Launched Soil Nail Slope Stabilization, Moosonee, Northern Ontario

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ABSTRACT
Revillon Road in the Town of Moosonee, northern Ontario, runs parallel to and some 7 m above high tide level of Moose River that flows northerly into James Bay. Slope failures have occurred along an 800 m section of the roadway embankment, threatening buried utilities. A geotechnical investigation was conducted by excavating test pit trenches from brow of slope down to a few metres below river level at three locations along the roadway embankment. The soil stratigraphy consisted of fill and/or a desiccated crust of about 2 m thickness followed by a sulphide rich soft marine clay of low sensitivity that extended to the limit the excavator bucket could reach, some 2 m below river ice level in November 2007. The results of index property tests on disturbed samples were correlated with published engineering parameters for slope stability analysis. Due to geographic and environmental constraints, soil nailing was selected as the most economical solution to stabilize the endangered slopes. Over 1300 hollow 6 m long steel rods were "shot" into the slope face using air cannon pressures ranging from 14 MPa to 17 MPa. The rods, or soil nails, penetrated anywhere from their full length to about 4 m. Excess nail stick-up was cut off at ground level. A neat cement grout was poured into each nail, followed by the insertion of 19 mm reinforcing bars to provide protection against potential corrosion of the nails. The paper describes, with photographs of the site and ice conditions that prevail during spring break-up, details of shot rod soil nailing for slope stabilization and shoreline protection with imported granite armour stone.

RÉSUMÉ
À Moosonee, au nord de l'Ontario, la rue Revillon est parallèle à Moose River, une rivière qui se découle dans la Baie James. La rue est environ sept mètres au-delàs du niveau de la marée haute. Il y a des escarpements dans le talus le long de l'autoroute dans une section de 800 m qui pourraient poser des problèmes aux utilités dans le sol. Une simple investigation géotechnique qui consiste de trois excavations le long de l'autoroute a été entreprise pour évaluer la stratigraphie. La stratigraphie du sol inclus: deux mètres de sol de remplissage et/ou une croute desséchée sur une couche d'argile marine moue, peu sensible et riche en sulfures qui s'étend plusieurs mètres sous le niveau de la marée basse. Les propriétés des sols dérangés on été corrélés avec des paramètres publiés du secteur de l'ingénierie pour l'analyse de stabilité. Pour stabiliser le talus le long de l'autoroute, au-delàs de 1300 clous de sols d'acier de six mètres ont été installés avec un lanceur d'air comprimé à environ 14-17 MPa. Les clous de sols pénètrent le sol entre quatre et six mètres. Les bouts de clous ont été coupés au niveau du sol. Les clous de sols on été remplis d'un coulis de ciment et de barres de renforcement de 19 mm ont été installées dans les clous pour les protéger les clous de corrosion. Cet article décris les détails de stabiliser le talus avec des clous de sols et de protéger le rivage avec des bermes de sol protégés avec des pierres de granit importées.

1. INTRODUCTION

Revillon Road is oriented more or less north-south along the eastern edge of the Town of Moosonee near James Bay in northern Ontario. The road is situated 7 m above high tide level and 25-45 m away from Moose River that flows northerly. Slope failures have occurred between Revillon Road and Moose River, threatening buried utilities beneath Revillon Road. An old remnant ice floe covered slide is shown in Figure 1.

Figure 1. Old large slide adjacent to Revillon Rd. covered with remnant ice, looking north (May 2008). Note closeness of scarp to road in some locations.

During spring break-up large ice floes tend to gouge out sparsely vegetated sections of the slope between Revillon Road and Moose River. Figure 2 illustrates one of the smaller ice floes. Diurnal tidal variations of about 2 m and rapid drawdown during spring thaw, along with toe erosion caused by the tides and boat wakes, have caused small to large slides of the river bank slope adjacent to some 800 m of Revillon Road.

Figure 2. Ice floes, May 2008.

This paper presents a case history of soil nailing using launched soil nails. These are steel pipe projectiles that penetrate the ground when fired from a compressed air cannon-like device mounted on standard construction equipment. In this project, the launched soil nails were used in critical sections of the river bank. Slope stabilization with launched soil nails and toe of slope shoreline protection with imported armour stone was started and completed during the latter half of 2008.

2. SUBSURFACE CONDITIONS

Subsurface conditions along the river bank adjacent to Revillon Road were investigated by means of three test pit trenches dug in two stages near the south, middle and northern limits of the project. In the first stage, a trench was excavated with a locally available backhoe from brow of slope to about the mid-slope region. In the second stage, the trench was continued along the same cross-section from the mid-slope region to some 2-3 m below river ice level. This work was conducted in November 2007 when the river was already partially frozen. The remoteness of the site precluded the use of conventional geotechnical investigative methods, such as boring, sampling and in-situ testing.

The soil profile consisted of a desiccated crust of about 2 m thickness and/or fill material underlain by blue-grey silty clay of marine origin. The exposed soil in one trench base is shown in Figure 3.

Figure 3. Grey-blue marine clay in trench base.

Small isolated lenses and pockets of peat are present at the contact between the desiccated crust and the softer clay. The marine silty clay is rich in sulphide inclusions and occasional shell fragments. The average liquid limit of the soil below a depth of 2 m was 32 per cent, with low sensitivity (≤4), estimated on the basis of tactile examination.

Figure 4 shows the liquidity index of the soil was greater than unity at depths of 4-6 m below the level of Revillon Road. The weakest part of the soil profile was thus thought to be located at a depth of 5-6 m below the level of Revillon Road.

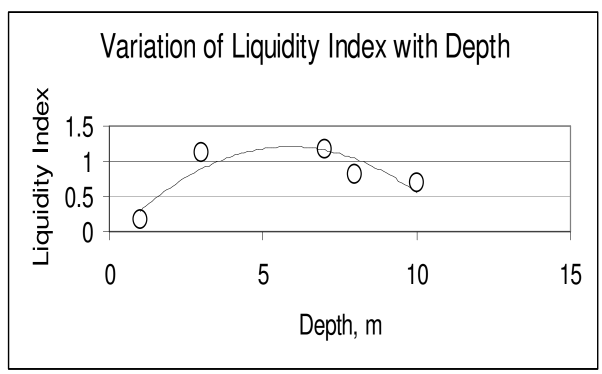

Figure 4. Average liquidity index.

Soil index properties (moisture content and Atterberg limits) were correlated with soil strength parameters published by Skempton (1957), Bjerrum and Simons (1960), Tavenas and Leroueil (1987), Wroth and Wood (1978), Mesri (1989), Kulhawy and Mayne (1990), and Carter and Bentley (1991).

Due to the uncertainties associated with reliably obtaining the shear strength parameters of the Moosonee clay, the application of sophisticated computer programs to assess slope stability could not be justified. The factors of safety against slope failure were estimated from published slope stability charts (Bishop and Morgenstern, 1960; Morgenstern, 1963; Spencer, 1967; Hunter and Schuster, 1971; and Huang, 1975). The results of the estimates of factors of safety obtained from these charts are summarized in Table 1.

Table 1. Factors of safety for Revillon Road.

Method	r_u*	Slope 2:1	3:1	4:1	Remarks
Bishop & Morgenstern	0 0.5	2.0 1.25	2.3 1.4	2.9 1.7	D = 1.5
Morgenstern (Rapid Drawdown)	-	0.8 0.6	1.3 1.0	1.6 1.3	L/H = 0.5 L/H = 1.0
Hunter & Schuster	-	1.0	1.3	1.4	M = 0.48
Huang	0 0.5	1.5 0.8	2.0 1.2	2.6 1.5	CF = 3.6

In November 2007, cross-section surveys were taken at 50 m intervals. The results are summarized in Figure 5.

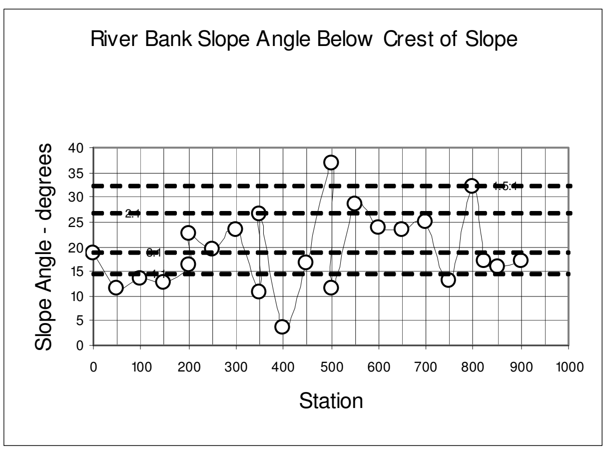

Figure 5. Cross-section data.

From the results of Table 1 and the data of Figure 5, it became obvious that re-grading the river bank slopes to 4:1 or flatter to assure stability, especially during spring thaw rapid drawdown, was impractical due to encroachment into the river and the attendant environmental and navigational constraints. It was therefore decided to improve slope stability with launched soil nails with only some slight slope re-grading and biotechnical slope protection treatment, augmented with shoreline toe protection. The decision to use launched soil nails was taken on the basis of prior experience with them in western Canada and the USA. It was felt that launching soil nails in a predetermined pattern in the more critical slope sections would help to improve the factor of safety against slope instability; however, rigorous analysis of the potential improvement in stability with soil nailing was not conducted for reasons cited earlier and due to the fact that analytical techniques have yet to be developed to reliably predict the contribution of launched soil nails in augmenting slope stability, as opposed to soil nails installed by conventional means of drilling holes and grouting the nails within them.

Both conventional and launched soil nails contribute to slope stability improvement by reinforcing the soil and to a lesser extent by the shearing resistance of the nails where they intersect the potential failure surface within the soil mass. Examples of the mechanism can be found in any recently published college text book on soil mechanics and in special soil nailing publications, such as by Elias and Juran (1988) for field applications.

3. SOIL NAILING

Launched soil nails were introduced to the USA in the early 1990's. There are four soil nail launchers in existence – two in the USA, one in New Zealand and one in Canada. High air pressure causes the nail to penetrate through a shock-wave created opening in the ground that closes up once the nail has reached its final penetration. Results of launched soil nailing are instantaneous since there's no waiting time for grout to cure as is the case with drilled and grouted soil nails.

For the Moosonee project soil nails were launched with a track mounted CAT 315CL excavator equipped with its own air compressor and a soil nail launcher attachment. The nails consisted of 6 m long hollow steel pipe rods with an external diameter of 38 mm and a wall thickness of 3 mm. High strength solid steel 100 mm long multi-cone drive ends were welded to the bottom of each nail before shipment by rail to the site. The soil nail launcher in action is shown in Figure 6.

Figure 6. Hy-Speed soil nail launcher (red assembly attached to the backhoe stick).

A disposable plastic collar seal is attached just above the multi-cone tip. The rod assembly is inserted into a receiver housing. Compressed air is built up in the housing compartment to the desired pressure and released in a single burst of energy that propels the rod at extremely high speed (≥ 350 km/h) into the ground. The plastic collar shatters and is collected in a special compartment. During soil nailing using this method, there were no complaints of excessive noise or vibrations from nearby home dwellers. Soil nailing was not performed during Sunday Church service hours.

The pattern of soil nailing adopted was 1.0 m along the strike of the slope and 1.5 m along the dip of the slope. This was purely an arbitrary decision, based on previous experience with slope stabilization using launched soil nails. Along the dip, the nails were launched perpendicular to the dip rather than vertical in order to ensure maximum penetration and intersection with any potential failure arc at depth. Nearer the base of the slope it would make more sense to launch the nails vertically. However, since shoreline protection works were also included in this project, the emphasis in soil nailing was on protecting the upper parts of the slope from sliding. This is illustrated in Figure 7.

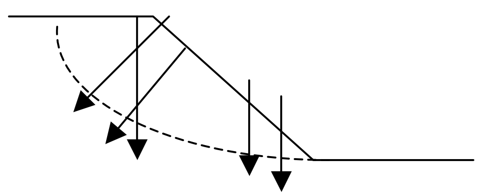

Figure 7. Soil nail orientation with respect to slope.

Soil nailing locations are summarized in Table 2. Station 0+000 was at the south end of Revillon Road. The uppermost row of nails was designated Row 1.

Table 2. Soil nailing summary.

From Station	To Station	No. Rows	No. Nails
0+030	0+153	4	489
0+280	0+310	2	64
0+405	0+480	3	120
0+530	0+670	4	556
0+670	0+710	3	120
		TOTAL	1349

The compressed air pressure used for most of the launched nails was 14 MPa (range 11-17 MPa). Soil nailing production rates varied from 22 to over 150 nails per day, with a working average of about 100 nails per 9 hour day using a 2-person crew. All nails were cut off at or just below ground level.

In anticipation of corrosion that could occur within the sulphide rich marine clay, a Portland Type 10 cement grout with a flow time of 12-15 seconds (standard funnel with a 12 mm diameter nozzle) was poured into the interior of each launched nail. Reinforcing bars (19 mm Φ) were inserted into each grout-filled nail. The cross-sectional area of the reinforcing steel is much larger than the cross-sectional area of the soil nail. If the soil nail corrodes the cement grout protected reinforcing bar continues to act as soil reinforcement and offers shearing resistance. Nail grouting and reinforcing consumed 530 bags of 40 kg cement and 6700 m of re-bars.

Soil nail penetration varied considerably at all locations, even when the same compressed air pressure was used. Some nails penetrated well blow ground level while others hung up 1-2 m above ground surface, as shown in Figure 8.

Figure 8. Variability in launched soil nail penetration (same location as in Figure 1, looking south).

A statistical summary of the soil nails launched between Station 0+030 and 0+150 is shown in Figure 9. It will be seen that the fourth row of nails furthest down the slope generally penetrated about 200-300 mm deeper than the nails in the rows above, confirming the initial geotechnical assessment that the soil is softer at depths below 3-4 m (as indicated by the liquidity index, Figure 4).

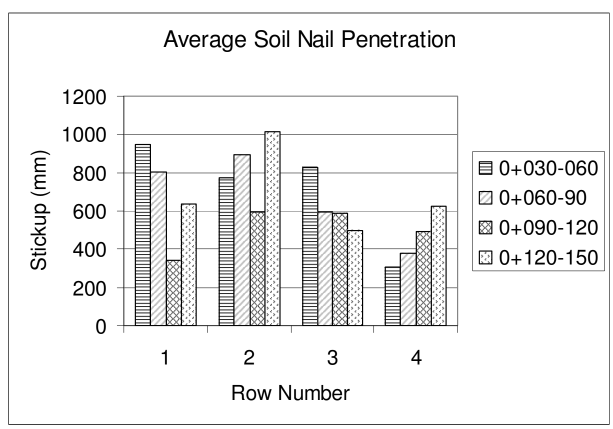

Figure 9. Variability in soil nail penetration (by Stations).

The variability in soil nail penetration can be attributed to factors such as launch air pressure fluctuations and the random presence of roots and stones in the upper 2 m of the stratigraphy. The 6 m long soil nails penetrated, on average, a depth of 5.5 m below ground surface. Nail penetration varied almost linearly with launch air pressure (Figure 10).

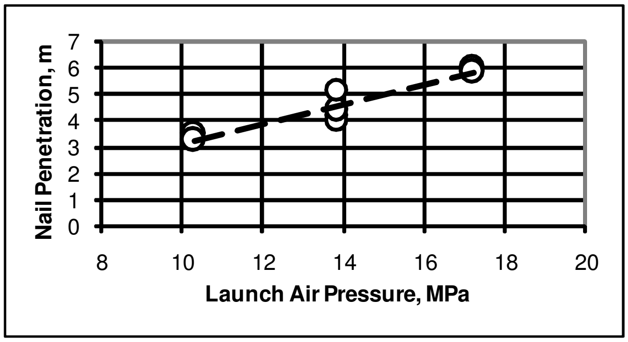

Figure 10. Average nail penetration vs. compressed air pressure.

Near the north end of the project a flat piece of land was selected for the vertical launch of 12 test nails for later exhumation to check corrosion. At that time, it was decided to conduct some pull out tests to confirm the probable shear strength of the soil. The pullout resistance of soil nails is not relevant in slope stabilization. It is the reinforcing action of the soil nails and the slight shearing resistance they offer against soil mass movement that is relevant.

An RA420 load cell mounted within the cabin of a CAT IT 28G front end loader was available locally. The load cell measures the load in pounds (force units) and is read off by the CAT operator. The method used was crude but it is described here to complement the case history of this project. Errors can occur due to the time difference between when the nail begins to just pull out of the ground and a signal is given to the CAT operator to read the load cell.

The load tests were conducted by wrapping a heavy chain around the nail stick-up and hooking the chain to the two tines of the front end loader fork assembly. There was no slippage between the pulled nail and the chain as the hydraulic lift was occurring. The uplift load was read by the equipment operator when a hand signal was given as the nail began to move above an independently supported reference beam. The results of pullout tests on five vertically launched soil nails, conducted 24 hours after launching, are summarized in Table 3.

Table 3. Soil-nail adhesion from pull up tests.

Test No.	Launch Pressure (MPa)	Stick-Up (mm)	Pull-Up Load (lbs)	Adhesion (kPa)
1	17.2	1500	3300	21.1
2	13.8	1600	2700	22.9
3	13.8	800	2740	19.7
4	13.8	1600	5700	48.3
5	20.7	2750	300	17.9

Excluding the high value of soil-nail adhesion of Test No. 4, the average soil-nail pullout adhesion is 20.4 kPa. Assuming an adhesion factor α of 0.8 for the soft marine clay, the average undrained shear strength is 25.5 kPa. The average effective stress at a depth of 5.5 m is 110 kPa. From this, the s_u/σ' ratio is 0.23, more or less within the range expected for such clays.

4. SHORELINE STABILIZATION

Granite armour stone of 3-12 tonne mass was imported from a quarry near Peterborough, Ontario, by truck and rail to a municipal yard in Moosonee. Locally available free-draining granular fill was placed as a toe berm on overlapping 4.6 m wide heavy thick geotextile sheets placed directly upon and along the base of the shoreline. One course of blocky armour stone was placed as a barrier wall on the native shoreline soil. The geotextile was brought up against the inside of the barrier stone wall and wrapped around granular fill placed on the inside and along the inner base of the shoreline. More armour stone was placed above the encased granular fill. Figure 11 shows the construction of the shoreline protection scheme.

Figure 12. Shoreline stabilization (low tide, Sept. 2008).

Figure 13 shows the condition of the armour stone protection after spring break up in mid-May 2009. The effectiveness of soil nailing in preventing future slope failures will not be known until thaw is completed later in June-July 2009.

Figure 13. Berm condition in mid-May 2009. Note beached remnant ice floe behind a displaced granite armour stone (view looking downstream towards the north. Photo courtesy website: *lantz.ca/)*.

Shoreline stabilization work also included slope re-vegetation using local willow shrub wattles, Figure 14 (Grey and Leiser, 1982).

Figure 14. Willow wattling.

ACKNOWLEDGMENTS

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