MICROTUNNEL IN BIRMINGHAM ROCK

Carson Loop Water Main - Challenging 1,165 LF Drive in Mixed-Face & Mixed-Reach Conditions

By: Mike Wanhatalo,
Bradshaw Construction Corporation

DIP carrier pipe readied for installation with casing spacers in place

Bradshaw Construction Corporation (Bradshaw) recently completed work on the **Carson Loop Phase VI-B project** in Leeds, Alabama. The project owner was the Birmingham Water Works Board and the design engineer was Volkert and Associates. Bradshaw was chosen as the microtunneling subcontractor by the prime contractor Rast Construction. The project increased water capacity delivered to a rapidly developing commercial and residential area by adding 7,165 LF of 36-inch DIP water main. The project required a single 1,165 LF microtunnel drive of 60-inch steel casing.

This article discusses the challenges overcome, actual performance, and conclusions drawn from successfully completing this long microtunnel drive through mixed-face and mixed-reach ground conditions.

Challenges & Solutions

The microtunneling drive was necessarily long, since the planned location of the water main was under six lanes of Interstate 20 and four lanes of State Highway 78, which left no area for an intermediate shaft. Long single drives in microtunneling, such as this, pose unique challenges because of increased jacking loads due to pipe friction and greater difficulty with guidance.

The challenge of increased jacking load was even more difficult to overcome because of the requirement for casing spacers when installing the DIP. This requirement made use of an Intermediate Jacking Station (IJS) impractical due to reduced Inner Diameter (ID) of the casing of 4 to 6 inches. In order to alleviate the increased jacking load a telescopic tail can (tele-can) was used behind the microtunnel boring machine (MTBM). The tele-can added jacking thrust capacity, allowed isolation of pressure on the MTBM disk cutters, and enabled oscillation of the casing string if mining was delayed. As an additional measure, the overcut space of the MTBM versus the casing diameter was maximized by installing 59-inch casing instead of the 60-inch. Doing this reduced friction with the self-supporting rock. The increased overcut enabled nearly complete filling with the bentonite lubrication, further reducing friction.

Proper guidance for a long microtunnel is problematic because the MTBM operator is normally dependent on the laser beam from the shaft. Temperature deviations within the tunnel and shaft can cause the laser beam to deflect, and ground vibrations can cause the laser beam to blur. The project crew innovated and overcame these problems by using adequate ventilation in the tunnel to balance temperatures and shock-absorbers in the laser mount. An electronic water level was used to ensure accuracy on elevation.

Geologic Conditions

Perhaps the greatest challenge for this long microtunnel drive was the geological conditions encountered throughout, which consisted of variable sticky shales and hard sandstones. By definition, the Carson Loop microtunnel drive was mixed-face and mixed-reach. Mixed-face is when the MTBM face encounters two (or more) distinctly different ground types at the tunnel face at any one location throughout the drive. Mixed-reach is when the MTBM encounters a full face of any two (or more) different ground types at separate locations along the drive.

The first 575 feet of drive length was through decomposed shale with some thinly interbedded coal and medium clay seams (N=50+). The next 200 feet was mixed-face shale with sandstone above. The final 390 feet was a full face of moderately hard to hard sandstone - up to 19,470psi Unconfined Compressive Strength (UCS) and 87% to 100% Rock Quality Designation (RQD).

Launch shaft, under 230kv power lines, with view of Highway 78 and Interstate 20 in background.

In a mixed-face and mixed-reach tunnel the MTBM cutter-wheel is selected for its ability to deal with the hardest rock in the drive. This can often slow the tunnel excavation through the softer ground, as evident on this project. A hard rock cutter wheel with 14 disk cutters was chosen to handle the hard sandstone. Mining the first 575 feet was extremely laborious and slow, as the soft shale acted like plastic clay. Disk cutters are meant to break rock not scoop sticky clay! In response the microtunneling crew tried various tooling methods on the cutter wheel. There was some success with the different cutting tools, but the time required for face intervention to make tool changes offset any productivity gains. What proved ultimately most helpful in the excavation and separation of the claylike shale was proper use and chemistry of drilling fluids.

The hard sandstone mined in the final 390 feet of the drive impacted productivity because a 60-inch diameter MTBM is the smallest that allows access to the back of the cutter wheel to change tools. But, as true with any piece of construction equipment, a smaller machine means less power and durability to handle the wear and tear of the hard, abrasive rock. Face access in a 60-inch MTBM involves entry through a tiny 18-inch port. That makes it very difficult for even a small person to get in the cutting chamber to change the heavy disk cutters.

Site Challenges

Site challenges in the Carson Loop project were not critical to productivity, but were important considerations in the pre-construction phase. One such challenge was proximity to overhead power lines. The launch shaft was located directly underneath 230kv lines requiring 20 feet of clearance at all times. Fortunately, the line towers were high enough and the launch shaft was down in a valley that the minimum clearance was easily achieved with a lift restriction on the crane. As additional precautions, all mechanized equipment was grounded, and spotters were used when the crane was set-up.

Additional site factors were the steep grade of the tunnel drive (1.1%) and high water table up to 63 feet above tunnel profile. The steep grade was less impactful because the tunnel was driven

MTBM recovery in receiving shaft

upstream. It did result in increased flows at the launch seal, but this was handled by the shaft sump pump.

Performance

The overall average production rate achieved for installation of the 59-inch steel casing was 10.8 feet per shift including interventions. Once the MTBM got through the shale/sticky clay the average rate was 16 feet per shift. 22 shifts were spent changing disk cutters/tooling with a total of 6 separate interventions at the face. All the efforts taken during setup to improve guidance over the drive length paid off as the tunnel finished on-line and just .01 foot off plan grade. The same applied to the measures taken to minimize jacking thrust. Though 336 tons of jacking force was predicted, only 320 tons of thrust was needed at peak. This reduction was accomplished through proper lubrication, increased overcut space, and tight guidance control.

Conclusions

Initially, at the bid phase of the Carson Loop project, it was estimated that the soft shale segment would yield the best production rates of the entire drive. In actuality, the soft shale acted like sticky clay, which plugged up the rock cutter wheel, and bogged down the separation plant. Therefore, contrary to expectations, the poorest production rates on the job were in the first 575 feet, through the softest part of the shale. Still, to avoid running the risk of a complete stoppage, the rock cutter

"contrary to expectations the poorest production rates on the job were in the first 575 feet, through the softest part of the shale"

wheel had to be used in order to mine the hard sandstone rock later on in the drive. This meant proper drilling fluid chemistry during the soft shale was even more critical both to clear the face of the MTBM and to separate the soils more quickly.

When predicted jacking thrust is a concern, measures must be taken beginning in the preconstruction phase to alleviate the thrust necessary over the length of the drive. Measures used in this project that

ROCK MICROTUNNELING

Following is an excerpt from "Microtunneling in Rock: Fact or Fiction?" originally presented at the Colorado School of Mines. (Lester M. Bradshaw, Jr. President, Bradshaw Construction Corporation.) Download the full paper @ www.bradshawcc.com/docs/MT_ROCK_WHITE_PAPER.pdf

Rock microtunneling presents unique challenges for the MTBM and jacking pipe as well as the means and methods utilized. After nearly a decade of experience, we have the following observations and recommendations:

1) MTBM Advance Rate – A simple formula for calculating rock TBM mining rates per shift is instantaneous penetration rate per revolution x cutter wheel revolutions per minute x mining hours per shift. Conventional hard rock TBM cutter wheels turn at 10-18 RPM while MTBM cutter wheels turn at 2.5 to 5 RPM. MTBMs also have significantly lower instantaneous penetration rates due to their disk cutter's lower thrust capacity. Therefore, MTBMs mine hard rock substantially slower than any conventional TBM and this difference gets greater as the rock gets harder.

2) Cutting Gage – Perimeter gage disk cutters mine the tunnel opening. They do it by being turned nearly perpendicular to the direction of the tunnel and thus are subject to significantly greater wear from abrasion than the other disk cutters. If they wear too much, then the MTBM becomes obstructed by its own shell. The microtunnel drive must be short enough or the MTBM must allow face access to replace them in hard abrasive rock for the drive to be successful.

3) Overcut - For rock microtunneling, where settlement is rarely an issue, we recommend the overcut selection be left up to the contractor. From experience, we generally set the overcut 25% to 50% greater than in soft ground microtunneling to allow the gage cutters to wear down and not obstruct the MTBM. Debris in the overcut void can create substantial and damaging increases in friction since the rock tunnel walls do not yield like soft ground soils do. Increasing the overcut seems to minimize the impact of such debris build up. However, the overcut cannot be so large as to limit the MTBMs ability to develop articulation steering reactions.

4) Cam Locking and Pipe Wedging – Cam locking creates point loading from an object trapped in the overcut void. Wedging involves slurry cuttings passing under the MTBM cutter wheel which leads to lifting then wedging the MTBM and pipe string against the roof of the tunnel. These two conditions can happen repeatedly during a rock microtunnel drive and can cause jacking loads to spike by 50% to 100%. This creates two critical problems.

a. Telescopic Tail Can – The jacking load spikes result in surges in the pipe string that in turn causes thrust load spikes to the MTBM cutting tools unless the MTBM is isolated from the pipe string advancement by the use of a telescopic tail can (tele-can). This is basically a pipe inter-jack station (IJS) that is directly attached to the rear of the MTBM. The operator uses the tele-can to advance the MTBM independent of the pipe string. This allows more careful control and measurement of the thrust applied to the MTBM and indirectly to the cutting tools. Surging from cam locking and wedging of the MTBM itself is minimal thus surging to the cutting tools is as well. Without a tele-can, surge loads can cause excessive wear and even shock load damage to the cutting tools particularly in harder rock formations.

b. Pipe Failures – All pipe materials subjected to cam locking and/or wedging can fail. Clay pipe should not be used for rock microtunneling because of its low tensile strength. Steel casing is by far the most conservative selection.

In conclusion, during the past ten years rock microtunneling has become far more fact than fiction. The key is to know when, where, and how to use microtunneling in these challenging conditions

59-inch steel casing was used in lieu of 60-inch to increase overcut in self-supporting ground

were confirmed to help minimize thrust included; increased overcut space, bentonite lubrication, use of a tele-can, quality steering control, and the use of Permalok steel casing to increase productivity and improve casing quality control.

The most important conclusion to be drawn from the Carson Loop project is that cooperation and close consultation between Owner/Engineer and Contractor/Subcontractor through project duration, from early in the preconstruction phase and then throughout construction, is crucial to the success of a challenging project. There were several instances of cooperation by the Owner/Engineer when methods proposed by the Contractor/Subcontractor were allowed: allowance of increased overcut by reducing casing size, and acceptance of Permalok joints as an alternate to welded joints. Because all members of the project team were able to work together cooperatively the tunnel was completed November 1, 2014 on-time and within budget.

ABOUT THE AUTHOR:

Mike Wanhatalo *is a project manager with 15 years of experience in heavy/civil construction, including 11 years at Bradshaw. Bradshaw Construction Corporation is a tunneling contractor with over 50 years of experience covering a wide range of trenchless techniques.*