Construction of a Multi-Use Pathway on Soft Compressible Deposits– Case Study

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ABSTRACT
As part of a road upgrade of Victoria Street in the Town of Whitby, in the Regional Municipality of Durham, Ontario, a Multi-Use Pathway (MUP) was constructed in 2018. A section of the MUP about 150 m in length with embankments up to 3.5 m high, traversed the marshy flood plain of the Lynde Creek, which comprised of peats/organic soils up to about 6 m thick with moisture contents in the upper 3.6 m as high as 260%. This MUP alignment included a buried gas main towards the southern end of the proposed cross-section. In view of the shallow gas main (at the shallowest point, the invert of the gas main (0.3 m dia.) was about 1.8 m below ground surface), intrusive ground improvement methods were not favoured. A light-weight fill approach was adopted using “Cematrix” cellular concrete for the lower portion of the embankment and granular fill was used above to suppress buoyancy. Field shear vane testing and CPTU testing which shed light on the shear strength and consolidation characteristics of the compressible deposits coupled with FEM modelling enabled construction to proceed in a two-stage approach. The various geotechnical challenges of this project are discussed in the paper.

RÉSUMÉ
Dans le cadre d’un réaménagement routier de la rue Victoria à Whitby, dans la municipalité régionale de Durham en Ontario, un passage chemin multi-usage (MUP) a été construit en 2018. Une section du passage chemin multi-usage (MUP) d’environ 150m de long avec des remblais atteignant 3,5m de hauteur traversant la plaine inondable marécageuse du ruisseau Lynde laquelle composée de sol tourbeux/sol organiques jusqu’à environ 6m d’épaisseur avec un taux d’humidité supérieures à 3,6m atteignant 260%. Ce tracé du MUP (passage chemin multi-usage) comprenait une conduite de gaz enterrée vers le sud de la section transversale proposée. Compte tenu de la conduite de gaz peu profonde [au point le moins profond, le radier de la conduite de gaz (0,3 m de diamètre) était d’environ 1,8 m du sous - sol], les méthodes intrusives d’amélioration du sol n’étaient pas privilégiées. Une approche de remplissage légère a.

1 INTRODUCTION

Geotechnical investigations were carried out by WSP for the Regional Municipality of Durham (“Region”), Ontario to facilitate the construction of a Multi-Use Pathway (MUP) as part of a road upgrade of Victoria Street in the Town of Whitby. Figure 1 shows the site location plan.

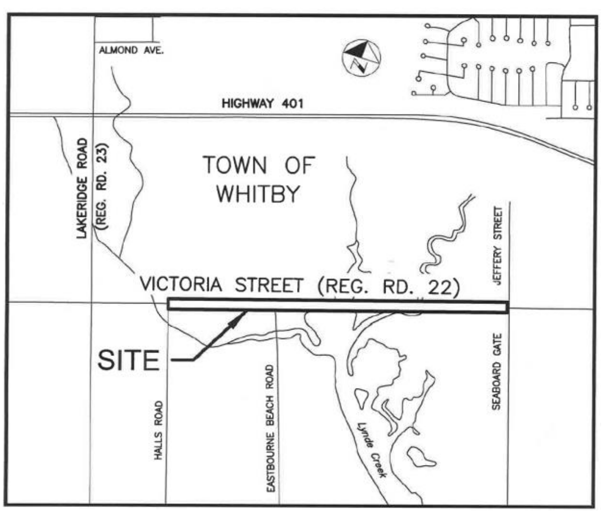

Figure 1: Site Location Plan

The proposed MUP alignment would occupy the eastbound carriageway of the then existing Victoria St.

It was identified that due to Right-of-Way (ROW) constraints on the south side, a conventional earthfill embankment would not be feasible for the MUP over certain sections of the alignment. A section of the MUP about 150 m in length with embankments up to 3.5 m high, traversed the marshy flood plain of the Lynde Creek. A compressible deposit up to about 6 m thick, with the upper 3.6 m comprising peats/organic soils with moisture contents as high as 260% was generally intercepted very close to the existing ground surface from Station 12+940 (west) to Station 13+260 (east). To put the stations into context with the site location plan, the west abutment of the Lynde Ck. Bridge is at Sta. 13+168 and the east abutment of the bridge is at Sta. 13+200. This MUP alignment (proposed between Sta. 12+940 to Sta. 13+260) was also underlain by a gas main towards the southern end of the proposed MUP cross-section. At the shallowest point of the gas main, the invert of the gas main (0.3 m dia.) was about 1.8 m below ground surface. The locational information of the gas main was confirmed with a limited number of careful exposures of the utility.

This ROW land constraint on the south required the construction of a vertical Reinforced Soil System (RSS) for a section of the multi-pathway embankment, from Station

12+940 to Station 13+260. The presence of the buried gas main precluded the use of intrusive ground improvements such as wick drains to be used in conjunction with conventional earthworks and an RSS system for the MUP. The paper describes the geotechnical investigations that were carried out to enable the MUP construction and how the geotechnical risks were managed.

2 GEOTECHNICAL CHARACTERIZATION OF SUBSOILS

The majority of the geotechnical investigations were carried out by others (Coffey, 2012 and Coffey 2014) prior to 2015. The first two WSP authors of this paper were associated with some of the previous investigations.

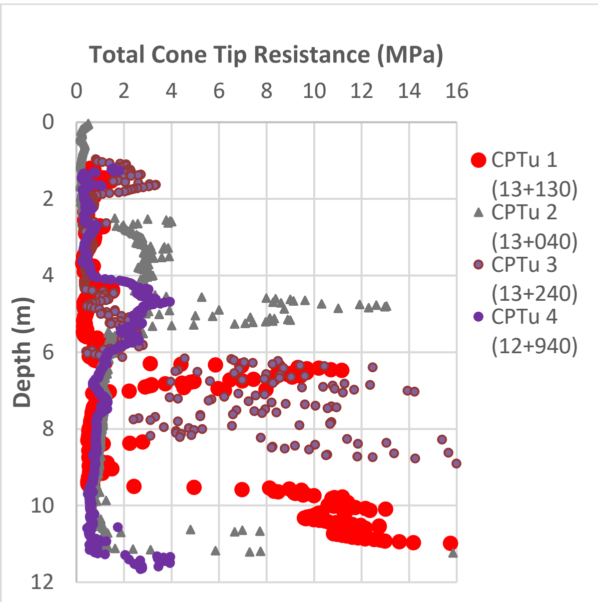

Figure 3: CPTu cone Tip Resistance Profiles

In addition to routine geotechnical investigations, the investigations comprised of CPTu testing including dissipation tests (DownUnder Geotechnical Limited, 2014), UU triaxial testing, one-dimensional consolidation testing, organic content determinations and field shear vane testing (FSV). The Borehole and CPTu test location plan is shown in Figure 2 (see end of text).

Piezocones 1 to 4 were located within the MUP alignment limits, with CPTu 1 and CPTu 3 on the west and east sides of and closest to the Lynde Ck., respectively. The subsoils can be generally grouped into four zones, upper compressible (with peaty/organic soils within the upper extents), loose to compact silty sand/sandy silt/firm to very stiff silty clay, soft to stiff silty clay and glacial till overlying bedrock. Based on the upper compressible layer being the most critical for the proposed construction, CPTu 1 indicated the deepest occurrence of the upper compressible deposit up to 6 m thick among the CPTu profiles. Figure 4 shows a detailed piezocone profile for CPTu 1 and this clearly indicates the presence organic deposits in the upper depths (high friction ratios) and the demarcation of the four zones described earlier. Although the upper deposit is very soft to firm and compressible, the organic inclusions did not result in generation of high

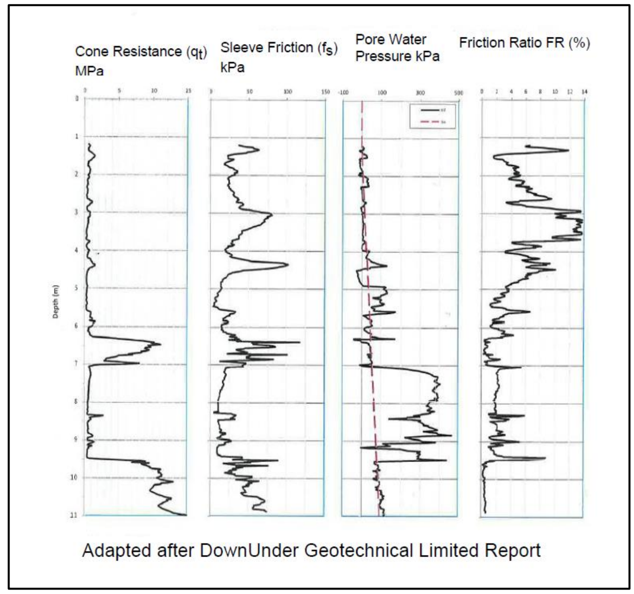

Figure 4. CPTu 1 - Profiles

undrained excess pore water pressures during cone penetration of this deposit. This "free-draining" nature was largely observed within the upper deposit in all the piezocone profiles.

The moisture content profiles shown in Figure 5 also broadly reflect the above mentioned stratigraphic zoning with the very high moisture contents generally confined to the upper 3 m below ground surface. Organic contents (with the Burning Method) within the upper 3.6 m were found to be within 55% to 75% (reflective of the peaty nature) and within the lower depths of the upper zone, i.e. below 3.6 m depth, the organic contents were found to be between 4% and 10% (reflective of the organic nature).

The laboratory incremental loading consolidation test results (void ratio vs (log(pressure)) are shown in Figure 6. The most compressibility is shown by the uppermost curve (highest void ratios) and was from the upper compressible deposit and gave a $C_c/(1+e_o)$ of 0.2. The stiffest compressibility is reflected in the bottommost two curves in the figure and they are from the lower clay deposit. Due to sampling difficulties, consolidation testing of the peaty deposits was not possible. The consolidation test based coefficient of volume compressibility, m_v was compared with that deduced from the piezocone (using $M = \boldsymbol{\alpha}_M * (q_t - \sigma_{vo})$ with $\boldsymbol{\alpha}_M = 2$; M =1-D Constrained Modulus; (Meigh, 1987) at the same depth level. The former gave a range of 1.4 to 2.2 m^2/MN while the latter gave a value of 1.5 m^2/MN. The pre-consolidation pressures were determined from laboratory void ratio Log(pressure) plots using the Casagrande graphical method and pre-consolidation pressures were also deduced from piezocone and field shear vane (FSV) results (see Figure 7) using the following empirical formulations:

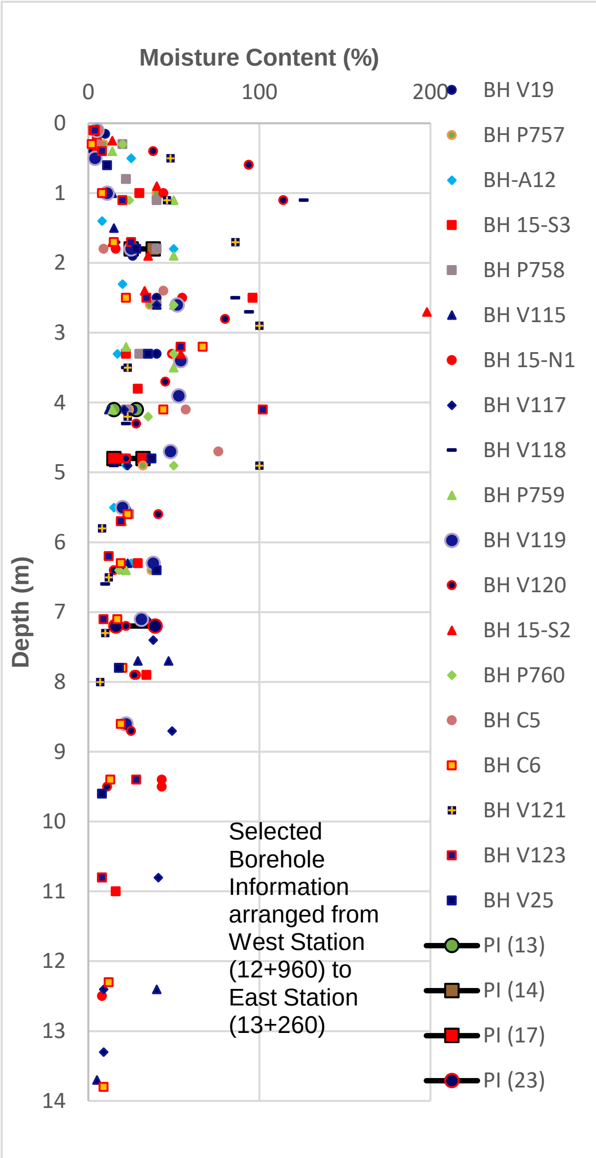

Figure 5. Moisture Content Profile

Piezocone: $\sigma_p' = k^*(q_t - \sigma_{vo})$; k = 0.25 (for the organic nature of the upper zone) - Kulhawy and Mayne (1990).

FSV: $\sigma_p' = \boldsymbol{\alpha}_{FV}{}^*Su_{FV}$; $\boldsymbol{\alpha}_{Fv} = 22(PI)^{-0.48}$ – Mayne and Mitchell (1988).

The k value of 0.25 appears to broadly follow the trends from the other two methods, i.e. consolidation and FSV. Piezocone dissipation testing carried out was particularly relevant to the understanding of the consolidation characteristics of the organic/peaty soils on site. The C_h (coefficient of horizontal consolidation) characteristics of the upper compressible zone (within the top 6.5 m) recorded high values ranging from 1172 m^2/y (reflective of peat) to about 100 m^2/y (probably reflective of the organic nature of the underlying deposit). Much lower values were recorded for the lower cohesive zone. Most of the dissipation curves were of the monotonic type.

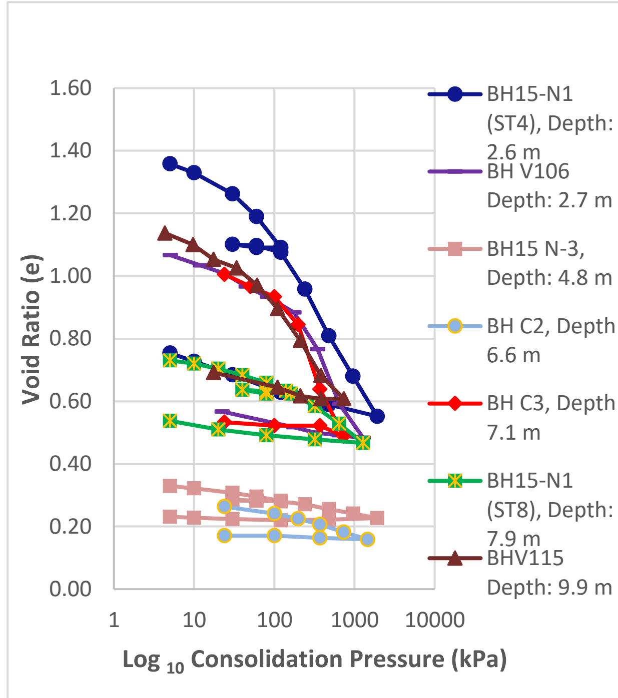

Figure 6: Incremental Loading 1-D Compressibility

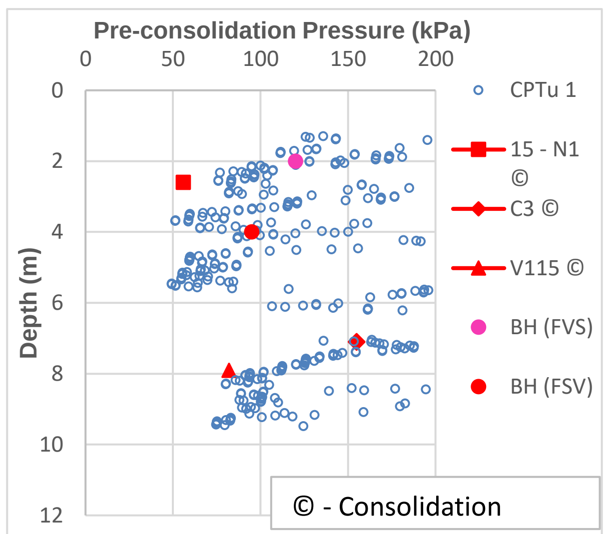

Figure 7: Pre-consolidation Pressure Profile

Undrained shear strengths were primarily measured with the FSV and were supplemented by limited triaxial UU tests and back-figured from piezocone testing (see Figure 8).

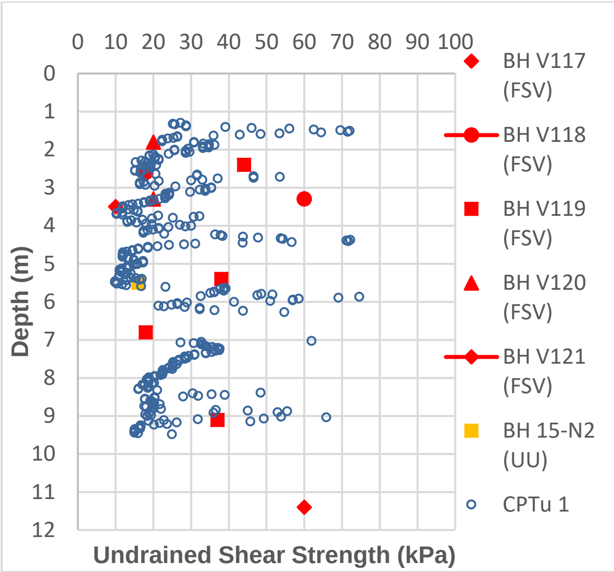

Figure 8. Undrained Shear Strength Profile

3 FOUNDATION DESIGN PHILOSOPHY

With the conventional earthwork option being ruled out due to potential instability and intrusive ground improvement methods being precluded with the buried gas main within the MUP cross-section, consideration was given to the use of light-weight fill options. After consideration of different light-weight options, based on geotechnical advice and cost and time considerations, the Region adopted the use of Cematrix, a cellular concrete, for the construction of the MUP embankment within the aforementioned stations.
Geotechnically there were the following considerations to be addressed:

- Embankment stability
- Edge bearing capacity of the RSS block with the cellular concrete as the reinforced backfill; Due to access issues the ground conditions were not well defined at the wall edge region due to the adjoining wetlands
- Buoyancy issues to balance the total weight without adversely impacting on stability
- Minimizing in-service settlements
- Erosion issues along the southern side slopes fronting onto the wetlands

Environmentally, containing the “green”, i.e. uncured, cellular concrete from inadvertently flowing into the water body needed to be addressed.
To limit the total load being applied on the compressible organic soils, it was decided to carefully sub-excavate to depths that would maintain a minimum separation of about 0.8 m and essentially replace with cellular concrete material. The objective of the sub-excavation and light-weight fill replacement was to ensure that the proposed applied loading (new construction) will not be significantly higher than the overburden soils it would replace, i.e. to strive to maintain vertical stress neutrality.

Maximizing the cellular concrete thickness subject to buoyancy constraints and addressing the less onerous pavement structure requirements for an MUP would be a step in the right direction in avoiding foundation distress.
The selection of the design cross-section was based on the following considerations/parameters: average cellular concrete block height, the offset of the toe of the cellular concrete base to the crest/side slope of the road embankment south side slope, road embankment side slope angle and the existing road embankment thickness above the cellular concrete base elevation which needs to be excavated. Based on these criteria, the design cross-section at Sta. 13+110 was selected for detailed analysis.

4 ANALYSIS

Analysis methods were chosen to address both stability scenarios, i.e. drained and undrained.
Three stages of stability were investigated as follows:

- Construction stage I: Cellular concrete block construction
- Construction stage II: The pavement structure overlying the cellular concrete block
- Construction stage III: With Victoria street east bound fully open including the new carriageway;

No traffic loading was simulated over the multi-pathway. Operational constraints were recommended to permanently restrict vehicular traffic over the MUP other than for regular maintenance with a light truck. For each stage, the organic silty clay deposit was modelled as follows:

- As a free-draining deposit based on the evidence from CPT pore pressure observations
- As a non-free draining cohesive deposit (likely worst-case scenario; to address the possibility that a cohesive deposit could be intercepted at some locations instead of a relatively free draining organic silty clay).

The cellular concrete block stability was investigated using two analytical methods, Limit Equilibrium Method (LEM, conventional stability analysis method) and the Finite Element Method (FEM). Since the LEM (conventional design practice) does not provide information on ground movements, it was complemented with FEM to get some idea about potential cellular concrete block movements. Also, FEM can address both stability and bearing capacity issues in a unified manner.

Embankment widening with grade raise was undertaken for the northern part of Victoria St. road embankment in a previous contract. As part of ground improvement for the embankment widening and grade raise, the organic deposits were sub-excavated under a section of the northern alignment works with Protection System Support, i.e. sheet-pile walls, both at the northern (with a permanent support system) and southern (with a temporary support system (TPS)) limits of the previous contract. The TPS at the southern limit was also present at the design cross-section, i.e. at Sta.13+110. It was approximately modelled only in the FEM analysis and not

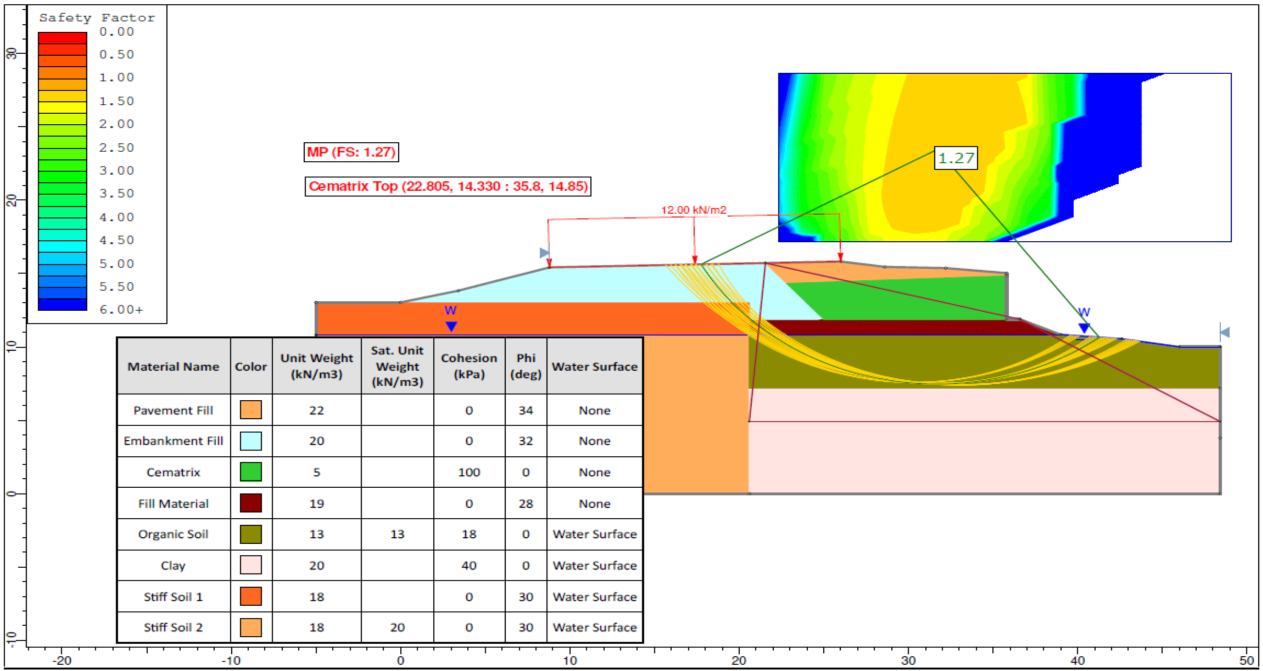

Figure 9. LEM Analysis (Cohesive)

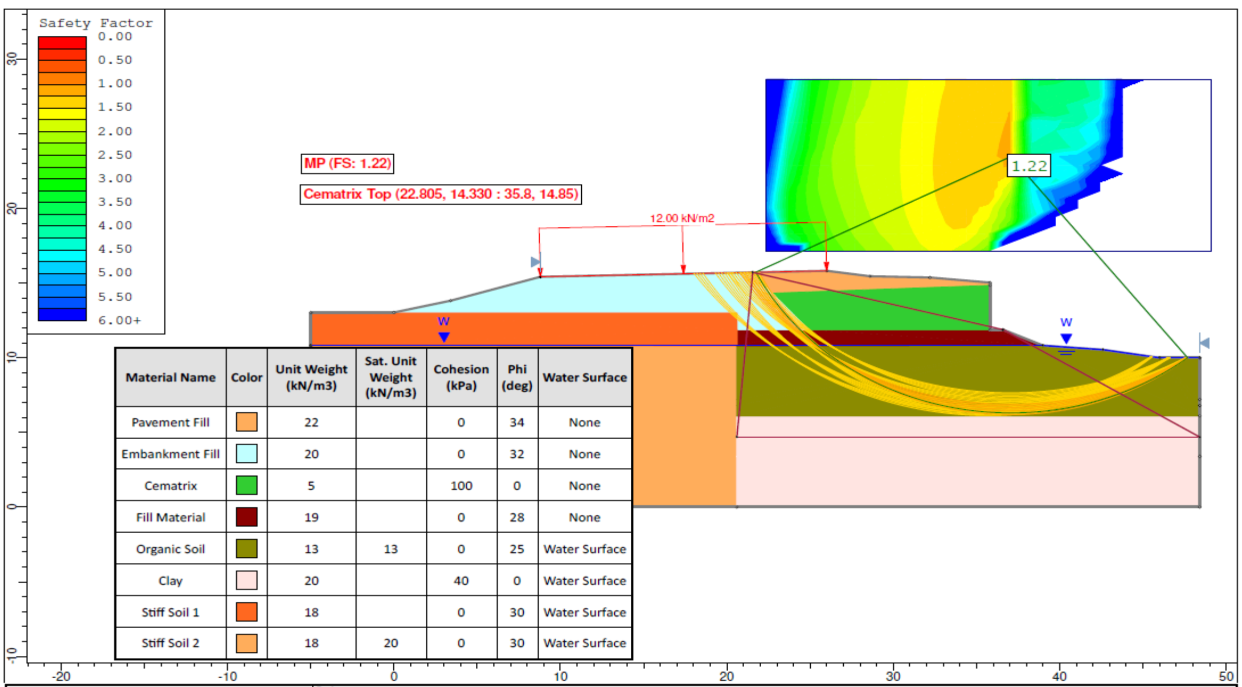

Figure 10. LEM Analysis (Free Draining)

under LEM, as shown in Figures 9 (LEM) and 11 (FEM), for example.

Rocscience SLIDE software was used for the LEM using the GLE/Morgenstern-Price Method. The FoS for the cohesive (undrained) and free-draining assumptions for the organic deposit, were 1.27 and 1.22 respectively, as shown in Figures 9 and 10 respectively.

Rocscience RS2 software was used for the FEM analysis using the Shear Strength Reduction (SSR) method (Griffiths and Lane (1999); Pandelidis and Griffiths (2015)) using an elastic-perfectly plastic Mohr-Coulomb

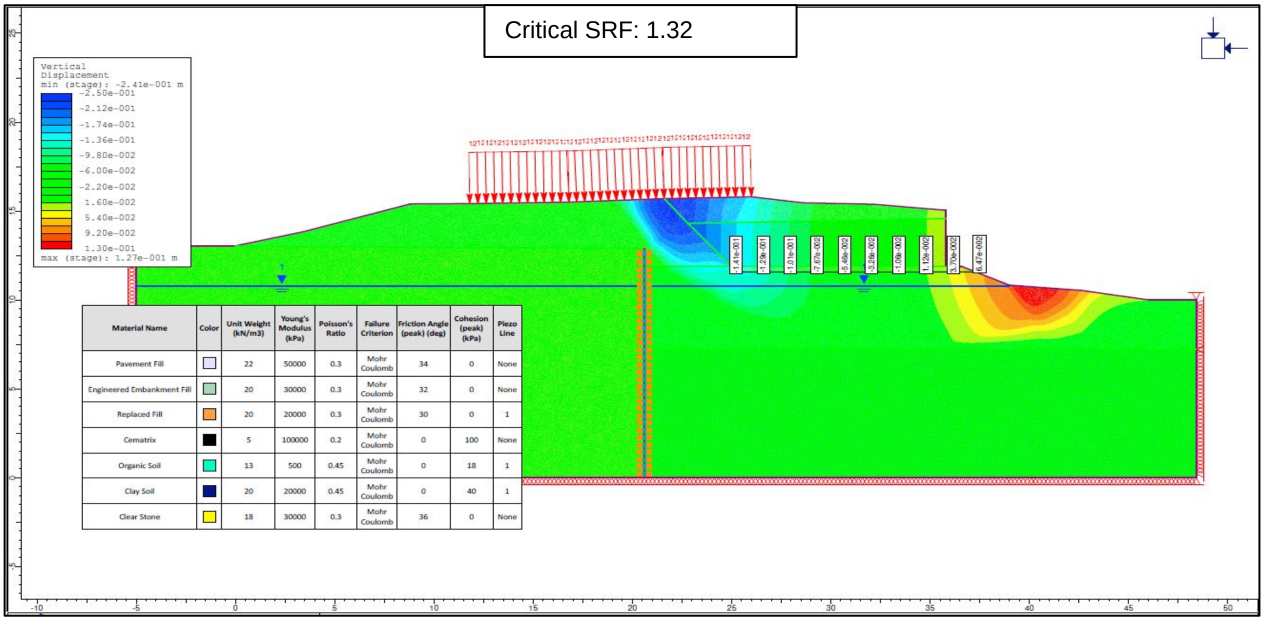

Figure 11. FEM Analysis (Cohesive)

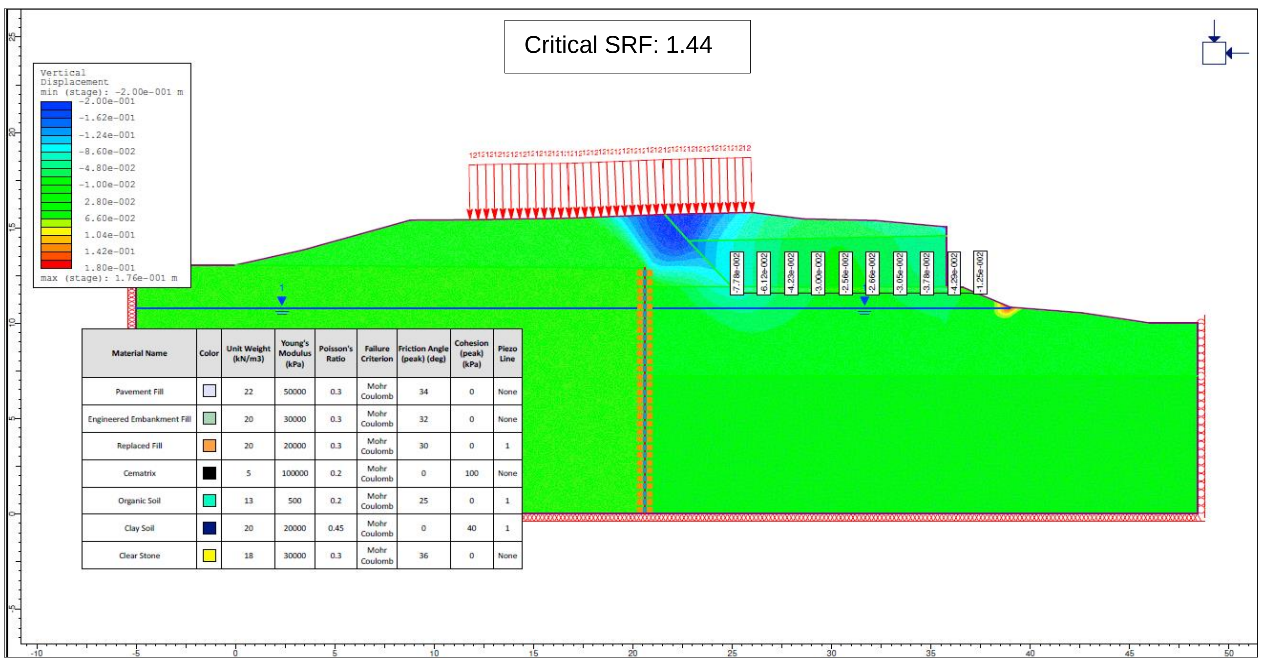

Figure 12. FEM Analysis (Free Draining)

constitutive model. The corresponding critical Strength Reduction Factors (SRF) were 1.32 and 1.44 (SRF is akin to FoS), as shown in Figures 11 and 12.

The higher FEM SRF ("FoS") compared to the LEM FoS could be likely due to the shielding effect of the sheet pile wall modelled with FEM. The predicted vertical settlements in the region under the buried gas main were less than 50 mm under drained loading as shown in Figure 12.

Taking the 100-yr. design flood elevation at 77.65 m with the invert elevation of the cellular concrete block at Stn. 13+110 (El. 75.4 m), a buoyancy check was undertaken which yielded an FoS greater than 1.3 (the target FoS was 1.2). Free draining conditions were assumed in the backfill behind the cellular concrete block.

MUP was constructed late spring in 2018. Settlement monitoring was undertaken on several targets following construction and the maximum settlement recorded during the monitoring period was less than 25 mm. It is our understanding that no adverse serviceability issues have been identified as of May 2019.

5 SUMMARY AND CONCLUSIONS

The paper has described a case study addressing the construction of a Multi-Use Pathway (MUP) founded on compressible organic deposits and constrained at the southern limit of the MUP cross-sections with a vertical retaining system to address ROW constraints. Further, a buried gas main towards the southern limit of the cross-sections ruled out intrusive type of ground improvement strategies.

Collating all the geotechnical information available from a previous contract, especially CPTu test results, has made a significant contribution towards understanding the geotechnical risks faced by the construction. Both LEM and FEM analyses have helped the design judgement.

The adoption of a light-weight fill material, i.e. cellular concrete, has enabled the balancing of competing stability and buoyancy constraints (cellular concrete by not being extremely lightweight such as polystyrene). Partial sub-excavation has helped to limit the applied load under the MUP with light-weight fill, not to significantly exceed the previous overburden stress.

Settlement monitoring and subsequent observational evidence of the MUP appear to have validated the design approach.

Acknowledgements

Mani Patchayappan, M.Eng., P.Eng. is thanked for his contribution in the early part of the MUP project.

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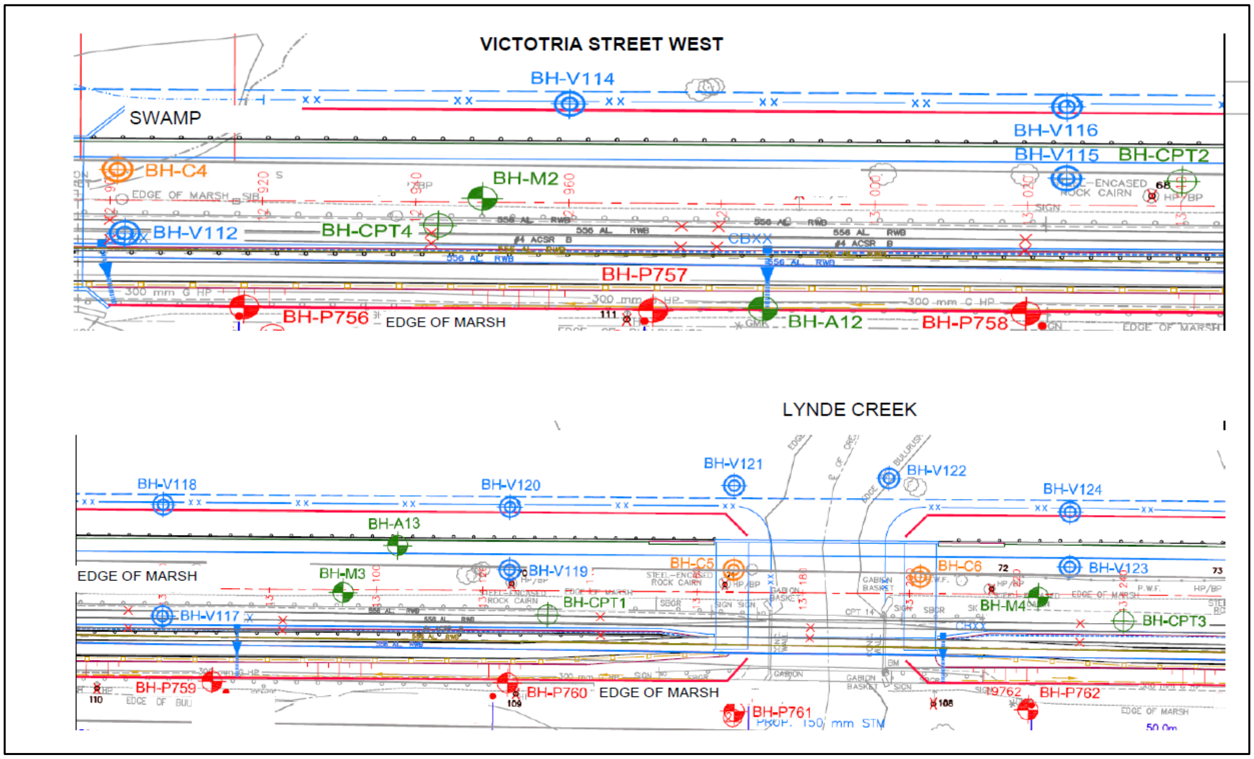

Figure 2: Borehole Layout Plan