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Problems Realized with Contractor-Proposed Pilot Tube Auger Boring

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1. ABSTRACT

A new sewer outfall alignment required trenchless crossings beneath two major roadways. The crossings were designed to be 320-ft and 125-ft long, finished with 45-in. Fiberglass Reinforced Plastic (FRP) pipe. The tunnels were relatively shallow in alluvial soils with high groundwater. Based on the anticipated ground conditions, microtunneling or closed-face TBM with dewatering tunneling methods were allowed.

The selected trenchless subcontractor proposed Pilot Tube Auger Boring (PTAB) as an alternate method. Dewatering was proposed by horizontal dewatering wells below the tunnel invert. Because the contractor was able to reduce the length of the tunnel by relocating the shafts and because additional subsurface information indicated more favorable ground and groundwater conditions, the design team considered PTAB a feasible method. The contractor assumed responsibility for all surface settlement determined to be caused by their proposed method.

Construction proceeded with the alternate PTAB method without applicable specifications, submittal requirements, or other formal contract documents. This fact caused numerous contract management challenges as construction progressed. Additional challenges for this project included long-standing relationships between the underperforming trenchless subcontractor and the owner. For the design team looking out for the best interests of the owner, this added to an already difficult situation caused by insufficient information and a desire to keep the project on schedule and budget. Ultimately the PTAB was only partially successful and the contractor needed to implement guided pipe ramming to complete the second crossing.

2. INTRODUCTION

Trenchless underground projects are challenging for owners, contractors, and designers due to their linear nature, partially known ground conditions, and difficult access. There can be significant consequences of failure relative to other construction methods. Shallow highway trenchless crossings below the groundwater table in coarse alluvium are even more challenging due to the clear risk and high consequences to owners and the traveling public. Sink holes in heavily traveled highways are not acceptable and lane closures to accommodate rescue shafts for stuck machines are undesirable.

These risks are well understood in the tunneling community, resulting in contracts, design, and trenchless construction methods having evolved to share, mitigate, and overcome the perceived risks. The standard contractual method to achieve risk sharing has become the Differing Site Conditions (DSC) clause incorporated with underground conditions described in a Geotechnical Baseline Report (GBR) and supported by geotechnical information provided in a

Geotechnical Data Report (GDR). The GBR describes ground behavior that should be expected based on the anticipated construction methods, and provides baselines of ground conditions for bidding and DSC evaluations. Tunnel design methods and other contract documents, such as specifications and drawings, have also been developed to be consistent with these contractual methods.

During construction, the construction management (CM) team represents the owner's interests by monitoring the work for compliance with the contract. Specifications usually require the contractor to submit construction work plans with details of the proposed means and methods; these submittals are relied upon by the CM personnel as they observe and document the work. The intent of the construction work plans is to verify that the construction meets specifications and to evaluate potential DSC claims.

On this project, the contractor proposed an alternate tunneling method, which the designer and CM team accepted with caveats. The CM team was unable to perform their work in the usual manner because there was not a specification and submitted detailed work plans related to this alternate method. When the tunneling work encountered difficulties and the alternate method ultimately proved unconstructable, the lack of specification and submittal details hindered the ability of the design and CM to evaluate the work effectively. Furthermore, if a DSC claim had been presented by the contractor or if a catastrophic failure had occurred, the design team would have been unable to effectively protect either the owner's interests or their own.

3. PROJECT DETAILS

The project consisted of design and construction of a new gravity pipeline, which was needed by a local municipality to update an aging sewer system. The new pipeline was approximately 10,000-ft long with varying diameters up to 54 in. The new sewer conveys wastewater via gravity flow at slopes up to 0.33%. The completed project was designed to carry up to 50 to 60 million gallons per day during peak conditions.

The project required trenchless crossings at two major roadways with the remainder of the alignment constructed using open cut methods. The first crossing was beneath a heavily traveled State Route (SR) with a roadway about 80-ft wide curb to curb. The proposed SR tunnel was 125-ft long. The second crossing was beneath an interstate highway with a roadway about 160-ft wide shoulder to shoulder. Due to easement restrictions, the proposed interstate tunnel was 320-ft long. The Department of Transportation (DOT) did not require a steel casing for either tunnel crossing. The depth of the tunnel crown below the ground/roadway surface ranged from 5 to 14 ft at each location. The construction shafts at each side of the roadways were approximately 15-ft deep.

Based on the anticipated ground conditions, allowed methods were microtunneling or closed-face Tunnel Boring Machine (TBM) with dewatering. The tunnels were bid with the option for a direct-jacked 48-in. reinforced concrete pipe (RCP) or a direct-jacked 42-in. FRP.

4. GEOLOGIC BACKGROUND

A geotechnical engineering consultant performed two phases of subsurface investigations consisting of 17 borings and five test pits along the entire alignment. In close proximity of the two tunnel alignments there were seven borings and two test pits. As indicated from the published geologic history of the region, the site investigations confirmed a complex subsurface stratigraphy.

Ground conditions at the tunnel and shaft locations generally consisted of uncontrolled fill for the upper 5 ft overlaying interbedded coarse- and fine-grained alluvial soils and fine-grained lacustrine deposits. Generally the fine-grained alluvium was encountered above the coarse-grained alluvium. The coarse-grained alluvium ranged from sand to gravel with varying combinations of coarse-grained fractions. Cobbles were not observed in the immediate vicinity during the subsurface investigation; however, due to other borings in the general area and the depositional environment the GBR baselined occasional cobbles in the alluvium. Lacustrine lean and fat clays were encountered beneath the alluvium in the bottom of the shaft excavations below the invert for the tunnels.

Relatively shallow groundwater was encountered during the subsurface investigation, about 9 ft above the proposed tunnel inverts. Due to the interbedded nature of the soils, multiple ground behaviors were likely to exist concurrently in the face of exposed excavation; the GBR baselined flowing ground to be the controlling ground behavior below the water table.

5. FEASIBLE TUNNEL METHODS

Due to the potential for flowing ground, a closed-face system was deemed necessary for successful trenchless excavation without dewatering. Lost ground at the tunnel face could have translated into settlement at the ground surface, which may have damaged the roadway and nearby utilities.

Implementation of an extensive dewatering system to allow open-face tunneling was not recommended but allowed. The heterogeneous nature of the alluvial soils could have resulted in difficulties achieving the required drawdown and the dewatering efforts could have induced settlement of the roadway, nearby structures, and buried utilities. However, limited dewatering at the shafts was anticipated to facilitate shaft excavation as well as benefit face stability during excavation with a controlled-face machine.

Based on the project constraints such as tunnel length, diameter, grade tolerance and subsurface conditions, potential tunneling methodologies evaluated during design included a microtunnel boring machine (MTBM), controlled-face TBM with dewatering, earth pressure balance TBM (EPBM), and pilot tube auger boring (PTAB; also known as pilot tube microtunneling). Excavation methods that were not considered to be feasible included open-face tunnel shields, horizontal directional drilling, and pipe ramming. These methods were not considered feasible due to the length of the drives, line and grade requirements, and the presence of groundwater.

EPBM technology was considered feasible and appropriate for the anticipated ground conditions but more commonly used on larger tunnel diameters. Therefore, EPBM could have been a viable option for a two-pass method installing a larger diameter casing.

PTAB was also considered feasible, but the anticipated project parameters (ground type, drive length, pipe diameter, and ability to resist groundwater inflow) were barely within the technical limitations of this method. If adverse deviations from the anticipated ground conditions were encountered, this method may not have been feasible. Cobbles can present a problem by obstructing the advancement of the pilot hole during a PTAB operation, and although not encountered in the subsurface investigation it was anticipated that some cobbles would be encountered. With PTAB, drives longer than 300 ft can be difficult to keep on line and grade. The drive length under the interstate was originally 320 ft. The project originally allowed for a 48-in. ID RCP which would produce a minimum 59-in. hole; this size is currently at the upper range of the possible diameters for PTAB. The auger systems may be designed to resist flowing ground but are limited to a maximum head of about ten feet. Based on the available subsurface information, a head of 9 ft was anticipated. Additionally, PTAB was not considered economically viable since it would take up to three reamers to produce the final hole diameter.

Use of a wheeled TBM operated in closed-face mode would have prevented ground from flowing into the excavation. The wheel of a TBM can be closed off so only a small portion of the face is exposed at any time. During times when the TBM was not operating, it would have been necessary to support the face to prevent flowing soil and associated loss of ground. Dewatering at the shaft locations would likely have resulted in a partial lowering of the water table for much of the alignment, reducing hydrostatic pressure encountered at the face, which would have made the use of this technology feasible.

MTBM was also determined to be a technically feasible method to deal with the flowing ground conditions and loose sandy soils and available for any of the required diameters. The MTBM would likely have employed bentonite slurry for positive face support. Ground fracturing due to pressurized injection of bentonite was a concern at the low cover areas and along potential buried utilities near the tunnel alignments. Cobbles were anticipated to be encountered, so the machine would need to have been tooled accordingly to crush and transport the cobble fragments.

6. CONTRACTING

Due to project constraints discussed above, the tunneling methods deemed acceptable per the contract documents were closed-face TBM with external dewatering or MTBM. The designer prepared specifications for these two methods. This project employed a contractor pre-qualification process where the designer provided input for the pre-qualification form for rating trenchless contractors based on which allowed method they proposed to use. Through cost competitive bidding, the project was awarded through to a general contractor specializing in shallow open cut construction teamed with a prequalified trenchless subcontractor. The trenchless subcontractor was prequalified and initially proposed to complete the trenchless crossings using the closed-face TBM alternative with dewatering.

6.1 Contractor modifications to the contract

After the project was awarded, an approved change order allowed the contractor to reduce the tunnel pipe diameter from 48-in. to 45-in. Next, the contractor was allowed temporary access by the DOT and the Federal Highway Administration to relocate the shafts for the interstate tunnel within the "no-access" easement. This relocation of the shafts decreased the tunnel length from 320 ft to 208 ft. Additionally, the contractor dug exploratory test pits at the proposed shaft locations that encountered groundwater slightly deeper than indicated in the geotechnical borings, and ponding of groundwater only occurred in one pit after several minutes of observation.

Based on the approved changes and new information, the contractor requested a change to install the tunnels using PTAB, instead of closed-face TBM. The contractor proposed the first pass for this approach to be the pilot tube and the second pass would be an open reamer with 24-in. diameter cased augers. The final pass would entail jacking the 45-in. FRP from one shaft and transporting the spoils through the 24-in. casing with the same augers used for the second pass.

Following review of the contractor's proposed installation plan, the designer expressed concern that the PTAB method might not be ideally suited for the anticipated ground conditions, due to the relatively shallow groundwater, granular soils, and the presence of cobbles. Specifically, the following risks were brought to the owner's attention:

- Potential for steering issues due to the presence of cobbles, which could become obstructions;
- The possibility of cobbles jamming the augers, resulting in elevated jacking pressures, and possibly inhibiting forward progress;
- Groundwater and saturated soils flowing uncontrollably into the tools, resulting in over-excavation, and possible surface settlement.

The trenchless subcontractor countered these concerns by asserting that they had successfully completed other PTAB installations in similar ground conditions. The subcontractor also argued that the PTAB would involve less risk than other trenchless methods. Although the subcontractor had only prequalified for closed-face TBM, the subcontractor's position was that for this ground, microtunneling was a more risky method than PTAB. The contractor stated that the primary concern was that without access to the tunnel face, man-made obstructions (if encountered under the roadway) could stop the tunnel. The change request offered a relatively small credit to the owner. In the change request the subcontractor assumed responsibility "for surface ground settlement determined to be caused by [their] proposed method".

Although still a large diameter for PTAB, due to the reduction of the tunnel diameter and length along with the additional subsurface information at the proposed shaft locations, the designer believed the PTAB method was worth consideration, but with caution.

6.2 Consideration of PTAB

Because PTAB was not part of the original contract documents, it was difficult to get the contractor to submit equivalent and relevant work plans and submittals for the alternative method. This situation strained relationships among the owner, the project engineer, and the designer trying to review the contractor's approach.

Without a specification for PTAB, the design team agreed that the contractor would be responsible to provide specifications for the contractor-proposed method. The contractor chose to modify the specification for the closed-face TBM. The contractor proceeded with the proposed method without satisfactory specifications, submittals, or other formal contract documents for the contractor or the design team to follow which caused numerous challenges as construction progressed. Frequent changes to the contractor's means and methods further aggravated the situation.

The contractor resisted providing detailed information regarding the proposed work and contingency plans. For example, the augers the contractor proposed were not truly a closed-face system. Considering the potential dewatering difficulties in the interbedded alluvial soils, the designer requested that the contractor provide a closed-cell "water auger" for each size reamer. The contractor claimed to have alternate tools/methods available so that changes could be made as necessary due to encountered ground conditions during any stage of the PTAB installation. However, it quickly became apparent that the contractor did not have the promised tools and did not own or have experience with alternative equipment, including microtunneling.

6.3 Horizontal Dewatering

Given the granular soils and elevated groundwater table indicated during the subsurface investigation, the designer was concerned about the potential for ground instability using an open auger system. To reduce the potential for flow of water and sand into the tools, the contractor proposed to dewater each crossing with two horizontal slotted PVC pipes installed with the pilot tube equipment below the tunnel invert. Although the designer expressed some concern about the ability of a passive system to effectively dewater the silts and clays from the tunnel horizon, it was felt that this dewatering method would be more effective than vertical wells. With vertical wells, the cone of depression would be affected by a clay layer in the shaft invert, which may have allowed for groundwater mounding between the shafts. Using the horizontal system would allow dewatering of specific stratigraphic zones sandwiched between the clay layers, which also might have been difficult to effectively dewater with vertical wells.

The subcontractor had some difficulty with fusing of the filter fabric to the slotted PVC, and modified this approach by wrapping duct tape every few feet to keep the filter fabric snug. The first horizontal well at the SR crossing initially produced 15-20 gallons per minute (gpm), and reduced to about 10-15 gpm after a few days. The subcontractor had difficulties getting the pilot tube through at the proposed elevation for the second well and eventually installed it near spring line. Very little water was produced from this well.

6.4 Tunnel Construction

During installation of the first crossing beneath the SR, the trenchless subcontractor refused to submit the daily reports that were required by the contractor-modified specification. Therefore, the CM field personal maintained the only records of muck removal, jacking forces, lack of lubrication, and other standard data. There were numerous weather and other unrelated delays that significantly extended the proposed tunneling schedule adding more than a month for the SR crossing.

At this crossing, the pilot tube advance was successfully completed despite the subcontractor's struggle with oversized materials. Frequently the subcontractor encountered cobbles which stopped forward progress. Fortunately, the subcontractor was able to gradually push these cobbles aside, although this forced the pilot tube off- line and off-grade. Ultimately, the spoils retrieved during subsequent auger boring revealed that the soils along the tunnel alignment consisted of gravelly sand, with approximately three to five percent cobbles by volume. Although the SR crossing was eventually completed, it was determined that the installed tunnel grade was not within the tolerances provided in the specifications, and would result in a few inches of hydraulic surcharging at peak flows. The owner accepted the installation, despite being out of tolerance.

Once the final pass for the SR crossing was completed, the subcontractor had three days by specification to begin contact grouting the annulus between the pipe and the ground. The trenchless subcontractor initially resisted contact grouting, but eventually complied with the contract requirement and installed contact grout ten days after tunnel completion. By this time it was apparent that the general contractor wanted to "do the right thing" but that the trenchless subcontractor was uncooperative with the CM and design team.

Even though shaft excavation and installation of the horizontal dewatering wells at the interstate crossing indicated more cobbles than at the SR tunnel, the subcontractor proceeded with the installation of the pilot tube. Unfortunately, the subcontractor was unable to get the pilot tube across on grade blaming the deviation on an obstruction. The contractor indicated that the obstruction must be manmade and claimed a DSC. This obstruction was encountered approximately 20 ft from the retrieval shaft. The obstruction caused elevated pressures on the equipment and a loss of grade and target. The pilot tube was blinded through the last approximately 20 ft of the alignment, coming into the retrieval shaft roughly ten inches higher than the targeted grade. The contractor attempted to jack a 60-in. steel casing pipe from the retrieval shaft past the location of the assumed obstruction; however, the casing began egging short of the drive length and the jacking was stopped. With hand excavation inside the jacked casing, the location of the pilot tube deviation was exposed and did not reveal a manmade obstruction.

The CM and design team frequently discussed alternative tunneling methods with the contractor. The general contractor did not want to remove the trenchless subcontractor for a better suited subcontractor due to schedule and financial reasons, and also due to historic relationships between the general contractor and the trenchless subcontractor. The designer recognized that the trenchless subcontractor did not have the adequate tools and experience to complete the crossing. Despite tremendous pressure from the owner, the general contractor, and even the trenchless subcontractor, the designer refused to dictate the subcontractor's means and methods.

At this point, the subcontractor proposed to switch to pipe ramming the 24-in. casing but was unwilling or unable to provide any documentation indicating that the casing pipe was rated for ramming. The contractor proposed to ram the casing with a Hammerhead Mole 16-in. hammer and weld each joint of the casing with four reinforcement straps across the joint. Prior to receiving approval, the trenchless subcontractor commenced ramming. After advancing about 5 ft, the casing tore at the first joint strap weld. After significant delay, a larger hammer was procured from another trenchless subcontractor and used to successfully ram a 54-in. casing over the abandoned 24-in. casing and pilot tube.

7. CHALLENGES AND LESSONS LEARNED

After significant delay the project was ultimately completed. There was a large potential for a claim which would have been difficult to defend due to the lack of appropriate specifications and submittals. There are several lessons that the designer will apply to future projects.

Technically, the evaluation of potential tunneling methods in the design phase seems appropriate. PTAB was partially successful; however, the combination of drive length, cobbles, and groundwater put the project at the limit of the technology. It seems likely that either of the originally specified methods, with proper application, would have been more successful. On a positive note, the horizontal dewatering wells, when installed as intended, did seem to be effective dewatering tools, possibly significantly more effective than traditional vertical methods from the tunnel ends.

Contractually, a better prequalification process may have resulted in a trenchless subcontractor more suited for the project. Ultimately, it was determined that the trenchless subcontractor had grossly misrepresented their experience with closed-face TBM tunneling, and did not actually possess the equipment to complete the installations as originally designed. It became apparent that the contractor proposed PTAB after the award because this was the only trenchless equipment they had in their possession.

Careful consideration for acceptance of contractor deviations from specification may have helped maintain a CM process that would have minimized risks to the owner, designer, and CM team. Allowing a contractor to continue working without approval of their means and methods can be a slippery slope that leads to further lack of control over the implementation of the work. However, refusing to stray outside the contract by dictating specific means and methods to the contractor during construction did limit the exposure of the designer to claims when the contractor's methods were unsuccessful.

It is essential for the owner, project engineer, and/or CM team to have a good understanding of how a GBR and DSC clause should be used together to control risk. Otherwise, this may lead to partial contract implementation, which may result in the owner and CM team accepting additional liability of which they may not be aware. Had a catastrophic failure occurred on this project, such as injury to the travelling public due to a highway sinkhole, the design and CM team would have been in a difficult position to defend themselves and the owner from subsequent claims. Additionally, the long standing relationships among the owner, general contractor, and trenchless subcontractor may not have counted for much because the insurance companies would have become the ultimate decision makers about litigation. The designer should have better educated their project engineer /CM client and the owner about the importance of good contract administration specific to underground construction.

8. CONCLUSIONS

Ultimately the PTAB was only partially successful and the contractor needed to implement guided pipe ramming to complete the second trenchless crossing. Although the project was claim free, the designer believes that the owner and CM team accepted substantially more risk than necessary had the contractor's submittals been in accordance with standard practices. Possibly due to an incomplete understanding of standard contract management for underground construction, the owner and CM team may not have understood the potential implications of the increased risk due to improper contract management. As the project evolved, it became clear that the trenchless designer could have done a better job of educating both their client and the owner about why and how to properly manage successful underground construction.