MICRO-TUNNELING LARGE DIAMETER SEWER MAY BE THE BEST OPTION FOR YOU

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ABSTRACT

You're designing a large diameter parallel gravity interceptor, up to 72 inch, in deep, wet conditions along an alignment that requires several crossings under City Streets, NCDOT highways, railroad tracks and railroad bridges…which crossing installation method are you going to use? We were faced with this question going into Phase I of the Crabtree Basin Wastewater System Improvements project for the City of Raleigh Public Utilities Department (CORPUD).

KEYWORDS

CORPUD, fiberglass reinforced pipe, jacking pipe, large diameter gravity sewer, micro-tunnel boring machines, micro-tunneling, MTBM, pipe jacking

INTRODUCTION

CORPUD is currently in the process of designing and constructing a major upgrade to its Crabtree Creek Interceptor system. The initial step in the multi-phased project consisted of the design and construction of 19,000 linear feet of 72-inch and 60-inch gravity sewer. A major consideration during the design phase of the initial Phase I was the selection of the crossing methods at the three roadways located along the Phase I alignment. The project design team of Hazen & Sawyer and McKim & Creed undertook an evaluation of multiple trenchless crossing methods suitable for large diameter gravity sewer.

PROJECT HISTORY

In October 2004, CORPUD undertook an effort to comply with the Capacity, Management, Operations, and Maintenance (CMOM) program that was being developed by the Environmental Protection Agency (EPA). One element of the CMOM process involved understanding the hydraulics and capacity of the City's sewer system in an effort to identify deficiencies. To perform this task, CORPUD hired the team of Hazen and Sawyer and CDM to complete a system-wide Sanitary Sewer System Capacity Study (SSCS), which was completed in 2008. The study included a comprehensive effort to estimate current and future flows throughout the City's entire wastewater collection system, develop complete systems models for each drainage basin, evaluate alternatives to meet the City's future wastewater conveyance needs through 2030, and develop a Capital Improvements Program (CIP) for the recommendations. The SSCS included evaluations of 2-year and 10-year wet-weather return frequencies, and the final recommendations and CIP were developed based on the 10-year wet-weather event.

One of the more significant needs identified was in the Crabtree Basin. This basin includes a significant portion of the Raleigh area and stretches from Brier Creek in the northwest corner of the City to the Neuse River on the east side of Raleigh. While the ultimate findings of the SSCS identified several projects within the Crabtree Basin for repair or upgrade, the most significant finding was the need for additional wet weather capacity within the Crabtree Interceptor system from the existing Crabtree Lift Station, located beneath the interchange of US 264 and I-440, upstream to the confluence of Mine Creek and Crabtree Creek near Crabtree Valley Mall. The modeling work and observations during significant wet weather events revealed overflows in the existing Crabtree Interceptor system in this reach. These events are a result of gravity interceptors and siphons that do not have the capacity to convey the wet weather flows associated with severe wet weather events.

During completion of the SSCS, projects were identified that were necessary to alleviate hydraulic restrictions, accommodate future projected flows, and minimize sanitary sewer overflows (SSOs) in the system. In identifying these projects, the ultimate goal for the Crabtree Interceptor system was to essentially divert wet weather flows entering the system from portions of the system north of the I-440 beltline near Crabtree Valley Mall around to the south near the confluence of the Crabtree Creek and the Neuse River. The original concept provided in the SSCS called for a pump station and equalization tank near the Crabtree Valley Mall with an associated 10-mile force main that would deliver the wet weather flows downstream beyond the areas of the system where the flows were causing SSOs. Ultimately, CORPUD moved forward with these recommendations and budgeted approximately $75 million for the design and construction of the project.

In 2009, CORPUD moved forward with the recommendations for an equalization tank, pump station, and force main, and advertised for engineering services to design these components. The team of Hazen and Sawyer and McKim & Creed was selected to perform the work. An initial step in the project was the development of a preliminary engineering report (PER) to investigate the pump station and equalization concept, as well as to determine appropriate routing of the required force main. As the report was developed, it was apparent that a force main routed along the existing Crabtree corridor would be the most advantageous, due to the ability to minimize length, achieve favorable hydraulics for pumping, and save overall project cost. However, upon further review during the development of options in the PER phase, it was decided that an investigation of the potential for installing a new interceptor in the existing interceptor corridor was prudent. The installation of an interceptor would remove the requirement for a pump station and equalization tank. Ultimately, as the PER progressed, it was determined that a new interceptor was both feasible and also the lowest cost alterative identified. The PER recommended a three-phase approach to completing the parallel Crabtree interceptor project. The first phase would consist of a new 72-inch and 60-inch interceptor from the existing Crabtree Lift Station upstream to near Capital Boulevard where the Pigeon House interceptor connects to the Crabtree Interceptor System. Phase II would consist of a 54-inch interceptor from the end of the Phase I interceptor to the Mine Creek interceptor north of the I-440 beltline near Crabtree Valley Mall. Phase III would include a new 40 million gallon per day (MGD) Crabtree Lift Station that would operate in parallel with the existing screw lift Crabtree Lift Station, and an associated 36-inch force main that would discharge into the existing sewer system near the confluence of the Neuse River and Crabtree Creek.

PROJECT CROSSINGS

The project, formally called the Crabtree Basin Wastewater System Conveyance Improvements, included three (3) roadway crossings in Phase I that necessitated trenchless installations. These crossings included the following;

1. The I-440 interchange ramp to the US-64/264 Bypass and two (2) existing 60-inch RCP sewer interceptors
2. New Bern Avenue – NCDOT Secondary Road
3. Raleigh Boulevard – NCDOT Secondary Road

Geotechnical investigations were performed at each crossing to evaluate the subsurface soil conditions, ground water table, and the presence and hardness of rock. The subsurface conditions varied at each crossing with alluvial soils with very low blow-counts to hard rock with unconfined compressive strength measuring as high as 26,000 psi.

The groundwater table was measured to be higher than the proposed interceptor pipe at each crossing, presenting a concern with the impacts that dewatering could have on the subsurface material and ground surface above the pipe. With the proposed interceptor located parallel and in close proximity to Crabtree Creek, the potential for the water table to drop significant was low.

The mixed subsurface conditions and groundwater would be significant factors to consider during the crossing method selection process. An additional site specific factor to consider at each crossing included the location of existing utilities in the construction corridor.

Extensive subsurface utility engineering (SUE) was performed by McKim & Creed as part of the project design to designate existing subsurface (underground) utilities and locate these utilities both horizontally and vertically. Existing subsurface utilities were located horizontally as part of the Quality Level B SUE through use of electro-magnetic (EM) equipment and ground penetrating radar (GPR). Based on the results of the Level B SUE work, the project team selected critical existing subsurface utilities to be vertically located through vacuum excavation. Test holes were implemented above these existing utilities as close to the proposed points of crossing as feasible. The existing utilities were exposed and the top of pipe/conduit elevation was surveyed and the pipe/conduit outside diameter and material was recorded. Some of the existing subsurface utilities included gravity sewers (sanitary and storm) where pipe elevations were estimated from survey elevations on either end of the pipe at manholes or catch basins. At the first crossing underneath the I-440 ramp, the interceptor had to be installed underneath two existing 60-inch RCP gravity sewer interceptors connecting immediately downstream to the Crabtree Creek Lift Station. At the New Bern Avenue crossing, the proposed interceptor had to be installed underneath a 16-inch water main, fiber optic duct bank and several storm drainage pipes. At the Raleigh Boulevard crossing, the proposed interceptor had to be installed beneath a 42-inch RCP sanitary sewer pipe. Many of these existing subsurface utilities were deep and vertical separation between the bottom of these utilities and the top of the proposed interceptor was minimal. These "tight" utility crossings, along with the stringent line and grade specified for the proposed interceptor, required that an accurate crossing method be employed.

In summary, there were several crossing conditions at each location that were taken into account in the crossing evaluations. Three of the key crossing conditions that the team considered when selecting the initial crossing methods for evaluation and ultimately in selection of the final crossing methods, included the following;

- The mixed subsurface soil conditions and hard rock
- The elevated groundwater levels and influence from Crabtree Creek
- Locations and elevations of existing subsurface (underground) utilities

CROSSING DESIGN CONSIDERATIONS

In additional to the consideration of the conditions at each crossing location, overall design criteria had to be considered in selecting crossing methods to evaluate as well.

Due to the 60-inch and 72-inch pipe diameters of the proposed interceptor, the project team was able to rule out some trenchless installation methods based on technology limitations, equipment sizing and availability, and limited experience by qualified contractors. The CORPUD had traditionally used bore and jack (auger boring) and hand tunneling for some of their larger diameter (36-inch and larger) sewer crossings.

Also due to the pipe diameters for the proposed interceptor, certain pipe materials would not be available for the crossing installation including PVC and Ductile Iron pipe. The CORPUD and project design team had performed a detail evaluation of suitable pipe materials for the overall project and it was determine that fiberglass reinforced pipe (FRP) would be utilized as the primary pipe for the proposed interceptor. FRP was one pipe material that would be considered for the crossings if the installation was made as a "single pass" with no carrier pipe.

The design slope for the proposed sewer interceptor had to be very "flat" to do the upstream and downstream tie-in elevations and to provide for cover of the interceptor at the creek and tributary crossings. In additional to the vertical design constraints, the horizontal alignment had very little room for adjustment, primarily due to the location of the proposed interceptor adjacent to the existing interceptor(s), Crabtree Creek and adjacent properties. Therefore, the line and grade for the interceptor had to be maintained to as close to design as possible during construction.

NCDOT's Policies and Procedures typically require utilities six-inches in diameter and larger to be encased in a larger casing pipe when installed beneath their roadways. NCDOT has also become very restrictive on allowing open cut installations across NCDOT roads, especially roads with high daily traffic counts. The three NCDOT roadways crossed in Phase I are vital transportation corridors for the NCDOT with significant daily traffic counts, and therefore had to be crossed utilizing trenchless methods and designs approved by the NCDOT. The COPRUD would not be capable of securing an encroachment agreement with the NCDOT for the proposed crossings without first receiving the NCDOT's approval of the crossings.

Many other design considerations were taken into account when selecting crossing methods to evaluate however the three (3) listed below were some of the most important.

- Pipe Diameter – Impact on pipe material and crossing methods
- Vertical and horizontal alignment restrictions
- NCDOT review and approval required for encroachment agreement

CROSSING METHODS ELIMINATED

Some of the more traditional crossing methods and new technologies were eliminated from further consideration due to limitations of these methods and technologies when considering the crossing location and design conditions.

Open cut is a method that has been traditionally utilized for crossing roadways with larger utility pipes due to the lower construction cost when compared to trenchless methods. Open cut is most commonly used today for larger utility pipe installations when a new roadway is being constructed at the time the utility is being installed. Impacts to traffic and the public in general are generally minimal for new road construction compared to an open cut crossing when a roadway is already in service. As stated earlier, NCDOT is very strict about requiring trenchless methods to be used when crossing major roads and thoroughfares. Due to the significance of the three crossings in Phase I, the open cut method was eliminated from consideration.

Horizontal directional drilling (HDD) was also eliminated due to the limitations in the method's ability to maintain accurate line and grade for gravity sewer installations and due to size limitations on the pipe diameter that can be installed by HDD.

Traditional hand tunneling using manual labor or with open face shields utilizing mechanical excavation equipment with liner plates was also eliminated. This method of tunneling would require extensive dewatering along the alignment which was not viable at some locations and presented a concern of settlement over the tunnel that could result in roadway failures. Additionally, traditional tunneling requires workers to be in the tunnel during excavation which caused concern for safety given the potential for influx of loose soils and groundwater.

Pilot Tube Mirco-tunneling was considered but due to limitations in allowable pipe diameter for the current pilot tube micro-tunnel technology, this method was eliminated from further consideration.

For the reasons stated above, open cut, HDD, traditional hand tunneling, and pilot tube micro-tunneling were eliminated from further consideration.

PRELIMINARY TRENCHLESS METHODS EVALUATED

Preliminary trenchless methods evaluated can be categorized in two groups as follows;

Pipe Jacking

- Bore and Jack (Horizontal Auger Boring)
- Compressed Air Hand Tunneling
- Slurry Microtunneling

Tunnel Boring Machines (TBM)

- Tunnel Boring Machine – Single Shield or Gripper Type
- Earth Pressure Balancing Machine (EPBM) or Slurry Shield

Definitions

Pipe Jacking

For the purposes of this evaluation pipe jacking is defined as: A cyclic procedure using thrust power generated by hydraulic jacks to force prefabricated pipe or casing forward through the ground as the tunnel face is removed via a variety of excavation techniques. The spoil is transported through the inside of the pipe to the drive shaft, where it is removed and disposed of.

Bore and Jack or Horizontal Auger Boring

Horizontal Auger Boring, a type of Pipe Jacking, is defined as: The installation of a casing pipe utilizing pipe jacking in conjunction with a rotating auger contained within the casing that conveys spoil material back through the casing to the bore pit.

Compressed Air Hand Tunneling (CA Hand Tunneling)
Installation of a tunnel utilizing an open-faced shield and compressed air to balance groundwater, prevent material migration into the open excavation, and provide worker safety.

Slurry Microtunneling
Utilizes a remote controlled Microtunnel Boring Machine (MTBM), where excavated material at the tunnel face is mixed with bentonite and other lubrication fluids to create a slurry. Pressure at the cutting face is balanced with earth removal, groundwater head, and propulsion of the tunnel support without manned entry. Excavated material which is captured in the slurry is pumped to the surface and separated.

TBM (Single Shield)
A full-face, open-faced circular mechanized shield machine, usually of worker entry diameter, steerable, and with a rotary cutting head used to excavate a tunnel with a two-pass tunnel support and carrier system installed behind the TBM.

Earth Pressure Balance Machine (EPBM)
The EPBM excavates spoil by balancing the machine face pressure with the soil pressure. Spoils from the cutter chamber are removed through the screw conveyors. Operators, in a control console located within the EPBM, guide the machine and monitor data.

These forms of trenchless installation use mechanized means of excavation, but differ in the following:

- worker entry required,
- cutting face accessible through compressed air intervention,
- one-pass or two-pass installation,
- line and grade accuracy capabilities,
- ability to deal with high groundwater pressure and fluidized material (closed face cutter head),
- ability to excavate hard, competent rock

All these differences in installation methods provide differing levels of risk mitigation through

- prevention and reduction of surface subsidence or heaving potential, and
- site impacts –
  - size of area impacted,
  - length of construction from variability in productivity,
  - length of time and to what degree the impact to contiguous residents and local businesses, and
  - potential impacts to environmental.

	Worker Entry Req'd	**Cutting Face Accessible[1]**	**One-pass Capable**	**Line & Grade Accuracy**	**Open or Closed Faced**	**Hard Rock Capable**
Bore and Jack	No	No	No	No	Open	No[4]
CA Hand Tunneling	Yes	Yes	No	Yes	Open[3]	Yes
Slurry Microtunneling	**No**	**Yes**	**Yes**	**Yes**	**Closed**	**Yes**
Single Shield TBM	Yes	No	No	Yes	Open	No
EPBM or Slurry Sheild	Yes	Yes	No[2]	Yes	Closed	No[5]
Maximum Risk Mitigation Response	**No**	**Yes**	**Yes**	**Yes**	**Closed**	**Yes**

[1] Cutting Face accessible in high groundwater conditions through compressed air intervention procedures.
[2] One-pass is available in some machines but not in the diameter range for this project
[3] Due to compressed air capabilities, CA Hand Tunneling operates essentially the same as a closed face cutting head.
[4] Requires modifications similar to adding an open-faced TBM but with steel casing jacked in-place instead of installing liner plate or other assembled tunnel support.
[5] Not capable in EPBMs for this diameter range.

As indicated throughout this document, severe and varied in-situ subsurface conditions were present throughout the project location including high groundwater table, close proximity of recharge source, poorly graded, alluvial material with the potential to become fluidized (“running sands”), and competent rock. In addition to the difficult and varied subsurface conditions, the project design parameters of a large gravity sewer installation also dictate deep excavations and tight tolerances for line and grade. Due to all of the difficulties outlined above and the input from all stakeholders, the trenchless crossings evaluation required a thorough effort to mitigate all risks possible.

Outlined in the chart above are the many differences in capabilities to mitigate different known risks between the evaluated trenchless methods. Provided on the bottom line of the chart are the maximum risk mitigation factors available for each condition. Slurry Microtunneling is the only method that has the capability in the diameter range necessary for this project to mitigate all the risks identified for this project as shown in the chart above.

MICRO-TUNNEL DESIGN CONSIDERATIONS

Three key considerations in the design of the micro-tunnel crossings included the geotechnical subsurface investigations, the tunnel launch shaft construction, and appropriate pipe materials for installation by microtunneling.

Geotechnical Subsurface Investigations
As with any trenchless crossing, geotechnical information is critical to the success of the design, competitive bidding and a successful installation. It is important to scope an appropriate level of geotechnical subsurface investigation at the start of the project keeping in mind what information will be of value to the design engineer and the contractor responsible for installing the crossing. The project design team utilized the geotechnical services of Falcon Engineering located in Raleigh, North Carolina for the geotechnical field investigations, testing and analysis, and reporting.

<u>Soil Classification Testing:</u> Multiple soil borings were taken at each crossing to a certain depth below the design invert of the tunnel pipe and if auger refusal was encountered due to rock, rock coring was implemented to extend the soil borings to the intended depth. Standard penetration testing was performed at the crossing locations in general accordance with ASTM procedure 1586 “Penetration Test and Split-Barrel Sampling of Soils”. Soil classification testing included Atterberg Limits (ASTM D4318), natural moisture content (ASTM D2216), and mechanical sieve analysis (ASTM D6913). Plasticity indices ranged from non-plastic to 40 and moisture contents ranged from 6 to 39%. Grain size distribution (GSD) curves were also developed. Overall, soil conditions varied greatly along the proposed alignment.

<u>Rock Compressive Strength Testing</u>: The unconfined compressive strength of rock along the interceptor alignment was performed in accordance with ASTM D2938. The strengths ranged from 3,123 psi to 25,910 psi. Rock quality designation (RQD) ranged from 31% to 100%. Rock was mostly comprised of granite, both metamorphosed and Granite Gneiss.

<u>Corrosion Series Testing</u>: Corrosion testing included moisture content (ASTM D2974), Resistivity (EPA -120.1), pH (EPA 9045), and Chloride Content (SM 4500-Cl-E). It was determined that the subsurface conditions in general were moderately corrosive to ferrous and concrete pipe material.

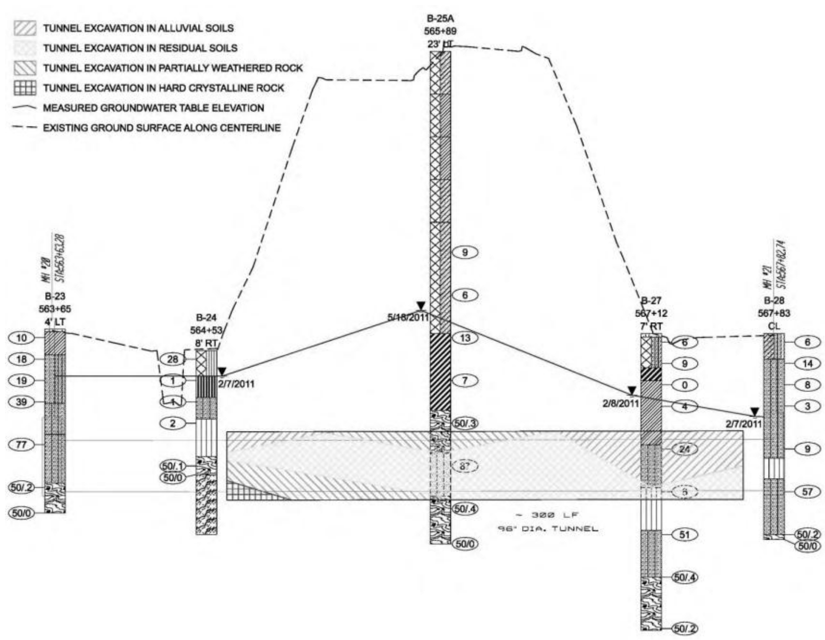
The static 24-hr groundwater table was determined to be over the pipe inverts (and top of pipe in most cases) along the entire Phase I sewer alignment which included over 20,000 LF, primarily along Crabtree Creek.

Various subsurface conditions consisted of loose to hard residuum and alluvium, partially weathered rock (PWR), and hard rock present in the proposed tunnel locations. As explained in the geotechnical subsurface investigation report, *the tunnels would have to be excavated using equipment capable of penetrating soft soil conditions, hard rock conditions, and mixed subsurface conditions safely and efficiently.*

To help provide a better understanding of the varying subsurface conditions, profiles of the tunnel crossings were developed from the design drawings, showing soil boring profiles with the correlating soils stratigraphy and the measured groundwater levels. These profiles provided for comprehensive graphical representations of the subsurface conditions and were very useful in the design of the micro-tunnels. The design engineer could utilize the combined information displayed on the profiles to address the following design criteria;

- Using the soil type, blow-counts, groundwater elevation, and other soil characteristics, calculate the jacking force required to install the selected pipe.
- Determine if there is an advantage to starting the tunnel on one side or the other to achieve a consistent tunnel alignment and avoid deflection or shearing along the pipe.
- Review the stratification between the softer/looser and hard/stiffer materials and the groundwater table to evaluate potential issues with settlement of the pipe or MTBM due to softer soils below the pipe or settlement of soils above tunnel due to softer/looser soils above the pipe.
- Inspect for material (debris, boulders, etc.) that could potentially cause the MTBM to bind-up and become inoperable.

Below is the tunnel profile for the New Bern Avenue tunnel crossing included in the geotechnical investigation report.



While micro-tunneling equipment can be very versatile and capable of tunneling through mixed-faced conditions with high groundwater tables, it is very important that the Engineer to understand the subsurface conditions in order to minimize the risk of potential pitfalls. These pitfalls can include unknown conditions that may otherwise be realized by review of geotechnical information including, but not limited to, buried materials that are difficult for a MTBM to excavate, loose and non-compact soils in the bottom of the tunnel, a sharp angled face of hard rock, and very high strength and plastic rock. While these conditions making micro-tunneling a challenge, if the conditions are known up front the Engineer can likely design the tunnel to minimize risk. Just as important, the contractor responsible for performing the micro-tunnel needs to know as much about the subsurface conditions as available information will allow to help minimize his/her risk and increase the change of success.

A thorough geotechnical investigation and proper documentation of the geotechnical information obtained will help the Engineer provide a sound micro-tunnel design, reduce the unknown factors and lower bid pricing, and ultimately help the contractor install the crossing successfully.

Shaft Construction

One of the most critical components to the overall micro-tunnel operation is construction of the tunnel (launch) shaft that houses the pipe jacking equipment, thrust blocking and seal for the tunnel entry/penetration point.

During the design of the micro-tunnel crossings, the design team had to evaluate the spatial constraints of the crossing locations to determine if the launch shaft and receiving shaft/pit could be installed at the intended beginning and end points of the tunnel. Additionally, adequate space had be available on the same side as the launch shaft for the various micro-tunnel operation equipment including a crane, power and controls/operators trailer, separation tank, and the water, lubrication and slurry tanks and pumps. Depending on the size and length of the tunnel this footprint can be as large as 40’ x 150’.

Spatial constraints that were reviewed during the design of the micro-tunnels included the following items;

- Existing Utilities
- Wetlands and Creeks
- Adjacent Development
- Roadway Embankments

With the proposed sewer being a parallel interceptor, the location of the existing interceptor(s) at the proposed tunnel locations had to be reviewed to ensure there was adequate space for the shaft installation and allow for the micro-tunneling operation equipment to be placed such that operation of the existing sewer would not be impacted. In addition to the existing parallel interceptor, utilities crossing the easement and the proposed sewer alignment were located and identified to assess whether or not the tunnel needed to be extended to avoid conflicts between the shaft installation and other utilities.

The sewer alignment parallels Crabtree Creek and therefore, the location of the top of bank and adjacent wetlands had to be considered in placement of the shafts, not only for constructability, but for accessibility and location of the micro-tunnel operation equipment.

Adjacent development including bridges, buildings and roadways were potential concerns for the location of the shaft construction. In addition to the concern over how close the tunnel path was in relation to road and bridge supports, the shafts had to be constructed to avoid posing a threat to the stability of these structures. Bridges, roadways and buildings also impacted accessibility and available footprint for the tunnel operations.

Two of the three micro-tunnel crossings in Phase I involved tunneling perpendicular to elevated roadway sections where roadway embankments, along with existing utilities, impacted the proposed locations of the tunnel shafts and receiving pits. Where possible, shafts were placed outside of a theoretical 1:1 embankment extended from the edge of the roadway pavement. In some locations, shoring designs were required to gain full acceptability of the tunnel crossings from NCDOT prior to issuance of the NCDOT encroachment agreements.

Shoring is one of the most important parts of the physical tunnel shaft construction. A proper shoring plan must be prepared based on the geotechnical information available and the actual site conditions. Typically, the contractor is responsible for preparing a shoring plan based on the shaft configuration and style that the micro-tunnel contractor plans to install. The shoring plan design should incorporate live loads, hydrostatic pressure and earth loads including embankment loads. Even though it may be the responsibility of the contractor to prepare a formal shoring plan, the Engineer should consider the various design loads and site conditions affecting the shaft during design as part of the evaluation for the shaft location. Considering the shoring design requirements during design will help minimize the complexity of the shaft construction and ultimately reduce safety risk and reduce construction cost.

Another important consideration in shaft construction is the need for dewatering and protection against flooding. With installations required to be as deep as those for the Crabtree Phase I interceptor, the shafts had to be constructed to well below the normal water table. In a couple of locations, the shafts had to be located in close proximity to Crabtree Creek further increasing the chance for groundwater intrusion. It was important that the Crabtree tunnel shafts we constructed as watertight as possible due to the limited ability to dewater close to the tunnel for concerns of settlement above the tunnel. While this was more of a function of proper construction than design, the Engineer had to make clear in the bid documents that the shafts were to be constructed such that dewatering was maintained to a minimum and did not create a potential for dewatering along the tunnel path which could cause settlement above the tunnel.

Pipe Selection

A third major design consideration for the micro-tunnel installations was the pipe selection. Micro-tunneling can be achieved with a variety of pipe diameters and materials. The interceptor design diameter for the micro-tunnels at the I-440 bypass ramp and at New Bern Avenue was 72-inch and 60-inch for the micro-tunnel at Raleigh Boulevard. The open cut (direct buried) portion of the interceptor which makes up the large majority of the sewer line installation for the project was designed primarily as fiberglass reinforced pipe (FRP). The design team was considering options for jacking FRP pipe along with carbon steel pipe and reinforced concrete pipe (RCP).

The criteria evaluated to select the pipe for the micro-tunnel installations included;

- Single-pass vs. Two-pass (casing included) Installation
- External Loading and Potential Long-term Deflection
- Pipe Jacking Forces
- Regulatory Requirements
- Compatibility and Adjoining Material

The design team initially considered a two-pass design with a casing pipe included with the interceptor as a carrier pipe. However, the casing pipe size for the two 72-inch interceptor tunnels was limited to 88-inches based on available MTBM equipment in the eastern United States. This size casing did not allow for much adjustment of grade for the interceptor (carrier pipe) within the casing, which is one significant advantage of having a casing during installation. Additionally, the NCDOT requires the annular space between the casing and the carrier pipe to the filled with grout so the carrier pipe could not be removed in the future if there was a problem with the pipe. For these reasons and for cost savings associated with eliminating the larger diameter casing pipe, the design team decided to design single-pass micro-tunnels at each of the three crossings. *Installing a single-pass micro-tunnel, meant that the pipe selected for the installation would be the same pipe to convey the sewer and therefore must be corrosion resistant, watertight, and capable of withstanding the jacking forces required for the installation and the external loads imposed after installation.*

Once a single-pass design approach was adopted, the design team had to perform external loading, deflection and bucking calculations for each of the pipe material being consider. Additionally, jacking force calculations were performed based on the geotechnical subsurface investigation report. Carbon steel pipe, RCP and FRP were all evaluated for each crossing. The fiberglass reinforced jacking pipe evaluated was a centrifugally cast, fiberglass reinforced, polymer mortar pipe specifically designed to be used for pipe jacking.

While each of the three pipe materials were capable of withstanding the jacking forces and external loading with the appropriate specified pipe stiffness, the CORPUD had concerns about corrosion resistance with the steel pipe and concrete pipe options. Both pipe materials would require an interior coating system to provide corrosion protection against the sanitary sewer and possibly require external coating to protect against corrosive soil conditions. *The FRP provides corrosion resistance without the need for a coating system, requires less force to install than the other two pipes (due to weight), and is compatible with the other pipe material specified for the project*.

One challenge with selecting fiberglass reinforced jacking pipe was that the pipe material was fairly uncommon to the NCDOT for tunnel crossings under roadways, especially in a single-pass scenario. The design team met with multiple design groups within the NCDOT Design Unit in Raleigh to present the proposed crossing methods and intended pipe material. The meeting was a success and with submittal of a very thorough NCDOT encroachment packet, the design team obtained an NCDOT encroachment approval for the CORPUD in less than three months after the initial submittal. All three microtunnels were designed and approved as single pass installations with FRP jacking pipe.

CONCLUSION

Slurry Micro-tunneling is a very versatile and sophisticated tunneling method that offers many advantages over other trenchless methods, especially for large diameter sewer installations. To summarize the pros and cons of microtunneling;

Pros:
- Remote Controlled/ No Worker Entry Required
- Dewatering not Required
- Potential for Subsidence and Surface Heave Minimized
- High Line and Grade Accuracy
- Medium-Sized Footprint/Flexible
- Can Handle Mixed Face Conditions
- Capability to Install One-Pass Tunnel

Cons:
- Expensive (have to consider cost versus risk)
- Can Have Issues with Large Cobbles and Boulders

While other trenchless methods may be suitable for many crossings, you may find that certain crossings necessitate the use of a MTBM to safely and reliably complete the installation. Some project conditions that may warrant the use of a MTBM include those with;

- Limited / No Ability to Effectively Dewater Tunnel Area in High Groundwater Areas
- Dewatering in Areas with High Conductivity and/or Non-Cohesive Soils near Roadways Or Railroads – Subsidence or Heave is Critical
- Gravity Sewer with Critical Line and Grade and Minimal Allowance for Variation
- Tunnel Installations with Varying Subsurface Conditions – Mixed Face Conditions

The Crabtree Phase I project contained all four of the conditions mentioned above. Micro-tunneling has proven to be a good choice for the CORPUD. The design team quickly gained approval from NCDOT to install the single-pass installations which eliminated unnecessary cost associated with a two-pass approach. The approval for the single pass installations allowed the required jack pipe diameter to be decreased and thereby increased the availability of MTBM equipment suitable for the project. This increased bidder competition, potentially lowering the project cost.

All three micro-tunnel installations have been successfully installed and not subsidence, settlement, or heave has been observed. The crossings were installed on grade and within the allowable tolerances established for the project. During the installation of the micro-tunnel beneath the existing I-440 overpass ramp and twin 60-inch RCP interceptors, the subsurface rock tended to be more plastic than anticipated and resulted in excessive wear to the MTBM cutters on the front of the boring machine. Several cutters had to be replaced during the installation but the design of the boring machine allowed for this to be done with the MTBM in-place and the MTBM was put back into operation each time and the tunnel was successfully completed. Mixed-faced conditions and even unexpected material (buried trees) were encountered at the other tunnels but the MTBM was operated with caution and at specific mining rates to minimize risk of binding the cutter head or encountering misalignment. These crossings were also completed successfully.