TBM tunneling design in challenging Geological Setting in York Region, Ontario. The West Vaughan Sewage Servicing Project.

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ABSTRACT

The planned West Vaughan Sewage Servicing (WVSS) Project includes a 14km long trunk sewer system located in a developing area of York Region, just North of Toronto. Through the preliminary design process, the preferred tunneling method was chosen as TBM with precast segmental liner system. The major drivers are related to social-environmental risk mitigation measures obtained through reducing the extent of surface works. This paper presents the WVSS project and outlines the detailed tunneling design which has been carried out following a general risk mitigation process. Challenges in tunneling can often be related to hydrogeological and geotechnical issues, thus requiring an extensive field investigation campaign as a basis for both the risk management process and the design criteria included in the Geotechnical Baseline Report. For tunneling in Greater Toronto Area, it is relevant to highlight the typical local geological environment, where subsequent deposition, erosion, glaciation, and finally fluvial (river) actions produced a high variability of rock and soil geotechnical setting, including a number of challenges, each imposing specific constraint on the design. For the WVSS project, in fact, overburden materials are anticipated to be highly variable, ranging from hard glacial tills to fluvial materials including boulders, sands and gravels, with potential gas pockets and artesian water-table. The bedrock is characterized as the Georgian Bay Shale Formation, which is typically a weak shale material, intercalated with decametric bands of much harder limestone. The bedrock is also subjected to high-horizontal regional stresses, relic of glacial isostatic loading, as well as chemically induced swelling associated with the shale materials and saline groundwater. A comprehensive geotechnical investigation program was conceived to define a Geological-Geotechnical Reference Model (GGRM), capable to offer the tunnel designers elements to mitigate the potential geotechnical / hydrogeological risks.

1 THE WEST VAUGHAN SEWAGE SERVICING (WVSS) PROJECT IN YORK REGION

The Regional Municipality of York (York Region) completed the West Vaughan Sewage Servicing Class Environmental Assessment (Class EA) in 2013. The study’s findings are summarized in the Environmental Study Report (ESR). The Class EA was initiated by the findings of the York Region Water and Wastewater Master Plan Update (2009), which identified the need to provide additional servicing capacity for the North West Vaughan area to meet the demands of future growth up to the year 2051. The objective of the Class EA was to develop a regional sewage servicing plan for the West Vaughan area to accommodate the approved population growth within the servicing boundaries to the year 2031 and the projected population growth to 2051.

The conceptual design identified in the ESR proposed the construction of a trunk sewer from the Kleinburg Water Resource Recovery Facility (WRRF) to the Humber Sewage Pumping Station (SPS), and the expansion of the existing Humber SPS from a capacity of 1700 L/s to 2400 L/s. A Conceptual Design Report (CDR) was prepared in 2014 to present the design requirements and criteria for the proposed WVSS Project. The project was approved by York Region to proceed to the next phases, and the preliminary design works were carried out by Delcan-Geodata Joint Venture throughout 2016, including the preparation of an amendment to the Class EA study.

Figure 1. Preliminary Design Report preferred alignment plan view (in black) compared with Conceptual (in blue)
After approval of the EA Amendment and Preliminary Design Report (PDR), the project has been proceeding into its final design phases, with a constant implementation of risk management approach allowing for a continuous update of design requirements as new constraints and requirements arise. The development of the project currently includes about 14km of 3m internal diameter tunnels, 9 shafts, and the Humber SPS rebuild.

2 THE PRELIMINARY DESIGN PROCESS

The WVSS preliminary design process included five main steps (Figure 2). The outcome of the preliminary design was to identify major risks and apply risk mitigation measures to address them. Although these risks were quite immediate to identify and mitigate, the impacts of the design changes brought forth through this process would likely have profound positive impacts on the overall project.

Through the preliminary design process, residual risks remained. These residual risks have subsequently been dealt with in the final design stages of the project, through the risk management method. The preliminary design steps are discussed further in the following sections.

2.1 Conceptual Design Review

The first major step carried out within the preliminary design process was a review of the conceptual design developed through the Class EA assessment (ref. Gaspari, 2018). The identified major risks and risk mitigation measures are summarized in Figure 3.

The major risks were associated with reducing the potential for environmental and social impacts associated with the sewer construction works. For example, roughly one third of the sewer tunnel was planned for open cut and microtunneling. The open cut construction (upwards of 10m depth) was recognized to have significant impact on surface. The microtunneling works would be less impactful, however would still require surface construction works for tunnel access shafts spaced at roughly 250m centers. A high-level multi-criteria analysis (MCA) was carried out to assess the various parameters and trade-offs between the microtunnel vs TBM tunnel approach.

Figure 3. WVSS Conceptual Design Review framework.

Due to the sensitive environmental issues associated with the Humber River valley, the decision was made to eliminate the cut and cover and micro-tunnelling works in favor of an all-TBM tunnel method. A summary of design modifications, from the conceptual design to the preliminary design, is provided in Table 1.

As noted previously the main driver for the changes was the elimination of major portions of surface works, including a significant reduction in the number of shafts. In addition to the MCA, a high-level cost estimate was also performed which demonstrated that the overall costs of the project would likely stay within a reasonable statistical tolerance. The all-TBM approach was also thought to be more conducive to risk controls through the construction process, since the number of contractors would be reduced, and the projects residual risks are now focused on the TBM constructability aspects.

Table 1. Changes from Conceptual to Preliminary Design

<table>
<thead>
<tr>
<th>Design Component</th>
<th>Conceptual</th>
<th>Preliminary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microtunnel length</td>
<td>3,949 m</td>
<td>0 m</td>
</tr>
<tr>
<td>Cut &amp; cover tunnel length</td>
<td>1,140 m</td>
<td>0 m</td>
</tr>
<tr>
<td>TBM tunnel length</td>
<td>8,830 m</td>
<td>13,907 m</td>
</tr>
<tr>
<td>Total tunnel length</td>
<td>13,919 m</td>
<td>13,907 m</td>
</tr>
<tr>
<td>TBM launch/extraction shafts</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>TBM maintenance shafts</td>
<td>11</td>
<td>3</td>
</tr>
</tbody>
</table>

Another important risk mitigation measure was the adjustment of the tunnel alignment and shafts to adapt different additional constraints. An example of alignment modification can be recognized in Figure 1 in proximity of the Compound 6 location. In this case, the tunnel was shifted away from surface infrastructure including two bridge foundations, as well as was deepened to provide additional cover below river crossings. This was also done in an effort to place a TBM extraction shaft uphill from the potential flooding and just at the tunnel transition from soil to bedrock, in order to allow for separate mostly homogeneous excavation runs in either rock or soil. The
trade-off to this approach was the property access requirements for the adjusted shaft and compound placement. This required external stakeholder buy-in, for which York Region has been instrumental in providing consultation with property owners.

2.2 Assessment of contractor provided TBMs versus using York Region refurbished TBMs

The WVSS project is relatively unique in that York Region owned its own TBMs which could have been refurbished and used in the project. The TBMs were previously used on another York Region wastewater tunnelling project and were being stored under optimal conditions at a facility owned by York Region. The TBMs were 3.6m diameter single shield earth pressure balance Lovat RME142SE Series 26300, acquired in 2010. An assessment was carried out in order to identify the cost and technical tradeoffs of refurbishing the used TBMs or having the tunneling Contractor provide its own machines. Ultimately for risk mitigation considerations, the decision was made to sell the TBMs and have the Contractor supply its own ones as part of the Contract bid requirements. The cost analyses results associated with either approaches were not significant enough to justify keeping the machines, particularly if delays in the WVSS construction schedule were encountered. The residual risks associated with this approach are related to the machine selection and specification, which would need to be addressed through the projects contract strategy and specifications, as per Figure 4.

2.3 Geotechnical Design Input

A comprehensive geotechnical investigation program was conceived in order to reduce the potential geotechnical / hydrogeological risks. The goal of the investigation was to thoroughly characterize the material behavior, to reduce uncertainty in design, as well as to provide useful baselines for the Contractor. However even through such a rigorous program, gaps will also remain in the site understanding, therefore the use and reporting of such data needs to be done carefully and risks are required in the different design stages to be adequately considered through the adoption of document, the “Risk Register”, that is supposed to be “live”, continuously updated by the design team as data are processed and new constraints or information are found.

The geotechnical investigation components used for the program are summarized in Gaspari, 2018. The relatively tight borehole spacing has been supplemented through geophysical works, insitu testing, and thorough laboratory testing of the soil and rock units.

The geotechnical investigation was carried out in a phased approach (refer to Gaspari et al, 2017) in order to support iterative development of the sites geotechnical model and provide design basis in real time. All current and historical data is being integrated and queried into a 3D geological model using the program Datamine® (CAE Mining Ltd) by the geotechnical subconsultant, Golder. The preliminary geological profile is illustrated in Figure 5.

Figure 5. Pseudo 3D Geological Model of the WVSS Project tunnel alignment (view from South-West)

2.4 Construction Staging and Sequencing

For a relatively complex project such as the WVSS, the choice of suitable construction staging, and sequencing alternatives is driven by multiple factors which do not always have straightforward outcomes. For example, one option might be best for solving schedule constraints, but worse for dealing with environmental constraints or costs. When many potentially suitable alternatives are under consideration, a Multi Criteria Analysis (MCA) is used to quantify the relationships and trade-offs of any particular scenario. Through the MCA, the various technical, cost and environmental/social factors are identified, and weightings are applied to these factors based on their perceived degree of importance to the overall project. The numerical results obtained through the MCA represent a culmination of the various factors.

There are numerous factors and parameters involved in the MCA for deciding on optimal staging and sequencing. The process is quite involved and draws upon input from multiple disciplines with knowledge of the
potential options and impacts related to constructability, costs, social-environmental impacts, etc. The shaft compound types would directly impact the size and construction requirements (environmental impacts, traffic, noise, etc.) for each area. The detailed process and outcome is not discussed within this paper. Moreover, this chapter only reports design considerations and results at the preliminary design stage. The definitive design is still ongoing at the time of writing and it will produce a further update of the overall construction staging accordingly with updated inputs and constraints. In short, the process followed three main steps: 1) identification of the reference scenario, 2) preliminary screening of all alternatives to generate a shortlist of preferred options, and 3) the detailed MCA to quantify the various input parameters and identify the overall optimum approach.

The reference scenario was developed through the conceptual design review. It was determined that the all-tunnel option with an assumption of 2-TBMs would provide the best overall approach for the project. The all-tunnel construction method would reduce social-environmental aspects. The 2-TBM approach was required for completion of the project according to the clients preferred schedule, as well as the constructability factors related to applying specific TBM designs to the variable soil and bedrock ground conditions. With this approach, several shaft compound locations were identified. The selection of these locations was typically constrained by the termini of the various tunnel stretches, as well as property availability.

Some example inputs and outputs of the preliminary and detailed MCA are provided in Figure 6. The reference scenario provided specific focus to the overall tunnel and shaft design requirements, however there still remained upwards of 32 possible alternatives of construction staging and sequencing options.

The preliminary screening MCA involved the assessment and scoring of five main factors including: 1) number of launching or retrieving shafts/compounds, 2) number of TBM transfers over the ground surface between launching and retrieving shafts, 3) excavated shaft volumes, 4) length of launching / starter tunnels, and 5) the direction of excavation. From the assessment of the 32 alternatives, 6 preferred staging and sequencing options were identified.

A detailed MCA was carried out on the preferred 6 options. The detailed MCA analysed, quantified and scored various parameters related to: a) infrastructure and environmental impacts (10 parameters), and b) constructability and implementation aspects (14 parameters). Each parameter required the development of scoring criteria derived from past experience and reference projects, or regulatory requirements. Several parameter weighting schemes and impact scenarios were also analysed to better assess the MCA outcome with respect to alternative risk tolerance preferences.

Ultimately through the MCA a construction staging, and sequencing approach was derived for the WVSS project which represented an optimal trade-off between the various alternatives. The multi-disciplinary input was key to developing this agreeable solution. The identification of the optimal scenario allowed to proceed the preliminary design of the shaft and compound construction arrangements.

3 THE TUNNEL DESIGN

3.1 TBM Selection and Specification

Due to various design challenges, not last the requirement to be guaranteed a completely watertight excavation, the required mechanized method was identified with the need to avoid partial face, or non-rotation excavation methods. This automatically excluded the use of road-header and mechanical/hand excavation methods.

An open gripper TBM may have been feasible in bedrock portions of the tunnel, however during preliminary design phase all tunnel segments within the WVSS were characterized with portions of mixed face or soils. An open TBM (without shield) would also not be feasible for dealing with soft flowing ground conditions and potential high-water-inflows anticipated for the WVSS sewer alignment.

A shielded TBM with precast segmental liner with the ability to provide an active pressure at the face would be the most feasible approach for mechanized excavation under the specific outlined conditions. This is due to its ability to handle the variable ground conditions and water pressures likely to be encountered along the tunnel. The segmental liner provides immediate support to the ground, also helping to mitigate the need for multiple phases of ground support installation.

In the selection of mechanized tunneling methods, there are inherent trade-offs between slurry/hydro-shield TBMs and EPB-TBMs, predominantly related to the mode of cutting and supporting the face. The advantages and limitations to either option applied to specific hydro-geological conditions and geotechnical hazards of the WVSS project are summarized in the following tables.

The TBM mined tunnel will be required to be carried out in pressurized mode. This technical choice is based on lessons learnt from previous experiences, and particularly to guarantee that no groundwater inflow and drawdown will take place during tunnel excavation (Figure 7).

For the EPB-TBMs to be effective in controlled excavation through the variable ground and groundwater conditions expected along the alignment, it will be necessary to use appropriate types and quantities of soil conditioning agents. It will be required to select the type, mix and injection rates of the ground conditioning system (GCS) for proper control of the support pressure for all
ground conditions indicated in the GBR. Field and lab tests on the ground conditioning system are required in order to define the proper characteristics.

Table 2. Advantages and limitations of Slurry Shield TBMs.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applicable uses in variable soil conditions including mixed face soil/rock</td>
<td>High ground permeability makes slurry cake formation more difficult</td>
</tr>
<tr>
<td>Good face control ability, even under poorly self-supporting materials, or high-water table</td>
<td>Higher costs associated with the slurry production, removal, recycling, and disposal. Slurry disposal requires special environmental consideration.</td>
</tr>
<tr>
<td>Good applications where excavation induced settlements are of concern</td>
<td>Slurry separation plants and circuit occupy additional area on surface</td>
</tr>
<tr>
<td>Applicable to bedrock with proper application of cutting tools</td>
<td>Fine particles create issues with slurry separation from the muck, creating additional cost and waste</td>
</tr>
<tr>
<td>Hydro shield technology allows for quick adjustment of face pressure if encountering rapidly changing conditions</td>
<td>Potential for hydraulic connections leading to frac-outs of the slurry materials into the ground, creating environmental issues</td>
</tr>
</tbody>
</table>

Table 3. Advantages and limitations of EPB-TBMs.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applicable uses in variable soil conditions including mixed face soil/rock, with addition of foam and if necessary polymers</td>
<td>Difficulty for short drives or for uniform sandy conditions with high permeability</td>
</tr>
<tr>
<td>Conditioning agents used within the soil chamber to deal with variable ground types and permeabilities</td>
<td>High water pressures can be an issue for infiltration through the screw conveyor</td>
</tr>
<tr>
<td>Good applications where excavation induced settlements are of concern. Reduced risk of fluid loss through the cutter head in comparison to slurry shield</td>
<td>Potential environmental restrictions regarding soil disposal with soil conditioning materials, which will require confirmation from local regulatory agencies</td>
</tr>
</tbody>
</table>

The selection of the appropriate machines and technology has been predicated by the ground conditions potentially encountered, as well as various considerations of technical, cost, and environmental impacts. Currently, there are more advantage to the EPB-TBM approach over the slurry shield approach, mainly through the easier management of the muck created from the slurry process, and with less potential for environmental impacts.

The multimode TBM was also investigated but found not ideal for this project, due to larger compound space requirements associated with the slurry circuit system.

As per the selected EPB-TBM, cutter heads will have to incorporate disc cutters to excavate the harder layers encountered within the shale bedrock. Over-break should be expected due to the tendency of the shale rock to delaminate along bedding planes. The presence of harder layers over portions of the tunnel face and not in others will have an adverse effect on the tunnel alignment and corrective measures will be required throughout the excavation to keep the EPB-TBM on alignment.

3.2 Tunnel Segmental Lining Characteristics

The tunnel has been designed to be lined with a Precast Concrete Tunnel Lining (PCTL) system suitable for the ground condition baselines described within the GBR, and with the tunneling performance requirements that will be indicated in the Contract Documents.

The PCTL system has been designed as universal ring (Figure 8) to allow adapting to minor TBM mistakes in following the alignment and to guarantee its capability to excavate along the minimum curvature radius in this project. Its design considered three stages:

1. precast processing (extraction from mould and first handling, storage, lifting by erector, handling in shafts and in the tunnel);
2. advance of the TBM (application of the maximum thrusting force transmitted directly to last installed ring by hydraulic jacks and its shoes);
3. long-term stability of the tunnel (application of all the loads acting during service life of the tunnel: ground and water loads, seismic conditions, verification of the sealing gasket and connectors).

Figure 8. Universal ring design concept for PCTL (courtesy of Mechanized Tunneling in Urban Areas, 2007)

The design of the PCTL system for tunnelling in overburden and mixed face conditions (rock/overburden) has considered the following:

- Groundwater level;
- Strain-strength properties of the overburden material;
- Long-term behaviour of soils (drained conditions).

The design of PCTL system applied in rock conditions (example in Figure 9) has considered the following:

- Delamination and slabbing in the crown of the tunnel due in part to planes of weakness and bedding;
The preliminary tunnel design in conjunction with the construction staging and sequencing requirements have led to the preliminary shaft design configurations, which have taken into consideration the following basic design criteria in order to mitigate the highlighted risks:

1. Shaft footprints will be kept to a minimum to reduce surface disturbance and for cost considerations;
2. Shafts will be designed circular helping to reduce temporary support requirements, thanks to their ability to carrying lateral pressures through arch-effect and redistribution of stresses in the ground and rock;
3. Shafts will be designed water tight to minimize/mitigate local drawdown of the groundwater table;
4. The shafts are anticipated to be founded in soil or rock depending on the shaft locations;
5. The shaft diameters depend on the requirements of construction staging and sequencing. Currently, four different typology of shafts are planned: 1) launch shafts, for the TBM to be assembled and start excavation, 2) extraction shafts, to allow the TBM to be disassembled and retrieved after completing its run of excavation, 3) TBM maintenance shafts as “safe-heavens” where TBM cutter-head can easily be refurbished if necessary, and 4) sewer maintenance shaft to be used during the operation of the system. It has to be noted that all shafts will be converted to maintenance shafts with manhole access to the trunk sewer, upon completion of tunnel construction.

The launch shaft diameters are anticipated to range between 14m to 20m. The 14m diameter launch shafts are considered a minimum requirement for this project TBM staging and will likely require special design measures for TBM launching such as the development of conventional starter-tunnels if needed, and/or thrust platforms installed on the wall of the shafts. The 20m launch shaft would be adequate for standard assembly and launching of the TBM without special provision.

A special double-shaft design configuration (two connected shafts of 16 m internal diameter) has been considered for Shaft 7L at Humber SPS, as shown in the 3D numerical model developed for its design in Figure 10.
Extraction shafts are currently planned for 8m to 10m finished internal diameter to allow for the sequenced removal of the TBM, if the TBM will end its work at that point. One extraction shaft will be 14m diameter to allow the extraction of the TBM in one piece to reduce the TBM transfer time when moving between shafts.

The excavation support design for shafts considers a sealed excavation support system that precludes the rate of groundwater infiltration. The rationale for requiring sealed shafts is related to the York Region requirement not to have groundwater inflow and drawdown during the excavation of the shafts. Excavation support systems for sealed shafts will then be limited to secant piles, diaphragm walls or equivalent (Table 4 and Table 5).

Table 4. Advantages and limitations of Secant Piles.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deflection restrained and controlled by strutting/anchoring</td>
<td>Need extensive temporary works and subsequent final structures: time, costs and risks associated</td>
</tr>
<tr>
<td>No conflict of operations with sequential construction of substructure and superstructure</td>
<td>Bracing system by props impedes clear access to excavation and construction area for non-circular</td>
</tr>
<tr>
<td>Flexibility of the solution according with complex geometries and variable geology (bedrock level)</td>
<td>Anchoring requires available space outside the structure for tie-back installation (and removal)</td>
</tr>
<tr>
<td>Possibility of combining with open cut excavation below variable bedrock level at different locations</td>
<td>High abrasion risk for excavating tools in case of presence of quartz in the glacial till and in rock</td>
</tr>
<tr>
<td>Deflection restrained and controlled by strutting/anchoring</td>
<td>Need extensive temporary works and subsequent final structures: time, costs and risks associated</td>
</tr>
</tbody>
</table>

Table 5. Advantages and limitations of Diaphragm Walls.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provides a stiffer support system thus minimizing wall displacement</td>
<td>Hard materials such as till and rock may require the use of the hydro-mill instead of traditional excavation techniques</td>
</tr>
<tr>
<td>Temporary strutting and anchoring can be replaced by permanent reinforced concrete walls acting as the final lining</td>
<td>The hydro-mill requires availability of large areas for the worksite, due to separation plant, traffic diversions</td>
</tr>
<tr>
<td>Promotes reasonable water-tightness and verticality in comparison to secant piles</td>
<td>Potential quality issues regarding the final wall surfacing and quality control along panel joints</td>
</tr>
</tbody>
</table>

4.2 Facing Hydro-geological & Geotechnical Hazards

As described in the previous paragraph, the WVSS Project includes several shafts of varying diameter and width. Alternative construction methodologies are considered for the various shafts, which will be driven by geometry, functionality, constructability, cost, and ground conditions.

Additional considerations were analyzed and mitigated throughout the preliminary design and the first development of the final design which are related to the behavior of the glacial till that overlies the bedrock. This geological unit is mostly composed by fine materials, clays and silt, and is likely to contain cobbles and boulders that may result in deviation from verticality of secant piles or diaphragm wall panels. Such deviations could result in decreased overlap of adjacent secant piles or slurry wall panels, which may allow for groundwater infiltration. The Risk Register has been considering mitigation measures to address this potential, which could include reducing the centre-to-centre spacing of secant piles or extending diaphragm wall panel lengths to ensure overlapping.

In the overburden (soil conditions), one key element is represented by the loading conditions generated by the in-situ hydrostatic pressures and in-situ effective stress conditions resulting from the weight of the retained earth, groundwater and surcharge loads, including loads from adjacent foundations and job site equipment. As per ground-water, the temporary shoring system will have not to impact the water-table to both protect the environmental conditions and the existing surrounding structures from induced settlements due to consolidation phenomena.

Excavation support for the rock portions of the shafts, when applicable, need to accommodate the rock loads coming from potential different conditions, including the following: sliding/falling of rock wedges, rock expansion due to stress relief of the rock mass, shale rock swelling if exposed in an excavation and groundwater pressure.

An additional consideration is related to shaft base instability when in soil. Depending on excavation support methodology, base instability in the form of base heave, boils, piping of fines, for example, could lead to lost ground and settlement outside of the shaft excavation.

For those shafts with base in soil, particularly for soils of low cohesion and high permeability, there is unlikely a practical way to cut-off the water flow path with the shoring system embedment. In this case, soil pre-conditioning is likely required to form a lower permeability plug at the shaft bottom prior to dewatering and excavation. A preliminary analysis has been developed to identify various possible treatment options to be done in accordance with the hydrogeological and geological conditions, but it will be contractor experience and judgement to detail the one that will work accordingly with baseline information provided.

4.3 Introducing TBM in/out solutions from/into shafts

One of the critical construction points of each tunneling project is represented by the launch and retrieval of TBM. As a matter of fact, the problem starts to be a geometrical one as a circular tunnel needs to fit into a circular shaft in the case of the WVSS project, without producing any water inflow or leakage during the life-time of the system.
The most suitable solution for the TBM “exits” is to foresee a sealant ring installed over a shuttering pipe which allows the TBM to pass over the shafts structures without any leakage between the shield and sealant ring.

This solution is most effective where the retaining structures of the shafts are made by diaphragm walls, and if the starting wall is perpendicular to the tunnel alignment. In diaphragm walls, a so called “soft eye” is designed within the steel cage of the diaphragm. The soft eye is a portion of wall reinforced with fiberglass bars which can be excavated by the TBM.

In case of secant piles, the “soft eye” will also be needed as the steel cages need to be fiber-reinforced in those piles to be excavated by the TBM for a height of at least 1.5 times the tunnel diameter. In case of soft piles, even if the starting wall is perpendicular to tunnel alignment, an additional temporary wall hosting the shuttering pipe needs to be constructed into the shaft in front of the piles to be sure the sealing ring will be effectively constructed against a continuous surface. This solution has been considered for the biggest shafts of the WVSS project (including the shaft 7L at Humber SPS).

The sealant ring and soft eye embedded in the wall technique is also theoretically suitable for the shaft “entry”, which is the stage when the TBMs enter the retrieval shaft. However, in this case an added challenge is the requirement to ensure the TBM reaches the exact point where the sealing ring is located, within required deviation tolerances.

As an alternative, the solution is to improve the ground with consolidation (grouting) from inside the shaft itself, or from the surface. The consolidation could include low pressure grouting or jet grouting, depending on the permeability of the material, and/or to use umbrella arches to promote a barrier through either spilling, forepoling or installing injected steel pipes depending on the mechanical properties of the ground.

The extension of the consolidated block is connected to the length of the TBM and of the PCTL ring. The common rule is to have an extension of at least the TBM shield plus one to three segmental lining rings, and a width of at least 1.5 times the diameter of excavation, depending on the soil/weathered rock mass properties.

If the expected groundwater pressures are limited, or the permeability is low, it is often adopted the “TBM-tunnel-cover” as a solution to seal the chamber between the shaft and the cutter-head, before gently releasing the water pressure and finally allowing the TBM to enter in the shaft.

A “concrete block” poured inside the extraction shaft is another alternative in case there is no availability of surface space in the area to be consolidated. In this case, the volume of the block shall be the same as the improved ground outside the shaft. The downside of this solution is represented by the long construction time and even longer demolition time to set up first and clean up afterwards the job site into the shaft for the TBM arrival.

In the extraction shaft, similarly to what discussed above for the launching type, a “soft-eye” is required in the temporary shoring or on the diaphragm panels at the point of TBM entry for a similar extension to the one defined above, capable to safely include the TBM diameter.

5. ACKNOWLEDGEMENTS

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6. REFERENCES


