Final Tunnel Liner at Mill Creek 3 Project-Case Study

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ABSTRACT

The 20 foot diameter cast-in-place tunnel lining for Phase 3 of the Mill Creek Tunnel (MCT-3) has been completed. This paper will summarize aspects of liner design and address the construction approach in placing the liner in areas of tunnel that experienced crown overbreak. Tunnel lining production rates, installation procedures and form buoyancies experienced during concrete placement will also be presented.

INTRODUCTION

The Mill Creek, Phase 3, Tunnel (MCT-3) is currently under construction with planned completion in the year 2008. It is one of the largest tunneling projects undertaken by the Northeast Ohio Regional Sewer District (NEORSD) to date. The tunnel horizon is situated within the Devonian Chagrin Shale rock formation at an average depth of 280 feet. The tunnel was excavated using a two-pass method. A full face, fully shielded, Robbins, 23.8 ft diameter tunnel boring machine (TBM) was used to excavate approximately 15,000 feet of tunnel and facilitate installation of initial supports (first pass). The final lining (second pass) consists of 12-inch thick cast-in-place reinforced concrete and integral low flow channel. A total of seven (7) shafts were constructed on the project with the excavation of the tunnel commencing at Shaft 14, and proceeding down grade to Shaft 9, the terminus shaft. Due to the presence of overbreak in the tunnel crown, measures were required to support the form and counteract the effects of buoyancy during concrete placement. The means implemented to address the buoyancy effect will be addressed in this paper. The paper will also reflect on liner design, liner placement methods and placement of backfill grout behind the liner.

LINER DESIGN

Final lining design 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. The three cases considered are as follows:

- Case 1: Loading imposed on the liner from internal pressure with no external hydrostatic pressures.

- Case 2: Internal hydrostatic pressure with external water pressure.
- Case 3: External water pressure with no internal pressure.

Where the tunnel lining intersects shafts and shaft adits, additional reinforcement was required to carry loads around the intersecting opening. In this case, concrete reinforcement was configured to create hidden ring beams inside the tunnel walls.

LINER PLACEMENT METHOD AND SPECIFICATION CRITERA

The Contractor chose to utilize collapsible steel forms to install the final concrete liner. Each section of form consisted of a 270 degree top panel and a 90 degree invert panel. A total of eight, 24-ft long full circular form sections and one extra form section with just an invert panel were utilized on the project. A view of the concrete reinforcement and main tunnel form is shown in Figures 1 and 2.

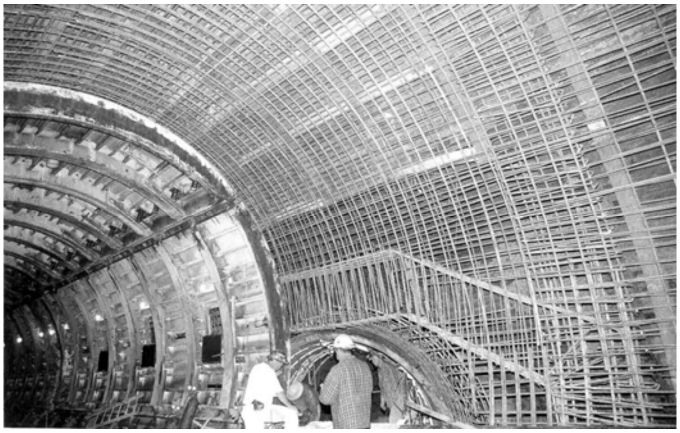

FIGURE 1 View of steel reinforcement and concrete form

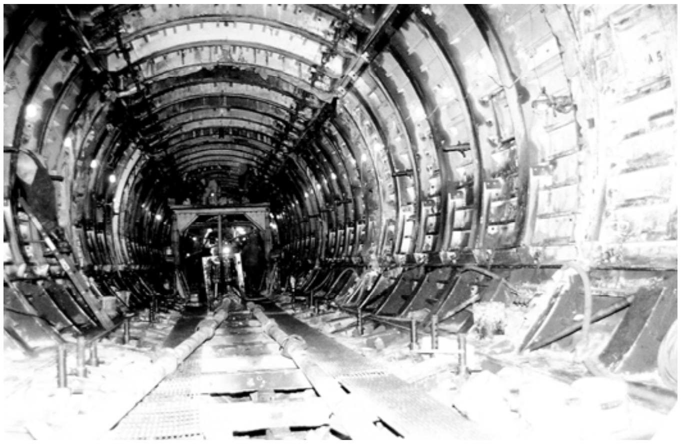

FIGURE 2 Full view of concrete form

Prior to the commencement of tunnel lining operations, the Contractor expressed concern regarding the condition of the tunnel crown. The Contractor stated that due to the extent of overbreak, the tunnel crown might not be capable of supporting the buoyancy load generated during the tunnel lining concrete placement. If movement of the form occurred, the tunnel form would be lifted potentially damaging the form and losing tunnel grade.

In preparation for lining operations, the areas of tunnel exhibiting crown overbreak were inspected to determine if the form spud pins in the tunnel crown could be placed on stable rock surfaces. Crown overbreak did occur at various locations of the tunnel, ranging in depth anywhere from half a foot to two feet. Based on this inspection it was determined that the overbreak areas could potentially allow the forms to be lifted during concrete placement.

To properly support the tunnel form, two steel beams (Z-beams) were installed in the tunnel crown. The fabricated Z-beams were fastened to the primary tunnel support system (W6x20 steel ribs) in the 10:30 and 1:30 clock positions. The form support beams were erected in a manner creating two continuous beams running the entire length of the tunnel. With the installation of the Z-beams, the loads generated during the placement of concrete were transferred to the tunnel ribs resulting in a wider distribution of the rock load. A photo of the installed Z-beams is shown in Figure 3.

FIGURE 3 View of Z-beams and tunnel support

The concrete specifications required that the forms remain in place until both a strength of 1,000 psi was achieved and not less than 8 hours of curing time had passed. In order to meet this requirement, the Contractor submitted multiple concrete mix designs for review. Approval was granted for two mixes providing the Contractor with concrete suitable for both cold and warm weather conditions. Regular quality control tests were performed in the field to verify the mix met the specification requirements.

FORM BUOYANCY MONITORING

With the installation of the form support Z-beams, the buoyancy loads were transferred to the ribs and shale in the tunnel crown. However, in distinct areas of the tunnel the overbreak was extensive enough that no rock was present behind the ribs. In these areas the Contractor expressed concerns that additional measures might be required to resist the effects of buoyancy.

In order to determine the significance of the buoyancy effect, a load-cell monitoring program was performed in the initial stage of the concrete lining operation. The following summarizes the monitoring, performed from Nov. 22 to Dec. 13, 2006:

- A total of 36 load cell tests were conducted, using Geokon type, Model 3000-100-1.
- Immediately before the placement of concrete, load cells were placed on the end of several spud pins in the crown of the tunnel and pre-loaded to an average of 8 tons, using an air impact tool. The load cells were fitted with a custom made bracket which allowed the cell to be installed between the spud pin and Z-beam as shown in Figure 4.
- As concrete was pumped in behind the tunnel forms, data loggers continuously monitored the change in load to the spud pins for the duration of the concrete placement.
- As shown in Figure 5, buoyancy loads were detected. However, all recorded loads were below the manufacturer's maximum expected buoyancy load of twenty (20) tons.
- As anticipated, the highest loads occurred in the last tunnel form at the end of the concrete pour.

FIGURE 4 Load cell reading in progress

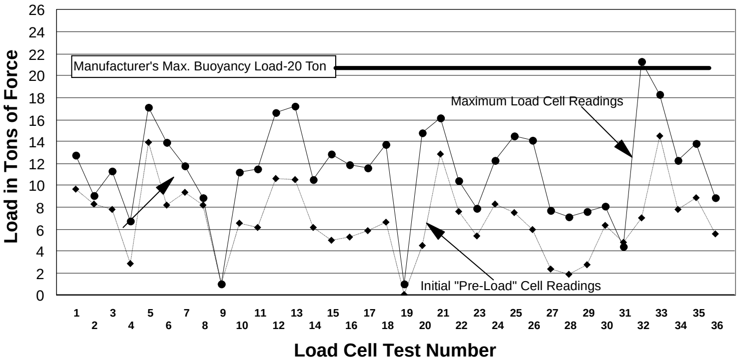

FIGURE 5 Summary of buoyancy monitoring results

Based on the results of tunnel mapping and load-cell monitoring data, it was determined that additional means of resisting forces generated by buoyancy would be required in areas of the tunnel with more extensive crown overbreak. As a solution, the invert of the tunnel form was fitted to allow rock bolts to be installed. In areas of the tunnel requiring additional support, a series of "tie-downs", consisting of 10-ft long resin bolts, were installed through the form invert, anchoring the form to the tunnel invert to help resist buoyancy. Figure 6 shows tie-downs installed in the form invert.

FIGURE 6 View of tie-downs at form invert

CONSTRUCTION SEQUENCE

The final liner was placed after completion of all tunnel excavation and removal of the TBM. The Contractor used the following steps to install the liner:

- The reinforcing steel was placed in two separate operations. The upper two thirds of tunnel was installed first in order to maintain the operation of the rail system. This operation was accomplished from two platform cars riding on two outer tunnel rails. The top steel was set at about 1,500 feet in advance of the poured concrete.

- Concrete was pumped from the surface through a series of down holes and shafts, using a five-inch delivery line. The concreting operation commenced at Shaft 14 and ended at Shaft 9. Figure 7 shows locations of shafts and down holes. The concrete pump was capable of an instantaneous delivery rate of 200 cy/hr, and was capable of a maximum pumping length of 1,400 feet. However, the Contractor chose not to exceed a 1,000-ft pumping length. Typically during the placement, two concrete trucks were simultaneously discharging concrete into the pump hopper. See Figure 8.

- Concrete placement was performed every other day during first shift, between 7:00 AM and 4:00 PM. At the beginning of a placement, concrete was poured through an opening on the top of the form, located at the upper reach of a slopping concrete joint. During the previous day's pour this port was cleaned and readied for this purpose. Placement was continued through this hole until the next intended hole was reached with the crown concrete. Then the delivery line was quickly moved to the next hole (about 60-ft away) and pumping was resumed. The pour was terminated when concrete covered the arch just past the last form joint (about 20 feet from the bulkhead at the end of the last form that extended up to its spring line). Using this approach, the joint at the downgrade end of each concrete placement consisted of a vertical joint from the tunnel floor to the tunnel spring line, and a sloping joint from the tunnel spring line back about 20 feet to the crown of the tunnel. The next day's pumping port in the crown of the form was cleared of concrete at the upper end of the sloping joint. At the beginning of the next day's pour, grout was then injected through this port along the sloping joint to promote bonding between the fresh and previously placed concrete.

- Provided that 8 hours of curing time and 1,000 psi of strength had been achieved, the forms were stripped and moved for the next placement. Stripping and setting the formwork was done on the second and graveyard shifts.

- The final clean up of the tunnel invert and installation of invert steel was done just ahead of form placement. Finishing the tunnel clean up and invert steel placement were first and second shift operations.

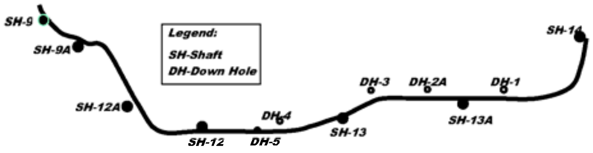

FIGURE 7 Location of shafts and down holes

FIGURE 8 Concrete delivery at down-hole position

PRODUCTION SCHEDULE

It took at total of 118 pours to install the liner. The length of the lining pours varied from 96 to 168 feet with typical pour length raging from 120 to 144 feet. The actual construction time required to line the tunnel was approximately a year, from Sept. 6, 2006 to Sept 11, 2007. Figure 9 shows production and total footage placed.

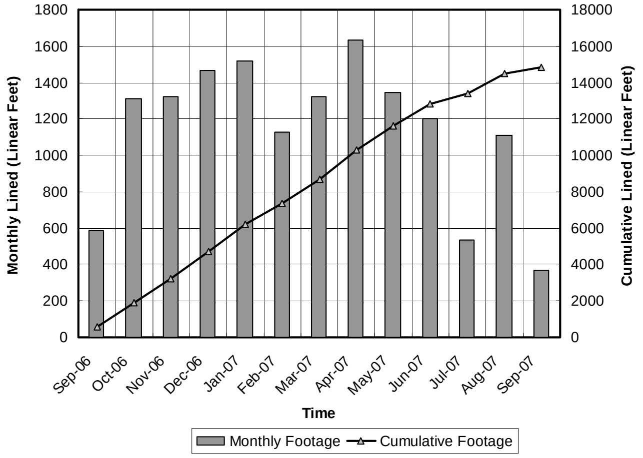

FIGURE 9 Concrete lining production

CONTACT GROUTING BEHIND THE LINER

The primary objective of contact grouting is to fill any remaining voids between the rock and concrete liner.
The MCT-3 Contract Documents required that the grout have a minimum 24-hour compressive strength of 100 psi. and a minimum compressive strength of 1,500 psi at 28 days. It also specified that the grout should consist of a mixture of water and Portland cement, with fillers as necessary to achieve a non-shrink, non-bleeding and non-corrosive, flowable grout.

In order to meet the specification criteria, the Contractor in collaboration with his concrete supplier, formulated a grout mix, consisting of water (1,000 lbs), Type 1 cement (658 lbs), fly ash (1,075 lbs) and fluidifier additive (17 lbs).

At the time of writing this paper, the contact grouting is in progress. It is being accomplished by drilling through the concrete liner every 25 feet and installing a packer. Starting at the downgrade end of the tunnel, grout will be forced through each packer and pressurized to 60 psi. Once the contact grouting is completed, check holes will be drilled in select areas to confirm that the voids behind the tunnel lining have been properly filled with grout.

SUMMARY

At the time of finalizing this paper, the tunnel-lining task was complete and the contact grouting operation is in progress. A team from the Northeast Ohio Regional Sewer District (NEORSD) and MWH Americas provides oversight on tunnel construction by KMM&K-Joint Venture the Contractor.

ACKNOWLEDGEMENT

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