Shallow slump stabilization using percusion soil nails at Hamelin creek site on Highway 725:02, Peace Region, AB

2011 Pan-Am CGS
Geotechnical Conference

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ABSTRACT
A precast concrete arch culvert was constructed to pass Hamelin Creek under the 24 m high embankment of Highway 725:02 in Northern Alberta. During construction in 2003, several slides occurred on the marginally stable valley slopes. Extensive mitigation works were constructed to stabilize the site, however deep seated slope creep movements continue on the northwest quadrant of the highway embankment subjecting the culvert structure to distress. Rapid downcutting of the streambed upstream of the culvert following construction has also resulted in shallow slumps along the toe of the northwest slope. There was concern that these slumps could retrogress and further destabilize the large deep seated slide. It was therefore necessary to improve the stability of these shallow slumps along the toe of the slope. The method chosen consisted of using “soil nails” to reinforce of the slide mass. The soil nails consisted of 6 m long by 38 mm diameter hollow steel bars that were installed using a percussion and rotary hammer that drove the nails in a 1 m by 1 m pattern. The paper describes the percussion soil nail installation technique and provides details about the installation equipment. The results of soil nail pullout tests and an assessment of the stability improvement is also provided.

RÉSUMÉ
Un ponceau voûté en béton préfabriqué a été construit afin de permettre au ruisseau d’Hamelin Creek de passer en-dessous d’un talus routier de 24m de hauteur le long de l’autoroute 725:02 dans le nord de l’Alberta. Lors de la construction en 2003, plusieurs glissements ont été entamés le long des pentes marginalement stables de la vallée. Plusieurs travaux correctifs ont été entrepris afin de stabiliser le site. Malgré tous ces efforts, des mouvements de fluage profonds persistent dans le secteur nord-ouest du talus routier infligeant des dommages au ponceau. Une érosion rapide du lit de la rivière en amont du ponceau a aussi initié des glissements superficiels le long du pied du talus nord-ouest. Le recul de ces glissements superficiels pourrait déstabiliser davantage le glissement plus profond. Il a donc été nécessaire d’améliorer la stabilité des ces glissements moins profondes le long du pied du talus. La méthodologie adoptée consistait d’utiliser un system de cloutage afin de renforcer la masse du sol. Le system de cloutage du sol utilisé comprenait des clous creux ayant une longueur de 6 m, avec un diamètre de 38 mm, installés selon un espacement de 1m par 1 m au moyen d’un marteau à percussion rotative. Cet article décrit la technique de cloutage du sol par percussion et présente des détails sur le type d’équipement utilisé à cette fin. Les résultats des essais d’arrachement effectués sur les clous ainsi qu’une évaluation de l’amélioration de la stabilité sont aussi présentés.

1 INTRODUCTION

In 2002 Alberta Transportation (TRANS) replaced two large diameter SPCSP culverts under a 24 m high roadway embankment across Hamelin Creek. The site is located approximately 560 km northwest of Edmonton, Alberta. The replacement culvert consisted of a 6 m high by 10 m wide precast concrete arch, 129 m long founded on a 1 metre thick reinforced concrete base slab.

During construction temporary stockpiling operations triggered several slides on the marginally stable valley slopes (Tweedie et a 2006). These slides were remediated during construction by removal of the temporary stockpiles and some slope flattening. However, a deep seated landslide that occurred on the northwest quadrant of the highway embankment continues to show slow but continual creep movements since construction completion. This continued movement has subjected the new culvert to structural distress.

Since the culvert completion, the streambed has degraded 3 m upstream of the culvert inlet as far as 250 m upstream from the culvert inlet. The previous culverts acted as an artificial geomorphological control feature and the culvert invert was lowered intentionally to permit the natural creek bed degradation to continue upstream. However, as an unintentional outcome of this rapid down cutting, two shallow slumps have occurred at the toe of the embankment adjacent to the culvert. These slumps have retrogressed and have raised concerns that they could further destabilize the larger northwest deep seated slide, and thereby increase the rate of deep seated movement and cause more structural distress to the culvert. In addition, the slumped mass had encroached into the creek and was partially blocking the creek flow as shown in Figure 1.

A common method for repair of these shallow slumps would be to subexcavate the slumped material and replace it with more suitable compacted fill. However, there was concern that excavating at the toe could further destabilize the deep seated landslide. As a result, the approach adopted to remediate these shallow slumps was to use 6 m long by 38 mm diameter steel rods, or 'soil nails' to reinforce the slump mass and improve the local stability. This would also enable removing the slump debris that was partially blocking the creek.

Figure1. General view of the south slump.

The construction tender provided the option to use launched nails or rotary percussion nails. The Contractor opted to use rotary percussion nails.

The paper describes the rotary percussion soil nail installation technique and provides details about the installation equipment. The results of pullout test performed on eight soil nails and an assessment of the stability improvement based on the results of the pullout tests are also provided.

2 SOIL CONDITIONS

The soil conditions within the highway embankment typically consisted of high plastic clay fill over native medium to high plastic clay with occasional sand and gravel lenses.

The results of two direct shear tests conducted on samples of the clay fill yielded peak strength parameters of c' = 18 kPa; Φ' = 18^o; and c' = 9 kPa, Φ' = 20^o and residual strength parameters of c' = 0; Φ' = 11^o and 13^o. (Tweedie et al 2006). Atterberg limit tests yielded liquid and plastic limits of 56 and 19 % respectively. A triaxial test conducted on a sample of recompacted fill at 95 % of Standard Proctor Density gave strength parameters c' = 13 kPa and Φ' = 19^o.

3 SLUM REPAIR DESIGN DETAILS

The authors are not aware of currently available commercial stability analyses software based on limit equilibrium that addresses reinforced slopes specifically with percussion or launched nails. In addition, there is limited information on the soil to nail shear strength parameters for input into conventional stability analyses software.

The FHWA (1994) provides some designs plots based on a wedge slide approach for the assessment of slope reinforced with launched soil nails; however, these design plots were developed for a very specific slope configuration that were not applicable for this project slumps.

It is recognized that soil nails improves the slope stability mainly by providing reinforcement to the disturbed soil mass and also, to a lesser degree, by improving the slip surface shear strength (Mirza, et. al., 2009).

Based on the above, the design approach used to remediate the Hamelin creek slumps consisted of using closely spaced nails in a triangular mesh (1.0 m by 1.0 m) configuration and 6 m long that would provide adequate soil reinforcement and would also be long enough to intercept the failure surface improving the slip surface shear strength.

As noted previously the slumped mass had spilled over the creek banks partially blocking the channel. The creek channel needed to be re-established which required the excavation of the slumped toe material, thereby reducing the local slope stability. To reduce the potential impacts on stability, the percussion soil nails were installed in two phases. The first phase consisted on the reinforcement of the upper section of the slump to improve the overall stability and allow the excavation of the toe of the slump to re-establish the creek channel. The second phase consisted of the nailing of the trimmed toe and replacement of the erosion protection riprap.

Figure 2 shows the original ground condition after the slump as well as the interpreted slide plane. Based on the slump topography, the depth of slumping was estimated to range from about 2.5 m to 4 m deep. Therefore a 6 m long soil nail was considered long enough to penetrate beyond the failure surface and provide some improvement to the shear strength.

Figures 3 and 4 provide an overview of the design cross-sections for the Phase 1 and 2 soil nails installation.

To improve groundwater drainage, the nails installed during the second phase at the toe of the slump were supplied perforated to aid in the dissipation of excess pore water pressure from the slope.

4 PERCUSSION SOIL NAILS INSTALLATION

The percussion soil nails were installed by Beck Drilling Environmental Services Ltd. of Calgary, Alberta. The nails were installed using a track mounted excavation equipped with a rotary percussion drill that installed the nails by simultaneously rotating and hammering the nails into the ground as shown in Figure 5.

The soil nails consisted of threaded hollow steel bars (R38N) 38 mm outside diameter and 22 mm inside diameter with 250 MPa yield strength and axial capacity of approximately 500 kN. The bars came in 3 m lengths which were spliced with a 52 mm outside diameter threaded coupler to form the 6 m long nail as shown in Figure 6.

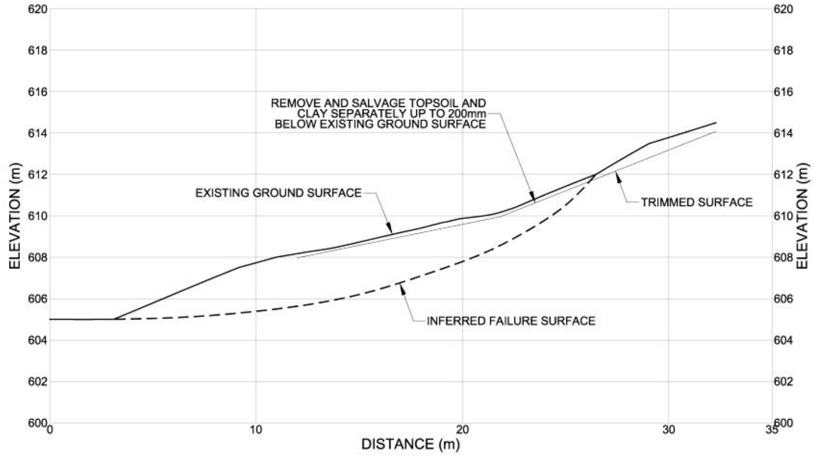

Figure 2. Original ground surface after slump.

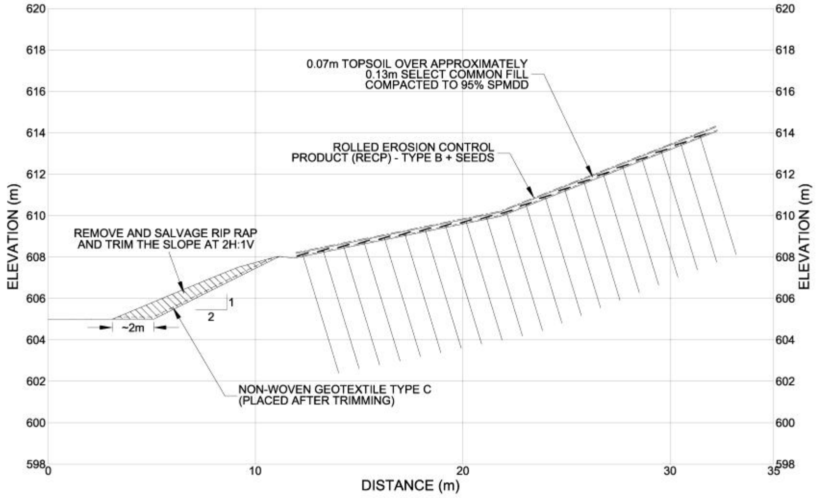

Figure 3. Phase one of percussion soil nails installation.

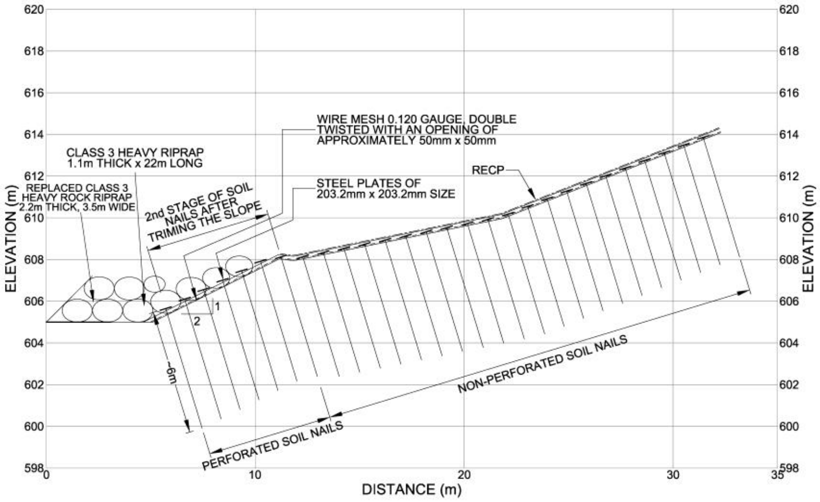

Figure 4. Phase two of percussion soil nails installation.

Figure 5. Percussion soil nail installation equipment.

Basically the full nail length was installed leaving approximately 100 mm protruding above the ground to allow for the welding of a 200 mm x 200 mm x 6 mm thick steel plate that was used to pin a wire mesh over the slide mass to provide additional support to the loose debris. Once the mesh installation was completed the area was topsoiled and seeded.

After installation, each soil nail was checked for excessive curvature or kinking by inserting a steel rod into the hollow nail and checking if the rod would penetrate the full 6 m length of the soil nails. The checking rod was able to penetrate the full extent of all nails.

The average rate of the soil nail installations during this project was approximately 50 nails per day using one rig.

5 SOIL NAIL PULLOUT TEST

5.1 General

During the nail installation it was noted that nail coupling was creating a slightly oversized hole, raising some concerns about the adhesion between soil and nail on the trailing second half of the nail.

It was therefore decided to carry out eight pullout tests to measure the soil nail pullout capacity to allow for an assessment of the nail’s shaft friction.

Figure 6. Splicing the second 3 m segment of the nail.

5.2 Test Procedure

A hollow centre hydraulic jack (530 kN) was placed on a steel reaction beam as shown in Figure 7. The soil nail displacement was measured using a dial gauge (0.01 mm per division) placed on a 25 mm thick steel plate installed at the end of the jack.

An alignment load of 3.5 kN was applied to remove any slack from the loading frame and then the dial gauge was set to zero. The load was applied in stages of approximately 2.5 kN until failure.

To assess whether the nail’s shaft friction would improve with time the nails were tested at different ages varying from 0 day to 12 days after installation. In addition, to test the effect of the coupling to the soil nail shaft friction one nail was spliced by welding so that nail would have the same diameter throughout its length. Another nail was installed to a depth of 9 m which had 2 couplings instead of the regular single coupling used on the 6 m long design nail.

Figure 7. Soil nail pullout test setup

5.3 Soil Nail Pullout Test Results

Figure 8 shows the load versus displacement plot for all soil nail pullout tests.

Table 1 provides a summary of the test results including the tested nails age, length, ultimate pullout resistance and unit shaft friction based on the full penetration length of the soil nail.

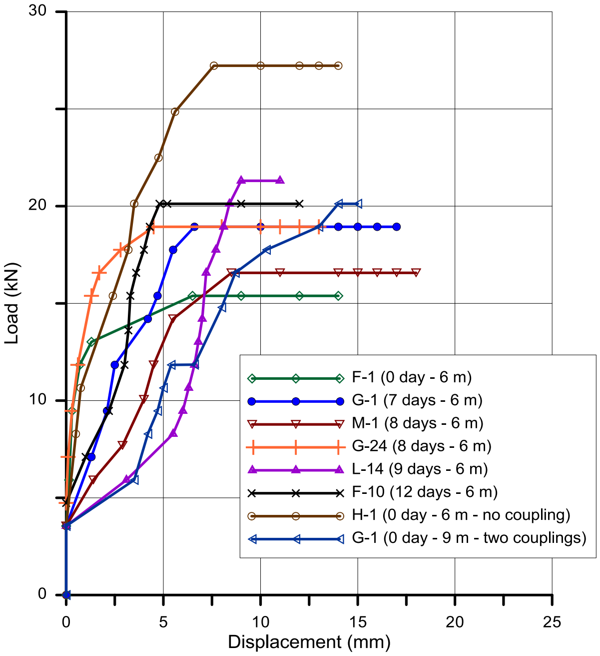

Figure 8. Soil nail pullout test - load versus displacement

Table 1. Soil nail pullout test results.

Soil Nail #	Age (day)	Length (m)	Pullout Capacity (kN)	Unit Shaft Friction (kPa)
F-1	0	6	15.4	22
G-1	7	6	18.9	27
M-1	8	6	16.6	24
G-24	8	6	18.9	27
L-14	9	6	21.3	30
F-10	12	6	20.1	29
H-1	0	6 (no coupling)	27.2	39
G-1	0	9 (two couplings)	20.1	19

Figure 9 shows the soil nails ultimate pullout resistance versus age after installation time for the specified nail design (i.e. the six first nails in Table 1 which were 6 m length with one coupling).

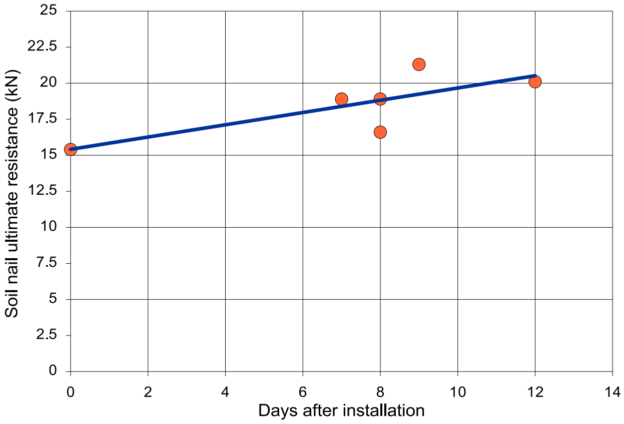

Figure 9. Soil nail capacity versus time.

5.4 Discussion of Test Results

The pullout test results indicate that the hole oversize caused by the coupling affected the nail's pullout capacity. Comparison of Nail F-1 and Nail H-1, both installed and tested on the same day, indicated a shaft pullout capacity of 15.4 kN for F-1 with coupling, versus 27.2 kN for H-1 without coupling (i.e. welded nail sections). This represents an increase of 77 % between nail with and without coupling.

Nail G-1 length was increased to 9 m (two coupling) and re-drove into the ground after being first tested with the original 6 m length. The capacity of the 9 m long nail was 20.1 kN, which was about 33 % greater than the equivalent 6 m long coupled nail (F-1 at 15.4 kN at day 0). However, the pullout capacity for the 9 m long coupled nail was still 26 % less the capacity of the 6 m long nail H-1 that was installed without coupling. This result supports the conclusion that the oversize coupling affected the nail pull-out capacity.

If required, the skin friction of percussion soil nail could be improved the installing the nails using an oversize bit to create an open annulus around the nail then grouting the nail through the hollow bar and filling the annulus with grout.

Figure 9 shows the increase in capacity with time after installation up to a maximum of 12 days for the 6 m long soil nails. The soil nails show an apparent "set-up" with time similar to driven steel piles. This set-up is likely due to dissipation of excess pore pressures resulting from the driving process and possibly also closure of the void around the soil nail that was created by the oversized coupling.

The unit shaft friction, or adhesion, presented in Table 1 is consistent with the values presented by Mirza, et. al. (2009) for 6 m long launched soil nails installed in silty clay of marine origin. However, they were much lower than the adhesion of 188-375 kPa reported by Antunes, et.al. (2006) also for launched soil nails.

6 STABILITY ANALYSIS

Limit Equilibrium Stability Analysis was performed using the software program Slope W to provide an estimation of the potential improvement in slope factor (FS) of safety due to the installation of the percussion soil nails. A back analysis was first performed to assess the soil parameters. The results of the back analyses indicated that an average friction angle of 18^o and cohesion of 0.5 kPa was required to produce FS = 1. The friction angle values is consistent with the result obtained from the direct shear tests, however the cohesion is much lower, indicating that the slump had resulted in a loss of cohesion at shallow depth.

The results of the pullout test provided the unknown nail unit skin friction to be inputted to the modeling. As shown in Figure 10, the stability analysis indicated that the soil nail should increase the FS to 1.5 which was considered adequate.

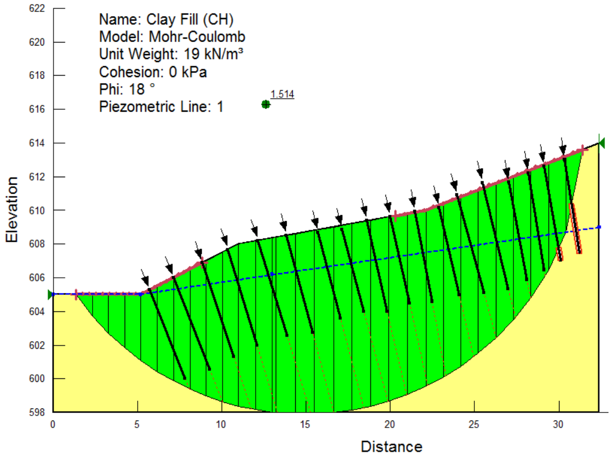

Figure 10. Stability analysis result.

7 CONCLUSIONS

Percussion soil nails were successfully used to remediate shallow embankment slumps at the Hamelin Creek site on Highway 725:02 in Peace Region, Alberta.

Results of pullout tests performed on 6 m long soil nails, with one coupling, have shown soil nail unit shaft friction varying from 22 to 30 kPa and presenting an apparent "set-up" with time similar to driven steel piles.

A pullout test was also performed on a 6 m long soil nail, without coupling, and on a 9 m long nail, with two couplings, which has shown that the nail's coupling provides an adverse effect to the unit shaft friction.

A stability analysis performed using the soil nail unit shaft friction, provided by the pullout test results, has indicated that the soil nails improved the slump stability to a factor of safety of 1.5.

ACKNOWLEDGEMENTS

The authors wish to acknowledge Alberta Transportation Peace Region personnel, especially Mr. David Morrison, for their support throughout the project and for their permission to publish the results. The authors acknowledge also the contribution of Beck Drilling Environmental Services Ltd. for their support performing the pullout tests. In addition the authors would like to thank Mr. Shawn Russell of Thurber Engineering Ltd. for the French translation of the abstract.

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