Technical Memorandum

To: James Clift (EGLE), Ryan Mitchell (MDOT)	Project:	Enbridge Line 5 Tunnel Project	
From: Sam Swartz	cc:	Dan Adams, David Crouthamel, Marco Moccichino	
Date: January 12, 2021	Job No.:	6191.0	
Subject: Slurry systems with excavation by TBM			

1.0 Introduction and Questions

The Enbridge Line 5 Tunnel Project is anticipated to utilize a slurry tunnel boring machine (TBM) or a variable density (VD) TBM to excavate an approximately 4 mile tunnel below the Straits of Mackinaw that will house the new section of the Line 5 pipeline as replacement of the two existing pipelines on the lakebed of the Straits. The TBM is anticipated to excavate through bedrock with high hydrostatic pressure (up to 17 bars from available information) and with the potential for open seams and highly fractured rock conditions.

This document discusses techniques for slurry containment, treatment and disposal similar to those expected for the excavation of the Line 5 Tunnel Project. It addresses the following questions raised by the EGLE Representative on October 20, 2020 (received via email) as part of the permit review process:

"*Provide examples of slurry containment, treatment and disposal for slurry TBM projects, as well as examples of water treatment plants for bentonite slurry wastewater treatment and tunnel infiltration groundwater inflows. Even for use of a slurry TBM on this project, we would anticipate certain locations to require open mode of the TBM (typically maintenance and repair), which may have higher short term inflows.*

- *Is it typical for the bentonite slurry to only contain approximately 99% water and 1% bentonite clay, or does the slurry potentially contain other additives to modify the slurry.*
- *Other than bentonite, what other products are typically used to cement/grout the walls and tunnel structure during construction?*
- *Is the bentonite slurry system typically a closed-loop system with tanks and/or ponds used for holding and storage?*
- *What practices are used to limit the potential for bentonite to be discharged during wet weather events.*"

2.0 Answers to Questions

Slurry TBMs have been used to improve advance rates in the excavation of tunnels through granular materials. This document highlights two recent projects, Second Narrows Water Supply Tunnel and Portland East Side CSO, that utilized slurry TBMs to excavate tunnels. While ground conditions for these two projects differ from those expected during the Line 5 Tunnel Project, overall set-up and operations should be similar. Both operations were in close proximity to major water bodies, similar to Line 5.

From past experience, slurry consists of a mixture of water and bentonite clay, with a bentonite content typically ranging from 3% to 8% by weight, depending on the desired properties of the final mixture. A two-part mixture is used in most excavations, however additional materials can be added to further fortify the bentonite if necessary. Additives include, but are not limited to: sodium bicarbonate, sulfuric acid, carbon dioxide, soda ash, KR-B4001, and Aquagel. A bentonite slurry system is typically a closed loop. Slurry is mixed in a treatment plant, cycled through the excavation face, and returned to the treatment plant where the spoils are separated out for disposal. The separated slurry is then recirculated in the tunnel or diverted to the water treatment plant, if it does not meet design criteria. Slurry diverted to the water treatment plant is treated for discharge into allowable discharge points subject to meeting regulatory criteria. Solids from the water treatment plant are disposed of off site. The closed loop nature of the cycle, combined with significant measures often used to control stormwater on site, such as limiting the volume stored in tanks and containing the perimeter of a treatment plant with a berm, help eliminate the potential for bentonite run off into waterways. The latter arrangement has been adopted in the Second Narrow Water Supply Tunnel (SNWST) in Vancouver, BC. Differently, on the East Side Combined Sewer Overflow (ESCSO) Tunnel in Portland, OR, a full enclosure of the slurry treatment plant was selected.

In terms of other products or materials that may be encountered during tunneling operations, the main one is cement-based concrete, shotcrete, or grout. At the start and end of tunneling, the TBM will pass through excavation support systems that are likely to be concrete or shotcrete, but only for very short distances. For portions of the tunnel that require pre-excavation grouting, likely as at locations where open mode interventions are used, cementitious-based grouts (typically microfine or ultrafine) will be used. These locations are anticipated to be of limited extent. Tail void grout that is placed around the segmental lining has the potential to be washed up to the TBM heading for situations where the TBM is not in fully pressurized mode. This grout is anticipated to be a cement-bentonite grout with accelerating admixtures. Chemical grouts typical to the tunneling industry could also be used on occasion, but would be anticipated to have limited usage on this project. The slurry system, slurry treatment plant, and water treatment plant would need to be set up in anticipation of small quantities of mostly cementitious materials in the system for the situations above.

3.0 Discussion

The following sections expand on the answers above and provide further details of the two reference projects.

3.1 Slurry Properties

Slurry is typically a mixture of water, bentonite clay, and additives that helps improve the efficiency of TBM tunneling projects in some ground conditions. The bentonite content typically ranges from 3% to 8% by weight. It is common to use a slurry composed of only water and bentonite, but occasionally environmentally friendly non-toxic polymers are used to fortify the bentonite. The types of polymers used in tunneling are similar to those of the food industry and they are mostly considered non-toxic and biodegradable. Another example is sodium bicarbonate which is used for cement contamination. In general, these additives are not needed during routine slurry excavation.

Additives such as sulfuric acid, carbon dioxide, soda Ash, KR-B4001, and Aquagel are used to control the pH and viscosity of a slurry mixture. These specific products are currently called out in the NPDES permit. The exact concentration of the mix depends on bleed rates, barrel yield and viscosity requirements for the soils being excavated as determined by the mud engineer.

3.2 Slurry System Flow Cycle

The flow cycle details the steps in the process of mixing, utilizing, and recycling slurry during a slurry TBM excavation. Typically, water from a local source is mixed with bentonite and other additives in a slurry treatment facility. The resulting slurry then enters the slurry circuit via the feeding line, is pumped into the excavation chamber at the tunnel face, mixes with the excavated material, and then is circulated back to the treatment facility via the return line. Within the treatment facility, the slurry undergoes a multi-step process to separate out the excavated material, which is temporary stored on site and then transported for final disposal.

Slurry separation plant (STP), holding tanks, and waste bentonite tanks form a closed loop. Once slurry is treated through the STP, properties are checked. If within the acceptable criteria, the slurry goes back into the tunnel. If not, it is removed from the circuit, diverted to a separation equipment (centrifuge or filter press) and disposed of. Slurry is then topped up by fresh bentonite stored in the holding tanks. Typically, the local environmental disposal facilities have a specified capacity. If local disposal capacity is limited, it is recommended to keep excess storage capacity (tanks) on site. This storage will buffer a sudden influx of slurry and allow for disposal over a number of days or weeks.

3.2.1 Separation of Slurry and Disposal

There are two types of slurry within the closed system:

1) fresh slurry (bentonite & water); and
2) spent slurry (slurry laden with fines).

The STP separates the suspended excavated material of the spent slurry and recycle the bentonite mix. Nevertheless, after multiple excavation cycles, the bentonite mix cannot be regenerated to its initial properties and it becomes laden by fine particles. At this point, the laden slurry is separated into fine particles and discharge water using a centrifuge and/or filter press. The fine particles are dry and can be readily trucked away.

For the fresh and spent slurry, the following should be noted:

- For a situation where a large quantity of slurry needs to be disposed of, it is most likely fresh, and not spent.
- The centrifuge method works well with spent slurry but not with fresh slurry.
- For spent slurry, a centrifuge can produce water that is acceptable for discharge into the environment, or close enough to acceptable that it can be readily treated. For fresh slurry, the

centrifuge does not remove all the fine bentonite particles, and produces turbid water which is difficult to treat.
- The filter press method works well for all types of slurry and produces water that is acceptable for discharge into the environment (or close to acceptable).

Ultimately and where allowed by local authority, spent slurry could be also discharged into sanitary sewer avoiding the separation process above. In this scenario, the capacity of the network could become the restricting factor of discharging large quantities of spent slurry for prolonged time. This option could be left as an emergency mitigation such as malfunction of the centrifuge.

Per discussions with Enbridge and their consultants, the water treatment plant is designed with a factor of safety equal to 3 and it can cope with an aggregate flow up to 5 MGD. This arrangement seems adequate to the purpose subject to monitoring that tunnelling with partial face pressures doesn't generate excessive water inflows that could stress the plant capability.

3.2.2 Disposal of Discharged Water

Water generated by the centrifuge or filter press can be disposed of in different ways:
- Treated at a water treatment plant, and discharge into the environment.
- Discharged into storm drain - Most municipalities don't allow 'earth' in the storm system, and very likely this won't be an option for this project.
- Discharge into sanitary sewer. This is preferred over the storm system as the sanitary typically has a higher tolerance for dissolved solids.

3.3 Discharge to Waterways

One major concern from tunneling near waterways is the discharge of slurry (or otherwise contaminated water) into waterways. Slurry flow systems are typically designed to minimize these discharge events; however, the process can be complicated by heavy rainfall events.

As mentioned, the bentonite system is a closed loop, limited volume system. Additional controls are in place to eliminate the possibility of discharge during wet weather events, such as not filling tanks to holding limits and containing the perimeter of the separation plant area using a berm, with any spillage directed to a sump area by site grading. The sump is regularly emptied by pumping to the waste bentonite holding tank. The waste bentonite holding tank is drawn down by feeding a centrifuge system specifically designed for this purpose, whereby water and solids are separated with water recycled to the slurry plant and bentonite and soil solids discharge hauled away to an approved dump site.

Slurry recirculation is common, but if it has been contaminated with fresh water, it can be difficult to get it back within the desired property range.

3.4 Prior Project Experience

This section discusses the slurry containment systems designed for specific projects. These projects use(d) excavation diameters similar to the Line 5 Replacement Tunnel, the alignments are near or cross under a body of water, and the work sites for the project are or were close to major bodies of water.

3.4.1 Second Narrows

The Second Narrows Water Supply Tunnel consists of an approximately 3,600 ft crossing with a maximum depth of 215 ft below the Burrard Inlet in Vancouver, BC. The tunnel connects two shafts on either side of the inlet, one excavated through granular soils and one excavated through bedrock. The TBM excavated tunnel begins in soft ground conditions, transitions into a mixed face section, and then into a hard rock section. A slurry TBM (22 ft diameter) was chosen as the preferred excavation method through this varied geology and for the ability to manage high water pressure up to 7 bar (in the soil section). This project is currently in construction.

This project has very high environmental standards including “process water treatment” for any rain water landing within the site and for any pump water from tunnel or shaft. As noted above all waste bentonite is processed through a centrifuge bentonite/water separation system whereby solids including bentonite and very fine excavated materials are separated from the slurry and water returned to a holding tank for reuse. Separated solids at the centrifuge discharge are hauled away periodically from a lined bin to an approved dump site. Figure 1 shows the indicative layout of the Slurry Treatment Plant for the Second Narrows project. The plant is within approximately 500 feet of the Burrard Inlet.

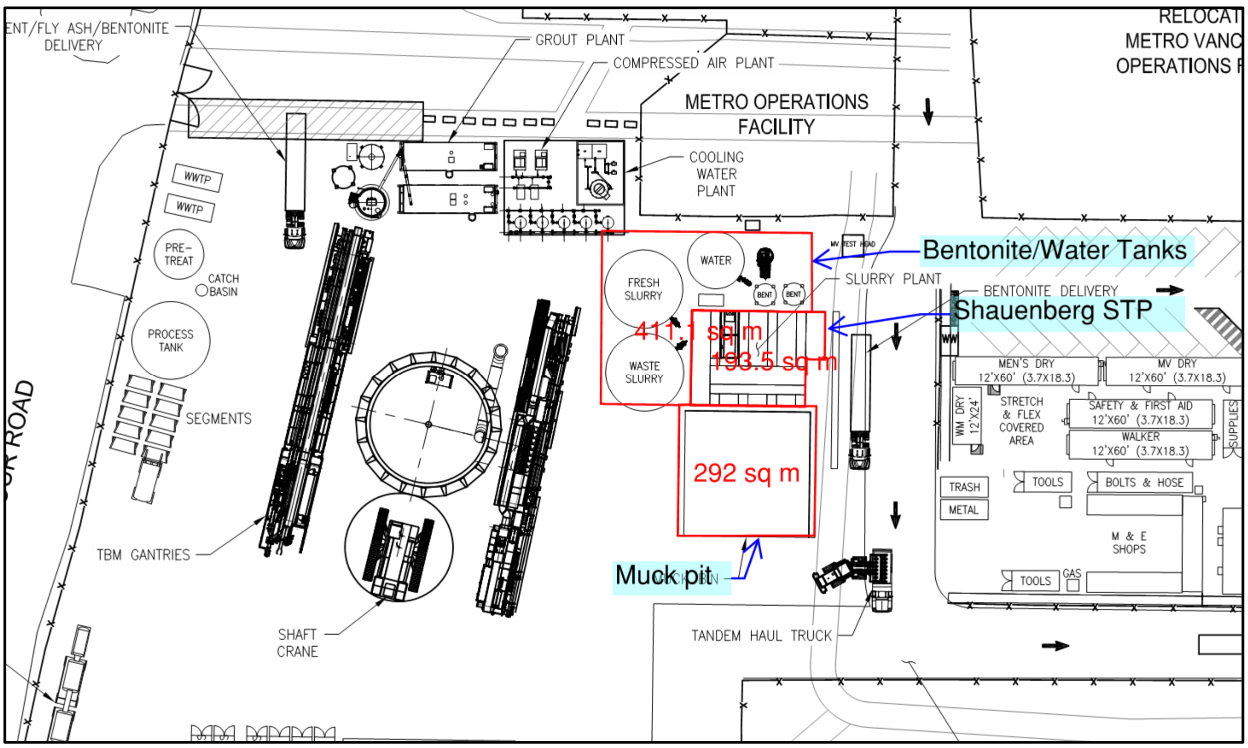

Figure 1. Slurry Treatment Plant Site Layout Second Narrows

Figure 2. Slurry Treatment Plant Site Layout Second Narrows

3.4.2 Portland East Side CSO

At the time of completion, the Portland ESCSO was the largest slurry TBM tunnel in North America. The Portland ESCSO consisted of 30,000 ft long 22 ft diameter tunnel with anticipated groundwater pressures up to 4.5 bar. This tunnel does not cross a large body of water, however its entire length was constructed in close proximity to the Willamette River, and water pressure from the river was expected to impact tunneling conditions. Based on the granular material combined with the anticipated hydrostatic pressures, a slurry TBM was utilized during excavation.

The slurry used on this project consisted of 2 -5 % bentonite and, under normal operations, no additives were included in the mixture. During intervention for cutterhead maintenance, additives were included to promote filter caking of the material.

Figures 3 and 4 show images of the slurry treatment plant utilized for the project. The treatment plant contained large storage tanks capable of storing the volume necessary for the longest piping run. The storage tank levels were monitored using automated software to manage the volumes and prevent overflows in the system. Figure 5 shows a diagram of the automated system. The slurry plant was in close proximity to the Willamette River, within 500 to 1000 feet.

Figure 3. Storage Facility Outside of Slurry Treatment Plant

Figure 4. Inside Slurry Treatment Plant

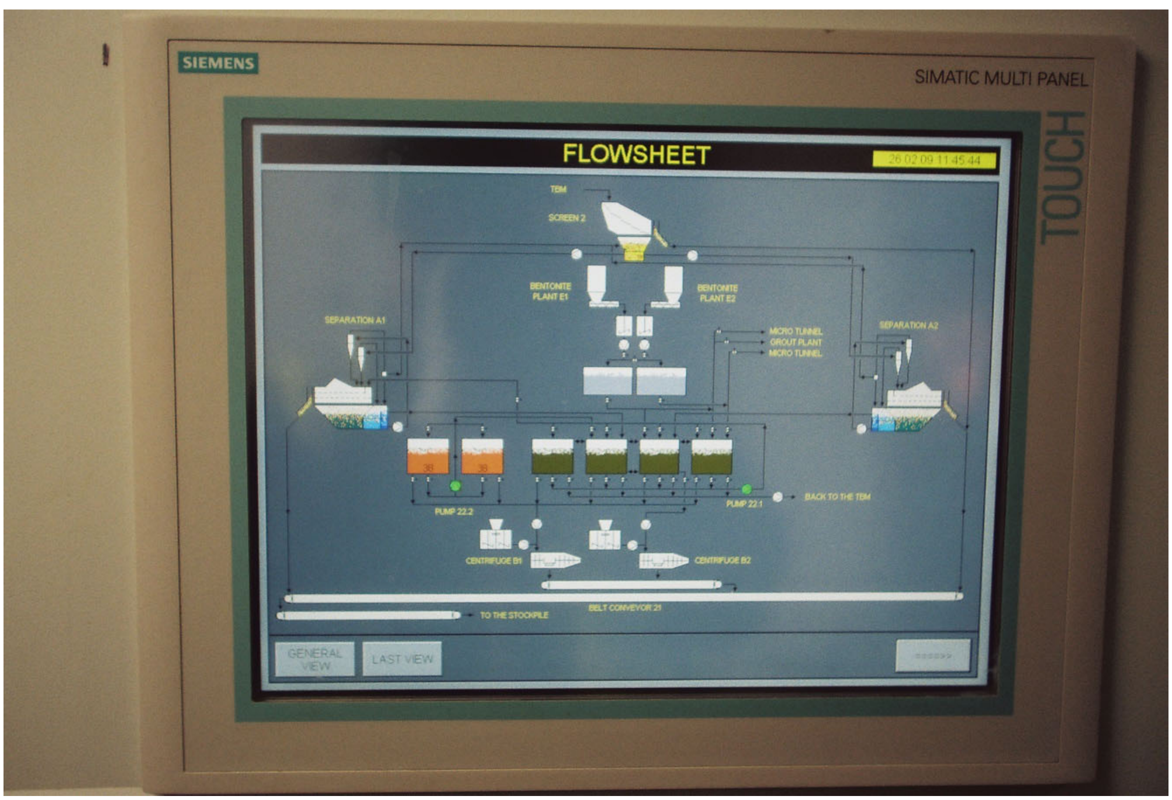

Figure 5. Automated Slurry storage system

4.0 References and Additional Information

M. Holfelder, N. Kofoed, G. Irwin - Slurry TBM tunneling on the east side CSO tunnel project, Portland, Oregon, RETC Proceedings, 2013

KRB4001 (Polyaluminium Chloride) Product Data: http://www.geosc.com/products/polyaluminum-chloride-(pac)

Aquagel Product Data: https://www.baroididp.com/idp/products-applications/products/nsf-products/aquagel.html.html

Soda Ash Product Data: https://www.epa.gov/sites/production/files/2020-09/documents/8.12_sodium_carbonate.pdf

Herrenknecht slurry plant website: https://www.herrenknecht.com/en/products/productdetail/separation-technology/