BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

GOVERNMENT OF YUKON

CLINTON CREEK

INDEPENDENT ENGINEER'S CHANNEL ASSESSMENT

FINAL

PROJECT NO.: 0533-019 DATE: October 31, 2016

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October 31, 2016
Project No.: 0533-019

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Government of Yukon
Energy, Mines and Resources
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Whitehorse, YT Y1A 2C6

Dear Dr. Rainey,

Re: Independent Engineer's Channel Assessment, Clinton Creek, Yukon – FINAL

Please find attached the above referenced report. Should you have any questions or comments, please do not hesitate to contact the undersigned. We appreciate the opportunity to work with you at Clinton Creek.

Yours sincerely,

BGC ENGINEERING INC.
per:

Rebecca Lee, P.Eng., P.Geo.(BC)
Water Resources Engineer

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LIMITATIONS

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1.0 INTRODUCTION

The Yukon Government (YG) Assessment and Abandoned Mines (AAM) branch manages the abandoned Clinton Creek Mine site in western Yukon. In 2015, construction activities were undertaken by third-parties to remediate down-cutting and erosion of the channel outlet of Hudgeon Lake, including placement of an articulated concrete block (ACB) mat. Based on information and photos supplied by YG AAM, a number of deformities ("ripples") have developed in the ACB mat placed in 2015. As a result, YG AAM has requested that BGC Engineering Inc. (BGC) conduct an independent engineer's assessment of the deformities that have formed in the mat since 2015.

This work was completed under an existing Standing Offer Agreement (#AAM-13-008-BGC) with YG and Engineering Agreement No. C00035030, dated August 11, 2016.

1.1. Objectives and Tasks

A proposal, dated July 27, 2016, was submitted to YG AAM for the proposed work. The objectives of this assessment are to understand the root cause(s) of the issues, the technical risks associated with the issues and to provide an opinion on what party (or parties) may be responsible for these issues. It should be noted that the work scope provided herein would not be appropriate by itself for litigation support as the level of work required for that type of service would be more comprehensive and detailed. Additional field work and detailed survey of the final mat installations, along with a detailed review of root causes, would be required as a next level of due diligence required to support potential litigation.

The work scope included three main tasks:

1. Review of existing background information, drawings, reports and photos that are relevant to 2015 design and construction activities on the channel (as provided by YG AAM).
2. Undertake a one-day site visit to observe the site conditions first hand and collect additional site information.
3. Preparation of this assessment report.

Within the original work scope, testing of the proposed fill was included as a possible optional task, but this specific task was not undertaken[1].

1.2. Information Review

BGC reviewed the following reports documenting the design and construction of the 2015 repair of the outlet channel:

[1] A sample was collected on site, however following review of potential mat failure modes, it was determined that fill settlement was a less likely failure mode. (Table 4-1).

- Advisian 2015. Clinton Creek Drop Structure No. 4 Repair Construction Report. Rev o. Prepared for Government of Yukon Energy, Mines and Resources – Assessment and Abandoned Mines. December 18, 2015.
- WorleyParsons Canada (WP) 2015a. Clinton Creek Drop Structure No. 4 Repair Design Summary. Rev 2. Prepared for Government of Yukon Energy, Mines and Resources – Assessment and Abandoned Mines. April 10, 2015.
- WP 2015b. Clinton Creek Drop Structure No. 4 Repair Design Summary. Rev 4. Prepared for Government of Yukon Energy, Mines and Resources – Assessment and Abandoned Mines. July 28, 2015.
- YG AAM 2015a. Clinton Creek Drop Structure No. 4 Specifications Package - Short-term Repair Works. Revision 1. June 10, 2015.
- YG AAM, 2015b. Repair of Clinton Creek Drop Structures. Contract Number C000229695. Yukon 2015-16. Final Report. Prepared by Wayne Emery – Project Inspector.
- YG AAM, 2016a. Clinton Creek drop structure site visit photo collection. 109 digital photographs.

The following specific information was contained within the above reports:

- Issued for Construction drawings by WP, dated July 3, 2015
- Daily construction reports from WP[2] and YG AAM
- Record Drawings by WP, dated December 18, 2015
- Various photos.

Additionally, photos taken during construction by WP and YG AAM but not included in the daily construction reports were reviewed. YG AAM maintains a remote camera that automatically takes a photo of the drop structures every couple of days and uploads them to a satellite. BGC was provided with a series of these photos from the spring 2016 freshet (YG AAM 2016b).

In preparation of the draft report, BGC was not provided with WP's design basis reporting or supporting calculations. YG-AAM requested this information from WP on September 19, 2016. On October 25th, BGC was provided an email from WP which contained the following design basis information:

- A statement that: "The design flow rate of 28.9 m^3/s for the DS4 repair was taken from the Environmental Liability report prepared by UMA (2003) and is the flow rate used for the design of the original gabion drop structures.
- A pdf copy of the design summary report (WP 2015b).
- A pdf file named, "Clinton Mine Hydraulic Run March 4, 2014", which contains a design report summary from Armorflex block stability design software.

[2] Construction QA/QC and construction reporting was conducted by Advisian which is a subsidiary of WorleyParsons. There was crossover by individuals between the two organizations. For clarity, activities undertaken by Advisian are credited to Worley Parsons in this report.

A copy of the email (WP 2016) and the block stability design software report (WP 2014) are included in Appendix B.

It should be noted that the design information provided by WP is limited and this in turn limits the review undertaken by BGC.

2.0 BACKGROUND INFORMATION REVIEW

2.1. Project History Overview

The Clinton Creek Mine site is a former asbestos mine located 80 km northwest of Dawson City, Yukon. During mine operations, ore was extracted from open pits on the south side of Clinton Creek. Serpentine (containing asbestos) was taken by tram across Clinton Creek to the north side, while the waste rock (largely shale) was stockpiled on the south side (YG AAM 2015b)

In 1974, failure of the Clinton Creek waste rock dump resulted in the formation of a landslide dam across Clinton Creek and the formation of Hudgeon Lake. Clinton Creek formed a new channel along the interface between the waste dump and the original valley wall over a distance of approximately 700 m at a gradient of 3 to 6% (Robinson 2005). Erosion of the new channel at the lake outlet, prompted concerns of a potential landslide dam outbreak flood and efforts were made starting in 1981 to stabilize the channel from erosion using riprap. Multiple failures and high flow events resulted in damage and subsequent re-building of the erosion protection over the years since 1981. Between 2002 and 2004, a series of 4 temporary gabion drop structures were constructed along the outlet channel (Figure 2-1). In 2010, a high flow event on the order of the 100 to 200-year return period resulted in headcutting of the creek and damage to the most downstream structure, which is known as Drop Structure 4 (DS4) (WP 2015b). This damage is apparent on Figure 2-1.

Figure 2-1. Site overview prior to 2015 DS4 Repairs. May 21, 2014. Looking upstream (west) with Hudgeon Lake in the background, and the Clinton Creek waste rock dump slide on the left (Advisian 2015).

In 2014, WP was retained by YG AAM to design a short-term measure to protect the Clinton Creek channel against erosion that may undermine the stability of the adjacent waste rock and/or cause a rapid release of water from Hudgeon Lake (WP 2015b). That project contained the following scope of work (WP 2015b):

- Developing concept designs for three potential repair options using existing survey data;
- Assembling quantity and AACE Class 4 (±40%) cost estimates for the three options;
- Presenting the results of this options assessment to YG AAM and Aboriginal Affairs and Northern Development Canada (AANDC);
- Developing construction drawings, engineering specifications, a material take-off (MTO), and an AACE Class 2 (±20%) cost estimate for the preferred option; and
- A report documenting the results of the development of the preferred option.

WP presented three options to YG AAM and AANDC on February 12, 2014:

- Option A: stabilize the waste rock slope and construct a chute downstream of DS4 using riprap (A1), gabions (A2), Armorflex® articulated concrete revetment mat (A3), or precast concrete lock blocks (A4);
- Option B: install stacked grout-filled bags downstream of DS4; and
- Option C: install a launching windrow revetment upstream of DS4.

From these options, YG AAM and AANDC selected Option A3 (WP 2015b), and WP proceeded as the design engineer.

As noted earlier, BGC was provided with only limited design basis information from WP. The only design documents provided were two of the five versions of the design summary report, including the third revision (WP 2015a) and the final revision (WP 2015b)[3], and a block stability design report summary dated March 4, 2014 (WP 2014). The design summary reports also included design drawings.

The design summaries included a text description of the drawing contents, and a statement that the design life was intended to be 5-10 years[4], and that the design discharge was the 25-year return period[5] peak flow of 29 m^3/s (WP 2015b). One of the significant changes to the design between the 2nd and 3rd revisions of the design summary report, was the addition of ground anchors to the mat for added stability. No stability calculations were included in the design summary reports.

The block stability design summary report (WP 2014) is a 2-page output from the Armorflex Design Software, which had been scanned from a hard copy. It identifies the project as the Clinton Mine, but it does not identify the designer (e.g., WP or Manufacturer/Supplier). It identifies the design flow rate, trapezoidal channel dimensions, use of open cell, tapered blocks – all of which are consistent with the values shown in the final design. It shows the software output which

[3] The WP documents begin with Revision 0. Therefore revision 2 is the third revision.
[4] Assumed based on the planned, future site-wide remediation.
[5] This value is consistent with the original drop structure designs (Robinson et. al. 2005).

includes flow velocities and factors of safety for different block types. Block type 60-T, the type specified in the final design, is underlined in blue pen. The design summary report does not include any information on anchors or cables. This document is discussed in further detail in Section 4.2.WP provided Issued for Tender Drawings and Issued for Construction Drawings, as well as a specifications package to YG AAM.

The construction tender included the following main tasks (YG AAM 2015a):

- Construct a temporary construction access road connecting the Site to the Clinton Creek Access Road;
- Temporarily divert flows in Clinton Creek from Hudgeon Lake to a point downstream of the Site;
- Regrade the waste rock to stabilize the slope on the south side (right bank) of Clinton Creek, downstream of the damaged gabion structure, at a slope of 2H to 1V;
- Fill the eroded channel with excess waste rock[6] from the slope stabilization;
- Armour the drop structure chute with Class 60T Armorflex® mats (a proprietary product manufactured by Armortec Canada Inc.), including gravel bedding, geotextile, microgrid, and ground anchors;
- Construct an in-stream transition from the upstream channel section (i.e., damaged gabion structure) and downstream channel (i.e., existing unarmoured channel) to the Armorflex® mats using site-sourced rock;
- Complete minor repairs to the other drop structures (extent to be confirmed in the field by the Engineer); and
- Reconstruct the Clinton Creek Access Road as necessary to suit the regraded slope.

On July 17, 2015, the tender was awarded to P. S. Sidhu Trucking Ltd. (Sidhu). Mobilization occurred on Aug 8, 2015 and on September 26, 2015, construction was completed (YG AAM 2015b).

During construction, YG AAM retained Advisian (a subsidiary of WorleyParsons Group, and herein referred to as WP) to provide QA/QC services[2]. WP documented the construction in daily construction reports and a final construction report. An Armortec representative (manufacturer's representative) was on site during construction of the plunge pool from September 12 to 15, 2015. YG AAM was also on site during construction. Wayne Emery of YG AAM acted as the Project Inspector and documented construction activities with daily reports and a final report.

In June 2016, YG AAM staff were conducting a regularly scheduled site inspection with WP and noticed deformities in the ACB mat (i.e., Armorflex® mats) in the centre of the chute, as shown on Figure 2-2. On July 19, 2016, YG AAM staff conducted a follow-up site visit.

On August 11, 2016, YG AAM retained BGC as the Independent Engineer to conduct the scope of work outlined in Section 1.1.

[6] During construction, waste rock fill was substituted for material referred to as "orange rock fill" due to compaction issues with the waste rock (Advisian 2015).

The design and repair of the Clinton Creek drop structures, which took place in 2014-2015, is herein referred to as "the project".

Figure 2-2. Channel chute with deformities as observed by YG AAM on July 19, 2016.

2.2. Articulating Concrete Block (ACB) Mats

The term "ACB mat" is a generic term for a manufactured product that is made by a number of manufacturers, under different trademarks with differences in specific features. The ACB mats used in this project are a proprietary product (ArmorFlex® by Armortec).

ASTM (2015) defines ACB mats as:

> *"An articulating concrete block system is comprised of a matrix of individual concrete blocks placed together to form an erosion-resistant overlay with specific hydraulic performance characteristics. The system includes a geotextile underlay compatible with the subsoil that allows hydraulic infiltration and exfiltration to occur while providing particle retention. The blocks within the matrix shall be dense and durable and the matrix shall be flexible and porous."*

Depending on the specific design of the mats, the blocks may be interconnected in a number of ways such as their shape (like puzzle pieces), or by metal cables.

Articulation of the mat comes from the ability of the individual blocks to conform to small changes in the subgrade while still remaining interconnected. While the mats themselves are the most identifiable part of the erosion protection, the mats work together with the following elements:

- a properly prepared and stabilized subgrade,
- a geotextile, and
- a drainage layer with geogrid (if required).

The blocks weigh down the subgrade and geotextile, and resist the hydraulic forces of the flowing water as shown in Figure 2-3. Blocks or mats of blocks that do not abut, have a lower inter-block resistance and therefore, a lower stabilizing force. A block that projects into the flow will receive a greater impact force and therefore, a larger destabilizing force. Therefore, the way in which blocks and mats are installed at a site can impact the long term stability of the structure. Complex flow hydraulics (i.e., not smooth, uniform flow) can introduce larger destabilizing forces at angles not parallel to the block surface.

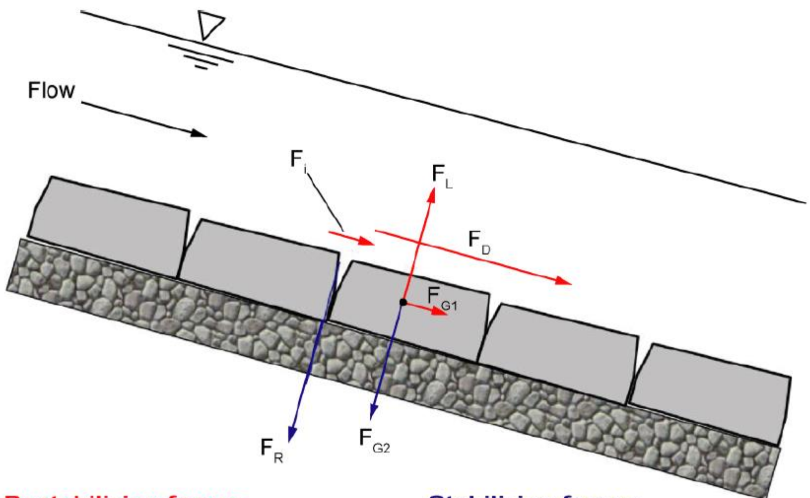

Figure 2-3. Typical force-balance on a single unit in a typical cable-tied ACB mat (FEMA 2014).

A drainage layer may also be incorporated into the design to help relieve uplift pressures from below the blocks, protect the subsoil from erosion from groundwater seepage or other drainage flow, and/or provide a smooth bedding surface (FEMA 2014).

2.2.1. Standard Design Considerations for ACB Mats

Armortec provides a design manual for its ArmorFlex® ACBs. The abridged version (2002) provides a methodology for assessing the hydraulic stability of the blocks within the mats which calculates the factor of safety against overturning individual blocks at the toe of a channel side slope (considered the most vulnerable location in the cross-section). The method is not proprietary, but includes factors determined from laboratory testing of specific blocks, and is similar to riprap sizing methodologies.

This method does not account for complex hydraulics (such as converging flow or at a hydraulic jump), nor does it give credit to cables or soil anchors. Therefore, special analysis is needed for sites with complex hydraulics. It is generally accepted that an inherent conservatism exists in cable-tied systems (FEMA 2014). In the past, soil anchors were routinely installed with cable-tied systems, however they are currently used only to provide an extra measure of conservatism (FEMA 2014).

In general, it is recommended that only products which have been tested[7] under similar conditions as the design application, be considered for use (FEMA 2014). Therefore, FEMA recommends that the drainage system and anchor details being specified in a given project be closely matched to those tested.

As the sub-grade is an integral part of the revetment, for high consequence sites such as embankment dam spillways, a geotechnical assessment of the sub-grade stability is recommended (FEMA 2014). If soil anchors are used, cable anchors allow the mat to flex and perhaps conform to a slightly deformed subgrade. However, anchors puncture geotextiles and geogrids, in which case grouting of the holes is recommended to prevent piping.

2.2.2. Standard Practice for Installation of Articulating Concrete Block (ACB) Revetment Systems

ASTM provides a standard practice (2015) for the installation of ACB systems. The standard highlights the importance of proper installation of the mats to the performance and stability of the mats.

The phrase "intimate contact" is routinely used to describe the sandwiching of the ACB mat, geotextile filter and subgrade. Preparation of the subgrade – including stability, compaction, grades, slope transitions, surface texture, moisture content, etc. – must be done so that the ACB mat (and geotextile) will be in intimate contact with each other. This also results in a smooth finished surface, where the standard requires that the following:

- Individual blocks within the plane of the finished system shall not exceed a 0.5 in. (13 mm) protrusion or greater protrusion than the tolerance referenced in the contract documents
- Individual mats should abut one another. If spacing is greater than 50 mm, it should be grouted.
- Grade changes should be smooth. A grout seam at the grade change location can be placed to smooth the transition.

Each layer of the system (subgrade, geotextile, mat) as well as the finished installation should be inspected[8].

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[7] ASTM D7276 (2008) is a standard for analysis and interpretation of ACB revetment system hydraulic test data collected under steep-slope, high-velocity conditions in a rectangular open channel, and this standard is intended to be used in conjunction with the ASTM D7277 (2008) standard for performance testing of ACB revetment systems.

[8] The standard does not specify who is qualified to inspect.

2.2.3. Failure of ACB Mat

During performance testing of ACB mats, failure is considered to have occurred when individual blocks have lost "sustained, intimate contact with the subgrade" (FEMA 2014). FEMA summarizes two types of failures, each with a series of possible mechanisms (2014):

Failure due to removal of individual blocks or entire mat occurs when:

- *"The shear forces produced by the flowing water exceed the frictional force between the blocks and the bedding layer, and/or the confinement of the blocks,*
- *The uplift forces produced by the water beneath the system exceed the weight of the block and/or the confinement of the blocks,*
- *Erosion occurs at an open joint in the system, (e.g., toe, crest, side, or adjacent to an individual block),*
- *An improperly placed or lifted block exposes the upstream edge of the block to high velocity flow that is redirected beneath the system."*

Failure as a result of foundation deformation occurs when:

- *"Water during operation of the system saturates the subsoil leading to a reduction of shear strength and a deep slip failure of the embankment,*
- *Shallow slip along a plane parallel to the face of the embankment caused by down-slope forces on the blocks and an adjacent layer of soil exceeding the local shear resistance along the underside of the soil layer,*
- *Settlement of the block system caused by removal of the drainage layer beneath the blocks through the geogrid."*

Failure of the mat can result in the progressive failure of the mat downstream from the initial failure. Failure of the mat can lead to foundational failure and the formation of a headcut which can regress upstream. The rate of failure is dependent on factors such as flow rates and the type of failure.

3.0 2016 SITE OBSERVATIONS

A site visit was conducted by Rebecca Lee, P.Eng., P.Geo., of BGC and Dustin Rainey, Ph.D., P.Geo., of YG on August 23rd, 2016. At the time of the site visit, Clinton Creek was experiencing high flows (estimated to be 2-3 m/s) due to heavy rains immediately prior to the site visit. Therefore, BGC was unable to wade into the flow and directly observe and inspect the mat deformities. Access was limited to observations made from the right bank.

Figure 3-1 provides an annotated photo of the mats, their row number and the locations of the major deformities. At the site of the 2015 repair of DS4, BGC observed[9] the following:

- The chute and plunge pool were located instream and are therefore subject to regular use (as opposed to an emergency spillway, for example, that would experience flows infrequently, if at all).
- The deformities were a series of deformations of the mat located on the channel invert of the chute.
- There were five deformation ripples which were linear, oriented perpendicular to flow, and located close to lateral mat connections (i.e. mat connections perpendicular to flow). Therefore, these deformations appeared to be associated with the lateral mat connections.
- As shown in Figure 3-1, the chute is comprised of 10 rows of mats and five deformation ripples were observed:
  a. Between mats in row 11 and 12, the downstream mat (row 11) was observed to be protruding above the upstream mat (row 12) in the centre of the channel. Also, adjacent to the left bank and immediately downstream of the lateral mat connection, highly turbulent flow was observed.
  b. Between mats in row 12 and 13, the downstream mat (row 12) was observed to be protruding above the upstream mat (row 13).
  c. Between mats in row 13 and 14, turbulent water obscured the mat, but indicated a deformity.
  d. Between mats in row 14 and 15, the mats appeared to have developed a wave-like profile with a depression, followed by a bulge in the downstream direction
  e. Between mats in row 15 and 16, the mats appeared to have developed a wave-like profile with a depression, followed by a bulge in the downstream direction

  Also shown in Figure 3-1, there appeared to be several other smaller deformities that affected a smaller mat area. These smaller deformities were located on mats 9 and 10.
- No deformities were identified at the upstream or downstream end of the chute.
- No large-scale movements of the mats located on the banks were identified, nor soil loss beneath the mats on the right bank[10].
- Some woody debris was caught in the gabion mesh of each of the drop structures, but none was observed in the chute or stilling pool.

9 Observations were made from the right bank only.
10 The term "right bank" and "left bank" are in reference to the observer facing downstream.

- As shown in Figure 3-1, Figure 3-3 and Figure 3-4, there were large gaps between rows 11 and 12, and rows 12 and 13, where the mats did not abut one another at commissioning and the gaps were never grouted. Between rows 11 and 12 on the right bank, the geogrid was observed to be bunched, some of the blocks were cracking, and a 10 cm gap was measured at the surface of the blocks. Between rows 12 and 13 on the right bank, the geogrid was observed to be bunched, the site was associated with a geogrid overlap location, and a 6 to 7 cm gap was measured at the surface of the blocks.
- At the locations where blocks had been excluded from the mat, the voids had been filled with grout; however, the grout was not finished flush with the adjacent blocks. Instead the grout surface was smooth, but angled such that it was approximately 6 cm lower than adjacent blocks in the upslope, upstream corner (Figure 3-2).
- As shown in Figure 3-2, the grout texture suggests that it was likely thick during placement, and therefore, it is unlikely that the grout penetrated both the geogrid and drain rock to seal the holes in the geotextile generated by anchor placement, as per standard practice (ASTM 2015).
- Grouting locations appeared to be only along the two rebar mat connections[11], at the block voids, and at one location at the toe on the left bank between mat rows 13 and 14 where a two-block long grout wedge had been installed.
- The bedding located directly beneath the blocks on the right bank appeared to be granular and low in fines content.

[11] As shown in Figure 4-3, the revetment consisted of three mats placed across the channel to form a mat row. Nine mat rows formed the plunge pool and the remaining 9 rows formed the chute. Rebar was used to connect the mats along the longitudinal seams (i.e. parallel to flow). The lateral seams (i.e. perpendicular to flow) were connected by the ground anchor attachments.

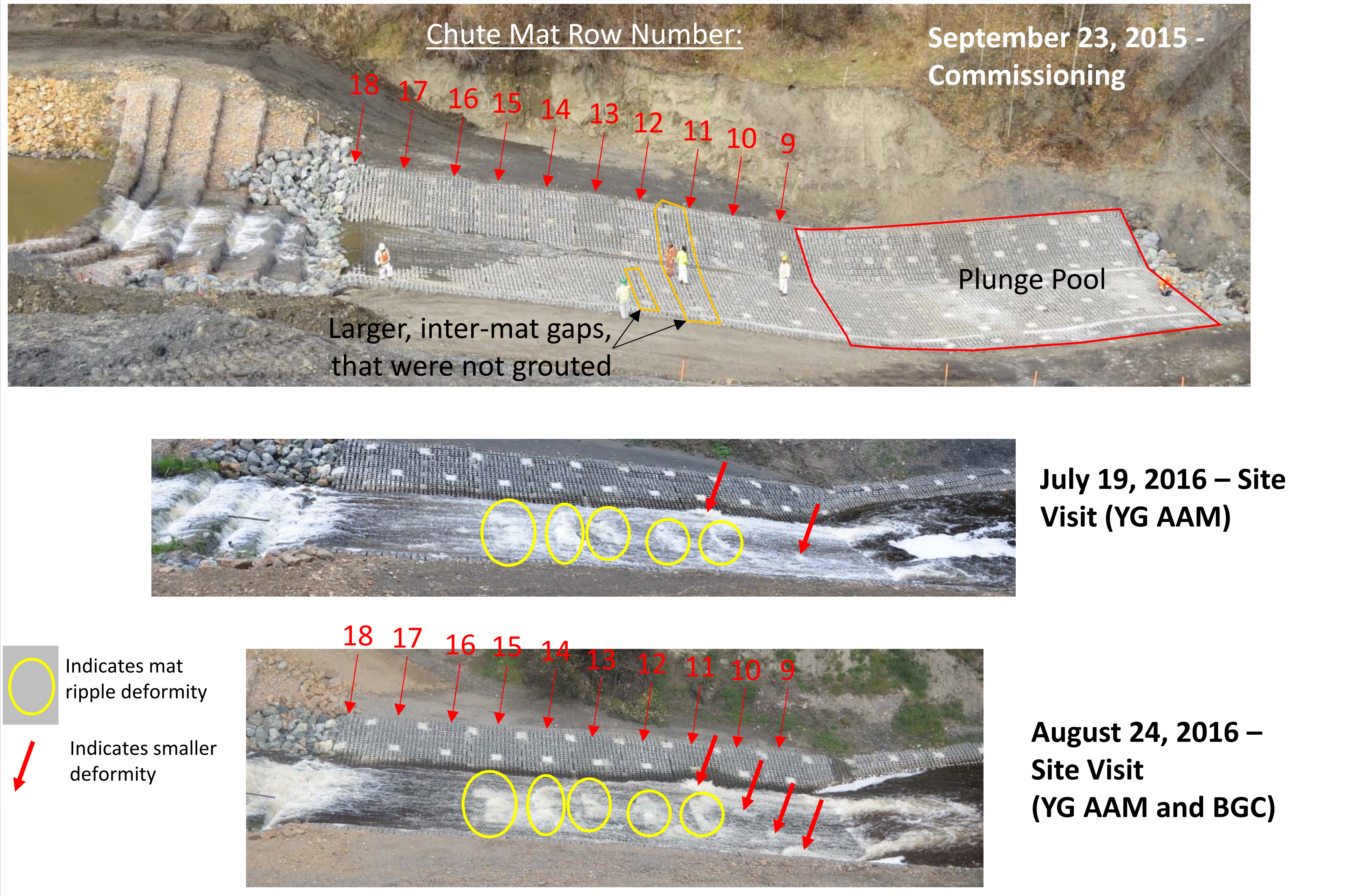
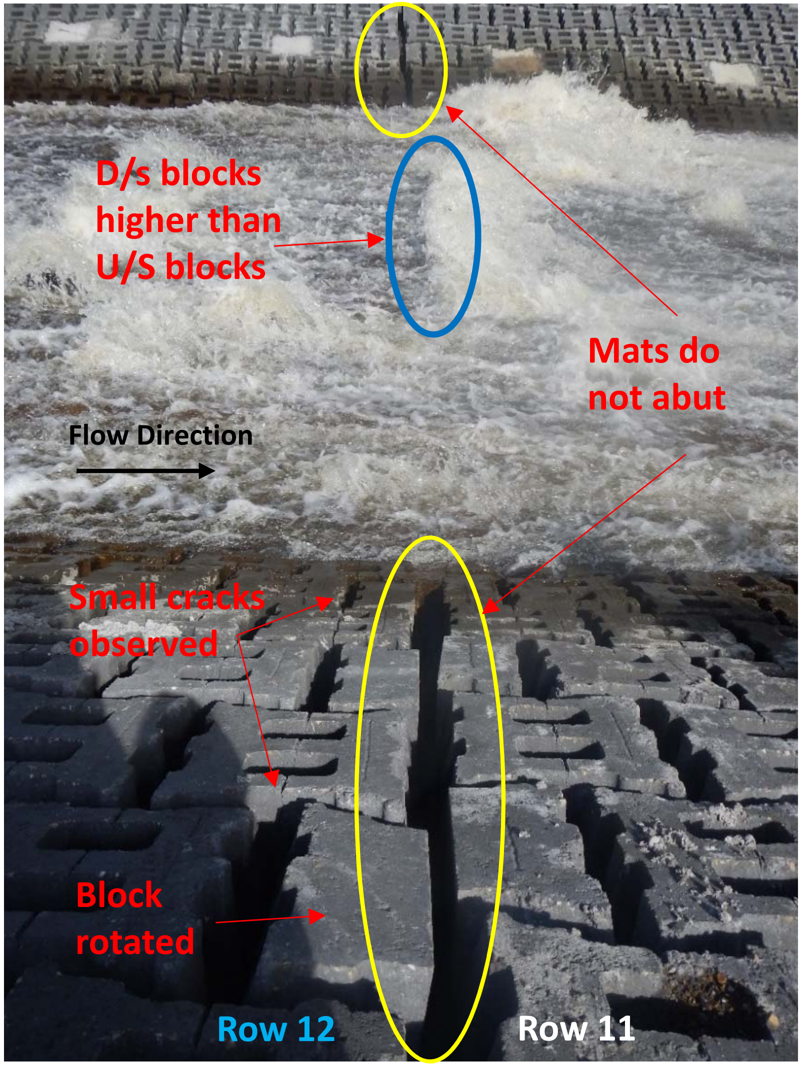


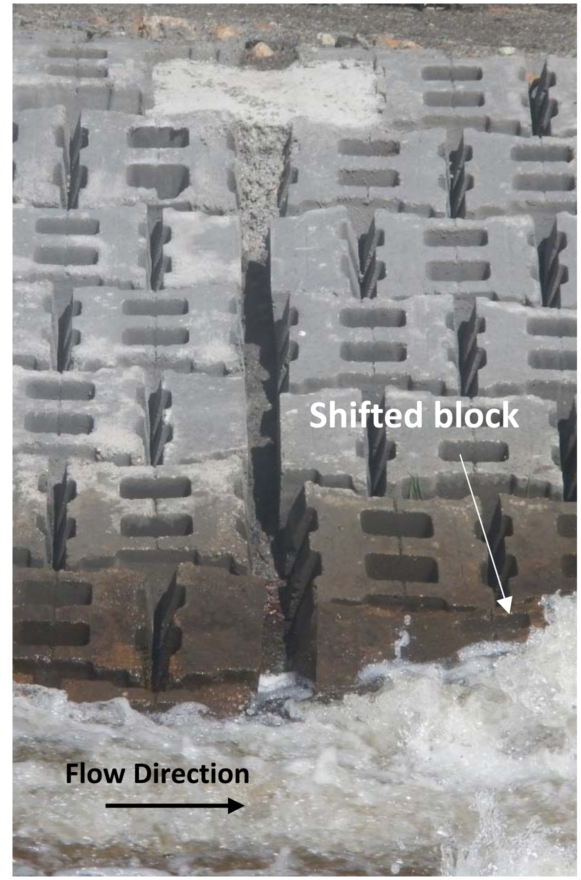
Figure 3-1. Photos of spillway during commissioning, and two site visits. Flow direction is left to right.

Figure 3-2. Example of grouting of void blocks not flush with adjacent blocks. Flow direction is from right to left.



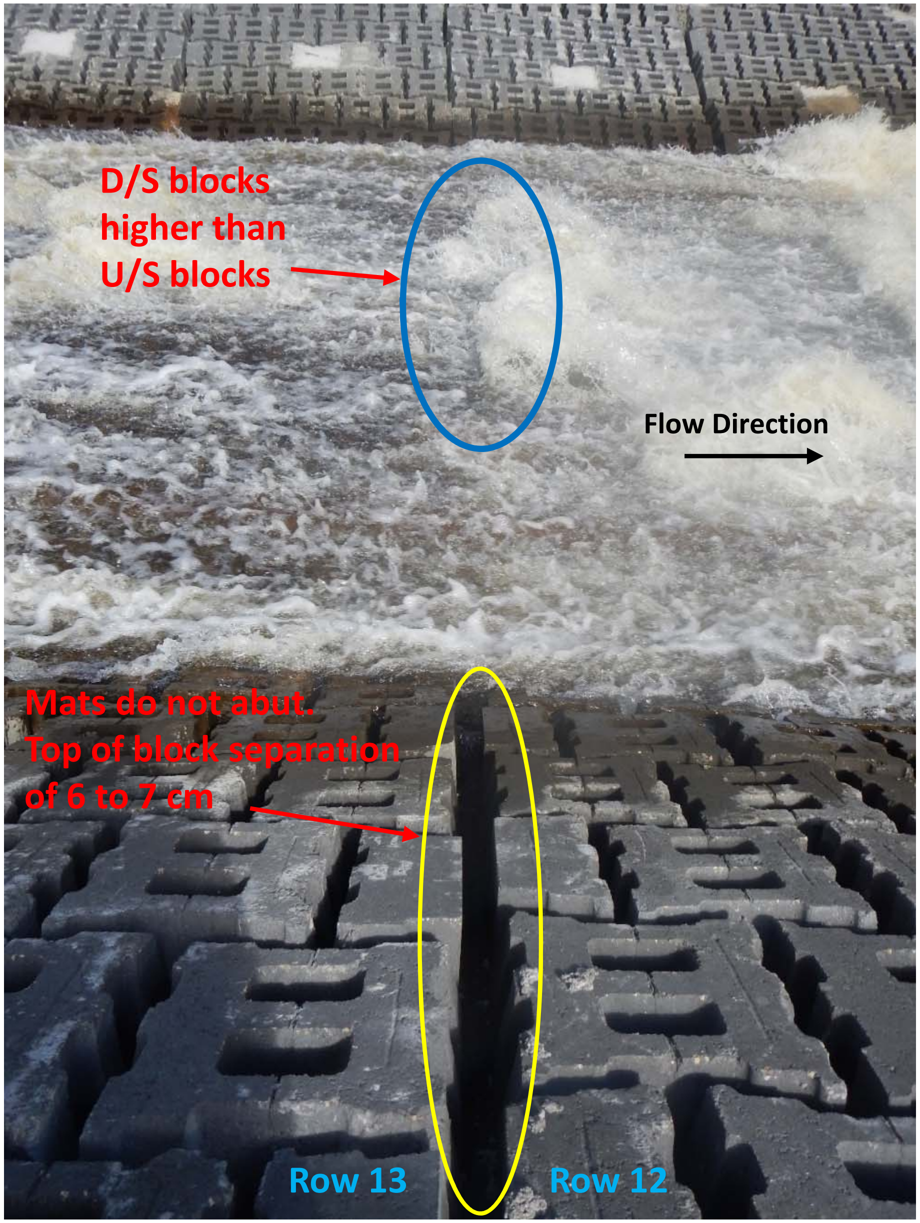
Mats do not abut one another. Approximately a 10 cm gap on mat surface. Half block has partially rotated. Geogrid is bunched the length of the right bank

Enlarged View of Right Bank at Water's Edge



Enlarged View of Left Bank

Figure 3-3. Observations of ACB Mats at Row 11/Row 12 Connection (August 23, 2016)



Enlarged View of Left Bank

Figure 3-4. Observations of ACB Mats at Row 12/Row 13 Connection (August 23, 2016)

4.0 ROOT CAUSE ASSESSMENT

As BGC was unable to closely inspect the mat deformities, the root cause of their development can only be inferred, based on the noted observations and the background information provided to BGC. Limited calculations of anticipated hydraulic forces by the design discharge and block resistance forces were provided; however, no mat/cable/anchor resistance forces or design assumptions were provided by WP to YG AAM and BGC.

YG AAM maintains a remote camera that automatically takes a photo of the drop structures every two to three days and uploads them to a satellite. BGC was provided with a series of these photos from the spring 2016 freshet (YG AAM 2016b). As shown in Figure 4-1, on April 22, 2016, prior to the freshet, the mat does not appear to have any deformities. Three days later, discharge increased and a mat deformity is visible in the chute. The flows appeared to peak around May 4th, during which the tailwater in the plunge pool appears to reach the top of the bank. On May 18th, the flows had decreased and five ripple deformities are visible in the chute. YG AAM monitors flow in the channels and estimates that the freshet peak discharge was approximately 6 m^3/s (2016c). This is significantly less than the design flow of 29 m^3/s (WP 2015b).

The fact that the deformities appeared after the passage of the freshet, suggests that their development was triggered by the increase in discharge.

4.1. Potential Failure Modes

Table 4-1 provides a list of potential failure modes and an assessment of the likelihood the mode contributed to the mat deforming using a relative rating of Unlikely, Less Likely, Possible, and Likely. It is also possible that several failure modes worked together to generate the mat deformities.

April 22, 2016 – Prior to freshet

April 25, 2016 – Early stages of freshet

April 27, 2016

May 4, 2016 – image closest to peak flow*

May 18, 2016 – Tail of Freshet

Visible Mat Deformity

*** Freshet Peak Discharge Estimated by YG-AAM to be approximately 6 m^3/s**

Figure 4-1. Remote Camera Images of the 2016 Freshet (YG AAM 2016b)

Table 4-1. Potential failure mode and site observations.

Potential Failure Mode	Observations	Likelihood Mode Contributed to Mat Deformity
Failure of upstream anchor trench	• No mat deformation at upstream end	• Unlikely
Failure at downstream end of chute due to hydraulic jump forces	• No mat deformation observed at downstream end	• Unlikely
Failure of anchors on the bank	• No mat movement or deformation observed on banks	• Unlikely
Subgrade too steep and mat slid downhill	• No mat movement or deformation observed on the banks, which are steeper than the channel, but have not experienced flow like the channel • No deformations prior to the freshet. • Deformations were located in the middle of the slope, with largest failure closer to the top. If subgrade too steep and there was no anchoring, would expect failure along entire slope.	• Less Likely
Lack of sufficient anchoring allowed part of the ACB mat to move.	• As designed, each mat is anchored at 9 locations. However, the holes for the anchors were located in incorrect locations in both the rejected delivery of 170 mm thick mats (rejected for their incorrect thickness), and the accepted 190 mm mats (YG AAM 2015b). As shown in Figure 4-3, and discussed in detail in Section 4.2.2, this change in anchoring pattern moved the mat to mat connection anchors at the upstream and downstream ends of each mat towards the banks. Although the number of anchors did not change, this resulted in a less uniform distribution of anchors, and reduced anchoring and mat to mat connections in the middle of the channel – where deformities are located.	• Likely
	• Six of the anchors were not placed due to bedrock encounter (YG AAM 2015). However, the missing anchor locations are along the northeast edge of the channel, adjacent to plunge pool, and do not appear to be related to the observed deformities (Advisian 2015).	• Unlikely
Change in anchor attachment method.	• Anchors not crimped to mat cables as designed. Instead, looped back on itself (Figure 4-2) rather than a fixed ring. Inadequate anchor tension could allow loop to open more than the diameter of the fixed ring. • If anchor failed, loop could more easily open than crimped ring. If failure point was at a mat to mat transition, this could allow the mats to separate, further weakening the integrity of the mat structure • Although it appears that one anchor has failed (Figure 4-7), mat deformity locations don't appear to correlate with anchor locations.	• Less Likely
Anchors pulled out of the ground	• The substitution of "orange fill" material for waste rock as a sub-base meant that the rocks made installation of anchors difficult (YG AAM 2015b). YG AAM notes that the orange material was sorted to have the large rocks removed (2015b), but WP notes that due to large rocks in the orange fill, anchor holes were pre-drilled (2015). Lab tests for the orange fill show 30% of the material was larger than 50 mm (Advisian 2015). Both construction reports discuss the difficulty with installing the anchors due to the presence of rocks. • YG AAM notes that on September 16, it was decided by WP, Sidhu and YG AAM and approved by YG AAM, to change the anchor attachment method and that this would also help reduce the slack in the anchor cable. • It appears that one anchor has failed (Figure 4-7). The failure is at a location where there is a bulge in the mat that appears to be the result of soil deposition beneath the mat. • Mat deformity locations such as at the connection between rows 11 and 12 and also between 12 and 13 don't appear to correlate with anchor locations.	• Possible
Fill settlement due to low compaction or due to saturation upon wetting	• No observed settlement of blocks on banks, which are steeper than the chute • Testing showed the orange fill to have a fines content of 4%, while the waste rock had a fines content of 20% (Advisian 2015). The upstream gabion weirs were constructed over granular drain rock placed over waste rock (Robinson 2005). The gabion weirs appeared stable. • Fill was placed and compacted to 98% of the control strip maximum dry density (Advisian 2015). At such a high degree of compaction, further settlement is unlikely. • The drain rock was placed and compacted to 87% of MDMDD, rather than the specified 95%. As this layer was only 150 mm thick, minor settlement should not be a significant issue. • Mat deformities are not widespread across the entire chute and appear to be associated with the mat connections only. This suggests that any problems with the fill contributing to the deformations are localized.	• Less Likely
Settlement of the block system due to failure of the geogrid	• Geogrid and drainage layer appeared intact on the banks. • Mat deformity locations appear to be associated with mat connections.	• Unlikely
Movement of the waste dump	• Mat deformities are perpendicular to the toe of the waste dump. Movement of the waste dump would have linear features parallel to toe.	• Unlikely
Flows in excess of the design flow (Q_{25})	• The 2016 freshet was estimated by YG AAM to be approximately 6 m^3/s (2016c), significantly less than the design flow of 29 m^3/s WP (2015b).	• Unlikely
Groundwater discharge	• During construction of the upstream gabion structures, groundwater seepage was noted to be a challenge (Robinson et al. 2005); however, groundwater was not noted to be a concern during 2015 repairs to DS4. • A drainage layer was placed beneath the mats which should reduce any seepage forces. YG AAM noted a disagreement between WP and Armortec regarding the suitability of the 100mm minus drain rock on September 12 (2015b). Lee Martin (WP) confirmed that the material was free draining and accepted the material as meeting WP's specification (YG AAM 2015b). Laboratory results show a fines content of 6% (Advisian 2015).	• Unlikely

Mats placed too far apart, exposing subgrade to flow	• At the two locations where the mats were placed further apart, mat deformities have developed (Figure 3-1, Figure 3-3, Figure 3-4). As discussed further in Section 4.2.3, at these two locations, the mats were not placed in intimate contact.	• Likely
Problems with block taper	• As discussed in detail in Section 4.2.4, the Armorflex 60T blocks are designed to have a tapered shape in the direction of flow, so that the upstream side of the block is 0.5 inches less than the downstream side (Advisian 2015 – Appendix 11). This supposedly improves the factor of safety in high velocity flows, such as at Clinton Creek (Contech 2012). • In order for the hydraulic properties of the tapered block to be realized, they must be installed in the correct orientation and placed on a smooth surface so that the blocks taper as intended. • The design summary document (WP 2015b) and tender documents and drawings do not discuss the taper and do not explain how to identify the taper direction, which direction to place the taper nor the construction tolerances for placement of the taper. • The construction documents (Advisian 2015 and YG AAM 2015b) do not identify that the mats supplied were in fact tapered, nor that they were placed with the taper layout as intended.	• Possible
Problems with individual blocks	• Problem with concrete quality noted in construction records (Advisian 2015). Blocks on right bank were intact, while some cracking of blocks observed at the water's edge on the right bank of mat row 12 (Figure 3-3). • The half-blocks are attached to the mat with a single cable, and therefore, if not held in place by grout or adjacent blocks, they are free to rotate (Figure 3-3). Their shorter width in the direction of flow, and smaller weight would also make them easier to rotate than full blocks if they are not held in place by adjacent blocks. Figure 3-3 and Figure 3-4 show partially rotated blocks on the banks where the mats do not abut. A partially rotated block could redirect flows under the mat, causing scour of the subgrade or lifting of the mats.	• Possible
Problems with grout "blocks"	• Mat designed with gaps (missing blocks), that were infilled with grout on site. • Site observations that the grout blocks on left bank, right bank, and in the channel against the right bank, were not finished flush with adjacent blocks – contrary to design intent for a smooth finished surface as outlined in the design report (WP 2015b), and as stipulated in the construction specifications (YG AAM 2015a). This would change the local hydraulics, and depending on the sensitivity of the design, could result in increased uplift forces on the mat. • Grout not necessarily constructed to the same strength, weight and quality requirements as the individual blocks. Weight of the blocks is important for resisting flow forces. If grout block broke or floated, it could allow flow to get underneath the mat.	• Possible
Subgrade preparation not smooth enough for block placement	• As discussed in detail in Section 4.2.4, the prepared subgrade was to be inspected by the Engineer, the Owner, and the manufacturer's representative prior to block placement. However, the manufacturer's representative was not on site during construction of the chute. • As discussed in detail in Section 4.2.4, poor preparation of the subgrade could interfere with correct placement of tapered blocks.	• Possible
Migration of subgrade through holes in geotextile and geogrid at anchor points	• As shown in Figure 3-2, the grout texture suggests that it was likely thick during placement, and therefore it is unlikely that the grout penetrated both the geogrid and drain rock to seal the holes in the geotextile generated by anchor placement, as per standard practice (ASTM 2015).	• Less Likely
Damage to the mat from large woody debris	• Woody debris was observed entangled in the gabion structures, but no debris was observed in the DS4 chute or plunge pool. • The photo taken by YG AAM on a previous site visit (Figure 4-8) shows a small wood stick adjacent to a mat deformity, suggesting that woody debris has been transported down the chute and perhaps the debris was large enough to snag the mat. • Remote camera images do not show the passage of woody debris during the freshet, however the frequency of images is approximately 1 every 3 days (YG AAM 2016b).	• Less Likely
Damage to the blocks or subsoil from cold temperatures	• Blocks on the banks were intact. Unable to observe instream blocks • The drain rock was tested and showed a fines content of 6% (YG AAM 2015a). The orange fill was tested and showed a fines content of 4% (Advisian 2015). Frost heave would not be anticipated with a low fines content.	• Less Likely

Notes:
Limited calculations of anticipated hydraulic forces by the design discharge and block resistance forces were provided; however, no mat/cable/anchor resistance forces or design assumptions were provided by WP to YG AAM and BGC.

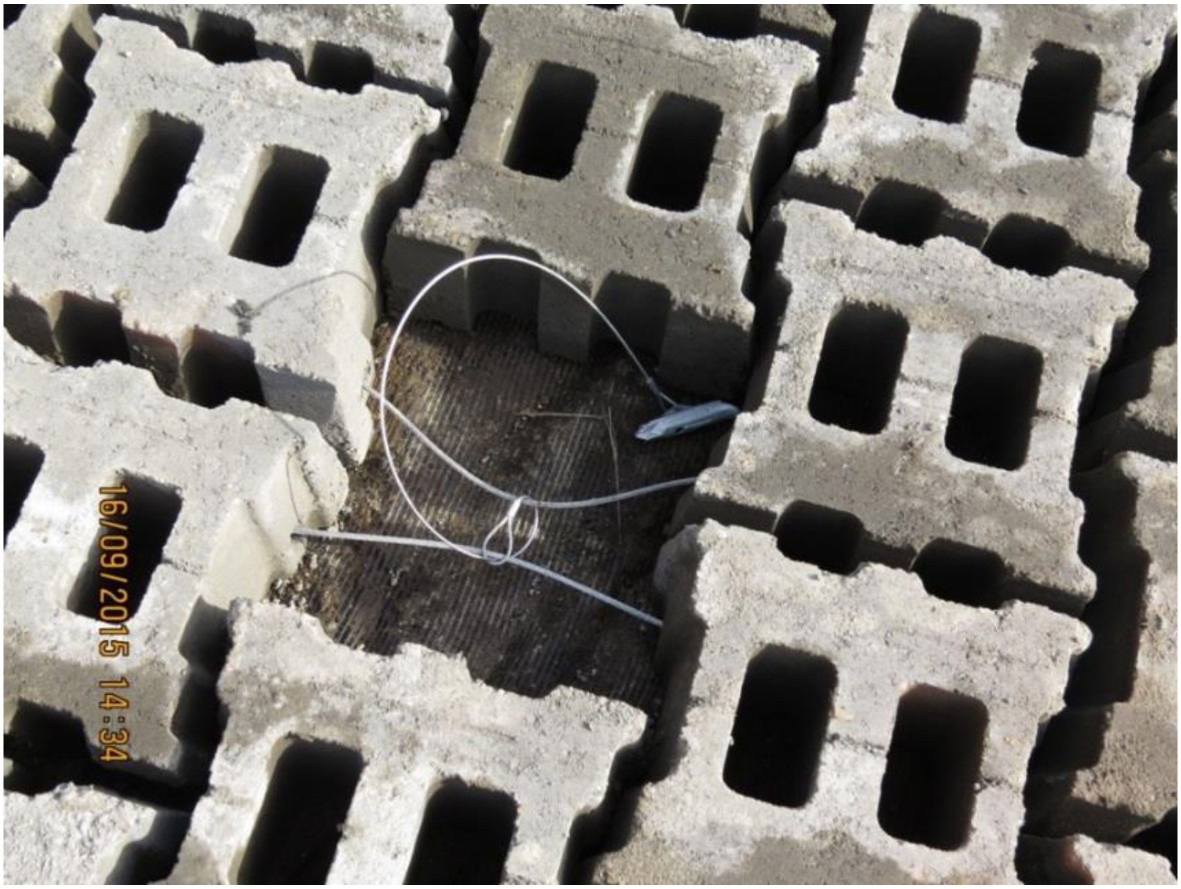
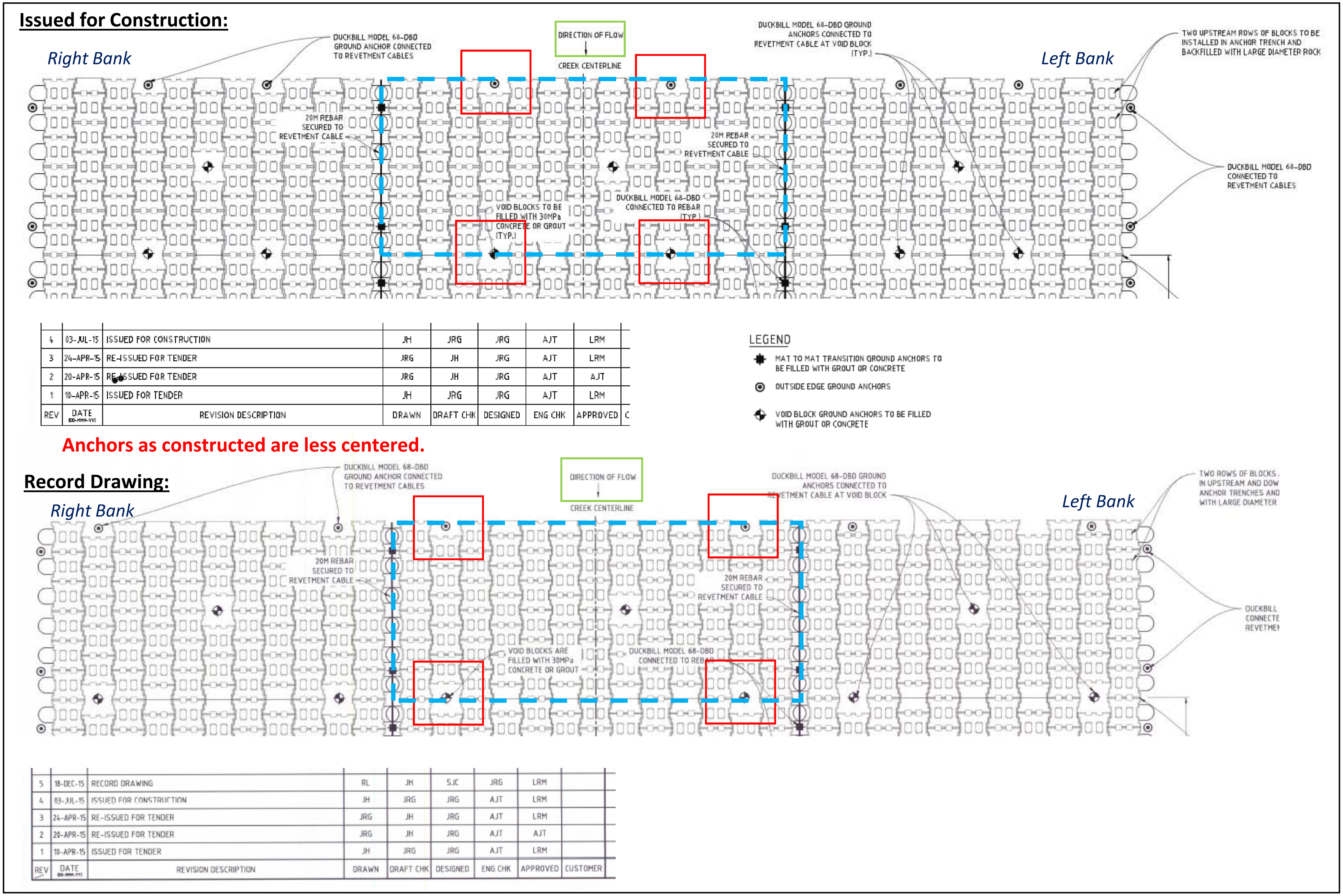


Figure 4-2. Example of modified mat-to-anchor attachment method (photo from YG AAM 2015b).



REV	DATE	REVISION DESCRIPTION	DRAWN	DRAFT CHK	DESIGNED	ENG CHK	APPROVED
4	03-JUL-15	ISSUED FOR CONSTRUCTION	JH	JRG	JRG	AJT	LRM
3	24-APR-15	RE-ISSUED FOR TENDER	JRG	JH	JRG	AJT	LRM
2	20-APR-15	RE-ISSUED FOR TENDER	JRG	JH	JRG	AJT	AJT
1	10-APR-15	ISSUED FOR TENDER	JH	JRG	JRG	AJT	LRM

REV	DATE	REVISION DESCRIPTION	DRAWN	DRAFT CHK	DESIGNED	ENG CHK	APPROVED	CUSTOMER
5	18-DEC-15	RECORD DRAWING	RL	JH	SJC	JRG	LRM	
4	03-JUL-15	ISSUED FOR CONSTRUCTION	JH	JRG	JRG	AJT	LRM	
3	24-APR-15	RE-ISSUED FOR TENDER	JRG	JH	JRG	AJT	LRM	
2	20-APR-15	RE-ISSUED FOR TENDER	JRG	JH	JRG	AJT	AJT	
1	10-APR-15	ISSUED FOR TENDER	JH	JRG	JRG	AJT	LRM	

Figure 4-3. Changes in anchor pattern between Issued for Construction (YG AAM 2015a) and Record drawings (Advisian 2015).

A summary of possible and likely failure modes listed in Table 4-1 is as follows:

Possible:

- Problems with block taper
- Problem with individual blocks
- Problem with grout "blocks"
- Subgrade preparation not smooth enough for block placement
- Failure of mat anchors

Likely:

- Lack of sufficient anchoring allowed part of the ACB mat to move
- Mats placed too far apart, altering the local flow hydraulics and exposing the drain rock layer and subgrade to water flow, resulting in erosion and destabilization of the mats.

Section 4.2 discusses the design stability of the blocks and mat which highlights the importance of both the cables and anchors to the overall stability of the structure, as well as the smooth subgrade and finished surface that results when mats and blocks are placed correctly.

Section 4.3 discusses the mat deformities in relation to the potential failure modes.

4.2. Hydraulic Stability

This section begins with a hydraulic stability assessment of the ACB mats. Section 4.2.2 then discusses the change in anchor layout and connection type (i.e., Likely failure mode) in more detail. Section 4.2.3 discusses mat separation distances (i.e. Likely failure mode), while Section 4.2.4 discusses block placement (block tapers, subgrade smoothness and finished grades) (i.e., Possible failure modes).

4.2.1. Hydraulic Stability Assessment

In preparation of the draft report, BGC was not provided with any detailed design work by WP as part of this project, as YG AAM did not have a design report. As such, BGC was not able to review their assessment of hydraulic forces and mat / block / cable / anchor resistance. To that end, BGC undertook its own hydraulic stability assessment on the ACB's.

On October 25th, as discussed in Section 1.2, WP did provide a block stability design software summary report (WP 2014, Appendix B), which provides limited design information for the blocks alone.

Following the Armortec methodology for sizing ArmorFlex® blocks (2002), a hydraulic stability assessment for the mat was carried out by BGC. Input variables are shown in Table 4-2 for the Class 60T blocks, the chute design parameters, and design flow.

Table 4-2. Hydraulic stability calculation for Class 60T ArmorFlex® blocks.

Parameter	**Value**	**Note**
Channel Slope	20%	(1)
Channel Side Slope	2H:1V	(1)
Channel Bottom Width	7 m	(1)
Manning's n	0.028	(2)
Design Discharge (Q_{25})	29 m^3/s	(3)
Flow Depth	0.45 m	(4)
Flow Velocity	8.5 m/s (28 ft/s)	(4)
Block Submerged Weight	56.0 lbs	
Momentum Arms (l_1, l_2, l_3, l_4)	0.313, 0.971, 0.971, 0.5 ft.	(5)
Critical shear stress of lining	42.10 lb/ft^2	(5)
Height of projecting surface normal to flow	0.5 inches (1.25 cm)	(6)
Factor of Safety	**0.6**	

Notes:
(1) Source: Record Drawings by WP.
(2) Typical value range identified in FEMA (2014) for unvegetated systems of 0.026 – 0.033.
(3) Rounded value (WP 2015b).
(4) Calculated from Manning's equation for uniform flow. Supercritical flow conditions.
(5) Values provided by Armortec (2002) were measured or extrapolated from testing programs, which for the T-series blocks included a drainage layer between the geotextile and revetment. The values assume block orientation of the block with the long axis parallel to flow.
(6) Standard value for assessment. The value is also the construction tolerance as outlined in the construction specifications (YG AAM 2015a)

The results of the analysis show a factor of safety against block overturning of 0.6, which implies that individual blocks under design flow conditions, and elevated 0.5 inches into the flow[12], would be unstable and subject to movement and rotation.

The hydraulic stability calculations in Table 4-2 assume the blocks are oriented with the long axis parallel to flow. However, at the project site, the design specified that the blocks were to be installed with the mat cables perpendicular to flow. This resulted in the blocks being installed with the short axis parallel to flow. If a block that is oriented with the long axis perpendicular to flow, projects into the flow, it is subjected to a greater force than if it were oriented with the short axis perpendicular to flow. The momentum arm values would also depend on the block orientation. Therefore, the calculated factor of safety could be less than the 0.6 shown in Table 4-2. The analysis also assumes that the lift and drag forces are equal, which may not be valid for velocities greater than 3.3 m/s (Schweiger and Shaffer 2013).

[12] This value is the construction tolerance as outlined in the construction specifications (YG AAM 2015a).

The calculated factor of safety of 0.6 is low. A value less than 1.0 indicates that the blocks are unstable under the assumed hydraulic conditions and site geometry (FHWA 2009). Typically, a minimum factor of safety of 1.2 is used for bank protection applications where the project hydraulic conditions are well known and the installation can be completed in a well-controlled environment (FHWA 2009). For high consequence applications, the target factor of safety should be higher.

As the stability calculations only examine the blocks, and the factor of safety for the blocks alone is low, it is likely that the design relies on the cables and anchoring to increase stability of the blocks and increase the factor of safety. In addition, the design likely relies on proper placement of the blocks so that the high velocity flow stays on the block surface.

The block stability design software output report provided by WP (WP 2014) shows the same channel and flow input values as Table 4-2; however, the "height of projecting surface normal to flow" (projection height) is listed as 0 inches. As noted in Table 4-2, the standard value for assessment is 0.5 inches, which is also the construction tolerance, as outlined in the construction specifications (YG AAM 2015a). Assuming no projection height of the blocks, assumes perfect installation; while the construction specifications permit a tolerance of up to 0.5 inches.

The block stability design software output report shows a Factor of Safety of 1.8. When no projection height is used, BGC obtains similar results. Figure 4-4 shows that the block stability is very sensitive to projection height, particularly between 0 and 0.5 inches. The block stability software output report (WP 2014) suggests to BGC that WP selected the block type using inappropriate input assumptions by selecting no projection height (value of zero).

The hydraulic stability calculations by BGC indicate that the mat design may not be adequate for the design flows, thereby magnifying the impact of changes between the design intent and construction.

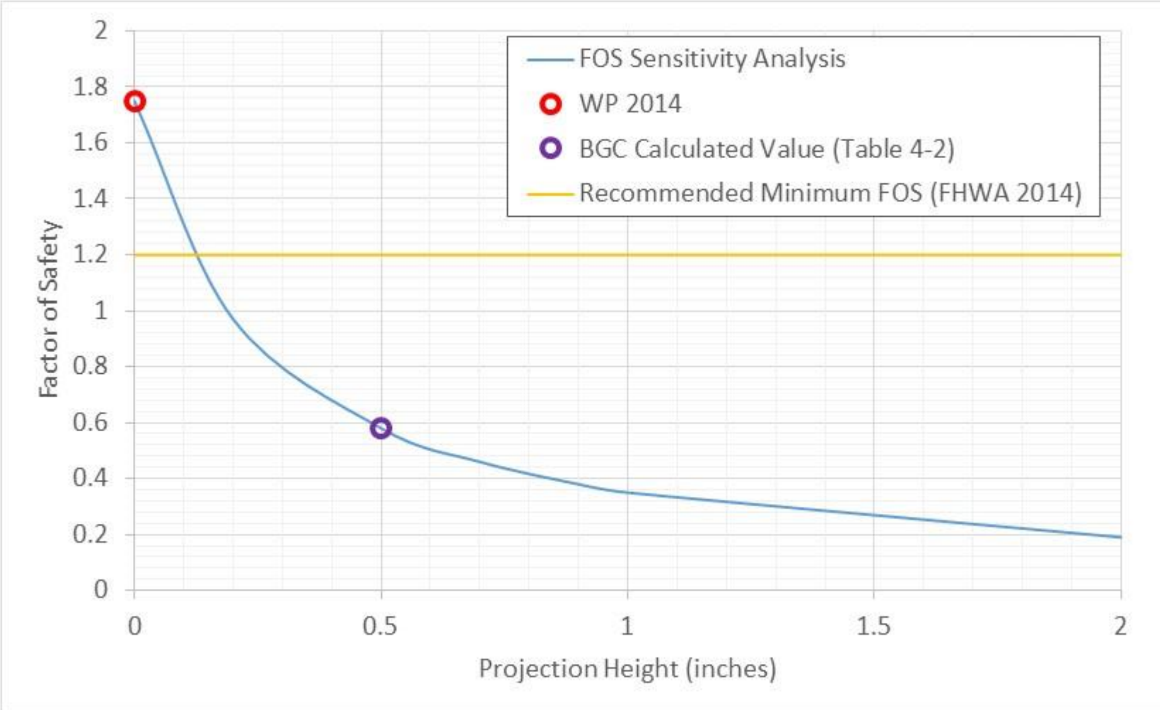


Figure 4-4. Factor of safety sensitivity analysis for block projection height.

4.2.2. Anchors

<u>Anchor Layout</u>

As designed, each mat was to be anchored at 9 locations. However, the holes for the anchor placements were located incorrectly in both the rejected delivery of 170 mm thick mats (rejected for their incorrect thickness) and the accepted 190 mm mats (YG AAM 2015b). As shown in Figure 4-3, this change in anchoring pattern moved the mat to mat connection anchors at the upstream and downstream ends of each mat towards the banks by approximately 0.9 m for each anchor. This resulted in:

- less uniform distribution of anchors, and
- an approximately 50% increase in the distance between anchors (and mat to mat connection points) at a high flow location (middle of the channel) – where deformities are located.

Based on the data provided, this change in anchor layout appears to have originated sometime between when the construction drawings were issued on July 3, 2015 by WP, and when the mats were manufactured. The Armortec Canada drawings shown in the WP construction report appendix for material construction specification data sheets (Advisian 2015) have a revision date of July 27, 2015, and show an anchoring plan that is partly as per the construction drawings, partly as per the record drawings and partly neither. The Armortec drawings are provided in Appendix A. In the information provided to BGC by YG AAM, there is no information to explain which anchor layout design the manufacturer was given.

The YG AAM daily construction report for August 24, 2015 states the following with regards to the anchor locations (2015b):

> *"- Also, the mat has blocks missing for anchors to be placed but the missing blocks on the edge of the mat are in the wrong place. On plan 307076-06729-00-CI-DGA-1004 the missing block on the edge of the mat 4.5m long are in columns 4 and 8. The missing blocks are in column 2 and 10 on the mats delivered. The 5.3 m mats have a similar problem."*

and

> *"- If WorleyParsons will not approve the delivered mat and Nylex cannot make and send correct mat by Sept 8 at the latest, the project will not be completed this year."*

The WP construction report (Advisian 2015) only mentions the change in anchor locations stating that WP had discussions with Armortec, who stated that this change would have no significant impact on the performance of the Armorflex mats.

The YG AAM construction report (2015b) notes under Payment by Item that: "All 54 Armoflex mats inspected and approved by WP". The daily report for September 13 states that:

> "*Installation of microgrid and armoflex mat started around 1230. The placement of the first row was completed at a slow pace and it took some time for the crew to get familiar with the process... Tom [Croskey of Armortec] confirmed that he was satisfied with the installation and will be back on site tomorrow to oversee additional mats placement as well as the repair of the damaged mats and installation of anchors."*

<u>Anchor Connection</u>

The change in anchor to mat connection method appears to have arisen out of discussions between WP, Sidhu and YG AAM, and was approved by YG AAM. The following YG AAM daily construction report entries (2015b) discuss the change in method as follows:

September 14, 2015 prior to change in method:

"Discussion between WP, Sidhu and AAM took place with respect to the approach for installation of the anchors. There was a concern that the cable would not be in tension due to the length of the loop on the duckbill cable following the placement in the ground and pulling of the anchor. It was discussed that the middle anchors will be fine since they will be grouted in. The outside anchors will be installed at an offset in order to ensure that the anchors can be pulled out prior to the placement of the cable that connect to the mat revetment. This should ensure some level of tension in the cable. Duckbill were installed on the first 3 rows of mats with the exception of the downstream end and the north side which will be completed later. The crew damaged 2 out of the 3 rods for the installation of the anchors and are therefore focusing on the placement of the anchors within the channel."

September 16, 2015:

"Also, Stephen [WP] has suggested that the anchors be looped around the block cables rather than crimped. This holds the cable tighter, totally secure and faster for Sidhu. The crimping had to be perfect to not slip using the old method. AAM approved the looping. Over half of the anchors are now installed."

The new anchor connection method was used for most of the anchors in the project, and for all of the anchors located on the chute (YG AAM 2015b).

4.2.3. Mat Seams

The construction specifications (YG AAM 2015a) for the Armorflex mats (Section 31 36 19) state that:

> *"3.4.4 Mat seams or openings between mats greater than 5 cm (2 inches) shall be filled with 30 MPA concrete or non-shrink grout. Whether placed by hand or in large mattresses, distinct changes in grade that results in a discontinuous revetment surface across the channel shall require a grout seam at the grade change location so as to produce a continuous surface."*

This statement is not explicit as to whether the separation is measured at the mat surface or at the subgrade. Due to the shape of the blocks, the surface separation would be greater than the subgrade separation; however, the subgrade separation would be difficult to measure.

As shown in Figure 3-1, Figure 3-3 and Figure 3-4, there were large gaps between rows 11 and 12, and rows 12 and 13, where the mats did not abut one another at commissioning and the gaps were never grouted. The surface separations were measured between 6 and 10 cm.

Grouting was also not applied at the grade change between the chute bottom and the chute banks.

As discussed in Section 2.2, mats that do not abut, have a lower inter-block resistance and therefore, a lower stabilizing force. Large gaps between mats introduce complex local flow hydraulics that can push flow under the mat and introduce destabilizing forces not accounted for in the stability calculations for the blocks/mats.

4.2.4. Block Placement (Block Tapers, Smooth Subgrade, and Finished Grade)

<u>Block Tapers</u>

The Armorflex Class 60T mats specified by WP are constructed of tapered blocks (Nilex 2016). An Armorflex installation brochure from the American supplier, Contech[13], highlights one of the features of the 60T blocks used in the Clinton Creek ACB mats (2012):

> *"Armortec's unique Tapered Series ArmorFlex block design offers superior protection for embankment dams, spillways, high velocity channels and down chutes. The essential design*

[13] The Canadian supplier for Armortec products is Nilex Inc.

component of ArmorFlex Tapered series is the 0.5 inch taper that virtually eliminates destabilizing impact flow forces, thereby providing a high factor of safety."

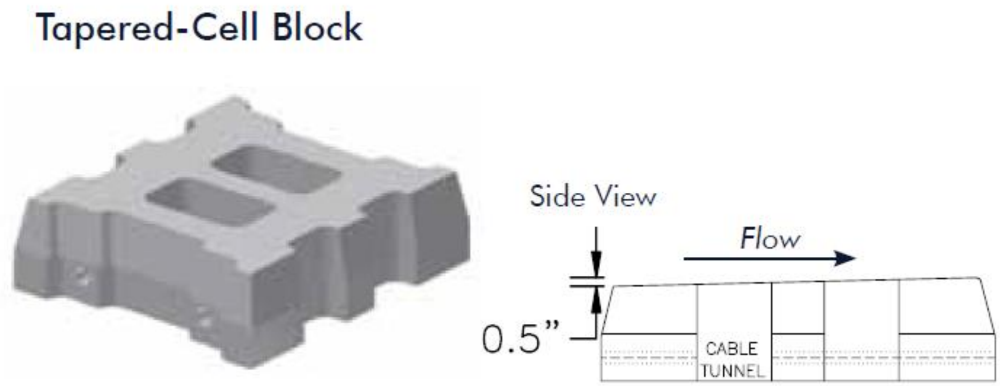


Figure 4-5. Armorflex Tapered Series Block. (Contech 2012).

The supplier stresses that the tapering of the blocks is important to the stability of the blocks in high velocity flows. For the benefit of block tapering to be realized, the blocks must be placed in the correct orientation to flow direction and on a perfectly smooth drain rock/subgrade layer so that the blocks align with a 0.5" (1.3 cm) offset, as shown in Figure 4-5.

Neither the design summary document (WP 2015b), Issued for Construction drawings by WP, nor the tender documents and drawings discuss the taper, nor explain how to identify the taper direction, which direction to place the taper nor the construction tolerances for placement of the taper.

The WP construction report (Advisian 2015) states in the overview that: "Due to the tapered block design, mats were oriented such that the thicker edge of each block was positioned downstream. Blocks with the leading (i.e., upstream) edge visibly protruding into the flow were repositioned and, where necessary, grouted in place". However, there is no discussion about the block taper in daily reports, or photos to substantiate this statement.

The YG AAM construction daily reports (2015b) note on August 22nd that the rejected mats were tapered, measuring 160 mm thick at one end and 170 mm at the other end, but there were no similar comments with respect to the accepted mats. On September 13, YG AAM notes:

"Installation of microgrid and armoflex mat started around 1230. The placement of the first row was completed at a slow pace and it took some time for the crew to get familiar with the process. The tapered end is to be installed on the downstream side and there is a line on the block on the tapered end."

This last statement is incorrect – as shown in Figure 4-5, the blocks are to be installed with the taper on the upstream side. A spot check of YG AAM construction monitoring photos show the marker lines on the downstream side. The supplier was contacted by BGC to confirm whether the line indicates the tapered end or the upstream end of the block, however no response had been received by the date of this report.

Subgrade and Finished Grade

Table 4-3 highlights sections in the tender package construction specifications related to subgrade smoothness and finished grades of the Armorflex mats, and where there are inconsistencies with the actual construction. The specifications do not mention the block tapering.

Table 4-3. Tender Package Construction Specifications (YG AAM 2015a) select sections related to subgrade smoothness and finished grades of Armorflex mats.

Construction Specification Section 31 36 19 Armorflex® Mats:	Actual Construction Inconsistency
3.1.1 Granular bedding shall be constructed to the elevations, grades, and geometry shown on the Contract Drawings and to the tolerances specified in the Specifications. The gravel bedding shall be approved by the Engineer and the Manufacturer's representative prior to placement of the Armorflex® mats. and 3.2.1 Immediately prior to placing the Armorflex® mats, the prepared subgrade shall be inspected by the Engineer, the Owner, and the manufacturer's representative. No blocks shall be placed theron until that area has been approved by each of these parties.	Advision 2015: "An Armortec representative was on-site from September 12 to 15, 2015 to inspect the quality of the Armorflex mats, direct any necessary repairs to damaged mats, approve sub-grade material, and monitor the placement of the first nine mats." Photos in the WP daily reports show that the subgrade material was largely placed on the chute by the end of day on September 15. However, the subgrade in the channel was driven on by the excavator in order to place the mats. Therefore, the manufacturer did not inspect the granular bedding/prepared mat subgrade immediately prior to placement of mats in the chute.
3.1.2 The gravel bedding shall be graded to a smooth plane surface to ensure that intimate contact is achieved between the slope face and the Armorflex® mats. All slope deformities (e.g., roots, grade stakes, and stones) which project normal to the local slope face must be re-graded or removed. No holes, pockmarks, slope board teeth marks, footprints, or other voids greater than 2.5 cm (1.0 inches) in depth normal to the local slope face shall be permitted. No grooves or depressions greater than 1.25 cm (0.5 inches) in depth normal to the local slope face with a dimension exceeding 30 cm (1.0 feet) in any direction shall be permitted. Where such areas are evident, they shall be brought to grade by placing compacted homogeneous material. The slope and slope face shall be uniformly compacted, and the depth of layers, homogeneity of soil, and amount of compaction shall be as required by the Engineer.	Advision 2015: "Typical base for Armorflex. Generally smooth but difficult to have all blocks sit flat." and "Challenging to get some concrete blocks to sit properly due to slightly uneven surface"

Construction Specification **Section 31 36 19 Armorflex® Mats:**	**Actual Construction Inconsistency**
3.4.2 The cellular concrete blocks shall be placed on the gravel bedding in such a manner as to produce a smooth plane surface in intimate contact with the gravel bedding. No individual block within the plane of placed cellular concrete blocks shall protrude more than 1.25 cm (0.5 inches) or as otherwise specified by the Engineer. To ensure that the cellular concrete blocks are flush and develop intimate contact with the subgrade, the blocks shall be "seated" with a roller or other means as approved by the Engineer.	This item does not mention tapered blocks and does not explicitly define tolerances for tapered blocks which could be described as the upstream end of the block being depressed by 0.5" or that the downstream end of the block protrudes by 0.5". This could also be interpreted that the blocks should not taper. WP notes in their construction report that "Crowbars were used to shift individual concrete blocks or to "seat" the blocks properly" (2015). This would result in a less even surface than if a roller was used.
3.4.6 Blocks in the mats shall be voided by the manufacturer to facilitate installation of ground anchors. These voided blocks shall be filled with 30 MPa concrete or grout, hand finished so that it is flush with the top of the surrounding blocks.	From 2016 site observations, grout was not installed flush with the top of the surrounding blocks on the right and left banks. At two locations on the right edge of the chute, the grout surface and adjacent block measured a vertical separation of 6 cm (2.4") between the tops of the blocks.

4.3. Mat Deformities

There appear to be two sets of deformities:

- five large mat deformation ripples between mat rows 11 to 16
- several smaller deformities on mat rows 9 and 10.

Each of these deformities are discussed in relation to the Possible and Likely failure modes in the following two sections.

4.3.1. Mat Deformation Ripples (Mat Rows 11 to 16)

Due to the locations, the five mat deformation ripples appear to be associated with water flow at the mat to mat connections/seams.

The two downstream mat ripple deformities (between mats in row 11 and 12, and between mats in row 12 and 13) appear to match the two locations where the mat separation distance is large. During the site visit, the top of block separation distances were measured to be 6 to 10 cm on the right bank, while the bottom of block separation distances were slightly less due to the block shape. The mat separations are so large as to be clearly visible in the photo of the chute at the start of commissioning (Figure 3-1).

Figure 4-6 shows a close up view of the left bank of mat row 11 and the highly turbulent flow immediately downstream of the lateral mat connection. The photo shows two dislodged blocks on the bank and that the rebar/anchor/grout connection appears intact. The record drawings show that the mat is anchored both immediately upstream, and upstream and to the right, of the turbulent flow. The photo suggests that the anchors are intact. Therefore, the turbulence is likely not a result of changes in anchor placement or anchor failure.

However, the turbulence could be associated with the large mat separation which was observed on both banks and is visible on the chute invert in the construction photos. During commissioning, water flow was directed initially to the left bank, so possibly there is a greater concentration of flow on the left bank than on the right bank. In addition, the upstream mat deformities also help to concentrate flow on the banks.

The construction specifications required: mat seams with openings larger than 5 cm to be grouted and mat seams with a grade change to be grouted (YG AAM 2015a).

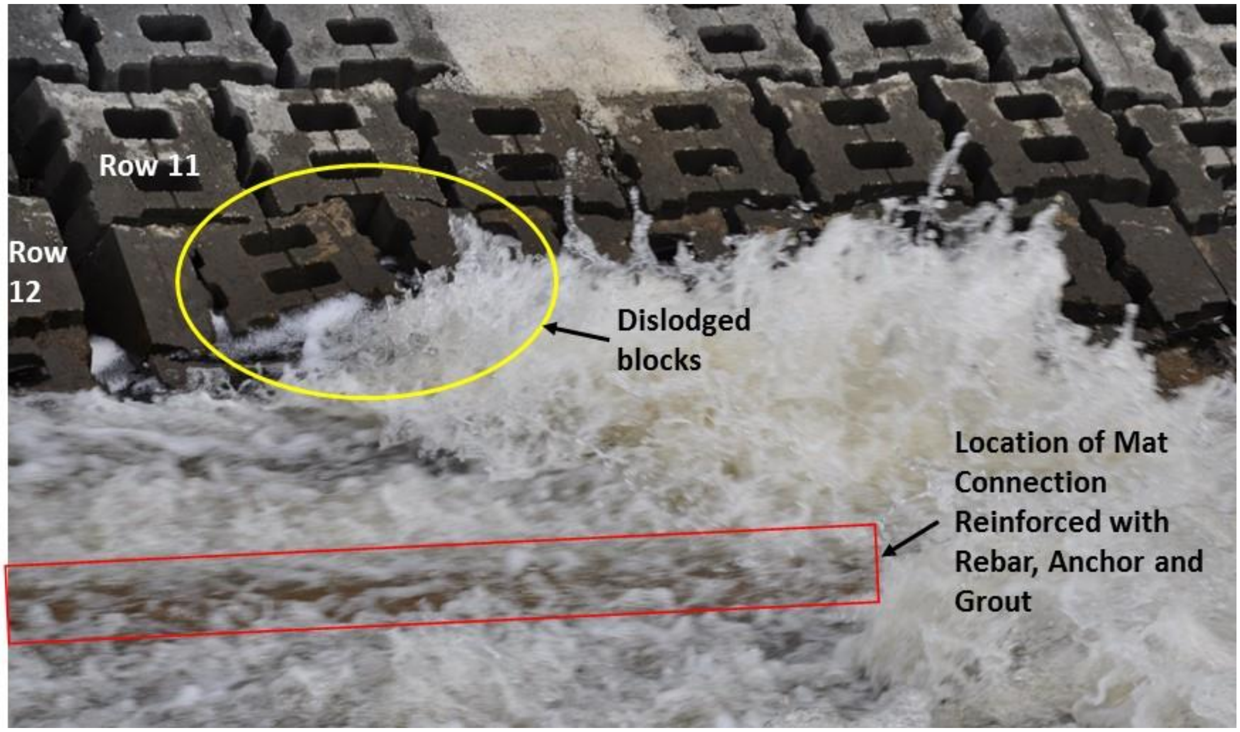


Figure 4-6. Close up view of the left bank of mat row 11 and the highly turbulent flow immediately downstream of the lateral mat connection. Photo taken July 19 2016 (YG AAM 2016a).

For the three upstream mat deformities (between mats in rows 13 to 16), it is likely that the anchor spacing is greater than design spacing, allowing the mat to move under flow. The wave-like profile of the two upstream locations (mat rows 14 to 16) with a depression followed by a similar-sized bulge suggests that the subgrade was exposed to flow at the mat connection point, and that the subgrade material was eroded and transported downslope to the location of the bulge. Figure 4-7 shows a close up of one of the bulges during lower flow. The bulge includes a grout block, suggesting that the anchor at this location has failed either by pulling out of the ground or because of the anchor connection method (too slack as a result of poor installation or poor connection method).

In addition to the anchor spacing, the deformities between mats in rows 13 to 16 could have also been generated by any of the potential failure modes highlighted as possible contributors in Table 4-1:

- Problems with block taper (correct blocks supplied? correct installation? how critical is this feature to the design?)
- Problem with individual blocks (concrete quality? half-blocks able to rotate?)
- Problem with grout "blocks" (finished surface not flush with adjacent blocks? grout blocks not made to the same quality as concrete blocks and therefore less able to resist forces?)
- Subgrade preparation not smooth enough for block placement
- Failure of mat anchors.

Figure 4-7. Close up view of the bulge downstream of mat connection between rows 14 and 15. Photo taken July 19 2016. (YG AAM 2016a)

4.3.2. Smaller Deformities (Mat Rows 9 and 10)

The smaller deformities on mat rows 9 and 10 appear to be localized problems at the block-level rather than the mat-level.

Figure 4-8 shows a close up view of a smaller deformity located adjacent to the right bank of mat row 10. The photo shows a block protruding into the flow. Immediately upstream of the deformity is a grout block. On the bank is a piece of woody debris. The cause of the deformity at this location could be the result of one or more of the following failure modes as highlighted in Table 4-1:

- Problems with block taper
- Problem with individual blocks
- Problem with grout "blocks"
- Subgrade preparation not smooth enough for block placement

In addition, this deformity could be a result of flow being concentrated on the banks due to the upstream mat deformities.

Figure 4-8. Close up view of a smaller deformity located adjacent to the right bank of mat row 10. Photo taken July 19 2016. (YG AAM 2016a)

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The root causes of the development of the deformities have been inferred based on site observations and the background information provided. During the site visit, BGC was unable to wade into the flow and directly observe and inspect the mat deformities for items such as broken blocks, failed anchors, subgrade and drain rock condition.

BGC developed a list of potential failure modes, and an assessment of the likelihood the mode contributed to the mat deforming using a relative rating of Unlikely, Less Likely, Possible, and Likely. The Possible and Likely modes are:

<u>Possible</u>:

- Problems with block taper
- Problem with individual blocks
- Problem with grout "blocks"
- Subgrade preparation not smooth enough for block placement
- Failure of mat anchors

<u>Likely</u>:

- Lack of sufficient anchoring allowed part of the ACB mat to move
- Mats placed too far apart, altering the local flow hydraulics and exposing the drain rock layer and subgrade to water flow, resulting in erosion and destabilization of the mats.

It is also possible that several failure modes worked together to generate the mat deformities. Given the information available and potential failure modes listed above, it is BGC's opinion that the following are the root causes for the ACB mat deformations:

1. *Based on the information supplied to BGC, the design procedure does not appear to meet generally accepted design standards; further context follows.*

Limited design hydraulic stability calculations were made available to YG AAM and BGC. The block stability software output report provided by WP (WP 2014) suggests to BGC that WP selected the block type using inappropriate input assumptions by selecting no projection height (value of zero).

Based on a standard factor of safety assessment method for ACB mats which considers the blocks only, BGC determined that it is likely, due to the steepness of the slope and the high design velocities, that the individual blocks would not be hydraulically stable under the design flow. Therefore, the design relies on the mat cables and ground anchors to provide a suitable factor of safety.

One of the significant changes WP made to the design between the 2nd and 3rd revisions of the design summary report was the addition of ground anchors to the mat, supposedly for added stability. However, BGC's assessment suggests that the ground anchors may have been critical to stability. No stability calculations for mat cables or ground anchors were included in the design summary reports available to BGC. The designer should be contacted to provide their specific hydraulic stability assessment relative to the one undertaken by BGC herein.

The mat design included the use of half blocks. During flume testing for stability, half blocks are not tested, and factor of safety calculations use design parameters developed for full blocks only (Nadeau 2016).

During construction, the mats that were supplied had incorrect anchor locations (when compared to the Issued for Construction drawings). However, the manufacturer's drawings provided by WP in their construction report show an anchor plan that is partly as per the construction drawings, partly as per the record drawings and partly neither. The WP construction report (Advisian 2015) only mentions the change in anchor locations stating that WP had discussions with Armortec, who stated that this change would have no significant impact on the performance of the Armorflex mats. This suggest that WP was relying on the manufacturer to provide engineering design and that communication between WP and the manufacturer may not have been clear.

WP's design required the use of Armortec 60T blocks, which are a tapered concrete block. However, the construction specifications and drawings did not identify that the blocks were tapered and therefore, did not address how these particular blocks should be installed so that they perform as intended.

Nadeau notes that flume testing of tapered blocks has shown that ACB mats on a 2H:1V, 30.5 m flume will deform at flow depths greater than 0.91 m, as a result of the stone drainage layer becoming unstable and moving beneath the mats (2016). Based on this observation, standard practice for tapered ACB systems on 2H:1V slopes is to limit velocities to a maximum of 6.4 - 7.9 m/s (Nadeau 2016). Although the chute slope is less than 2H:1V, BGC calculates the design velocity to be approximately 8.5 m/s, which is in excess of the recommended maximum.

As shown in Figure 4-1, the mat began deforming during the 2016 freshet flows which were estimated by YG AAM to be only one-fifth of the design flow. On May 4th, the water level in the plunge pool can be seen to be close the top of bank which suggests that the height of the hydraulic jump was not considered during the design of the pool.

It should be noted that, if the design was inadequate for hydraulic stability, even the best construction and installation procedure would not correct such a deficiency. An inadequate design also magnifies the impact of changes made between the design intent and construction. WP was responsible for the design of the project.

2. *Construction was inconsistent with the construction specifications*.

The following inconsistencies were identified between the construction specifications and the actual construction which possibly or likely lead to the formation of the mat deformities:

- The Armortec representative did not inspect nor approve the granular bedding immediately prior to placement of the ACB mats

- The specifications required that the gravel bedding be graded to a smooth surface. However, WP noted during construction that it was challenging to get some of the concrete blocks to sit properly due to the unevenness of the surface
- The specifications require the blocks to be seated with the use of a roller to ensure that blocks are flush with each other and in intimate contact with the subgrade. WP notes that a crowbar was used to shift individual blocks.
- Mat seams or openings between mats greater than 5 cm were to be filled with concrete or grout. However, this was not completed.
- Voided blocks in the mat were to be filled with grout flush with the top of the surrounding blocks, but instead the grout was placed with vertical offset.
- The mats supplied to site did not meet the design specifications for anchor placement

The Armortec representative was on site for the placement of the first 9 rows of mats. It is not documented in the construction records whether the representative approved of anything more than the subgrade. The construction specifications noted that Sidhu, the contractor, was responsible for ensuring that the manufacturer's representative was on site and for covering the representative's costs associated with the work (YG AAM 2015a). WP notes that Armortec was responsible for design of the Armorflex system (jointly with the engineer), the supply of Armorflex mats, and quality control of Armorflex mat fabrication and installation (jointly with the engineer) (Advisian 2015).

It is noted that WP was on site for the duration of construction and that WP approved the mats for use. WP was responsible for quality assurance and approval of field changes.

5.2. Recommendations

As discussed in Section 2.2.3, failure of an ACB mat is defined as when individual blocks have lost "sustained, intimate contact with the subgrade" (FEMA 2014). It is BGC's opinion that the mat deformities constitute failure at those locations. Despite this, the mat structure as a whole was still functional at the time of BGC's site visit, as flow was still being safely conveyed down the drop structure and there did not appear to be wide spread slope instabilities as a result of the mat deformities.

Although the mat structure was still functional at the time of BGC's site visit, the mat is expected to continue to deform, particularly during high flow events. Nadeau notes that the factor of safety for tapered blocks decreases very rapidly with increasing projection height. The existing mat deformities developed during the 2016 freshet, which was calculated by YG AAM to be only one-fifth of the design flow.

The original purpose of the drop structures was to stabilize the channel from erosion and mitigate the likelihood of a landslide dam outbreak flood from Hudgeon Lake. In addition, all of the Clinton Creek drop structures were built as temporary structures until a permanent closure plan could be developed and implemented. However, the gabion structures have been in place for over 12 years and there is no confirmed date for when all of the drop structures will be replaced with a permanent solution. With this in mind, BGC recommends that YG AAM consider the following:

1. Contact the design engineer and obtain confirmation of the adequacy of the hydraulic design for the entire DS4 structure.
2. Develop a monitoring plan to monitor mat integrity, particularly during and following high flow events, that may occur during the 2017 freshet.
3. Develop a risk management plan for the ACB-lined chute, as well as the upstream drop structures that would provide procedures for managing items such as: a failed structure; design flow exceedance; public safety.
4. Engage a suitably qualified engineer and the manufacturer's representative to:
    - Assess the adequacy of the design for the design flow, and recommend changes as necessary.
    - Conduct a site visit during very low flows so that the deformities can be inspected and the failure mechanisms confirmed.
    - Develop and implement a rehabilitation plan, which may include mat removal, subgrade preparation, mat replacement, grouting and anchor placement.

As the ripples may become worse during high flow events, ideally the mat should be mitigated prior to the 2017 freshet. However, the 2016 construction season is coming to an end and full rehabilitation of the mat is unlikely to occur prior to the 2017 freshet.

To that end, BGC recommends developing a risk management plan prior to the 2017 freshet and rehabilitating the mat during the 2017 construction season.

6.0 CLOSURE

We trust the above satisfies your requirements at this time. Should you have any questions or comments, please do not hesitate to contact us.

Yours sincerely,

BGC ENGINEERING INC.
per:

Rebecca Lee, P.Eng., P.Geo. (BC)
Water Resources Engineer

Reviewed by:

James W. Cassie, M.Sc., P.Eng.
Principal Geotechnical Engineer

RL/JWC, HW/vc

REFERENCES

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YG AAM, 2015b. Repair of Clinton Creek Drop Structures. Contract Number C000229695. Yukon 2015-16. Final Report. Prepared by Wayne Emery – Project Inspector.

YG AAM, 2016a. Clinton Creek drop structure site visit photo collection. 109 digital photographs.

YG AAM, 2016b. Remote Camera Images of the 2016 Freshet at DS4. 105 digital photographs.

YG AAM, 2016c. Personal Communication. September 7, 2016.

APPENDIX A
Armortec Canada Inc – Clinton Creek Drop Structure 4 Repair Drawings (as originally shown in Advisian 2015)

CLINTON CREEK - DROP STRUCTURE 4 REPAIR

DRAWING INDEX:

SHEET TITLE: ARMORFLEX CL 60T - PLAN SHEET

CH'KED BY: TC | DATE: 05-08-15 | REVISION DATE: 07-27-15 | CAD FILE: ARMORTEC CANADA

DRAWN BY: MDD | SCALE: N.T.S. | DRAWING NO: AC008-15 | DRAWING NAME: CLINTON CREEK-T

SHT. 1 OF 4.

McCOY DRAFTING & DESIGN, LLC

ARMORTEC CANADA, INC.
17113 MINNETONKA BLVD., SUITE 223
MINNETONKA, MN. 55345
PHONE: (952) 476-5979
FAX: (952) 476-7475
tscroskey@qwest.net

PROJECT NAME: CLINTON CREEK DROP STRUCTURE 4 REPAIR

NO.	DESCRIPTION	BY

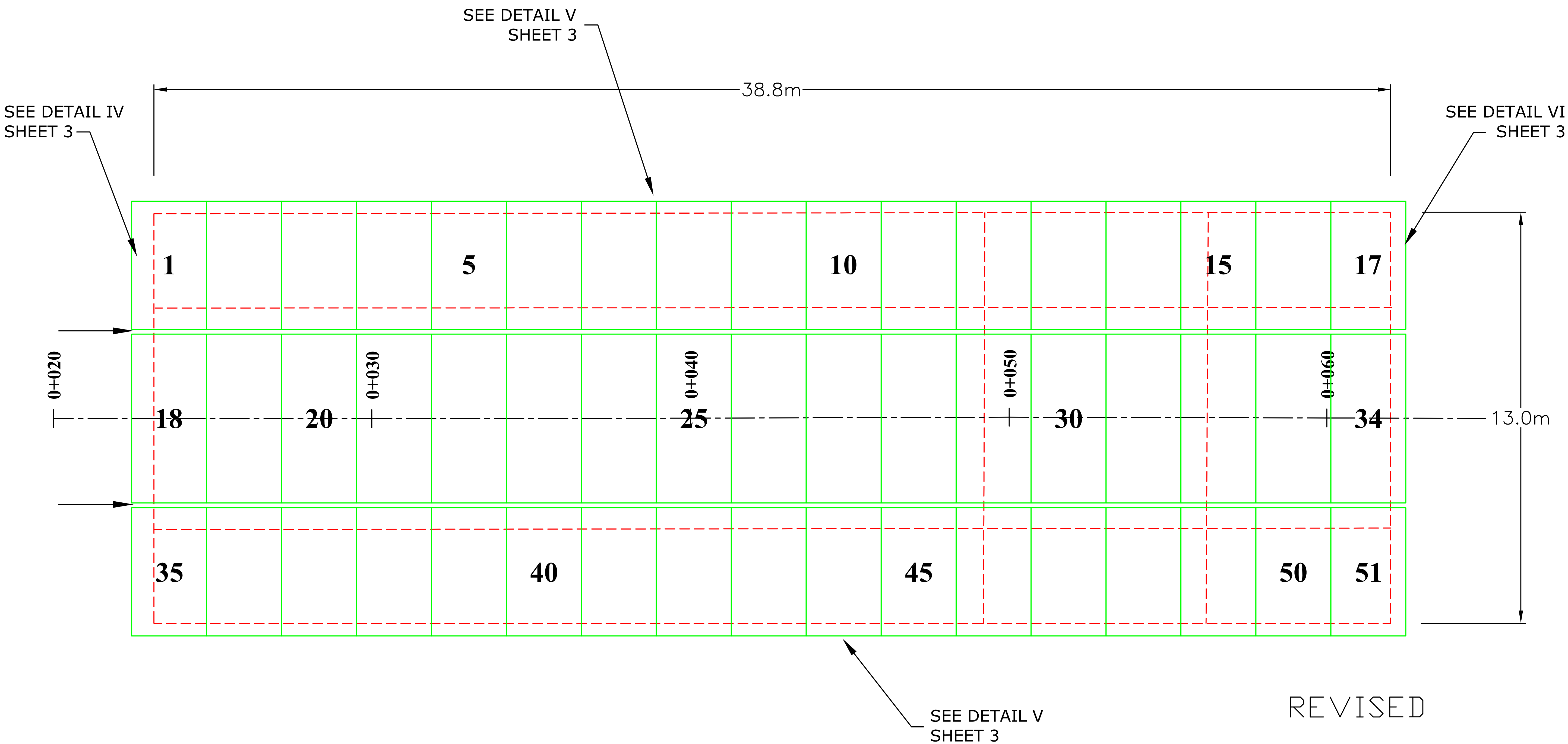
REVISIONS

NOTES:

1. ALL MAT SIZES ARE AS SPECIFIED ON CORRESPONDING SPREADSHEET.
2. TOE ANCHORS AND SLOPE FACTORS HAVE BEEN ADDED TO LENGTHS OF ALL MATS.
3. ⟶ INDICATES GROUT SEAM LOCATIONS. (SEE DETAILS ON SHEET 3)
4. – – – – INDICATES AREAS TAKEN FROM SUPPLIED PDF FILES, PROVIDED BY WORLEY PARSONS.

CL 60T MATTRESS TOTALS:

RECTANGULAR MATS	583.4 SQ.M
SQ.M. TOTAL	583.4 SQ.M



REVISED

SHEET TITLE: ARMORFLEX CL 60T – PLAN SHEET

CHKED BY: TC	DATE: 05-08-15	REVISION DATE: 07-27-15	CAD FILE: ARMORTEC CANADA
DRAWN BY: MDD	SCALE: N.T.S.	DRAWING NO: AC008-15	DRAWING NAME: CLINTON CREEK-P

McCOY DRAFTING & DESIGN, LLC

ARMORTEC CANADA, INC.
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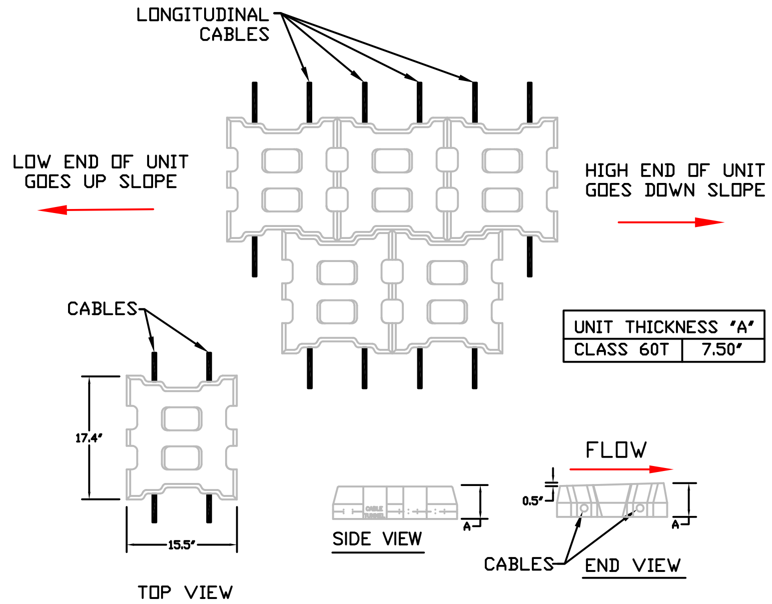
MINNETONKA, MN. 55345
PHONE: (952) 476-5979
FAX: (952) 476-7475
tscroskey@qwest.net

PROJECT NAME: CLINTON CREEK DROP STRUCTURE 4 REPAIR

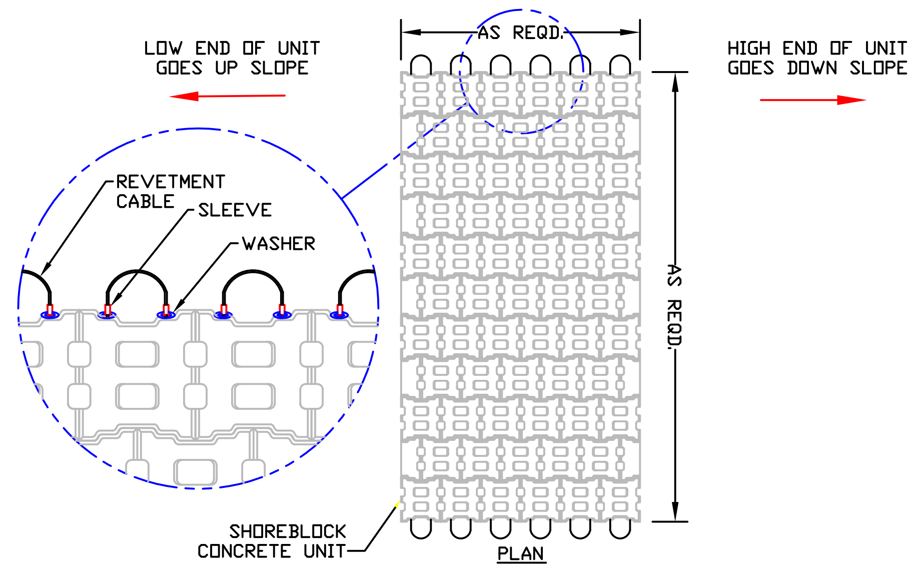
REVISIONS

NO.	DESCRIPTION	BY

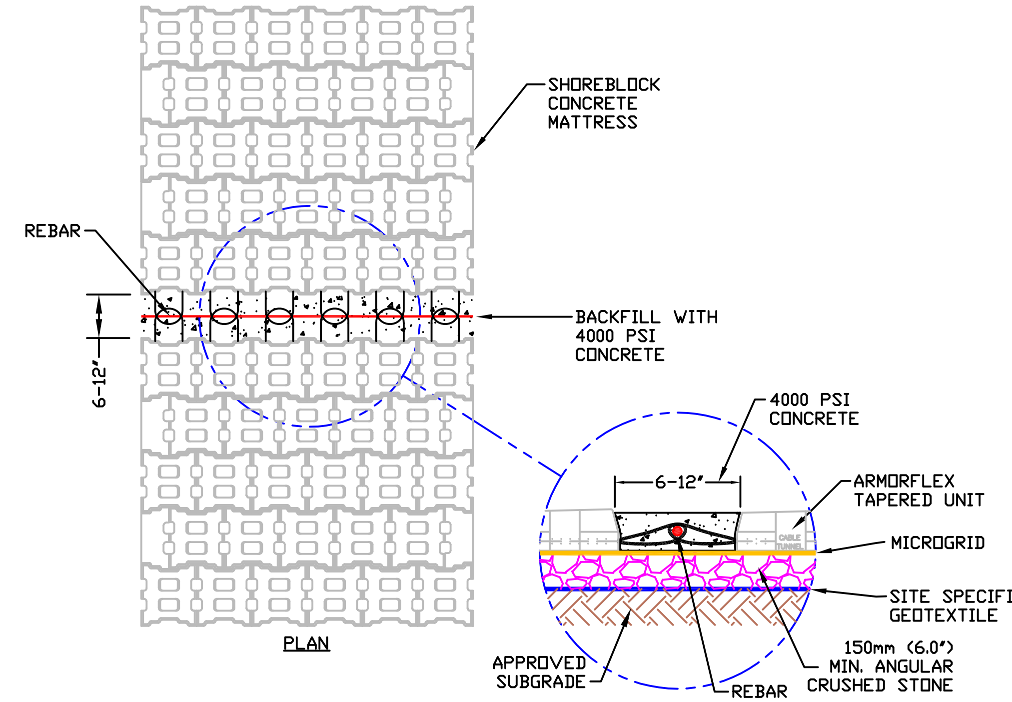


UNIT THICKNESS 'A'	
CLASS 60T	7.50"

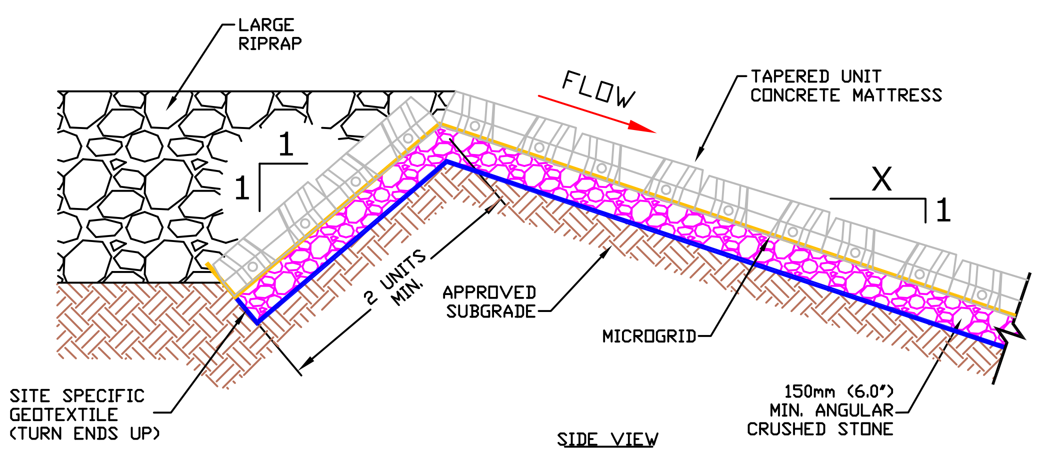
I ARMORFLEX TAPERED UNIT
NOT TO SCALE



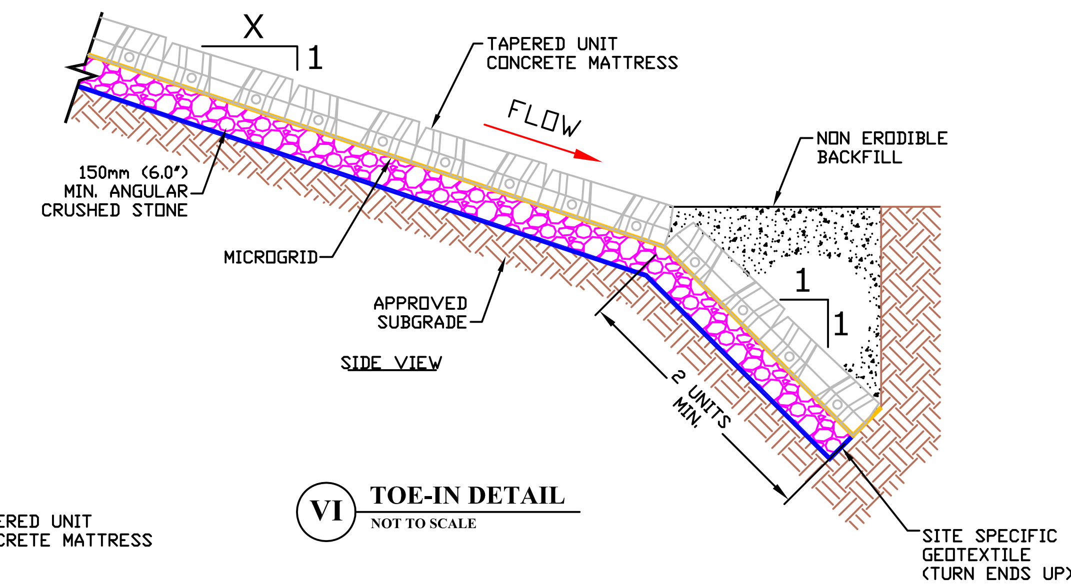
II ARMORFLEX TAPERED MATTRESS
NOT TO SCALE



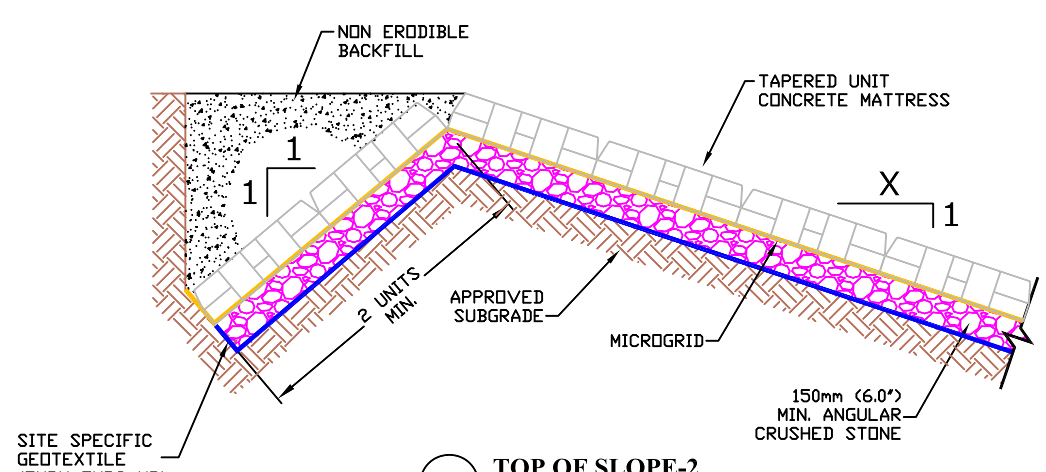
III MAT TO MAT CONNECTION
NOT TO SCALE



IV TOP OF SLOPE
NOT TO SCALE



VI TOE-IN DETAIL
NOT TO SCALE



V TOP OF SLOPE-2
NOT TO SCALE

SHEET TITLE: ARMORFLEX CL 60T - PLAN SHEET

CHK'ED BY: TC | DATE: 05-08-15 | REVISION DATE: 07-27-15 | CAD FILE: ARMORTEC CANADA
DRAWN BY: MDD | SCALE: N.T.S. | DRAWING NO: AC008-15 | DRAWING NAME: CLINTON CREEK-D

SHT. 3 OF 4.

McCOY DRAFTING & DESIGN, LLC

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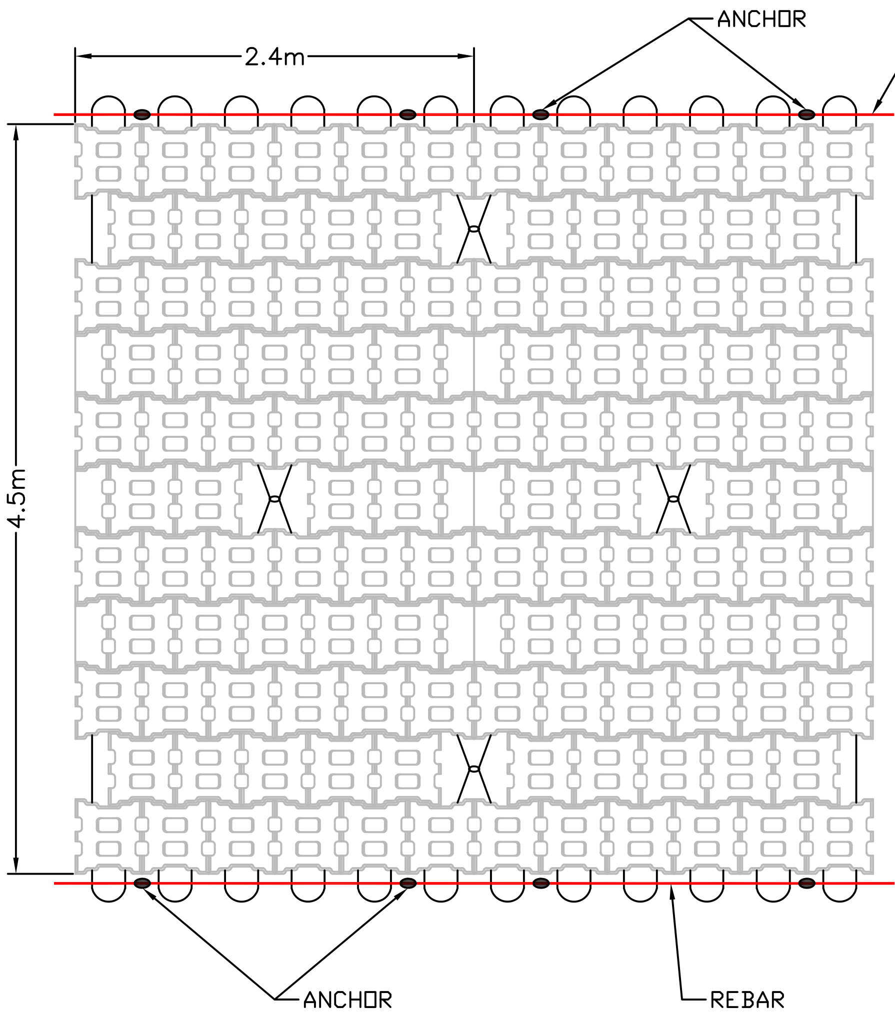
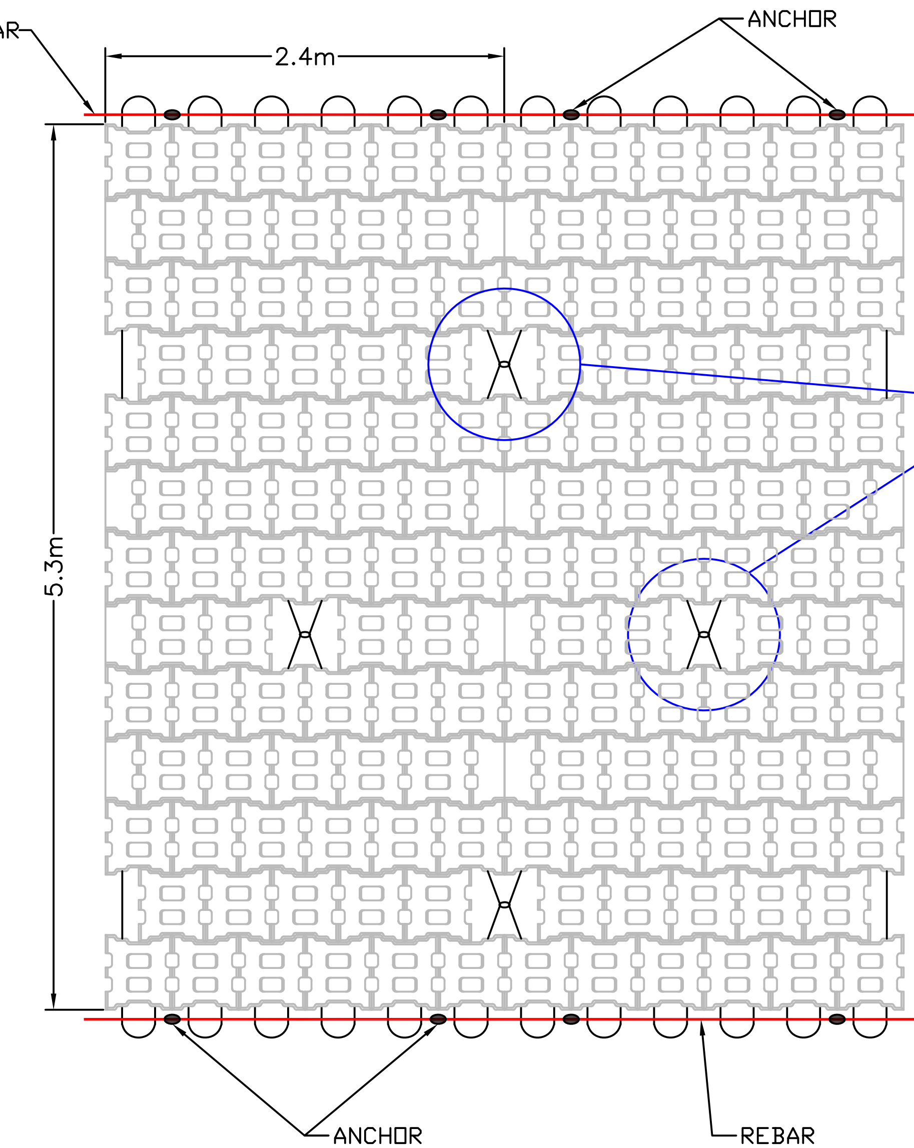
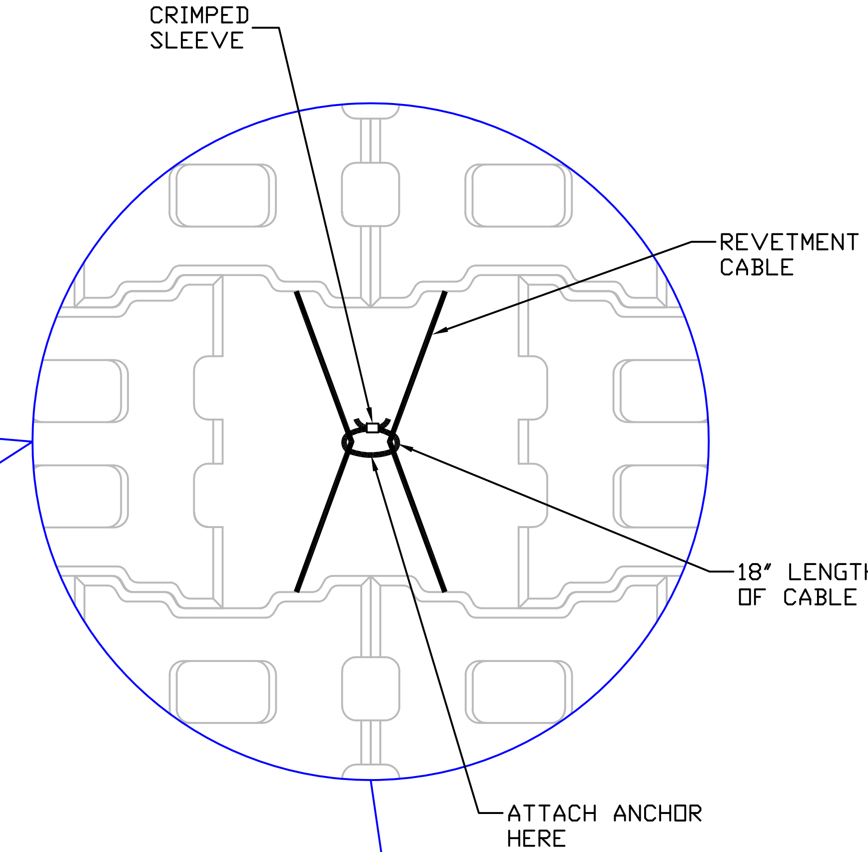
PROJECT NAME: CLINTON CREEK DROP STRUCTURE 4 REPAIR

NO.	DESCRIPTION	BY

REVISIONS







VII **MAT ANCHOR PLACEMENT**
NOT TO SCALE

SHEET TITLE: ARMORFLEX CL 60T - PLAN SHEET

CHKED BY:	DATE:	REVISION DATE:	CAD FILE:
TC	05-08-15	07-27-15	ARMORTEC CANADA
DRAWN BY:	SCALE:	DRAWING NO:	DRAWING NAME:
MDD	N.T.S.	AC008-15	CLINTON CREEK-D2

SHT. 4 OF 4.

McCoy Drafting & Design, LLC

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PROJECT NAME: CLINTON CREEK DROP STRUCTURE 4 REPAIR

NO.	DESCRIPTION	BY

REVISIONS

APPENDIX B
Design Basis References WP 2016, WP 2014

Rebecca Lee

From:	Amanda.Rust@advisian.com
Sent:	Tuesday, September 27, 2016 12:56 PM
To:	Erik.Pit@gov.yk.ca
Subject:	RE: Drop Structure 4 Report Files
Attachments:	Clinton Mine Hydraulic Run March 4 2014.pdf; 307076-06729-00-WW-REP-0001 _Rev4.pdf

Hi Erik,

I had a chance to review the project files from the DS4 Repair. Since Josee Perron, Lee Martin and Jake Gentles have all moved on, I had to make a couple of assumptions. Here is a summary of what I found:

We do not have a separate design basis memorandum for this project. The basis of design was summarized in the attached design summary report, which I guess was issued in place of the "technical letter describing the basis of design" required under contract # C00021890. The same document was subsequently updated in accordance with the scope of work outlined in contract # C00027285.

The following additional source files were used to develop design parameters / calculations:

Hydrology - The design flow rate of 28.9 m3/s for the DS4 repair was taken from the Environmental Liability report prepared by UMA (2003) and is the flow rate used for the design of the original gabion drop structures.

Armorflex Design Report – Presents the results from Armorflex Design Software (see attached pdf).

Please feel free to call me to discuss if you have any additional questions.

Regards,

Amanda Rust
Engineer, Water Resources

Suite 600, Willingdon Park Phase 6, 4321 Still Creek Drive | Burnaby BC V5C 6S7
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Advisian
WorleyParsons Group

From: Erik.Pit@gov.yk.ca [mailto:Erik.Pit@gov.yk.ca]
Sent: September-21-16 8:52 AM

To: Rust, Amanda (Vancouver)
Subject: RE: Drop Structure 4 Report Files

Hello Amanda,

Thanks for looking into it; I have what are considered a 'design summary' reports from Worley Parsons, although it does not seem to contain the information that would typically go into a 'design basis memorandum'.

Thanks again,

Erik

From: Rust, Amanda (Vancouver) [mailto:Amanda.Rust@advisian.com]
Sent: Tuesday, September 20, 2016 4:46 PM
To: Erik.Pit <Erik.Pit@gov.yk.ca>
Subject: RE: Drop Structure 4 Report Files

Hi Erik,

I just wanted to let you know that I received your email. I am quite busy this week with other deadlines, but will try to pull the information together for you later this week. We might not have a "technical letter describing the basis of design" because this information is usually incorporated into the overall design report for a project.

Regards,

Amanda Rust
Engineer, Water Resources

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WorleyParsons Group

From: Erik.Pit@gov.yk.ca [mailto:Erik.Pit@gov.yk.ca]
Sent: September-19-16 5:08 PM
To: Rust, Amanda (Vancouver)
Subject: Drop Structure 4 Report Files

Hello Amanda,

I have been looking for a few files that are missing in our database and I was hoping you may be able to help. The following is what I am looking for:

- All the raw data and source files (including all files used to complete any calculations) used to develop the Drop Structure #4 Repair Design (i.e. as per contract # C00021890 & C00027285).

- The "technical letter describing the basis of design" as specified in contract # C00021890.

Thanks,

Erik

Erik Pit, M.Env.
Type II Senior Project Manager

Yukon
Energy, Mines and Resources
Assessment and Abandoned Mines
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Whitehorse, Yukon
(867) 456-6154 office
(867) 456-6780 fax

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ARMORFLEX DESIGN REPORT

ArmorFlex Blocks by ARMORTEC Erosion Control Solutions

4301 Industrial Drive
Bowling Green, Kentucky 42101
Phone (270) 843-4659
Toll free (800) 305-0523
Fax (270) 783-8952

Design Report Printed from Armorflex Design Software
Report Type: Summary

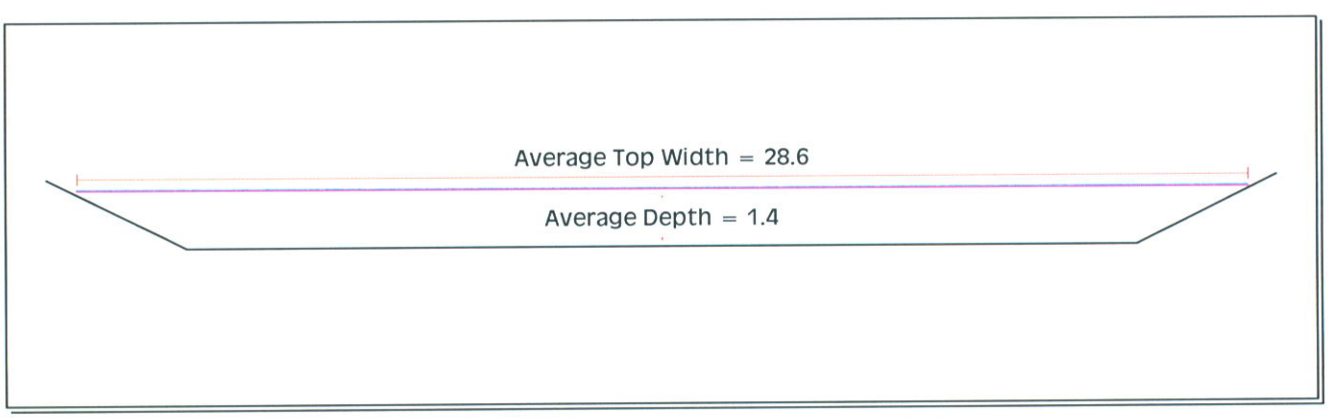
Company: Company not supplied
Designer: Designer not supplied
Project No.: Project No. not supplied
Report Date: 3/4/2014

Client: Client not supplied
Waterway: Clinton Mine
Location: Yukon
Event: Q = 29.0 m3/s

Flow Scenario: Trapezoidal Channel
Block Cell Type: Open Cell Block
Block Taper Type: Tapered Block

Design Input for Factor of Safety Calculations

Left Side Slope (_H:1V) = 2
Right Side Slope (_H:1V) = 2
Channel Bottom Width (ft) = 22.96
Channel Bed Slope (ft/ft) = .2
Bend Coefficient = 1
Discharge (cfs) = 1024
Projection Height (in.) = 0
Vertical Exageration for Plot = 1



Graphical Output of Normal Depth Calculations

Output from Factor of Safety Calculations

Block Type	n-Value	Depth (ft)	Velocity (ft/s)	Froude No.	Shear (psf)	Factor of Safety
40-T	0.027	1.41	28.09	4.16	17.3	1.5
50-T	0.027	1.41	28.09	4.16	17.3	1.7
60-T	0.027	1.41	28.09	4.16	17.3	1.8
70-T	0.027	1.41	28.09	4.16	17.3	1.9