Geotechnical Characterization of Peatlands for a Remote Road Development Project in Northern Ontario, Canada

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ABSTRACT
Webequie First Nation, located approximately 525 km north of Thunder Bay, Ontario, is developing an all-season road between the community of Webequie and the Ring of Fire mineral exploration area, approximately 110 km to the east. The Webequie Supply Road (WSR) Project is the first Indigenous-led environmental assessment in Ontario. Once completed, the WSR will offer year-round access between the community and the promising future mining area. It will also provide an all-season link to Marten Falls First Nation and the provincial highway system to the south via the Northern Road Link and Marten Falls Community Access Road projects. Beginning in 2018, studies have been conducted to characterize extensive peatland terrain crossed by proposed alternative road routes to assist with route selection and engineering design. Studies began with remotely sensed terrain analysis to identify peatland types and delineate their boundaries, followed by ground truthing with visual assessment, hand probes and non-intrusive geophysics. In fall 2024, a geotechnical testing program was completed using a hand-operated heli-portable drill, vane shear testing and cone penetrometer (CPT). Integrated drilling and CPT data provide valuable peat characteristics including degree of humification (von Post classification), physical properties (e.g., woody vs non-woody, size and types of fibers), groundwater levels, undrained shear strength, and peak and remolded vane shear strength. Disturbed and undisturbed peat samples and underlying mineral soil were collected for lab analysis. Study results demonstrate the effective integrated implementation of these low-impact investigation methods in terms of cost, environmental impact, field logistics and data quality.
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RÉSUMÉ
La première Nation de Webequie, à environ 525 km au nord de Thunder Bay en Ontario, travaille sur le développement d'une route toutes saisons entre la communauté de Webequie et la zone d'exploration minérale du Cercle de Feu, située à environ 110 km à l'est. Le projet de route d'approvisionnement de Webequie (RAW) est le premier projet d'évaluation environnementale géré par les Autochtones en Ontario. Une fois complété, ce projet permettra de relier en toutes saisons la communauté non seulement à la prometteuse zone minière, mais également à la Première Nation de Marten Falls et au réseau autoroutier provincial vers le sud grâce aux projets de la route de raccordement du nord et de la route d'accès de la communauté de Marten Falls. Des études débutées en 2018 avaient pour but de caractériser une vaste tourbière traversée par des tracés de routes alternatives proposés pour aider à la sélection et á la conception d'ingénierie des routes. Les premiers travaux, qui incluaient des analyses de terrain par télédétection pour identifier les types de tourbière et les délimiter, ont été suivis par des travaux de terrain de vérification par inspection visuelle, par sondes manuelles et par géophysique non-invasive, puis en automne 2024, par un programme d'évaluation géotechnique incluant du forage par machine héliportée opérée à la main, des essais au scissomètre et des essais de pénétration au cône (CPT). Les données intégrées de forage et de CPT ont permis d'obtenir de précieuses informations sur les caractéristiques des tourbières telles que le degré d'humification (classification von Post), les propriétés physiques (c'est-à-dire boisée ou non, taille et type de fibres), les niveaux d'eau souterraine, la résistance au cisaillement non drainée et la résistance au cisaillement de pic et remaniée para essai au scissomètre de pic et remanié. Des échantillons perturbés et non perturbés de la tourbière et des sols minéraux sous-jacents ont été collectés à des fins d'analyse en laboratoire. Les résultats de l'étude démontrent l'efficacité de l'implantation intégrée des méthodes à faible incidence décrites ci-dessus en termes de couts, d'incidence sur l'environnement, de logistique de terrain et de qualité des données.

1 INTRODUCTION

Webequie First Nation, located approximately 525 km north of Thunder Bay, Ontario, is developing an all-season road between the community of Webequie and a proposed Ring of Fire mining development around Esker Camp near the Mukutei River, approximately 110 km to the east (Figure 1).

The Webequie First Nation Supply Road (WSR) project is the first Indigenous-led environmental assessment in Ontario. Once completed, the WSR will offer year-round movement between the community and the future mine site and will facilitate economic opportunities for the community.

The preferred corridor, selected by the community, is approximately 107 km in length (extending about 51 km toward the south-southeast from Webequie before turning east for about 56 km toward Esker Camp), and 2 km in width. It is within this preferred corridor that the road route is to be selected.

As part of the Environmental Assessment and Preliminary Engineering Services for Webequie First Nation's Supply Road Project, J.D. Mollard and Associates (2010) Limited conducted terrain mapping within the proposed community corridor to facilitate identification of potential aggregate sources, characterize stream crossings, and assess foundation conditions along several competing route alternatives. Following that work, the first stage of a peatland investigation field program was implemented in fall 2024. That field program included measurement of peat depth, collection of disturbed samples for in-field von Post classification of peat humification (ASTM D5715) and routine peat specific laboratory testing, and collection of undisturbed peat cores for complex laboratory testing for organic soils. The program also included in situ ConeTec ball penetrometer testing and field vane shear testing.

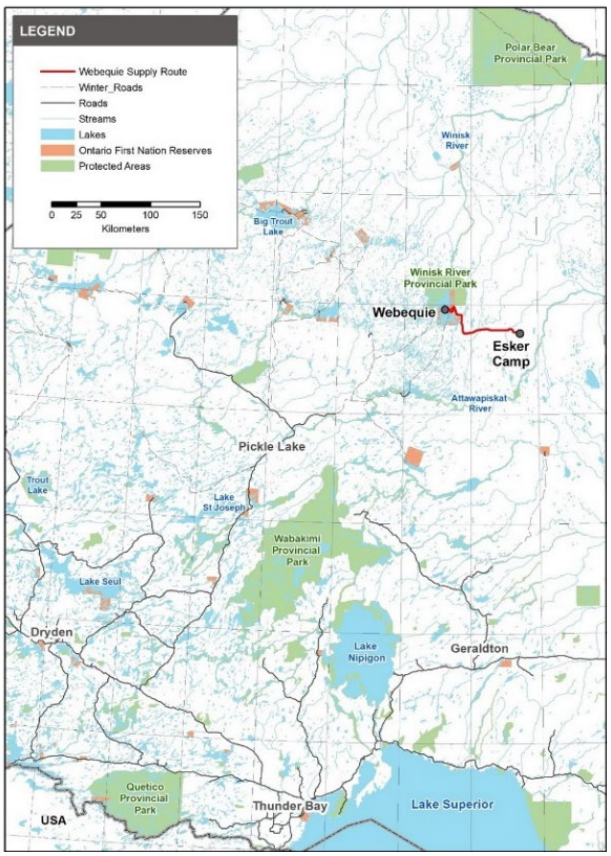

Figure 1. Location of the Webequie First Nation Supply Road Project.

2 METHODOLOGY

2.1 Site Selection

Selection of field investigation sites was based on terrain mapping conducted using aerial and satellite imagery, digital elevation data, and existing surficial geology and land cover maps. The primary source of desktop information for terrain mapping was high-resolution orthoimagery (20 cm resolution) and LiDAR elevation data (1 m resolution) acquired within the 2-km wide road routing corridor. Satellite imagery available through ESRI World Imagery Basemap and Google Earth offered supplemental imagery at high-resolution. Air photo interpretation was also conducted at select locations using 1954 black & white photos at 1:60,000 scale, which, when viewed stereoscopically, provide 3-D perspectives to evaluate terrain and topographic conditions. These multiple sources of imagery assist with terrain unit classification, particularly for resolving the distribution and classification of peatland types, including potential permafrost-affected terrain.

Terrain units were classified and mapped according to a project-specific legend developed from previous report information and mapping (Cosford and Penner, 2022, JDMA, 2010). The route corridor crosses extensive organic terrains of various bogs and fens along the east-west section of the corridor west of Esker Camp. Glacial terrains with mineral soil at the surface are present on the roughly north-south section leading to the community of Webequie. Mineral terrains include till with a discontinuous lacustrine clay veneer, glaciofluvial ice-contact sediments in esker ridges, and alluvial floodplains. Organic terrains include diverse bogs and fens covering large extents. Dredge and Dyke (2020) describe the peatland types in the study area, which include domed, northern plateau, net, treed and thermokarst bogs. Fen types include string, ladder, channel, watertrack and horizontal fens (see also, National Wetlands Working Group (1988) and Glaser et al. (2004).

Approximately 40 peatland sites have been selected for Talon drilling and sampling in the overall geotechnical field program, plus an additional 82 sites that will be tested with a hand probe to determine peat depth and von Post classification with depth. To date, the nine (9) sites shown in Figure 2 were investigated in 2024. The remainder of the field investigation program is to be completed in 2025. The nine sites investigated in 2024 are located in thermokarst bog (1), plateau bog (2), domed bog (2), ladder fen (1) and watertrack fen (3).

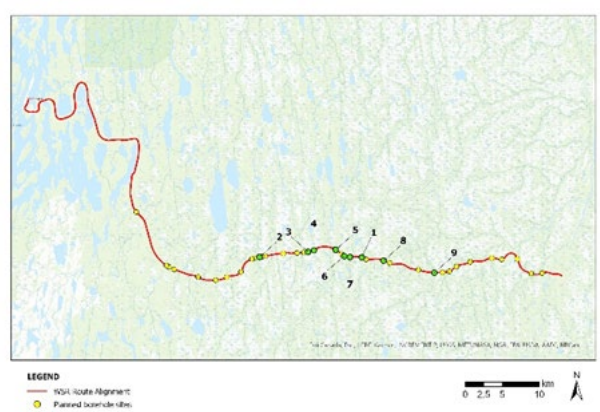

Figure 2. Field investigation sites.

Figure 3 is an oblique aerial view of a string fen in the study area, flanked by plateau bogs on either side.

Figure 3. String fen flanked by plateau bogs.

2.2 Field Equipment & Methods

2.2.1 Talon Drilling

A Talon drill (Figure 4) was used to determine peat depth, to collect disturbed and undisturbed core samples of the peat and underlying mineral soil for laboratory testing and in-field von Post classification of the peat. The Talon drill's compact size and light weight make it ideal for working in remote areas where helicopter support is required, and the peat surface is highly compressible with the water table at or near the surface.

Figure 4. Talon drill used for sampling peat

The Talon drill is a hand-operated drill powered by an electric hammer drill mounted on a 1.8 m high mast. The drill advances a 45 mm core tube through the peat into the underlying mineral soil. Samples of mineral soil can also be obtained using a 45 mm auger bit at sites where the core tube meets refusal in the mineral soil. Disturbed samples are extracted from the core tube as drilling advances in 50 cm drives (Figure 5).

Figure 5. Disturbed peat samples.

A separate drive with the Talon drill was used to collect 73 mm diameter undisturbed peat cores (Figure 6). Because of the larger diameter and limited capacity of the hammer drill, the penetration depth of the 73 mm core tube is restricted to 2 m. Core samples were wrapped in cellophane in the field and encased in a split PVC tube for transport.

Figure 6. Undisturbed 73 mm peat core.

The peat sampling protocols were developed to facilitate conducting the following laboratory and field tests:

<u>Disturbed samples (45 mm core):</u>

- Fibers content (ASTM D1997)
- Moisture, ash and organic content (ASTM 2974)
- Degree of decomposition/humifications (ASTM D5715) (completed in the field)
- Standard method for pH of soils (ASTM D4972)

Undisturbed samples (73 mm core):

- Oedometer Tests (ASTM D2435)
- One-dimensional consolidation with controlled-Strain Loading (ASTM D4186)
- Permeability test (ASTM D4511)
- Triaxial CIU Test (ASTM D4767)

2.2.2 ConeTec Testing

A ball penetrometer was employed to measure ball resistance, pore pressure and temperature through the peat and into the underlying mineral soil. ConeTec analytical methods were then applied to determine the undrained shear strength profile from surface to full depth of penetration. Figure 7 shows the hand-operated apparatus used to push the ball penetrometer into the peat. Figure 8 is a photograph and schematic showing the ConeTec ball penetrometer

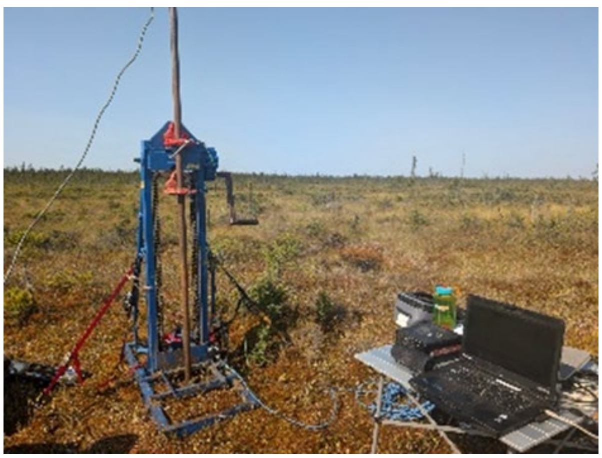

Figure 7. ConeTec ball penetrometer probe.

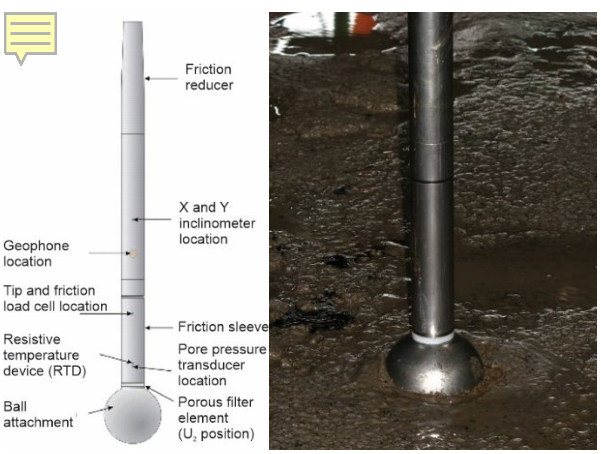

Figure 8. ConeTec ball penetrometer.

At each site one or two peak and remolded vane shear measurements were made with a 75x150 mm field shear blade. These values were plotted at the appropriate depth on the ball penetrometer profile and serve as an independent site-specific undrained shear strength measurement. A photograph of the vane shear blade is shown in Figure 9. Figure 10 shows a plot of shear resistance vs degree of rotation for the initial test used to determine peak vane shear strength and the recycle test used to determine remolded shear strength.

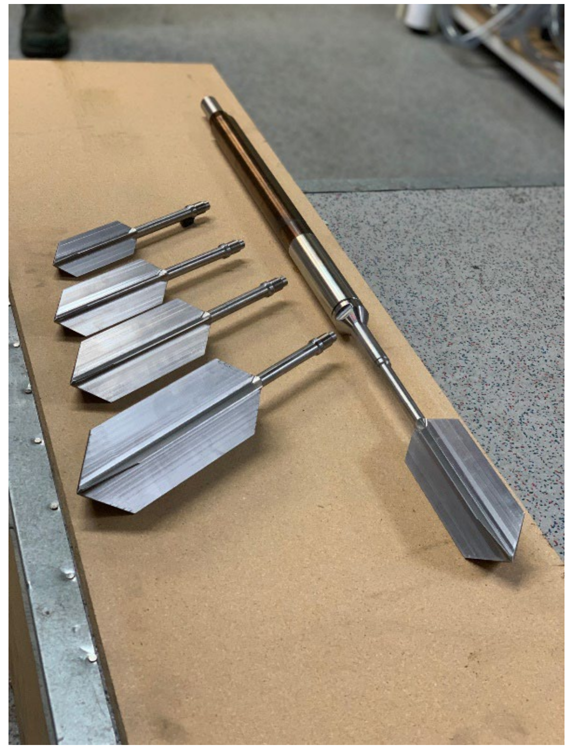

Figure 9. ConeTec vane shear blade.

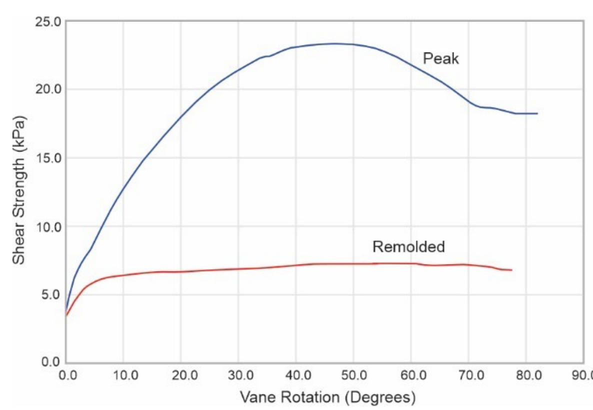

Figure 10. Vane shear test results showing peak and remolded undrained shear strength.

Depth to the water table at each site was measured manually and also recorded by ConeTec probe, along with soil temperature.

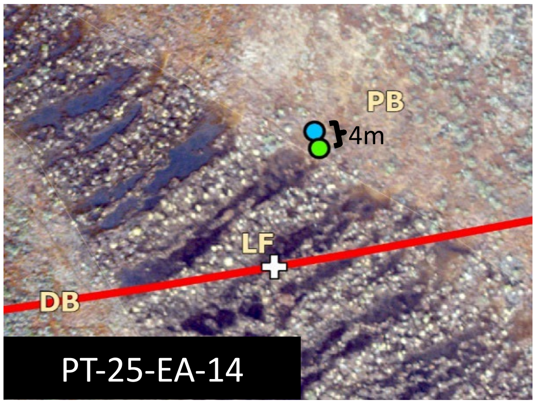

Figure 11. Investigation site located on the margin of a ladder fen.

3 RESULTS

Table 2 presents a summary of drilling results at each site including: peatland type, peat depth, underlying mineral soil type, undrained shear strength from ball penetrometer, peak and remolded field vane shear strength, von Post classification range, water table depth and subsurface temperature. Average shear strength and temperature values are shown at the bottom of Table 2.

As an example, Figure11 shows the location of a testing site on the margin of a ladder fen in high resolution aerial imagery. Note that the Talon drilling site and ConeTec probe site are located a short distance apart as drilling at these sites was done simultaneously.

The combined Talon drill and ConeTec probe logs for the site PT-25-EA-14 (Figure 11) is shown in Figure 12. A description of peat encountered in 50 cm drives is shown on the log along with the in-field von Post classification. The undrained shear strength profile is shown on the left side of the log along with peak and remolded vane shear strengths measured at a depth of 2.5 m. Depth to water table was 0.1 m.

Table 2: Summary of field investigation results.

	Terrain			Peat Su (kPa)			Vane Shear (kPa)				Temperature (°C)		
ID	Peatland Type	Peat Depth (m)	Mineral Soil Type	avg	min	max	Peak	REM	von Post range	Water table depth (m)	Min. Temp (°C)	Max. Temp (°C)	Avg. Temp (°C)
1	Thermokarst	1.4	Clay	15.60	10.91	39.01	25.4	4.3	4-6	0.7	15.8	18.8	18.3
2	Plateau Bog	3.7	Clay	17.17	8.32	50.27	12.6	4	3-4	0.3	6.4	13.6	10.7
3	Ladder Fen	3.9	Clay	13.19	5.96	35.04	7.3	3.2	2-6	0.1	5.5	14.3	10
4	Watertrack Fen	2.35	Silty clay	23.24	16.10	41.74	11.9	4.7	1-5	0.4	11.4	19.9	15.9
5	Domed Bog	2.5	Silty clay	16.74	6.32	34.95	23.4	6.9	1-4	0.3	8.6	25.7	16.6
6	Watertrack Fen	3.1	Clay	25.81	7.26	48.53	14.3	3.8	2-5	0.3	7.8	28.4	16.7
7	Watertrack Fen	2.51	Clay	16.66	5.27	36.41	26.8	5.3	2-5	0.2	10.8	17.7	15.3
8	Plateau Bog	3.2	Clay	14.41	4.50	44.98	13.5	3.0	3-4	0.3	6.3	13.9	11.2
9	Domed Bog	2.85	Silty clay	4.44	0.61	17.65	4.2	1.8	2-7	-	8.1	21.9	15.5
	Averages			16.36	7.25	38.73	15.49	4.11			9.0	19.4	14.5

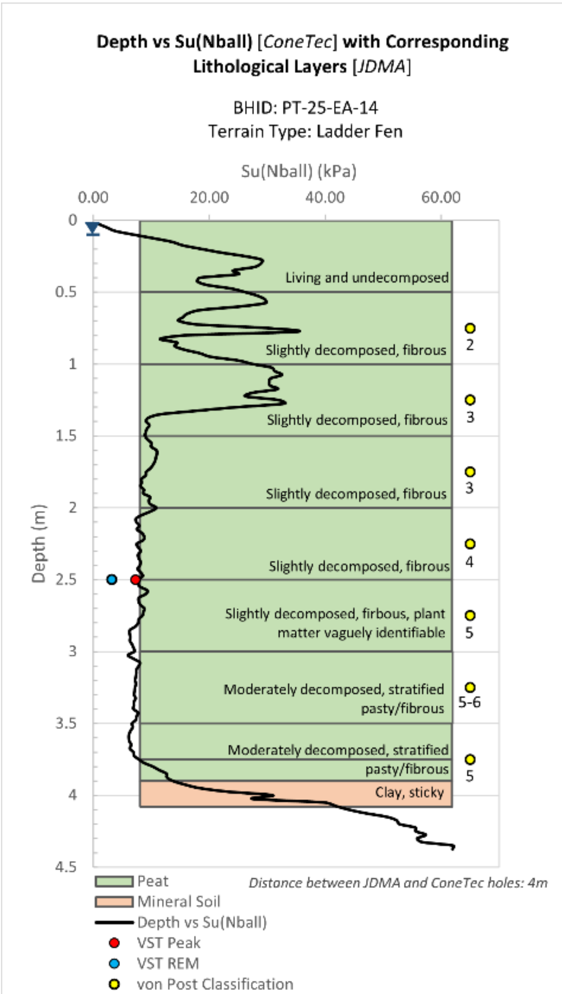

Figure 12. Talon drill log and ConeTec undrained shear strength profile and vane shear test results.

Figure 13 shows ConeTec probe results and von Post classification at two sites, one of which is also shown in Figure 12. The site on the left of Figure 13 shows higher strength in the upper 1.5 m and an abrupt transition to lower strength peat at 1.5 m depth. Shear strength gradually decreases from 1.5 – 4 m depth where mineral soil was encountered. At this location, an inverse relationship is apparent between shear strength and von Post classification. This appears to be due to higher strengths in less decomposed fibrous peat in the upper 1.5 m compared to more decomposed and less fibrous peat in the lower part of the section.

The second example shown in Figure 13 also shows an increase in decomposition with depth as indicated by increasing von Post classification values; however, at this location shear strength also increases with depth. This increase in strength appears to be due to an increase in the woodiness of the peat (i.e., a higher occurrence of larger diameter roots, twigs and branches) with depth.

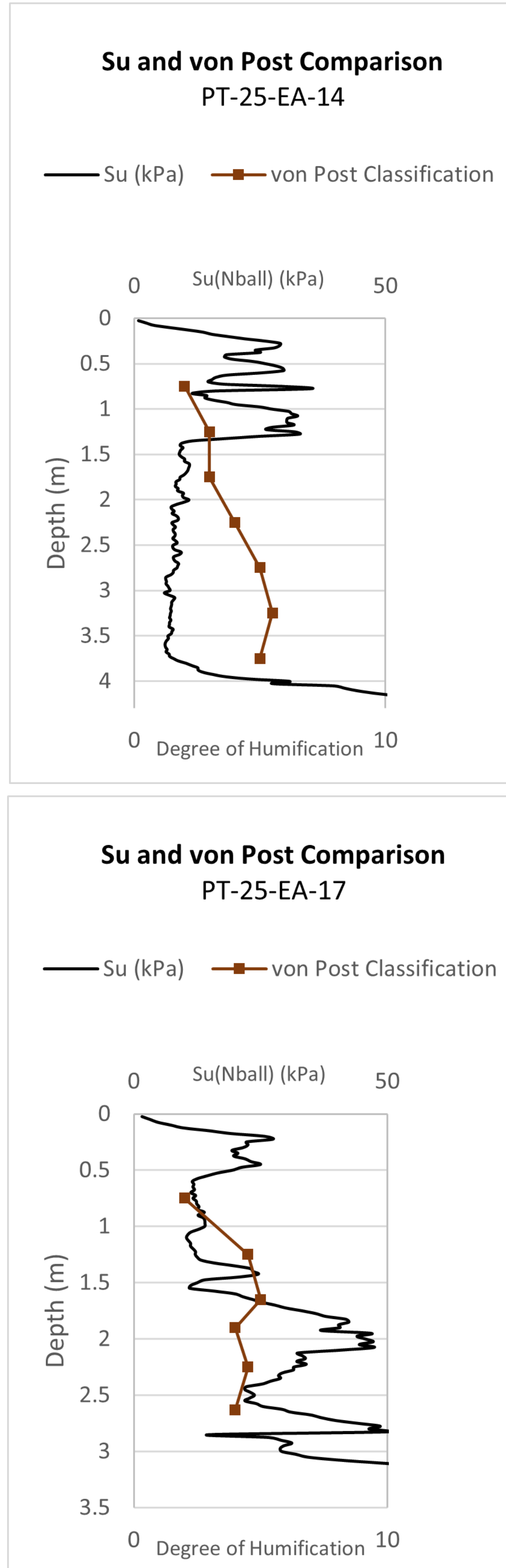

Figure 13: Examples of undrained shear strength profiles compared to von Post classification.

Despite the small number of sites available for this study, a review of the nine (9) sites tested in 2024 indicates a tendency for sites to fall into one of two categories. That is, either 1) low-fibrous peat at depth with higher von Post classification (i.e., higher degree of decomposition) and lower shear strength at depth; or 2) woodier peat at depth with higher shear strength at depth and mid-range von Post classification.

At the two sites with the highest degree of decomposition, von Post values increase with depth while shear strength decreases, one of these sites is in a ladder fen while the other is in a dome bog. Peat depth at these sites ranges from 3.5 to 3.9 m, which are among the deepest peat depths encountered to date. These sites also have the highest degree of humification (i.e., highest von Post values) investigated to date. At these sites there is a clear relationship between higher degrees of humification (decomposition) and decreasing strength with depth.

Another general relationship observed is that sites with higher variability in shear strength generally show increasing shear strength and von Post values with depth. At four of these sites, field logs indicate woody peat and very woody peat in the lower part of the peat. The higher strength in the lower peat is attributed to the added strength provided by woody fibres.

Many of the ‘woody’ sites display a shallow higher strength zone near the surface, underlain by a weaker zone and then increasing strength toward the bottom of the peat where more woody material is present.

The single thermokarst site investigated had the shallowest peat at 1.4 m. No permafrost was found in samples taken from this site.

Figure 14 is a graph of degree of humification vs undrained shear strength. Although there is considerable scatter, likely reflecting the influence of differing amounts of woody fibre in the peat, a general trend of decreasing strength with increasing degree of humification is suggested by the data.

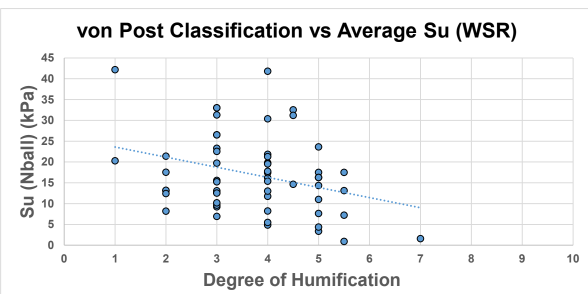

Figure 14. Degree of humification compared to undrained shear strength.

Table 3 is a summary of degree of humification vs vane shear strength with results plotted graphically in Figure 15. There is high variability in peak vane shear strength and much less variability in remolded shear strength. Neither peak nor remolded shear strength shows a relationship with degree of humification. The inferred reason is that vane shear strength is largely controlled by the nature of the fibres in the peat at the specific location where the test is performed rather than the degree of humification.

Table 3. Vane shear strength and von Post summary

BH ID	Depth (m)	VST Peak (kPa)	VST REM (kPa)	Nearest VP classification
1	1	25.4	4.3	5
2	1	12.6	4	3
3	2.5	7.3	3.2	4-5
4	1	11.9	4.7	2
5	1.75	23.4	6.9	4
6	1.25	14.3	3.8	4-5
7	1.5	26.8	5.3	5
8	1.75	13.5	3	3
9	1.75	4.2	1.8	4
	1.5	15.49	4.11	

Figure 15. Degree of humification vs. vane shear strength.

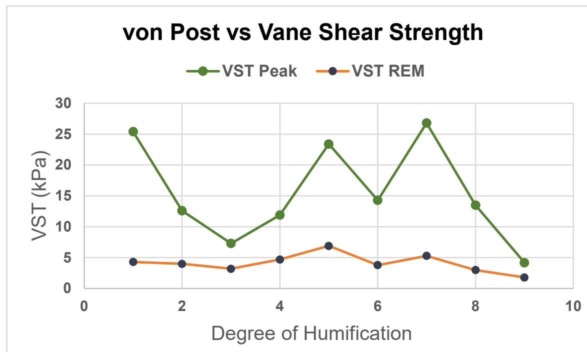

Table 4 is a compilation of results by peatland type. The shallowest peat depth (1.4 m) was measured in the single thermokarst-affected peat while the deepest peat occurred in plateau bog (3.5 m) and ladder fen (3.9 m). Although the number of sites investigate in 2024 is too small to draw general conclusions with respect to peat depth, these results are consistent with approximately 70 depth probes done across the study area.

Average undrained shear strength determined from the ConeTec probe ranges from 10.6 to 21.9 kPa. Peak vane shear strength ranges from 7.3 to 25.4 kPa.

Table 4. Compilation of results by peatland type

Peatland Type	Average Depth (m)	Average Su (kPa)	Average Vane Shear Peak (kPa)
Thermokarst	1.4	15.60	25.4
Watertrack Fen	2.7	21.90	17.7
Domed Bog	2.7	10.59	13.8
Plateau Bog	3.5	15.79	13.1
Ladder Fen	3.9	13.19	7.3

Future studies will be undertaken to collect data at more sites and to investigate the implications of these results for geotechnical design

4 SUMMARY

This study was undertaken as part of the Environmental Assessment and Preliminary Engineering Services for Webequie First Nation's Supply Road Project – the first Indigenous-led environmental assessment in Ontario.

Following is a summary of key findings from the 2024 field investigations.

1. Talon and ConeTec investigations worked effectively from both technical and logistical points of view.
2. None of the sites completed in 2024 required permitting because sites were selected where tree clearing was not required. Site impacts were negligible, and all work was completed safely and efficiently (1.5 – 2 sites/day).
3. Talon drilling proved effective for sampling and classifying the peat and for sampling the underlying mineral soil to maximum depths encountered (~ 4 m).
4. ConeTec methods recovered good data with a high level of detail in the peat.
5. Talon drilling results show generally increasing decomposition of peat with depth (i.e., increasing degree of humification).
6. There appears to be a tendency for shear strength to decrease with increase decomposition; however, strength is also affected by the fibre content (woodiness) of the peat. Presence of larger roots, twigs and other woody material increases strength even though the degree of decomposition may increase as well.
7. Undrained shear strength of peat ranges from 7-38 kPa with and average of 16.2 kPa. Average peak vane shear strength is 15.8 kPa; average remolded vane shear strength is 4.3 kPa. Undrained shear strength from ball penetrometer and vane shear tests varies considerably across this range of values but average values are similar across all sites tested to date.
8. Subsurface temperatures ranged from to 6.3 – 28.4 °C with an average minimum of 8.5 °C, average maximum of 18.4 °C and an overall average of 13.9 °C.
9. Overall, good results were obtained in the 2024 investigations, supporting further implementation of these techniques in the future. Lab analyses and further geotechnical assessment of results are pending.

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