Mill Creek Tunnel Geomechanics

B. Lukajic, M. Schafer, & R. Pintabona
Montgomery Watson Harza, Cleveland, Ohio, USA

M. Kritzer, S. Janosko & R. Switalski
Northeast Ohio Regional Sewer District, Cleveland, Ohio, USA

ABSTRACT: The purpose of this paper is to review technical considerations and summarize the methods used in constructing the large diameter Mill Creek tunnels in shale. The three-phase tunneling construction program encompasses nineteen (19) shafts and three (3) tunnels, totaling 12,727 m of tunnel length. The paper describes the experience gained during design and construction, relative to specialized techniques used for ground improvements and exploration.

1 INTRODUCTION

The Mill Creek project is located in the Greater Cleveland area and serves 134,000 people in 11 of the Northeast Ohio Sewer District’s sixty-member communities. The total contract cost for the three-phase development will be about $150,000,000. The first phase (MCT-1), a 3-m diameter conveyance tunnel, was completed in 1999. The second phase (MCT-2), a 7.3-m excavated diameter storage tunnel, was completed in 2005. The third phase (MCT-3), also a 7.3-m excavated diameter storage tunnel is currently under construction with planned completion in 2008. This paper will focus on the large diameter tunnels excavated under Phases 2 and 3 (MCT-2&3). Further details can be found in References [1] to [3].

2 GEOLOGICAL CONSIDERATIONS

2.1. Rock Structure

The MCT-2 and 3 tunnels are located within the Chagrin shale rock formation. This shale is known to contain closely bedded zones of siltstone, limestone and sandstone layers. Shale exhibits only local dampness in tunnel excavations. Gas, primarily methane, is commonly encountered in this formation. There are no supportive arguments on swelling characteristics of Chagrin Shale; it is therefore believed to be negligible.

2.2. Rock Strength and Stresses

The unconfined compressive strength generally ranges from 14 MPa to 55 MPa, which can be classified as weak to medium strong rock. Average rock strength for Mill Creek tunnels is illustrated in Figure 1. Higher strength values were noticed in rock samples where siltstone and sandstone interbeds were present.

To date, in-situ stress measurements have not been carried out in the project area. However, it is common knowledge that the major horizontal compressive stress in the Cleveland area rock formations trends approximately N80E and has a magnitude about two times the vertical stress. Based on the previous studies performed in the region, the GBR for Mill Creek tunnels suggests the horizontal stresses in the rock range from 6.9 to 28 MPa. The horizontal stress varies in relation to the tunnel alignment.

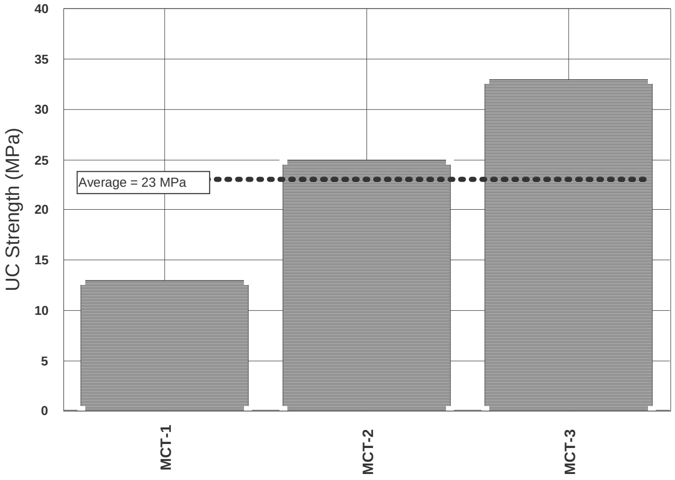

Figure 1. Chagrin Shale Average Strength.

2.3. *Rock Behavior while Mining*

Observations during construction indicate that stress is not the dominant mechanism in tunnel stability. This is evidenced by the fact that the tunnel roof remained intact, with little tendency for overbreak in massive shale beds. Occasionally, local rock blocks loosened due to separation along vertical joints and horizontal bedding.

When the tunnel intersected closely bedded shale/siltstone zones, more frequent slabbing and loosening occurred. Slabbing normally occurred in the crown at 11:00 and 1:00 o'clock positions. An example of thin shale slabbing is illustrated in Figure 2.

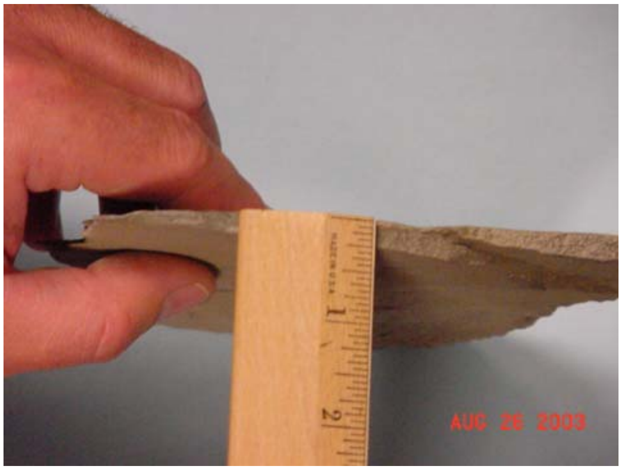

Figure 2. Chagrin Shale Thin Slab.

3 ISSUES RELATED TO GEOLOGY

Variations in geological conditions are often encountered in tunnel projects. Such variations sometimes require additional field explorations and adjustments to design and construction methods. Several geology related adjustments to the design and construction occurred at the Mill Creek project.

First, the presence of a deep soil valley within the alignment of the tunnel had a major bearing on design and construction methodology of two large diameter shafts.

Second, the presence of the soil valley required an exploratory tunnel to be constructed to investigate the depth of the valley and the bedrock beneath it, in advance of the main tunnel, as depicted in Figure 3.

Third, an eight-month shutdown of the MCT-3 main tunnel TBM drive was required to mitigate methane gas conditions.

A brief discussion of each issue is presented below.

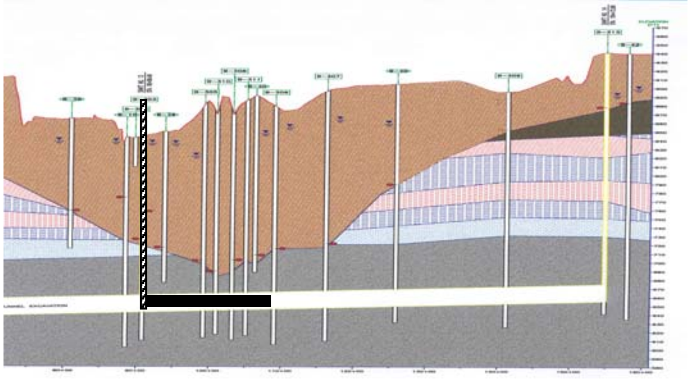

Figure 3. Location of the Exploratory Tunnel Under Buried Valley.

3.1. *Shaft Construction Within Buried Valley*

Constructing 10-m diameter, 55-m deep shafts in a buried valley presented several difficulties and risks to Owner (NEORSD) and the Engineer (MWH). Failure to successfully excavate the shafts could result in protracted construction delays and costly claims. Considering the fully saturated silt-sand soil condition and the risks involved, four alternative methods were evaluated for construction of two shafts. They included slurry wall, jet grouting, deep soil mixing, and ground freezing. Artificial ground freezing was chosen as an initial support method during construction of the shafts. It was determined that neither slurry wall nor jet grouting could be relied on to overcome boulder obstructions at the depth of 55 metres.

The ground freezing was performed by use of a brine coolant circulating through a series of vertical freeze-pipes installed at 1.2-m centers around the shaft perimeter. The coolant circuit included a brine chiller, down freeze pipes and two manifolds. The portions of the shafts located within soil above the groundwater table or in the weathered rock below the soil, were not frozen, but were supported with steel liner plate and steel ribs. Shaft excavations below the top of sound rock were supported by a combination of rock dowels and welded wire fabric. Excavation of the soft core was completed using a conventional backhoe. Mucking was completed utilizing a crane to hoist a skip box. Ground freezing proved effective in providing temporary support while excavating deep shafts in wet sandy soils. Figure 4 illustrates the soil excavated from the shaft, after freezing.

Figure 4. Excavated Soil From Frozen Shaft.

3.2. *Exploratory Tunnel Below Buried Valley*

Exploratory boreholes, including tomography survey, suggested that unfavorable geological features along the main tunnel could be encountered while tunneling beneath the buried valley. Tunneling below the valley presented risks that could not be mitigated effectively from the ground surface. Furthermore, encountering an incised part of the buried valley in the tunnel horizon could result in mining difficulties, claims and an expensive remediation program. This prompted the project team to launch the exploratory tunnel program, to define and evaluate the potential risks associated with tunneling underneath the valley. A layout of the 3-m diameter exploratory tunnel is shown in Figure 5.

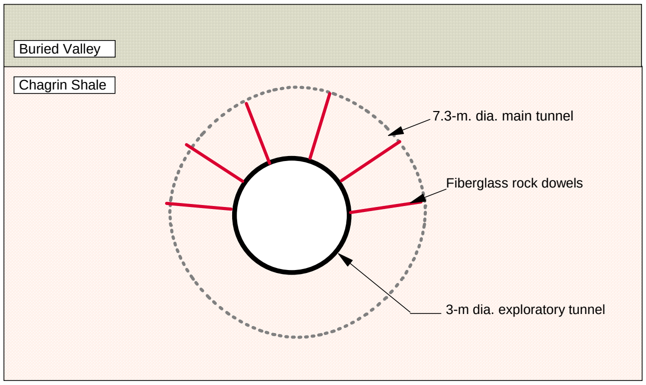

Figure 5. Exploratory Tunnel Arrangement and Configuration.

One of the questions related to the layout of the exploratory tunnel was its location in relation to the main tunnel. Initially, construction of a side-drift gallery was considered beneficial because it would provide the means to explore rock, provide a platform for grouting, facilitate drainage and reduce groundwater pressure on the crown of the main tunnel. In the final analysis, it was determined that a centrally located exploratory tunnel would be the most beneficial alternative. This arrangement provides direct evidence of ground conditions in the domain of the main tunnel. A concentrically located exploratory tunnel was selected to minimize complications when overboring the main tunnel. The most significant findings of the exploratory tunnel investigations were that the rock cover above the main tunnel crown consisted of good quality rock and that no evidence of a buried valley protrusion existed within the main tunnel domain. Although no adverse geological condition was encountered, the decision to construct the exploratory tunnel was correct considering the potential risks identified initially.

3.3. *Gas in Tunnel*

Encounters with natural gas are not uncommon in Chagrin Shale and have occurred on previous NEORSD projects. The GBR stipulated that natural combustible gases (primarily methane) and poisonous gases (such as hydrogen sulfide), under pressure, are to be anticipated in the shafts and tunnels of the Mill Creek project, classifying the tunnel as potentially gassy. Methane gas was encountered while the Contractor was drilling a downhole at the Mill Creek, Phase 3 Tunnel. The gas was permitted to completely dissipate. After 757 m of the tunnel drive had been completed, several large quantities of gas entered the tunnel from behind the TBM in the general vicinity of the aforementioned downhole. This situation was especially dangerous as the TBM gas monitoring equipment was designed to detect gas near the tunnel heading. As the frequency and volume of the gas incursions increased, the decision was made to suspend mining operations to safely address the gas issue. Steps taken to mitigate the gas conditions consisted of drilling de-gassing wells, installing a gas monitoring system and constructing an additional 5.5-m diameter vent shaft.

4 MAIN TUNNEL DRIVE SUMMARY

4.1. *General*

It is common knowledge that the ground conditions have direct bearing on the methods of tunnel design and construction. More specifically, they govern the selection of the excavation method and the type of temporary and permanent tunnel lining. In other words, all major aspects of the tunnel work.

Based on ground conditions (closely bedded shale), a two-pass tunneling method was designed by the Engineer as best suited for this project.

4.2. Primary Support

A primary support system (first pass) was installed concurrently with tunnel excavation. It consisted of Grade 50, W6 x 20 expanded circular steel ribs at 1.2-m centers and 150-mm thick timber lagging spaced at a maximum of 600-mm along the tunnel perimeter. Of all alternatives evaluated this support system was determined to have the greatest probability of successfully achieving desired performance requirements. Furthermore, this lining system takes advantage of existing experience held by the local labor force. View of primary support is illustrated in Figure 6.

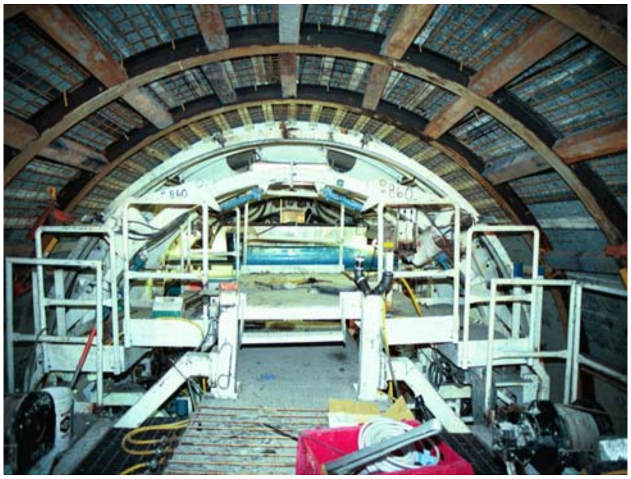

Figure 6. Close-up of Primary Support Behind TBM.

4.3. Mining

An open face (7.3 m diameter), Robbins type machine was used to excavate the tunnels. The primary requirement for the TBM was its suitability to negotiate through thinly bedded, closely jointed rock of variable strength. Primary support was installed within the finger–shield, located immediately behind the primary TBM shield. Ribs were initially expanded by rib-erector system and then jacked into the final position from the TBM platform. Typically the excavation sequence consisted of tunnel boring (advancing in 1.2-m. increments), rib-lagging installation and continuous mucking via conveyor system.

4.4. Final Lining

Design of final lining for the Mill Creek tunnel (second pass) was selected in accordance with the requirement for permanent tunnel support, groundwater control and hydraulics. The final lining consisted of cast-in-place reinforced concrete, 300-mm thick. Because the tunnel will experience internal hydrostatic pressures during storage, the use of steel reinforcement in the tunnel liner was considered beneficial. A view of tunnel liner is shown in Figure 7.

Figure 7. View of Cast-in-Place Concrete Liner– MCT-2 Tunnel.

CONCLUSION

As in many underground projects, geology played a significant role in the design and construction methodology employed for the Mill Creek tunnels. Firstly, because of the existence of a buried valley at the site, two deep shafts were designed offering a variety of construction options. Ultimately, ground freezing was considered as the best option and proved to be successful in this case. Secondly, the geology at the site made it prudent to construct an exploratory tunnel, which provided the design team with valuable data well in advance of the main tunnel drive. Thirdly, the gas related issue provided a valuable experience that could be of some benefit to future tunnel designers and constructors in the Cleveland area.

ACKNOWLEGEMENTS

The authors would like to thank Northeast Ohio Regional Sewer District, specifically Charles Vasulka, Director of Engineering, for his review and approval to publish this paper. Special thanks go to Carol Chavis for managing the paper design and production.

REFERENCES

1. Lukajic, B., R. Pintabona, M. Kritzer, and R. Switalski. 2003. Ground Freezing for Deep Shafts at the Mill Creek Tunnel Project. Rapid Excavation and Tunneling Conference, New Orleans, LA.
2. Schafer, M., R. Pintabona, B. Lukajic,, M. Kritzer, T. Shively, and R. Switalski. 2004. Rock Tunneling at the Mill Creek Project. North American Tunneling Conference. Atlanta, GA.
3. Pintabona, R., M. Schafer, B. Lukajic, M. Kritzer, T. Shively, and R. Switalski. Exploratory Tunnel at the Mill Creek Project. 2006. North American Tunneling Conference, Chicago, IL.