Mosquito Creek Debris Flood Barrier – The First Line of Defence in Protecting the Public from Geohazards

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ABSTRACT

In the District of North Vancouver, the Mosquito Creek watershed drains water from Grouse and Fromme Mountains through a densely populated residential area down to Burrard Inlet. The upper part of the watershed has had a number of landslides which have the potential to create debris floods, a significant geohazard to the residents of North Vancouver. The District of North Vancouver (DNV) requested the design and installation of a debris flood barrier at an optimal point on Mosquito Creek. Critical to this installation was careful sizing of the barrier for a 200-year debris flood event, locating the barrier within a fish bearing creek containing rare long tailed frogs and providing the most cost effective solution to the DNV. This paper presents the investigation of the mainstem of Mosquito Creek, including a detailed geohazard inventory map documenting notable features such as; significant sediment sources, natural barriers, landslides, bedrock canyons, waterfalls and debris jams. The paper also details some of the engineering design undertaken to construct the debris net within a bedrock canyon. The flexible net debris barrier at Mosquito Creek is only the second barrier of this type to be installed in British Columbia and when compared to alternatives is more cost effective, less intrusive and more easily repaired, making it a more sustainable solution.

RÉSUMÉ

Le ruisseau Mosquito draine les eaux provenant des montagnes Grouse et Fromme à travers une zone résidentielle densément peuplée pour finalement se déverser dans l'embouchure Burrard dans la région de Vancouver Nord en Colombie Britannique. La partie supérieure du bassin drainé par le ruisseau est sujette à des glissements de terrain qui ont le potentiel de provoquer des crue de débris. Le risque est significatif et le quartier de Vancouver Nord a demandé la conception et l'installation d'une barrière à débris à un lieu stratégique le long du ruisseau. Le défi consistait donc en la conception et l'installation d'une barrière capable de résister à une crue de récurrence 1 dans 200 ans tout en considérant les contraintes environnementales dues à la présence de poissons et d'une espèce de grenouille rare ainsi qu'un budget limité. Cet article présente les travaux réalisés par l'équipe de Tetra Tech EBA incluant les travaux d'investigation et de caractérisation géologique détaillée identifiant; les sources de sédiments, les barrières naturelles, les glissements de terrain, le roc de fondation du canyon, les chutes et les amas de débris. Cet article traite aussi en détail de certains aspects de la conception de la barrière. La barrière flexible du ruisseau Mosquito est seulement la deuxième barrière de ce genre à être installée en Colombie Britannique. Dans le cas du ruisseau Mosquito, cette solution s'avère plus économique, elle a un impact minimum, et est facile d'entretien ce qui en fait le choix durable privilégié.

1 INTRODUCTION

The District of North Vancouver (DNV) retained Tetra Tech EBA as the prime consultant tasked with the design and installation of a debris barrier across Mosquito Creek. Mosquito Creek drains portions of Grouse and Fromme Mountains, through a densely populated area, and discharges into Burrard Inlet. The upper part of the watershed contains a number of existing and potential landslide areas and debris jam sites with sediment wedges that could trigger a debris flood. The potential hazards posed by debris floods and debris flows are well understood, and previous events, such as the Upper Mackay Creek debris flow in 1995 (Kerr Wood Leidal Associates Ltd, 2003) have highlighted the requirement for mitigating this hazard and protecting the public within the District of North Vancouver.

The objective of the project was to protect the public from such events by providing an upstream first line of defense for the substantial protection afforded by the Evergreen Basin located downstream on Mosquito Creek.

The Evergreen Basin is a large concrete structure that could become blocked by large woody debris (LWD) rafted in a debris flood.

Secondary objectives were also vital for the success of this project; these included constructing a cost effective, low maintenance structure, with a low environmental impact and minimal aesthetic impact on the surrounding habitat. At every stage of the design and construction, it was necessary to ensure that the project objectives were achieved, whilst ensuring that strict environmental and aesthetic standards were met.

The project solution provides mitigation of debris floods propagating along Mosquito Creek, with minimal impact to the environment. Significant challenges (such as weather delays and a tight fish window construction schedule) were faced throughout the project and effective management was necessary in order to deliver the solution in a timely manner.

We understand that this is only the second such barrier in British Columbia and Canada (at the time of installation).

2 SITE DESCRIPTION

The average gradient of Mosquito Creek between the Baden Powell Trail Footbridge and the bedrock canyon (approximately 220 m) is 15%. The catchment area at this location is approximately 4.31 km^2 (Figure 1). This reach of the creek has a step-pool morphology dominated by boulders on the bed and banks with a limited floodplain area on both banks.

Approximately 75 m upstream from the footbridge a rock bluff outcropping defines the left bank valley slope. At this location, a side hiking trail to the Baden Powel Trail runs along a wooden supported walkway for a short distance.

Approximately 220 m upstream from the footbridge, the creek narrows through a bedrock canyon. At the base of the canyon, an old 3 to 4 m high timber crib wall spans the channel. The wall was constructed to provide water storage for early development in the area.

Behind the crib wall, sediment has infilled the basin and the barrier no longer provides any water storage capacity. The structure is now effectively acting as a retaining wall to the material behind it.

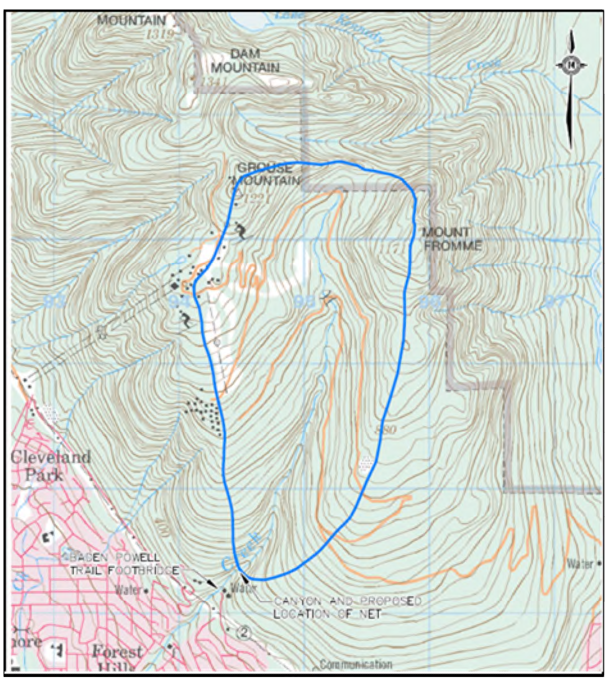

Figure 1. Location map of Mosquito Creek in the District of North Vancouver, British Columbia, Canada. The catchment area at the debris net is 4.31 km².

3 OBJECTIVE OF THE DEBRIS NET

The objective of the debris net is to filter LWD (logs, root wads and large branches) suspended and rafted by a debris flood. By filtering the LWD, the probability of the culvert being obstructed at the Evergreen Basin, located about 2 km downstream of the bedrock canyon, is reduced.

Should the culvert at the Evergreen Basin become blocked, flood water, debris and sediment could overtop the basin crest and creek banks, potentially damaging residential homes and other infrastructure downstream.

In developing the options for mitigating the hazard and risk of debris floods, it was important to consider several factors that might affect the performance of a debris net, including:

- Composition of debris floods in terms of the size of timber, size of boulders and quantity of water mobilizing these constituents;
- The velocity of the initial impact and the magnitude of the dynamic loading component, or if a more gradual increase in the pressure on the net occurs;
- How quickly material accumulates behind the net, and if staged surging occurs;
- The flood height within the creek when the event occurs;
- How much freeboard there is to the net (if any);
- What the potential is for the material to wrap around the sides of the net; and,
- How exposed the net supports are, and if these components could be damaged during an event.

4 BACKGROUND REVIEW TO CHARACTERIZE DEBRIS FLOODS WITHIN MOSQUITO CREEK

This section details the review of background information, the creek assessment that was undertaken in order to characterize the 200-year debris flood event, and the hydraulic analysis undertaken to determine water levels at the proposed net location in the bedrock canyon.

In order to design the debris net, a number of key parameters were required, such as; ascertaining the water level associated with certain return period events, the number of probable debris flood surges, and the volume and velocity of the debris flood when it passes through the canyon.

The investigation included a detailed on foot inspection of the creek and valley slopes so that the assessment, and hence analysis, were site specific for the design of the debris net at the proposed canyon location.

The most noteworthy information is summarized below (BGC Engineering Inc. 2011, Tetra Tech EBA, 2011):

- Single landslide dams could result in 100 and 200-year events. Larger 500 and 2500-year events would likely result from multiple landslide dams;
- Based on an “As Low As Reasonably Practicable” (ALARP) assessment of events, the highest risk return period corresponds to a 200-year debris flood;
- The debris net will likely reduce the risk of culvert blockage at the Evergreen Basin to tolerable levels;

- Slope length and overburden colluvium thickness cannot yield a single debris avalanche large enough to produce a breech with a peak discharge of 900 m^3/s;
- The only process by which even higher peak flows as determined for the 500-year event can be conceived is multiple quasi-simultaneous slope failures;
- Flow convergence to form a “super debris flow” is not conceivable because the channel is too low a gradient to allow bulk debris flow transport. Instead, multiple debris avalanches would create multiple landslide dams. Once one dam is overtopped and breached, downstream dams will likely fail in sequence. However, this process does not yield cumulative discharges due to flow attenuation within the intermittent creek reaches;
- A significant earthquake during very wet conditions could lead to widespread shallow land sliding and it is plausible that several simultaneous failures could occur;
- The channel gradient does not lend itself to debris flows but rather debris floods;
- In 2008, the DNV was notified of a large road related debris avalanche, portions of which had reached the mainstem;
- The upper watershed is characterized by convex slopes of shallow soil and till over bedrock. Drainage redirection or excessive precipitation and/or snowmelt can reduce local soil stability leading to failures that are most likely to occur as shallow debris avalanches that are likely to impact the mainstem at right angles thus resulting in possible damming of the creek;
- Debris nets have been designed to stop small (typically less than 5000 m^3) debris flows or reduce the volume of larger events;
- The goal of the Mosquito Creek debris net would not be to stop all bed load transport and debris flood material but rather filter the large and most destructive rock debris as well as organic debris that could obstruct the culvert intake downstream at the Evergreen Basin and which may lead to unwanted channel avulsions.

A journal article of interest, not specific to Mosquito Creek (Uchiogi, 1996), discusses the relationship between forested area and flood wood volume. This suggests the relationship can be expressed by the following:

A coniferous forest	Vg = (10 to 1000) Af
A deciduous forest	Vg = (10 to 100) Af

Where, Af is forest area (km^2) and Vg is wood debris volume (m^3).

The area of the Mosquito Creek basin at the point of the potential debris net location was estimated to be 4.31 km^2 as illustrated on Figure 1. Based on this information, the volume of wood debris might be expected to be between 43.1 m^3 and 4310 m^3 for a coniferous forest such as the Mosquito Creek basin.

5 SUMMARY PRINCIPLES OF THE DEBRIS NET DESIGN

The key aspect in the design of a flexible ring debris net is the designed volume the net needs to retain. This, in part, depends upon the flood event or debris flood event that is being considered and the characteristics of the catchment above the debris net.

Based on the Mosquito Creek Debris Flood report by BGC (2011), the 200-year debris flood event, with a 70 m^3/s discharge rate, forms the design event.

The 100-year event is within the As Low As Reasonably Practicable (ALARP) zone of the risk verse fatality graph. Such an event would not typically lead to fatalities according to the BGC report.

The 500 and 2500-year events are also within the ALARP zone, as these events are less frequent, and as such, the debris net did not need to be designed for such large events.

Considering the above, the Mosquito Creek debris net is designed to effectively mitigate a 200-year flood event by reducing the risk of culvert blockage downstream at the Evergreen Basin.

In order to mobilize the LWD within the creek, two potential causes have been considered with respect to the design.

The first is a 200-year rainfall and flood event that causes the creek to increase in volume and velocity, thereby transporting the woody debris in the creek, fallen trees near the creek and root wads.

The second potential cause is a debris flood event created when a large landslide blocks the channel causing a temporary damming of the creek, followed by collapse of the sediment dam, and an immediate and large pulse of water, sediment and debris is transported downstream.

In terms of design, the principles of the debris net are similar for each cause of debris flood.

The base of the debris net needs to be set at a height that allows lower return period events to pass underneath. However when the 200-year event occurs, the net height needs to be within the water column by a given amount in order to retain the LWD.

Similarly, in the case of a debris flood, the height of the net needs to retain the LWD floating near the surface, but allow boulders and cobble sized material travelling near the bed, or at the base of the debris flood column, to pass underneath.

In both cases, it is the force of water that needs to be dissipated by travelling through and over the retained material.

The actual height of the debris net itself needs to take into account the quantity of LWD that could potentially be mobilized in an event. It should be noted that in a debris jam, the interstitial space between the wood particles is high, and needs to be taken into account when considering the height of the net.

A further aspect that requires consideration is how far upstream the LWD can deposit. This aspect is a function of the creek gradient and sinuosity as well as the angle of natural repose of the LWD.

6 SITE RECONNAISSANCE AND ASSESSMENT

The site reconnaissance of Mosquito Creek was split into two phases.

The first phase consisted of a walkover survey of the creek from the Baden Powell Trail Footbridge upstream to where the deactivated logging road crosses the creek mainstem (Figures 1 and 2). This survey focused on evaluating the quantity of LWD in the creek and the amount which could be mobilized in various flow events.

The location of potential landslides and source locations for debris floods were also characterized and assessed.

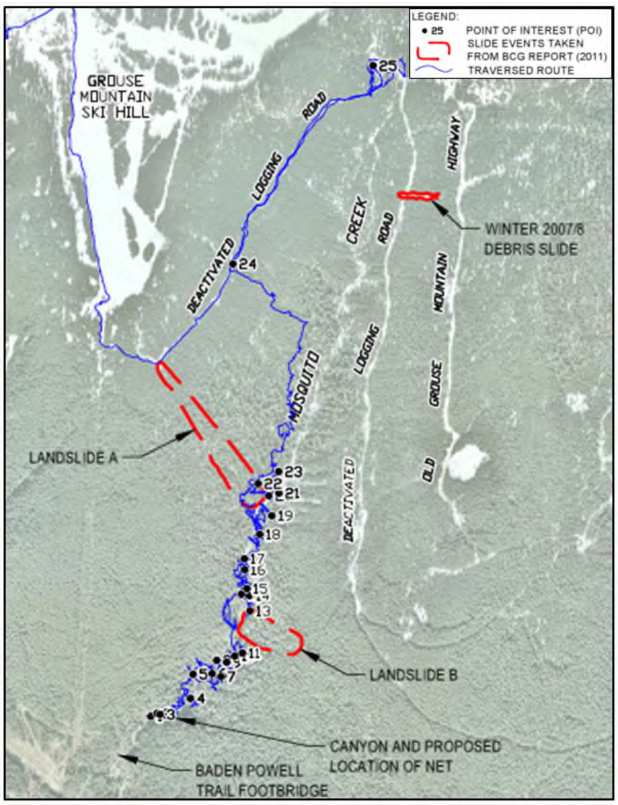

Figure 2. Geohazard map indicating points of interest (POI) identified during site recognisance.

Based on this examination and assessment, the size and quantity of woody debris could be estimated given a variety of events and magnitudes. Considering this, and recommendations made within the BGC report (2011), the 200-year event, with the potential to cause harm to the public and with a return period frequent enough to be of concern, formed our design event.

The second phase of the site reconnaissance consisted of an inspection of the bedrock canyon to determine the anchor locations and requirements for the detailed design of the debris net.

The creek assessment upstream of the Baden Powel Footbridge was carried out on April 3, 2011 by Mr. Jamie Stirling, M.Sc., P.Geo and a field assistant. The route walked by the crew was tracked with a hand held GPS and Points of Interest (POI) were waypoint marked, both indicated on Figure 2. Most of the POI refer to log jams, debris jams, sediment wedges, various types of slope instabilities, and eroding banks. Only the most significant features and largest events were marked with a waypoint.

Log jams, debris jams and sediment wedges were common throughout the mainstem of Mosquito Creek.

Photo 1 illustrates typical log jams, averaging approximately 10 m^3 each. Jams smaller than this estimated volume were not POI referenced as they were too frequent to document. Typical eroded slopes and small landslides result in about 5 to 20 m^3 of sediment being deposited directly into the channel.

Photo 1. Looking downstream at a typical medium sized debris jam creating a sediment wedge behind the jam.

Photo 2. Looking upslope at a typical medium sized landslide that has deposited sediment and debris directly into the channel.

Photo 2 shows a shallow landslide exposing the underlying bedrock. These are typical along the mainstem, and these events were effective in depositing large volumes of sediment and debris directly into the channel.

The very large debris jam at POI 18 on Figure 2 is the most significant single accumulation of debris and sediment on the mainstem. This jam is approximately 20 m wide, 10 m high and could be 5 to 10 m deep, suggesting a volume of 1000 to 2000 m^3.

This volume does not include the sediment wedge which has formed behind the debris jam, itself approximately 35 m long and identified as POI 20 on Figure 2. This jam and sediment wedge is at the base of an old landslide identified as Landslide A on Figure 2. It is likely that this jam and sediment wedge formed as a result of this slide.

Adjacent to this sediment wedge on the east valley slope are several landslide paths, some of which are old (POI 21) while others are still actively depositing material directly into the creek (POI 23). Upstream of this area the channel gradient and valley side slopes flatten as shown by the contours on Figure 1. As a result, there are fewer jams and slope instabilities.

Another significant feature on the mainstem was a bedrock canyon identified as POI 15 on Figure 2. This deep and narrow canyon was measured to be 5 m wide at the bed and about 15 m wide at a height of 7 m. This narrow cross section is a pinch point for debris floods and the probability of a jam and obstruction occurring here is high.

Based on the information gathered during the site visit, and the estimated volume of some of the larger log and debris jams, a debris net system designed to retain approximately 1500 m^3 of debris material was recommended.

Furthermore, it was prudent to design the net to accommodate three surges during a debris flood event.

7 LOCATING THE DEBRIS FLOOD NET

In terms of the overall location of net installation, one of the limiting factors is the length of an unsupported span that the net can extend. This unsupported span is approximately 12 m for a Geobrugg, Trumer Schutzbauten, or Maccerferri product.

At either side of this span a net requires support from a post or an anchor.

Three potential locations were selected for the installation of the debris net; (i) at or near the Baden Powel footbridge, (ii) between the footbridge and the bedrock canyon, and (iii) within the bedrock canyon.

In an effort to provide the DNV with the most cost effective system, also designed to fulfill all of the project objectives, a qualitative assessment of the three potential sites for the debris net was undertaken.

The assessment considered nine separate parameters, with the following primary factors contributing to the chosen debris net location;

- The chosen location is out of sight of the Baden Powell Trail, while other options would have been visible from the footbridge of the popular hiking trail.
- The net location was optimized so as not to undertake any permanent construction within the creek bed or riparian area.
- Considering the unsupported span limitation, downstream of the canyon at least three posts would have been required to create the net with a suitable span. These three posts, including one mid-stream, would have had challenging foundations and difficult in-stream construction. The cables supporting the net would have required lateral restraint using soil anchors, and access would have been challenging for the equipment to undertake this work given the forested area and boulder dominated creek bed and banks. This would have resulted in a greater environmental impact and less aesthetic design with challenging, costly foundation conditions.

The bedrock canyon was therefore selected as the most preferred site as no permanent in-stream structures were needed, and large posts were not required. This minimized costs, made the work feasible within the fish window construction period, and reduced aesthetic impacts, whilst performing in terms of capturing the required volume of debris.

8 HYDRAULIC ANALYSIS

A hydraulic analysis was carried out to determine the corresponding depths and velocities for various clear water and debris flood events.

As the debris net site is 12 m upstream of a sediment infilled timber cribwall (i.e. the crest is at bed level), the assumption was made that the flow would be at the critical depth in the vicinity of the debris net.

This enables a computation of depth based only on the channel cross-section and the flow per unit width.

Table 1 illustrates the corresponding depths and velocities for the different flood scenarios.

Table 1: Clear Water and Debris Flood Hydraulic Results at the Bedrock Canyon

Event	Flow (m^3/s)	Depth (m)	Wetted Area (m^2)	Velocity (m/s)
Debris Flood				
100-yr	70	2.31	15.17	4.61
200-yr	120	3.28	22.12	5.42
500-yr	310	6.11	45.38	6.83
Clear Water				
100-yr	25	1.17	7.46	3.35
200-yr	28	1.26	8.06	3.47

The 200-year clear water event depth of 1.26 m was used for the positioning of the bottom of the net. This reduces the frequency of regular maintenance associated with debris removal from behind the net.

In order for the net to be able to contain the design debris volume of 1,500 m^3, the top of the net position was set at an elevation of 7 m above the creek bed.

Figure 3 is a cross section illustrating the estimated depth of various events at the debris net location in the bedrock canyon.

9 DETAILED ENGINEERING DESIGN

A flexible net was chosen for its ability to effectively retain LWD rafted during a debris flood, and therefore to prevent an obstruction at the Evergreen Basin downstream.

In comparison to a concrete barrier, the flexible net has a lower environmental impact, and is also far more cost effective and efficient at catching LWD. To construct a concrete barrier at the location would have involved a difficult in-stream foundation and a more severe change to the Mosquito Creek landscape.

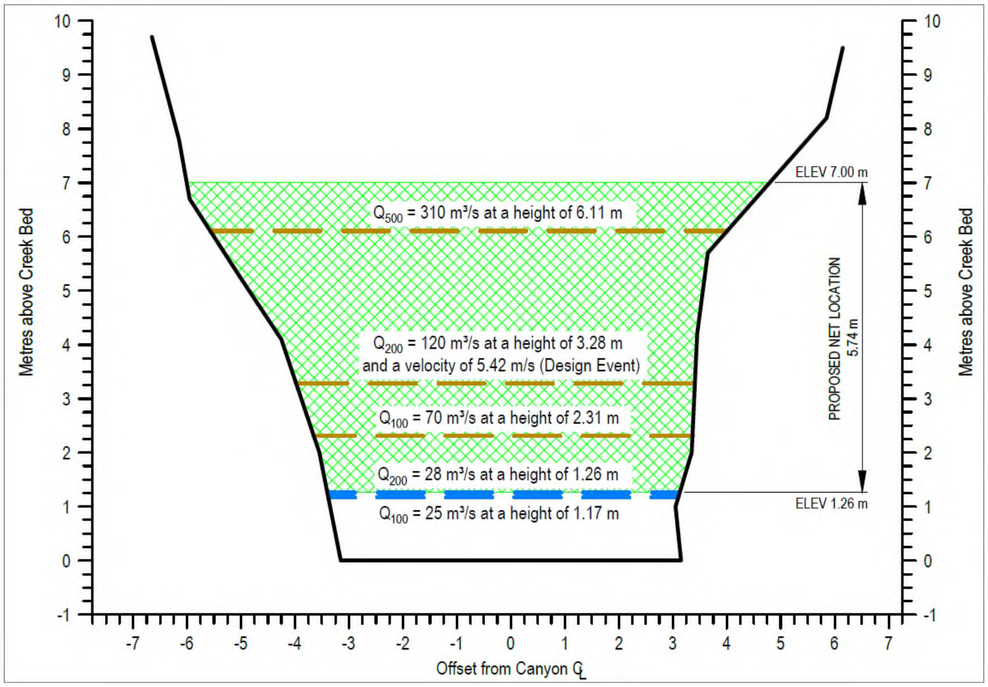

Figure 3. Estimated depths of various events at the location of constructed debris net.

The position of the debris net within the bedrock canyon was optimized such that the initial debris flood impact force is absorbed by the left bank (eastern) wall of the canyon, before turning almost ninety degrees and then impacting the debris net. By locating the net at this position in the canyon the velocity and impact forces from the event are reduced and naturally dissipated by the geometry of the canyon.

Fundamental to the design of the debris net was an understanding of the volume of material that could be retained following the design debris flood event. To that effect, with the results of our assessment of the catchment area and the optimization of the debris net location, a 3D model of the bedrock canyon in which the debris net would be located was completed. This allowed the determination of the dynamic and static forces that would be imparted onto the net during the design event.

9.1 Debris Net Design

Following a competitive process evaluating cost and performance from three suppliers of debris nets, Tetra Tech EBA enlisted the expertise of Trumer Schutzbauten, a provider of slope stabilization, rockfall products, and flexible net systems, to design a flexible debris net capable of meeting all of the design requirements.

Working within the canyon required the whole design to be augmented by human power as the location is inaccessible to machinery and cranes. In the design, all components had to be designed with this aspect in mind and that roped access construction would be carried out.

In this regard, it was necessary to employ a team experienced in roped access construction.

The net was specially designed and constructed in two parts, to the unique shape of the canyon at this location, in order to carry and lift the net into position manually.

The designed debris net also incorporated the use of yielding 'brake' elements attached to each bearing rope. These brake elements deform to absorb some of the initial impact force from a debris event, and therefore reduce the tensional loads applied to the rock anchors. (Refer to Figure 4).

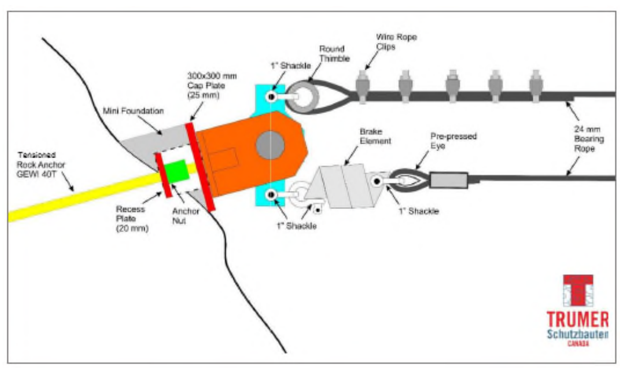

Figure 4. Rock anchor to bearing rope connection detail designed by Trumer Schutzbauten.

Following an event, controlled release of the debris retained is needed, but for safety the release must be undertaken remotely from the net.

A release mechanism, designed into the attachment of the net to the anchors, is protected by a cover plate from damage by the debris.

9.2 Rock Anchor Design

Based on anticipated static and dynamic forces, the Trumer Schutzbauten net required eight anchors on each side of the canyon, each tensioned to an average of 305 kN.

All eight anchors were pre-tensioned to different loads tailored to the anticipated forces that may be imparted during an event.

In order to prevent rock mass heave from the group anchor effect, the rock mass required modelling to understand the tensional and mass resistance to heave.

Innovative improvement of the rock mass using 24 six metre long un-tensioned rock dowels was undertaken.

A plan view of an anchor and dowel arrangement is shown in Figure 5.These were installed so as to be invisible and reduce the aesthetic impact.

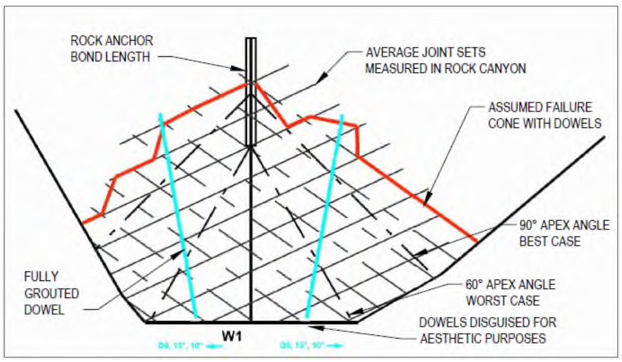

Figure 5. Use of passive rock dowels to improve the rock mass resistance to tensional forces.

The anchors were designed and tensioned in a recess, so that, should a large impact occur from a debris flow, only the exposed components would require replacing while the anchors could be re-used.

The cost of drilling and installing the anchors was proportionally one of the highest costs, and reducing the potential requirement for this after an event formed an important design component.

10 CONSTRUCTION CHALLENGES

Procurement of a Contractor by open tender required careful preparation of the contract specifications to ensure the design was correctly implemented and stringent environmental standards were upheld.

The environmentally sensitive location called for careful consideration of all construction processes.

Challenges during construction did arise including a clear water flood event with an estimated 5 year return period. The event highlighted the potential risks averted by minimising the quantity of in stream construction work, and once creek levels subsided, construction could continue with no damage to existing work.

Other challenges included, working in a pristine environmentally sensitive location with slopes near the net requiring rock scaling. All scaled rock was then removed from the canyon to sustain natural creek conditions.

During construction, on site monitoring of all high risk activities was undertaken by Tetra Tech EBA to ensure that the client's environmental commitments were upheld. It was during this construction supervision that a system for the innovative suppression of drilling related silica dust was developed ensuring that as little dust as possible entered the creek.

Following construction, remote cameras were set up to monitor the net in case of a debris flood. The DNV has a fully automated alarm system designed to monitor the flow along Mosquito Creek; the alarm triggers during high flows and if flow suddenly reduces.

11 CONCLUSIONS

In designing an effective mitigation system, it would have been easy to engineer more conventional rigid systems capable of filtering rafted LWD and boulders from debris floods.

These alternative systems have been used widely in the past with relative success, though typically require substantial construction efforts within the creek bed, and ultimately interrupt the movement of wildlife along the creek corridor.

It was because of this that Tetra Tech EBA enlisted the expertise of Trumer Schutzbauten in developing and constructing only the second flexible debris net to be constructed in British Columbia.

The base of the debris net was lifted to avoid any impact on local wildlife, and to reduce the frequency of maintenance by minimising the seasonal buildup of material.

Photo 3 shows the completed net located within the bedrock canyon.

When choosing the location of the debris net, environmental, economic, and aesthetic considerations played a pivotal role in the final decision.

Though access to the chosen site was more difficult, using a flexible debris net spanning less than 12 m, thus requiring no posts and lower construction costs, resulted in no construction materials, equipment, or personnel having to enter the creek water.

This dramatically reduced the potential for short or long term environmental impacts, especially important considering the known existence of fish and the rare long tailed frogs within the creek.

There were substantial economic savings in using this type of design and locating the net within the canyon. Tetra Tech EBA's rock engineering group are very experienced with roped access construction and therefore the cost of the design from concept to construction was kept to a minimum.

With innovative solutions to ensure all of the client's project objectives were achieved, and onsite monitoring to ensure that the environmental management plan was stringently adhered to, the Mosquito Creek debris net successfully provides effective mitigation against debris floods obstructing flow through the Evergreen Basin downstream, and hence impacting local residents.

Photo 3. Looking upstream from above at the completed debris net located within the bedrock canyon.

The system was constructed at relative low cost, with design solutions aimed at reducing future maintenance, while acting as the first line of defense in protecting the public in North Vancouver.

ACKNOWLEDGEMENTS

The writers would like to acknowledge the contribution of a number of individuals to the paper particularly, The District of North Vancouver in kindly giving permission to present this paper. Mr. Ahren Bichler of Trumer Schutzbauten for his assistance throughout the implementation of the work. Finally the Contractor engaged on the project, Global Mountain Solutions and the on-site project manager Mr. Sean Easton.

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