Rock Tunneling at the Mill Creek project

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ABSTRACT: The Mill Creek Phase 2 Tunnel (MCT-2) is the largest tunneling project undertaken by the Northeast Ohio Regional Sewer District (NEORSD). The 13,000-ft long tunnel was mined using a 24-ft diameter boring machine in shale ranging from 160 to 260 feet in depth. The tunnel will be utilized to convey and store combined storm and sanitary sewage collected from the member communities in the greater Cleveland area. The project was conceived as the backbone of an integrated solution to convey and store flows, relieving the existing undersized sewers. This paper will discuss the design of the tunnel and describe the construction progress to date. The discussion will include design of tunnel support and criteria for selection of tunnel boring machine (TBM).

1 OVERVIEW OF THE PROJECT

The Mill Creek project is located in the Greater Cleveland area and serves 134,000 people in 11 communities. A three-phase tunneling construction approach encompasses fourteen (14) shafts and three (3) tunnels, totaling about 42,000 feet in tunnel length. The first phase, a 10-ft diameter conveyance tunnel was predominantly completed in 1999. The second phase project, consisting of a 24-ft excavated diameter tunnel and four large diameter shafts is nearing its completion, while the third phase, also consisting of a 24-ft excavated diameter tunnel is currently under construction with planned completion in 2006. The total contract cost for the three phase development will be about $150, 000,000.

2 GEOLOGICAL SETTING

The tunnel horizon is situated within the Chagrin Shale rock formation. The Chagrin is approximately 500 feet thick in the Cleveland area and underlies the Cleveland Shale. No known major structural features are located in the project domain.

The shale is classified as weak to strong rock and thin to massively bedded. The project area shale is also known to contain zones of thin bedding with siltstone, limestone and sandstone interbeds. In addition, two joint sets are present and strike approximately northeast and northwest. Joint spacing is irregular.

Shale bedrock units, as observed from other underground projects in the region, yield very little water. Gas, primarily methane, is commonly encountered in the Cleveland Shale and Chagrin Shale.

3 TUNNELING METHOD

A full-face tunnel boring method was adopted to excavate the Mill Creek tunnel. For this purpose, the Contractor chose to deploy an open face (24-ft diameter), Robbins type machine, Figure 1.

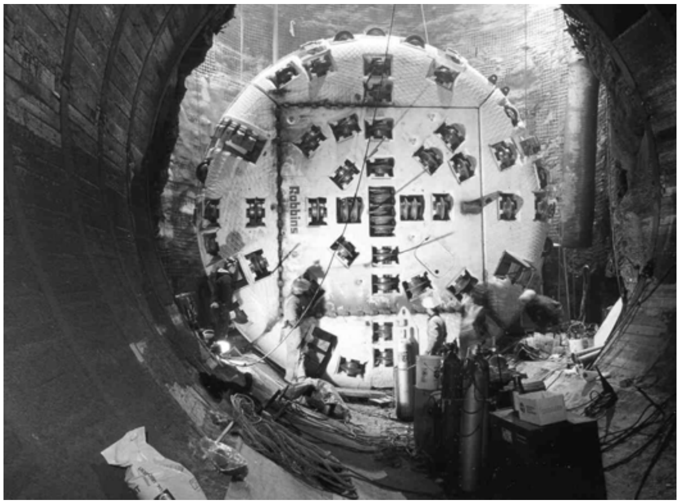


Figure 1. View of tunnel boring machine-cutting head in the tunnel

A Geotechnical Baseline Report (GBR) prepared for the project provided the following guidelines for selection of the TBM:

First, the TBM must be suitable to negotiate through thinly bedded, closely jointed rock. The GBR stated that overbreak and rock falls behind the tunnel face were potential problems during excavation. Additionally, the formation of wedges bounded by joints, bedding planes, and the tunnel perimeter would occur in the arch above springline. It is for this reason that the TBM was equipped with a protection shield between the cutterhead and the point of primary support installation. A total length of the shield was approximately 50 feet with the back portion consisting of a finger shield. This arrangement permitted the erection of the primary support system in a protected environment.

Secondly, the TBM must be capable of excavating efficiently through rock formations of variable strength. The rock unconfined compressive strength ranged from 2,000 to 12,600 psi.

Thirdly, the GBR also indicated that lenses of siltstone with unconfined compressive strengths in the range of 10,000 to 18,000 psi would be encountered. The presence of sandstone and limestone lenses of similar strength and thickness were also to be anticipated.

Finally, the GBR recommended that the jack bearing pad surface areas be increased to minimize local overstressing of the tunnel walls.

4 TUNNEL SUPPORT DESIGN

4.1 *Description of tunnel support*

It was determined during the design stage that the preferred lining method would be a two-pass lining system. In this manner, a primary support (first pass) is installed concurrently with tunnel excavation. The final lining (second pass) is installed subsequent to the completion of excavation.

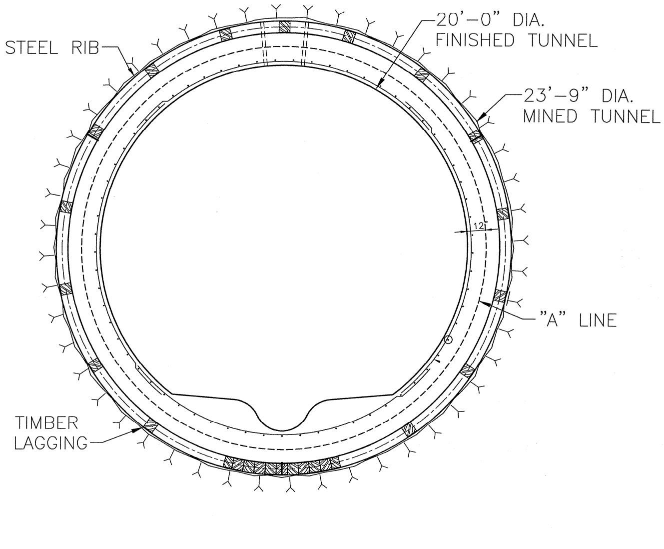


Figure 2. Tunnel configuration and support

This two pass lining system consists of a primary support system of steel ribs and timber lagging, and a final lining of cast-in-place reinforced concrete. Although this support alternative has a slightly higher unit cost than some of the other alternatives evaluated, it was determined that it has the greatest probability of successfully achieving desired performance requirements. Furthermore, this lining system takes advantage of existing experience held by the local labor force.

Performance of steel-rib and lagging primary support systems in NEORSD’s previously constructed tunnels proved to be satisfactory. In addition to local contractors having extensive experience in installation of this type of support, the system proved to be very efficient in providing worker’s safety and enhancing tunnel stability.

4.2 *Primary support design*

The tunnel primary support system was specified to consist of Grade 50, W8 x 31 expanded circular steel ribs at 5-foot centers and 7-inch thick timber lagging spaced at a maximum of 24 inches along the tunnel perimeter. The specifications required steel ribs to be expanded to a point of intimate contact with the excavated rock surface.

Anticipated rock behavior during mining operation was considered a primary criteria in designing the tunnel support. It was recognized that the shale rock units characteristically contain layers or partings of weaker material. It was assumed that these partings will sometimes break along these layers during excavation. The fissile nature of the shale accentuates this phenomenon.

Particularly, in soft, thinly bedded shale, overbreak and rock falls behind the face were considered as potential problems during tunneling. At locations where weak partings or thinly bedded zones were anticipated in close proximity of the tunnel crown, support requirements were specified to increase above average requirements, meaning closer rib-lagging spacing.

Based on the exploratory borehole data, local tunneling experience and empirical rock mass classification systems, the rock loads for primary rock support were determined to be 0.25B to 0.4B, where B is the tunnel excavated diameter (24 feet). In the areas of lesser rock quality, higher rock loads were recommended (0.5B to 0.7B).

Minor modification of the above criteria were made during construction, which resulted in use of lighter ribs and lagging. A view of primary support in the tunnel is shown in Figures 2, 3 and 4.

4.3 *Final lining design*

Design of final lining for the Mill Creek tunnel was selected in accordance with the requirement for permanent tunnel support, ground water control and hydraulics. Three load cases were considered, with constant rock loads of 0.5B to 0.7B for each load case:

1 Loading imposed on the liner from internal pressure with no external hydrostatic pressures.
2 Internal hydrostatic pressure with external water pressure.
3 External water pressure with no internal pressure.

If the internal hydrostatic pressure exceeds the ground water pressure, the liner must be able to carry the difference between these two pressures. Also, the liner carries the unbalanced internal pressure as a composite structure with the surrounding rock.

The final lining consisted of cast-in-place reinforced concrete. Where the lining meets the shafts, it was prudent to allow for this section of the liner to be more reinforced, as the liner no longer forms a closed circle. It was decided that the liner should be more heavily reinforced for a distance equal to the diameter of the shaft and over the extent of the access adit junctions as well. Figure 2 shows tunnel-lining design.

5 TUNNEL CONSTRUCTION

5.1 *Excavation*

Excavation of the tunnel began in January 2001 and continued until December 2001. The tunnel was constructed using a full face Robbins boring machine. The Contractor chose to use a conveyer mucking system in conjunction with the TBM. Typically the excavation sequence consisted of tunnel boring (advancing in 4-ft. increments), rib-lagging installation and continuous mucking via conveyor system.

Figure 3. View of installed primary support

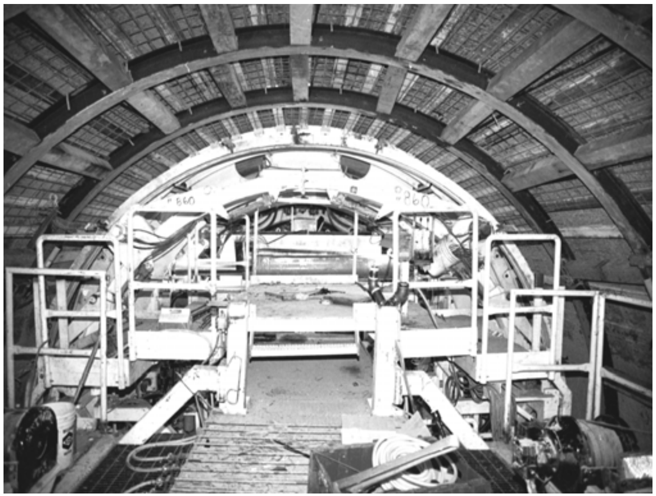


Figure 4. A close up of primary support

Primary support was installed within the finger–shield, located immediately behind the primary TBM shield. Mining production rates ranged from 6 to 10 ft/hour. A graphical presentation of the excavation progress is shown in Figure 5. As per GBR, some overbreak occurred in the crown of the tunnel, along individual bedding planes. This was evident in the areas where the tunnel intersected thin beds at an oblique angle or became essentially parallel to the low dip bedding formations.

5.2 *Concrete lining*

The final lining (second pass), consisting of cast in place reinforced concrete, was placed after completion of all tunnel excavation. The Contractor chose to use prefabricated steel forms, with concrete lining process consistently advancing at 96 feet per day.

The specifications required that the forms remain in place until a strength of 1000 psi. was achieved and not less than 8 hours of curing time had expired. In preparation for the lining operation, the Contractor submitted multiple concrete mix designs for review. Approval was granted on two mixes giving the Contractor an option to use during both cold and warm weather conditions. Regular tests were performed in the field to verify the mix met the specification requirements. A view of concrete placement set up is shown in Figure 6 and 7.

5.3 *Backfill grouting*

The contractor's construction schedule called for approximately 53 days to complete contact grouting. The actual construction time required to drill and grout the tunnel was a total of 33 days, which is about 60 percent of the original forecast. Approximately 1,135.5 cubic yards of grout was required between the reinforced concrete lining and the rock surface.

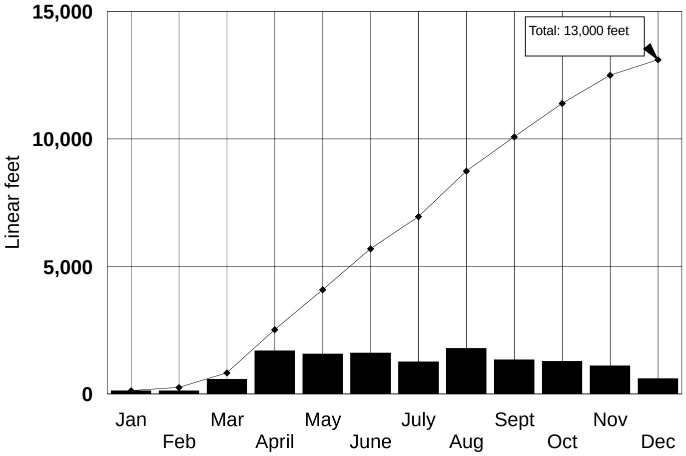


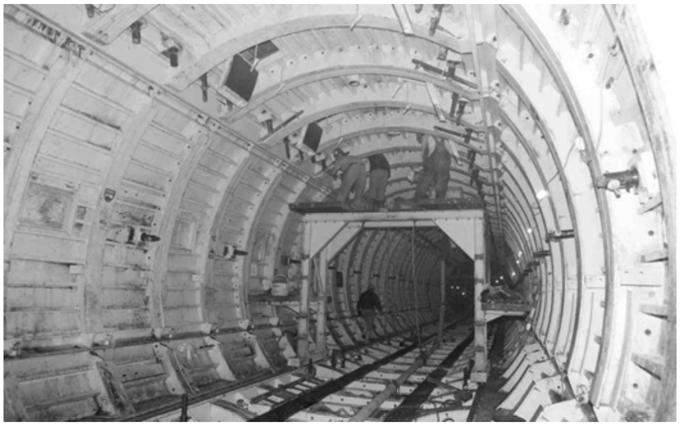
Figure 5. Excavation Progress

Figure 6. View of placed liner

5.4 *Contract arrangement*

A traditional approach of design, bid and construct was followed for this project. During the design stage of the project, a partnering workshop was arranged to include both the Owner (NEORSD) and Consultant (MWH) staff. The main objective of this process was to improve the efficiency of the project team and ensure proper communications at all levels of the project.

Figure 7. Concrete forms



6 CONCLUSIONS

The project, once fully in operation, will provide relief to an overstressed combined sewer system. Developing a project of this magnitude required extensive effort in planning by both the Owner (NEORSD) and the Consultant (MWH), as well as an acceptance and support from the Ohio Environmental Protection Agency and the surrounding communities.

In terms of both the cost and schedule, it has been demonstrated that a traditional competitive bidding process was a right choice for this project.

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