and ask detailed questions about proposed changes to the construction schedule for Sanitary Structure No. 11, which ensured thoughtful implementation became evident to all concerned. It is pleasing to report that at the last DRB meeting, when there were still no unresolved disputes or expectations of any, the city representative and Bradshaw Construction site staff noted that they were pleased that the DRB was in place and that simply having a DRB on the project had caused them to be extra vigilant in correctly handling the contractual issues that did arise on the project. Indeed, at the "Better Specifications for Underground Projects Workshop" held at the North American Tunneling Conference, June 20, 2010, Les Bradshaw (A principle of Bradshaw Construction Corp.) was quoted as saying "In the meantime, I strongly recommend the use of disputes review boards (DRB)s for mechanized tunneling projects as small as $5 million. A DRB cost of $50,000 to $100,000 is insignificant when you realize that daily crew cost for even a small 1,500-mm- (60-in) diameter microtunnel is rapidly approaching $20,000 per 10-hour shift. Minimizing just a few days of delay alone can easily pay for a DRB's time."

Certainly, based on the Belmont North Relief Interceptor–Section 1 experience, all of the role players on this project would endorse the recommendation made by Bradshaw.

Conclusion

The BNRI project is acknowledged by all concerned parties to be a successful project. True to form with underground structures, it was not without challenges. Even with the benefit of hindsight, preventing settlement above the MTBM near Structure No. 9 would be nearly impossible to prevent. The paper also outlined issues faced and overcome with steering forces causing Type B bell-and-spigot joint failures, difficult staging constraints that required rescheduling to overcome, revising Structure No.11 to minimize the contract duration and ingenuity required to use previously planned steel support for the 2,750 mm (108 in.) horseshoe tunnel instead of a 2,000 mm (78 in.) RCP existing sewer within structure No. 1.

Dealing with all of these issues required a dedicated, suitably experienced and professional team that included the city, contractor, design engineer and third-party construction inspector to work together. Perhaps the most important aspect was continuing dialogue, which is not to say that there were no differences of opinion.

In addition, Bradshaw brought technically superior solutions to the project. This started with carefully considered bidding strategies and continued with the liner plate and steel rib initial support for shaft excavations, aggressively pursuing schedule goals and rapid responses to the unexpected. Perhaps the most impressive aspect was their use of hydraulically powered, telescoping flow-diverters equipped with inflatable plugs on either end instead of expensive bypass pumping where active flow sewer tie-ins were required.

We should record that the use of a DRB on a relatively small project has proven to be successful and is endorsed for future use on underground projects. (References are available from the authors.) ■

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