Flexible Slope Stabilization In Cowichan Bay, BC – Using A High-Tensile Steel Mesh To Stabilize a Steep Eroding Soil Slope

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ABSTRACT
Over-steepened slopes above Cowichan Bay Road, in Cowichan Bay, BC have had numerous historic shallow slope failures. In recent years, re-vegetation has not been rapid enough to provide erosion protection before the winter season rainfall. As a result, sloughed material has overfilled the ditch and deposited on the roadway resulting in reduced traffic flow and disrupted local transportation. The British Columbia Ministry of Transportation and Infrastructure sought a long-term solution to stabilize the steep weathering glacial till slope that best protects the traveling public, and ultimately decided upon a flexible anchored mesh slope stabilization system.

Flexible anchored mesh stabilization systems have been developed for the stabilization of over-steepened soil slopes or weather rock cuts using a specialized design concept called RUVOLUM. This dimensioning tool is dependent on the ability of the system to transfer forces from the high-tensile facing material to the ground anchors tied into the stable subsurface using specialized anchor plates. Extensive full-scale field testing of this mesh have confirmed the performance of the complete system utilizing not only the mesh, but the anchor plate that optimizes force transfer from mesh to anchors. The open facing of the system allows ground water to drain through the mesh and performs well under seismic activity due to the flexible nature of the mesh. The anchored mesh is combined with an erosion control mat installed underneath the mesh to prevent fine material from washing through. In addition, hydroseed is applied to promote re-vegetation to further stabilize the surface as well as to promote an aesthetic and 'green' solution.

RÉSUMÉ
Des versants raides situés au-dessus de Cowichan Bay Road, dans la baie de Cowichan, Colombie Britannique, ont été sujets de nombreux glissements de terrain à faible profondeur. La revégétalisation ces récentes années, n'a pas été assez rapide pour agir en tant que protection contre l'érosion avant les pluies de la saison hivernale. En résulte un remplissage des fossés par le sol mobilisé, inondant également la route, causant un ralentissement et des perturbations locales du trafic routier. Le ministère du transport et de l'infrastructure de la Colombie Britannique a cherché une solution à long terme pour stabiliser ces versants de till glaciaire et protéger les usagers de la route. Le ministère s'est finalement prononcé pour un système de stabilisation de pente d'un treillis flexible à ancrages.

Ces systèmes ont été conçus pour des versants de sols très raides ou des faces rocheuses altérées utilisant un concept spécialisé nommé RUVOLUM. L'outil de dimensionnement est dépendant de la possibilité du système à transférer les forces depuis le matériel à haute résistance vers les ancrages au sol, eux-mêmes rattachés au sous-sol stable par des plaques d'ancrages spéciales. Les essais de terrain grandeur nature de ce treillis ont confirmé la performance du système au complet et non pas seulement du treillis seul mais aussi des plaques d'ancrages qui optimisent le transfert de forces entre treillis et ancrages. Les mailles du treillis permettent un drainage des eaux et réagit bien lors de séismes grâce à sa nature flexible. Le tout est combiné est avec un tapis contrôlant l'érosion installé sous le treillis pour éviter que du matériel plus fin soit emporté. Finalement l'hydro-ensemencement est utilisé pour favoriser la revégétalisation et augmenter la stabilité de la pente ainsi que pour améliorer l'esthétique du système et promouvoir une solution « verte ».

1 INTRODUCTION

Over-steepened and/or truncated slopes are characteristic where infrastructure encroaches upon a slope and right-of- way is limited. Along such corridors, slope stability issues can be significant and recurring. Other contributing factors can include groundwater conditions, the geology of the slope, or environmental factors such as heavy rainfall or erosion. All factors combined can cause two main types of instability: deeper instability and shallow and, or surficial degradation of the slope (sloughing failure).

The British Columbia Ministry of Transportation and Infrastructure (BCMoTI) Cowichan Bay Road Slope Stabilization Project addresses a failing cut slope, identified as the latter of the two types.

2 BACKGROUND

Cowichan Bay Road is a busy commercial strip and vital hub for the local community, especially in the summer season. There have been numerous shallow landslides and soil falls east of the project location. Where treated, the failures have typically been addressed with concrete block walls see (Figure 1). Concrete block walls have been successful in addressing the slope concerns, but are regarded as somewhat undesirable because they diminish the aesthetics and carry a large footprint, where area is limited.

In the specific project area, surficial failures had become more frequent as localized zones within the slope became further over-steepened and vegetation was either absent or less mature than before the failures. The length of slope needing treatment is approximately 80 meters long and ranges from 8 to 18 meters high. Overall the slope is approximately 45^o, but sloughed areas are steeper and typically range from 55^o to 70^o.

The increased frequency of road closures motivated BCMoTI to find a solution that would allow for safe travel and be cost effective. Due to property restrictions, utility locations and the existing parking and rest area, it was neither possible to increase ditch capacity nor realign the road, therefore any potential design solution would have to maintain the same cross section.

Figure 1. Cowichan Bay Road Slope Stabilization, Plan View.

Through 2012 to 2016, several site visits were made by both the BCMoTI geotechnical engineers and by consulting geotechnical engineers, either following a failure or as a part of the design work. At every outing it was noted that there were no tension cracks at the crest of the slope, and there is no apparent toe forming at the base of the slope or within the roadway.

Based on observation the failure surface is considered to be shallow, as material sloughs off caused by over-steepened slopes that become weaker in inclement weather. The thickness of failure, based on existing scarp heights, has been generally found not to exceed 1 meter, but for the sake of design was assumed to be a slab 1.25 meters thick.

The soil profile in the slope is apparent when looking at the failure surface. The soils are dense interbedded glacial till deposits of clayey silt, sandy silt and sandy gravel. The slope is typically dry, however seepage and wet zones are localized and apparent after rainfall events. The seams of clayey silt make the slope particularly sensitive to change in groundwater conditions.

A wide variety of mitigation measures has been considered at this location, among them: erosion mats, basic revegetation (hydroseeding), bioengineered revegetation, catchment barriers, concrete block wall and a soldier pile wall. After several design iterations, it was decided that anchored slope mesh would best protect the roadway from material deposition. The anchored mesh option was primarily favored because it was a cost effective solution with minimal change to the existing slope, and minimal disruption to traffic flow.

3 PROTECTION MEASURE

The use of flexible, wire mesh slope stabilization systems is a globally proven technology. Mesh systems have been applied in numerous climates including cold-climate installations, where the stabilizing facings need to be able to flex under the freeze/thaw cycle. To provide protection against deeper instabilities, these flexible materials must be anchored throughout the slope with a pattern of nails or bolts. Historically, the mesh used for these purposes is produced using mild steel wire with a tensile strength of 400 to 500 N/mm^2. These relatively low-strength meshes do not have the high-tensile strength that is required to retain an unstable slope and they ultimately require and anchor spacing that does not prove to be economical.

The development of mesh made from high-tensile steel wire offers new possibilities for the efficient and economical stabilization of slopes. The mesh has the high strength necessary to enable greater spacing between anchors, leading to a lower overall installed cost. Sophisticated dimensioning concepts serve to dimension these kinds of slope stabilization systems against superficial instabilities by taking the statics of soil and rock into account. The flexible slope stabilization system consists of TECCO G65/3 high-tensile steel wire mesh, system spike plates, and soil nails. The mesh is made from 3 mm high-tensile wire and uses a zinc-aluminum coating for protection against corrosion. The high-tensile steel wire used in the manufacture of the mesh has a tensile strength of 1770 N/mm^2 (compared to mild steel tensile strength of 400–500 N/mm$^{2)}$. The resulting tensile strength of high-tensile steel wires is 12.5 kN per 3mm wire and 22 kN for a 4mm wire, substantially higher than conventional mild steel wire mesh, allowing for optimum force transfer of slope loads at the anchor plates to the stable ground.

Figure 2. High-tensile wire mesh (upper) and spike plate to tension the high-tensile steel wire mesh against the slope surface (lower).

Aside from the higher bearing capacity, another advantage of high-tensile mesh over conventional mild steel wire mesh is that it has an even load transmission and no weak zones within the mesh. This is achieved by manufacturing high-tensile mesh with the same diameter wire, which forms a unified and homogenous mesh structure. This is achieved by manufacturing mesh with the same diameter high tensile wire, which forms a unified and homogenous mesh structure.

To insure optimal transfer of forces from the mesh to the anchors, a special diamond-shaped system spike plate has been developed. The spike plate matches the load capacity of the mesh and serves to fix the mesh to soil or rock nails. The spike plate design is specifically optimized and is diamond shape for force transmission using a plate designed with ribs (for stiffness), and has additional tabs designed to tightly secure the mesh. Once the nails are tensioned, the spike plates recess into the ground, tensioning the mesh to follow the surface contours (Figure 2 lower).

High-tensile mesh systems utilize T3 connection clips to allow for 100% force transmission at the seams and the system therefore has no weak links (Figure 3 lower). The specialized clip is made from the same high-tensile steel wire and the same corrosion protection as the high-tensile wire itself. The connection clip has a wire diameter of 4mm and has two reversed end hooks on the one side of the clamp. It can easily and quickly be installed by hand without any power tools (see Figure 3 upper). No overlap of the mesh is required saving significant materials and can be connected longitudinally and laterally with only one clip per diamond.

Figure 3. T3 Clip used to connect TECCO panels vertically in rock (lower) and in soil application (upper).

The main anchors of the system are installed in a grid typically ranging from 2.0 to 4.0m horizontal and vertical spacing. With this slope stabilization system the rows of nails are offset to each other by half a horizontal nail distance. This limits the maximum possible break out between the individual nails to a width “a” and a length of “2 x b”. Actual spacing depends on the results of site analysis and modeling. The staggered layout is shown in Figure 4, with the general arrangement (upper) and the installations at Cowichan Bay (lower).

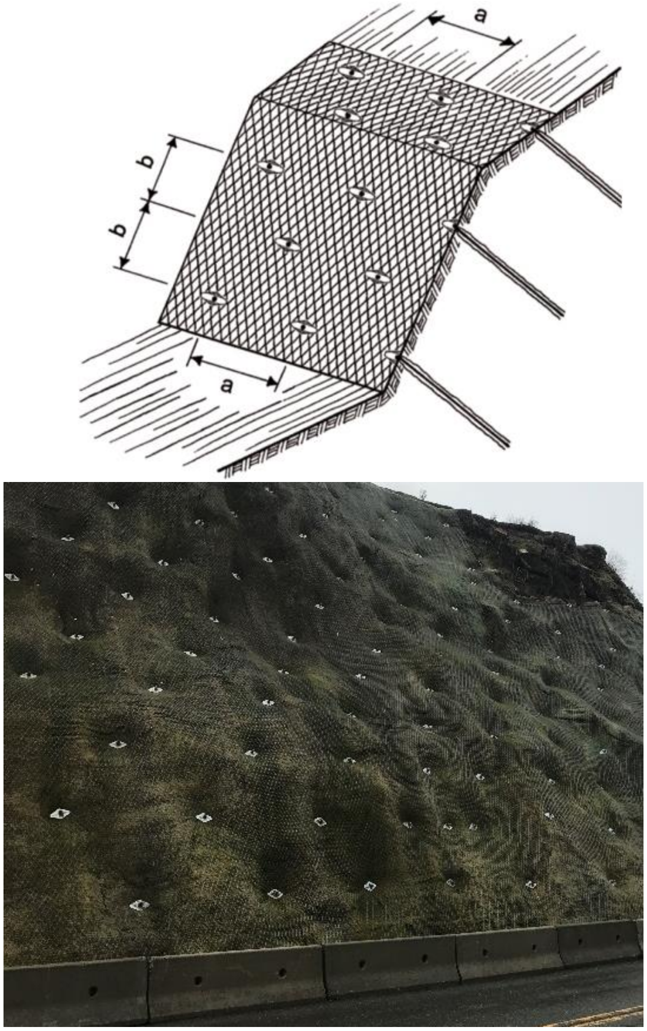

Figure 4. General profile with the nail arrangement (upper) and staggered pattern of nail installations at Cowichan Bay Road (lower).

Anchors consist of commercially available steel bars ranging from 20 to 40mm in diameter. Self-drilling hollow core grout injection anchors are also permitted in soils or weathered rock where it would be difficult to keep boreholes open. Additional anchors may be specified for added support at boundaries and in low points or hollows.

4 DIMENSIONING

The flexible slope stabilization system was dimensioned against superficial instabilities based on the RUVOLUM concept (Rüegger and Flum, 2006). The maximum nail spacing and the required nail length and type can be determined, and by utilizing the high bearing capacity of the mesh, significant cost savings can be realized by reducing the number of nails required. Using the material properties of the mesh along with the characteristics of a given slope as input, this model determines the optimum anchor spacing to provide stability to the slope (Figure 5). Global stability analysis is still required for deeper seated failure mechanisms.

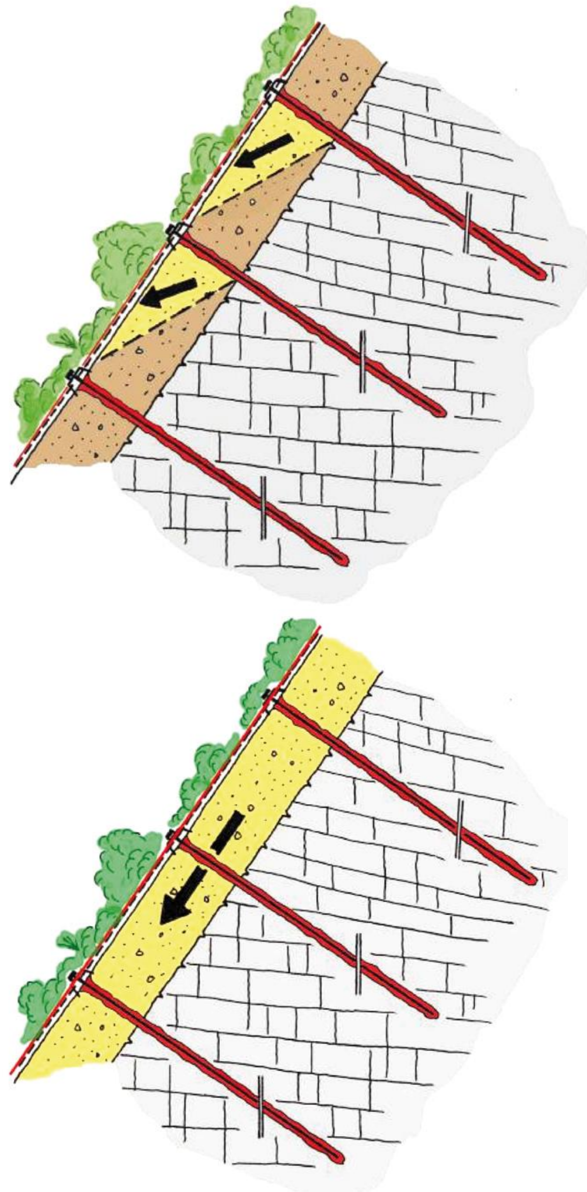

Figure 5. The dimensioning concept is based on the investigation of superficial slope-parallel instabilities (left) and on the investigation of the local instabilities between single nails (right).

5 PROJECT DETAILS

Initially there were three distinct zones of sloughing, with three distinct zones of mesh stabilization. However, between design and construction phases, an additional failure occurred, making the slope instability nearly continuous along the entire slope length.

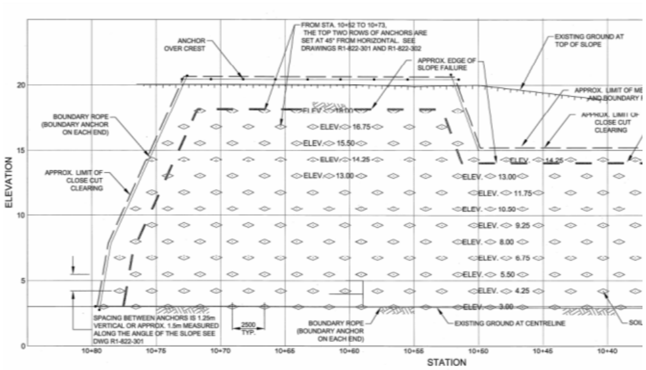

Figure 6. Conceptual Design Schematic for Cowichan Bay Slope Stabilization

The anchor length was calculated using the method outlined in FHWA-IF-03-017. The slope was analysed statically as well as with an applied seismic ground acceleration of 0.30 g, associated with the return period of 10% in 50 years (2010 NBC Model).

A double corrosion-protected, 25mm diameter (#8), Grade 75 (517/690 MPa) threadbar was selected for the installations. The factored shear strength of the ground/grout interface was calculated as 100 kPa, using PTI manual presumptive values for soil ranging from stiff clay to sandy silt and applying a resistance factor of 0.5. The minimum design length of the grouted portion was calculated at 3.7 meters, which was rounded up to 4 meters. The overall design length of the bar including the thickness of sloughed material was 5 meters.

A preliminary layout of the anchors was analyzed using the Ruvolum software, version 01.03.2015, available from the supplier. The nails were selected to be installed inclined 20º from horizontal, in a rhomboid pattern with minimum spacing of 2.0 m. Klohn Crippen Berger Ltd. was brought in as the geotechnical sub-consultant to assist with the drafting of contract documents and design drawings. They recommended a revised spacing of 2.5 meters horizontal and 1.25 meters vertical, which BCMoTI accepted. For the final design, factored anchor loads were calculated to be 106 kN.

In detailed design, the crest anchors needed to be redesigned to fit within the property line. Again, using Ruvolum software, the top two rows were redesigned at an inclination of 45 degrees (see Figure 7 below), and the bonded length of install was reduced to 3.5 meters (with an overall install length of 4.5 meters).

Because of the residential properties at the top of the slope, construction access was limited to an easement which permitted only human traffic and activity, and disallowed machine access. All activity was limited to 2 - 4 m past the crest of the slope, and only for the duration of construction. Construction at the base of the slope was limited by the roadway and maintaining traffic flow.

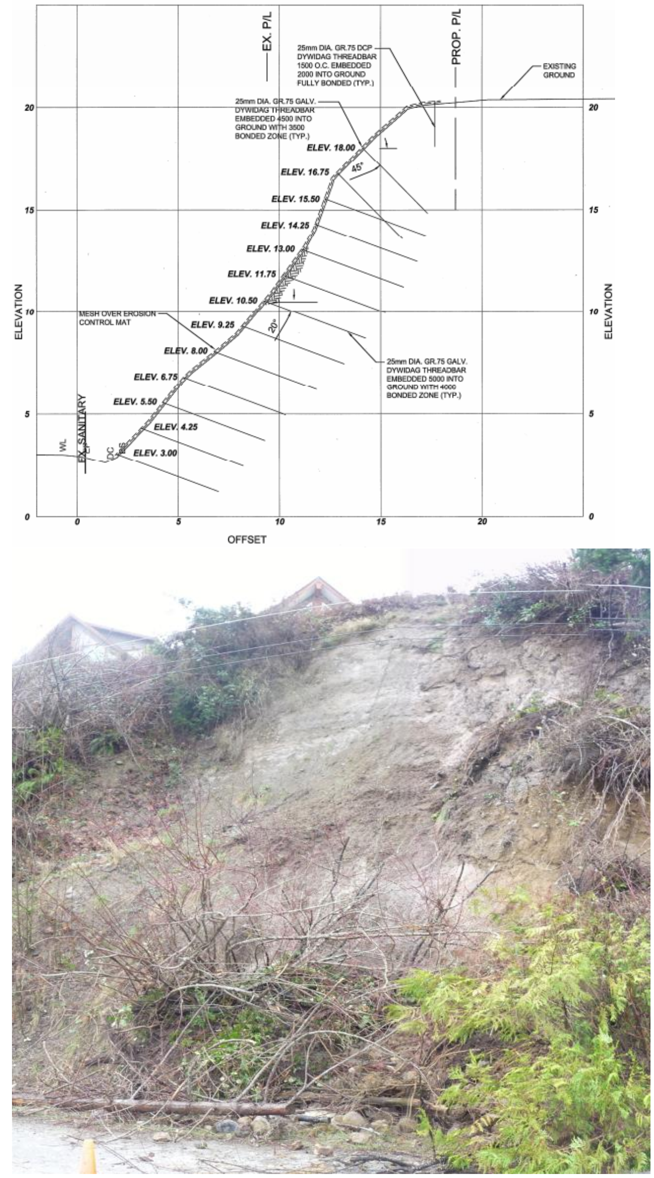

Figure 7. Cross section of the slope mesh installation (upper) and photo of slope at that location (lower).

6 CONSTRUCTION DETAILS

Through a competitive tender process, Kan-Arm Construction Ltd. was selected as the contractor for this project. Following planning and mobilization, the construction of the slope stabilization system lasted 52 days from September 19 to November 10, 2016.

Table 1 below shows a summary of the phasing of construction and length of time spent with each item.

Table 1 - Construction activities and duration

Clearing Grubbing and slope shaping	2 days at onset, 2 additional days post failure
Installation of Nails	29 days
Testing	Concurrent with installation phase
Mesh System Install	8 days
Erosion Mat Installs	8 days
Hydro-seeding	2 - 4 days

First, the slope was cleaned of vegetation and eroded soil/rocks/debris in order to level the slope as much as possible and shape as needed, with the minimum disturbance.

When shaping, the major focus was a root mass at the crest of the slope directly above the highest and steepest area of sloughing (Figure 8). There was the possibility that in removing the root mass and soil material (potentially including boulders), that too much material would come out of the slope and that the stabilization could not stay within property limits. As a result it was decided to cut the trees as close to the ground as possible, making it possible the stumps could be covered by the erosion mat and tensioned into the slope by the mesh.

Figure 8. Roots and loose granular soils at the crest.

With the slope cleared, a baseline survey was conducted and the grid of design installations was marked out. Initially the planned locations (+/- 10 cm) were used, but added 10 additional installations mid-project, once vulnerability in another area at the crest was identified

The contractor decided to install (sacrificial) hollow bar anchors at the crest of the slope to hang polyethylene sheeting to protect the slope surface during adverse weather and to tie-off for rappelling down the slope. These installations were shorter than the crest anchors (1.2 meters versus 2.0 meters).

Two representative locations were chosen for performance tests: One soil nail was installed where the slope angle, soils and moisture condition were "typical" on one end of the project. The other performance test was on the other end of the slope near the critical failure where the soil was damp and seemed to have a greater clay fraction.

Following successful performance tests (as outlined in the PTI Recommendation for Prestressed Rock and Soil Anchors, 2004) the contractor began production using two drills mounted on a zoom boom and an excavator (Figure 9 upper). The thread bar installation and grouting was performed using a man-lift (Figure 9 lower)

The BCMoTI had written into the contract, as a contingency, that the soil nails may require casing. However, due to the stiffness of the soil and set-up in the slope soils, the casing was very difficult to remove. As a result, uncased installations were allowed so long as there was minimal grout loss in the slope and the bore holes stayed open.

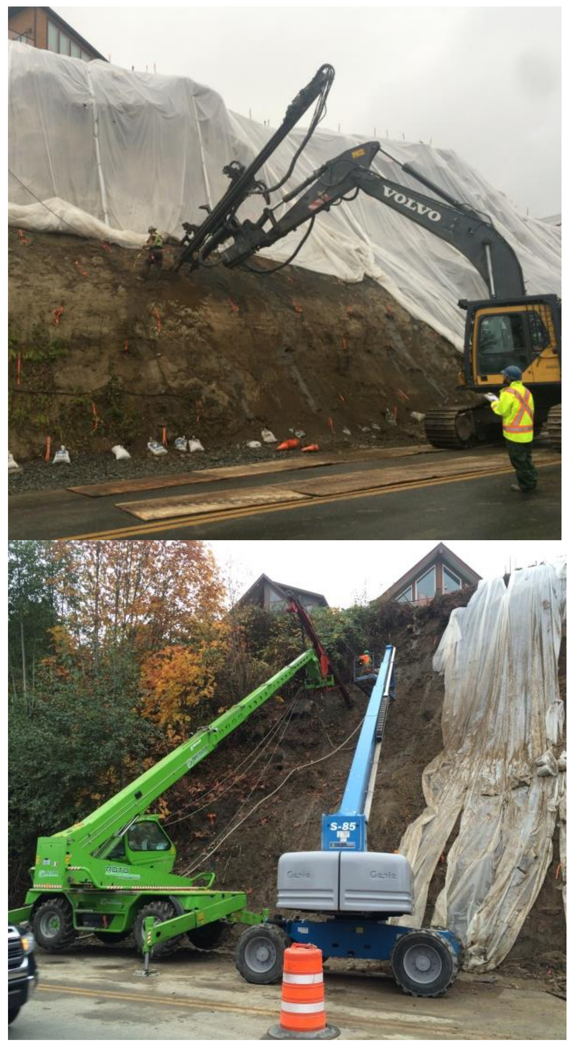

Figure 9. Installation of soil nails with excavator (upper) and zoom boom beside a man-lift (lower).

On a typical day the contractor completed drilling 10 to 15 anchors, with peak production at 24 anchors drilled in one day. Installation on the lower slope was faster and with fewer complications. Generally, progress slowed for installations at the top of the slope.

At the onset, all of the installations including the crest anchors and boundary anchors were proof tested as per PTI 2004. However, after more than half of the anchors had been tested and found 100% satisfactory, the proof testing regime was reduced.

7 SMALL SLAB FAILURE OCTOBER 14, 2016

During construction, following a very heavy rainfall, a small slab (< 1 m^2) of material came off from underneath the critical root mass. Upon visiting the site, the slope was found to be saturated with steady seepage coming from 3 distinct locations. Two of the seeps lined up near to the groundwater horizon assumed in modelling: the interface of the loose granular soils with the stiff clayey silt layer. The third seep occurred mid-slope from what appeared to be a seam of sand and gravel.

With the permission of the property owners, BCMoTI investigated upslope and discovered the ground was completely saturated with standing water on the lawn. The owners informed us that the perimeter drainage had failed due to a pump failure. The water in the cistern had suspended solids and the annulus of the pump was blocked by sand. The residents were in the midst of trying to get the pump in working order.

The slope was re-covered with the polyethylene sheeting and was closely monitored by the contractor throughout the night. The slope was inspected first thing the next morning and was found to be moist but no longer saturated. Seepage from the face was absent. It was determined that shortly after the site visit the night before, the malfunctioning pump was fixed.

Based on this event it was considered that the slope failure was a result of the drainage failure at the crest of the slope, and not directly related to precipitation. In fact, although it rained almost continually for 2 days following the event, the slope continued to dry out, while being protected from rainfall by the polyethylene.

Following this failure, the upper slope was again undercut and slope shaping in the vicinity of the problematic root mass needed to be readdressed. The contractor brought in a long reach excavator (370 Hitachi Long Boom) to reshape the slope. Unfortunately, the machine was only able to reach within the top meter of the crest. Also, the operator was concerned about boulders coming down the slope as the shaping progressed. At this point, scaling of the slope and manual shaping were required and using scaling bars, hatchets and shovels. The root mass and adjacent soils were carefully removed.

Where the slab dislodged, additional anchors were required between the grid anchors to ensure a tight fit of the mesh against the slope.

8 COMPLETION OF THE PROJECT

Following the anchor installation, small depressions (dells) were hand excavated around each bar to accommodate the spike plates. The shaping of the dells was important, because it determines how taut the mesh installation can be. Boundary anchors and ropes were installed to reinforce the outer edges of the mesh.

Finally, the erosion control mat (American Green SC 250 from Nilex) was rolled down the slope, and the mesh was then installed and pre-tensioned as per the design manual. The slope was hydroseeded on the soil slope before the erosion mat was installed and on top of the system installation (Figure 10 upper and lower).

Figure 10. Condition of the slope in October 2016 (upper) and in February 2017 (lower) – in the process of revegetation 4 months later.

9 OWNER'S COMMENTS ON CONSTRUCTION, SCHEDULE AND BUDGET

The scope of the project went as planned, with the exception of 10 additional anchor installations in a part of the upper slope not originally thought to be vulnerable. One additional anchor installation resulted from the aforementioned slab failure. 268 anchor installations were originally planned and the 279 actual anchors were installed. The stabilization was completed on time. The budget had to be amended because of activities relating to the October 14 failure which increased project costs by 8%.

In order for the contractor to complete work on time, and before seasonal rainfall, the BCMoTI made accommodations to speed up scheduling, namely: The contractor was permitted to work Saturdays, number of installations proof tested was reduced (once enough tests to confirm the adequacy of the anchorage), the sacrificial installations at the crest of the slope were deemed adequate as crest anchors once load tested and filled with grout (so as to not corrode).

10 CONCLUSIONS

Overall the project was successfully installed before seasonal precipitation and was well received by the local community. Many local residents commented during construction that they appreciated the design approach, and were pleased at how integrated the appearance of the slope mesh system was. High-tensile slope stabilization system was successfully adapted to the site specifics and static conditions in a very flexible manner, even allowing some changes during construction. A particular advantage to the BCMoTI is that this system can be expanded seamlessly to adjacent areas, in the event of failure at those locations.

Based on experiences gained with this project, it would have been beneficial to dedicate more time and resources to slope preparation, which would have saved the client both time and money in the long run. Specifically, it might have been helpful to have close cut clearing as one contract item, to be performed by the landscaping subcontractor, and scaling as a separate contract item to be performed by the contractor. These activities are interrelated, but close cut clearing (BCMoTI contract terminology for slope preparation) did not capture the scope of this work or its relative importance to the final product.

Slope shaping is efficiently done with excavation machinery, however in locations sensitive locations on the slope where there might be greater uncertainty, the hand scaling was the better method. Because the scaling was slower it gave BCMoTI more opportunity to investigate the slope materials and proceed incrementally. There was also a safety advantage of working from above the slope should larger stumps or boulders fall from the slope.

The polyethylene sheeting was beneficial to the project. It was helpful in protecting the slope, allowing BCMoTI to discern the groundwater condition during rain events, and beneficial for traffic flow and safety by shielding construction activities from drivers. In the future, this should be included in any applicable anchored slope mesh contract.

Finally, the contractor was permitted to grout the installation within 0.5 meters of the surface. Because the system installation operate as soil nail rather than as a tieback anchor, no free stressing portion should be required. This was easier from a quality management and constructability standpoint, even though the quantity of grout increased.

In conclusion, anchored mesh slope stabilization system can be adapted to the site specific and static conditions. It is a cost effective solution compared to shotcrete or rigid structures which allows revegetation natural appearance.

There is freedom of anchor placement and a range of meshes and plates allow application to a wide variety of slope conditions. The system provides effective static load transfer and can be pre-tensioned against subsoil that can be fully dimensioned with a design tool with the backing of full scale testing.

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