August 2017

Research Project Report

An Analysis on the Kinematics of the Ripley Landslide

Ashcroft-Thompson River Valley, British Columbia Canada

Submited in partial fulfillment of the requirements for the degree of

Master of Engineering in Geotechnical Engineering at the

University of Alberta, Canada

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Submitted on: 21 August 2017 via email

Executive Summary

The Ripley Landslide is one of the smallest among the 12 landslides at the Ashcroft-Thompson River Valley, located approximately 10 km south of Ashcroft, B.C. Since it was first identified in 1951, it has been studied by numerous researchers to understand the kinematics controlling its behaviour. Such studies have become vital due to railway tracks owned by Canadian National Railway (CN) and Canadian Pacific Railway (CP) traversing the valley. Both CP and CN have concluded that the most feasible option to mitigate the risks associated with a slide is to actively monitor the behaviour of the slide using precise technology and instrumentation. The site is currently instrumented with GPS devices to monitor the surface displacement at 3 locations, 10 Vibrating Wire Piezometers (VWPs) to monitor the build up of porewater pressure (PWP), and 2 Shape Accel Arrays (SAAs) to monitor the displacement at the primary shear zone.

Purpose of this study was to process, analyze, interpret, and discuss the raw data obtained from these instrumentations. Establish correlations where applicable. Also, verify existing correlations from published literature using newer data. Aside the instrumentation, barometric data and river flow rate data was also obtained from Environment Canada web data base. The fluctuation of the river matched the fluctuation of the PWP recorded by the VWPs. In addition, from August to April, when the slide is active, the low river level accommodated the slide at velocities averaging 0.15 mm/day. The velocity increased to an average 0.34 mm/day from April to August when the slide was inactive and the buttress effect from the river was in effect. Unusual precipitation events can lead in to an increase in the PWP within the sliding mass, thus disturbing the equilibrium between the driving and resisting forces against sliding. Such precipitation event was identified in mid-February 2017 which resulted in the slide velocity to increase from 1.04 mm/day to 1.14 mm/day pushing the estimated Factor of Safety via Limit Equilibrium Method below 1.0. The accelerated movement observed in mid-February was concluded to have happened due to precipitation event combined with the river dynamics.

Throughout its life, the Ripley slide will continue to undergo active and inactive periods of movement. Changes in topography and PWP conditions will continue to alter the face of the slide posing an imminent risk to the safe operation of the railways. The current GPS system would provide CP and CN personnel a warning of significant surface deformations based on real-time measurements. An alarm system feature of the SAA would also provide an automated warning and should be implemented if costs are not constrained. Once the warnings are received and proper precautions are taken, data from the instrumentation should be processed and analyzed at earliest convenience to understand the changes in subsurface soil and groundwater conditions. Ultimately, based on the historical data, a significant amount of capital would be needed to continue to field monitoring program until a feasible remediation work with can be determined.

Table of Contents

Appendices

List of Tables

List of Figures

1.0 Introduction

1.1 Background

The Thompson River Valley, located approximately 10 km south of the Village of Ashcroft in British Columbia has been subjected to on-going landslide activities. A total of 12 landslides, collectively known as the "Ashcroft Thompson River landslides", were identified within the valley as seen in **Figure 1.1**. The focus of the study presented in this report is the Ripley Slide (the Site, the Slide). The Ripley Slide is among the smallest out of the 12 slides and first identified by Charles Ripley in 1951. It is located east of the Thompson River and bounded by the Napa Slide to the north and the Basque Slide to the South. The Red Hill Slide is located opposite to the Ripley Slid, across the Thompson River. The estimated soil mass of the Ripley slide is 750,000m^3 and it is approximately 200 m and 300 m in length and width, respectively. The height between the toe and the highest open tension crack was estimated to be 40 m. According to the classification system presented by Cruden and Varnes (1993) and the observed deformation rate of 25 to 180 mm/year, the Ripley slide is classified as a "very slow (Class 2)" moving landslide.

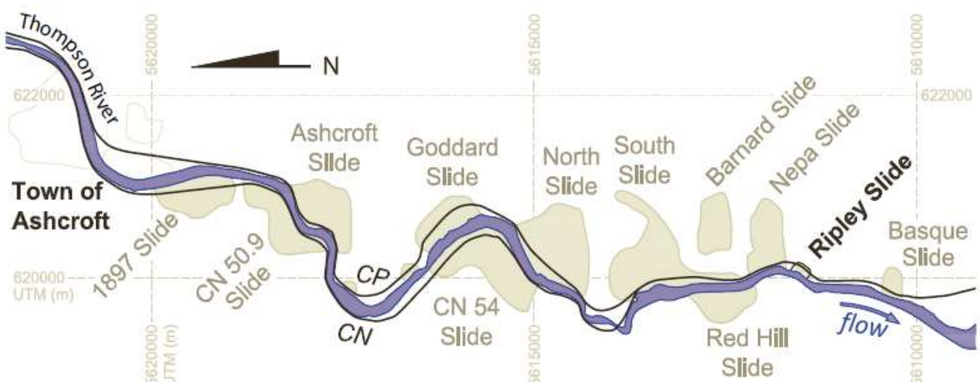

Figure 1.1 – Location of the Ripley Slide along the Thompson River Valley
(Hendry et al, 2015, reprinted with permission)

Figure 1.2 below shows the view of the Ripley Slide; the photograph was taken from across the Thompson River. The retaining wall, which was constructed in 2005, the three GPS stations, railways, and the back scarp of the slide is noted on the figure.

Figure 1.2 – View of the Ripley Slide looking East (Maciotta et al., 2013, reprinted with permission)

1.2 History

The proper understanding of the kinematics controlling the Ripley slide has become essential due the presence of three railway tracks traversing the river valley. The Canadian National Railway (CN) track (constructed in 1926) runs parallel to the toe and two Canadian Pacific Railway (CP) tracks (constructed in 1886 and 2005) run behind and east of the CN track. Between 1951 and 2005, the rate of deformation was very slow and insignificant. Thus, regular maintenance was sufficient to maintain the operations of the railway tracks. However, after the construction of the second CP track in 2005, which required cutting of the slope to provide adequate space for the railway track and carts and installation of a lock-block retaining wall structure, deformations were observed both in the slope and in the wall.

Major site investigations, paired with instrumentation programs, were conducted in 2005, 2013 and 2016. Type of instrumentation installed at the site, to date, include: Vibrating Wire Piezometers (VWPs) and Standpipe Piezometers for subsurface groundwater level monitoring; survey pins and Global Positioning System (GPS) for surface deformation monitoring; and Slope Inclinometers (SIs) and Shape Accel Arrays (SAAs) for subsurface deformation monitoring. A map of the Site along with the location of drilled boreholes and instrumentation can be found in **Figure 5.1** in Section 5.

2.0 Problem Statement

The safe and uninterrupted operation of railways, preferably with minimal delay/interruption time, if any, is of uttermost importance for CP and CN, in order to assure the cost-effectiveness of routine business operations. The uncertainty of the risk associated with the active landslides in the Thompson River valley hinder the said motive and could result in serious damages to life, public and private property and the surrounding environmental system. Thus, safety has become the highest priority. The primary stakeholder includes: CP, CN, Transport Canada, B.C. Provincial Government (Transportation and Environment), and the Department of Fisheries and Oceans. A feasibility study carried out by the CP revealed that the cost of a slope remediation program is high and a reliable performance is not guaranteed. After analyzing the degree of risk to life, property and environment in case of a rapid slope failure, it was determined that the most feasible option is to monitor the deformation of the slope via high quality instrumentation. Numerous studies have been conducted since and the Ripley Slide is still the subject of ongoing research and monitoring.

2.1 Objectives

The primary objectives of this investigation were to:

- Analyze available GPS data to quantify the results and compare against the previous analyses;
- Analyze Vibrating Wire Piezometer (VWP) data and relate the measured porewater pressure (PWP) head against measured flow rates of the Thompson River at the Spences Bridge;
- Analyze and quantify Shape Accel Array (SAA) data and identify failure plane location(s);
- Conduct a slope stability analyses to determine the Factor of Safety under various PWP conditions;
- Comment on the relationship between the estimated deformation rate versus the historical water level of the Thompson River; and
- Discuss the significance of the analyzed data and in need for future monitoring systems, if any.

The historical water levels of the Thompson River are based on recorded data between 2011 and 2013. The recording station is located at the Spences Bridge (approximately 40 km South from Ashcroft) and the data was retrieved from the Environment Canada website. In addition, barometric pressure data from the Kamloops AUT weather station was also used for the analyses. The AUT data was verified against an on-site barometer. However, the river flow data is assumed to be reasonably accurate for the use of this study.

3.0 Review of Literature

3.1 A time-line of historical events

In order to understand the history, the monitoring, and remediation measures taken, it is beneficial to review the published literature to familiarize oneself with the Slide. There are many technical publications written by the faculty and graduate students from the University of Alberta with primary contributions coming from CN and CP. A list of publications reviewed and used to prepare this report can be found under References section at the end of this report in Section 11.

In order to provide the reader with a better understanding of what has been done and observed at the Ripley Slide to date, below is a brief timeline of events and activities.

1886 – CP railway is constructed and traverses the Ashcroft-Thompson river valley;

1926 – CN railway is constructed between the Thompson River and the CP railway;

1951 – Charles Ripley identifies a new slide in the Ashcroft Thompson River Valley, which is later named after him. No significant movements were observed from 1951 to 2005, regular maintenance of the tracks were sufficient to maintain the safe operation of the railway tracks;

2005 – Geotechnical site investigation commissioned by CP was carried out prior to the construction of the second track in 2005. As part of the investigation, 5 boreholes were drilled/cored in which 4 of them were instrumented. The instrumentation included 2 SIs (in boreholes DH05-24 & DH05-27) and 5 VWPs (in boreholes DH05-23 and DH05-26). Borehole DH05-25 was not instrumented;

2005/2006 – CP down cuts the slope, constructs a second railway track. A lock-block retaining wall was constructed to support the slow moving slope. Movement of the slope and wall were observed. Instrumentation monitoring initiated and carried out by BGC Engineering at a frequency of 2 field visits per year;

2006/2007 - SIs from 2005 installation are sheared off within 17 months from installation. Increased maintaining of the railways required during winter months where the water level of the Thompson River is at the lowest, reducing the buttress effect on the slope;

2007 - Development of a tension crack and a scarp observed. The back scarp of an approximately 40,000 m^3 portion of the landslide became visible in the excavated cut slope track increased maintaining of the railway required during winter months. A total of 18 survey pins were installed on the slope in April as part of a conventional optical survey. The pins were surveyed in May and June by EHS Consulting Ltd. Survey results yielded a sliding velocity between 25 to 180mm/year;

2008 – Installation of a Global Positioning System (GPS) to obtain continuous deformation measurements;

2013 – Geotechnical site investigation carried out in April replaced the sheared SIs from 2005 field program and to obtain high quality soil samples. One SAA was installed. Two boreholes (BH13-01 & BH13-02) were drilled near the existing DH05-27. SIs were installed in BH15-02 and BH15-06; and

2015 – A drilling and instrumentation program was carried out in April/July to aid the M.Sc. thesis by Matthew Shafer from U of A. Deformation and PWP measurements were obtained at more locations. In addition, the SIs from the 2013 investigation was replaced (as there were approaching the manufacturer's recommended life-span) with one SAA.

4.0 Geology

4.1 Anticipated Local Stratigraphy and Landforms

Ashcroft Surficial Geology Map (1976):

According to the 1:126.720 Ashcroft surficial geology map (MAP 1405A) produced by the Geological Survey of Canada in 1976, the surficial unit is identified as “dCh” – landslide. The CP and CN railway tracks as well as the Town of Ashcroft is visible in the map. The surficial deposits are described to be “heterogeneous, mixture of silt, gravel, and till”. The landform is described as “hummocky and undulating ground in front of steep slide scar”. Additional comments on this unit mentions “landslides of unconsolidated Quaternary sediments (originally silt, till and gravel”). South of the “dCH” unit and east of the Thompson River is the unit “R” – rock outcrop. The source is provided as bedrock. The landform is described as “plain undulating sloping” and the approximate slope angel is provided to be between 0 and 30 degrees. Adjacent to and east of units “dCh” and “R” is the unit “Mb” - till blanket. The approximate thickness of the till is provided to be greater than 2.0 m. It is stated that the “topography and the landform is controlled by the underlying bedrock surface” and the unit is known to include “small areas of bedrock outcrop”. Finally, across the Thompson River, opposite to the Ripley Slide is the unit gAt – river terraces, alluvial terraces which consists fluvial gravel and boulders less than 10 m thick. The approximate slope angle is given as 0 to 3 degrees with terraces typically cut in to the older unconsolidated valley-fill deposits. Combined with the unit gAt is the unit dAf – alluvial fan (mudflow), which is source of gravel. The typical slope angle ranges from 0 to 15 degrees.

Geological Survey of Canada - Open File 7531 (2014):

In their 2014 report to Geological Survey of Canada, Huntley and Bobrowsky provided a more up-to-date model of the surficial geology of the site as seen in **Figure 4.1** below. According to the report, the surficial geology of the sliding mass belongs to the Holocene formation and identified as the unit “Cv” – Colluvial veneer. The Cv unit is said to include “silt, sand, cobbles and boulders reworked by soil creep, hillslope wash, debris flows and gully erosion” overlying “till and Glaciolacustrine deposits”. Between the Colluvial veneer and the rail ballast and train tracks is a strip of the unit “GLb” – Glaciolacustrine deposits which includes “interbedded silt, sand, clay and diamiction. The plasticity of the Glaciolacustrine clay is said to range from medium to high. About six gullies are present east of the active head scarp in the Cv unit. In addition, a late glacial terrace was identified and located in the unit “Af” – Alluvial fan deposits. The Af unit contains “clay, silt, and sand draped over bedrock. Till and glaciofluvial sediments”.

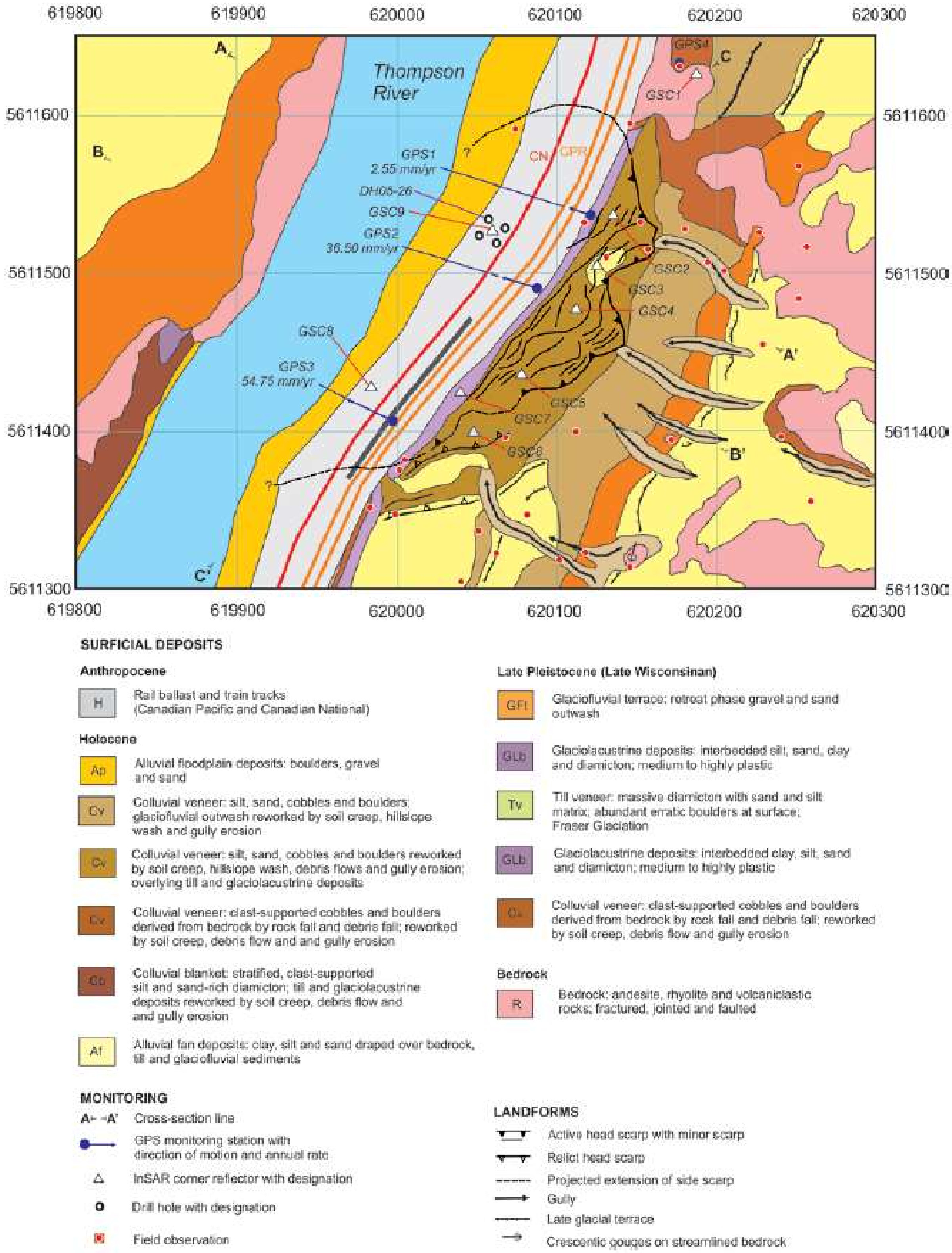

Figure 4.1 – Provisional surficial geology & landforms at the Ripley Slide

(after Huntley and Bobrowsky, 2014, reprinted with permission)

4.2 Encountered Stratigraphy

The encountered stratigraphy during field drilling confirmed the anticipated local stratigraphy for the Site. Borehole logs from the actual field investigations were unavailable. However, the existing literature provided a summary of the encountered stratigraphy. The first detailed site investigation was conducted in November 2005 by CP prior to installing a second railway line and constructing an embankment and a retaining wall structure. The investigation included a five borehole drilling program at the Ripley site. Two additional investigations followed in 2013 and in 2015. In 2013, CP commissioned BGC Engineering Inc. (BGC) to replace some of the instrumentation and install new data acquisition systems. In 2015, more instrumentation was installed to further understand the site condition and to refine the geological model for the Site. Section 3.1 above provides a description of the instrumentation.

The geology of the Site is represented in the following geological model as shown in **Figure 4.2**. The original figure represents the stratigraphy at Ashcroft, about 10 km north of the Ripley Site. Note that the geodetic elevation axis was removed from the original figure to avoid yielding a false impression of a consistent stratigraphy. It is important to note that the interface boundaries between each of the subsurface soil and the soil-bedrock boundary has a high variability. However, the geological model is typically consistent throughout the Ashcroft-Thompson River Valley and therefore, could be used to lay a foundation for the geological framework.

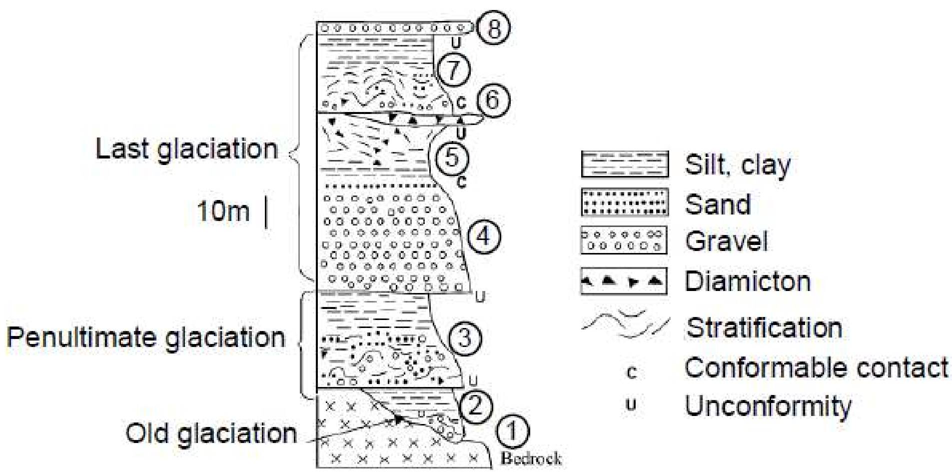

Figure 4.2 – Subsurface soil profile of Thompson River valley at Ashcroft (Clague and Evans, 2003, reprinted with permission)

As shown in **Figure 1.1**., the Ripley Slide is located between the South Slide and the Basque Slide, closer to the latter. The vertical height of the Ripley slide, which is approximately 45 to 50 m, spans units 1 to 3. **Figure 4.3** below shows the variability in the subsurface soil profile between Slide CN50.9 to Basque Slide (north to south). The primary shear plane, as identified by the red arrows, is located within the Unit 2 – Silt and clay, which are Glaciolacustrine deposits. The bedrock at the Site was identified as andesite – a fine grained fractured crystalline igneous rock.

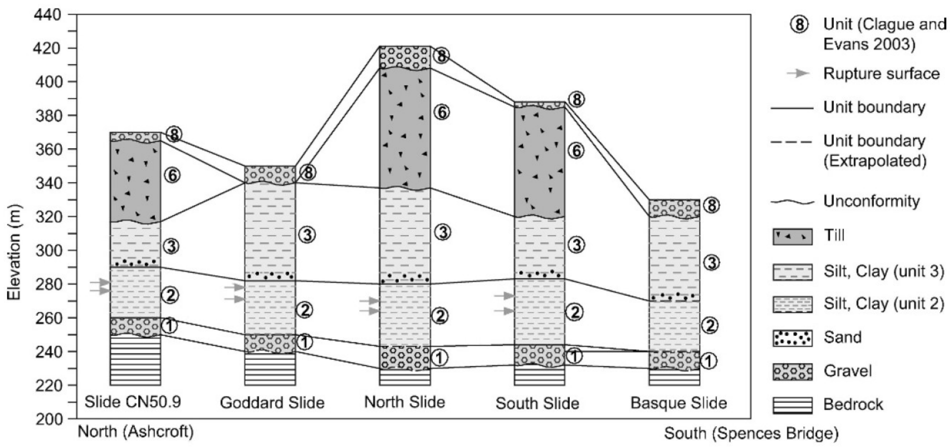

Figure 4.3 – Provisional surficial geology and landforms at the Ashcroft-Thompson River valley (Eshraghian et al., 2007, reprinted with permission)

Since the failure plane is located within the Glaciolacustrine deposit, which overlays the unconsolidated, approximately 2 m thick, Colluvial (unit 1), the main focus of here within is given to Unit 2. These Glaciolacustrine deposits belongs to the early/mid Pleistocene formation. At the transition zone between Unit 1 and 2, a coarse deposit of cobbles and sand were identified during the 2013 and 2015 geotechnical drilling programs (Schafer, 2016). These coarse deposits can be seen in the bottom half of **Figure 4.4** below.

4.2.1 Unit 2 – Glaciolacustrine Sediments (Silt & Clay)

The silts and clays were deposited by suspension in a glacial lake, thus the name "Glaciolacustrine". The clay, silt, sand and diamiction are rhythmically laminated. The lamination is a result of seasonal influences. During the spring/summer, only the coarser sand is deposited. In the winter, where the lake is covered with ice, the finer clay and silt is deposited. About 2 to 3 m of Unit 2 is exposed on the east side of the river at the railway cut bank. Also, Unit 2 is exposed at the steep cut bank west of the river (Huntley and Bobrowsky, 2014).

Rare pebbles and cobbles (dropstones) can be also found dispersed within Unit 2. It is estimated that Unit 2 is primarily composed of Clay, approximately 70% or more. The dominant clay mineral is believed to be Illite, which is typically 5 to 25 nm thick. It is suggested that the fine-grained sediments of the Unit 2 are a "result of low-energy deposition in a proglacial lake confined to the Thompson River valley prior to the ice advance in to the valley" (Huntley and Bobrowsky, 2014).

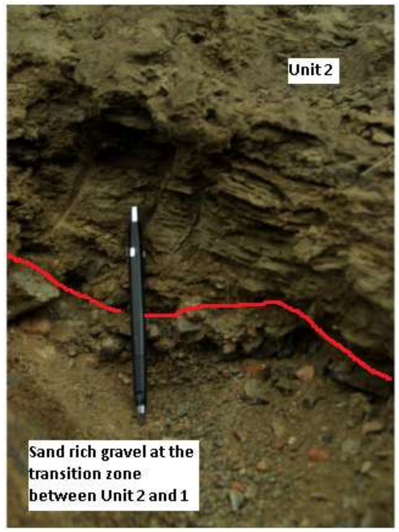

Figure 4.4 – Glaciolacustrine deposits (Unit 2) and gravel rich sand at the bottom transition zone (Huntely & Bobrowsky, 2014, photograph used with permission)

4.3 Groundwater

The subsurface groundwater flow can be categorized as regional flow, intermediate flow, and local flow. For the Ripley Site, the effect of local groundwater flow is analyzed. Since the site is adjacent to the Thompson River, it is understood that groundwater table daylights in to the river. The VWPS installed during the 2013 and 2015 geotechnical site investigations help to determine the piezometric head level at the corresponding drilled borehole locations. The VWP data could be then used to draw a reasonable representation of the local groundwater table.

It should be noted that seasonal factors can have a significant impact on the variation of the local groundwater flow. For example, infiltration associated with snowmelt during the spring time results in a rise in the water table. Precipitation could also result in a slight increase in the water table. However, the amount of recharge from the surface run-off and infiltration depends on the topography of the surface at the site. In addition, the seasonal fluctuation of the Thompson River water level could be related to the fluctuations seen in VWPs. The relationship between the river level and the VWP data are discussed in detail in Sections 7.1 and 7.3. In the bedrock, fractures can increase the flow rate. However, it depends on the thickness of the factures/joints, orientation, and infilling, if any. Due to the effects such as slope erosion and excavation of the over burden, the soil can undergo vertical relaxation (unloading). The relaxation can result in fractures and is attributed to the increased flow of the groundwater in the bedrock.

5.0 On-Site Instrumentation

This section presents a summary of instrumentation present on site as the time of this report preparation. The on-site instrumentation includes Vibrating Wire Piezometers (VWPs), Shape Accel Arrays (SAAs), Slope Inclinometers (SIs), and Global Positioning Units (GPSs).

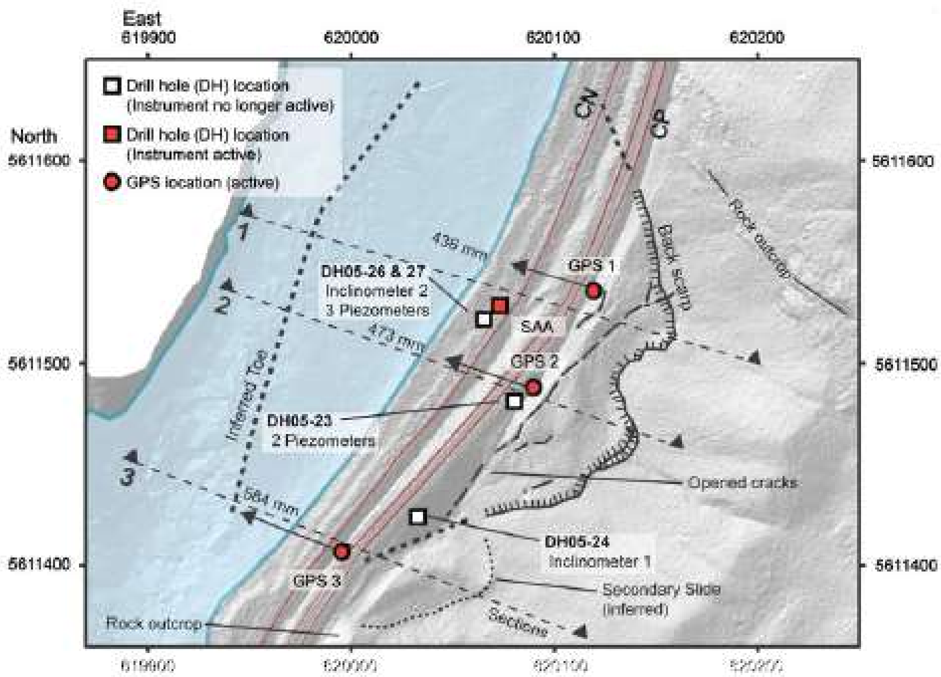

Figure 5.1 – Approximate locations of active and inactive instrumentation at the Ripley Site along with identified landform features (Macciotta et al., 2014, reprinted with permission)

5.1 Global Positioning Systems (GPS)

There are three (3) GPS devices, namely GPS1, GPS2 and GPS3, installed on the landslide along with a one stationary reference GPS antenna in February of 2008. The reference antenna can be seen in **Figure 5.2** below, it is fixed to a concrete pillar, which is anchored in to the stable bedrock. All four units are connected to a central data processing and logic controller which is housed in a prefabricated bungalow. The approximate location of each GPS unit is shown in **Figure 5.1** above. The Leica GPS system is based on the single phase GMX901 receiver and the real-time monitoring software used is Spider/GEOMoss (Bunce and Chadwick, 2012). The GPS devices are programmed to take a reading at 24-hour intervals with an accuracy better than 5 mm. A brief summary of the definitive starting coordinates for each GPS unit is provided in **Table 5.1** below.

Table 5.1 – Summary of the Definitive GPS Starting Coordinates at the Ripley Site

Unit	Latitude (N)	Longitude (W)	Elevation (m asl)
GPS1	50° 38' 31.8192"	121° 18' 10.6884"	262.293
GPS2	50° 38' 34.3494"	121° 18' 5.6268"	261.335
GPS3	50° 38' 31.8192"	121° 18' 10.6884"	260.025

The first recorded data set is from 11 April 2008. Due to equipment down-time, power cuts and railway maintenance activities, etc., the recorded data is not continuous. As part of the railway risk management, maximum threshold of 20 mm of displacement is set for the GPS devices during a 24-hour time period. In the event the recorded displacements exceed the said threshold, an automatic warning is set to CP and CN personnel. A successful trial of the automated trigger mechanism was carried out in February 2013 (Hendry et al., 2013).

Figure 5.2 – The single fixed GPS antenna and the junction box at the Ripley Site (Bunce and Chadwick, 2012, reprinted with permission)

5.2 Vibrating Wire Piezometers

VWPs were installed in 2013 and in 2015. The VWPs from 2013 were installed by BGC Engineering Ltd. All VWPs installed on site are the standard VW2100 series manufactured by RST Instruments Ltd (RST). An image of a RST VWP can be seen in **Figure 5.3** below. **Figure 5.4** shows the layout inside the VWP. The VWPs were grouted in and connected to a CR1000 data logger manufactured by Campbell Scientific Ltd. The CR1000 records the raw porewater pressure (PWP) in B Units. A conversation from B Units to kPa can be found on the calibration sheets for each VWP provided by RST Instruments Ltd. RST's calibration sheets are included in Appendix D and further discussed in Section 6.3.

The resolution and the accuracy is 0.025% F.S. minimum (0.35 kPa) and 0.1% F.S., respectively. An error of ±0.35 kPa corresponds to approximately ±3.5 cm of PWP head. The NTC 3K ohms (at 25°C) type thermistor has a resolution of 0.1°C. The high accuracy allows to measure porewater level changes as small as 0.5 mm. (RST, 2017).

Figure 5.3 – A Vibrating Wire Piezometer (standard type) manufactured by RST Instruments Ltd. (image obtained from rstinstruments.com, accessed 6 July 2017)

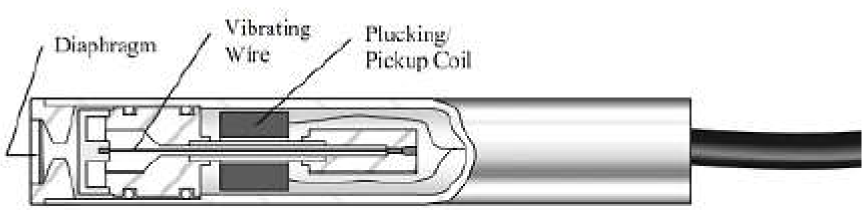

Figure 5.4 – A standard vibrating wire sensor (from CR6 data logger manual by Campbell Scientific, page 361, dated 26 March 2015)

In addition to the PWP, each data entry is recorded as a "record number", the time is recorded in YYYY-MM-DD HH-MM format and the temperature at each VWP and also at the CR1000 logger is recorded in degrees Celsius.

Currently, all data is recorded at 5-minute intervals. The data is available from 4 May 2013, approximately 1700 HRS.

Table 5.2 – Summary of Vibrating Wire Piezometers Installed on-site on 2013 by BGC Engineering					
Borehole ID	RST VWP Serial No.	Mux Slot	Depth (m bgs)	Geodetic Elev. (m asl)	Soil Unit
BGC-BH13-01	24278	1	11.28	261.60	Glaciolacustrine Clay
BGC-BH13-01	24281	2	15.85	258.00	Glaciolacustrine Clay
BGC-BH13-01	24282	3	20.42	252.50	Glaciolacustrine Clay
BGC-BH13-01	24279	4	32.61	240.30	Bedrock
BGC-BH13-02	24283	5	16.76	257.10	Glaciolacustrine Clay
Thompson River	24280	6	1.5	N/A	N/A

N/A = data not available

The VWP24280 was installed in the Thompson River to measure the fluctuation of the river level as the buttress effect provided by the river has a direct impact of the stability of the soil mass under motion. It is understood that the VWP24280 was destroyed by a rock fall event. The raw data suggests the said event occurred at approximately 0100 HRS on 5 May 2014, which corresponds to the last reliable reading from the VWP24280. The Logger permanently stopped recording Linear Digits (B bar values) from VWP2480 on approximately 2305 HRS on 13 March 2017. Between 5 May 2014 and 13 March 2017, the temperature data does not reflect the seasonal variations and the Linear digits are about 1,000 units consistently lower. Therefore, the data between the said internal is assumed to be erroneous and shout be discarded.

The top elevation of Borehole BH15-01 and BH15-03 is 282.5 m asl and 278.1 m asl, respectively. **Table 5.3** below tabulates a summary of VWPs installed during the 2015 geotechnical site investigation.

Table 5.3 – Summary of Vibrating Wire Piezometers Installed on-site on 2015					
Borehole ID	RST VWP Serial No.	Mux Slot	Depth (m bgs)	Geodetic Elev. (m asl)	Soil Unit
BH15-01	N/A	8	8.5	274.0	Till
BH15-01	N/A	7	13.1	269.4	Glaciolacustrine Clay
BH15-01	N/A	6	18.3	264.2	Bedrock
BH15-03	N/A	1	6.4	271.7	Till
BH15-03	N/A	2	9.5	268.6	Glaciolacustrine Clay
BH15-03	N/A	3	12.2	265.9	Glaciolacustrine Clay
BH15-03	N/A	4	14.9	263.2	Glaciolacustrine Clay
BH15-03	N/A	5	16.7	261.4	Bedrock

N/A = data not available

5.3 Shape Accel Arrays (SAA)

The SAA included 0.3 m (305 mm) long segments in which each segment has an axis sensor to record the acceleration and the temperature. The sensorized segments are connected by a durable and flexible joint. The smaller segment length allows for high spatial resolution opposed to using 0.5 m segments. Note that 0.2 m segments are also available. However, a higher spatial resolution would result in higher instrumentation costs. For Ripley Slide, based on the previous slope inclinometer data, a 0.3 m segment is adequate. The SAA segments are installed within a 1-inch PVC casing, which is then grouted in to the borehole using a predetermined grout mix. The ratio of water to cement to bentonite in the grout mix is determined such that the stiffness of the hardened grout is close to the expected stiffness of the in-situ soil.

Figure 5.5 below shows a photograph of the SAA installation during the 2015 site investigation program.

Figure 5.5 – The ShapeAccelArray (SSA2) before installation on site in 2015
(Schafer, 2016, reprinted with permission)

At the time of this report preparation, there are two (2) SAAs installed on site. The first one (SAA1, Serial # 55468, 32 segments) was installed in 2013 in Borehole BGC13-02 between 261.3 m asl and 251.6 m asl (approximately 9.7 m in length). Entire length of SAA1 is within Glaciolacustrine Clay and Silt. The second one (SAA2, Serial # 62049, 30 segments) was installed in 2015 in Borehole BH15-04 between 274.2 m asl and 265.0 m asl (approximately 9.2 m in length). The SAA2 is embedded within a boulder overlaying till overlaying Glaciolacustrine Clay and Silt. The primary shear surface measured by the two SAAs are located within the Glaciolacustrine deposit.

6.0 Methodology of Analysis

6.1 Thompson River Water Level data

In order to analyze if the Thompson River has a direct influence on the kinematics of the Ripley Slide, it is important to understand the dynamics of the river. At the Site, the river flows from north (Ashcroft, located approximately 10 km away) towards South (Spences Bridge, located approximately 40.3 km away along the Thompson River). Location of the Spences Bridge with respective to Ashcroft is shown in **Figure 6.1** below and in **Figure A1** in Appendix A. A view of the Thompson River from the Ripley Slide is shown in **Figure 6.2**. The historic river data available from Environment Canada are recorded at the Spences Bridge. It is assumed that the river data at this location is an adequate representation of the river data adjacent to the slide. The historic data include daily flow from 1 October 1951. In addition, hourly flow data and river water level data is also available and the time period from 29 November 2015 to 29 May 2017 is analyzed.

Figure 6.1 – Location of Spences Bridge along the Thompson River with respect to Ashcroft (Google Maps imagery, 2017)

Figure 6.2 – A view of the Thompson River at the Ripley Slide
(Photo courtesy of Jorge Rodriguez, May 2015)

In order to obtain more accurate river data, a VWP (VWP24280) was installed in the Thompson River at depth of 1.5 m (i.e., 1.5 m below the river level at the time of installation) in 2013. The geodetic elevation of the VWP24280 was determined by trial and error as described in Section 7.1. Data from VWP24280 is available from 5 May to 2013 to 5 May 2015. When the VWP is below the river level, the recorded porewater pressure would result in the river level with respect to the location of the VWP. Consequently, when the VWP is exposed to air, the recorded pressure indicates the pressure due to suction resulted by the barometric pressure.

Analyses were carried out to determine/observe:

- How the seasonal variations in the Thompson River relates to the cumulative displacement trend of the Slide;
- How the suction recorded by the VWP24280 relates to the barometric pressure data;
- How the variation in the PWP recorded by the VWP24280 compare to the variation of the river flow rate data measured at the Spences Bridge for a given time interval; and
- Validate the existing empirical correlation between the historical river flow data and the river level.

6.2 Global Positioning System (GPS) Data

For each one of the 3 GPS units, the position is recorded in terms of latitude, longitude and elevation above sea level, along with a time stamp. The raw data is broken down to degree-minute-second format. Once this conversion is done, the latitude is multiplied by a scalar factor of 111,319 to convert to meters. Similarly, the longitude is multiplied by a scalar factor of 111,319 x 0.639 in order to obtain meters. These conversion factors were provided within the data file “Flow and Climate Data Plots (003).xlsx” provided to Menuka Dassanayake, E.I.T. via email by Dr. Michael Hendry, Ph.D., P.Eng. on 16 June 2016. The raw data records the elevation (height) in m asl. Once all the raw data are in Cartesian unit (i.e., meters), the cumulative vertical (based on height) and horizontal displacement (2-demensional displacement based on longitude and latitude) is calculated. In addition, the dip of the movement can be also approximated by taking the tangent of horizontal and vertical displacement. All the GPS data were processed using Microsoft Excel for simplicity.

6.3 Vibrating Wire Piezometer (VWP) data

In order to properly analyze and make sense of the VWP data, it is important to first understand how the VWP functions. The VWP consists of two main components, the vibrating wire (VW) and the piezometer. The VW contains a high tensile steel wire. The wire is anchored at one end and the other is connected to a diaphragm which is in contact with porewater. The tension in the wire is proportional to the resonant frequency of the vibration. The readout unit detects the alternating current in the wire induced by the frequency. The piezometer consists a stainless steel porous filter to protect the migration of fine soil particles in to the diaphragm. The thermistor is built in to the thermometer (RST, 2017).

The PWP data recorded by the CR1000 data logger is in B Units (B units = $Hz^2/1000$) and the data CR6 logger is set-up to record the PWP in both B Units and in kPa. The conversion from B units (also = L, linear digits) to pressure (P) could be carried out using either the linear function or the polynomial function provided by RST in their calibration sheet for each VWP. RST recommends using the polynomial function when the average linear error provided in the Calibration Record for each VWP exceeds ±0.2%. In addition, the polynomial fit provides a better accuracy. More information about using these two functions can be found in Section F2 of Appendix F.

Linear function:

$$P\,(kPa) = C.F.\,(L_i - L_c) - [T_k(T_i - T_c)] + [0.1(B_i - B_c)]$$

Polynomial function:

$$P\,(kPa) = A(\,L_c\,)^2 + BL_c + C + [T_k(T_c - T_i)] - [0.1(B_c - B_i)]$$

Where,

C.F. = linear calibration factor;

Tk = temperature correction factor;

Li and Lc = initial (at installation) and current readings;

Ti and Tc = initial (at installation) and current temperature readings in °C;

Bi and Bc = initial (at installation) and current barometric pressure readings in in mbar; and

A, B, and C = polynomial gage factors (kPa).

The raw VWP data from the CR6 was not converted to kPa to validate the B Units to kPa conversion provided within the raw data file as no calibration records were available. It assumed that the kPa data accounts for the temperature variation but not barometric pressure variation. The maximum variation and the average value of the barometric pressure recordings from the CR6 logger between 7 May 2015 and 30 April 2017 was approximately 5.7 kPa and 98.0 kPa, respectively. The barometric pressure at the time of installation was determined to be approximately 98.2 kPa. Therefore, the influence of barometric pressure on PWP recorded by the CR6 VWPs was determined to be between 2.6 to 3.1 kPa. These values correspond to approximately 26 and 32 cm of extra PWP head, respectively and are negligible.

6.4 Shape Accel Array (SAA)data

Both SAAs record data in TOA5 format. The raw data includes a time stamp (in YYYY-MM-DD HH: MM format), temperature records in degrees Celsius, and acceleration values. The raw acceleration values from SAA's MEMS sensors needs to be converted to engineering units (Cartesian) using Measurand's SAACR_raw2data program available for free from their website. The converted Cartesian file (ex. Multi_saa_allcart.mat) file can be opened in Measurand's' SAAView program or SAA3D program (also available free of charge) to plot and analyze the recorded deformation against time. SAAView is an interactive tool which offers 3D-animations of the deformed SAA segments and provides many options for data viewing and analysis. During the conversion of the raw data file using SAACR_raw2data program, it is also possible to export the processed data directly in to a third-party program like Microsoft Excel (needs to be manually converted to. xlsx format from .DAT). The shear plane observed in the SAA is compared to the previously identified shear planes. In addition, the displacement and the velocity of the slide as observed by the SAA is compared to those observed from the GPS system at the surface. The deviations between the two observational methods are explained and the significance is discussed.

6.5 Ashcroft Daily Precipitation data

Historic precipitation data from the Ashcroft area was accessed from the Environment Canada web data base to determine if high precipitation activities (based on the historical average for the month) correspond to accelerated movements observed in the GPS and SAA data. Note that "precipitation" is the summation of the measured rain fall and the equivalent water content of the snowmelt. Focus was given during the late fall/early winter months where the river level is at the lowest. When the river level is low, the buttress effect provided by the river on the sliding soil mass is minimal and any increased precipitation could potentially accelerate the movement. The PWP data is also looked to see if any usual spike, if present, correspond to unusual precipitation events. A sudden spike in the porewater pressure could disturb the equilibrium by decreasing the effective stress, resulting in decreasing shear strength at the relatively weak Glaciolacustrine clay and slit zone (in Unit 2 as described in Section 4.2.1).

6.6 Limit Equilibrium Method

Due to the observed slow displacement rate of 20 to 180 mm/year, it is understood that the statistics of the sliding mass is close to equilibrium. Thus, a limit equilibrium method (L.E.M.) analysis should result in a Factor of Safety (F.O.S.) value close to unity (i.e., 1.0). Using newly available geological cross sections of the Ripley Slide (Schafer, 2016), a comprehensive L.E.M. was carried out by analyzing different combinations of PWP and Thompson River level data. It is assumed that the cross sections presented by Schafer is valid up to May 2017 and the only variable would be the PWP conditions. For the L.E.M., Morgenstern Price method is used with a forced slip-plane to match the observations from the SAA data. The advantage of the Morgenstern-Price method is that it can be applied to a non-circular slip plane. In addition, this method also considers both force and moment equilibrium. Therefore, for L.E.M., Morgenstern-Price method is the current standard of practice in the local consulting engineering field. The groundwater level is interpreted from the PWP data processed from the VWPs.

The updated cross sections are re-created in the slope-stability analysis program Slope/W by GeoStudio. The Slope/W program enables the user to: build a cross section, assign soil engineering properties to it, draw a piezometric head ground water table, apply a surcharge load (if any), choose a L.E.M. method, specify a failure plane, etc. and outputs a F.O.S. It is understood that the local GWT daylights in to the Thompson River. During the drilling programs conducted, it is understood that no perched water tables were discovered. Field borehole longs from 2005, 2013 and 2015 geotechnical drilling programs were not available for interpretation at the time of this report preparation.

6.6.1 Limitations of the Limit Equilibrium Method

It is important to understand that the L.E.M. is purely based on the principles of statics – i.e., it does not account of displacement nor strain compatibility (Krahn, 2002). Therefore, the variations with the F.O.S. value with the sliding mass is not considered, rather, an “average” F.O.S. value is obtained along the idealized slip surface. The alternative approach would be to conduct the stability analysis using a stress-strain based approach. For example, stress-strain based stability approach based on Finite Element Method (F.E.M.). The difference between the F.O.S. value computed using a L.E.M. and a F.E.M. along an idealized slip surface is shown in **Figure 6.3**. below.

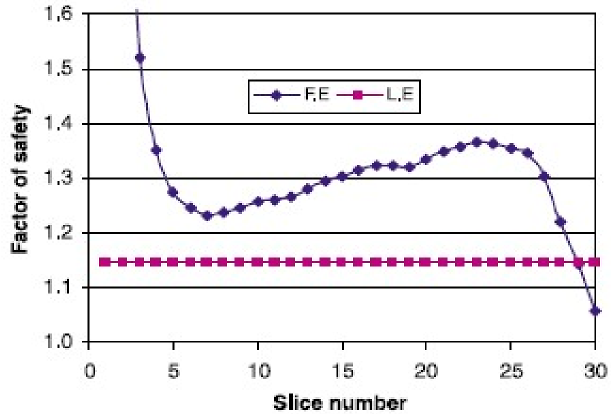

Figure 6.3 – The variation of the local F.O.S. between the L.E.M and the F.E.M. for an idealized slope at the toe (Krahn, 2002, reprinted with permission)

However, the L.E.M. can be effectively used given the modeller understand the method, the capabilities, and the limitations. Given that the Ripley slide is a "natural" slide where the slip surface does not have any sharp corners in which there are high stress concentrations, the L.E.M. is deemed adequate, despite the said limitations. Also, due to the complex geological processes underlying the formation of landmass containing the Ripley Slide, it is rather difficult to assess the stress distributions with in the slope. Therefore, L.E.M. is considered suitable for the slope stability modelling.

6.6.2 Cross Sections and soil properties

The three updated cross sections (Schafer, 2016) used for the L.E.M. analysis are provided below in **Figure 6.4**. The location of the cross sections 1, 2, and 3 can be seen in **Figure 5.1** in Section 5.0. The soil properties presented in **Table 6.1**. below are based on previous studies and geotechnical investigations done on the site (Hendry et al., 2015).

Table 6.1 – Estimated Unit Weights and Effective Friction Angles for Ripley site

Soil unit	Description	Unit weight, γ (kN/m³)	Effective friction angle, ϕ' (°)
8	Gravel (pebbles to cobbles)	20	34
6	Till (Diamiction)	18	26
2	Glaciolacustrine Silt and Clay, interbedded	17 to 20	Peak: 16 to 21 Residual: 9 to 16
N/A	Bedrock (andesite)	N/A	N/A

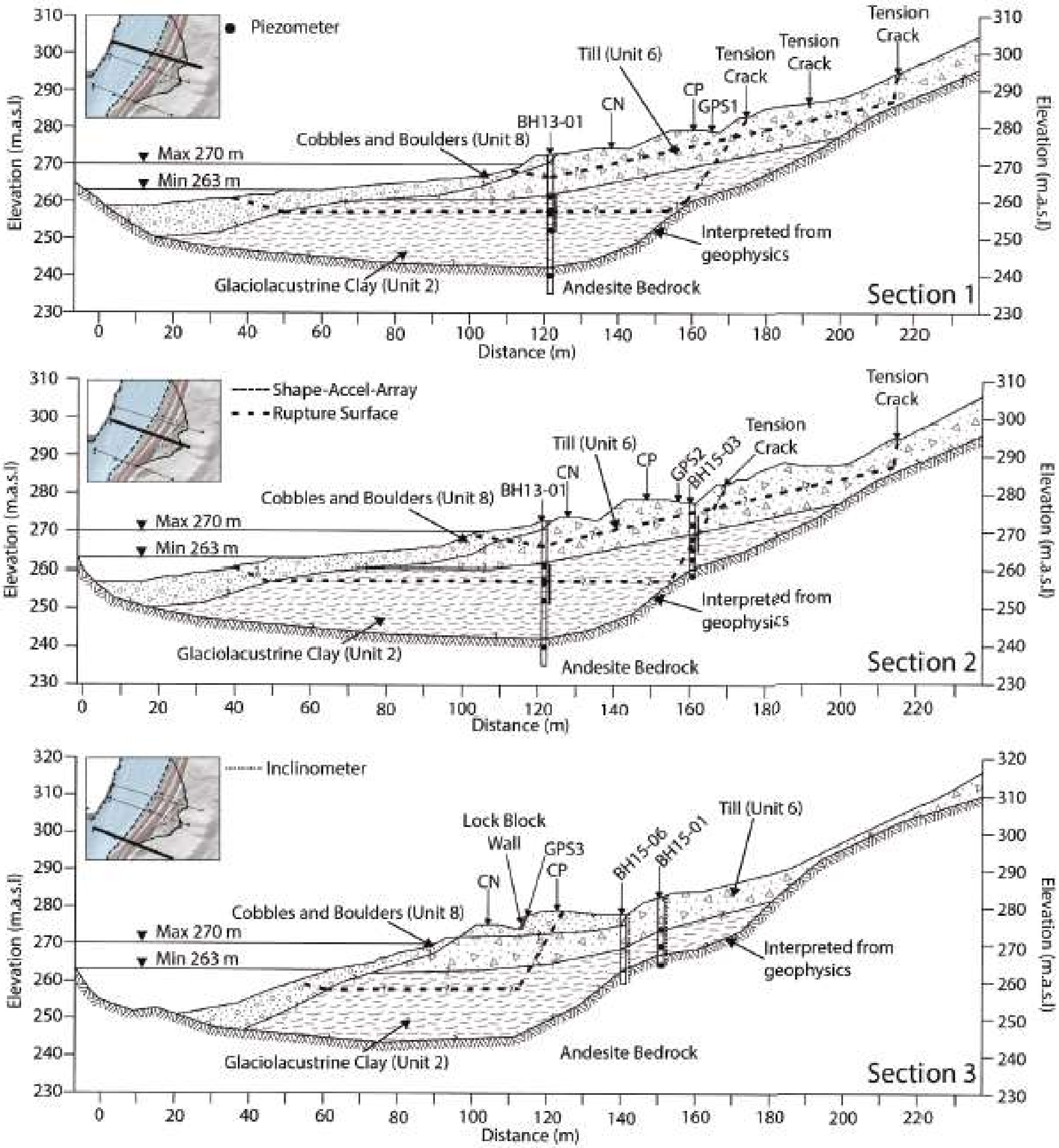

Figure 6.4 – Revised and the most recent cross sections of the Ripley Slide (Schafer, 2016, reprinted with permission)

7.0 Results

7.1 Thompson River Water Level data

The analysis of the river data shows that the presence of the river at the site has a significant impact on the kinematics controlling the displacement of the slide. The historic river flow data from Spences Bridge station (Environment Canada web database) is analyzed with the river water level recorded by VWP24280 between 5 May 2013 to 15 May 2014. The result is illustrated in the **Figure 7.1** below.

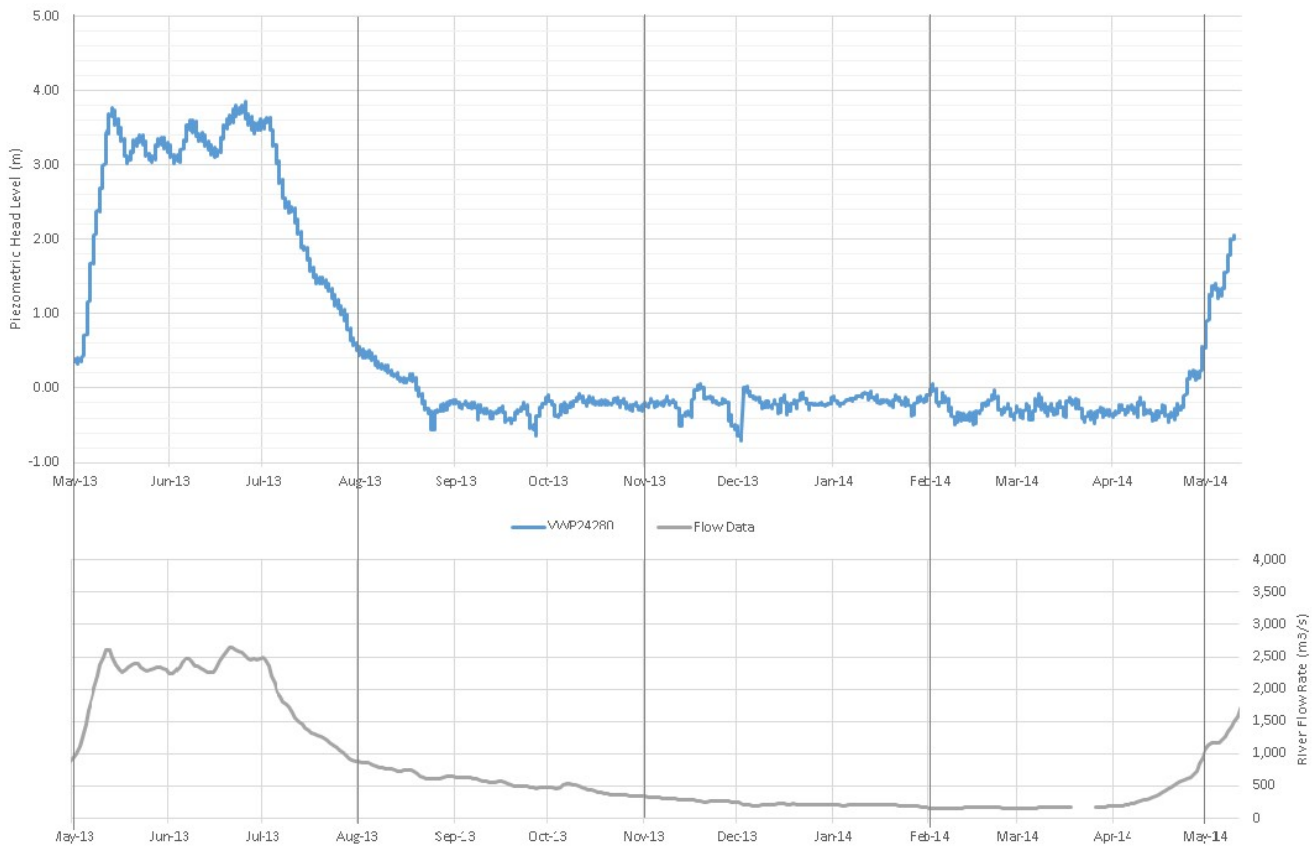

Figure 7.1 – VWP24280 raw data (top) and Thompson River Flow data (bottom) from May 2013 to May 2014

From the above figure, it is clear that the flow rate measured at the Spences Bridge correlates well with the trend of the piezometric head measured by the VWP24280 installed in the river by the toe of the Ripley slide. Therefore, use of the flow data to interpret the river level is deemed adequate. To convert the flow rate "Q" (m^3/s) measured at the Spences Bridge in to river level elevation "L" (m asl) adjacent to the Ripley slide, the following equation can be used.

$$L = \frac{Q^{0.562}}{74.10} + 261.50$$

This equation proposed by Schafer (2016) as Eq. 4-1 to predict the flow rate Q as a function of the river height (L). It was developed by computing the "residual sum of the squares of the power law with respect to the piezometer [VWP2480, approximately 3,500 data points used] data". It is understood that Eq. 4-1 is valid for river elevations ranging between 261.92 and 270.26 m asl.

From the available records, it is understood that the VWP24280 was installed approximately 1.5 m below the river elevation at that time. The geodetic elevation of the river at the time of installation was not available. Therefore, the geodetic elevation of the VWP 24280 is unknown. However, a crude estimate of the VWP24280 can be made using the Eq. 4-1 proposed by Schafer (2016). Using Eq. 4-1, the flow rate Q is estimated based on an assumed VWP24280 elevation of 264.90 m asl. The results are tabulated in **Table 7.1** below. Note that the negative PWP head in the third column indicate the suction in the air, i.e., the data was recorded when the VWP was above the river level.

Table 7.1 – A Comparison Between Measured and Estimated Thompson River Flow Rate Data

Date	Q, measured (m^3/s)	PWP head from VWP (m)	River Elev. (m asl)	Q, estimated (m^3/s)
15 May 2013	2,500	3.52	268.42	2,316
5 Aug. 2013	873	0.50	265.40	835
20 Nov. 2013	288	-0.08	264.82	627
1 Jan. 2014	214	-0.23	264.67	577
11 May 2014	1,260	1.7	266.60	1,345

It can be seen that when the VWP24280 is located below the river level, the estimated flow rate is within 4.39 to 6.77% of the measured flow rate. A maximum percent different up to 10% is considered acceptable for the analysis. Therefore, Eq. 4-1 provided a reasonable estimate to predict the water level of the Thompson River using the flow rate data measured at the Spences Bridge. The deviations are attributed towards the accuracy of the data collection system deployed at the Spences Bridge, the degree of care and precautions taken during installing the VWP24280 (i.e., lose cables, spliced cables, etc. can introduce some error), changing river cross section profile between the Spences Bridge and the Ripley Slide, and the limitations of the conversion. The equation used to convert the river level in to flow rate is an "approximate only" – it is by no means an accurate and precise method.

The estimated elevation of the VWP is 264.90 m asl. When the VWP24280 is above the river level, Eq. 4-1 is not valid for estimating river level as the PWP recorded by the VWP represents barometric pressure. From the data analyzed, the error due to barometric pressure was 117.63 to 169.75%. **Figure 7.2** below depict the estimated and measured flow rate listed in **Table 7.1** when the VWP24280 is located below the river level. The effect of barometric pressure variation on the VWP24280 data is further illustrated in **Figure 7.13** under Section 7.3.4.

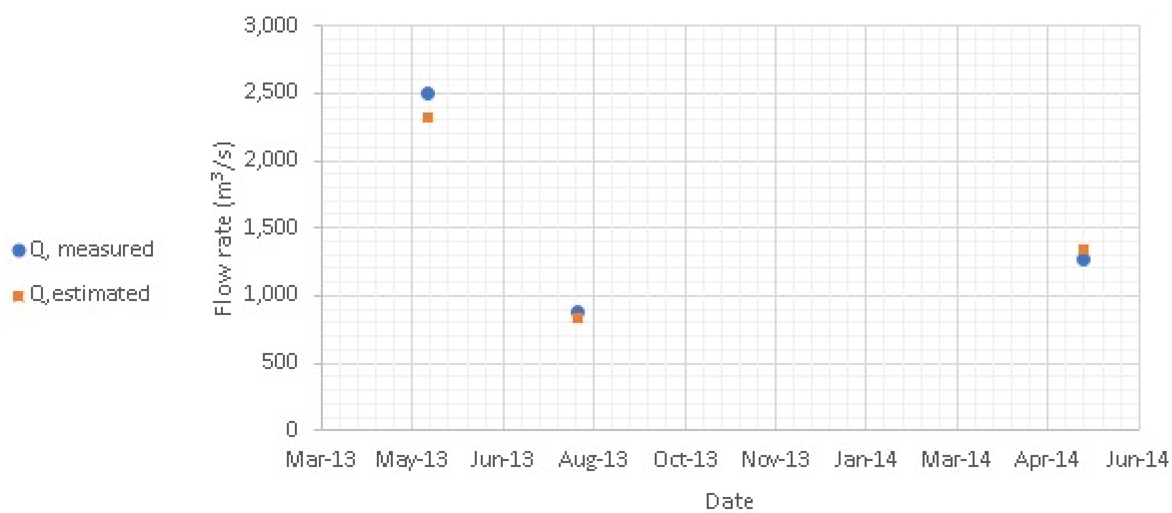

Figure 7.2 – A comparison between measured and estimated flow rate data for Thompson River

7.2 Global Positioning System (GPS) Data

The raw data from the three GPS devices (GPS1, GPS2 and GPS) was analyzed as mentioned in Section 6.2. The cumulative displacement curves indicate that the soil mass is sliding towards the Thompson River. The direction of the movement is shown in **Figure 7.3**. below with respect to the location of each GPS.

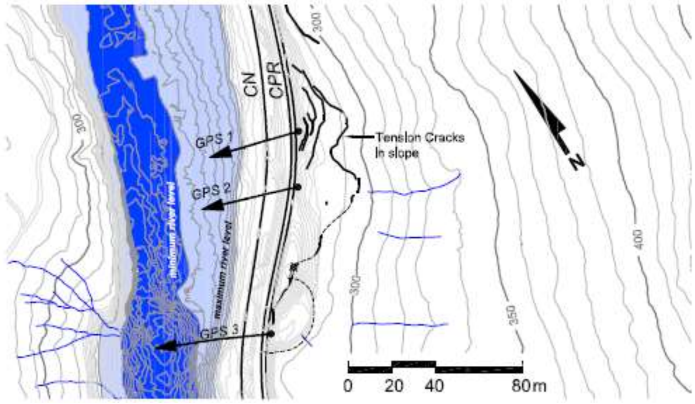

Figure 7.3 – Approximate locations of the GPS devices depicted on a contour map with direction of movement (Hendry et al., 2013, reprinted with permission)

The cumulative displacement curves for each GPS device clearly shows an active period (i.e., the average slope of the curve over time t_1 is > 0, velocity is slow) and an inactive period (i.e., the average slope of the curve over time period t_2 is close to 0, velocity is very slow). The time periods t_1 and t_2 relates to the time periods where the water level of the Thompson River is low and high, respectively. Since the water level directly correlates to the flow rate, the flow rate is used to analyze the effect of the river on the landslide displacement. **Figure 7.4**. shows the trend of the horizontal cumulative displacement alongside the Thompson River water level. And **Figure 7.5**. below shows the trend of the vertical cumulative displacement.

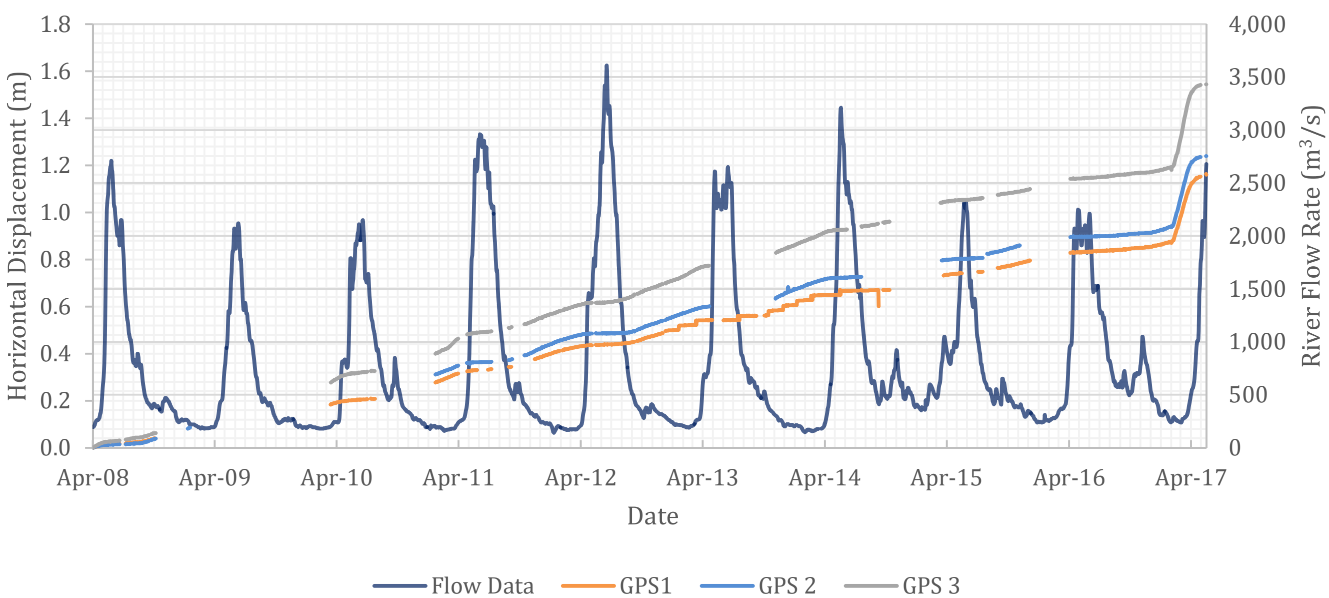

Figure 7.4 – Cumulative horizontal GPS displacement and the Thompson River flow rate (flow rate data obtained from Environmental Canada)

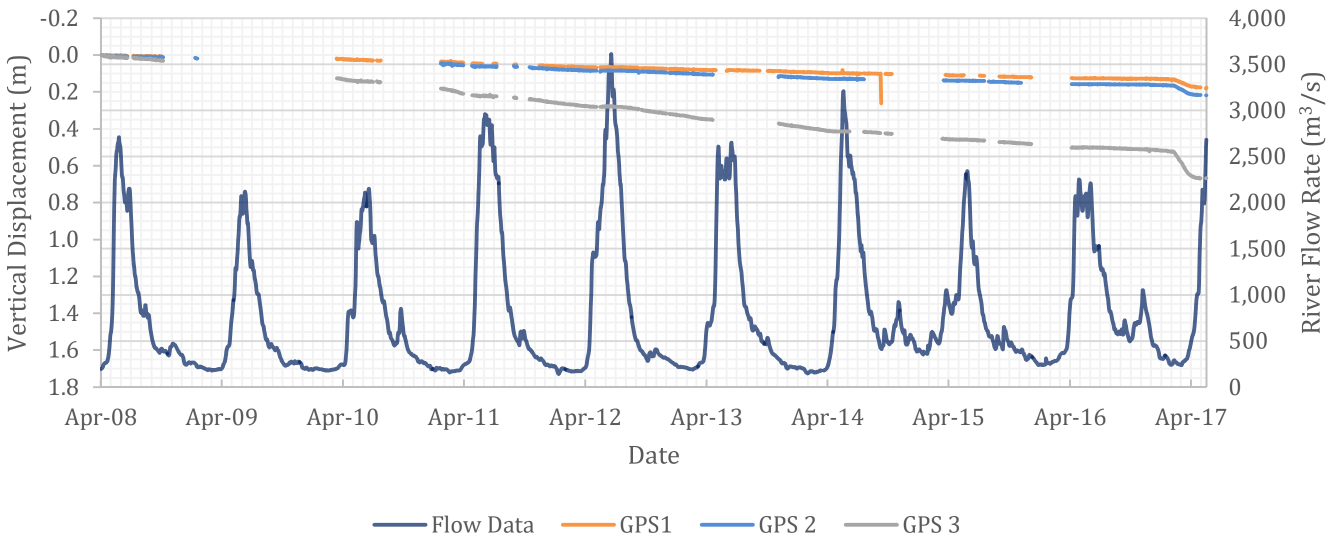

Figure 7.5 – Cumulative vertical GPS displacement and the Thompson River flow rate (flow rate data obtained from Environmental Canada)

On average, the active time period t_1 is from August to April (approx. 8months). Similarly, the average inactive time period t_2 is from April to August (approx. 4 months). Based on these established time periods, the estimated landslide velocity (mm/day) since 2010 is listed below in **Table B1 to B3** in Appendix B.

Figure 7.6 below summarizes the data listed the said three tables. From the figure, it can be seen that, in general, the maximum velocity of the slide does not exceed 0.2 mm/day during the inactive time period. During the active time period, the slide velocity is generally observed to be twice the inactive case, typically 0.4 mm/day. The slide velocity represents an averaged value over a time period. The time periods were chosen from April to August to represent the inactive time of the slide from August to April to represent the active time of the slide. For example, for GPS3, the estimated slide velocity from 1 August 2016 to 1 April 2017 was estimated to be approximately 1.28 mm/day. In **Figure 7.6**, last two data points represents the points (1 August 2016, 1.28 mm/day) and (1 April 2017, 1.28 mm/day). The location observed by GPS seem to be moving relatively further than GPS1 and GPS2, which indicate similar velocities. Thompson River flow rate measured at Spences Bridge is also plotted on **Figure 7.6** on a secondary vertical axis. The flow rate directly corresponds to the river elevation. It can be seen that the low river elevation corresponds to high slide velocities and the high river elevations corresponds to low slide velocities.

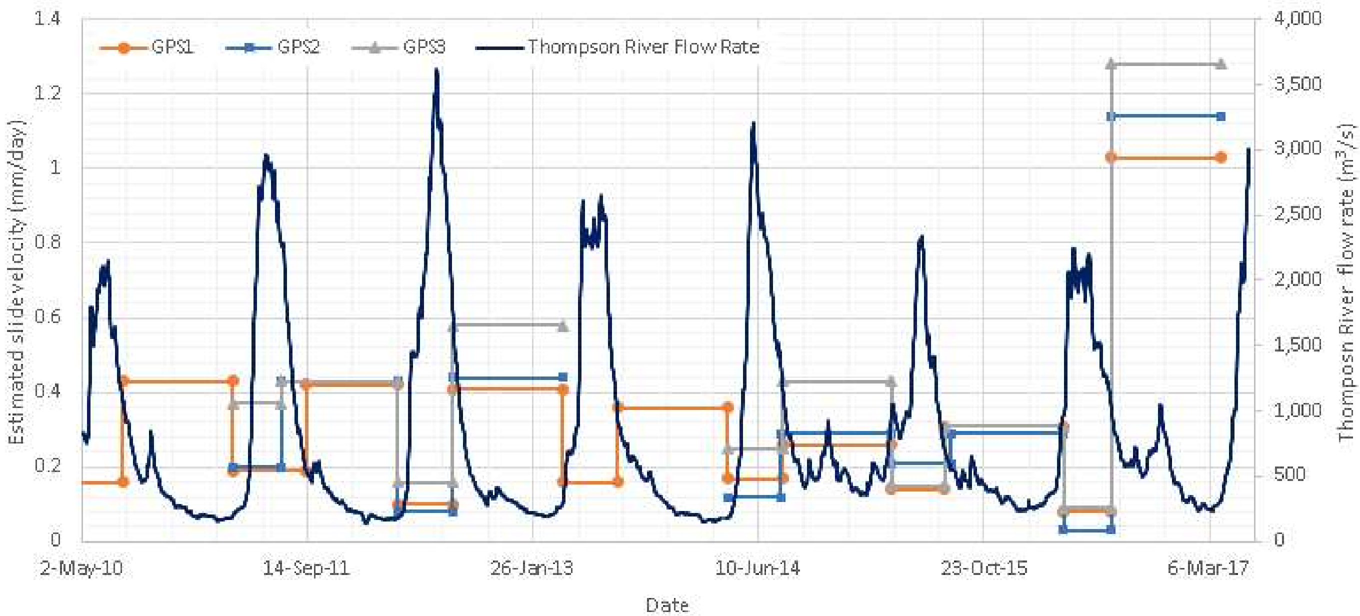

Figure 7.6 – Estimated landslide velocities from GPS1, GPS2 and GPS3 measurements

7.2.1 Accelerated movement observed during mid February to March 2017

As seen on **Figure 7.4** and **Figure 7.5**, all GPS devices indicate accelerated movement within the monitored soil mass. From the raw data, the acceleration was initiated approximately on 24 February 2016, during the "inactive period" of the slide. The increased movement was observed during an approximately time period of 45 days. For the inactive time period, where the accelerated movement occurred, **Figure 7.6** indicates that the maximum and minimum velocities were recorded by GPS3 and GPS1, respectively. Historic data agrees that GPS3 recorded the highest horizontal and vertical displacements since the GPS monitoring initiated in 11 April 2008. From **Figure 7.4** and **Figure 7.5**, it can be seen that the slope of the cumulative displacement curve begins to decline around beginning of April. This could be due to a combination of the buttress effect from the Thompson River coming in to effect around April and the excess PWP generated during mid-February gradually becoming dissipated within Unit 2. The SAA data was downloaded on 5 July 2017 to specifically analyze the aftermath of the accelerated movement – the results are presented in Section 7.4. In addition, the observed accelerated movement, may be also explained by analyzing the climatic forces and the porewater pressure. Any significant observations made during the interpretation of the VWPs in Section 7.3 and climatic forces in Section 7.5 are discussed in Section 8.0.

7.3 Vibrating Wire Piezometer (VWP) data

The VWP data from both data loggers were plotted to observe any significant variations in the PWP. The results are categorized under the corresponding data logger.

7.3.1 CR1000 VWP Data (2013-present)

The CR1000 data contains a total of six (6) VWPs. As mentioned in Section 5.2, VWP24280 installed in the Thompson River was damaged on 5 May 2014. The raw data was processed using the polynomial function and a temperature correction was included. A PWP data was not compensated for the barometric pressure variation but the effect of the barometric pressure on PWP was analyzed. The processed PWP data are illustrated in **Figure 7.7** along with flow rate of the Thompson River measured at the Spences Bridge. Note than an increase flow rate results in increase in the river level and vise versa. The following observations were made during the interpretation of **Figure 7.7**.

- The peak flow rates were typically observed in June. When the flow rate is peaking, the trend of the PWP curves also reaches a peak. The increase in the PWP as the river level peaks is especially visible in VWP24279 which is installed within the bedrock at 240.3 m asl;
- VWP24278 is the deepest VWP and it is installed in the bedrock at 240.3 m asl and corresponds to the highest observed PWP;
- VWP24283 is installed at the primary shear zone within Unit 2 at 257.1 m asl and corresponds to the second highest observed PWP;
- VWP24281 is installed 0.9 m above VWP24283 within Unit 2 at 258.0 m asl indicates a PWP trend very close to the one observed in VWP24283;
- VWP24278 is the shallowest VWP (VWP 24280 installed in the Thompson River is disregarded as its primary use is to approximate the river level) and it is installed within Unit 2 at 261.6 m. VWP24279 asl and corresponds to the lowest observed PWP; and
- As indicated in Section 7.1, the PWP trend observed in VWP24280 installed in the Thompson River at an estimated depth of 264.1 m asl strongly corresponds with the variation of the measured flow rate at the Spences Bridge.

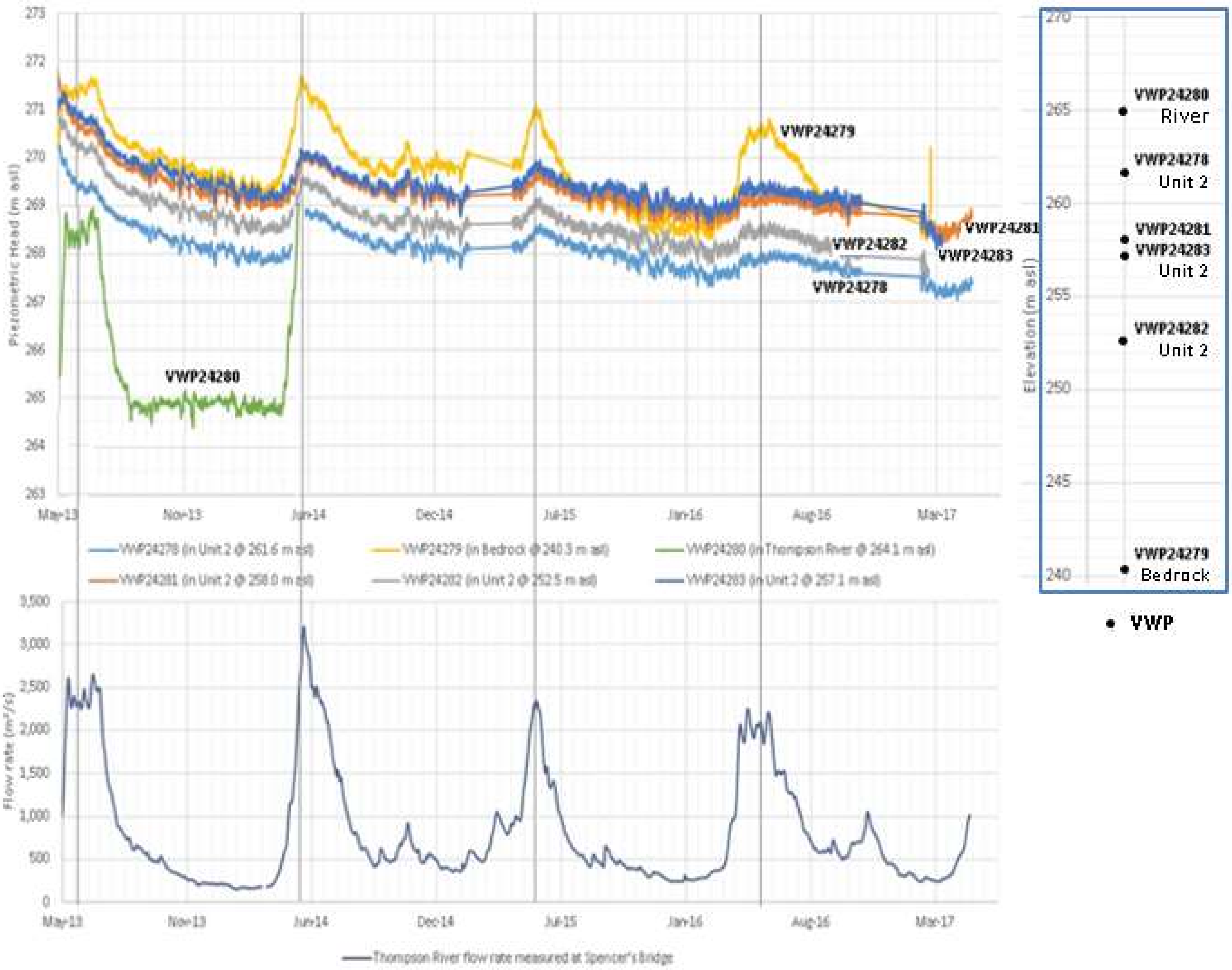

Figure 7.7 – A comparison of the processed PWP data from CR1000 logger and Thompson River flow rate data (left) and CR1000 VWP elevations (right)

The CR1000 raw data does not contain barometric pressure data as the on-site barometer was only installed during the 2015 site investigation. However, the historic weather data from the Kamloops AUT weather station can be accessed via the Environment Canada web database. Historic barometric pressure data from Kamloops AUT was analyzed during September of 2013. This data is then compared against the VWP24280 installed in the Thompson River. Note that the VWP2480 records barometric pressure when the VWP is located above the river level. The VWP24280 data shown in **Figure 7.7** above indicates that the VWP records PWP from 1 to 12 September 2013 and barometric pressure from 12 to 30 September 2013. The variation of the pressure with respect to 1 September 2013 was calculated for both VWP data and barometric pressure data. The calculated variations are plotted in **Figure 7.8** below. It can be seen that the variation of the barometric pressure matches with the variation of the suction recorded by VWP24280. Therefore, the use of historic barometric pressure data from the Kamloops AUT weather station is adequate for the analysis of the Ripley slide.

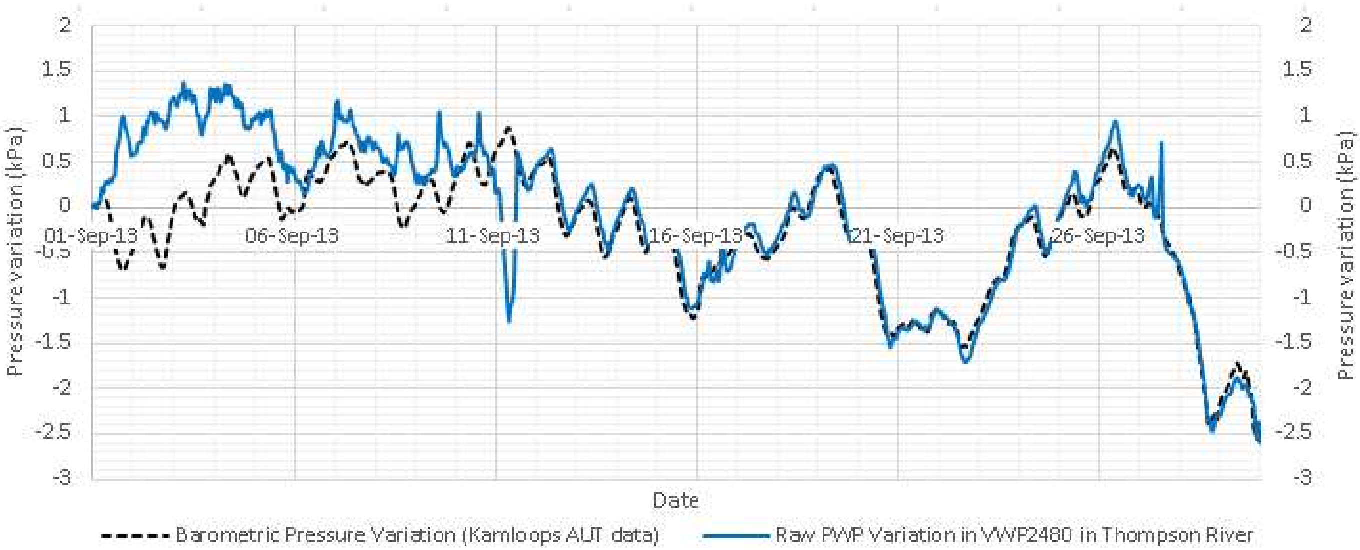

Figure 7.8 – A comparison of the variation between the barometric pressure and the VWP2480 PWP

7.3.2 CR6 VWP Data (2015-present)

The raw VWP data logged by the CR6 logger contain PWP in B Units and in kPa. It is assumed that the kPa data accounts for the temperature correction. There is also barometric pressure data recorded by an on-site barometer. Since the RST Calibration Records are not available, the barometric pressure at the time of VWP installation is unknown. However, since the time/date is known, it is reasonable to use the barometric pressure recorded by the Kamloops AUT weather station as the initial barometric pressure. **Figure 7.9** below depicts the raw data recorded by the CR6 logger interpreted in terms of PWP head. Note that corrections have been made to the raw pressure data.

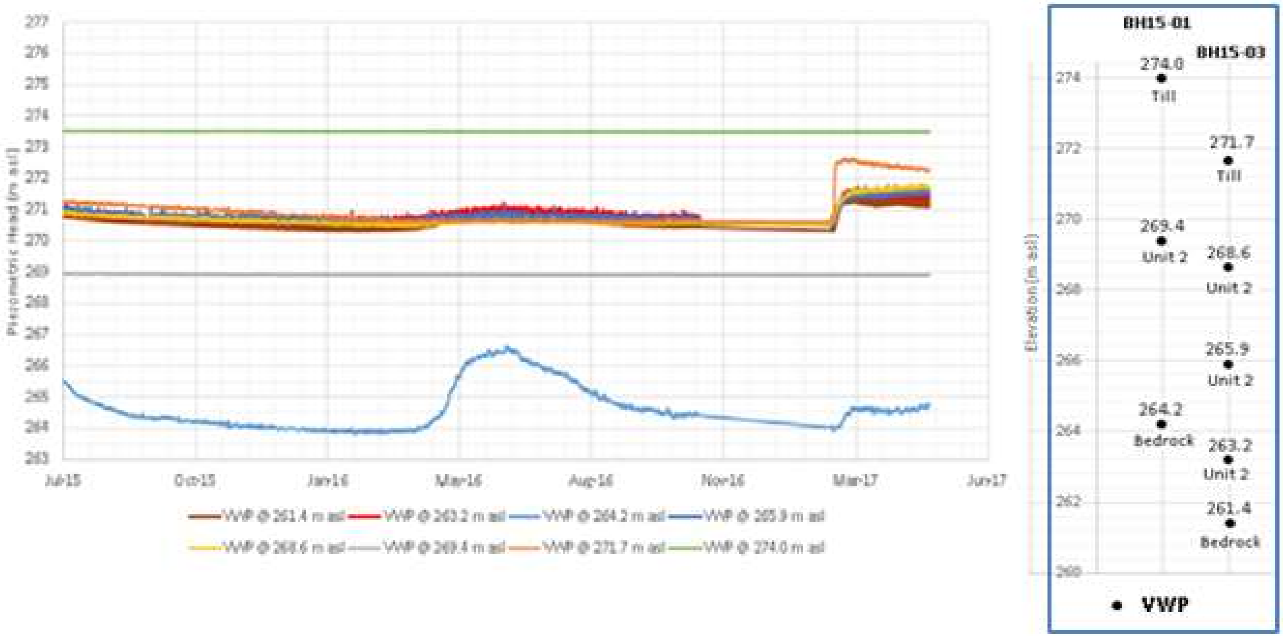

Figure 7.9 – Raw PWP data from the CR6 data logger (left) and CR6 VWP elevations (right)

From the **Figure 7.9** above, following observations can be made:

- The increase in the PWP as the river level peaks in especially visible in VWP @ 264.2 m asl in borehole BH15-01, which is installed within the bedrock. This variation of the PWP within the bedrock indicates that the bedrock is fractured with groundwater flow running through the fractures. Since the PWP inside the bedrock response relatively quick to the flow rate variation in the river, it is unlikely that the fractures of the bedrock are filled with low permeability silt and clay from the overlaying Unit 2. Other PWP do not seem to have a significant affect due to the presence of the river;
- The two VWPs installed in borehole BH15-01 at 274.0 m asl in till and at 269.4 m asl in Glaciolacustrine deposits (Unit 2) shows no response. This is due to the said VWPs being installed above the local groundwater table;
- The five (5) VWPs installed in borehole BH15-03 show relatively similar responses and the PWP head typically ranges between 271.5 to 270.5 m asl;
- The borehole BH15-03 VWPs indicate a sudden spike in the PWP from 17 to 27 February 2017, a maximum increase of approximately 1.35 m; and
- It can be seen from **Figure 6.4** in Section 6.6.2 that the primary shear zone is inclined at the borehole BH15-03 location. The inclined idealized slip surface runs between the VWPs located at 271.7 m asl in till and 268.6 m asl in Unit 2. These two VWPs shows the highest spike in PWP due to the inclined shear forces acting on the soil mass. The effective stress is decreased at the shear zone resulting in an increased PWP response. The results are further discussed in Section 8.0.

7.3.3 Effect of High Frequency

The raw VWP data showed a great amount fluctuation due to high frequency noise. However, RST state that the "frequency signal is exceptionally immune from cable effects, including length (to several kilometers), splicing, resistance, noise pickup and moisture". The source of high frequency is thought to be due to the reduced sampling rate as seen in **Figure 7.10** and **Figure 7.11** below. However, as of 28 June 2017, RST is analyzing the raw data to determine the cause of the noise observed in the example **Figure 7.11**. These plots were generated using data from VWP24279 which is installed in the bedrock in Borehole BGC-BH13-01. Note how the high frequency effects are clearly visible when the sampling frequency was changed from 1 hour to 5 minutes. The change in the sampling frequency was made on 15 January 2015 and to aid a total stress analysis. Another possible explanation is the fluctuating river level. Based on the kinematics of the slide, the 1-hour sampling frequency is deemed adequate for monitoring purposes. The increased sampling frequency also require more memory usage in the data loggers as well as increased data processing time. The high frequency could be eliminated using a moving average.

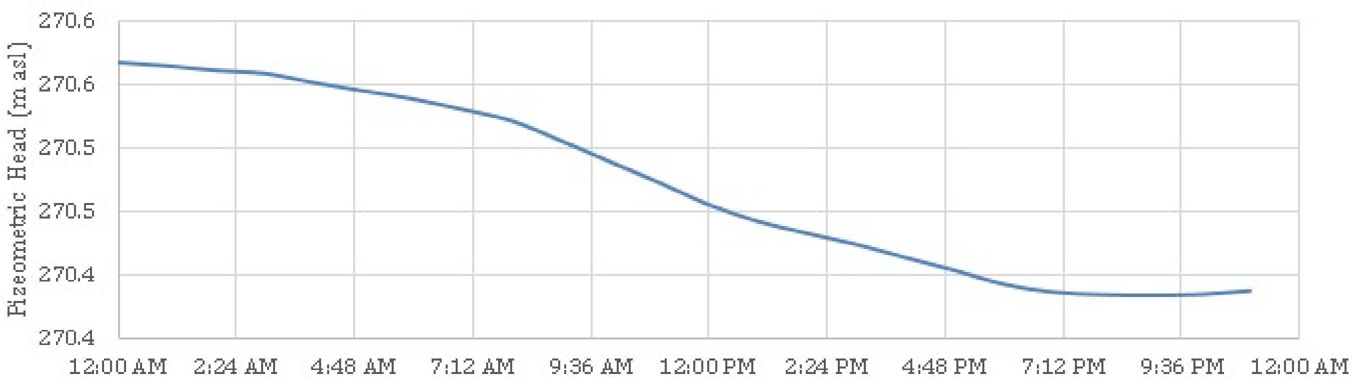

Figure 7.10 – Daily PWP measurements from VWP24279 on 5 May 2013 with 1-hour sampling rate

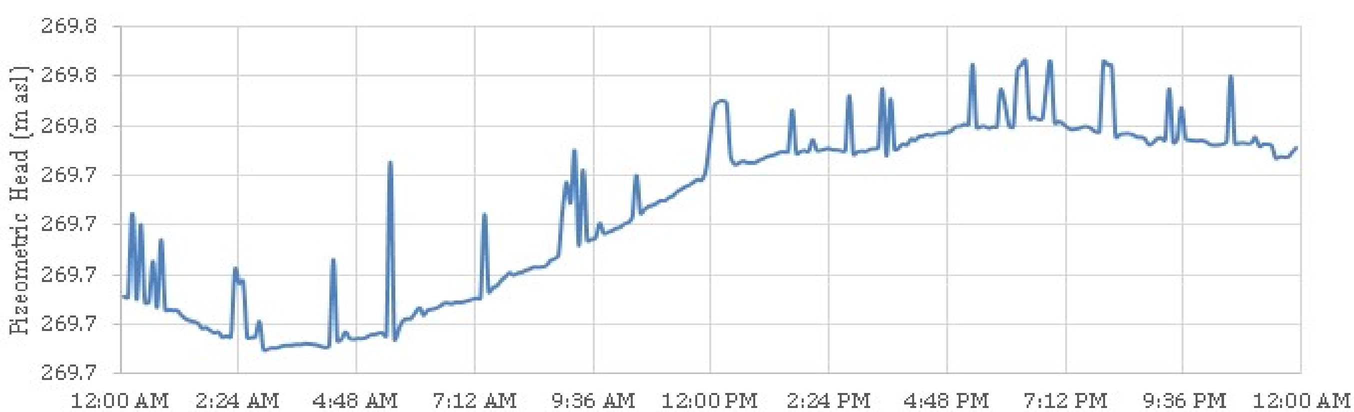

Figure 7.11 – Daily PWP measurements from VWP24279 on 16 January 2015 with 5-minute sampling rate

Figure 7.12 below illustrated the raw data from BH15-3 VWP at 263.2 m asl filtered using 1-day, 3-day, and 7-day moving averages. In comparison, the 3-day and 7-day moving averages provide a smooth line which falls closely within each other. The 1-day moving average captures the fluctuation of the data slightly but significantly reduces the high frequency variation as well. Therefore, it is recommended to use a 1-day moving average should data reduction becomes important.

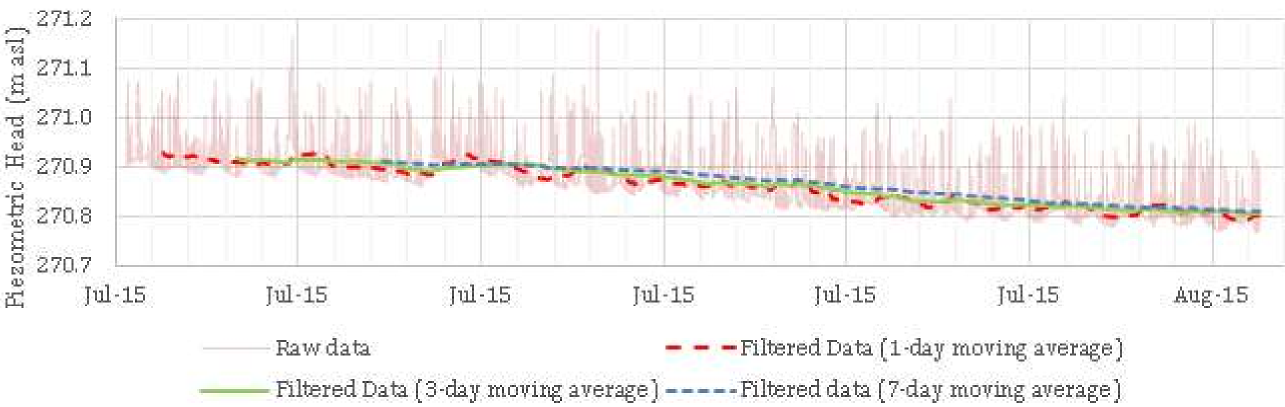

Figure 7.12 – Effect of moving-average for removal of high frequency effects on raw PWP data from BH15-3 VWP installed at 263.2 m asl

According to the CR6 Operator's Manual Section 8.1.2.1., it is said that the filtering time is inversely proportional to the frequency being filtered. If the filtering time is not properly minimized, it would result in an increased time skew between successive measurements. In addition, significant error in the voltage measurement can be attributed to electronic "noise" when measuring voltages less than 200 mV. The CR6/CR1000 raw data does not contain voltage measurements to verify the above statement. Certain "noise" frequencies can be filtered out from the analog signal by selecting the first notch frequency "fN1". However, no information is available with regard to setting up the CR6 and CR1000 data loggers. Ideally, for a VWP, the non-resonant frequencies should quickly decay and the resonant frequency shall continue.

7.3.4 Effect of Barometric Pressure

Review of the existing literature (Slope Indicator, 2013) suggest that a barometric correction is not required for grouted VWPs. Such a correction would only be required for open standpipes. To verify the effect if barometric pressure on the PWP, VWP24279 from CR1000 data logger is analyzed. The barometric compensation was made as described in Section 6.3 using RST Calibration Record of VWP24279 and Kamloops AUT weather data. **Figure 7.13** below shows the comparison of the VWP24279 PWP data with and without the barometric compensation for a 1-month time period, from 5 July 2015 to 5 August 2015.

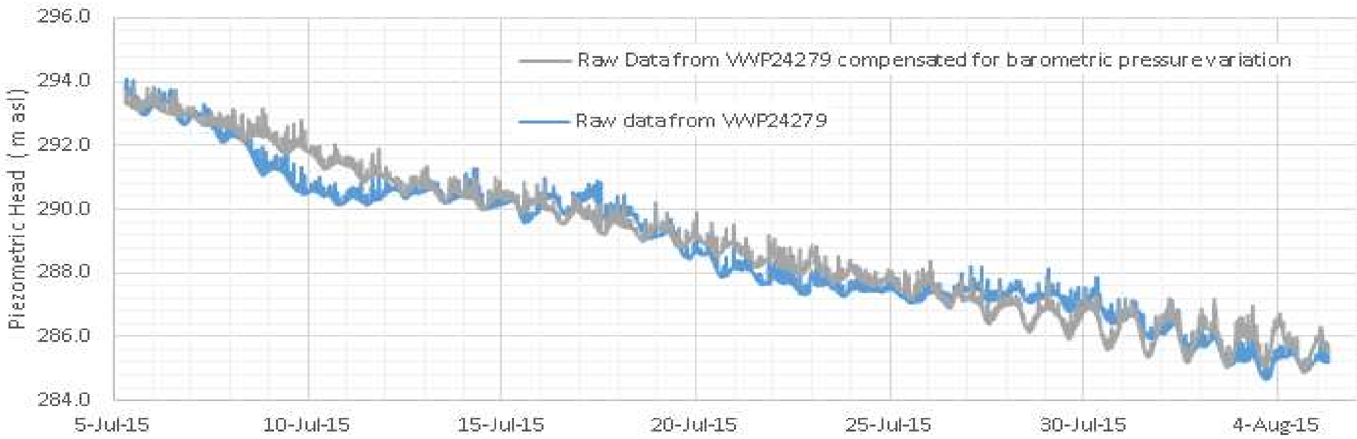

Figure 7.13 – VWP24279 raw PWP data with and without barometric pressure compensation

After the barometric pressure correction was applied, the extra PWP head due to barometric pressure influence ranged from approximately -90 mm to 150 mm. The extra PWP head is shown in **Figure 7.14** below over the same time period. Since the PWP can vary up to 2.0 m due to seasonal factors (as seen on **Figure 7.9** on VWP at 264.2 m asl), maximum variations of 0.09 to 0.15 m are relatively negligible.

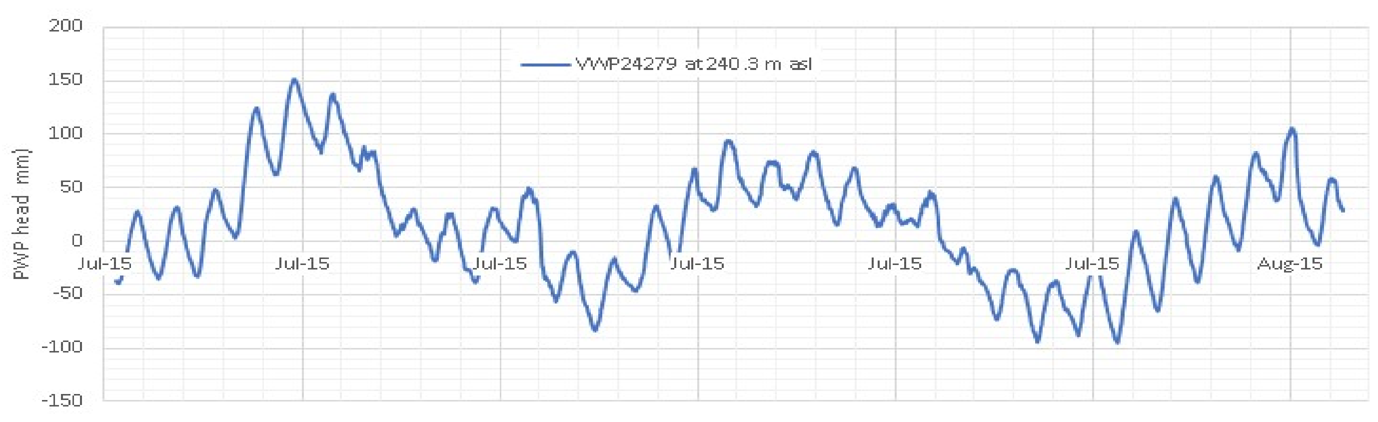

Figure 7.14 – Extra porewater pressure head acting on VWP24279 due to barometric pressure variation

7.3.5 Damage to CR1000 VWPs During February to March 2017

Based on the data analysis, it is believed that the accelerated movement which occurred in mid-February has permanently damaged three (3) VWPs installed during the 2013 site investigation. They are as follow:

- VWP24279 installed at 240.3 m in bedrock stopped recording valid data on 24 February 2017;
- VWP24282 installed at 252.5 m in Unit 2 stopped recording valid data on 20 February 2017; and
- VWP24283 installed at 257.1 m in Unit 2 stopped recording valid data on 13 March 2017.

At this location (i.e., Boreholes BGC-BH13-01/02), the primary slip surface is located at approximately 257.5 m asl. VWP24281 and VWP24278 located at 258.0 m asl and 261.6 m asl, respectively are undamaged. This is a clear indication that the VWPs below the primary slip surface were sheared off.

7.3.6 Piezometric Head for Stability Modelling

For the slope stability modelling, maximum and minimum PWP conditions are established for each cross section depicted in **Figure 6.4**. in Section 6.6.2. **Table 7.2** below summarizes the idealized PWP conditions to be used for the stability modelling. These PWP conditions are based on the interpretation of the raw data as presented in Section 7.3.1 and 7.3.2. PWP conditions from VWPS installed above and below the primary shear zone was taken.

Table 7.2 – Summary of Piezometric Head Elevations to be Used in the Stability Modelling

Cross Sections	Borehole ID	Piezometric Head & Time, approx.		Comments
		Max/Min, (m asl)	Time (Month-Year)	
1	BGC-BH13-01	271.5/267.3	Jun-14/Mar-17	river level: June-14 at 269.5 m asl; March-17 - 263.5 m asl.
2	BGC-BH13-01 BH15-03	271.5/267.3 272.0*/270.2	Jun-14/Feb-17	river level: June-14 at 269.5 m asl; Feb 17 - 263.5 m asl. Max PWP in BH15-03 on Feb 17 is 272.5 m asl. *assumed.
3	BH15-01	267.5/267.0*	Jun-16/Feb-16	VWPs at 269.4 and 274.0 m asl are observed to be dry. River level: Feb-16 at 263.5 m asl; June-16 at 267.5 m asl. * assumed.

7.4 Shape Accel Array (SAA) data

The SAA data from both data loggers were plotted to observe any significant displacements at the pre-identified shear-zone during the 2005 geotechnical site investigation. The results are categorized under the corresponding data logger.

7.4.1 A Brief Review of the SI Data from 2005 Site Investigation

The two (2) slope inclinometers (SIs) from the 2005 field program were installed in Boreholes DH05-24 and DH05-27 over the entire drilled depth. Borehole DH05-24 was drilled from approximately 274.6 m asl (from till) and extended to approximately 263.5 m asl (to bedrock). And Borehole DH05-23 was drilled from approximately 273.5 m asl (from cobbles and boulders) and extended to approximately 235.2 m asl (to bedrock). One (1) shear zone was identified from the DH05-24 SI at approximately 271.5 m asl at the till to bedrock transition zone. Two (2) shear zones were identified in the DH05-27 SI, one at approximately 267.6 m asl (12 mm recorded displacement) within till and the other at approximately 256.7 m asl (32 mm recorded displacement) in the Glaciolacustrine Clay (Unit 2). Both SIs were sheared-off 17 months after installation.

7.4.2 CR1000 SAA Data (2013 – Present)

The SAA1 data from the CR1000 logger clearly shows 4 inactive time periods. The duration of the inactive periods is generally between April to August which agree with the GPS data as mentioned in Section 7.2. Note that during the inactive time periods, the displacement is virtually zero, resulting is no movement at all. The GPS however still indicate very slow movement during this period. This is thought to occur due to a shallow secondary shear zone presented above the zone measured by the SAA.

Unlike the SAA2 from 2015, the SAA1 contains a mangometer. A quite time of 4 June 2015 was chosen for the mangometer. Significant amount of rotation, up to 10°, was noticed in the SAA1 since July 2014. The rotation becomes gradual since September 2015 as seen in **Figure 7.15** below. Near the shear zone, at approximately 257.51 m asl, the bend angles are observed to be approximately 0.3 m the radius of curvature, which exceeds Measurand's specified limit of minimum 2.0 m for 27 mm PVC conduit. The SAA2 is currently operating well. However, it should be noted that when the bend angle exceeds the said limit, there is a high risk of breaking or bending of the 0.3 m SAA segments. Since the bend angle at the shear zone is 0.3 m. unfortunately the SAA would not be retrievable to re-use in another location/project.

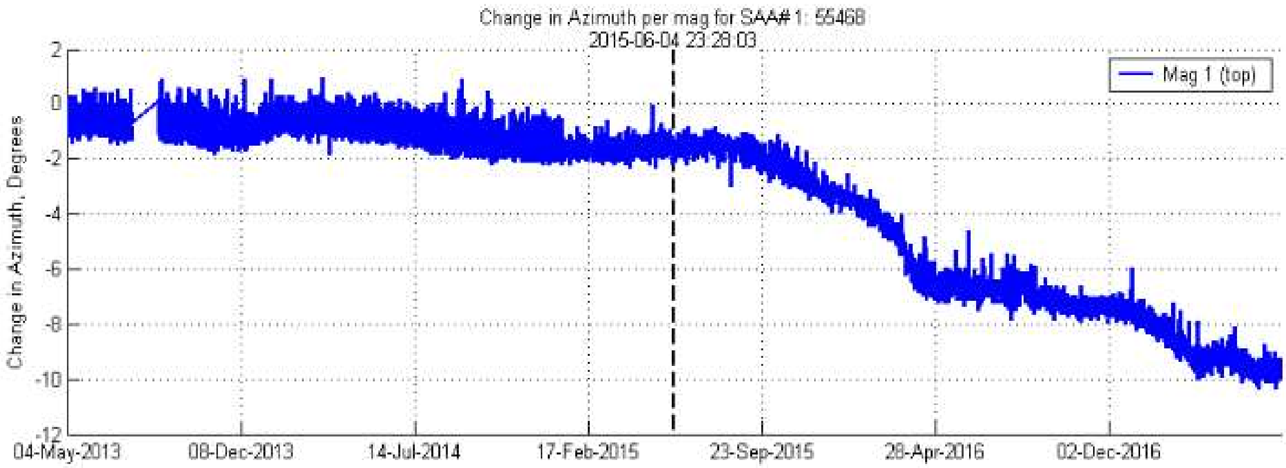

Figure 7.15 – The variation in azimuth in SAA1 between May 2013 to July 2017

As per **Figure 7.16** below, the cumulative displacement (i.e., deformation) in the X (horizontal) and Y (vertical) directions at the primary shear zone at 257.51 m asl as of June 5 is approximately 85 and 330 mm, respectively. A sudden increase in the displacement is observed around 20 February 2015. The increase occurs at a rate of 620 mm/year over approximately 50 days till 11 April 2017. The previous studies (prior to 2017) have estimated the velocity to be between 25 to 180 mm/year. The enhanced rate of movement is gradually declined to near zero as it enters in to the inactive time period starting in April.

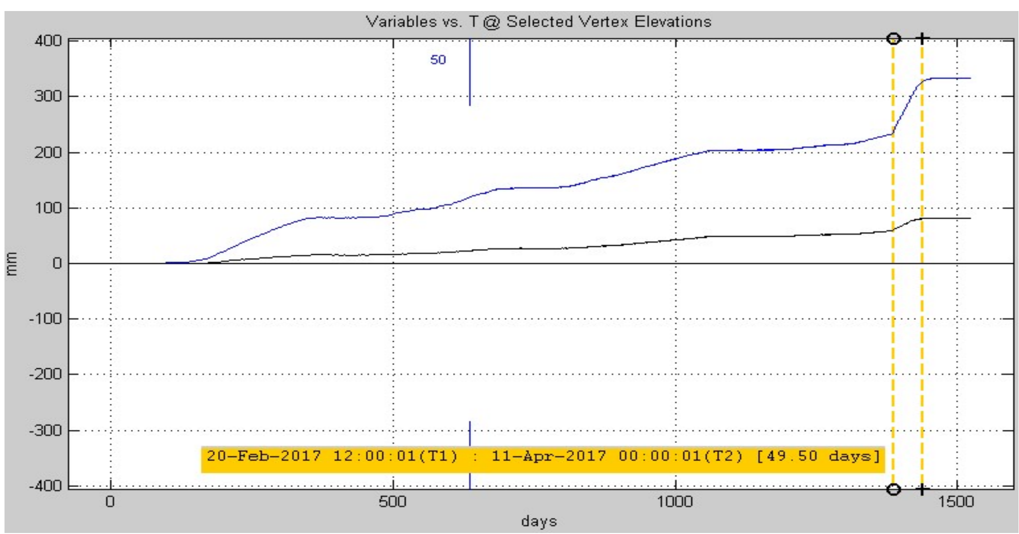

Figure 7.16 – The cumulative X (black) and Y (blue) deformation of CR1000 SAA against time at 257.51 m asl

Figures 7.17 and **Figure 7.18** shows the variation of the incremental displacement at the primary shear zone against time and the variation of the incremental displacement along the SAA against geodetic elevation profile, respectively. From **Figure 7.18**, the location of the primary shear zone is very vivid due to the obvious spike in the incremental displacement at approximately 257.51 m asl.

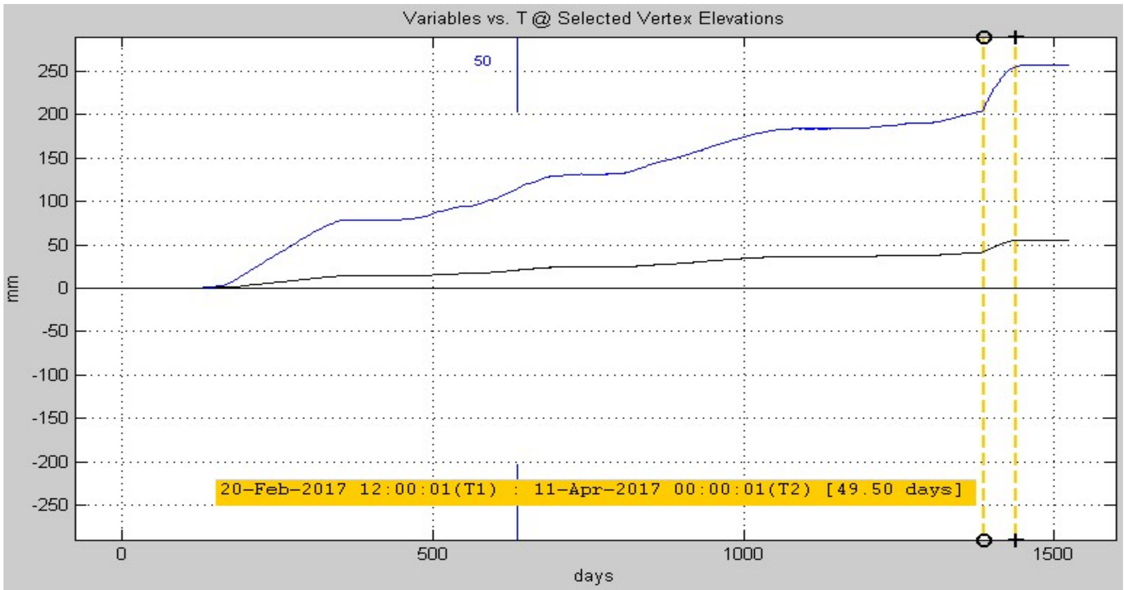

Figure 7.17 – Incremental X (black) and Y (blue) displacement of CR1000 SAA against time at 257.51 m asl

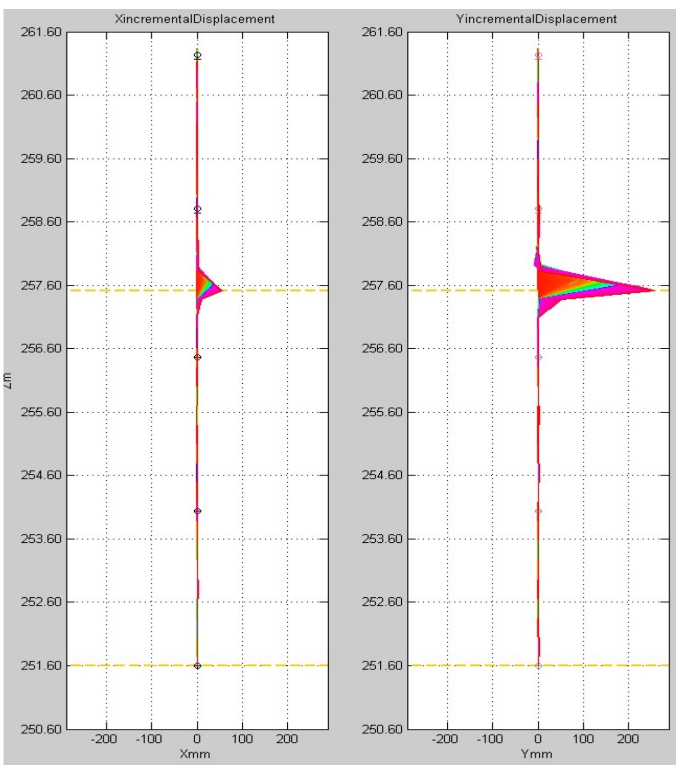

Figure 7.18 – The XZ (left) and YZ (right) incremental displacement plots of C1000 SAA

Data plots with respective to absolute shape (cumulative deviation), incremental deviation, magnitude, shear, and temperate along the SAA2 can be found in **Figure A2 to Figure A9**, respectively under Appendix A.

7.4.3 CR6 SAA Data (2015 – Present)

The first data point available is from 13 July 2015 and the last data point is from 5 July 2015 (cut-off for this analysis, data is still continued to be recorded). The deformation (i.e., cumulative displacement) from the CR6 SAA (SAA2) data are plotted against time as seen in **Figure 7.19** below at SAA vertex #14. Unfiltered data was used. Vertex #14 corresponds to an approximate depth of 4.87 m asl was identified to be at the shear-zone. The black and blue lines indicate X and Y deformations, respectively. From the incremental displacement plot seen on **Figure 7.20**, the 'active" and "inactive" periods as on the GPS plots can be seen. From approximately April (day 280) to August (day 400) 2016, the incremental deviation seems to be at a minimal, indicating very slow movement. The inactive time period observed in the SAA2 agrees to the one identified by the GPS systems. A sharp increase in the deformation can be seen after approximately 17 February 2015. This increase in deformation continues to until May 2017 and then seem to be levelling-off as the Thompson River water level rises.

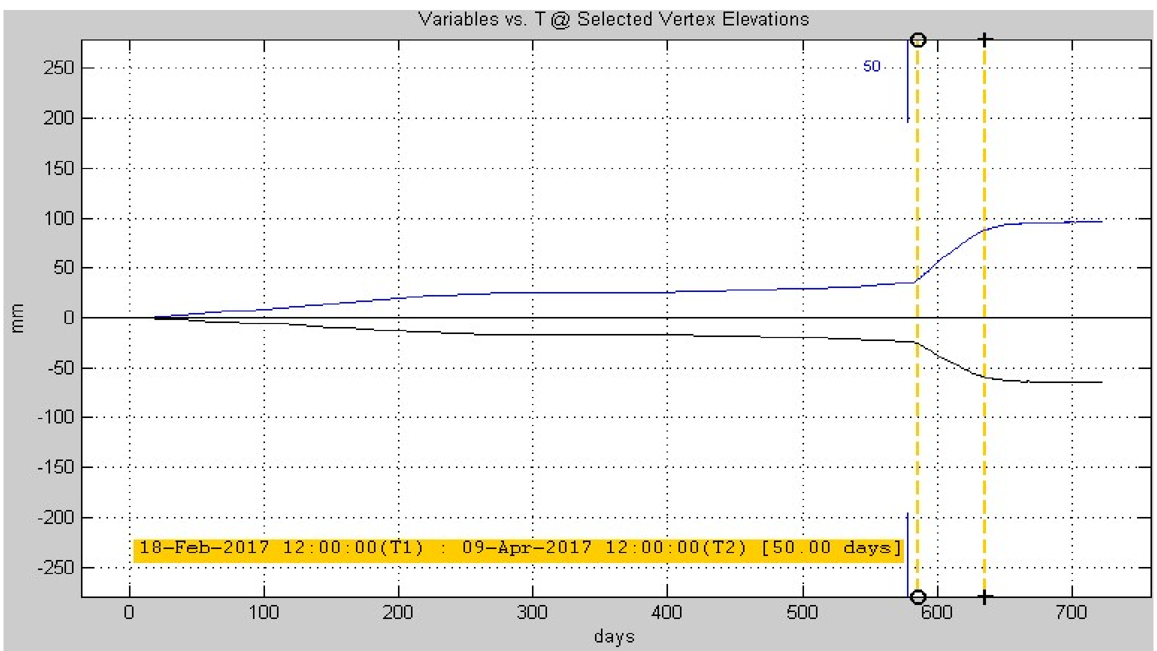

Figure 7.19 – The cumulative X (black) and Y (blue) deformation of CR6 SAA against time at 269.27 m asl

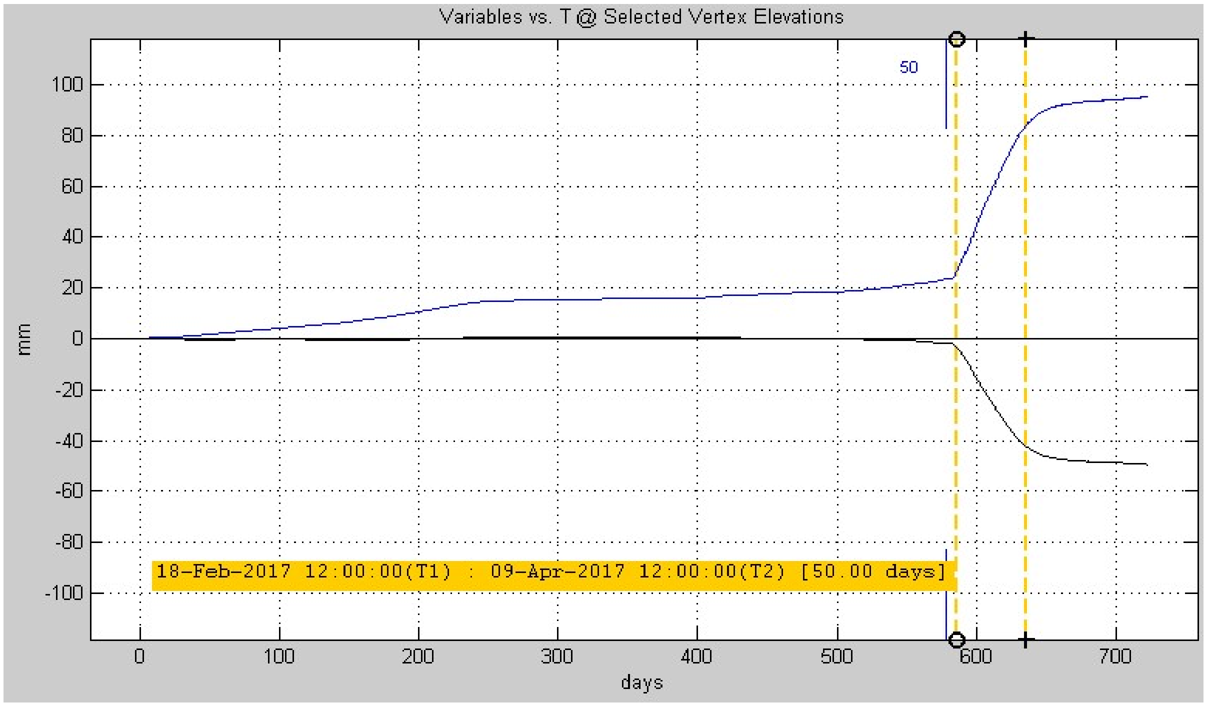

Figure 7.20 – The incremental X (black) and Y (blue) displacement of CR6 SAA against time at 269.27 m asl

The maximum X and Y cumulative displacements recorded are approximately 110 mm and 220 mm, respectively. In addition, the maximum X and Y incremental displacements recorded are approximately 50 mm and 95 mm, respectively, and occur at the shear zone. **Figure 7.21** below shows the variation of the incremental displacement along X and Y planes. From the cumulative displacement, the average during the "accelerated movement" seen from February to May 2016 was estimated to be approximately 100 mm/month, changing the landslide type from very slow moving to slow moving according to the Cruden and Varnes's 1996 Classification. Data plots with respective to absolute shape (cumulative deviation), incremental deviation, magnitude, shear, and temperature along the SAA2 can be found in **Figure A10 to Figure A17**, respectively under Appendix A.

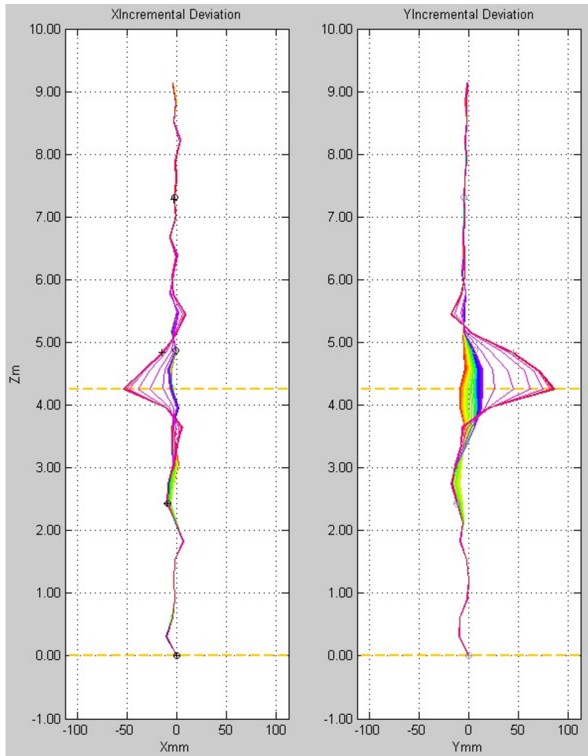

Figure 7.21 – The XZ (left) and YZ (right) incremental displacement plots of CR6 SAA

7.4.4 Comparison of the SAA and the GPS Data

The main difference between the displacement monitored by the GPS and the SAA is the location of the movement. The GPS monitors the surface displacement where as the SAA allows the monitoring of any subsurface displacement. Therefore, the SAA is particularly useful in identifying the approximate location of any shear zones. The cumulative displacement from the GPS systems and the SAAs are calculated from April 2016 to April 2017. The results are presented in **Table 7.3** below.

Table 7.3 – Summary of Estimated Cumulative Displacement Values from GPS and SAA

Estimated Cumulative Horizontal Displacement (mm) from April 2016 to April 2017				
GPS1	GPS2	GPS3	SAA1 (2013)	SAA2 (2015)
300	320	370	135	180

From the **Table 7.3** above, it can be seen that, during the time period analyzed, on average the GPS devices recorded doubled the displacement recorded by the SAA. As seen on the Cross Section 3 on **Figure 6.4** in

Section 6.6.2, it is appropriate to compare the SAA data to GPS2 as they are located within close proximity. This discrepancy is due to the SAA is only installed to capture the primary shear zone – it does not bisect the upper (shallow) shear zone. The surface displacement is attributed towards to shear zones and thus the greater displacement observed. In addition, the installation depth for GPS 1 to 3 are unknown. It is possible for these devices to record further movement due to near surface sliding/creep which are not particularly associated with the upper (shallow) shear zone. Effects of surficial erosion should be also considered.

7.5 Ashcroft Daily Precipitation data

Since the focus of the observed movement is constrained to February 2017, where a sudden acceleration was observed, the daily precipitation data and maximum temperature data for this time period is analyzed. **Figure 7.22** below shows the variation of daily precipitation and maximum temperature from 1 January to 28 February, 2017. Note that, the historic average precipitation and the maximum temperature for Ashcroft in February is approximately 23 mm and 1.1 °C, respectively.

On 10 February 2017, the recorded precipitation is approximately 12 mm. The trend of the maximum temperature indicates a gradual increase of for about 1-week and averages around 7°C. Interesting, this time period corresponds to the time period where accelerated movement was observed in the SAA and in the GPS data. No significant increase in the river flow level was observed during this time, indicating much of the precipitation is would have been due to snow-melt compared to rain-fall. And most of the water of the precipitation is infiltrated in to the soil rather than running on the surface and to the river. The VWPs on **Figure 7.9** shows an increase in PWP between February 17 to 27. This could be a delayed response to the 10 February precipitation. The relatively low permeability of the Glaciolacustrine clay (Unit 2) could explain the delay.

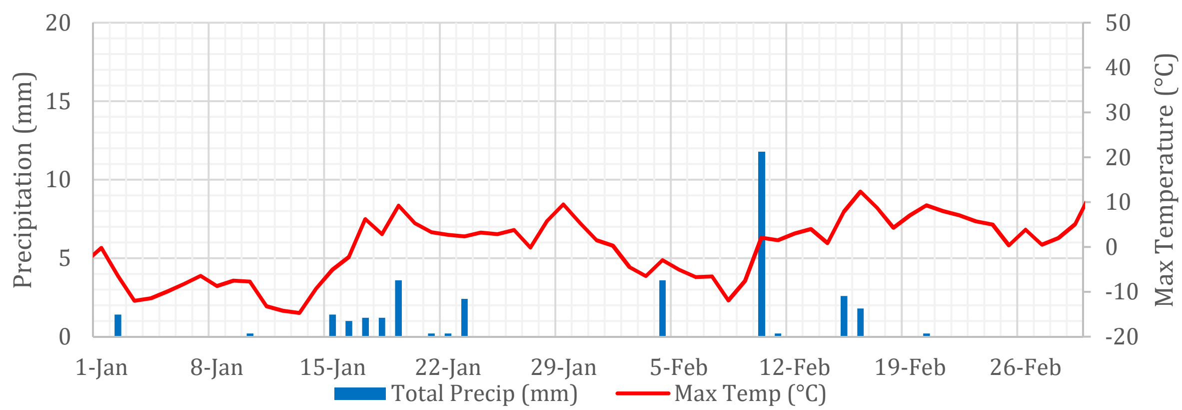

Figure 7.22 – Historic precipitation and maximum temperature data for Ashcroft during Jan-Feb, 2017

7.6 Slope Stability Assessment

The stability of the Ripley slide was assessed using Morgenstern-Price L.E.M. method and the soil properties as described in Section 6.6. The three cross sections found in **Figure 6.4** under Section 6.6.2 were modelled in GeoStudio Slope/W software. The location of the cross sections with respect to the 3 GPS locations are illustrated in **Figure 7.23** below.

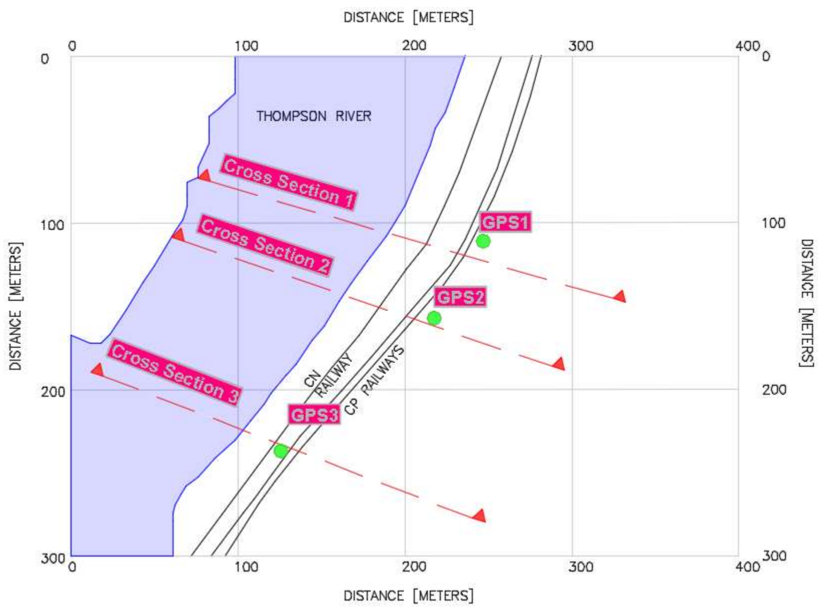

Figure 7.23 – Cross Sections with respective to GPS locations (modified after Maciotta, 2014)

For each one of the three cross sections, the F.O.S. for select dates within active (August to April) and inactive (April to August) time periods was analyzed. The estimated F.O.S. values are presented in **Table 7.4** below. The results from the Slope/W analysis is presented from **Figure C1 to Figure C12** in Appendix A. For cross sections 1 and 2, the F.O.S. was evaluated for both primary and shallow slip surfaces. For cross section 3, the F.O.S. was evaluated only for the primary shear surface. For cross section 1, VWPs from Borehole BH 13-01 was used to obtain the PWP. Similarly, VWPS from boreholes BH13-01 and BH15-03 were used to determine PWP conditions for cross section 2 and VWPs from borehole BH15-01 was used for cross section 3 PWP conditions.

Each evaluated F.O.S. value corresponds to specific PWP conditions and river level for the date analyzed. For the PWP conditions, two cases were analyzed: all time (only within the time span the data is available) high and all-time low from the applicable VWPs. Once the high and low PWP conditions were identified for each cross section, the approximate river levels were selected based on the date corresponding to the PWP record. River levels are based on the converted flow rates. A total of 10 cases were analyzed for the three cross sections.

Note that the soil profile and the groundwater table represent interpreted boundaries from the observations made from the on-site instrumentation and drilled logs. No changes were done to the soil profiles presented in **Figure 5.4** in Section 6.6.2. The only changes reflect to PWP conditions and the river elevations. The actual soil profile may vary significantly between drilled borehole locations. For each cross section, maximum and minimum porewater pressures and the river elevations as tabulated in **Table 7.2** in Section 7.3.6 were used.

Table 7.4 – Estimated F.O.S. for Cross Sections 1 to 3 During Select Active and Inactive Time Periods

Date	F.O.S.	Shear Plane	Cross Section	River Level (m asl)
June, 2014	1.00	primary	1	271.5
June, 2014	1.94	shallow	1	271.5
June, 2014	1.22	primary	2	270.0
June, 2014	2.39	shallow	2	270.0
February, 2016	0.99	primary	3	267.5
June, 2016	1.00	primary	3	263.5
February, 2017	1.16	primary	2	263.5
February, 2017	2.56	shallow	2	263.5
After the accelerated movement in mid-February, 2016				
February, 2017	1.09	primary	2	263.5
February, 2017	2.49	shallow	2	263.5
March, 2017	0.93	primary	1	263.5
March, 2017	2.33	shallow	1	263.5

For the time periods analyzed, as expected, the estimated average F.O.S. values during the inactive time period at the primary and secondary (shallow) shear zones are approximately 1.08 and 2.14, respectively. And in general, during the active period, the river level and the PWP conditions decreases to yield estimated average F.O.S. values of 1.04 and 2.46 for the primary and secondary shear zone, respectively. The respective reduction in the F.O.S. are estimated to be 2.8% and 21.7%.

In addition, the variation of the estimated F.O.S. against the approximated velocity of the slide is illustrated in **Figure 7.24** below.

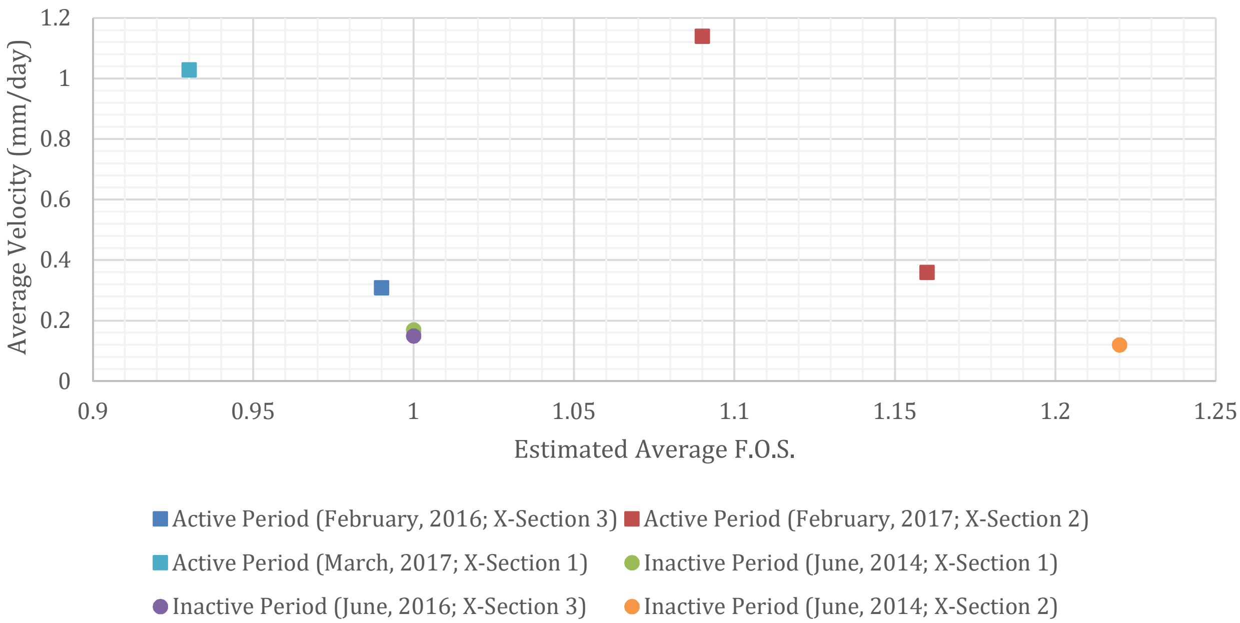

Figure 7.24 – Estimated F.O.S. for different soil profiles as a function of slide velocity

From the figure above, it can be seen that the slide velocity during the inactive time period decreases as the corresponding F.O.S. value increases. For the active time period, an overall trend for the 3 soil profiles are not established. However, when analyzed individually, the said trend is visible. For example, during February 2017, the F.O.S. for cross section 2 decreases from 1.16 to 1.06, resulting in an increase of slide velocity from 0.36 to 1.14 mm/day. It can be seen that cross section 1 is more prone to instability and the least prone is observed to be cross section 2. However, a more detailed analysis should be conducted to confirm the latter statement.

7.6.1 Change in F.O.S. during February 2017

Note that during February 2017, the PWP conditions from the BH15-03 VWPs experienced an approximate 2.3 m increase, specially VWP installed at 271.7 m in the till. The average PWP head increase in the other four VWPS installed in BH15-03 during this time is approximately 1.5 m. The fluctuation in the PWP conditions during relatively small period of time resulting in the average F.O.S at the primary shear zone varying from 1.16 to 0.93 – an approximately 19.83% reduction. Knowing the F.O.S. of the slide during the active period should be within equilibrium (i.e., F.O.S. = 1), the friction angle of the shear zone in the Glaciolacustrine clay (Unit 2) was reduced until a F.O.S close to 1.0 was reached. The friction angle was reduced from 16° (peak) to 9° (residual), approximately 43.75%. These values relate to the lower bound of the strength parameters listed for Unit 2 listed in **Table 6.1**.

8.0 Discussion

It is understood that the driving forces behind a Ripley Slide is due to various factors. A layer of weak Glaciolacustrine silt and clay (Unit 2) with mobilized shear strength near or at residual shear strength can initiate sliding of the overburden soil. In addition, the upward seepage pressures were also identified to act on the site. The upward gradient of the seepage flow causes an increase in the driving force at the slip surface, thus increasing the like hood of sliding.

An analysis on the Thompson River level and the displacement of the soil mass clearly shows a correlation - the river has a direct impact on the stability. When the river level is low during August to April (i.e., the active period), the slide is subjected to movement. When the river level is high from April to August (i.e., the inactive period), the buttress effect of the river on the sliding mass significantly slows the displacement. The flow rate of the river has a direct relationship with the river level (elevation). It has been observed that when the river level increases, the PWP measured by the VWP also increases and vise versa. Thus, the PWP conditions within the slide fluctuates according to how the river level fluctuates. Generally, for a landslide, when the PWP within the slide mass increase, it reduces the effective stress and results in instability. However, in the case of the Ripley Slide, the buttress effect from the river compensates for the seasonal reduction in the effective stress. The cobbles and boulders (Unit 8) and till (Unit 6) have a relatively lower permeability compared to Unit 2. And these two units have a higher resistance to shearing compared to Unit 2. Thus, as expected, the shear zone is located within the Unit 2. It is worth noting that, due to the complex geological history, the weak zone within Unit 2 could have been pre-sheared.

During the inactive period, the surface deformations from the GPS units show very slow rates of velocity ranging from 0.12 to 0.17 mm/day. However, for the same time period, the velocity at the primary shear zone, as measured by the SAAs, are virtually zero. If the slide is purely translational, the measured surface deformations should theoretically match the deformations measured at sliding base. However, since Ripley Slide has two shear zones and the SAAs only measure the primary shear zone, there is a deviation between the surface and surficial deformations.

Unusual precipitation events can also trigger a slide. The approximately 12 mm/day precipitation event occurred on 10 February 2017 is believed to have played to key role in the accelerated movement observed from mid February to March, the same year. Due to the relatively low permeability of Unit 2, some time is taken for the PWP at the shear zone to rise due to the February 10th precipitation. The ambient air temperatures were also reported to be above the historical averages, which would have aided to precipitation. The PWP increase in the VWPs were only observed during mid-February. In general, the SAAs indicate movement shortly after the VWPs record an increase in PWP as seen from **Figure 7.25** below. Select VWPs and the SAA from CR6 logger is plotted against time. Note that data between 7 November 2016 to 15 February 2017 is absent from the VWPs – cause of the missing data is unknown. The missing data are linked with straight lines. However, it is very likely that the increase in the VWPs is gradual and best represented by smooth curves as illustrated on the figure in dotted lines.

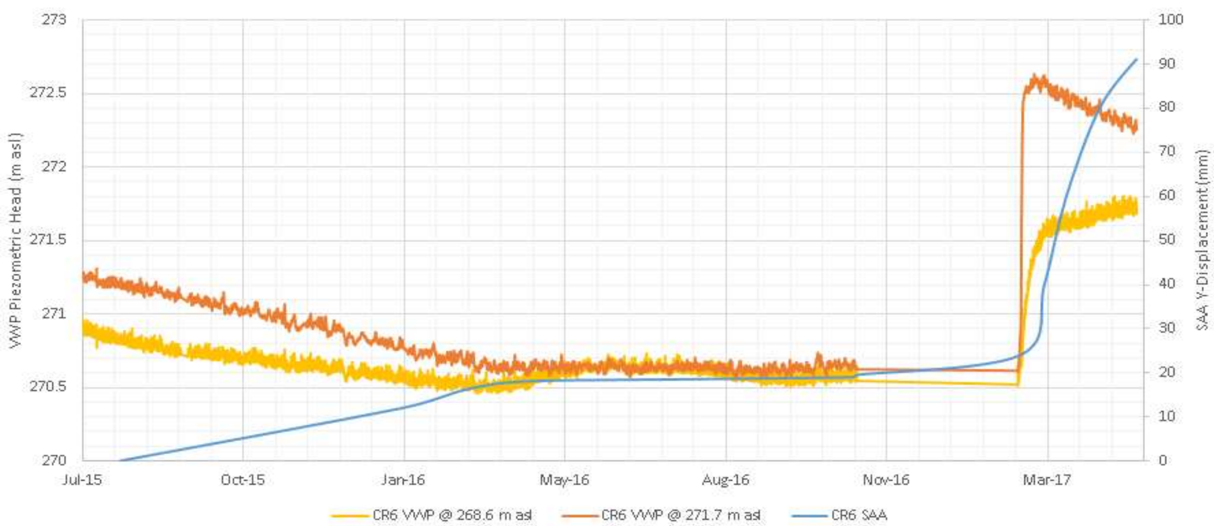

Figure 7.25 – Select VWPs and SAA Y-displacement from CR6 data logger against time

Some case studies around the world, from areas prone to landslide, have reported slides occurring after 7 to 14 days after a major rainfall event. The slope stability analysis conducted on the three cross sections as illustrated in **Figure 5.4**, showed a F.O.S. value typically close to equilibrium, i.e., a F.O.S. of 1.0. As expected, after mid February 2017, F.O.S. values ranging from 0.93 to 0.99 were estimated. It should be kept in mind that these F.O.S. are "averaged" over the slip plane and are depended on the assigned soil properties, interpreted soil and groundwater profiles, the idealized slip surface, river level, topography, and the method of analysis. The method used for the analyses, the Morgenstern-Price (M-P) method, currently serves as the "standard of practice" for L.E.M. However, the M-P assumes vertical slices, which is seldom the case in reality. The Sarma method would be more realistic as it accounts for non-vertical slices. It is understood that a separate research is been currently carried out by another graduate studies candidate to analyze the variation of F.O.S. between M-P and Sarma methods for the Ripley Slide. It is understood that the soil properties available (Hendry et al.,2015) are based on actual lab testing and back analyses. Soil specimens used for lab tests are subjected to scale effects as well as sample disturbance. Also, the quality of the test results depend on how well the test equipment are calibrated, maintained, and operated. Given the scale of the Ripley Slide, it is not realistic to assume that the test results are representative of the site conditions. However, it is possible to approximate the shear strength at the weak zone within Unit 2. Knowing the F.O.S. likely fell slightly below 1.0 from Mid February to March, it is possible to back-analyze the stability using reduced strengths at the shear zone. Ideally, the reduction analysis should have yielded the residual shear strength. In this particular case, the residual strength obtained using the strength reduction technique were within the residual strength ranges established from previous studies.

As of July 2017, the Ripley slide is undergoing the inactive period and is stable. It was determined that 3 of the VWPs from the 2015 site investigation has been sheared-off due to the accelerated movement in mid February. In addition, due to the same reason, the two SAAs are not retractable as the conduit is bent beyond the maximum allowable bend angle near the shear zone. Since instruments are very costly, specially the SAAs, attention must be paid during active time periods and any unusual weather events to assure their safe operations. Some recommendations with regard to instrumentation is provided in Section 9.0 below.

9.0 Recommendations

Given the sudden accelerated movement observed during mid-February 2017, it is very likely that a similar acceleration will occur during the upcoming winter season should unusual weather events take place. December, January and February are identified as critical months. Should such an event occur, the two SAAs currently on-site would like to shear-off at the primary shear plane. Upon analyzing the history of the slide and the instrumentation data between 2013 to 2017, the following comments and recommendations can be made:

9.1 General

- Monitoring of the slide will be critical during the winter 2017. Should a high precipitation (typically > 10 mm per day) occur during the winter months, where the buttress effect provided by the Thompson River is at a minimum, a second accelerated movement is to be expected;

- The accelerated movement is not "instantaneous". The gradual increase of PWP at the primary shear zone was visible in the VWP readings. The GPS and the SAA data only showed the movement after a delayed time period. Therefore, focus should be given on the VWP measurements as they provide an early warning; and

- A "precipitation threshold" should be determined for the critical time period where the landslide is "active". Should the threshold exceed during the critical times, special precautions must be taken and monitoring of the instrumentation should be done regularly for a minimum period of 14 days from the date the threshold is surpassed.

9.2 Instrumentation

- It is recommended to switch back the sampling frequency for VWPs back to 1-hour time intervals. The current 5-minute time interval introduces significant amount of high frequency in to raw data. It also requires more memory for data storage in the loggers as well as data processing time. Given the observed rate of movement, 1-hour sampling frequency is deemed adequate. However, should the current 5-minute frequency is to be kept, it is recommended to use a 1-day moving average to get rid of the high frequency effects;

- The current SAAs onsite have exceeded the maximum allowable bend angle due to the high velocity experienced in mid-February 2017. Therefore, it will not be possible to extract them for possible re-use. As of 5 July 2015, the two SAAs were functioning properly. However, they are functioning at a limit beyond a level which is set by the manufacturer and could be subjected to failure at any point in time. Since replacing SAAs can be very costly, it is recommended to monitor the bend angles during winter months at least bi-weekly. If the bend angle is close to exceed the limit of 2.0 m (i.e., fall below 2.0 m) set for the 27-mm conduit, it is recommended to extract the SAA and install it in a newly drilled adjacent hole.

- In addition, three VWPS (VWP24279, VWP24282, and VWP24283) were identified to be defective due being sheared-off during February to March 2017 during the accelerated movement. Consideration should be given to replacing the VWPs near the identified major shear plane; and

- It is understood that the current GPS system is setup to trigger an alarm when the monitored displacement exceeds a threshold value of 10 mm over a 24-hour time period. A warning is sent automatically to select CP and CN personnel. It is recommended to utilize displacement and tilt alarm features of the SAA recorder as a back-up warning system to the GPS system. This alarm system can be utilized to send automated emails when a threshold for displacement and/or tilt is exceeded. SAA recorder is able to log data in real time. It is recommended not to customize the alarm over a single joint, rather set the monitor interval ±1.5 m from the major shear plane.

10.0 Conclusion

This study was conducted to analyze the dynamics controlling the Ripley Slide near Ashcroft, B.C. With the aid of on-site instrumentation data and historical weather and river data, the factors affecting the stability of the slide were identified. The fluctuation of the river matched the fluctuation of the PWP recorded by the VWPs. In addition, from August to April, when the slide is active, the low river level accommodated the slide at velocities averaging 0.15 mm/day. The velocity increased to an average 0.34 mm/day from April to August when the slide was inactive and the buttress effect from the river was in effect. Unusual precipitation events can lead in to an increase in the PWP within the sliding mass, thus disturbing the statics between the driving and resisting forces against sliding. Such precipitation event was identified in mid-February 2017 which resulted in the slide velocity to increase from 1.04 mm/day to 1.14 mm/day. The accelerated movement observed in mid-February was concluded to have happened due to precipitation event combined with the river dynamics. No earthquake or fracking activities were identified as a probably cause. Throughout its life, the Ripley slide will continue to undergo active and inactive periods of movement. Changes in topography and PWP conditions will continue to alter the face of the slide posing an imminent risk to the safe operation of the railways. As per the current risk mitigation measurements, monitoring the movement of the slide with instrumentation proves to be a viable solution. The current GPS system would provide CP and CN personnel a warning of significant surface deformations based on real-time measurements. An alarm system feature of the SAA would also provide an automated warning and should be implemented if costs are not constrained. Once the warnings are received and proper precautions are taken, data from the instrumentation should be processed and analyzed at earliest convenience to understand the changes in subsurface soil and groundwater conditions. The loss of instrumentation due to the mid-February 2017 event is estimated to be $45,000. Ultimately, based on the historical data, a significant amount of capital would be needed to continue to field monitoring program until a feasible remediation work can be successfully established.

Respectfully submitted by:

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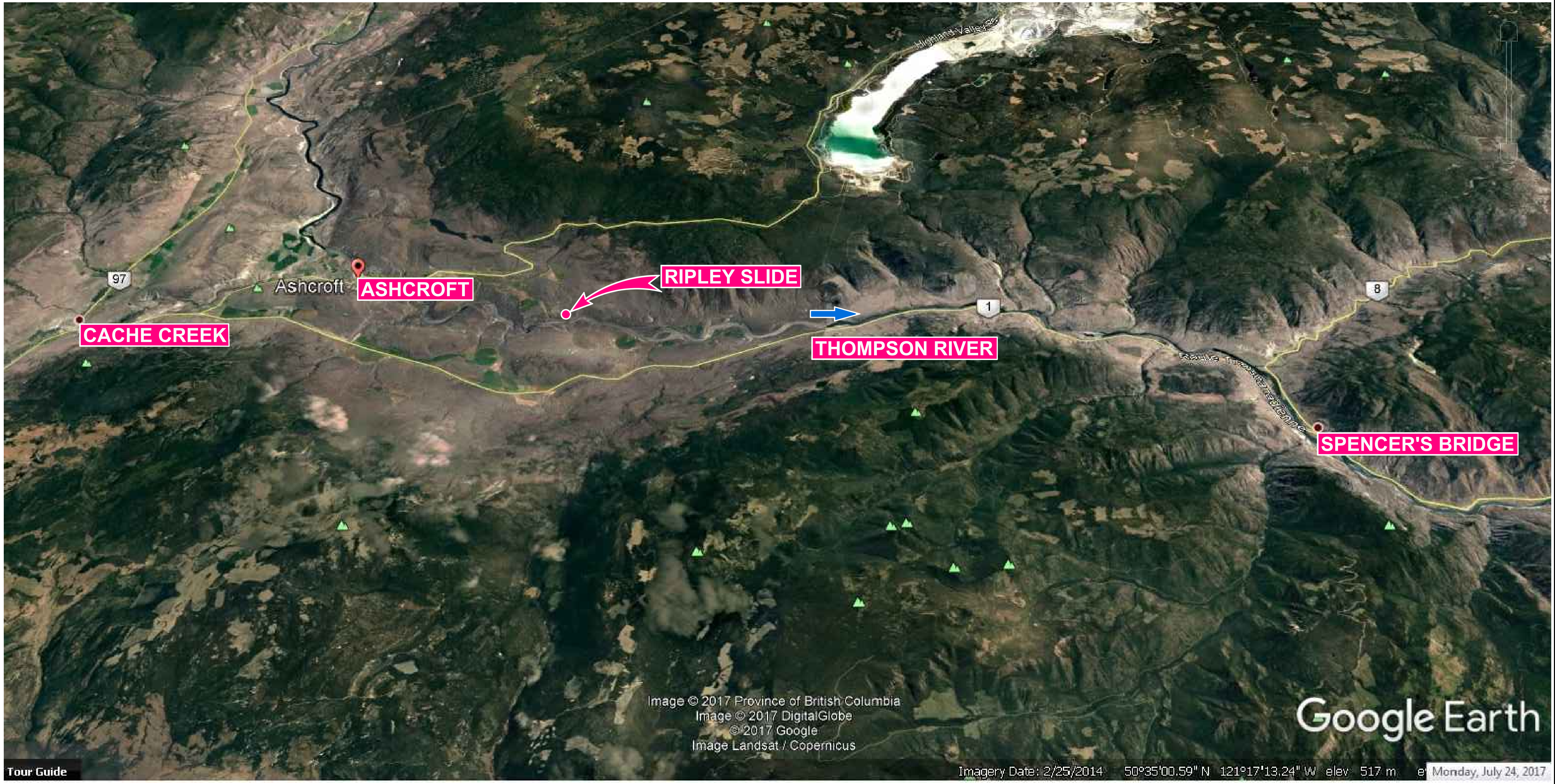
Appendix A

Figures

Figure A1 – Site Location Plan

Figure A2 to A9 – Plots from CR1000 SAA

Figure A10 to A17 – Plots from CR6 SAA



NOTES :

1. IMAGE OBTAINED FROM GOOGLE MAPS, JULY 2017;
2. APPROX. DISTANCE FROM ASHCROFT TO SPENCER'S BRIDGE ALONG THE THOMPOSN RIVER IS 40.3 KM; AND
3. LOCATIONS ARE APPROXIMATELY ONLY.

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PROJECT TITLE
ANALYZING THE KINEMATICS OF THE RIPLEY LANDSLIDE, ASHCROFT, B.C.

DRAWING TITLE
SITE LOCATION PLAN

PROJECT NO. MENG-04082017		FILE NO. RIPLEY17	
DATE 27-JUL-2017	SCALE AS_SHOWN	FIGURE A1	REV. 1
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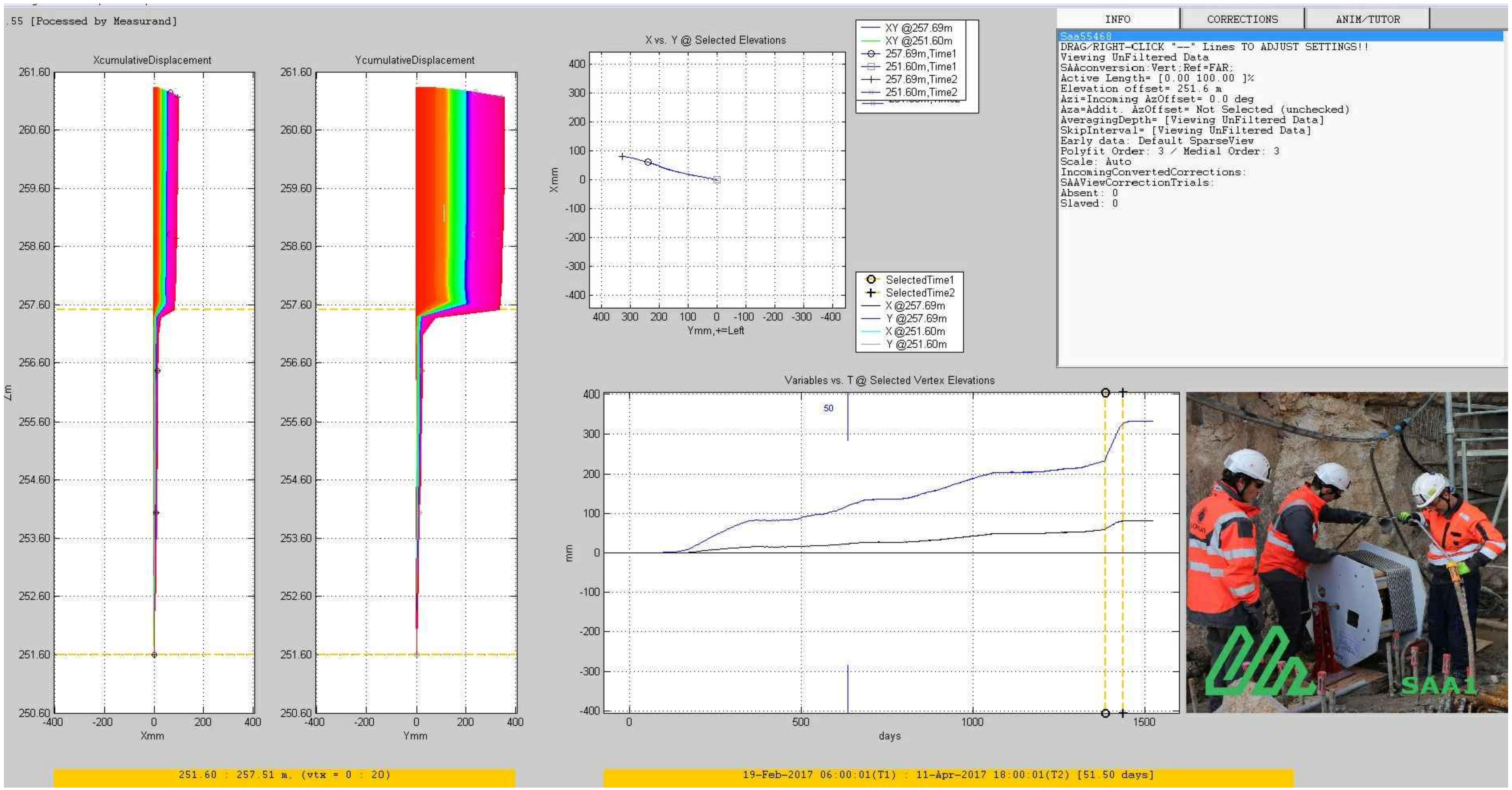

NOTES :

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DRAWING TITLE
CUMULATIVE DISPLACEMENT PROFILES FROM CR1000 SAA

PROJECT NO. MENG-04082017		FILE NO. RIPLEY17	
DATE 27-JUL-2017	SCALE AS_SHOWN	FIGURE A2	REV. 1
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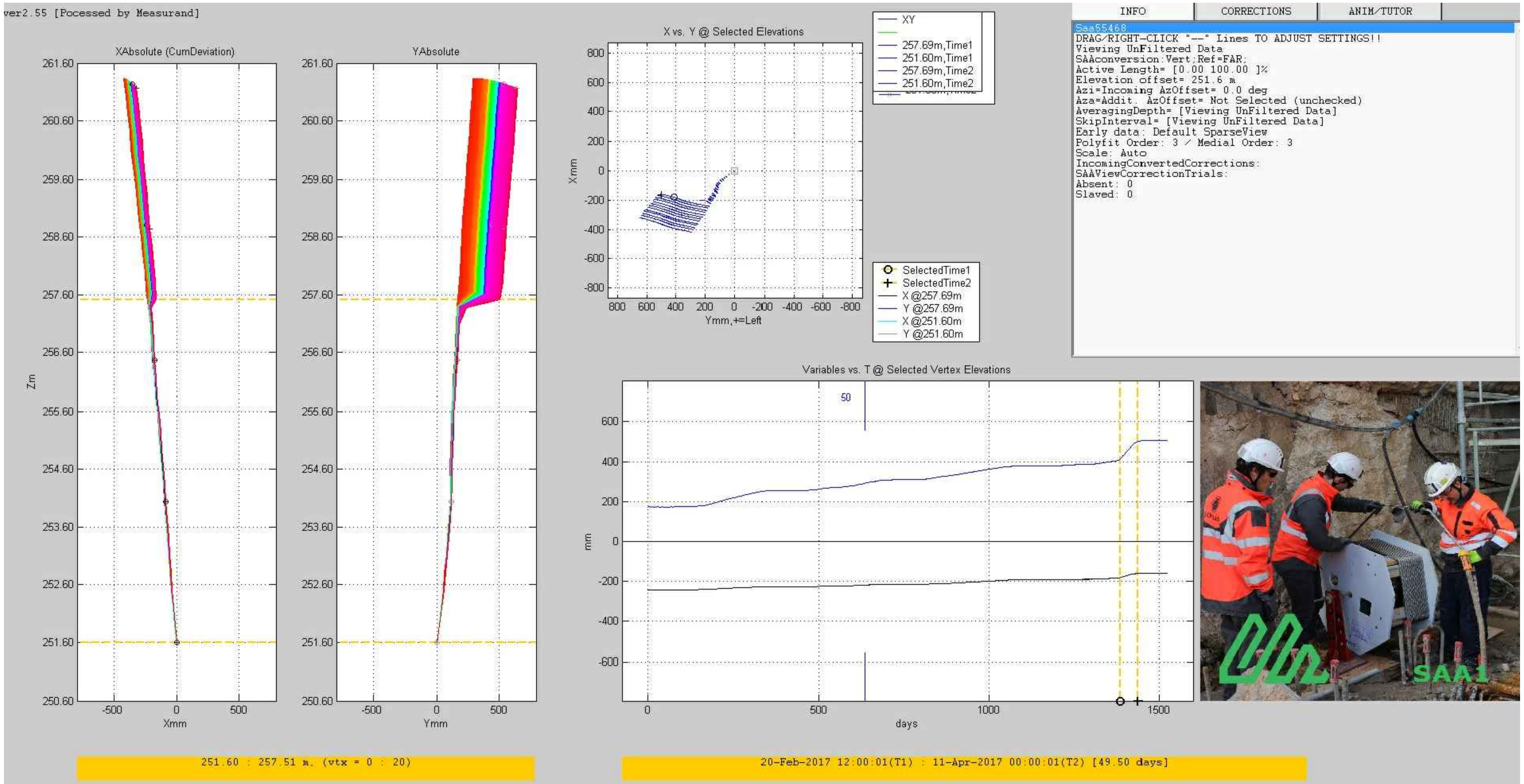

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CUMULATIVE DEVIATION PROFILES FROM CR1000 SAA

PROJECT NO. MENG-04082017		FILE NO. RIPLEY17	
DATE 27-JUL-2017	SCALE AS_SHOWN	FIGURE A3	REV. 1
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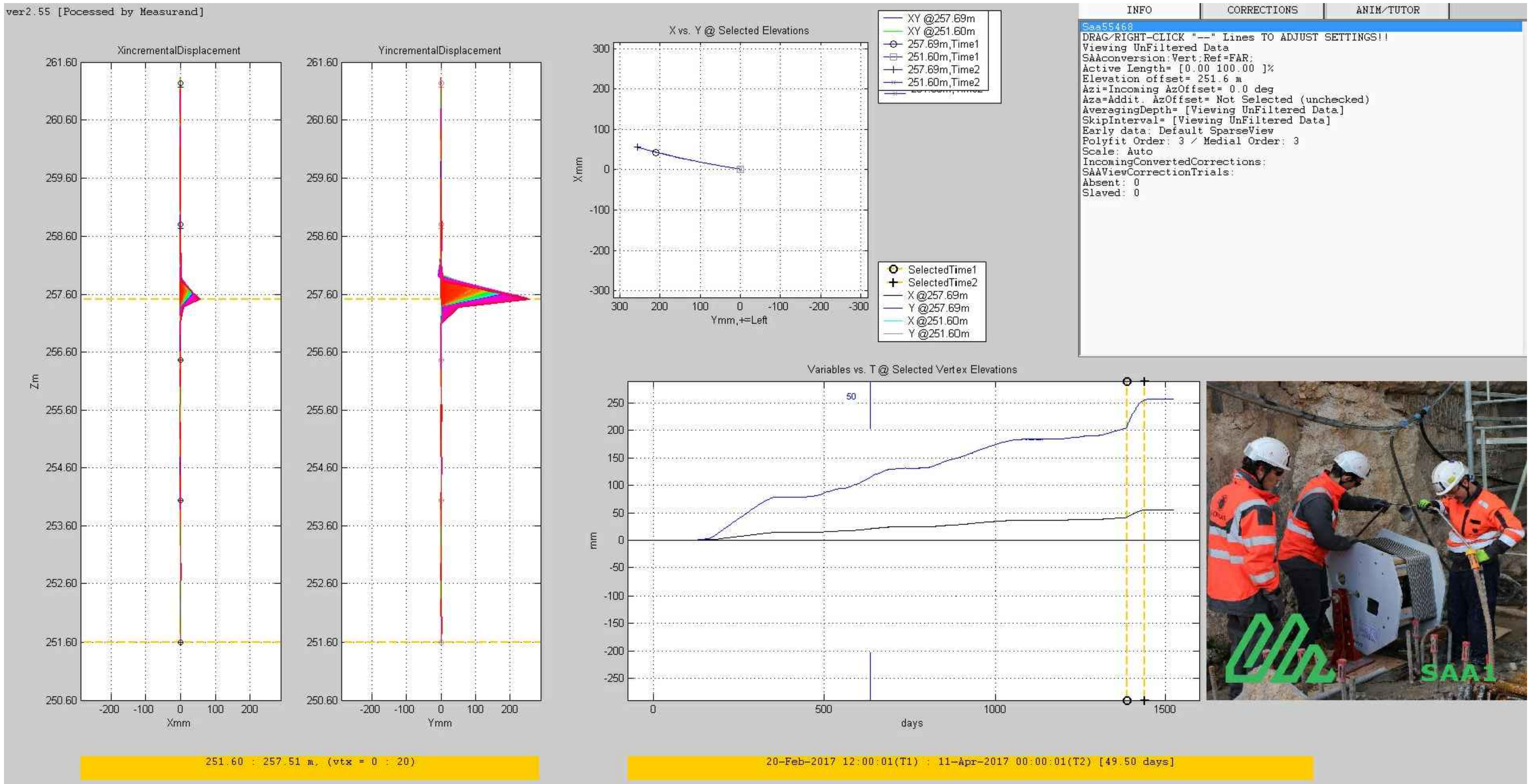

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INCREMENTAL DISPLACEMENT PROFILES FROM CR1000 SAA

PROJECT NO.		FILE NO.	
MENG-04082017		RIPLEY17	
DATE: 27-JUL-2017	SCALE: AS_SHOWN	FIGURE: A4	REV.: 1
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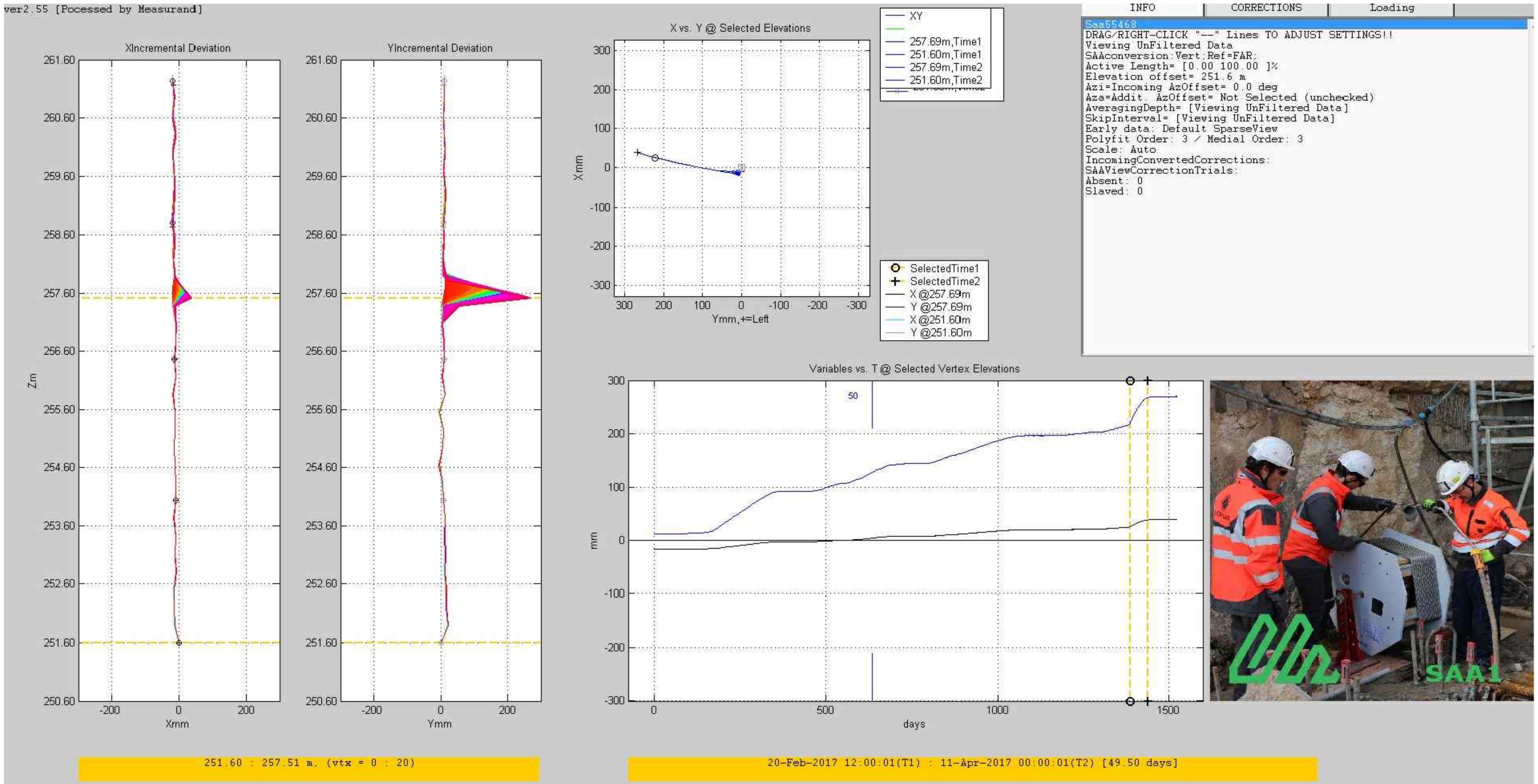

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ASHCROFT, B.C.

DRAWING TITLE
INCREMENTAL DEVIATION PROFILES
FROM CR1000 SAA

PROJECT NO. MENG-04082017		FILE NO. RIPLEY17	
DATE 27-JUL-2017	SCALE AS_SHOWN	FIGURE A5	REV. 1
DRAWN MSD	CHECKED MSD		

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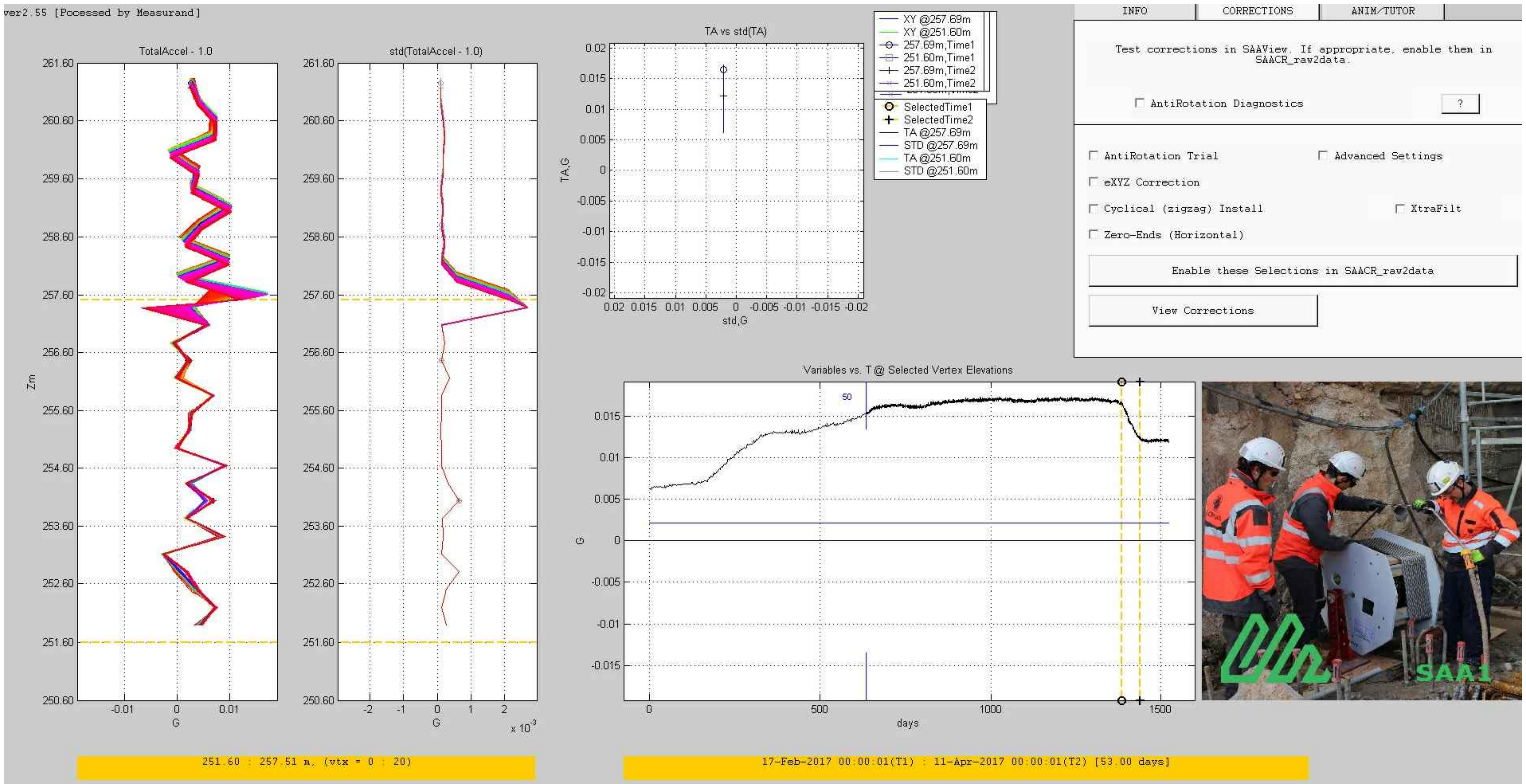

NOTES :

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DRAWING TITLE
TOTAL ACCELERATION PROFILES FROM CR1000 SAA

PROJECT NO. MENG-04082017		FILE NO. RIPLEY17	
DATE 27-JUL-2017	SCALE AS_SHOWN	FIGURE A6	REV. 1
DRAWN MSD	CHECKED MSD		

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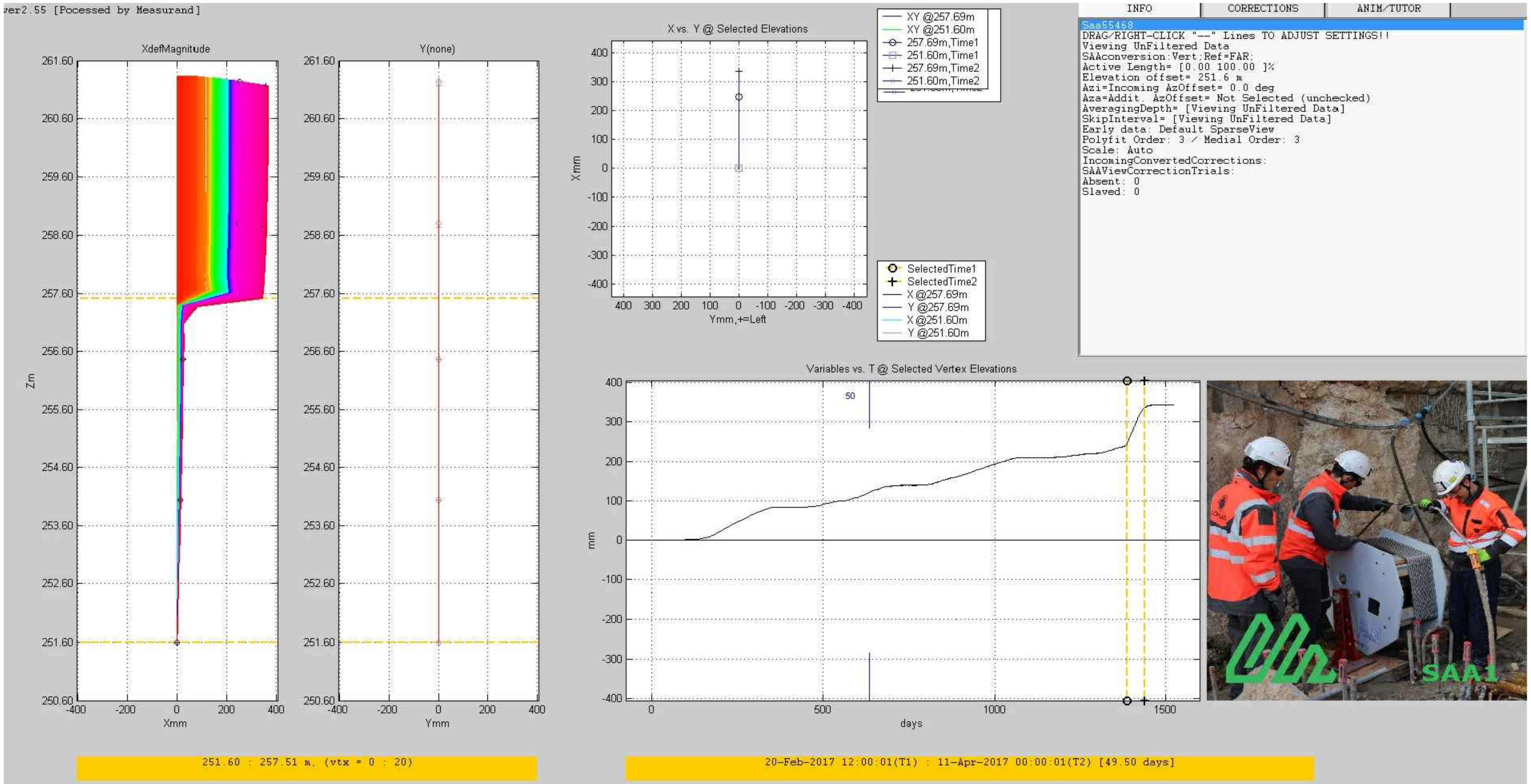

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DRAWING TITLE
DISPLACEMENT MAGNITUDE PROFILES FROM CR1000 SAA

PROJECT NO. MENG-04082017		FILE NO. RIPLEY17	
DATE 27-JUL-2017	SCALE AS_SHOWN	FIGURE A7	REV. 1
DRAWN MSD	CHECKED MSD		

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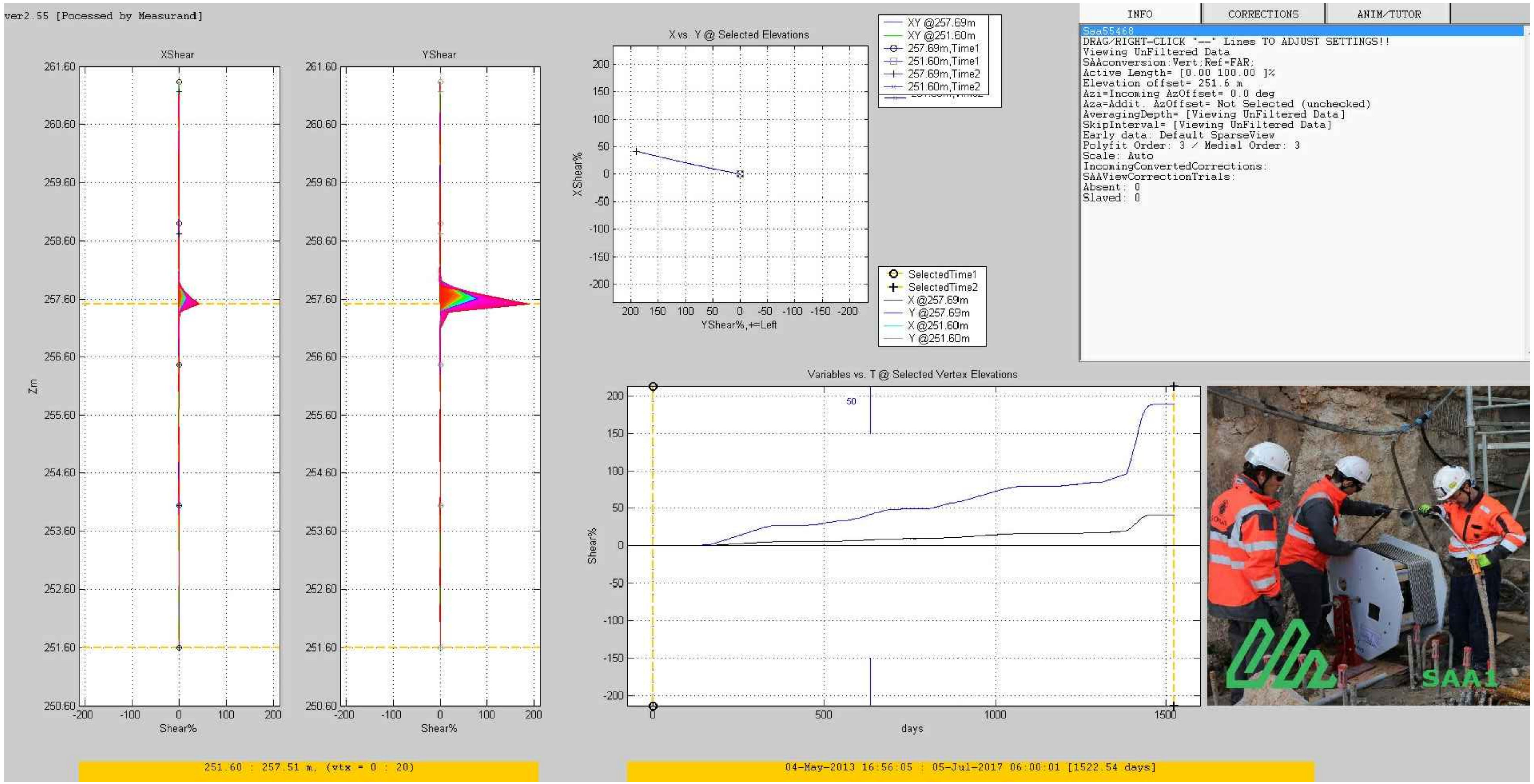

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SHEAR PROFILES FROM CR1000 SAA

PROJECT NO.		FILE NO.	
MENG-04082017		RIPLEY17	
DATE 27-JUL-2017	SCALE AS_SHOWN	FIGURE A8	REV. 1
DRAWN MSD	CHECKED MSD		

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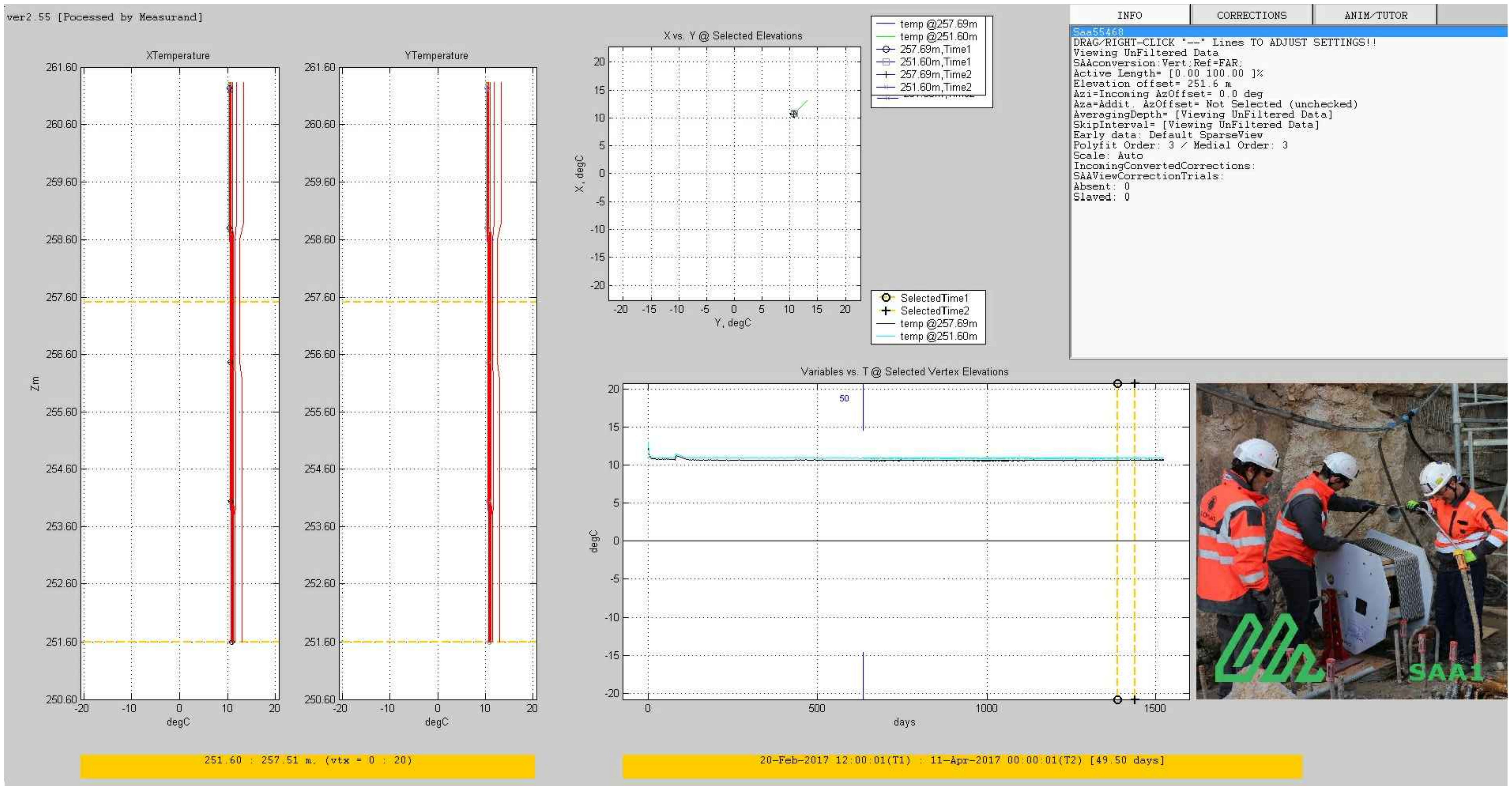

NOTES :

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DRAWING TITLE
TEMPERATURE PROFILES FROM CR1000 SAA

PROJECT NO.		FILE NO.	
MENG-04082017		RIPLEY17	
DATE 27-JUL-2017	SCALE AS_SHOWN	FIGURE A9	REV. 1
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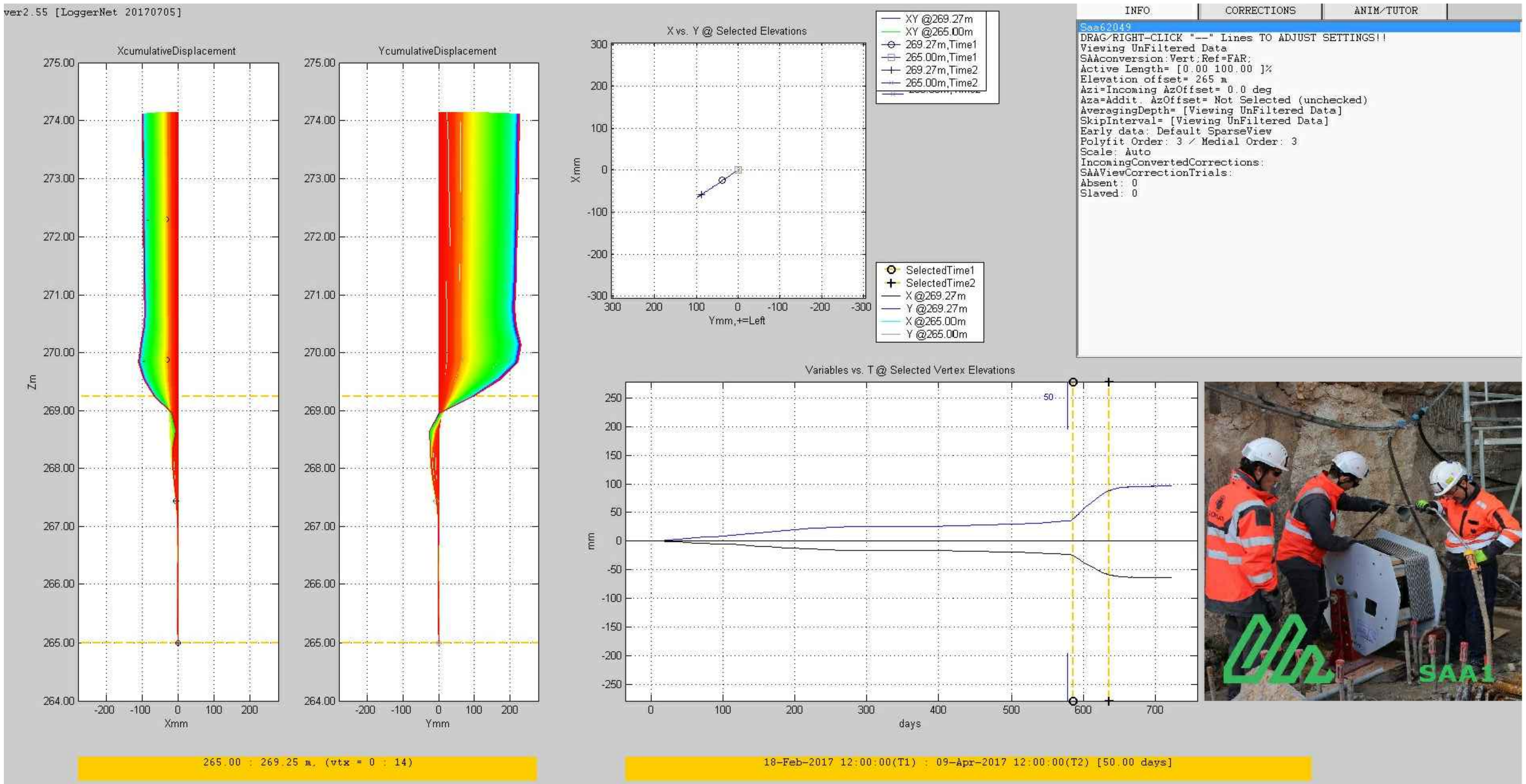

NOTES :

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ANALYZING THE KINEMATICS OF THE RIPLEY LANDSLIDE, ASHCROFT, B.C.

DRAWING TITLE
CUMULATIVE DISPLACEMENT PROFILES FROM CR6 SAA

PROJECT NO. MENG-04082017		FILE NO. RIPLEY17	
DATE 27-JUL-2017	SCALE AS_SHOWN	FIGURE A10	REV. 1
DRAWN MSD	CHECKED MSD		

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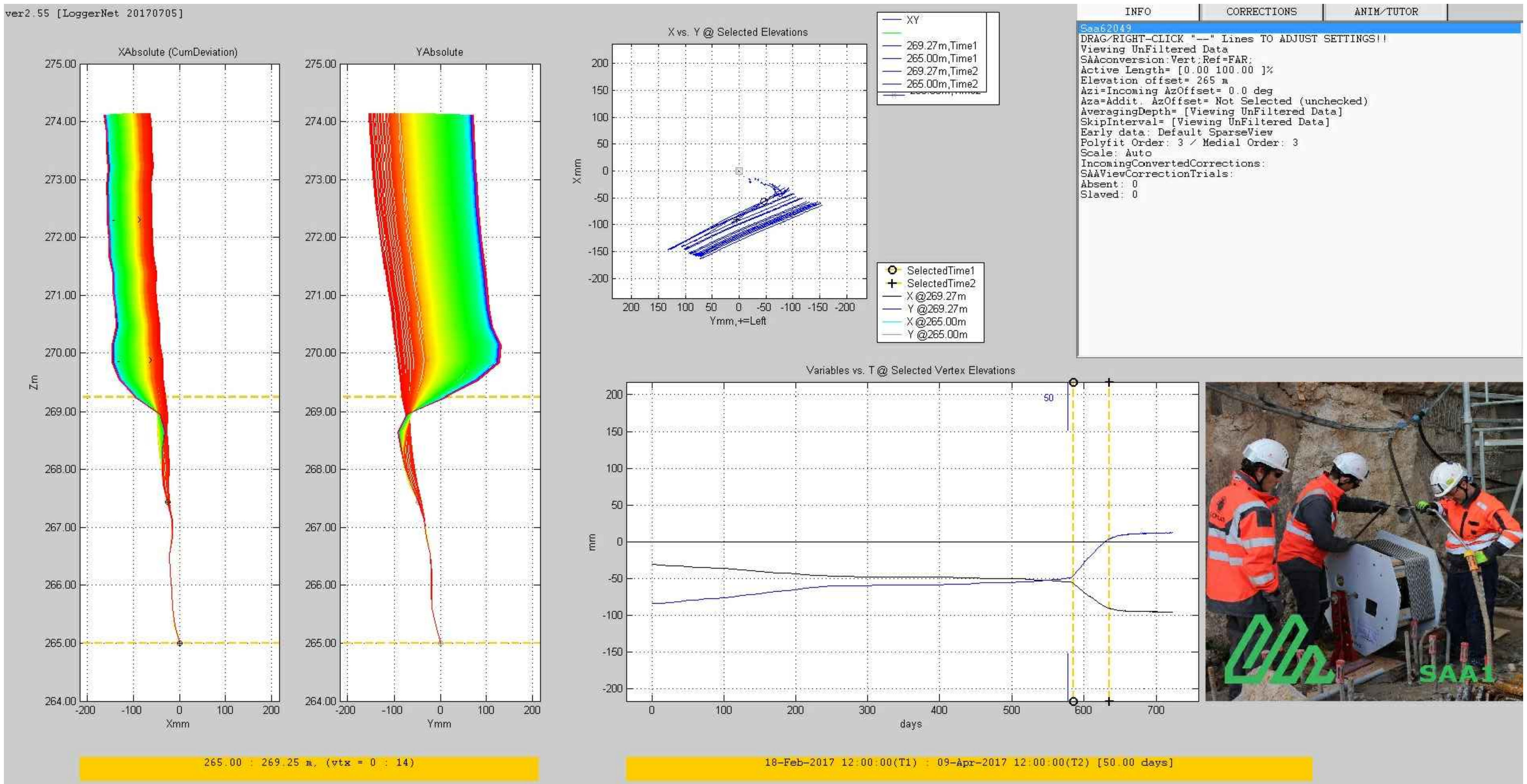

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CUMULATIVE DEVIATION PROFILES FROM CR6 SAA

PROJECT NO. MENG-04082017		FILE NO. RIPLEY17	
DATE 27-JUL-2017	SCALE AS_SHOWN	FIGURE A11	REV. 1
DRAWN MSD	CHECKED MSD		

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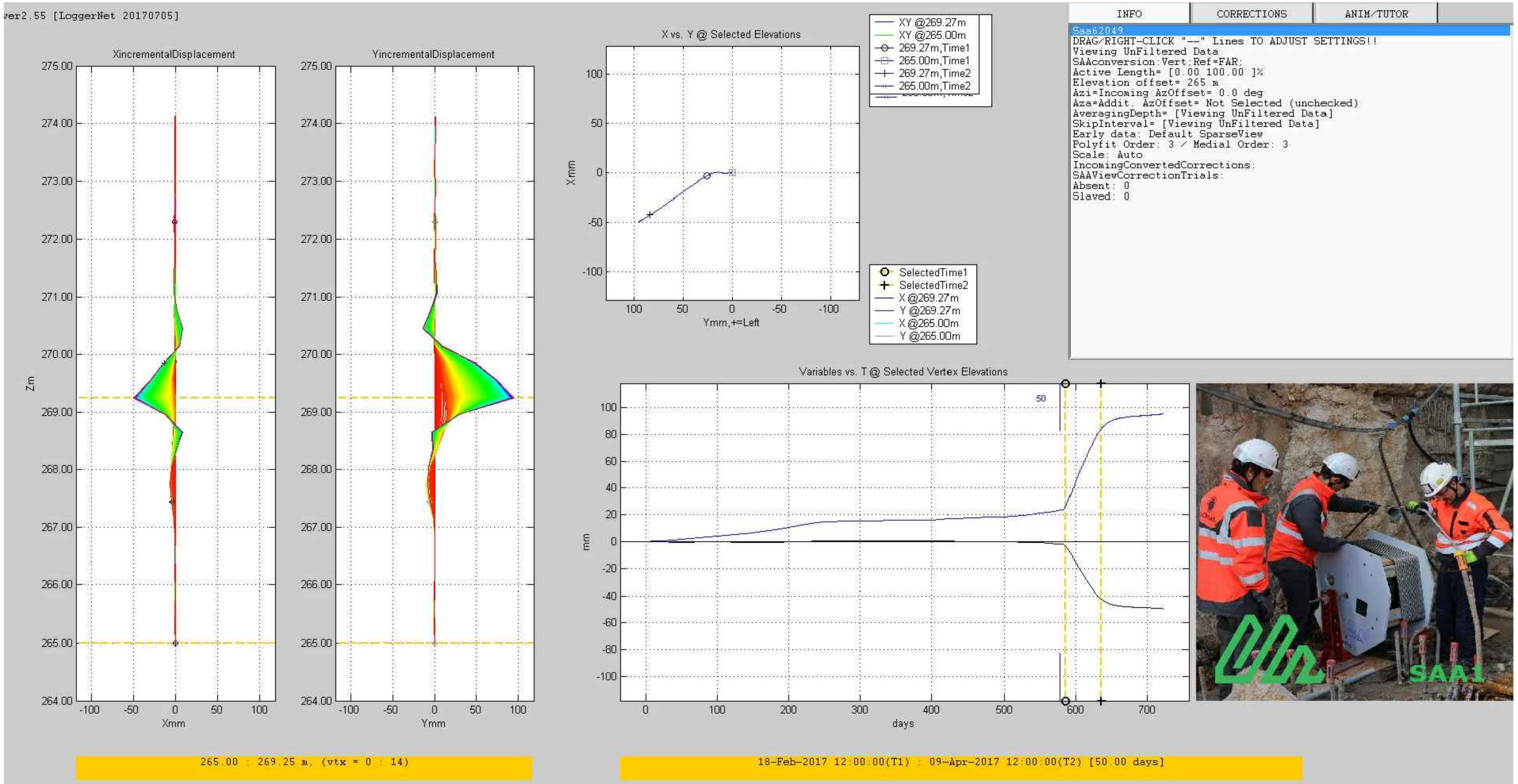

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DRAWING TITLE
INCREMENTAL DISPLACEMENT PROFILES FROM CR6 SAA

PROJECT NO. MENG-04082017		FILE NO. RIPLEY17	
DATE 27-JUL-2017	SCALE AS_SHOWN	FIGURE A12	REV. 1
DRAWN MSD	CHECKED MSD		

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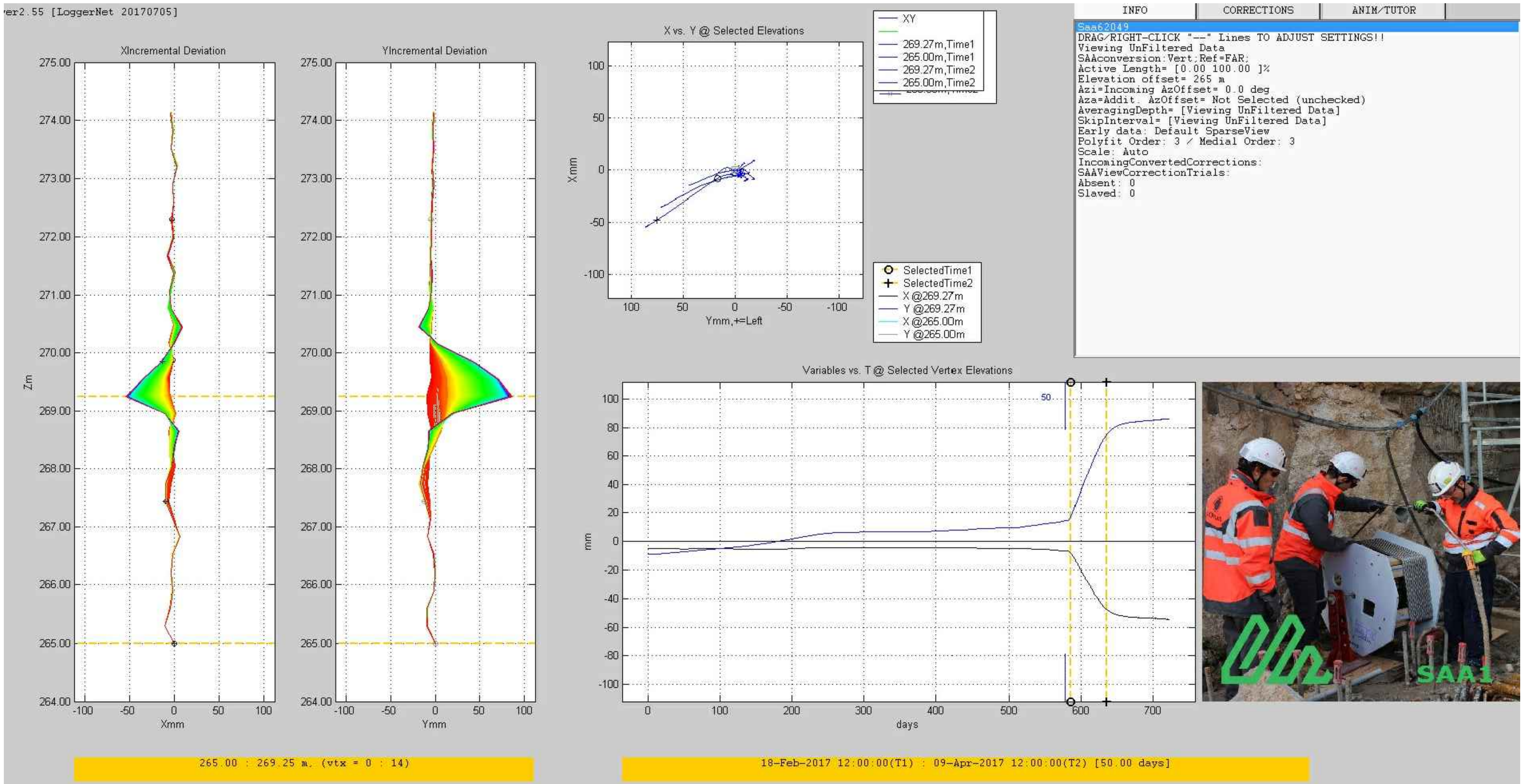

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ANALYZING THE KINEMATICS OF THE RIPLEY LANDSLIDE, ASHCROFT, B.C.

DRAWING TITLE
INCREMENTAL DEVIATION PROFILES FROM CR6 SAA

PROJECT NO. MENG-04082017		FILE NO. RIPLEY17	
DATE 27-JUL-2017	SCALE AS_SHOWN	FIGURE A13	REV. 1
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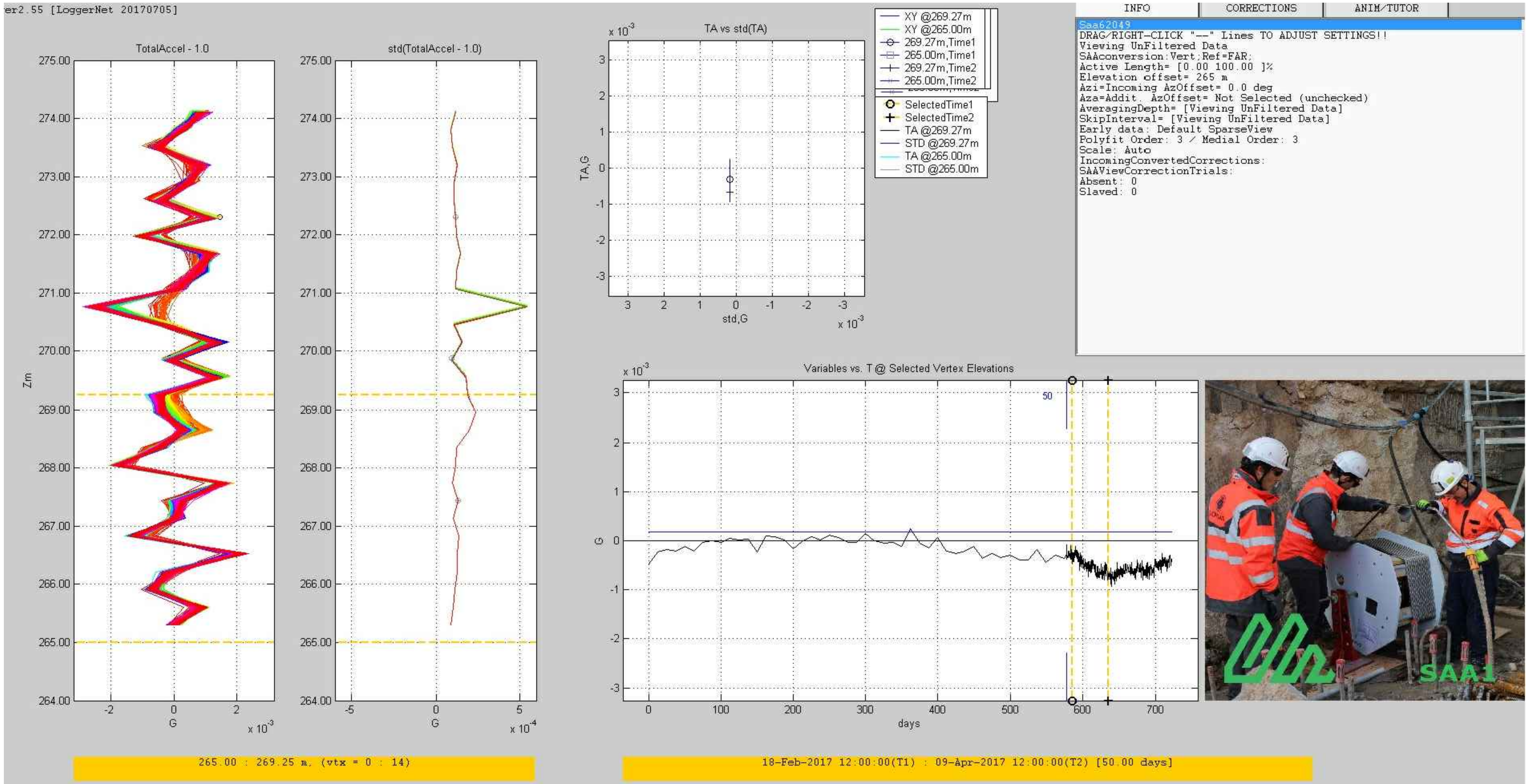

NOTES :

1. PROFILES GENERATED USING SAAVIEW SOFTWARE AVAILABLE AT MEASURANDGEOTECHNICAL.COM;
2. UNFILTERED DATA USED; AND
3. GEODETIC ELEVATIONS BASED ON SCHAFER (2016).

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FOR:
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PROJECT TITLE
ANALYZING THE KINEMATICS OF THE RIPLEY LANDSLIDE, ASHCROFT, B.C.

DRAWING TITLE
TOTAL ACCELERATION PROFILES FROM CR6 SAA

PROJECT NO. MENG-04082017		FILE NO. RIPLEY17	
DATE 27-JUL-2017	SCALE AS_SHOWN	FIGURE A14	REV. 1
DRAWN MSD	CHECKED MSD		

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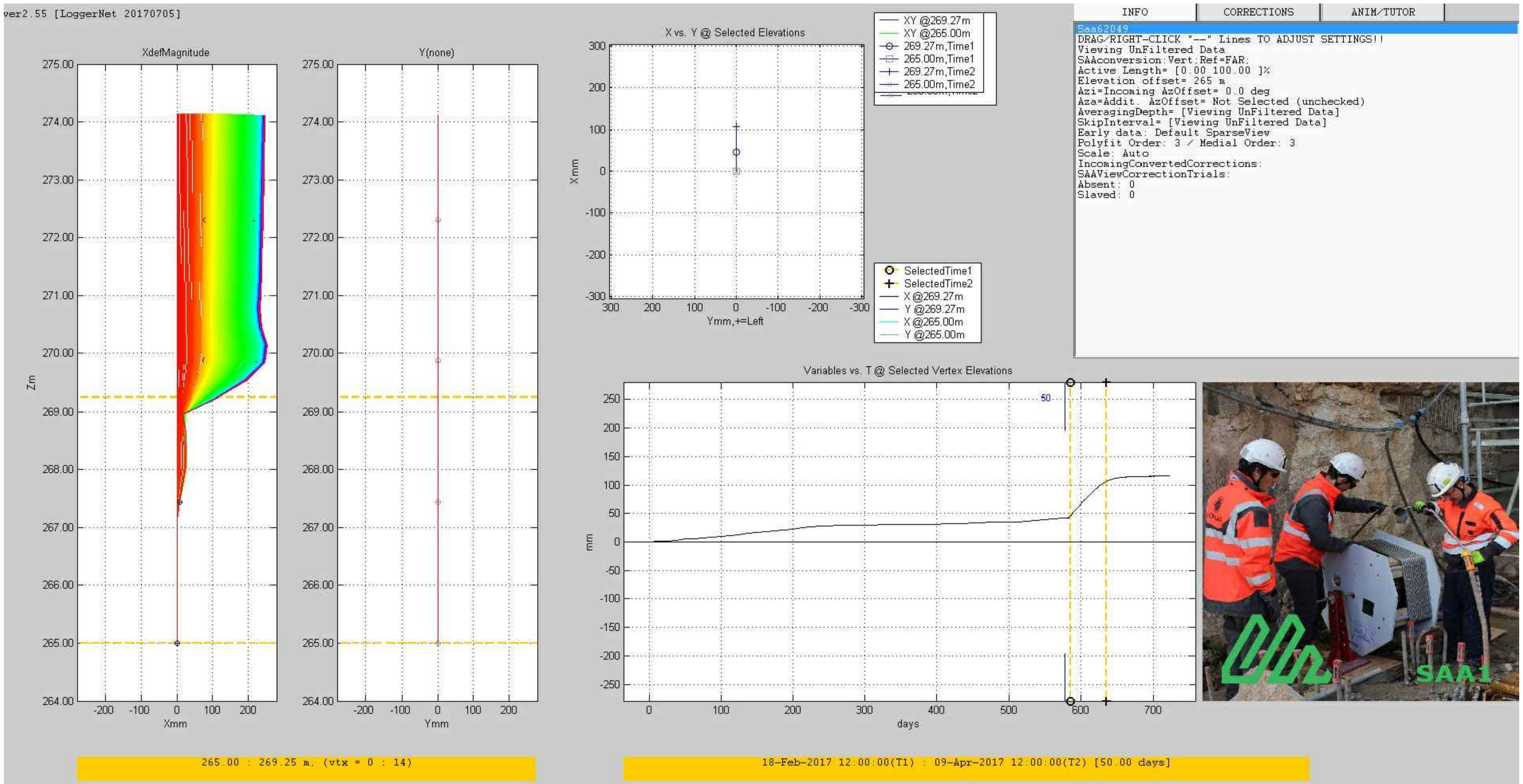

NOTES :

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PROJECT TITLE
ANALYZING THE KINEMATICS OF THE RIPLEY LANDSLIDE, ASHCROFT, B.C.

DRAWING TITLE
DISPLACEMENT MAGNITUDE PROFILES FROM CR6 SAA

PROJECT NO. MENG-04082017		FILE NO. RIPLEY17	
DATE 27-JUL-2017	SCALE AS_SHOWN	FIGURE A15	REV. 1
DRAWN MSD	CHECKED MSD		

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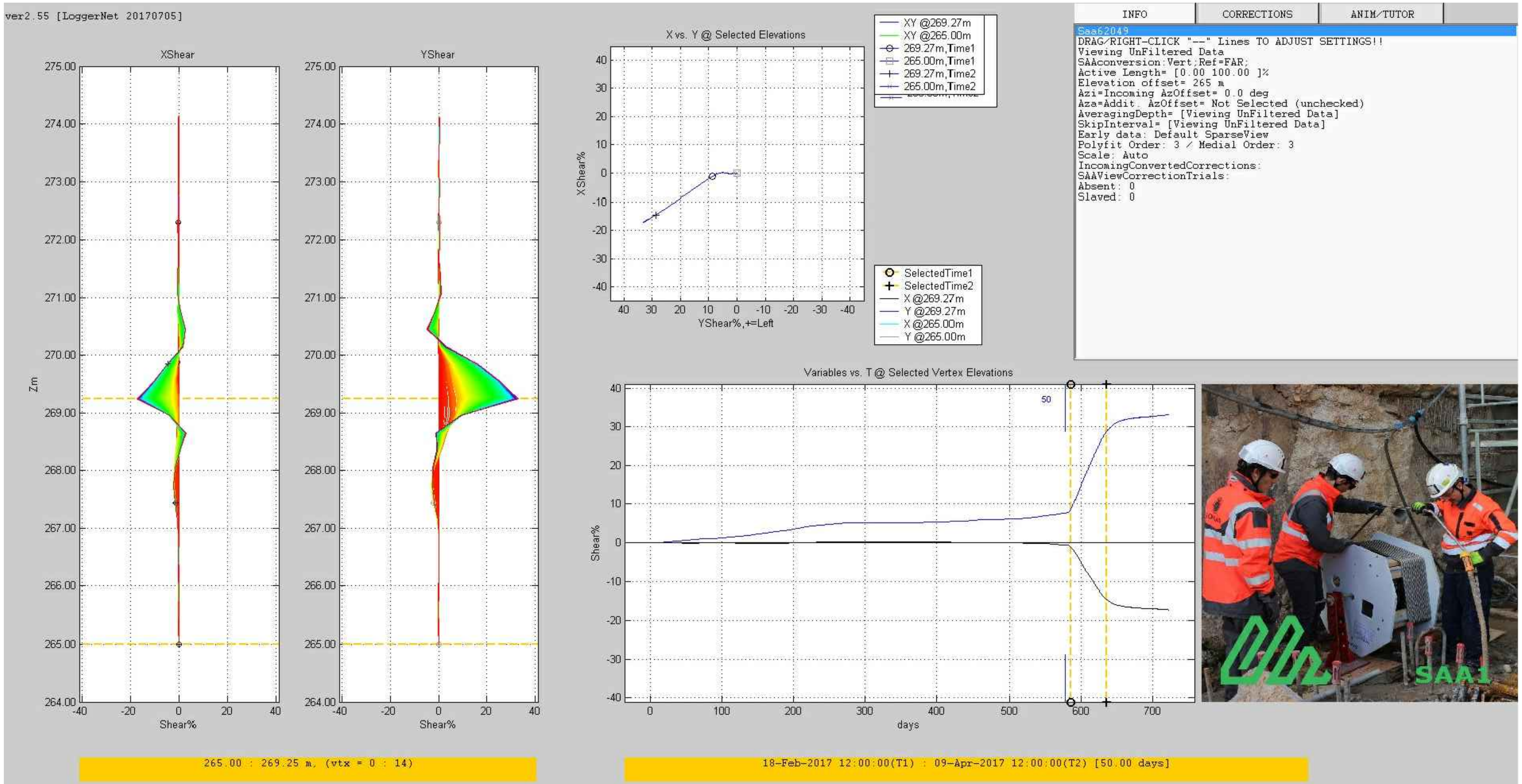

NOTES :

1. PROFILES GENERATED USING SAAVIEW SOFTWARE AVAILABLE AT MEASURANDGEOTECHNICAL.COM;
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PROJECT TITLE
ANALYZING THE KINEMATICS OF THE RIPLEY LANDSLIDE, ASHCROFT, B.C.

DRAWING TITLE
SHEAR PROFILES FROM CR6 SAA

PROJECT NO.		FILE NO.	
MENG-04082017		RIPLEY17	
DATE 27-JUL-2017	SCALE AS_SHOWN	FIGURE A16	REV. 1
DRAWN MSD	CHECKED MSD		

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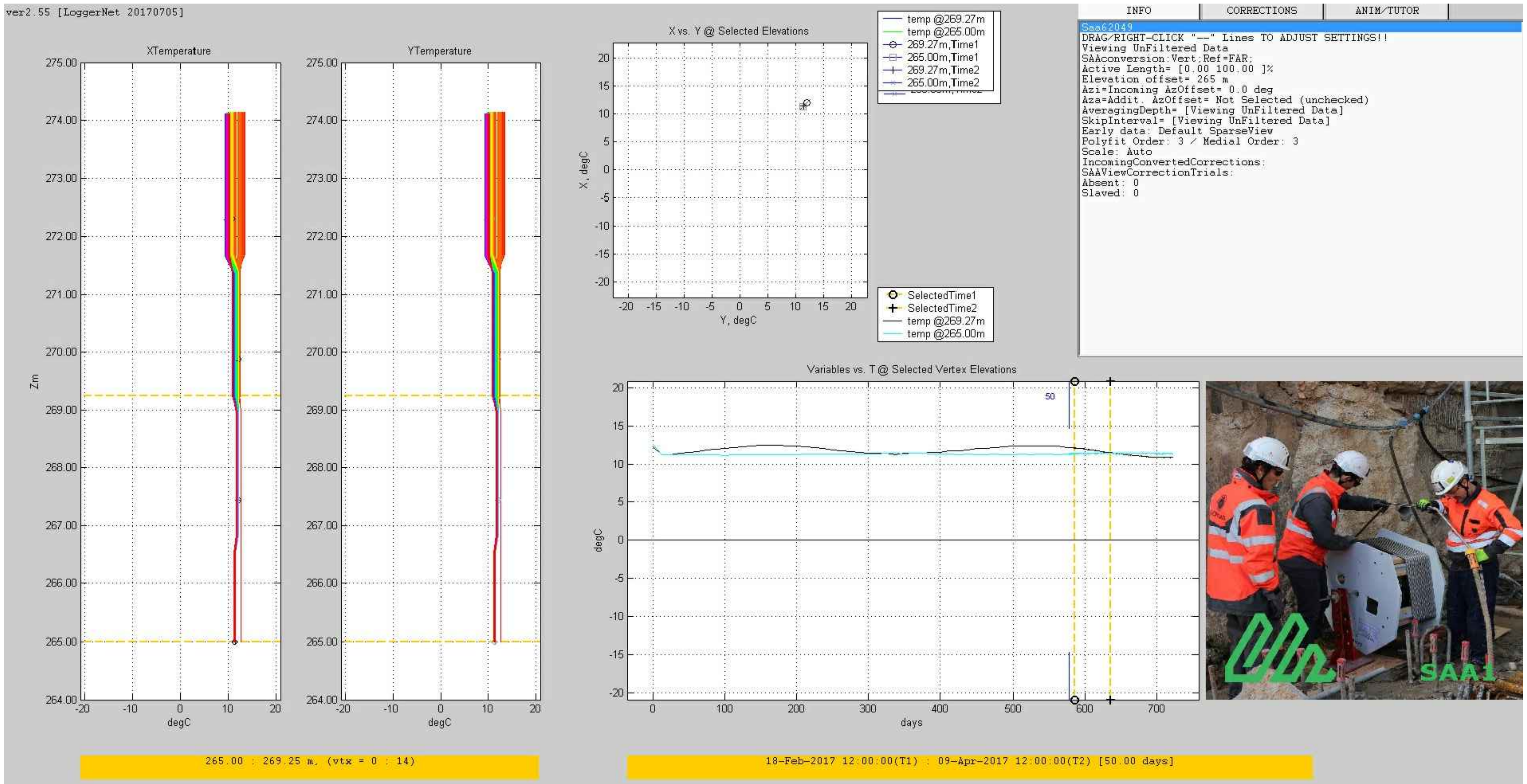

NOTES :

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3. GEODETIC ELEVATIONS BASED ON SCHAFER (2016)

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PROJECT TITLE
ANALYZING THE KINEMATICS OF THE RIPLEY LANDSLIDE, ASHCROFT, B.C.

DRAWING TITLE
TEMPERATURE PROFILES FROM CR6 SAA

PROJECT NO. MENG-04082017		FILE NO. RIPLEY17	
DATE 27-JUL-2017	SCALE AS_SHOWN	FIGURE A17	REV. 1
DRAWN MSD	CHECKED MSD		

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Appendix B

Tables

Appendix B - Tables

Table B.1 – Summary of estimated slide velocity from GPS1 measurements					
Status	Time period		Total 2D Displacement (m)	Days	Avg. velocity (mm/day)
	From	To			
Inactive	1 Apr 2010	1 Aug 2010	0.020	122	0.16
Active	1 Aug 2010	1 Apr 2011	0.104	243	0.43
Inactive	1 Apr 2011	11 Sep 2011	0.032	163	0.19
Active	11 Sep 2011	1 Apr 2011	0.085	203	0.42
Inactive	1 Apr 2011	1 Aug 2012	0.013	122	0.10
Active	1 Aug 2012	1 Apr 2013	0.010	243	0.41
Inactive	1 Apr 2013	1 Aug 2013	0.019	122	0.16
Active	1 Aug 2013	1 Apr 2014	0.087	243	0.36
Inactive	1 Apr 2014	1 Aug 2014	0.021	122	0.17
Active	1 Aug 2014	1 Apr 2015	0.064	243	0.26
Inactive	1 Apr 2015	27 Jul 2015	0.016	117	0.14
Active	27 Jul 2015	15 Apr 2016	0.080	263	0.31
Inactive	15 Apr 2016	1 Aug 2016	0.009	108	0.08
Active	1 Aug 2016	1 Apr 2017	0.250	243	1.03

Table B.2 – Summary of estimated slide velocity from GPS2 measurements

Status	Time period		Total 2D Displacement (m)	Days	Avg. velocity (mm/day)
	From	To			
Inactive	1 Apr 2011	18 Jul 2011	0.021	108	0.20
Active	18 Jul 2011	1 Apr 2012	0.112	258	0.43
Inactive	1 Apr 2012	1 Aug 2012	0.010	122	0.08
Active	1 Aug 2012	1 Apr 2013	0.107	243	0.44
Inactive	1 Apr 2014	29 Jul 2014	0.014	119	0.12
Active	29 Jul 2014	1 Apr 2015	0.070	246	0.29
Inactive	1 Apr 2015	10 Aug 2015	0.028	131	0.21
Active	10 Aug 2015	15 Apr 2016	0.071	249	0.29
Inactive	15 Apr 2016	1 Aug 2016	0.003	108	0.03
Active	1 Aug 2016	1 Apr 2017	0.278	243	1.14

Table B.3 – Summary of estimated slide velocity from GPS3 measurements

Status	Time period		Total 2D Displacement (m)	Days	Avg. velocity (mm/day)
	From	To			
Inactive	1 Apr 2011	18 Jul 2011	0.040	108	0.37
Active	18 Jul 2011	1 Apr 2012	0.110	258	0.43
Inactive	1 Apr 2012	1 Aug 2012	0.020	122	0.16
Active	1 Aug 2012	1 Apr 2013	0.140	243	0.58
Inactive	1 Apr 2014	1 Aug 2014	0.030	122	0.25
Active	1 Aug 2014	1 Apr 2015	0.104	243	0.43
Inactive	1 Apr 2015	27 Jul 2015	0.017	117	0.15
Active	27 Jul 2015	15 Apr 2016	0.081	263	0.31
Inactive	15 Apr 2016	1 Aug 2016	0.010	108	0.09
Active	1 Aug 2016	1 Apr 2017	0.312	243	1.28

Appendix C

Slope Stability Assessment

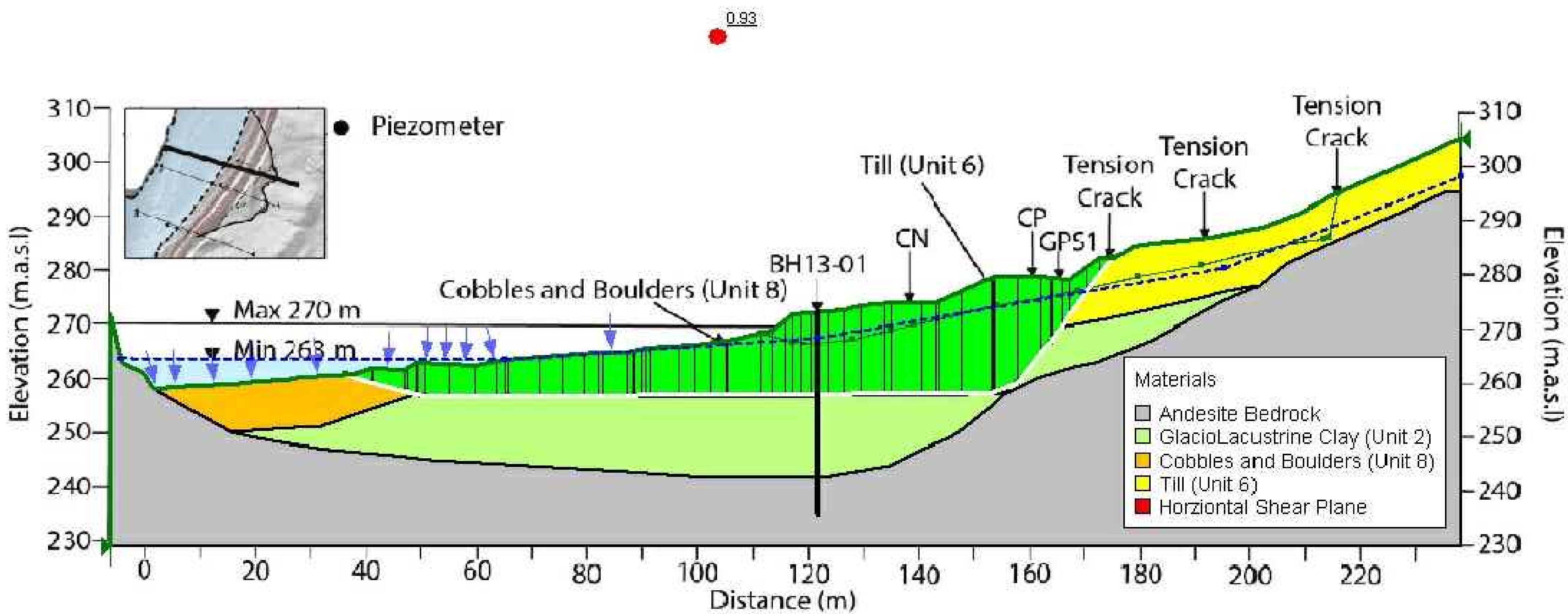
Figure C1 to C4 – Slope Stability Analysis on Cross Section 1

Figure C5 to C10 – Slope Stability Analysis on Cross Section 2

Figure C11 to C12– Slope Stability Analysis on Cross Section 3

Project: Ripley Slide - Slope Stability Analysis
Cross Section ID: 1A
Case: PWP in BH13-01 at lowest (Since 2013)
Thompson River Level at: Approx. 263.5 m asl
Approx. Time Period: March 2017

Analysis Info:
Type: Mohr-Coulomb
Method: Morgenstern-Price
Date: 19 July 2017
By: MSD



NOTES :

1. CROSS SECTION IS BASED ON FIGURE 5-5 ON SCHAFER (2017);
2. GROUNDWATER TABLE INTERPRETED FROM VWPS INSTALLED ABOVE AND BELOW THE PRIMARY SHEAR ZONE; RIVER LEVEL BASED ON HISTORICAL DATA RETRIEVED FROM ENVIRONMENTAL CANADA WEB DATA BASE;
3. THE BEDROCK INTERFACE IS BASED ON A GEOPHYSICAL SURVEY;
4. FAILURE PLANE IS ASSUMED, THE DEPTH OF THE FAILURE PLANE ONLY MATCHED AT THE SAA LOCATION WHERE APPLICABLE.

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FOR:
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PROJECT TITLE
ANALYZING THE KINEMATICS OF THE RIPLEY LANDSLIDE, ASHCROFT, B.C.

DRAWING TITLE
SLOPE STABILITY ANALYSIS FOR CROSS SECTION 1A(P)

PROJECT NO.	FILE NO.		
MENG-04082017	RIPLEY17		
DATE: 27-JUL-2017	SCALE: AS_SHOWN	FIGURE: C1	REV.: 1
DRAWN: MSD	CHECKED: MSD		

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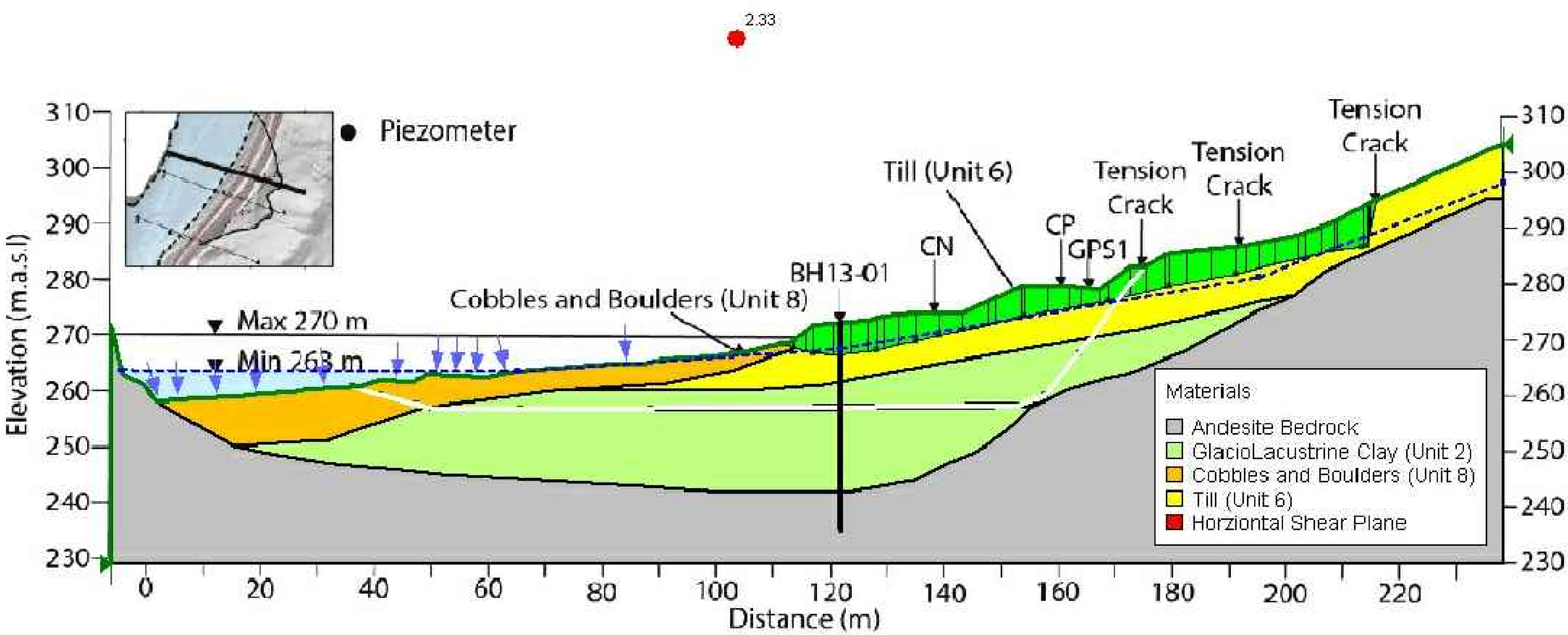
Project: Ripley Slide - Slope Stability Analysis
Cross Section ID: 1A
Case: PWP in BH13-01 at lowest (Since 2013)
Thompson River Level at: Approx. 263.5 m asl
Approx. Time Period: March 2017

Analysis Info:
Type: Mohr-Coulomb
Method: Morgenstern-Price
Date: 19 July 2017
By: MSD



NOTES :

1. CROSS SECTION IS BASED ON FIGURE 5-5 ON SCHAFER (2017);
2. GROUNDWATER TABLE INTERPRETED FROM VWPS INSTALLED ABOVE AND BELOW THE PRIMARY SHEAR ZONE; RIVER LEVEL BASED ON HISTORICAL DATA RETRIEVED FROM ENVIRONMENTAL CANADA WEB DATA BASE;
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PROJECT TITLE
ANALYZING THE KINEMATICS OF THE RIPLEY LANDSLIDE, ASHCROFT, B.C.

DRAWING TITLE
SLOPE STABILITY ANALYSIS FOR CROSS SECTION 1A(S)

PROJECT NO.	FILE NO.		
MENG-04082017	RIPLEY17		
DATE: 27-JUL-2017	SCALE: AS_SHOWN	FIGURE: C2	REV.: 1
DRAWN: MSD	CHECKED: MSD		

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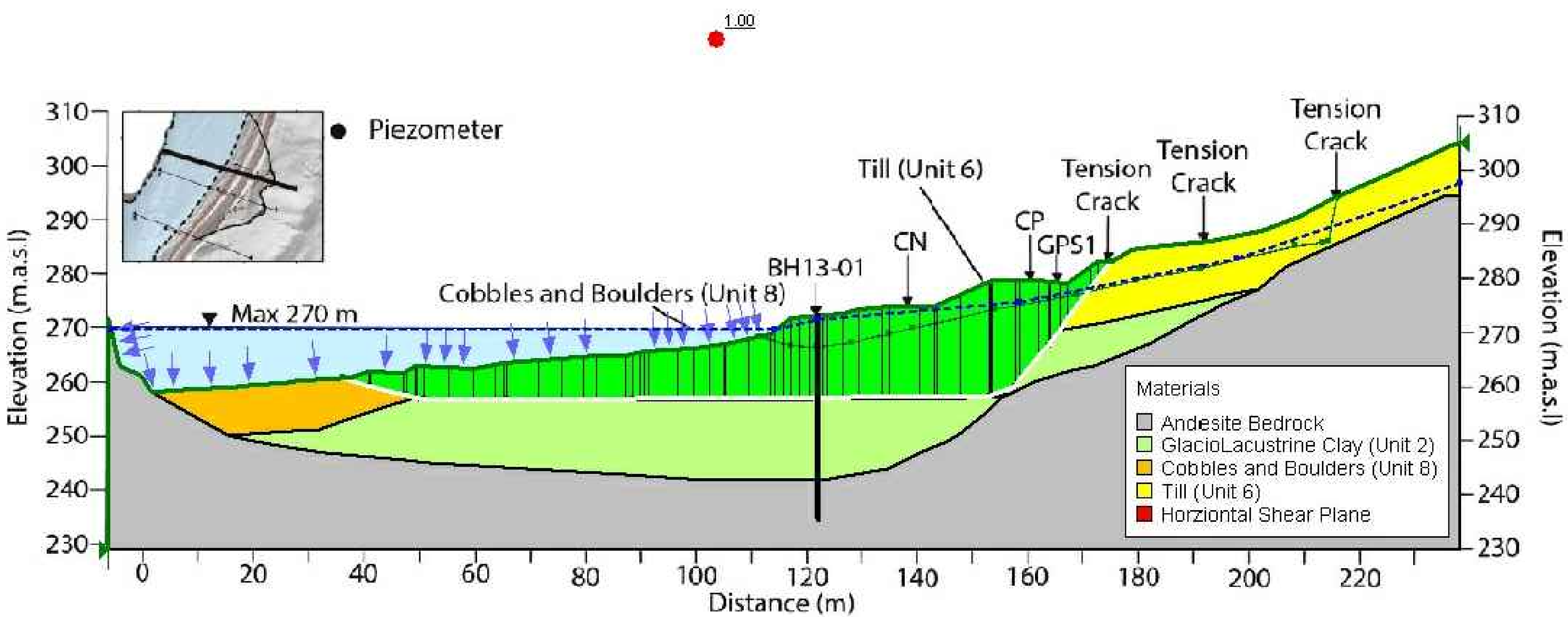
Project: Ripley Slide - Slope Stability Analysis
Cross Section ID: 1B
Case: PWP in BH13-01 at highest (Since 2013)
Thompson River Level at: Approx. 271.5 m asl
Approx. Time Period: June 2014

Analysis Info:
Type: Mohr-Coulomb
Method: Morgenstern-Price
Date: 19 July 2017
By: MSD



NOTES :

1. CROSS SECTION IS BASED ON FIGURE 5-5 ON SCHAFER (2017);
2. GROUNDWATER TABLE INTERPRETED FROM VWPS INSTALLED ABOVE AND BELOW THE PRIMARY SHEAR ZONE; RIVER LEVEL BASED ON HISTORICAL DATA RETRIEVED FROM ENVIRONMENTAL CANADA WEB DATA BASE;
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PROJECT TITLE
ANALYZING THE KINEMATICS OF THE RIPLEY LANDSLIDE, ASHCROFT, B.C.

DRAWING TITLE
SLOPE STABILITY ANALYSIS FOR CROSS SECTION 1B (P)

PROJECT NO.	FILE NO.		
MENG-04082017	RIPLEY17		
DATE 27-JUL-2017	SCALE AS_SHOWN	FIGURE C3	REV. 1
DRAWN MSD	CHECKED MSD		

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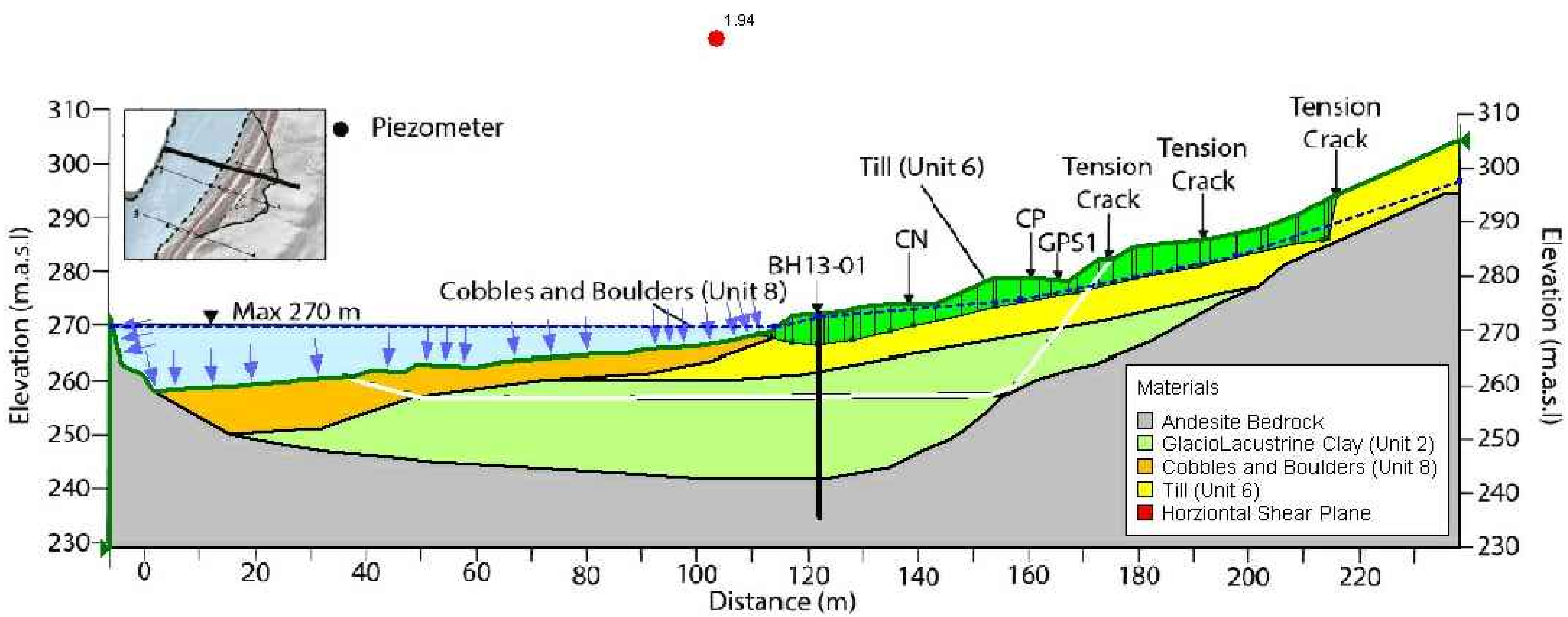
Project: Ripley Slide - Slope Stability Analysis
Cross Section ID: 1B
Case: PWP in BH13-01 at highest (Since 2013)
Thompson River Level at: Approx. 271.5 m asl
Approx. Time Period: June 2014

Analysis Info:
Type: Mohr-Coulomb
Method: Morgenstern-Price
Date: 19 July 2017
By: MSD



NOTES :

1. CROSS SECTION IS BASED ON FIGURE 5-5 ON SCHAFER (2017);
2. GROUNDWATER TABLE INTERPRETED FROM VWPS INSTALLED ABOVE AND BELOW THE PRIMARY SHEAR ZONE; RIVER LEVEL BASED ON HISTORICAL DATA RETRIEVED FROM ENVIRONMENTAL CANADA WEB DATA BASE;
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PROJECT TITLE
ANALYZING THE KINEMATICS OF THE RIPLEY LANDSLIDE, ASHCROFT, B.C.

DRAWING TITLE
SLOPE STABILITY ANALYSIS FOR CROSS SECTION 1B (S)

PROJECT NO.		FILE NO.	
MENG-04082017		RIPLEY17	
DATE 27-JUL-2017	SCALE AS_SHOWN	FIGURE C4	REV. 1
DRAWN MSD	CHECKED MSD		

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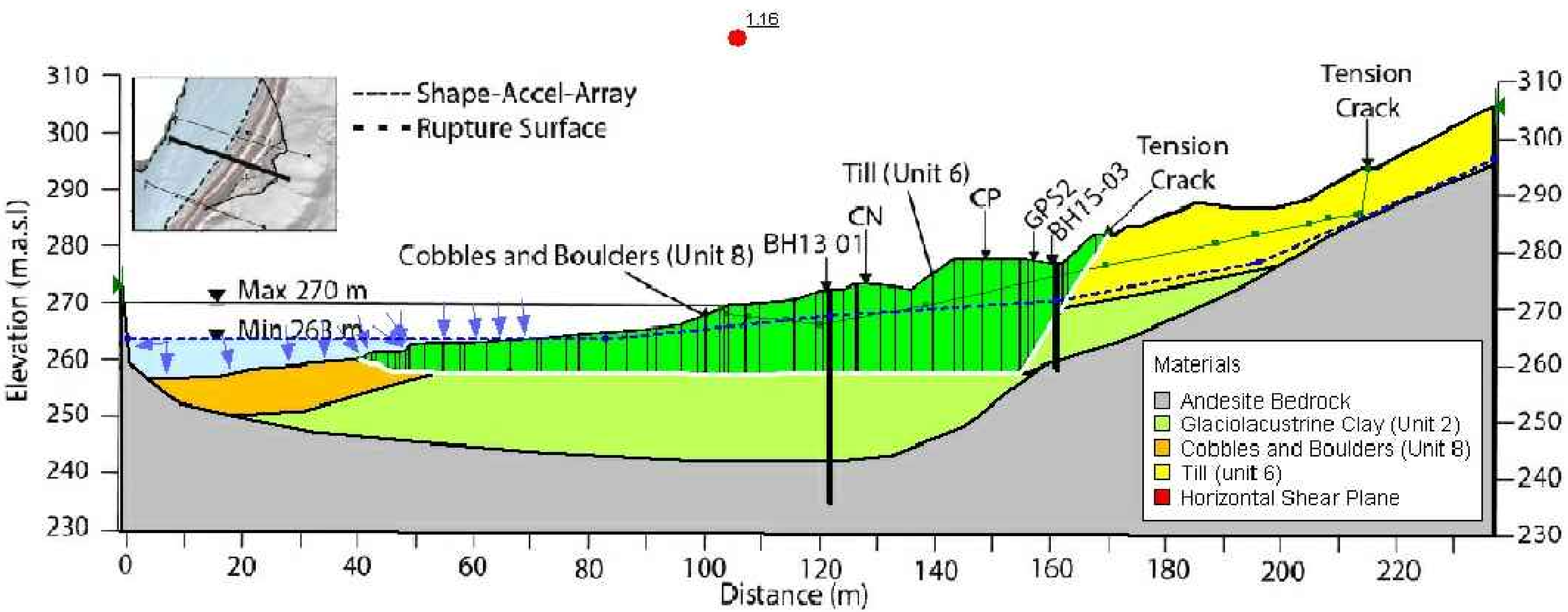
Project: Ripley Slide - Slope Stability Analysis
Cross Section ID: 2A
Case: PWP in BH13-01 and BH15-03 are at lowest (Since 2013)
Thompson River Level at: Approx. 263.5 m asl
Approx. Time Period: Feb 2017

Analysis Info:
Type: Mohr-Coulomb
Method: Morgenstern-Price
Date: 19 July 2017
By: MSD



NOTES :

1. CROSS SECTION IS BASED ON FIGURE 5-5 ON SCHAFER (2017);
2. GROUNDWATER TABLE INTERPRETED FROM VWPS INSTALLED ABOVE AND BELOW THE PRIMARY SHEAR ZONE; RIVER LEVEL BASED ON HISTORICAL DATA RETRIEVED FROM ENVIRONMENTAL CANADA WEB DATA BASE;
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PROJECT TITLE
ANALYZING THE KINEMATICS OF THE RIPLEY LANDSLIDE, ASHCROFT, B.C.

DRAWING TITLE
SLOPE STABILITY ANALYSIS FOR CROSS SECTION 2A(P)

PROJECT NO. MENG-04082017
FILE NO. RIPLEY17
DATE 27-JUL-2017
SCALE AS_SHOWN
FIGURE C5
REV. 1
DRAWN MSD
CHECKED MSD

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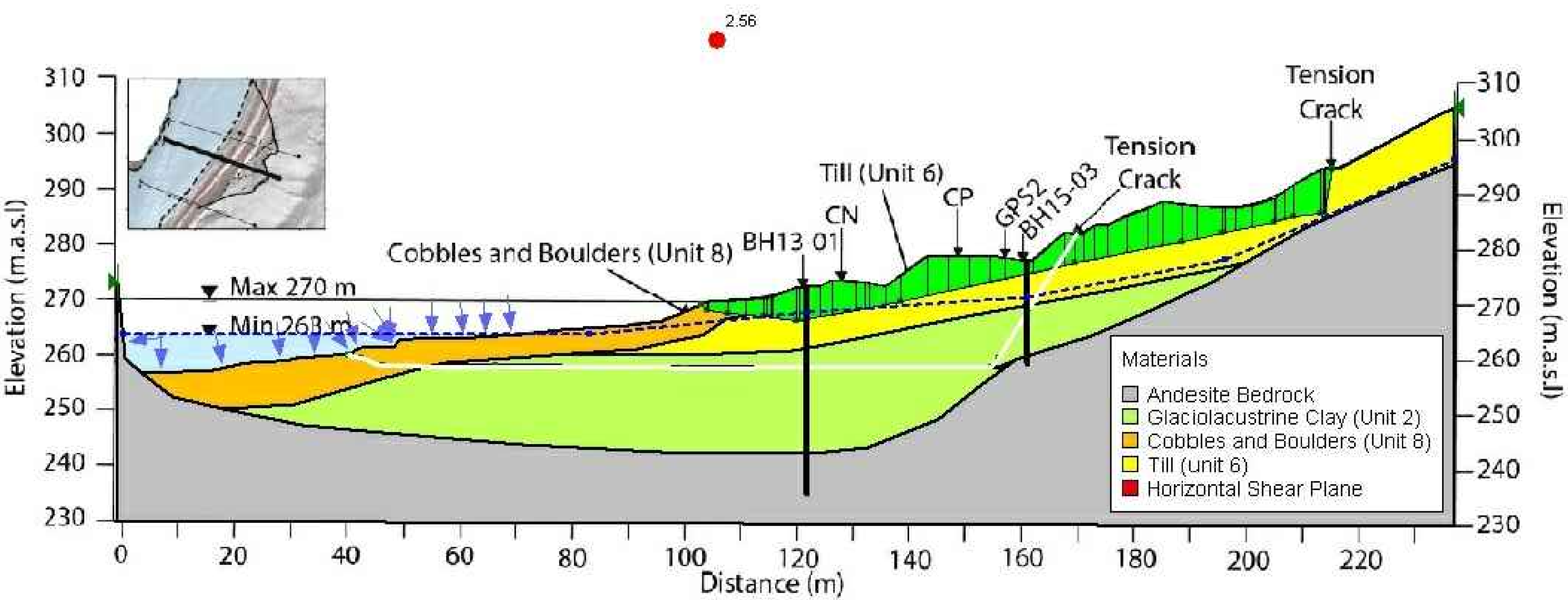
Project: Ripley Slide - Slope Stability Analysis
Cross Section ID: 2A
Case: PWP in BH13-01 and BH15-03 are at lowest (Since 2013)
Thompson River Level at: Approx. 263.5 m asl
Approx. Time Period: Feb 2017

Analysis Info:
Type: Mohr-Coulomb
Method: Morgenstern-Price
Date: 19 July 2017
By: MSD



NOTES :

1. CROSS SECTION IS BASED ON FIGURE 5-5 ON SCHAFER (2017);
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PROJECT TITLE
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DRAWING TITLE
SLOPE STABILITY ANALYSIS FOR CROSS SECTION 2A(S)

PROJECT NO. MENG-04082017		FILE NO. RIPLEY17	
DATE 27-JUL-2017	SCALE AS_SHOWN	FIGURE C6	REV. 1
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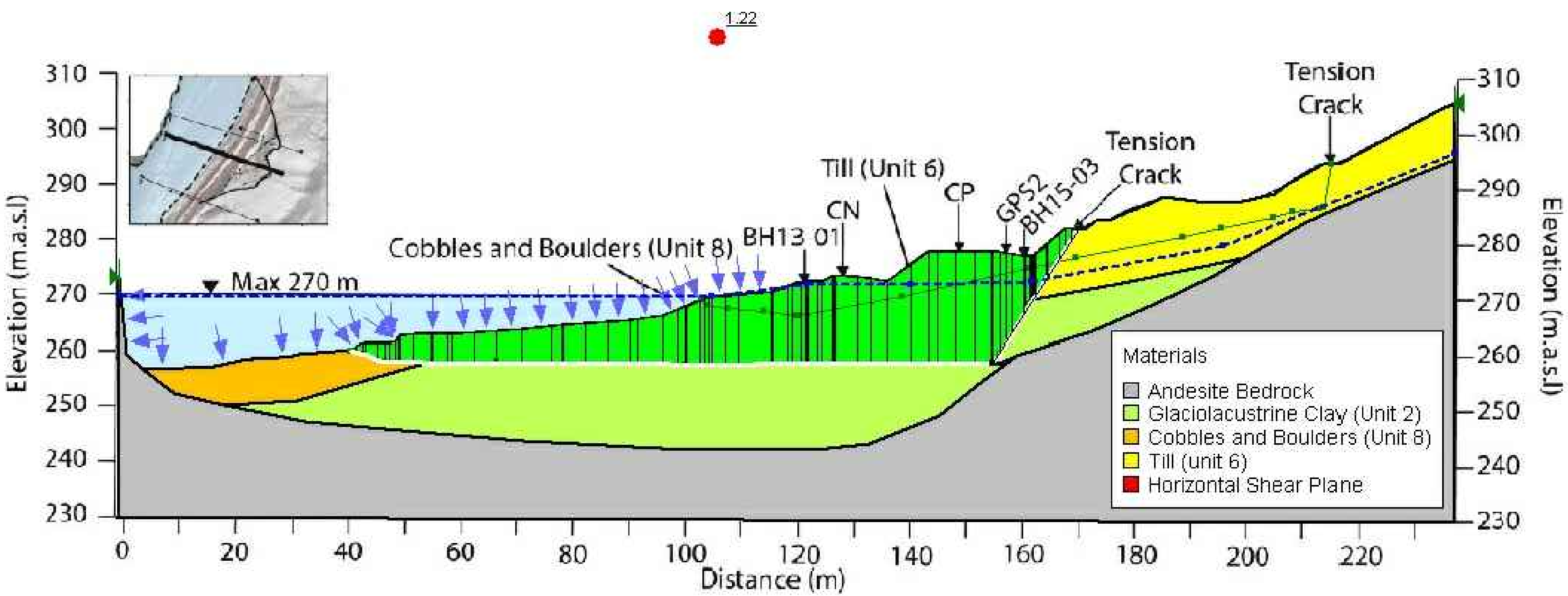
Project: Ripley Slide - Slope Stability Analysis
Cross Section ID: 2B
Case: PWP in BH13-01 and BH15-03 are at higest (Since 2013)
Thompson River Level at: Approx. 270.0 m asl
Approx. Time Period: June 2014

Analysis Info:
Type: Mohr-Coulomb
Method: Morgenstern-Price
Date: 19 July 2017
By: MSD



NOTES :

1. CROSS SECTION IS BASED ON FIGURE 5-5 ON SCHAFER (2017);
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PROJECT TITLE
ANALYZING THE KINEMATICS OF THE RIPLEY LANDSLIDE, ASHCROFT, B.C.

DRAWING TITLE
SLOPE STABILITY ANALYSIS FOR CROSS SECTION 2B(P)

PROJECT NO.		FILE NO.	
MENG-04082017		RIPLEY17	
DATE: 27-JUL-2017	SCALE: AS_SHOWN	FIGURE: C7	REV.: 1
DRAWN: MSD	CHECKED: MSD		

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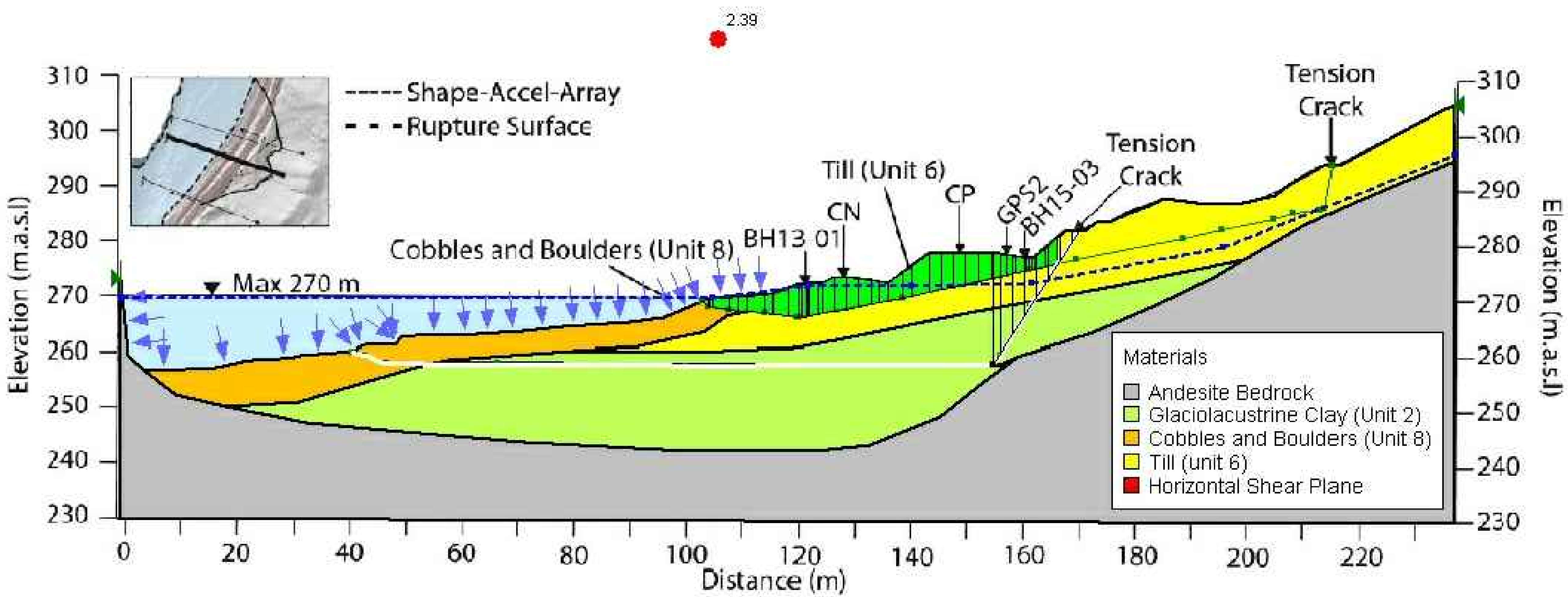
Project: Ripley Slide - Slope Stability Analysis
Cross Section ID: 2B
Case: PWP in BH13-01 and BH15-03 are at higest (Since 2013)
Thompson River Level at: Approx. 270.0 m asl
Approx. Time Period: June 2014

Analysis Info:
Type: Mohr-Coulomb
Method: Morgenstern-Price
Date: 19 July 2017
By: MSD



NOTES :

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2. GROUNDWATER TABLE INTERPRETED FROM VWPS INSTALLED ABOVE AND BELOW THE PRIMARY SHEAR ZONE; RIVER LEVEL BASED ON HISTORICAL DATA RETRIEVED FROM ENVIRONMENTAL CANADA WEB DATA BASE;
3. THE BEDROCK INTERFACE IS BASED ON A GEOPHYSICAL SURVEY;
4. FAILURE PLANE IS ASSUMED, THE DEPTH OF THE FAILURE PLANE ONLY MATCHED AT THE SAA LOCATION WHERE APPLICABLE.

UNIVERSITY OF ALBERTA

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PREPARED BY:
MENUKA DASSANAYAKE, E.I.T.
GEOTECHNICAL ENGINEER-IN-TRAINING
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FOR:
DR. MICHAEL HENDRY, PH.D, P.ENG.
ASSISTANT PROFESSOR IN
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UNIVERSITY OF ALBERTA

PROJECT TITLE
ANALYZING THE KINEMATICS OF THE RIPLEY LANDSLIDE, ASHCROFT, B.C.

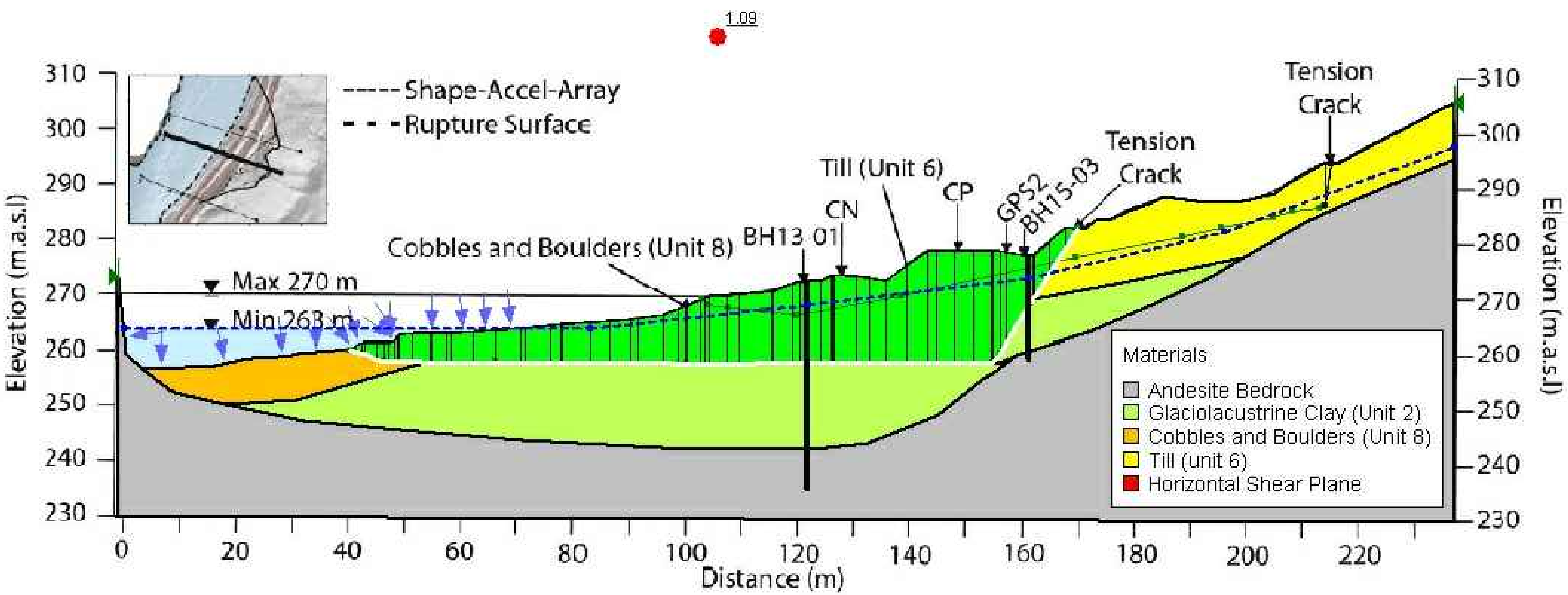
DRAWING TITLE
SLOPE STABILITY ANALYSIS FOR CROSS SECTION 2B(S)

PROJECT NO.	FILE NO.		
MENG-04082017	RIPLEY17		
DATE: 27-JUL-2017	SCALE: AS_SHOWN	FIGURE: C8	REV.: 1
DRAWN: MSD	CHECKED: MSD		

E:\M.Eng\DP\Report\CAD\Drawings_SlopeW_MSD.dwg

Project: Ripley Slide - Slope Stability Analysis
Cross Section ID: 2C
Case: F.O.S. after 2.3 m PWP head increase in BH15-03 in Feb 2017
Thompson River Level at: Approx. 263.5 m asl
Approx. Time Period: Feb 2017

Analysis Info:
Type: Mohr-Coulomb
Method: Morgenstern-Price
Date: 19 July 2017
By: MSD



NOTES :

1. CROSS SECTION IS BASED ON FIGURE 5-5 ON SCHAFER (2017);
2. GROUNDWATER TABLE INTERPRETED FROM VWPS INSTALLED ABOVE AND BELOW THE PRIMARY SHEAR ZONE; RIVER LEVEL BASED ON HISTORICAL DATA RETRIEVED FROM ENVIRONMENTAL CANADA WEB DATA BASE;
3. THE BEDROCK INTERFACE IS BASED ON A GEOPHYSICAL SURVEY;
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FOR:
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PROJECT TITLE
ANALYZING THE KINEMATICS OF THE RIPLEY LANDSLIDE, ASHCROFT, B.C.

DRAWING TITLE
SLOPE STABILITY ANALYSIS FOR CROSS SECTION 2C(P)

PROJECT NO. MENG-04082017		FILE NO. RIPLEY17	
DATE 27-JUL-2017	SCALE AS_SHOWN	FIGURE C9	REV. 1
DRAWN MSD	CHECKED MSD		

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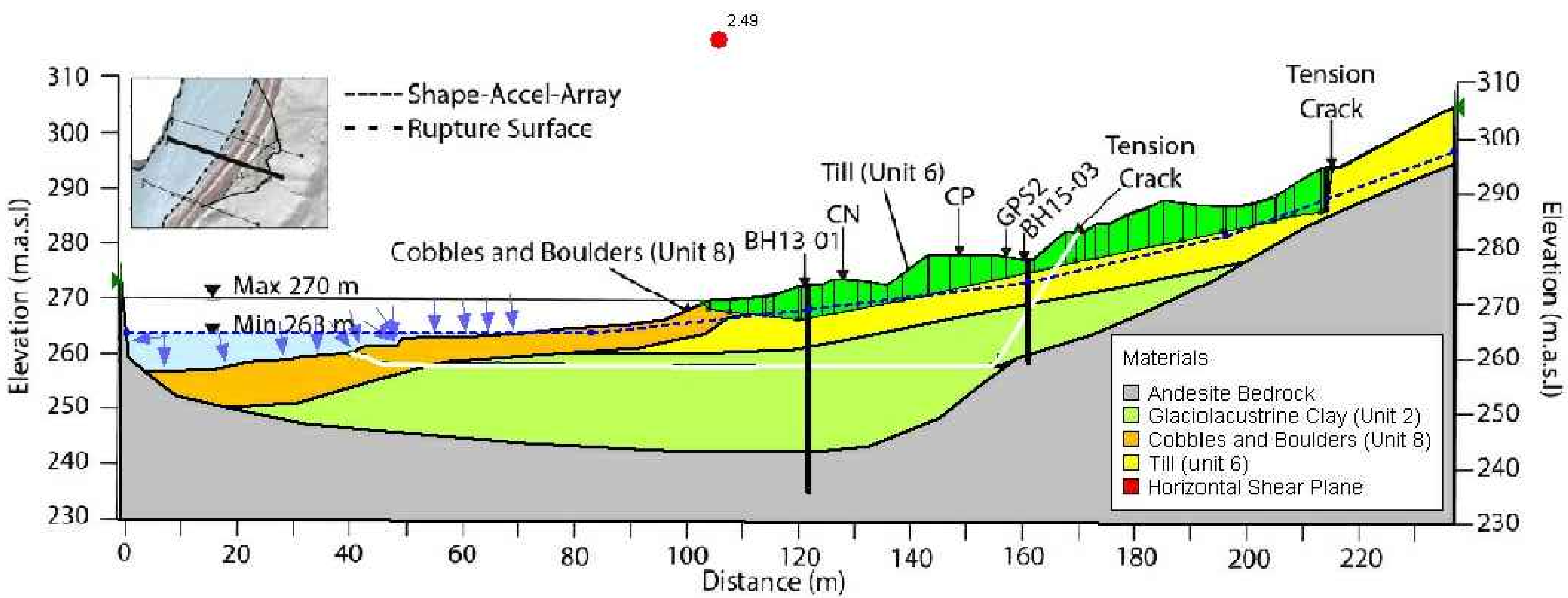
Project: Ripley Slide - Slope Stability Analysis
Cross Section ID: 2C
Case: F.O.S. after 2.3 m PWP head increase in BH15-03 in Feb 2017
Thompson River Level at: Approx. 263.5 m asl
Approx. Time Period: Feb 2017

Analysis Info:
Type: Mohr-Coulomb
Method: Morgenstern-Price
Date: 19 July 2017
By: MSD



NOTES :

1. CROSS SECTION IS BASED ON FIGURE 5-5 ON SCHAFER (2017);
2. GROUNDWATER TABLE INTERPRETED FROM VWPS INSTALLED ABOVE AND BELOW THE PRIMARY SHEAR ZONE; RIVER LEVEL BASED ON HISTORICAL DATA RETRIEVED FROM ENVIRONMENTAL CANADA WEB DATA BASE;
3. THE BEDROCK INTERFACE IS BASED ON A GEOPHYSICAL SURVEY;
4. FAILURE PLANE IS ASSUMED, THE DEPTH OF THE FAILURE PLANE ONLY MATCHED AT THE SAA LOCATION WHERE APPLICABLE.

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FOR:
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PROJECT TITLE
ANALYZING THE KINEMATICS OF THE RIPLEY LANDSLIDE, ASHCROFT, B.C.

DRAWING TITLE
SLOPE STABILITY ANALYSIS FOR CROSS SECTION 2C(S)

PROJECT NO. MENG-04082017		FILE NO. RIPLEY17	
DATE 27-JUL-2017	SCALE AS_SHOWN	FIGURE C10	REV. 1
DRAWN MSD	CHECKED MSD		

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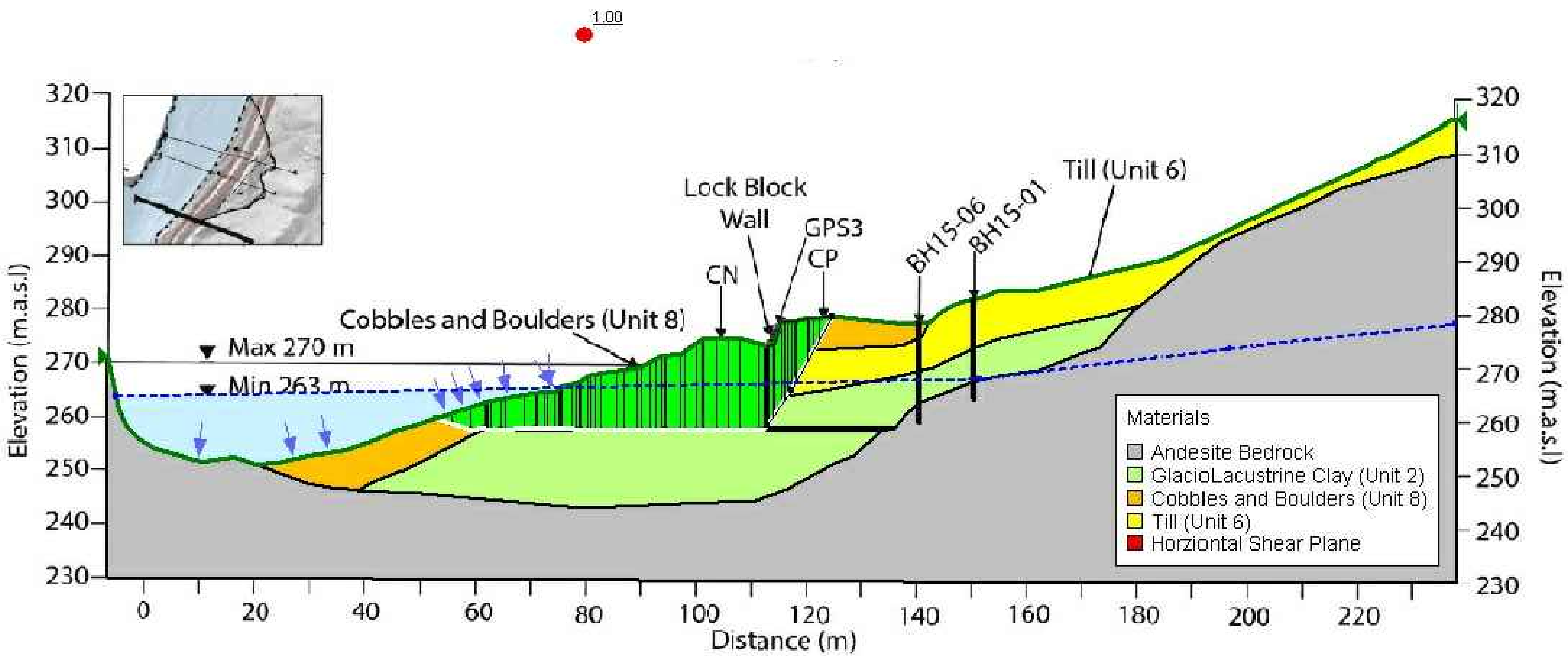
Project: Ripley Slide - Slope Stability Analysis
Cross Section ID: 3A
Case: PWP in BH15-01 at lowest (Since 2015)
Thompson River Level at: Approx. 263.5 m asl
Approx. Time Period: February 2016

Analysis Info:
Type: Mohr-Coulomb
Method: Morgenstern-Price
Date: 19 July 2017
By: MSD



NOTES :

1. CROSS SECTION IS BASED ON FIGURE 5-5 ON SCHAFER (2017);
2. GROUNDWATER TABLE INTERPRETED FROM VWPS INSTALLED ABOVE AND BELOW THE PRIMARY SHEAR ZONE; RIVER LEVEL BASED ON HISTORICAL DATA RETRIEVED FROM ENVIRONMENTAL CANADA WEB DATA BASE;
3. THE BEDROCK INTERFACE IS BASED ON A GEOPHYSICAL SURVEY;
4. FAILURE PLANE IS ASSUMED, THE DEPTH OF THE FAILURE PLANE ONLY MATCHED AT THE SAA LOCATION WHERE APPLICABLE.

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PREPARED BY:
MENUKA DASSANAYAKE, E.I.T.
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FOR:
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PROJECT TITLE
ANALYZING THE KINEMATICS OF THE RIPLEY LANDSLIDE, ASHCROFT, B.C.

DRAWING TITLE
SLOPE STABILITY ANALYSIS FOR CROSS SECTION 3A(P)

PROJECT NO. MENG-04082017		FILE NO. RIPLEY17	
DATE 27-JUL-2017	SCALE AS_SHOWN	FIGURE C11	REV. 1
DRAWN MSD	CHECKED MSD		

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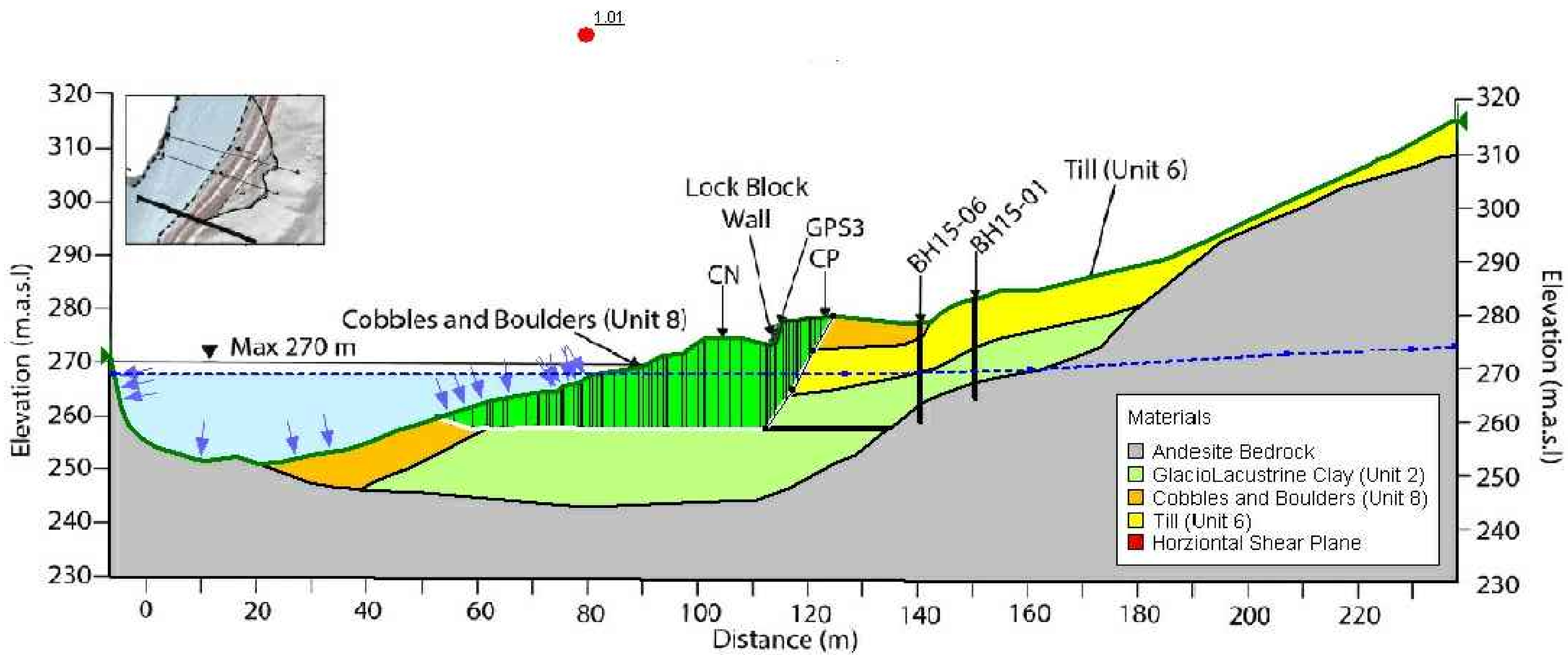
Project: Ripley Slide - Slope Stability Analysis
Cross Section ID: 3B
Case: PWP in BH15-01 at highest (Since 2015)
Thompson River Level at: Approx. 267.5 m asl
Approx. Time Period: June 2016

Analysis Info:
Type: Mohr-Coulomb
Method: Morgenstern-Price
Date: 19 July 2017
By: MSD



NOTES :

1. CROSS SECTION IS BASED ON FIGURE 5-5 ON SCHAFER (2017);
2. GROUNDWATER TABLE INTERPRETED FROM VWPS INSTALLED ABOVE AND BELOW THE PRIMARY SHEAR ZONE; RIVER LEVEL BASED ON HISTORICAL DATA RETRIEVED FROM ENVIRONMENTAL CANADA WEB DATA BASE;
3. THE BEDROCK INTERFACE IS BASED ON A GEOPHYSICAL SURVEY;
4. FAILURE PLANE IS ASSUMED, THE DEPTH OF THE FAILURE PLANE ONLY MATCHED AT THE SAA LOCATION WHERE APPLICABLE.

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FOR:
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PROJECT TITLE
ANALYZING THE KINEMATICS OF THE RIPLEY LANDSLIDE, ASHCROFT, B.C.

DRAWING TITLE
SLOPE STABILITY ANALYSIS FOR CROSS SECTION 3B(P)

PROJECT NO.		FILE NO.	
MENG-04082017		RIPLEY17	
DATE 27-JUL-2017	SCALE AS_SHOWN	FIGURE C12	REV. 1
DRAWN MSD	CHECKED MSD		

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Appendix D

RST VWP Calibration Records

D1 – Calibation record for VWP24278

D2 – Calibation record for VWP24279

D3 – Calibation record for VWP24280

D4 – Calibation record for VWP24281

D5 – Calibation record for VWP24282

D6 – Calibation record for VWP24283

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Calibration Record

RST Instruments Ltd., 11545 Kingston St., Maple Ridge, British Columbia, Canada V2X 0Z5
Tel: 604 540 1100 • Fax: 604 540 1005 • Toll Free: 1 800 665 5599 (North America only)
e-mail: info@rstinstruments.com • Website: www.rstinstruments.com

Vibrating Wire Piezometer

Customer: C.P. RAIL - ALBERTA
Model: VW2100-0.35
Serial Number: **VW24278**
Mfg Number: 1237451
Range: 350.0 kPa
Temperature: 22.9 °C
Barometric Pressure: 1003.1 millibars
Work Order Number: Q025214
Cable Length: 40 meters
Cable Markings: 103277 m - 103317 m
Cable Colour Code: Red / Black (Coil) Green / White (Thermistor)
Cable Type: EL380004
Thermistor Type: 3 kΩ

Applied Pressure (kPa)	First Reading (B units)	Second Reading (B units)	Average Reading (B units)	Calculated Linear (kPa)	Linearity Error (% FS)	Polynomial Error (% FS)
0.0	8960	8960	8960	0.5	0.14	0.02
70.0	8417	8417	8417	69.9	-0.04	-0.01
140.0	7873	7873	7873	139.4	-0.18	-0.08
209.9	7322	7321	7322	209.8	-0.02	0.08
279.9	6773	6773	6773	279.9	0.00	0.02
349.9	6223	6222	6223	350.2	0.09	-0.03
				Max. Error (%):	0.18	0.08

Linear Calibration Factor: **C.F.=** **0.12775 kPa/B unit**
Regression Zero: **At Calibration =** **8964.0 B unit**
Temperature Correction Factor: **Tk =** **-0.06462 kPa/°C rise**

Polynomial Gage Factors (kPa) **A:** **-4.2189E-07** **B:** **-0.12134** **C:** **1121.2**

Pressure is calculated with the following equations:
Linear: P(kPa) = C.F.(Li-Lc) - [Tk(Ti-Tc)] + [0.10(Bi-Bc)]
Polynomial: P(kPa) = $A(Lc)^2$ + BLc + C + Tk(Tc-Ti) - [0.10(Bc-Bi)]

	Date (dd/mm/yy)	VW Readout Pos. B (Li)	Temp °C (Ti)	Baro (Bi)
Shipped Zero Readings:	20-Dec-12	8962	19.3	1003.0

Li, Lc = initial (at installation) and current readings
Ti, Tc = initial (at installation) and current temperature, in °C
Bi, Bc = initial (at installation) and current barometric pressure readings, in millibars
B units = B scale output of VW 2102, VW 2104, VW 2106 and DT 2011 readouts
B units = Hz^2 / 1000 ie: 1700Hz = 2890 B units

Technician: J. Somphanthabansouk JS

Date: 20-Dec-12

This instrument has been calibrated using standards traceable to the NIST in compliance with ANSI Z540-1

Applied Science Technologists and Technicians of British Columbia
22724
A.C
AL CULLEY
AScT

Document Number.: ELL0130K

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Calibration Record

RST Instruments Ltd., 11545 Kingston St., Maple Ridge, British Columbia, Canada V2X 0Z5
Tel: 604 540 1100 • Fax: 604 540 1005 • Toll Free: 1 800 665 5599 (North America only)
e-mail: info@rstinstruments.com • Website: www.rstinstruments.com

Vibrating Wire Piezometer

Customer:		C.P. RAIL - ALBERTA
Model:		VW2100-0.35
Serial Number:		VW24279
Mfg Number:		1237452
Range:		350.0 kPa
Temperature:		22.9 °C
Barometric Pressure:		1003.1 millibars
Work Order Number:		Q025214
Cable Length:		40 meters
Cable Markings:		103359 m - 103398 m
Cable Colour Code:	Red / Black (Coil)	Green / White (Thermistor)
Cable Type:		EL380004
Thermistor Type:		3 kΩ

Applied Pressure (kPa)	First Reading (B units)	Second Reading (B units)	Average Reading (B units)	Calculated Linear (kPa)	Linearity Error (% FS)	Polynomial Error (% FS)
0.0	8790	8789	8790	0.3	0.10	0.01
70.0	8213	8214	8214	69.9	-0.02	0.00
140.0	7637	7637	7637	139.6	-0.11	-0.04
209.9	7057	7056	7057	209.7	-0.04	0.03
279.9	6476	6476	6476	279.9	0.00	0.02
349.9	5895	5894	5895	350.2	0.07	-0.01
				Max. Error (%):	0.11	0.04

Linear Calibration Factor:	**C.F.=**	**0.12084**	**kPa/B unit**
Regression Zero:	**At Calibration =**	**8792.3**	**B unit**
Temperature Correction Factor:	**Tk =**	**-0.07860**	**kPa/°C rise**

Polynomial Gage Factors (kPa) **A:** **-2.7983E-07** **B:** **-0.11673** **C:** **1047.6**

Pressure is calculated with the following equations:

Linear: P(kPa) = C.F.(Li-Lc) - [Tk(Ti-Tc)] + [0.10(Bi-Bc)]

Polynomial: P(kPa) = $A(Lc)^2$ + BLc + C + Tk(Tc-Ti) - [0.10(Bc-Bi)]

	Date (dd/mm/yy)	VW Readout Pos. B (Li)	Temp °C (Ti)	Baro (Bi)
Shipped Zero Readings:	20-Dec-12	8795	19.2	1003.0

Li, Lc = initial (at installation) and current readings
Ti, Tc = initial (at installation) and current temperature, in °C
Bi, Bc = initial (at installation) and current barometric pressure readings, in millibars
B units = B scale output of VW 2102, VW 2104, VW 2106 and DT 2011 readouts
B units = Hz^2 / 1000 ie: 1700Hz = 2890 B units

Technician: J. Somphanthabansouk JS Date: 20-Dec-12

This instrument has been calibrated using standards traceable to the NIST in compliance with ANSI Z540-1

Applied Science Technologists and Technicians of British Columbia 22724 A.C. AL CULLEY AScT

Document Number.: ELL0130K

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Calibration Record

RST Instruments Ltd., 11545 Kingston St., Maple Ridge, British Columbia, Canada V2X 0Z5
Tel: 604 540 1100 • Fax: 604 540 1005 • Toll Free: 1 800 665 5599 (North America only)
e-mail: info@rstinstruments.com • Website: www.rstinstruments.com

Vibrating Wire Piezometer

Customer:		C.P. RAIL - ALBERTA
Model:		VW2100-0.35
Serial Number:		VW24280
Mfg Number:		1237453
Range:		350.0 kPa
Temperature:		22.9 °C
Barometric Pressure:		1003.1 millibars
Work Order Number:		Q025214
Cable Length:		40 meters
Cable Markings:		103399 m - 103438 m
Cable Colour Code:	Red / Black (Coil)	Green / White (Thermistor)
Cable Type:		EL380004
Thermistor Type:		3 kΩ

Applied Pressure (kPa)	First Reading (B units)	Second Reading (B units)	Average Reading (B units)	Calculated Linear (kPa)	Linearity Error (% FS)	Polynomial Error (% FS)
0.0	8817	8817	8817	0.5	0.15	0.02
70.0	8220	8219	8220	69.9	-0.04	-0.01
140.0	7620	7620	7620	139.4	-0.16	-0.05
209.9	7015	7014	7015	209.7	-0.05	0.06
279.9	6411	6410	6411	279.8	-0.02	0.00
349.9	5803	5803	5803	350.3	0.12	-0.01
				Max. Error (%):	0.16	0.06

Linear Calibration Factor:	**C.F.=**	**0.11606 kPa/B unit**
Regression Zero:	**At Calibration =**	**8821.5 B unit**
Temperature Correction Factor:	**Tk =**	**-0.03971 kPa/°C rise**

Polynomial Gage Factors (kPa) **A:** -3.8755E-07 **B:** -0.11039 **C:** 1003.5

Pressure is calculated with the following equations:

Linear: $P(kPa) = C.F.(Li-Lc) - [Tk(Ti-Tc)] + [0.10(Bi-Bc)]$

Polynomial: $P(kPa) = A(Lc)^2 + BLc + C + Tk(Tc-Ti) - [0.10(Bc-Bi)]$

	Date (dd/mm/yy)	VW Readout Pos. B (Li)	Temp °C (Ti)	Baro (Bi)
Shipped Zero Readings:	20-Dec-12	8820	19.3	1003.0

Li, Lc = initial (at installation) and current readings
Ti, Tc = initial (at installation) and current temperature, in °C
Bi, Bc = initial (at installation) and current barometric pressure readings, in millibars
B units = B scale output of VW 2102, VW 2104, VW 2106 and DT 2011 readouts
B units = Hz^2 / 1000 ie: 1700Hz = 2890 B units

Technician: J. Somphanthabansouk JS Date: 20-Dec-12

This instrument has been calibrated using standards traceable to the NIST in compliance with ANSI Z540-1

Applied Science Technologists and Technicians of British Columbia 22724 A.C. AL CULLEY AScT

Document Number.: ELL0130K

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Calibration Record

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RST Instruments Ltd., 11545 Kingston St., Maple Ridge, British Columbia, Canada V2X 0Z5
Tel: 604 540 1100 • Fax: 604 540 1005 • Toll Free: 1 800 665 5599 (North America only)
e-mail: info@rstinstruments.com • Website: www.rstinstruments.com

Vibrating Wire Piezometer

Customer:		C.P. RAIL - ALBERTA
Model:		VW2100-0.35
Serial Number:		**VW24281**
Mfg Number:		1237454
Range:		350.0 kPa
Temperature:		22.9 °C
Barometric Pressure:		1003.1 millibars
Work Order Number:		Q025214
Cable Length:		40 meters
Cable Markings:		103440 m - 103479 m
Cable Colour Code:	Red / Black (Coil)	Green / White (Thermistor)
Cable Type:		EL380004
Thermistor Type:		3 kΩ

Applied Pressure (kPa)	First Reading (B units)	Second Reading (B units)	Average Reading (B units)	Calculated Linear (kPa)	Linearity Error (% FS)	Polynomial Error (% FS)
0.0	8837	8836	8837	0.5	0.16	0.01
70.0	8270	8269	8270	69.9	-0.04	-0.01
140.0	7700	7699	7700	139.6	-0.13	0.00
209.9	7128	7127	7128	209.5	-0.11	0.01
279.9	6553	6552	6553	279.8	-0.03	0.00
349.9	5975	5975	5975	350.4	0.15	0.00
				Max. Error (%):	0.16	0.01

Linear Calibration Factor:	**C.F.=**	**0.12227 kPa/B unit**
Regression Zero:	**At Calibration =**	**8841.0 B unit**
Temperature Correction Factor:	**Tk =**	**0.1014 kPa/°C rise**

Polynomial Gage Factors (kPa) **A:** **-4.8316E-07** **B:** **-0.11511** **C:** **1054.9**

Pressure is calculated with the following equations:

Linear: $P(kPa) = C.F.(Li-Lc) - [Tk(Ti-Tc)] + [0.10(Bi-Bc)]$

Polynomial: $P(kPa) = A(Lc)^2 + BLc + C + Tk(Tc-Ti) - [0.10(Bc-Bi)]$

	Date (dd/mm/yy)	VW Readout Pos. B (Li)	Temp °C (Ti)	Baro (Bi)
Shipped Zero Readings:	20-Dec-12	8842	19.3	1003.0

Li, Lc = initial (at installation) and current readings
Ti, Tc = initial (at installation) and current temperature, in °C
Bi, Bc = initial (at installation) and current barometric pressure readings, in millibars
B units = B scale output of VW 2102, VW 2104, VW 2106 and DT 2011 readouts
B units = Hz^2 / 1000 ie: 1700Hz = 2890 B units

Technician: J. Somphanthabansouk JS Date: 20-Dec-12

Applied Science Technologists and Technicians of British Columbia 22724 A.C AL CULLEY AScT

This instrument has been calibrated using standards traceable to the NIST in compliance with ANSI Z540-1

Document Number.: ELL0130K

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Calibration Record

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Tel: 604 540 1100 • Fax: 604 540 1005 • Toll Free: 1 800 665 5599 (North America only)
e-mail: info@rstinstruments.com • Website: www.rstinstruments.com

Vibrating Wire Piezometer

Customer:		C.P. RAIL - ALBERTA
Model:		VW2100-0.35
Serial Number:		**VW24282**
Mfg Number:		1237455
Range:		350.0 kPa
Temperature:		22.6 °C
Barometric Pressure:		1009.2 millibars
Work Order Number:		Q025214
Cable Length:		40 meters
Cable Markings:		103196 m - 103236 m
Cable Colour Code:	Red / Black (Coil)	Green / White (Thermistor)
Cable Type:		EL380004
Thermistor Type:		3 kΩ

Applied Pressure (kPa)	First Reading (B units)	Second Reading (B units)	Average Reading (B units)	Calculated Linear (kPa)	Linearity Error (% FS)	Polynomial Error (% FS)
0.0	8872	8873	8873	0.5	0.14	-0.02
70.0	8308	8308	8308	70.0	0.01	0.04
140.0	7743	7744	7744	139.6	-0.13	0.01
210.0	7176	7176	7176	209.5	-0.15	-0.02
280.0	6605	6605	6605	279.8	-0.06	-0.02
350.0	6030	6030	6030	350.6	0.18	0.02
				Max. Error (%):	0.18	0.04

Linear Calibration Factor:	**C.F.=**	**0.12318 kPa/B unit**
Regression Zero:	**At Calibration =**	**8876.5 B unit**
Temperature Correction Factor:	**Tk =**	**-0.06177 kPa/°C rise**

Polynomial Gage Factors (kPa) **A:** **-5.3467E-07** **B:** **-0.11521** **C:** **1064.2**

Pressure is calculated with the following equations:

Linear: $P(kPa) = C.F.(Li-Lc) - [Tk(Ti-Tc)] + [0.10(Bi-Bc)]$

Polynomial: $P(kPa) = A(Lc)^2 + BLc + C + Tk(Tc-Ti) - [0.10(Bc-Bi)]$

	Date (dd/mm/yy)	VW Readout Pos. B (Li)	Temp °C (Ti)	Baro (Bi)
Shipped Zero Readings:	20-Dec-12	8878	19.3	1003.0

Li, Lc = initial (at installation) and current readings
Ti, Tc = initial (at installation) and current temperature, in °C
Bi, Bc = initial (at installation) and current barometric pressure readings, in millibars
B units = B scale output of VW 2102, VW 2104, VW 2106 and DT 2011 readouts
B units = Hz^2 / 1000 ie: 1700Hz = 2890 B units

Technician: J. Somphanthabansouk JS Date: 20-Dec-12

Applied Science Technologists and Technicians of British Columbia 22724 A.C AL CULLEY AScT

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Calibration Record

RST Instruments Ltd., 11545 Kingston St., Maple Ridge, British Columbia, Canada V2X 0Z5
Tel: 604 540 1100 • Fax: 604 540 1005 • Toll Free: 1 800 665 5599 (North America only)
e-mail: info@rstinstruments.com • Website: www.rstinstruments.com

Vibrating Wire Piezometer

Customer:		C.P. RAIL - ALBERTA
Model:		VW2100-0.35
Serial Number:		VW24283
Mfg Number:		1237456
Range:		350.0 kPa
Temperature:		22.6 °C
Barometric Pressure:		1009.2 millibars
Work Order Number:		Q025214
Cable Length:		40 meters
Cable Markings:		103237 m - 103276 m
Cable Colour Code:	Red / Black (Coil)	Green / White (Thermistor)
Cable Type:		EL380004
Thermistor Type:		3 kΩ

Applied Pressure (kPa)	First Reading (B units)	Second Reading (B units)	Average Reading (B units)	Calculated Linear (kPa)	Linearity Error (% FS)	Polynomial Error (% FS)
0.0	8858	8859	8859	0.7	0.21	0.02
70.0	8251	8251	8251	69.8	-0.06	-0.02
140.0	7638	7639	7639	139.4	-0.16	-0.01
210.0	7023	7024	7024	209.3	-0.19	-0.03
280.0	6401	6401	6401	280.1	0.03	0.07
350.0	5781	5781	5781	350.6	0.16	-0.03
				Max. Error (%):	0.21	0.07

Linear Calibration Factor:	C.F.=	0.11367 kPa/B unit
Regression Zero:	At Calibration =	8865.0 B unit
Temperature Correction Factor:	Tk =	-0.02145 kPa/°C rise

Polynomial Gage Factors (kPa) A: -5.4893E-07 B: -0.10564 C: 978.92

Pressure is calculated with the following equations:

Linear: $P(kPa) = C.F.(Li-Lc) - [Tk(Ti-Tc)] + [0.10(Bi-Bc)]$

Polynomial: $P(kPa) = A(Lc)^2 + BLc + C + Tk(Tc-Ti) - [0.10(Bc-Bi)]$

	Date (dd/mm/yy)	VW Readout Pos. B (Li)	Temp °C (Ti)	Baro (Bi)
Shipped Zero Readings:	20-Dec-12	8873	19.4	1003.0

Li, Lc = initial (at installation) and current readings
Ti, Tc = initial (at installation) and current temperature, in °C
Bi, Bc = initial (at installation) and current barometric pressure readings, in millibars
B units = B scale output of VW 2102, VW 2104, VW 2106 and DT 2011 readouts
B units = Hz^2 / 1000 ie: 1700Hz = 2890 B units

Technician: J. Somphanthabansouk JS Date: 20-Dec-12

This instrument has been calibrated using standards traceable to the NIST in compliance with ANSI Z540-1

Applied Science Technologists and Technicians of British Columbia 22724 AL CULLEY AScT

Appendix E

Photographs

Photograph 1 – Looking east at the Ripley slide from across the Thompson River, dated 20 July 2016 (Photo Courtesy of Jorge Rodriguez)

Photograph 2 – The two CP railway tracks between the slide and the Thompson River, dated 25 May 2017 (Photo Courtesy of Jorge Rodriguez)

Photograph 3 – The two CP railway tracks (left) and the CN railway track (right) between the slide and the Thompson River, dated 25 May 2017 (Photo Courtesy of Jorge Rodriguez)

Photograph 4 – The two CP railway tracks (left) and the CN railway track (right) between the slide and the Thompson River, dated 25 May 2017, Extended View (Photo Courtesy of Jorge Rodriguez)

Photograph 1 - Looking east at the Ripley slide from across the Thompson River, dated 20 July 2016 (Photo Courtesy of Jorge Rodriguez)

Appendix E - Photographs

Photograph 2 - The two CP railway tracks between the slide and the Thompson River, dated 25 May 2017 (Photo Courtesy of Jorge Rodriguez)

Appendix E - Photographs

Photograph 3 - The two CP railway tracks (left) and the CN railway track (right) between the slide and the Thompson River, dated 25 May 2017

(Photo Courtesy of Jorge Rodriguez)

Photograph 4 - The two CP railway tracks (left) and the CN railway track (right) between the slide and the Thompson River, dated 25 May 2017, Extended View (Photo Courtesy of Jorge Rodriguez)

Appendix F

Select Brochures, Manuals, and Specifications

F1 – Vibrating Wire Piezometer by RST

F2 – Vibrating Wire Piezometer Model VW2100 Instruction Manual by RST

F3 – VW2106 Vibrating Wire Readout by RST

F4 – Digital MEMS Inclinometer System by RST

F5 – SAFF Model 003 by Measurand

F6 – CR6 Series Data Logger by Campbell Scientific

F7 – CR1000 Series Data Logger by Campbell Scientific

F8 – Manual for Measurments with Cambell Scientific Data Loggers

F9 – Slope/W 2012 by GeoStudio

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RST Instruments Ltd.
11545 Kingston St.,
Maple Ridge, BC V2X 0Z5 Canada

Certified System ISO 9001

PRODUCT CATEGORY:
PIEZOMETERS + TRANSDUCERS

VW2100 Standard Vibrating Wire Piezometer

VW2100-HD Heavy Duty Vibrating Wire Piezometer

VW2100-DP Drive Point Vibrating Wire Piezometer

Vibrating Wire Piezometer

The RST Vibrating Wire Piezometer provides excellent long-term accuracy, stability of readings, and reliability under demanding geotechnical conditions. Vibrating Wire Piezometers are the electrical piezometers of choice as the frequency output of VW devices is immune to external electrical noise and able to tolerate wet wiring common in geotechnical applications.

Vibrating Wire Piezometers contain a high tensile steel wire with a fixed anchor at one end and are attached to a diaphragm in contact with water pressure at the other end. The wire is electrically plucked, with the resonant frequency of vibration proportional to the tension in the wire. This frequency induces an alternating current in a coil which is detected by the readout unit, such as the VW2106 Vibrating Wire Readout (see separate brochure), and can then be converted to a pressure. The frequency output is immune to external electrical noise, and able to tolerate wet wiring common in geotechnical applications. Highly reliable lightning protection is incorporated in the vibrating wire transducer.

The frequency signal is exceptionally immune from cable effects, including length (to several kilometers), splicing, resistance, noise pickup, and moisture. The vibrating wire coil circuit contains no semiconductor devices and has built-in ionized gas discharge device protection against transient damage. As a result, the vibrating wire piezometer provides excellent reliability in typical geotechnical situations – i.e. long outdoor cables buried in saturated soil.

The piezometer is equipped with a standard sintered stainless steel porous filter to prevent soil particles from contacting the diaphragm. A thermistor is built into the piezometer body to permit temperature measurement and temperature compensation of the piezometer. Standard construction is all stainless steel. RST vibrating wire piezometers are shipped with extremely tough polyurethane-jacketed foil-shielded cable for maximum endurance in field conditions.

> APPLICATIONS

Slope stability investigations.	Monitoring well and standpipe water levels.
Assessing performance and investigating stability of earth fill dams and embankments.	
Monitoring pressures behind retaining walls and diaphragm walls.	
Monitoring pore pressures during fill or excavation.	
Monitoring pore pressure in land reclamation applications.	

> FEATURES

Field proven reliability and accuracy.	Integral lightning protection.
Signal transmission of several kilometer.	Data logger compatible.
High Accuracy - IE a low pressure vented model will measure water level changes as small as 0.5 mm (0.02 in.).	
Will tolerate wet wiring common in geotechnical applications.	
Thermistor for temperature measurement is standard.	Hermetically sealed, stainless steel construction.
Negligible displacement of pore water during the measurement process.	
Can read negative pore water pressure (contact RST for details).	
Heavy case to minimize reading errors caused by overburden pressure.	
Cable lengths may be changed without affecting the calibration.	

Available for **QUICK DELIVERY** Info on reverse.

> BENEFITS

✓ **Increase Safety**	✓ **High Accuracy**

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Vibrating Wire Piezometer

PRODUCT CATEGORY:
PIEZOMETERS + TRANSDUCERS

SPECIFICATIONS + ORDERING

SPECIFICATIONS

DESCRIPTION	SPECIFICATION
Over range	2 X F.S.
Resolution	0.025% F.S. minimum
Accuracy	0.1% F.S.
Operating Temperature	-20 to 80°C (-4 to 176°F)
Diaphragm Displacement	<0.001 cc at F.S.
Thermal Zero Shift	<0.05% F.S./°C
Materials	Hermetically sealed stainless steel housing
Thermistor Type	NTC 3K Ohms @ 25°C
Thermistor Interchangeability	±0.2°C
Thermistor Resolution	0.1°C
Filter	50 micron sintered filter. (High air entry alumina filter 1, 3, 5 Bar available)

ELECTRICAL CABLE SPECS

PART #	DESCRIPTION
EL380004	Two twisted pairs cable with polyurethane jacket

Other types of cables, depending on site conditions and atmospheric reference requirements, are available upon request. These include vented, FEP, PVC, polyurethane, and armored varieties.

VW2100-DPC-CT
Drive point model
with drop off shoe

OPTIONS

- Heavy-duty bodies for embankment use
- Push-in drive points for soft soils
- High air entry ceramic filters to exclude air
- Low range and vented piezometers
- Titanium construction for use with corrosive fluids
- Multi-point/mixed type sensor strings
- Kevlar® reinforced cable

OPTIONAL EQUIPMENT

- VW2106 Vibrating Wire Readout
- Data loggers
- Terminal stations
- Electrical cable
- Cable splice kits
- Installation geotextile and socks
- Increased lightning protection

ORDERING

Available for QUICK DELIVERY
Contact RST for Details

PART #	DESCRIPTION	PRESSURE RANGE	DIMENSION
VW2100	Standard model for general applications	0.35, 0.7, 1.0, 2.0, 3.0 MPa	19 mm Ø X 130 mm
VW2100-HD	Heavy duty piezometer for direct burial in fills and large dam embankments	0.35, 0.7, 1.0, 2.0 3.0, 5.0, 7.5, 10 MPa	25.4 mm Ø X 146 mm
VW2100-XHD	Heavy duty piezometer for direct burial in fills and large dam embankments	1.0, 2.0 3.0, 5.0, 7.5, 10 MPa	38.1 mm Ø X 146 mm
VW2100-DPC	Drive point model with CPT thread	0.07, 0.175, 0.35, 0.7, 1.0, 2.0, 3.0, 5.0, 7.5 MPa	33 mm Ø X 432 mm
VW2100-DPC-CT	Drive point model with drop off shoe	0.07, 0.175, 0.35, 0.7, 1.0, 2.0, 3.0 MPa	50.8 mm Ø (tip) 33.4 mm Ø (body) X 271 mm
VW2100-DPE	Drive point model with extension rod (1 1/4" diameter) (5' total length)		
VW2100-L	Low Pressure, unvented	70, 175 kPa	25 mm Ø X 133 mm
VW2100-LV	Low Pressure vented	70, 175 kPa	25 mm Ø X 133 mm
VW2100-M	Miniature version – 17.5 mm diameter	0.35, 0.7, 1.0, 2.0, 3.0 MPa	17.5 mm Ø X 133 mm
VW2100-MM	Micro-miniature version – 11.1 mm diameter	0.35, 0.7 MPa	11.1 mm Ø X 165 mm
VW2190	Heavy duty piezometer with bladder for brine environment	0.07, 0.175, 0.35, 0.7, 1.0, 2.0, 3.0, 5.0, 7.5 MPa	42 mm Ø X 319 mm
VW2191	Heavy duty piezometer with bladder for acidic environment with secondary corrosion protection	0.07, 0.175, 0.35, 0.7, 1.0, 2.0, 3.0, 5.0, 7.5 MPa	42 mm Ø X 319 mm

VW2190/VW2191 - Heavy Duty Piezometer with Bladder

RST INSTRUMENTS LTD.

Vibrating Wire Piezometer
Model VW2100
Instruction Manual

RST Instruments Ltd.
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Vibrating Wire Piezometer Model VW2100

Product:	Vibrating Wire Piezometer Model VW2100 Installation Manual
Document number:	ELM0005M
Revision:	1.8
Date:	November 15, 2014

Table of Contents

FIGURES

APPENDICES

1 INTRODUCTION

The RST Vibrating Wire Piezometer is a stable, robust pressure transducer, designed to allow very accurate remote measurements of piezometric levels and borehole pressures over long periods of time and through all conditions. The VW pressure transducer output is a frequency signal which is unaffected by line impedance and/or contact resistance of the conductor. This allows for the accurate transmission of the frequency signal over very long distances. These types of VW sensors can be installed in boreholes (models VW2100-1), or driven into soft ground (model VW2100-DP).

A standard integral thermistor is included within each transducer, which measures the temperature of the transducer and its surroundings. This temperature information is used to provide temperature correction to the output pressure readings.

A gauge calibration factor and temperature correction factor are supplied with each manufactured gauge based on the factory calibrations which are carried out for each sensor, immediately following manufacture.

A portable Vibrating Wire readout unit, such as the RST model VW2106, is used to display the frequency of the vibrating wire which is proportional to the pressure being applied to the VW transducer diaphragm.

Additionally, the VW2106 readout unit will display the transducer temperature directly, in degrees Celsius.

Complete datalogging systems are available from RST to provide automated data collection from VW transducers. Consult RST for more information, if required.

2 RST VW PIEZOMETER CONSTRUCTION

The RST VW piezometer is a Vibrating Wire diaphragm pressure sensor. Pressure applied to the transducer diaphragm will cause a change in the Vibrating Wire tension, resulting in a change to the resonant frequency, which is directly proportional to the pressure change.

The Vibrating Wire sensors are made of two small diameter cylindrical parts joined by a length of steel tubing. The diaphragm is welded to the front cylinder. . A high strength steel wire (the Vibrating Wire) is clamped to the center of the diaphragm, then is run through the first cylinder, and then clamped to the base of the second cylinder which is the end block. The Vibrating Wire is clamped to the diaphragm and end block by low temperature hydraulic swaging which virtually welds the parts together without affecting the elastic properties of the wire. All parts of the sensor, other than the actual Vibrating Wire are machined from a high-grade stainless steel, selected for its low yield and high corrosion resistance.

The Vibrating Wire is set to a pre-determined tension during the manufacture. The instrument housing is evacuated and sealed using electron beam welding to ensure a perfect seal and a long working life. An O-ring placed behind the diaphragm seals the back of the assembly within the housing. A coil/magnet assembly is built into every VW transducer which is used in conjunction with the RST readout box, to pluck the Vibrating Wire and measure the VW's vibration period.

2.1 MODEL VW2100

The model VW2100 VW piezometer is designed to be embedded in earth fills and concrete, or inserted into boreholes and pipes as small as 19mm (3/4 inch) diameter. These VW piezometers consists of a small diameter cylindrical housing containing a pressure transducer and thermistor. One end is fitted with an insert that holds a micrometric high air or low air entry filter. The opposite end contains the cable entry, sealed with an epoxy compound. All parts are made of stainless steel.

The entry filter is set in the front end of the housing and sealed with an O-ring. With the filter in place, the diaphragm is protected from solid particles, and senses only the fluid pressure to be measured. The filter housing is easily removable for calibration of the transducer

The filter assembly can also be replaced with a pipe thread adapter fitting to use the gauge as a pressure transducer (Model VW2100-PT).

2.2 MODEL VW2100-DP

The model VW2100-DP Vibrating Wire piezometer is designed to be driven into unconsolidated fine grain material such as sand, silt or clay. The external housing is a thick walled cylinder fitted with a pointed shoe at one end, and male thread adapter at the cable entry, which fits standard “EX” drill rods. Three port holes above the point are equipped with micrometric filters. The data cable passes through the threaded end, and can be fed up through the drill rods to the surface. The cable entry is sealed with an epoxy compound. Both high and low air entry filters are available.

3 VIBRATING WIRE PRINCIPLE

The sensing element of the Vibrating Wire piezometer is a high strength steel wire attached to the diaphragm, (see section 2 for details). The VW is excited by two coil/magnets set around the connecting over tube. In operation, external pressure on the diaphragm will move the diaphragm a very small amount, which changes the tension on the Vibrating Wire. This tension change is directly proportional to the resonant, or natural, frequency at which the VW will vibrate.

The VW2106 Readout Unit generates plucking voltages to the coil/magnet in a spectrum of frequencies, spanning the natural frequency of the vibrating wire. This plucking allows the VW to find it’s current natural frequency related to the pressure it is currently experiencing. In turn, the oscillation of the VW generates AC voltage in the coil. This output signal is amplified by the 2106 Readout Unit, which also discriminates against harmonic frequencies, to determine the resonant frequency of the wire. The VW2106 Readout measures 100 cycles of vibration with a precise quartz oscillator, and displays a value proportional to the frequency squared, which is called B Units ($\text{Frequency}^2 \times 10^{-3}$).The relationship between the B Unit readings and the pressure being exerted on the instrument diaphragm is expressed by the following equation:

$$\mathbf{P = CF\,(Li - Lc)}$$

where:

P	=	Corrected Pressure Reading.
CF	=	Linear Calibration Factor – in kPa per B Unit digit. The CF is a unique value for each manufactured VW sensor and is determined by the initial laboratory calibration.
Li	=	Initial B Unit Reading at zero applied pressure on the diaphragm. The Li is a unique value for each manufactured VW sensor and is determined by the initial laboratory calibration.
Lc	=	Current B Unit Reading under the currently applied pressure on the diaphragm

The Vibrating Wire technology offers the unique advantage of frequency output signal virtually unaffected by line impedance, or contact resistance. Cable lengths of up to 1.5 km can be used without signal deterioration.

4 CALIBRATION

All RST VW piezometers are individually calibrated in the laboratory before shipment. Each VW piezometer is calibrated over its full working pressure range. A Linear Calibration Factor (CF) is established by using the calibration data points to do a linear regression. In addition, the calibration data is also fitted to a polynomial regression which provides slightly more accurate data output over the full reading range. Both formulas are provided on the instrument Calibration Record sheet for use as appropriate. It is also noted that RST dataloggers are set-up to use either formula to calculate the instrument output in engineering units.

As part of the calibration procedure, all VW Piezometers are tested to 150% of the standard working range to prove their function at overpressure. In addition, the sensor calibration is carried out over a temperature range of -20º C to +80º C which proves their function at a wide temperature range and provides the input data for the Temperature Correction Factor for each sensor.

A Calibration Record sheet is provided with each VW sensor for use in calculating the applied loads on the VW sensors. The following general information is contained in the Calibration Record sheet. Refer to Appendix A for an example of a Calibration Record sheet.

- Model Number:
- Serial Number:
- Manufacturing Number:
- Pressure Range:
- Work Order Number:
- Cable Length:
- Cable Meter Markings:
- Cable Color Code:
- Cable Type:
- Thermistor Type and Linear Calibration Factor (CF)
- Temperature Correction Factor (Tk)
- Polynomial Gauge Factors (A, B and C)Barometric Pressure at time of Calibration
- Temperature at time of Calibration
- Calibration Data Table
- Linear and Polynomial Formulas
- Calibration Certification

4.1 FIELD CALIBRATION CHECK

The following procedure can be used in the field to verify the validity of a VW Piezometer calibration, as supplied on the instrument Calibration Record sheet.

1. For standard Model VW2100 Piezometers, saturate the filter stone and ensure the space between the instrument diaphragm and the filter stone is totally filled with water. Refer to Appendix B for more detailed information on the saturation of VW2100 Piezometers with Casagrande style filter assemblies and VW2100-DP Piezometers.
2. Lower the piezometer to depth in a a vertical, water filled borehole using the cable markings to accurately control and set the depth. To ensure adequate accuracy of this field calibration check, it would be best to have a minimum emersion depth of about 10 meters.
3. Allow 20 to 30 minutes for the VW piezometer to come to complete thermal equilibrium in the hole. Using a 2106 Readout Unit, record the B unit and temperature readings at that depth.
4. Raise the VW piezometer a known amount, while keeping it fully submerged. If the temperature readings is noted to be changing, allow the instrument to come to the new thermal equilibrium (up to 30 minutes, if required).
5. Record the new B Unit and temperature readings at the higher elevation. Calculate the instrument Calibration Factor (CF) (kPa per B Unit) from this information, given the change in pressure head and B Unit readings.
6. Compare this field calibration to the CF value provided on the Calibration Record sheet. The two values should agree within ± 0.5%. Repeat this calibration check as necessary to confirm the sensor is in proper working condition.
7. If the Calibration Record sheet CF value cannot be confirmed by this field calibration test, the piezometer should not be installed. The instrument will need to be inspected and undergo a full shop function test and re-calibration before being returned to service.

- Note of Caution Regarding the Above Field Calibration Check Procedure:

If the diameter of the water filled borehole is too small, the volume of water that the VW Piezometer cable displaces, when raised or lowered into position, could potentially raise or lower the borehole water level. This effect could seriously impact the accuracy of the above detailed Field Calibration Check. Noted that this potential effect will be further dependent on the available permeability of the borehole to absorb small amounts of volume change.

To avoid this potential problem, it is recommended that the water filled borehole used for Field Calibration Checks be large enough in diameter, so that the potential error caused by cable volume displacement, will be insignificant in the calculation of the pressure change. A good rule of thumb is to use a borehole diameter that is a minimum of 10 times greater than the wire diameter. In addition, a borehole with a moderate degree of permeability would be much preferred to a “tight” borehole.

5 READING PROCEDURES

5.1 VW INSTRUMENT READINGS

The Operator must become familiar with the function and operation of the VW2106 Vibrating Wire Readout Unit prior to taking any VW instrument readings. Failure to do this could potentially result in damage to the VW2106 Vibrating Wire Readout unit and/or the VW sensors that are connected to it.

The Operator is strongly encouraged to review the instruction manual for the VW2106 Readout unit before proceeding.

5.2 Initial Inspection and Check Readings

A full inspection of all received VW instrumentation equipment is required immediately upon receipt at site, to ensure that the VW instruments have not been damaged in anyway during shipment and are fully functional, and ready for use.

Test readings should be taken of each VW instrument and compared to the VW instrument reading information provided on the Calibration Record sheet. If any discrepancies are noted, they need to be fully investigated and satisfactorily resolved before the VW instrument is released for field installation and service. The Operator doing the inspection and initial test readings must be familiar with the VW instrument operation and the contents of this instruction manual (VW Piezometer, Model VW2100, Instruction Manual, ELM0005K).

5.3 Initial readings

Vibrating Wire Piezometers differ from other types of pressure sensors in that they have a positive B-Unit reading without any external pressure being applied. This is because the Vibrating Wire, in the core of the sensor, is manufactured with an initial tension. VW Piezometers are therefore acutely sensitive to pressure changes right at the zero point, because there is no zero point hysteresis to overcome. The determination of VW instrument Initial Readings at the “zero point” is very important for the accuracy of the subsequent readings.

Before installing the VW piezometer, it is necessary to take initial zero readings with no applied load. The initial zero reading should be taken with either the filter stone removed or with the stone installed and completely saturated (Section 4.1 and Appendix B). The temperature reading from the internal thermistor must also be recorded. And for piezometers with a total range lower than 250 psi, the barometric pressure must also be recorded. These values are needed to be able to apply the correct Correction Factors for changes in temperature and/or barometric pressure, which will impact the reading accuracy of the VW Piezometers though their intended range.

Generally, initial zero readings are obtained immediately prior to installation with no external pressure being applied and at a constant ambient temperature and barometric pressure.

The following checks are required to obtain accurate initial zero readings:

- Has the temperature of the VW piezometer body reached full thermal equilibrium? Variations in temperature across the mass of the piezometer body may result in a temperature reading which is not consistent with the entire Vibrating Wire instrument. This inconsistency will result in an error to the calculated pressure being read by the VW sensor. Allow 20 to 30 minutes for the temperature of the VW Piezometer to equilibrate. If required, sources of temperature fluctuation, such as water flow, may have to be eliminated.
- Is the filter stone saturated? If the filter stone is only partially saturated, then surface tension effects within the pore spaces of the filter could affect the zero readings. This can be a particular problem at low pressures (less than 5 psi). If there is any question regarding the adequate saturation of the filter stone, the filter stone should be removed to allow direct atmospheric connection with the transducer diaphragm.
- Be sure to record the VW piezometer temperature and the barometric pressure at the same time the B-Unit zero readings are taken.

5.4 Pressure equation (using the VW2106 readout)

The VW2106 VW Readout Unit displays VW piezometer readings in Frequency units called B-Units which equal $F^2 \times 10^{-3}$, where F = Frequency in Hertz.

The B-Unit values represent the absolute pressure and must be corrected for temperature and barometric pressure changes.

B-Unit ($F^2 x10^{-3}$) changes from the Initial Zero Reading are converted to the actual pressure changes using the below equations which include corrections for temperature and barometric pressure changes.

Linear Equation; $$P = CF(L_i - L_c) - T_K(T_i - T_c) + F(B_i - B_c)$$

Where:

P	= **C**orrected Pressure; in kPa
CF	= Calibration Factor; in kPa / B-Unit (From the VW Piezometer Calibration Record sheet for each individual sensor)
L_i L_c	= Initial and Current B-Unit reading ($F^2 x10^{-3}$)
T_K	= Temperature Correction Factor; in kPa / degree C Rise (From the VW Piezometer Calibration Record sheet in each individual sensor)
T_i T_c	= initial and current temperature readings; in (ºC)
F	**=** Barometric Pressure Constant = 0.1 kPa / Millibar
B_i B_c	= Initial and Current Barometric pressure readings; in Millibars

Example for a 350 kPa Range Piezometer::

CF	= 0.11594 kPa / B-Unit
L_i	= 8776 B-Units
L_c	= 7200 B-Units
T_K	= - 0.03413 kPa / ºC
T_i	= 22.9 ºC
T_c	= 5.0ºC
F	=0.1 kPa / Millbar
B_i	= 1003.1 mbar
B_c	= 995 mbar

$$P = [\ (0.11594) \times (8776 - 7200)\ ] - [\ (-0.03413) \times (22.9 - 5.0)\ ] + [\ 0.1 \times (1003.1 - 995)\ ]$$

$$P = [\ 182.72\ ] - [\ -0.61\ ] + [\ 0.81\ ] = \mathbf{184.14\ kPa}$$

Second Order Polynomial Equation; $\mathbf{P = \mathcal{A}(L_c)^2 + \mathcal{B}(L_c) + \mathcal{C} + T_K(T_c - T_i) - F(B_c - B_i)}$

Where:

P	= **C**orrected Pressure; in kPa
$\mathcal{A}$	= Polynomial Gauge Factor A; Second Order Polynomial Expression derived from the VW Piezometer Calibration data, for each individual sensor
$\mathcal{B}$	= Polynomial Gauge Factor B; Second Order Polynomial Expression derived from the VW Piezometer Calibration data, for each individual sensor
$\mathcal{C}$	= Polynomial Gauge Factor C; Second Order Polynomial Expression derived from the VW Piezometer Calibration Record sheet in each individual sensor
L_c	= Current B-Unit reading ($F^2 x10^{-3}$)
T_K	= Temperature Correction Factor; in kPa / degree C Rise (From the VW Piezometer Calibration Record sheet in each individual sensor)
T_i T_c	= initial and current temperature readings; in (ºC)
F	**=** Barometric Pressure Constant = 0.1 kPa / Millibar
B_i B_c	= Initial and Current Barometric pressure readings; in Millibars

Example for a 350 kPa Range Piezometer::

$\mathcal{A}$	= - 4.1484E-07 - Dimensionless
$\mathcal{B}$	= - 0.10991 - Dimensionless
$\mathcal{C}$	= 996.58 - Dimensionless
L_c	= 7200 B-Units
T_K	= -0.03413 kPa / ºC
T_i	= 22.9 ºC
T_c	= 5.0ºC
F	=0.1 kPa / Millbar
B_i	= 1003.1 mbar
B_c	= 995 mbar

$$P = [(-4.1484\text{ E-07}) \times (7200)^2] + [-0.10991 \times 7200] + [996.58] + [-0.03413 \times (5.0 - 22.9)] - [0.1 \times (995 - 1003.1)]$$

$$P = [-21.51] + [-791.35] + [996.58] + [0.61] - [-0.81] = \mathbf{185.14\ kPa}$$

> **Note**
> Barometric compensation is *not* required with vented and differential pressure transducers.

6 INSTALLATION

Vibrating Wire piezometers can be installed in various ways to suit the individual application. Specific guidelines for the installation of piezometers have been developed by various agencies and technical specialists. A list of references is given in Appendix E.

The following instructions summarize the generally accepted practice for:

- filter saturation,
- cable identification,
- piezometers installed in clay fill, granular material or boreholes,
- cable routing.

It is not recommended that VW piezometers be installed in wells or standpipes where an electrical pump and/or a power supply cable is present or nearby. Electrical interference from these sources can cause unstable readings. Ground fault currents from this type of equipment can easily damage the sensitive low voltage VW Piezometers. If for some reason, installation under these conditions is unavoidable, additional steps must be performed at the site to ensure complete isolation and adequate grounding of the instrumentation circuits. Care is also required to ensure that the instrument shield wire is well grounded, but isolated from sources of external electrical interference.

In situations where Vibrating Wire piezometers and packers are used at the same time in standpipes or wells, special care must be taken to avoid damaging or cutting the cable jacket with the packer equipment or tools. Any cuts in the cable jacket will allow water entry which will potentially result in damage or failure of the VW sensor.

6.1 FILTER SATURATION

Two types of filters are available; high air entry ceramic or low air entry sintered stainless steel filters.

These filters are intended to protect the delicate diaphragm area of the VW piezometer, while allowing the transmission of external pressures. The filters and bottom cavity of the piezometer body must be saturated to allow the accurate transmission of hydraulic pressures to the VW diaphragm. Filter saturation provides the following reading advantages:

- In a saturated environment, there is no fluid movement, only pressure transmission. This reduces the possibility of the filter becoming clogged with debris, due to oscillating water movement, .
- Decreased response times due to pressure changes, which means increased sensor sensitivity,
- In unsaturated soils, this will ensure hydraulic continuity between the pore water and the piezometer diaphragm, which will provide the highest accuracy of pressure measurement.

6.1.1 LOW AIR ENTRY SINTERED STAINLESS STEEL FILTERS

For accurate reading results, total saturation of the filter is necessary. For the low air entry filters, which are the standard filter type supplied, saturation will start to occur as the piezometer is lowered into the water. Water will be forced into the filter, compressing the air in the space between the filter stone and the pressure sensitive diaphragm. After a period of time, this air will dissolve into the water until the space below the diaphragm and within the filter is entirely saturated. This could take up to several days, which could mean slightly inaccurate initial reading results the first few days.

The following procedure will speed up the filter saturation process and will allow accurate readings to be taken immediately:

- Turn the VW piezometer upside down and remove the end filter assembly, which is held in place with an internal O-ring,
- Submerge the inverted piezometer in bucket of flat water (water which has been sitting for a day), This will ill the space above the piezometer diaphragm with water,

- While keeping the piezometer submerged, slowly replace the filter housing onto the inverted piezometer end, allowing the water to be forced out through the filter sinter. Noted that with a low pressure range piezometer (0,1 mPa or less) it is recommended that VW readings be taken with a VW Readout box while the filter housing is being pushed slowly into place, so as to ensure that the sensor does not over-range due to this operation,
- To maintain the filter saturation prior to installation, the VW piezometer should be stored in the bucket of water until ready to install downhole.
- Noted that a VW piezometer cannot be allowed to freeze when fully saturated, otherwise damage will occur to the transducer diaphragm, which will invalidate the transducer function and calibration.
- During the installation, the VW piezometers should be handled as gently as possible to keep the water in the filter sinter and the bottom chamber until being submerged in the borehole.

If the VW2100 piezometer must undergo multiple removals and reinstallations of the filter housing, the O-ring, which provides the friction fit, may become worn and the filter housing may become loose. If this is noted to be occurring, the O-ring should be replaced immediately.

If problems are experienced with salts, or other precipitates, clogging the stainless sinter filter, coarser screen housings are also available for use on VW piezometers, Unlike the standard stainless sinter filters, screens are less likely to become clogged by precipitates, and other debris, found in some water sources.

Noted that salts, and other dissolved solids, can be deposited within a stainless sintered filter, if the filter is allowed to dry out completely. To prevent filter clogging, it is recommended that the filter be thoroughly rinsed out with clean distilled water, prior to drying.

6.1.2 HIGH AIR ENTRY CERAMIC FILTERS

The ceramic filter on a high air entry piezometer is also removable for de-airing. Because of the high air entry characteristics of the filter, proper de-airing is particularly important for this type of filter assembly in order to ensure that accurate readings can be taken. High air entry filters are available with different air entry values, which will require different procedures. It is therefore very important to know which type of high air entry filter is installed.

One Bar High Air Entry Filters

1. Remove the filter housing from the piezometer body by carefully twisting and pulling on the filter housing assembly. Remove the filter housing slowly, so as not to cause a vacuum pressure on the piezometer diaphragm.
2. Boil the filter assembly in de-aired water for 30 minutes to force all air out of the filter and to saturate the filter material. When finished, place the filter into de-aired water.
3. Re-assemble the filter housing into the piezometer body under the surface of a bucket of de-aired water, while keeping the piezometer oriented with the diaphragm pointing upward. Must be certain that no air is trapped in the transducer cavity.
4. VW readings must be taken with a VW Readout box while the filter housing is being pushed slowly into place, Allow any over-range pressures to fully dissipate before pushing the filter on any further.
5. To maintain the saturation, a VW piezometer, with installed High Air Entry Filter, must be stored in de-aired water until the unit is installed.
6. Noted that a VW piezometer cannot be allowed to freeze when fully saturated, otherwise damage will occur to the transducer diaphragm, which will invalidate the transducer function and calibration

Two Bar (or Higher) High Air Entry Filters

The proper procedure for de-airing and saturating two bar (or higher) high air entry filters is complex and difficult to do properly. It should be done either at the factory or by carefully following the below instructions:

1. Place the assembled piezometer, with the filter housing facing downward, at the bottom of a vacuum chamber. The vacuum chamber is to have an inlet port at the bottom to allow later introduction of de-aired water into the chamber.
2. Close the valve for the de-aired water inlet and evacuate the chamber. The piezometer should be monitored with a VW Readout box while the chamber is being evacuated.
3. When the maximum vacuum has been achieved in the vacuum chamber, the piezometer is read by the VW Readout Box, until it has also reached the same maximum vacuum pressure.
4. At this point, the de-aired water inlet valve is opened to allow de-aired water to enter the bottom of the chamber and reach an elevation of about 50mm above the top of the piezometer high air entry filter.
5. Close the de-aired water inlet valve when the de-aired water has reached the required height.
6. Release the vacuum, allowing the vacuum chamber to return back to atmospheric pressure.
7. Observe the transducer output on the VW Readout Box. It will take as long as 24 hours for the filter to completely saturate (for a 5 bar high entry filter) and for the piezometer pressure to rise back to zero. The saturation of the high entry filter is considered to be completed at this point.
7. After saturation, the transducer must be kept in a sealed container of de-aired water until ready for installation. If de-aired at the factory, a special plastic cap is applied to the piezometer tip to maintain the saturation level. The plastic cap must be removed immediately before installation.
8. Noted that a VW piezometer cannot be allowed to freeze when fully saturated, otherwise damage will occur to the transducer diaphragm, which will invalidate the transducer function and calibration

6.2 INSTALLATION IN FILL

6.2.1 COMPACTED CLAY

Excavate a vertical trench, or recess, about 50 cm deep in the clay material. Form a horizontal cylindrical hole in the sidewall of the excavated trench, near the bottom. The hole diameter should be slightly smaller than the piezometer body, so that when the piezometer is inserted in the hole, it will have a snug fit.

Push the piezometer into the hole in the trench side and into the host clay material. If necessary, to ensure continuity with the saturated high air entry filter and the pore water, smear the filter ceramic with a thin paste of the saturated clay material.

Before back-filling the trench, the cable must be placed with the utmost care to avoid any damage due to kinking or stretching. Loop the cable and route it out of the trench, making sure it rests on a bed of hand placed and lightly compacted screened clay. Make sure that the cable does not come into direct contact with itself or other cables in the same area. Always maintain a few cm of compacted clay material between any two cables.

Backfill the trench with screened clay containing no particles larger than 3mm in dimension. The backfill should have a water content and density equal to that of the surrounding material.

Make sure that the cable is well protected from any potential damage caused by any angular fill material, the compacting equipment and any settlement that might occur due to construction work or subsequent fill placement.

6.2.2 GRANULAR MATERIALS

Excavate a vertical trench, or recess, about 50 cm deep in the granular material. Place the piezometer horizontally in the center of the trench, or recess, excavated for this purpose. Loop the cable and backfill the bottom 10 cm of the trench around the piezometer with screened granular material, not exceeding 3mm in dimension. Above that level, the trench can be backfilled in 10 cm lift with the same granular material that was excavated. The granular backfill should contain the same moisture content and should be compacted to the same density as the surrounding fill. Care must be exercised to not subject the piezometer instrument to damage during the compaction work

In rock fill (particle sizes greater than 10mm), the large interstitial voids will not allow fine backfill materials around the piezometer to stay in place. The fine filter materials will migrate into the rock fill, eventually leaving the piezometer body in direct contact with the angular rock fill material. In this case, it will be necessary to place a graded filter zone around the piezometer to ensure that the filter materials will not be moved. Fine grained clean sand, grading to pea gravel, or larger, will be required around the piezometer instrument. The particle size of the backfill will have to increase in size outwards toward the rock fill. The sand placed around the piezometer instrument and cable should range in size from 0.5 to 3mm in diameter and should not be angular.

Noted that when attempting to place a fine grained zoned backfill around a piezometer, within courser fill materials, it may be necessary, or advisable, to use geotextile filter fabric layers and/or envelopes to provide hard boundaries. This practice will ensure that fine grained backfill materials, used within a graded filter, will not become mobilized and wash away.

6.3 INSTALLATION IN BOREHOLES

6.3.1 SAND/BENTONITE METHOD

The method used to install a piezometer in a borehole depends on the technical requirements for the instrument, the drilling method that was employed, the particular downhole conditions and the materials which the installation must be carried out in. The general method described below will have general applicability to most installations. However, the Field Engineer must be aware of the unique conditions which may be present in the subject borehole which will make downhole installations a major challenge. Conditions such as artesian pressures, squeezing ground, shear zones, and borehole wall instabilities will impact the piezometric instrumentation method chosen and installation techniques required. For a description of other potential instrumentation methods, please consult the references listed in Appendix E.

General Installation Methodology:

The drill casing is drilled 30 cm below the required piezometer installation elevation. If the piezometer is intended to measure the pore water pressure at a specific horizon, it may be necessary to drill hole to 90 cm below the required piezometer elevation to provide room for the placement of a bentonite bottom seal.

After the drilling is completed to the required depth, the drill cuttings, and other downhole debris, must be removed from inside the drill casing. The borehole is washed to bottom, inside the drill casing, until the water emerging runs clear.

If the borehole walls are stable enough to remain open, the drill casing can be withdrawn, a certain distance above the hole bottom, to allow the piezometer installation to proceed in the open length of the borehole. This is the desired method because the work will able to proceed in much easier fashion.

If the borehole walls are considered to be unstable, and caving or collapse is likely, the piezometer installation will have to proceed with multiple small withdrawals of the drill casing to minimize the risk of losing the installation. This method is described below and it will be obvious why longer drill rod or casing pulls will be more desirable, if possible.

In general, boreholes in bedrock are more stable than boreholes in soil. And boreholes in cohesive soils are more stable than boreholes in less cohesive, granular soils.

<u>Installation Procedures – (Bentonite Plug Method):</u>

Bentonite Chips are recommended for downhole backfill work because they are a made from solid bentonite which will not hydrate as quickly when exposed to water as will Bentonite Pellets which are a manufacture product. Bentonite Pellets will become sticky very quickly when exposed to water and can easily clump together, bridging inside the casing, well above the target zone. Use of either of these Bentonite product for downhole seals should be limited to holes which are less that 20 meters, due to the difficulty involved with this method.

If required, place a 60 cm bentonite seal at the bottom of the borehole to seal the hole bottom. Raise the drill casing 15 cm and start placing the bentonite chips in 15 cm increments until the bentonite level is 30 cm below the required piezometer elevation. Pull the drill casing as the bentonite is set in place. Be very careful not to bridge or plug the drill casing with the bentonite. This is accomplished by making sure the bentonite level is at all times below the casing bottom and by <u>slowly</u> dropping the bentonite chips one at a time down the hole. Trying to feed the bentonite chips too rapidly will result in bridging of the chips in the drill casing or borehole. If bridging occurs, it will make it extremely difficult to complete the downhole installations. Once the bentonite chips are in place, tamping is not required because the natural swelling of the chips will provide an adequate seal to the borehole walls.

Prior to setting filter sand in place for the piezometer zone, lower a cylindrical weight down the drill casing to ensure that the hole is clear.of any obstructions, down to the top of the bentonite plug. If necessary, rinse the borehole with clean water to remove any obstructions or debris.

In the same general manner, place 30 cm of fine, clean sand, in 15 cm increments by dropping from surface. The drill casing will also have to be pulled as the sand back-filling proceeds. When compete, lower the piezometer into the hole and take the initial reading as described above.

Pull the drill casing 15 cm and backfill the hole around the piezometer with fine clean sand. Repeat until the sand and drill casing is 30 cm above the top of the piezometer. Then take a second reading on the piezometer.

Lift the casing in 15 cm increments and backfill with bentonite chips until a minimum four foot seal has been placed. During the bentonite chip placement, keep the piezometer cable taut to prevent the bentonite chips from holding up and adhering to the wall of the drill casing. Drop the bentonite chips into the hole one at a time to avoid bridging.

If more than one piezometer is to be installed in the drillhole, the intervening distance between the top of the first piezometer zone and the bottom of the next piezometer zone can be backfill with either cement grout or cement/bentonite grout delivered by tremie method. The second piezometer can then be constructed in the same general manner as described above..

Noted that when pulling the drill casing, it cannot be rotated, as this will likely result in damage to the installed piezometers. Once all the drill casing has been removed from the hole, the borehole collar should be topped off with grout and a protective steel collar casing.

6.3.2 FULLY GROUTED METHOD

The fully grouted method of piezometer installation involves the installation of the VW piezometers directly within a cement-bentonite grout mixture. This method has now become widely accepted based on the technical theory and on extensive field testing and application. It provides an simple and accurate method to obtain precision piezometric monitoring results. For a more detailed discussion of this method, the user is encouraged to read Mikkelson & Green (2003) and Contreras et al (2008) (Appendix E – References).

The general method described below, was taken from the two above technical papers and outlines the basic concepts and methodology of the Fully Grouted Method:

When using the fully grouted method, it is very important that proper filter saturation is performed. This ensures that there are no air filled voids in the filter and that cement-bentonite grout will not be able to plug the filter stone. Best practice is to install the piezometers upside down with the filter tips facing upwards which will ensure that the water stays inside the filter stone. The piezometer can be inverted and tied off to its own cable. Or, it can be inverted and taped onto a PVC pipe which can be used as either a downhole carrier pipe or as a tremie pipe for grout delivery .

The design of a bentonite-cement mixture is intended to approximate the strength and deformation characteristics of the surrounding soil or rock (rather than the surrounding permeability). The strength of the grout can be controlled by adjusting the Water-Cement ratio which is easy to control in the field. . The water and cement are mixed first, prior to adding any bentonite. This ensures that the water-cement ratio stays fixed and the strength/modulus of the mix is more predictable. Any type of bentonite drilling mud can be combined with Type I or II Portland Cement to make the mix. The quantity of bentonite powder will vary depending on the grade of the bentonite, the mixing agitation, the water pH and the water temperature. As the bentonite solids content increases, the mix density increases and the permeability decreases.

The final mix point has to be carefully monitored to ensure that the completed grout remains pumpable. Although the grout mix has a target bentonite content, it may be cut short or extra bentonite may be added to attain the required pumping viscosity. In the end, the low permeability cement bentonite grout will provide adequate permeability for the VW piezometer diaphragm to react any pressure changes occurring at the location. A number of installation methods have been identified using the fully-grouted method:

- Install piezometers one by one from the borehole bottom to the collar over multiple days. Use a single PVC plastic tremie pipe, which is reduced in length, as each successive installation is competed to the hole collar.
- Attach the multiple piezometers to a PVC plastic tremie pipe and install to depth in the borehole. Use the PVC plastic tremie pipe to grout the entire hole in one stage and leave it in place. Note that you need to ensure that the piezometers being grouted into the borehole will not be over ranged by the grout column being placed. VW piezometers can be over pressured to 200% of the full scale range. However, in practice, it is recommended that 150% of FS not be exceeded to ensure an adequate safety buffer.
- For deep holes with lower range piezometers, multiple grouted in PVC plastic tremie pipes may be required. If multiple PVC tremie pipes are used, they should have their annulus fully grouted to ensure that no internal to external pressure communication can occur, in the event that one or both of the PCV pipes should break..
- Install piezometers attached to a PVC plastic tremie pipe inside a casing or hollow stem auger. Leave in place while casing or auger stem is pulled out. Downhole grouting may be carried out before the casing or auger stem is pulled or following. This method is well suited to boreholes with wall stability issues.
- Complete drilling and then grout the hole with casing or hollow stem auger still in hole. Next, pull the casing or auger stem and top up the hole collar with grout. Install piezometers in the borehole, from the bottom to the top. Add weighs to each piezometer, as required, to overcome viscous resistance of the grout while lowering the piezometer.
- Attach piezometers directly to outside of inclinometer casing and grout in place. Piezometers should be placed midway between the casing couplings.
- Attach directly to the outside of corrugated polyethylene settlement pipe (Sondex) or similarly attach to magnet/reed switch casing between the magnet sensors so that pore water pressure and settlement can be measured along the same borehole.
- Install a series of Vibrating Wire piezometers inside a length of perforated 2-inch PVC plastic pipe. The piezometer filter housings will be located in close proximity to one or more of the perforation holes and will therefore be able to monitor the external pressures when fully grouted in-place. This technique is useful in deep installations inside of drill casing or hollow stem augers to prevent cable and/or sensor damage when rotation is required during casing extraction. Later tremie grouting outside the PVC pipe, will result in the piezometers being fully grouted in-place.

6.4 PIEZOMETERS DRIVEN IN SOFT GROUND

RST Model VW2100-DP is designed to be pushed into place from the surface in soft soil materials. For deeper installations where driving from the surface would not be possible, the piezometer may be pushed into place from the bottom of a pre-drilled borehole.

The model VW2100-DP piezometer comes with an adapter fitting which can be connected to AW, CPT, 1”NPT or 1-1/4”NPT threaded pipe or drill rod for pushing.

The drive rods are larger in diameter than the VW2100-DP and form an effective seal above the piezometer. The drive rods are left in the ground with the piezometers, and can only be retrieved when and if, the piezometer is recovered. Should other rods need to be adapted to push the VW2100-DP piezometer in place, it is important to ensure that the first 1.5 meters of these rod have a diameter which is larger than the outside diameter of the VW2100 piezometer housing.

Installation:

1. For accurate results, total saturation of the VW2100-DP filter is necessary. Refer to Appendix C which outlines the steps required to saturate a Drive Point piezometer filter.
2. Prepare the rods to be used downhole. Lay a sufficient number of rods for the push side by side, alternating between male threaded end and female threaded end..
3. The piezometer cable is threaded through the rods leaving a 0.5 meter loop of extra cable laying flat on the ground at each rod end.
4. Leave an 8 meter length of free cable extending beyond the lower extremity of the first rod (assuming 3 meter rod lengths). This should provide sufficient slack to allow easy manipulation of the rods as they are screwed together and pushed into the drillhole.
5. Pull back the spare cable and Screw the lower rod onto the piezometer body. Use a pipe sealing compound or Teflon tape on the threads to form a permanent seal preventing pore-water from flowing into the rod string, thus causing delay response
6. In sequence, add on the required number of rod to reach the push point.
7. When ready to push, connect the VW Readout Box to the VW2100-DP and start monitoring the readings prior to pushing.
8. Push the piezometer into place while monitor any pressure build-up at the tip. Should the pressure exceed the VW working pressure range, stop the driving and wait until the pressure dissipates.
9. Complete the installation and ensure the cable leads are protected.

6.5 CABLE IDENTIFICATION

The VW cables are identified with a VW serial number tag that is attached to the cable jacket at the readout end. If the cable must be cut, this VW serial number tag must be removed and reattached at the new cable end. As an added identification feature, the large cable rolls used in the manufacture of all RST VW sensors have meterage numbers marked on the cable, every meter. The start and end point of the numbering sequence is unique to each sensor and is recorded on the instrument calibration sheet for later reference. Inspection of the cable meterage numbers can therefore be easily be used to verify the ID of an installed VW sensor.

If the VW cable is cut and needs to be repaired, or the cable must be lengthened with a cable splice, RST recommends the use of an RST ELSPLICE4 Electrical Cable Splice Kit For VW Cable. Any cable splice that will be exposed to any moisture should be protected in this manner to eliminate the potential of water egress, short circuiting and conductor corrosion.

6.6 CABLE ROUTING

6.6.1 TRANSITION FROM VERTICAL BOREHOLE TO HORIZONTAL TRENCH

The VW sensor cable should be routed along a curved path as it goes from a vertical to a horizontal position. At the collar of the borehole, prepare a large radius circular transition path within a cushion of screened sand/5% bentonite mix hand compacted to the surrounding fill density. Embed the cable along this transition pathway and bury it in place. This will ensure that the cable will not be stretched or kinked by uneven loading.

6.6.2 HORIZONTAL CABLE RUNS

Two methods are currently used to protect horizontal cable runs from damage. The first method is embedment within selected materials on the surface of the fill. The second method is embedment within an excavated trench within the fill. The second method is the most commonly used because once the trench is backfilled and compacted, the surface can be used for access. Only the trench method is discussed below.

All surface cable installations require continuous surveillance and protection from traffic and earth moving equipment which must move around on the fill surface. For a description of this method, refer to Clements (1982) (Reference A-6) in Appendix E.

Some of the more important considerations that must be given to horizontal cable runs are:

- The trench dimensions should be 300 mm wider than the width required for the cable layout and a minimum 600 mm deep. A 100 – 150 mm bedding layer of 1 mm minus sand is then placed along the trench bottom. If required, bentonite can be added to the sand to form an impervious section or plug.
- The cable is then covered with a 150 mm lift of 10 mm minus select material.
- Completely backfill the trench with selected material and compact with light hand operated equipment.
- Avoid traversing transition zones in the fill where large differential settlements could occur and create excessive strain in the cable. If cables must traverse these zones, install them with additional length for cable snaking, which will allow slack for settlement to occur, rather than creating excessive cable strain.
- Avoid cable splices, but if required, only use an RST ELSPLICE4 Electrical Cable Splice Kit For VW Cable.. This will ensure a strong and waterproof splice.
- Spend time on the design of the cable layout in the trench, in an attempt to avoid overlaying or crossing of the cable runs one on top of the other. If overlaying and crossing cannot be avoided, the cables must be separated by a 50mm blanket of compacted fine grained soil.
- Use horizontal or vertical snaking of the cable within trenches to provide a certain amount of potential slack to avoid overstressing the cables during backfilling and the subsequent fill placement. For most materials, a pitch of 1.8m with an amplitude of 0.4 m will be suitable. In very wet clays, which could be subject to settlement, increase the amplitude from 0.4 m to between 0.6 m and 1.0 m.
- During the cable routing work, read the instruments at regular intervals to ensure their continued proper function. This is especially important prior to backfilling any of the trenches.

6.7 LIGHTNING PROTECTION

All RST Model 2100 Vibrating Wire Piezometers have highly reliable surge/lightning protection incorporated into the sensor circuitry. This surge protection is adequate for most applications. However, to be effectively isolated in all situations, the entire instrumentation system needs to be considered. This is of particular concern when multiple instruments are connected by wire into a large area network. In this cases, the network could be subject to transient and/or induced currents which could damage sensors and/or data acquisition equipment.

In cases where there may be additional risks of surge damage to the network and/or data loss, the following suggestions for additional surge protection, are provided:

- If a VW piezometer is connected to a terminal box or multiplexer on surface, components such as plasma surge arrestors (spark gaps) could be installed in the terminal box/multiplexer to provide an increased measure of transient protection. Terminal boxes and multiplexers available from RST provide built-in locations for the installation of these surge protection devices.
- Lightning arrestor boards and enclosures are available from RST that install at the exit point of an instrument cable from a drillhole or a structure. The enclosure can be easily accessed and opened, so that in the event that the protection board (Surge 4C) is damaged by a surge event, the user may easily service the components, or replace the board. A connection is made between this enclosure and earth ground to facilitate the passing of transients away from the VW instrument.

Additional information is available from RST on surge protection schemes and other alternatives

Additional sources of information on protecting instruments, junction boxes and data logging systems against power surges, transients and electromagnetic pulses are listed in references A-7, A-8 and A-9 in Appendix E.

7 TROUBLESHOOTING

Maintenance and troubleshooting of Vibrating Wire Piezometers is confined to periodic checks of cable connections and maintenance of terminals. The transducers themselves are sealed and are not user serviceable. The following are typical problems with suggested remedial actions.

- **VW Piezometer Fails to Give a Reading**
  1. Check the resistance of the VW coils by connecting an ohmmeter across the gauge terminals (red and black wires). Nominal resistance is approximately 180Ω (±5%), plus cable resistance at approximately 15Ω per 300 m of 22 AWG wire. If the resistance is very high or infinite, the cable is probably broken or cut. If the resistance is very low, the gauge conductors may be shorted.
  2. Check the VW Readout with another VW piezometer to confirm that the VW Readout is working.
  3. The VW piezometer may have been over-ranged or physically damaged. Inspect the diaphragm and housing for any obvious damage. Contact RST Instruments, if necessary.
- **VW Piezometer Reading Unstable**
  1. Connect the blue shield drain wire on the VW Readout to the shield wire of the VW instrument. In the absence of a shield wire on the VW instrument, the blue shield drain wire can be connected to the black or green wires from the VW instrument. If this does not result in more stable readings, proceed to the next item,
  2. Isolate the VW Readout from sources of ground by placing it on a piece of wood or similar non-conductive material. If this does not result in more stable readings, proceed to the next item,
  3. Check for sources of nearby electrical noise such as motors, generators, antennas or electrical cables. Move the VW piezometer cables as far away from and sources of electrical noise as possible. It the noise cannot be eliminated, Filtering and shielding equipment is likely required. Contact RST for technical advice.

4. The VW piezometer housing may be shorted to the shield. Check the resistance between the shield drain wire and the Piezometer housing. The resistance should very high.
5. The VW piezometer may have been over-ranged or physically damaged. Inspect the diaphragm and housing for any obvious damage. Contact RST Instruments, if necessary.

- **Thermistor Reading is Too Low**

1. If the calculated temperature from the thermistor resistance reading is unrealistically low, it is very likely that there is an open circuit or poor connection in the thermistor wiring which is resulting in excessive resistance.
2. Check all connections, terminals and plugs for any damage or corrosion that could cause excessive in-line resistance
3. If cable damage or a cut is located, a splice must be performed to return the function of the wire connection to normal. It is recommended that an RST ELSPLICE4 Electrical Cable Splice Kit For VW Cable be used to ensure proper strength of the splice and waterproofing.

- **Thermistor Reading is Too High**

1. If the calculated temperature from the thermistor resistance reading is unrealistically high, it is very likely that there is a short circuit in the thermistor wiring which is resulting in a lower resistance reading.
2. Check all connections, terminals and plugs for any damage or current leakage that could explain a partial short that could result in a reduced circuit resistance. If a short or partial short is located in the cable, the cable must be repaired with a splice. It is recommended that an RST ELSPLICE4 Electrical Cable Splice Kit For VW Cable be used to ensure proper strength of the splice and waterproofing.
3. If no obvious sources of shorting are found, it is possible that water may have penetrated into the interior of the piezometer. If this is concluded to be the case, there are no remedial actions available.

8 SPECIFICATIONS

PERFORMANCE:	
Models:	VW2100
Measuring range:	170, 340, 690, 1700, 3400, 6900 kPa (Note 1) 25, 50, 100, 250, 500, 1000 psi (Note 1)
Resolution:	0.025% Full Scale
Accuracy:	0.1% Full Scale
Maximum overload:	2 x Full Scale
Diaphragm displacement:	< 0.001 cc at Full Scale

1. Custom ranges available upon request

Model:	VW2100	VW2100-HP	VW2100-DP	VW2100-L	VW2100-LV	VW2100-M	VW2100-MM
Description:	Standard model for general applications	High pressure version of standard model	Drive point model with CPT adapter	Low Pressure, unvented	Low Pressure, vented	Miniature version	Micro-Miniature version
Material:	Hermetically sealed stainless steel housing						
Outside Diameter:	19 mm (0.75 in.)	19 mm (0.75 in.)	33 mm (1.31”)	25 mm (1.0”)	25 mm (1.0”)	17.5 mm (0.68”)	11.1 mm (0.43”)
Length:	133 mm (5.23 in.)	133 mm (5.23 in.)	432 mm (17.0”)	133 mm (5.23”)	133 mm (5.23”)	133 mm (5.23”)	165 mm (6.5”)
Filters:	Standard - 50 micron sintered stainless steel filter Optional - High Air Entry alumina ceramic filter. Available in 1, 3 and 5 Bar versions						

THERMISTOR AND ELECTRICAL CABLE:	
Temperature Range:	-40 to 65ºC (-40 to + 150ºF)
Accuracy:	± 0.2ºC (± 0.4ºF)
Thermistor Time Constant:	n/a
Electrical Cable:	Standard: 2 pair RST 4 Conductor, AWG 22, red polyurethane jacket, shielded and water blocked Optional: 2 pair, Gel Filled 4 conductor, AWG 24, shielded
Wiring Code:	Standard: 2 pair RST VW Gauge: Red – Black Thermistor: Green – White Optional: 2 Pair, Gel Filled VW Gauge: Blue - White Thermistor: Orange – White

CALIBRATION AND IDENTIFICATION

Etched on Housing:	Serial number and psi range
Calibration chart:	Calibration factor
	Temperature correction factor
	Barometric pressure at time of factory calibration
	Temperature at time of factory calibration
	Electrical cable type and length

9 RESISTANCE VS. TEMPERATURE RELATIONSHIP

3000 Ohm NTC Thermistors

Ohms	Temp º C	Ohms	Temp º C	Ohms	Temp ºC	Ohms	Temp º C	Ohms	Temp º C
201.1K	-50	16.60K	-10	2417	30	525.4	70	153.2	110
187.3K	-49	15.72K	-9	2317	31	507.8	71	149.0	111
174.5K	-48	14.90K	-8	2221	32	490.9	72	145.0	112
162.7K	-47	14.12K	-7	2130	33	474.7	73	141.1	113
151.7K	-46	13.39K	-6	2042	34	459.0	74	137.2	114
141.6K	-45	12.70K	-5	1959	35	444.0	75	133.6	115
132.2K	-44	12.05K	-4	1880	36	429.5	76	130.0	116
123.5K	-43	11.44K	-3	1805	37	415.6	77	126.5	117
115.4K	-42	10.86K	-2	1733	38	402.2	78	123.2	118
107.9K	-41	10.31K	-1	1664	39	389.3	79	119.9	119
101.0K	-40	9796	0	1598	40	376.9	80	116.8	120
94.48K	-39	9310	1	1535	41	364.9	81	113.8	121
88.46K	-38	8851	2	1475	42	353.4	82	110.8	122
82.87K	-37	8417	3	1418	43	342..2	83	107.9	123
77.99K	-36	8006	4	1363	44	331.5	84	105.2	124
72.81K	-35	7618	5	1310	45	321.2	85	102.5	125
68.30K	-35	7252	6	1260	46	311.3	86	99.9	126
64.09K	-33	6905	7	1212	47	301.7	87	97.3	127
60.17K	-32	6576	8	1167	48	282.4	88	94.9	128
56.51K	-31	6265	9	1123	49	283.5	89	92.5	129
53.10K	-30	5971	10	1081	50	274.9	90	90.2	130
49.91K	-29	56.92	11	1040	51	266.6	91	87.9	131
46.94K	-28	5427	12	1002	52	258.6	92	85.7	132
44.16K	-27	5177	13	965	53	250.9	93	83.6	134
39.13K	-25	4714	15	895.8	55	236.2	95	79.6	135
36.86K	-24	4500	16	863.3	56	229.3	96	77.6	136
34.73K	-23	4297	17	832.2	57	222.6	97	75.8	137
32.74K	-22	4105	18	802.3	58	216.1	98	73.9	138
30.87K	-21	3922	19	773.7	59	209.8	99	72.2	139
29.13K	-20	3748	20	746.3	60	203.8	100	70.4	140
27.49K	-19	3583	21	719.9	61	197.9	101	68.8	141
25.95K	-18	3426	22	694.7	62	192.2	102	67.1	142
24.51K	-17	3277	23	670.4	63	186.8	103	65.5	143
23.16K	-16	3135	24	647.1	64	181.5	104	64.0	144
21.89K	-15	3000	25	624.7	65	176.4	105	62.5	145
20.70K	-14	2872	26	603.3	66	171.4	106	61.1	146
19.58K	-13	2750	27	582.6	67	166.7	107	59.6	147
18.52K	-12	2633	28	562.8	68	162.0	108	58.3	148
17.53K	-11	2523	29	543.7	69	157.6	109	56.8	149
								55.6	150

Temperature calculated using:

Steinhart-Hart Linearization

$$T_C = \frac{1}{C_0 + C_1(\ln R) + C_3(\ln R)^3} - 273.15$$

3000 Ohm @ 25C NTC Thermistor

C_0 = 0.0014051
C_1 = 0.0002369
C_3 = 0.0000001019
lnR = Natural Log of Resistance
T_c = Temperature in ºC

Appendix A - VW Pressure Transducer Calibration

innovation in geotechnical instrumentation

Calibration Record

RST Instruments Ltd., 11545 Kingston St., Maple Ridge, British Columbia, Canada V2X 0Z5
Tel: 604 540 1100 • Fax: 604 540 1005 • Toll Free: 1 800 665 5599 (North America only)
e-mail: info@rstinstruments.com • Website: www.rstinstruments.com

Vibrating Wire Piezometer

Customer:		RST Instruments Ltd.
Model:		VW2100-0.35
Serial Number:		**VW24285**
Mfg Number:		1237447
Range:		350.0 kPa
Temperature:		22.9 °C
Barometric Pressure:		1003.1 millibars
Work Order Number:		Q025090
Cable Length:		10 meters
Cable Markings:		100022 m - 100031 m
Cable Colour Code:	Red / Black (Coil)	Green / White (Thermistor)
Cable Type:		EL380004HDL
Thermistor Type:		3 kΩ

Applied Pressure (kPa)	First Reading (B units)	Second Reading (B units)	Average Reading (B units)	Calculated Linear (kPa)	Linearity Error (% FS)	Polynomial Error (% FS)
0.0	8776	8776	8776	0.5	0.15	0.01
70.0	8178	8178	8178	69.9	-0.04	-0.01
140.0	7577	7577	7577	139.5	-0.13	-0.01
209.9	6973	6973	6973	209.6	-0.09	0.02
279.9	6368	6367	6368	279.8	-0.03	0.00
349.9	5759	5758	5759	350.4	0.14	0.00
			Max. Error (%):		0.15	0.02

Linear Calibration Factor:	**C.F.=**	**0.11594 kPa/B unit**
Regression Zero:	**At Calibration =**	**8780.6 B unit**
Temperature Correction Factor:	**Tk =**	**-0.03413 kPa/°C rise**

Polynomial Gage Factors (kPa) **A:** **-4.1484E-07** **B: -0.10991** **C: 996.58**

Pressure is calculated with the following equations:

Linear: $P(kPa) = C.F.(Li-Lc) - [Tk(Ti-Tc)] + [0.10(Bi-Bc)]$

Polynomial: $P(kPa) = A(Lc)^2 + BLc + C + Tk(Tc-Ti) - [0.10(Bc-Bi)]$

	Date (dd/mm/yy)	VW Readout Pos. B (Li)	Temp °C (Ti)	Baro (Bi)
Shipped Zero Readings:	18-Dec-12	8775	18.9	1014.0

Li, Lc = initial (at installation) and current readings
Ti, Tc = initial (at installation) and current temperature, in °C
Bi, Bc = initial (at installation) and current barometric pressure readings, in millibars
B units = B scale output of VW 2102, VW 2104, VW 2106 and DT 2011 readouts
B units = Hz^2 / 1000 ie: 1700Hz = 2890 B units

Technician: Benson Yu Date: 18-Dec-12

This instrument has been calibrated using standards traceable to the NIST in compliance with ANSI Z540-1

Document Number.: ELL0130K

Recycled MIG0106B

Appendix B – Vibrating Wire Piezometer with Casagrande Style Filter Assembly

Saturation Instructions:

1. Remove the sealing screw from the bottom end of the piezometer.

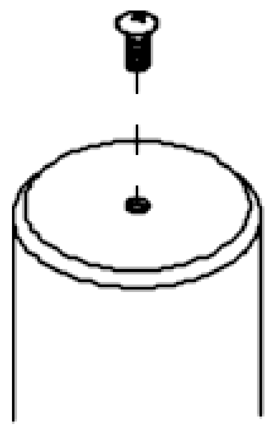

Figure 1 - Removing the Sealing Screw

2. Fill a bucket full of water.
3. Immerse the piezometer in the bucket of water so the sealing screw is pointing upwards.

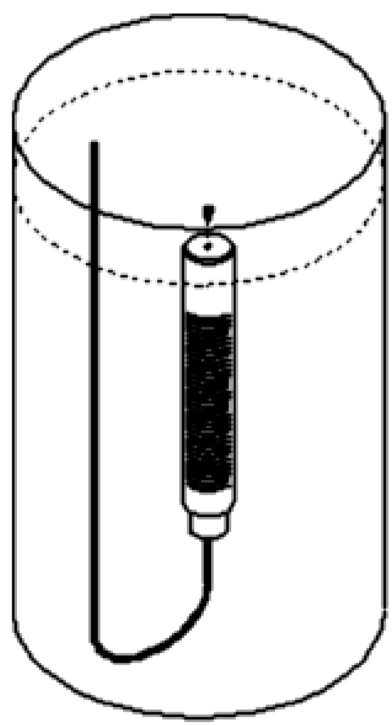

Figure 2 - Immersing the Piezometer

4. Allow the air within the piezometer to escape. Gently tap and move the piezometer around underwater.
5. Replace the sealing screw underwater after all the air has been removed from the piezometer.
6. Note that with a low pressure range piezometer (<10psi), readings must be taken with a readout box while carefully pushing the filter housing on, so as not to over-range the sensor.
7. To maintain saturation, the unit should be stored under water until installation.

Appendix C – VW2100-DP "Drive-point" Piezometer

Pre-Operation Instructions:

1. Remove the protective plastic bag from the piezometer. Avoid touching the ceramic filter element, as oil from fingers may affect the permeability of the filter material.
2. Fill a bucket full of water.
3. Unscrew the drive point of the piezometer, so that water can flow freely into the piezometer housing.

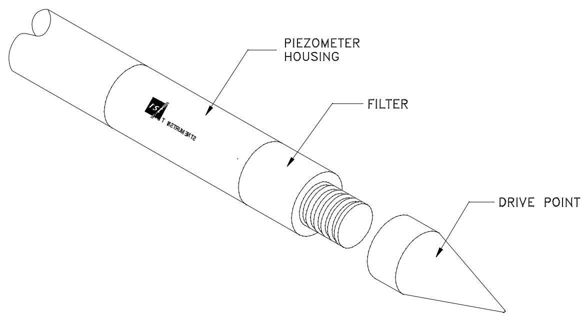

Figure 3 – Unscrew the drive point

4. Immerse the piezometer upside-down in the bucket of water, as shown in Figure 4, and ensure that all air is removed from the inside of the piezometer housing.
5. While the piezometer is still immersed in the water, thread the drive point back on. The drive point should be tightened snuggly by hand only. The filter should be slightly compressed by this process.
6. Note that with low pressure range piezometers (<10psi), readings must be taken with a readout box, while carefully pushing the filter housing on, so as not to over-range the sensor.
7. Remove the piezometer from the water and slide the wires through the adapter pipe. If the piezometer is not being installed immediately, the unit should be kept under water to maintain saturation.
8. Thread the adapter pipe onto the VW2100-DP piezometer. Install the piezometer.

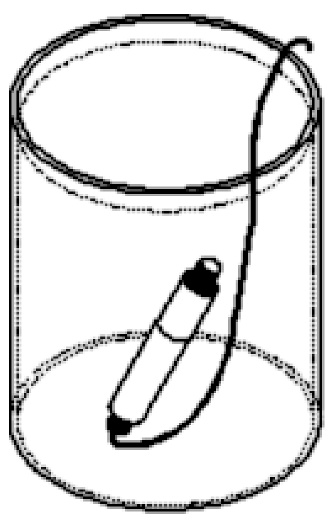

Figure 4 - Immerse the piezometer in water.

Appendix D – Non Linearity and the use of a Second Order Polynomial to Improve the Accuracy of the Calculated Pressure

Most Vibrating Wire Pressure Transducers are sufficiently linear (approximately $\pm$ 0.2% FS) that the use of a Linear Equation and a Linear Calibration Factor will satisfy most normal output requirements. However, it must be noted that the accuracy of the calibration data used to establish the Linear Calibration Factor, is dictated by the accuracy of the calibration procedure and apparatus, which is always approximately $\pm$0.1% FS.

The level of reading accuracy for a VW Pressure Transducer can be improved, especially when the transducer output is non-linear, by the use of a Second Order Polynomial Expression which gives a better fit to the real pressures, than the straight line Linear Equation.

The Second Order Polynomial Expression has the following form:

$$P\ (\text{pressure}) = A\,(Lc)^2 + B\,Lc + C$$

(Refer to Page 11)

Where, Lc is the Vibrating Wire reading (in B Units) and A, B, C are the polynomial coefficients determined by the individual instrument calibration procedure.

Appendix A shows a sample calibration sheet for a Vibrating Wire transducer which has a comparatively low non-linearity. In this case, there will only be a very small difference between the pressure value calculated by the Linear Equation and by the Second Order Polynomial Expression.

In contrast, it is noted that the Second Order Polynomial Expression method will provide more accurate pressure values for VW transducers which have a high non-linearity (greater than $\pm$ 0.2% FS). The VW calibration sheet contains a column labeled “Linearity Error (% Full Scale)”. This column displays the calculated linear error percentage for the calibration steps. If the average of these percentage values (usually 6) exceed $\pm$ 0.2 %, it would be advisable to carry out all pressure calculations using the Second Order Polynomial Expression.

The Linearity Error (% Full Scale) is calculated as follows::

$$= ((\text{VW Calculated Pressure} - \text{Applied Pressure}) \,/\, \text{Full Scale Pressure}) * 100 \text{ Percent}$$

The Second Order Polynomial Expression will provide a calculated pressure which is more accurate to the actual pressure monitored and will contain less error. However, it should be noted that where the accuracy of absolute pressure measurement is not required, such as monitoring relative water level changes, it makes little difference whether the Linear Equation or the Second Order Polynomial Expression is used.

Appendix E - References

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A-15 Contreras, I.A., Grosser. A.T., Ver Strate , R.H. (2012); `Update of the Fully-Grouted Method for Piezometer Installation``, Geotechnical Instrumentation News, Episode 70

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RST Instruments Ltd.
11545 Kingston St.,
Maple Ridge, BC V2X 0Z5 Canada

Certified System ISO 9001

PRODUCT CATEGORY:
READOUTS + DATA LOGGERS

VW2106 Vibrating Wire Readout

The VW2106 Vibrating Wire Readout shown connected to a Vibrating Wire Piezometer.

The VW2106 Vibrating Wire Readout shown connected to a Vibrating Wire Piezometer.

The portable VW2106 Vibrating Wire Readout reads, displays, and logs both vibrating wire sensors and thermistors. Vibrating wire load cells can be read without any additional accessories.

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Unprecedented accuracy, flexible memory options, and ease of use make the VW2106 invaluable for projects requiring vibrating wire sensor monitoring. Maximum download time is only 15 seconds.

Complementing its high level of accuracy, the VW2106 is also designed for maximum efficiency with the user in mind. In addition to the simple power requirements of only 3 “AA” batteries, the VW2106 comes well-equipped with standard features such as a large graphics display with backlight, a built-in multiplexer, “no-tools” vibrating wire transducer inputs (eliminating the need for alligator clips), and a convenient on-board speaker for sensor diagnostics.

> APPLICATIONS

Reads, displays, and logs both vibrating wire sensors and thermistors.

> FEATURES

- Durable, compact design for excellent portability and field use.
- Large graphics display with a convenient backlight.
- Readings in raw or engineering units.
- Built-in multiplexer for load cells up to 6 vibrating wire gauges.
- “No-tools” vibrating wire transducer inputs eliminates the need for alligator clips.
- Field-replaceable “AA” alkaline batteries eliminate the need for a large, bulky 12 V battery and charger.
- On-board speaker for sensor diagnostics.
- Stores up to 254 instrument locations per route, each with a text label, calibration constants, previous data, and up to 11,400 time/date stamped data points.
- Data transfer to a host computer via USB in a compatible file format for Microsoft Excel® and other spreadsheets. User friendly host software for Microsoft Windows® included.

> BENEFITS

- ✓ **High Reliability**
- ✓ **High Accuracy**

SPECIFICATIONS

DESCRIPTION	SPECIFICATION
Vibrating Wire Readout Excitation Range	400 Hz to 6000 Hz, 5 V Square Wave
Vibrating Wire Readout Resolution	0.01 μs
Vibrating Wire Readout Timebase Accuracy	±50 ppm
Supported Temperature Readout Sensors	NTC3000 (standard), NTC2252, NTC10K, RTD
Temperature Readout Accuracy	±0.1°C
Temperature Readout Range	-50°C to 80°C
Display	Graphic 128 x 64 pixels large character display
Display Backlight	High efficiency LCD with auto off
Max Instrument Locations	254
Memory Capacity	11,400 custom labelled points
Location Identification String	Up to 20 characters
Download Speed	15 seconds (full memory)
Battery	3 “AA” alkaline
Battery Indicator	On-screen, low battery indicator
Operating Temperature	-20°C to 60°C
Dimensions	W 22 cm x D 19 cm x H 9.5 cm (8.75 x 7.5 x 3.75in.)
Weight	1.1 kg (2.4 lbs)

ORDERING INFO

ITEM	PART #
Vibrating Wire Readout	VW2106

VIEW THIS SYSTEM IN ACTION!

YouTube http://youtu.be/1nqpiQUzh4o

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inclinalysis™ digital inclinometer analysis software

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DIGITAL MEMS TECHNOLOGY | WIRELESS COMMUNICATION

SINCE 2003

THE SHORTEST OVERALL LENGTH

The RST Digital MEMS Inclinometer Probe with industry leading system accuracy of ±2 mm per 25 m, shown connected to the cable.

DIGITAL MEMS INCLINOMETER SYSTEM

Since 2003, RST's Inclinometer systems have had the shortest overall length available for a given base length compared to competitive inclinometers. Undaunted, we've forged ahead and improved on our very own industry-leading specifications. With a new minimum negotiable casing radius of 1.99 m, RST's Digital MEMS Inclinometer can still traverse a smaller radius bend than all other inclinometers available in the industry. A local microcontroller in the probe manages data collection, applies precision digital calibration, and provides a fast settling time which results in very efficient data collection.

The Ultra-Rugged Field PC^2 functions as the data collector. It provides a high-level user interface, "at-the-borehole" data analysis and graphical comparison to previous data sets.

CONNECTOR COMPARISON

LEAST INTERFERENCE

Other Inclinometers | RST's Inclinometer

Interference

Interference at connector is visibly inherent in other inclinometers (left) while RST's Digital MEMS Inclinometer (right) can clearly traverse a smaller radius bend (1.99 m) than all other inclinometers.

Minimum Negotiable Casing Radius

Other Inclinometers:

3.12 m

RST Inclinometer:

1.99 m

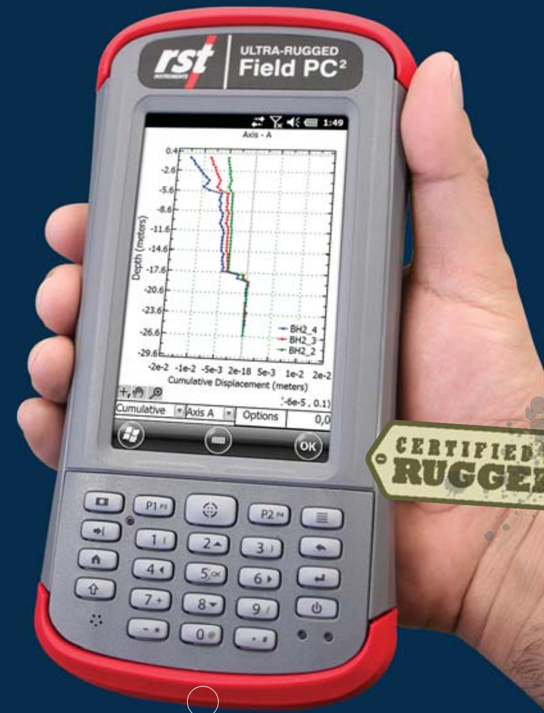
0.5 m wheelbase probes shown in 70 mm OD inclinometer casing.

RST Connector

Cable connector material made of 316 stainless steel.

Rating for underwater use, with wet connection at 5000 ft. (1524 m) in salt water.

Includes a spring strain relief to enhance cable durability at the connector entrance.



ULTRA-RUGGED Field PC^2

Rock solid and field ready for the most extreme environments. Wireless communication between the inclinometer control cable and the Ultra-Rugged Field PC^2 ensures ease of use and reliability since there is no concern with fragile connectors, cable related failure and reliability problems.

PROCESSOR
OPERATING SYSTEM
MEMORY

- 1.0GHz ARM Cortex A8 i.MX53 processor
- Microsoft® Windows Embedded Handheld 6.5.3
- Microsoft® Office Mobile 2010 (Word, Excel, PowerPoint, Outlook)
- Bluetooth® Wireless Communication
- Wi-Fi® 802.11b/g/n with extended range
- Internal solid state 512 MB Flash memory (2 million biaxial data sets)
- 8GB flash storage, user-accessible micro SD/SDHC slot
- Both USB Host and Client plus 9-pin RS-232
- Real-time clock keeps correct date & time, even without battery

DISPLAY

- Active viewing area of 109 mm (4.3 in.) diagonal
- WVGA LCD TFT (800x480)
  - portrait or landscape orientation
- High visibility backlit LCD
  - brilliant contrast in direct sunlight
- Projected capacitive touch interface, "optically bonded" to display for increased visibility.
- Scratch-resistant screen
- On-board stylus with tether

POWER

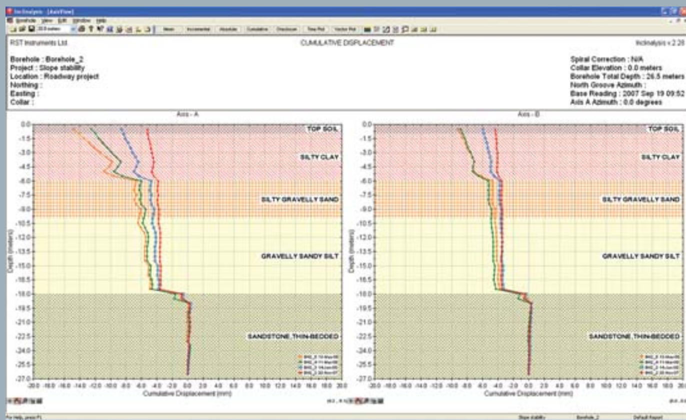
- Intelligent Li-Ion battery 3.7VDC @ 10600mAh, 38.16Whr
- 20 hour battery life on single charge (2 to 4 hrs. charge time)
- Battery easily changeable in field

ENVIRONMENTAL

- Operating temperature: -30 to 60°C (-22 to 140°F)
- Bluetooth® rated to -20°C (-4°F)
- IP68 waterproof and dustproof
- Shockproof (multiple drops from 1.5 m (5 ft.) on to concrete
- MIL-STD-810G: high/low temp., temp. shock, rain, humidity, sand & dust, immersion, vibration, altitude, shock.

ANALYSIS SOFTWARE

THE PERFECT PAIR



RST Inclinalysis™ Software screen capture
shows cumulative displacement of a borehole.

inclinalysis™
digital inclinometer analysis software

The RST Digital MEMS Inclinometer System and Inclinalysis™ Software offer a powerful combination for quick and efficient reduction of large volumes of inclinometer data. Data can be analyzed and presented quickly in a variety of formats.

RST Inclinalysis™ Software is powerful, yet easy to use. Plotting, manipulating data and printing are all only a few clicks away. Menu and plot functions are designed to be intuitive making the program very easy to learn. Designed to complement the Digital MEMS Inclinometer System, data is organized in a standard file structure which makes importing data seamless between Inclinalysis™ and the Ultra-Rugged Field PC^2.

Plot

Plot data at the click of a button. View several plots simultaneously across the screen. Ability to save multiple reports for a single borehole.

Customize

Create custom plot titles and change graph properties. Change reading units instantly to millimeters, metres, inches or feet. Specify top or bottom data reference. Correct for bias-shift.

Import

Import inclinometer data in a variety of formats from different manufacturers including spiral data.

Assess

Create vector plots displaying change in magnitude and direction, and time plots to assess the rate of movement at a particular depth or in a specific movement zone. Instant visual data validation by plotting checksum data.

Compare

Display data in tabular format and compare directly to plots. Take direct measurements off any plot.

Intuitive

Menu and plot functions are designed to be intuitive and easy to learn. Cascade windows to display multiple plots and tabular data on the same screen.

ORDERING INFO

SYSTEMS - Metric	
IC32003	30 m complete system with 0.5 m probe
IC32005	50 m complete system with 0.5 m probe
IC32075	75 m complete system with 0.5 m probe
IC32010	100 m complete system with 0.5 m probe
125, 150, 200, 250, 300 m and longer systems available	
SYSTEMS - Imperial	
IC32110	100 ft complete system with 2 ft probe
IC32115	150 ft complete system with 2 ft probe
IC32120	200 ft complete system with 2 ft probe
IC32130	300 ft complete system with 2 ft probe
400, 500, 600, 800, 1000 ft and longer systems available	
OPTIONAL SYSTEM ACCESSORIES	
IC35805	Dummy Probe 0.5 m wheelbase - METRIC
IC35802	Dummy Probe 2 ft wheelbase - IMPERIAL
IC32705	Digital MEMS Inclinometer Spiral Sensor (see separate brochure)
IC35600	RST Inclinalysis™ - Digital Inclinometer Analysis Software
IC35650	Protective Aluminum Carrying Case - for Inclinometer Probe
Horizontal MEMS Inclinometer (probe available in custom lengths in Metric and Imperial units - view separate brochure or contact sales at RST Instruments).	

INCLUDED SYSTEM COMPONENTS

MEMS Digital Inclinometer probe with protective case
Cable Reel with Wireless Communication System
Cable Reel Carrying Case
Silicone spray for probe/cable connectors
Data collection & transfer software
70 & 85 mm cable grips
Ultra-Rugged Field PC^2 (with rechargeable Li-Ion battery)
AC Adapter for Ultra-Rugged Field PC^2
AC Adapter for Reel Battery Charger
USB cable for Ultra-Rugged Field PC^2
Quick start guide for Ultra-Rugged Field PC^2
Ultra-wide hand strap for Ultra-Rugged Field PC^2
Stylus with tether for Ultra-Rugged Field PC^2

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DIGITAL MEMS INCLINOMETER SYSTEM

THE FIRST

IN EVOLUTION + INNOVATION

For measuring any lateral movement down in the earth, via inclinometer casing, the Digital MEMS Inclinometer System from RST Instruments Ltd. was the first, and is still the best, Digital MEMS Inclinometer System available.

MEMS TILT & INCLINATION SERIES

The inclinometer reel can be charged without removing the battery and offers up to 30 hours of continuous use from a full charge. Its battery life can also be viewed with the Ultra-Rugged Field PC²

SPECIFICATIONS

INCLINOMETER	METRIC SYSTEM	IMPERIAL SYSTEM
Wheelbase	0.5 m	24 in
Probe diameter	25.4 mm	1.00 in
Probe length (including connector)	719 mm	32.6 in
Probe weight	1.06 kg	2.45 lbs
Probe material	Stainless steel	Stainless steel
Full-scale range (other ranges available)	±30 degrees	±30 degrees
Data resolution	0.005 mm per 500 mm	0.00002 ft per 2 ft
Memory	>1,000,000 readings	>1,000,000 readings
Repeatability	±0.002°	±0.002°
System Accuracy	±2 mm per 25 m	±0.1 in. per 100 ft
Axis alignment	Digitally nulled	Digitally nulled
Temperature rating	-40 to +70°C	-40 to +158°F
Sensor Type	MEMS Accelerometer, Biaxial	
CABLE		
Cable diameter	6.40 mm (±0.1 mm)	0.25 in
Cable weight	2.3 kg / 50 m	3.1 lbs / 100 ft
Cable breaking strength	5.90 kN	1325 lbs
Cable reinforcement	Kevlar® ‡	Kevlar® ‡
Cable jacket	Polyurethane	Polyurethane
Cable stretch (suspended in 50 m dry borehole)	7.0 mm	0.27 in
CABLE REELS		
Up to 75 m cable reel diameter	310 mm	12.2 in
100 to 200 m cable reel diameter	380 mm	15 in
+225 m cable reel diameter	460 mm	18 in
Reel weight with 50 m (100 ft.) cable	4.7 kg	8.4 lbs

RST's newly developed connector is by far the industry leader for the least amount of connector interference.

RST also provides the most robust cable on the market with a breaking strength of 5.90 kN (1325 lbs.) Also, our new non-slip, swaged cable marks are unmatched in grip strength.

The compact reel system with 50 m cable weighs a very manageable 4.7 kg and can be easily held with one hand. A padded carrying case is included.

MEASURAND

SAAF

Model 003

The ShapeAccelArray Field (SAAF) is a type of SAA that is most commonly used. All SAA types have rigid segments separated by flexible joints. Triaxial MEMS gravity sensors measure tilt in each individual segment. SAAFs produce data equivalent to inclinometer data. Each SAA is a fully-calibrated measuring instrument delivered on a reel, and installable in a very small ungrooved casing. As a result, installation is rapid and lower in cost, and much larger deformations can be monitored.

An SAAF may be installed near vertical to track the magnitude and direction of lateral deformation, or near horizontal to track vertical deformation. It can also be installed along the cross-section of tunnels and used in “mixed H/V” mode to measure convergence. Due to the bandwidth of the MEMS sensors and communication protocol, it is possible to use the SAAF to monitor 3D vibration data at up to three selected locations along the instrument. The SAAF model 003 has a non-multiplexed structure where every segment has a microprocessor unit and a temperature sensor.

SAAF installations are designed for either manual or automated measurements with a PC or Data Logger and can be powered with either mains or solar power. Other custom solutions are also available, contact Measurand for more details. All communications in the SAA are digital and carried along a cable to the reading device. Standard software required to collect, process, and view SAAF data is available free of charge from the Measurand website within the SAASuite software package. A Measurand interface is required between an SAAF and logger or computer. Interface functions include protocol conversion, power control, and surge protection. Interfaces include SAA232, SAA Field Unit, and SAAUSB.

Related products: SAA232, SAA232-5, SAA Field Power Unit, SAAUSB

SPECIFICATIONS

PHYSICAL PROPERTIES

SEGMENT LENGTH[1]	305 mm or 500 mm (joint center to joint center)
MAXIMUM STANDARD LENGTH OF SAAF	Up to 100 m (500 mm segments) or 60.96 m (305 mm segments)
MAXIMUM CUSTOM LENGTH OF SAAF	Over 100 m (Contact Measurand for details)
LENGTH OF FAR TIP END	60 mm
LENGTH OF UNSENSORIZED NEAR CABLE END	340 mm (includes: Cable Terminator Segment underneath PEX, see diagram)
LENGTH OF HARDENED CABLE (INSIDE PEX)	175 mm
LENGTH OF PEX TUBING	1.5 m standard
LENGTH OF COMMUNICATION CABLE	Standard 15 m, (13.5 m extending past the PEX tubing)
WEIGHT	0.6 kg/m
JOINT DIAMETER IN EXTENSION	25 mm
JOINT DIAMETER IN COMPRESSION	27 mm
MAXIMUM TENSILE RESISTANCE	320 kgf
MAXIMUM AXIAL COMPRESSION	45 kgf (in casing), 22 kgf (no casing)
MINIMUM AXIAL COMPRESSION TO PROVIDE SNUG FIT IN CASING	10 kgf
MAXIMUM JOINT BEND ANGLES	45° (larger angles permitted when stored on factory reel in factory orientation)
SMALLEST BEND RADIUS FOR 27 MM ID CONDUIT WHICH ALLOWS FOR EXTRACTION	3.5 m for SAAF500 2.0 m for SAAF305
STORAGE TEMPERATURE	-40°C to 60°C
INSTALLATION TEMPERATURE[2]	-5°C to 60°C

OPERATING TEMPERATURE	-35°C to 60°C polynomial temperature algorithm corrected
WATERPROOF TO	2000 kPa (200m Water)
POWER REQUIREMENTS	12 VDC at 4.2 mA/segment

DYNAMIC ACCELERATION MEASUREMENTS

RANGE	± 1.7 G
3DB BANDWIDTH	50 Hz
NOISE FLOOR OF MEMS	110 µG/Hz0.5
DATA RATE	SAA232: 38.4 kbps to 230.4 kbps

STATIC SHAPE MEASUREMENTS

ANGULAR RANGE OF MEMS SENSORS	± 360° (software selection required for 2D/3D modes)
RANGE OF 3D MODE (VERTICAL)	± 60° with respect to vertical (SAARecorder alert at ±70° w.r.t. vertical)
RANGE OF 2D MODE (HORIZONTAL)	± 60° with respect to horizontal
RANGE OF 2D MODE (MIXED H/V)	± 180° with respect to horizontal
LONG-TERM ACCURACY RELATIVE TO STARTING SHAPE[4,6,7]	± 1.5 mm for 32 m SAA
SHORT-TERM RESOLUTION RELATIVE TO STARTING SHAPE[5,6,7]	± 0.5 mm for 32 m SAA
LONG-TERM ACCURACY OF TILT/SEGMENT WITHIN 20° OF VERTICAL[4, 6, 7]	± 0.0005 rad = 0.029°
RESOLUTION OF SINGLE SEGMENT:	+/- 2 arcseconds[8]
AZIMUTH ERROR IN JOINTS	< ±0.25°
ORTHOGONALITY WITHIN SEGMENTS	± 0.1°
LONG-TERM RELIABILITY MTBF[9]	38 years for 32 m SAA

NOTES

Minimum Capped SAA Length (A to B) = Min Cable Bend Radius + Unsensorized Length + Sensorized Length + TIP End – Compression

Sensorized Length = Near Cable End Sensorized Segment through Far Tip End Sensorized Segment

Compression = 1.9 mm per joint at 22 kg-force in vertical 27 mm PVC conduit

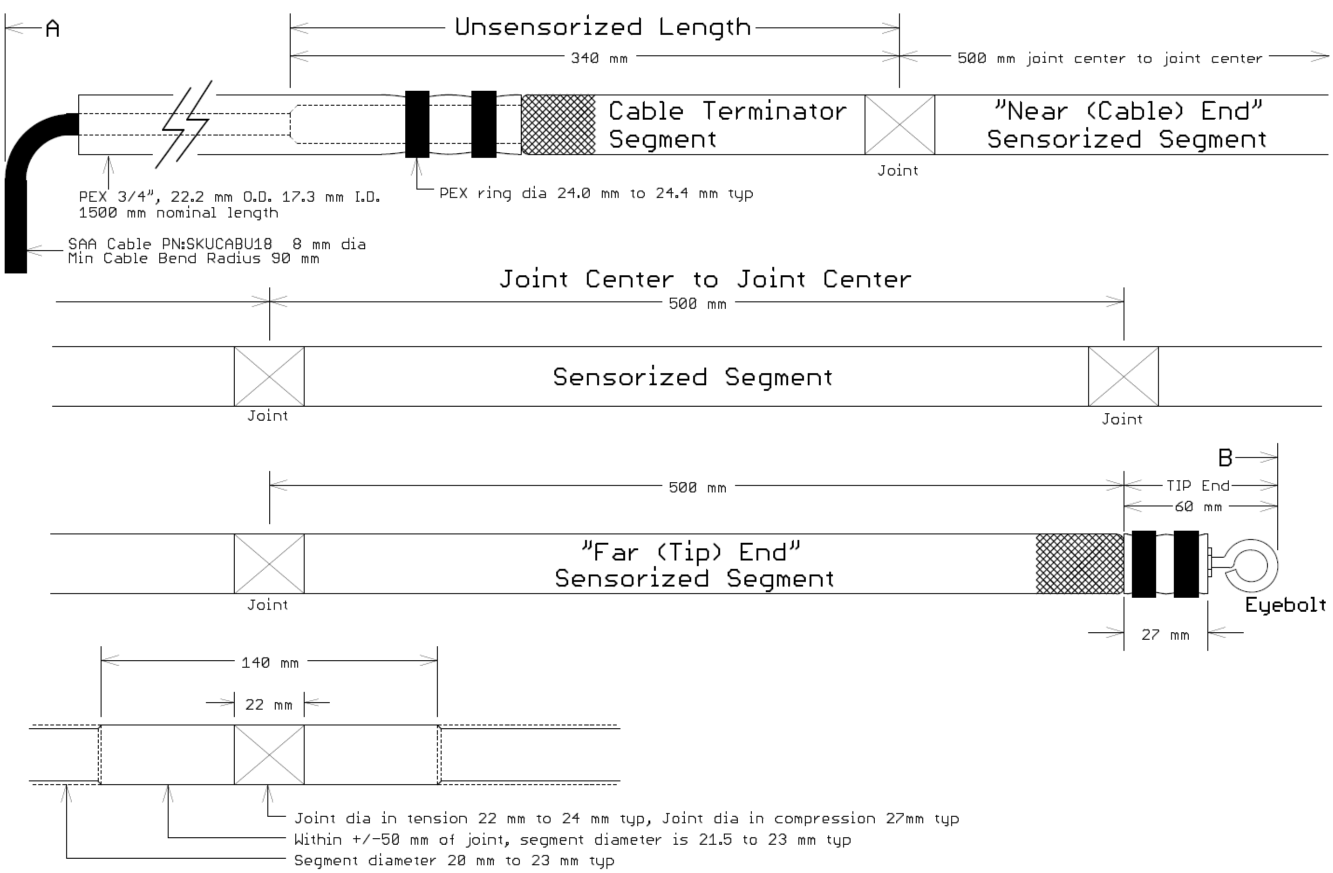
PVC conduit End Cap and Install Kit Top Stack require additional depth

Standard PEX Length 1500 mm

PEX is field-extendable using Measurand PEX Extension Kit, PEX must be at least 300 mm to accommodate the PEX coupler

PEX can be cut shorter, 200 mm minimum

Standard tolerance on measurements +/- 2 mm unless stated



NOTES

[1] Custom segment lengths between 200 mm and 305 mm are available at extra cost, contact Measurand for more information.

[2] Note that most PVC cement for the 27 mm ID PVC conduit is limited to working temperature of 0°C, though special low temperature PVC cement which will work to -20°C is available. Also, flexible SAA joints may be damaged by abrupt bending at low temperatures. As such installation below -5°C ambient must be accompanied by a means of warming the SAA joints and any cemented PVC couplings.

[3] Dynamic measurements require use of Vibration mode in SAARecorder software in a PC. In Vibration mode measurements at the speeds noted here are possible for two to three selected segments only. In Vibration mode it is not possible to simultaneously measure static shape.

[4] Value based on field measurements of vertical SAAs for 1.5 years of operation.

[5] Short-term ≤ 24 h.

[6] Value based on averaging 200 – 1000 frames per reading.

[7] Specification is for 3D mode within ± 20° of vertical. Vertical accuracy degrades with angular deviation from the vertical.

[8] RMS, calculated from published noise figure of sensor (verified by Measurand Inc.), and bandwidth of system using highest AIA setting of 25,600 samples.

[9] Conservatively based on longevity data for electronic components used in SAA, a) assuming total system failure if any single component fails, b) system powered on 100% of the time, c) ambient 6 deg C, d) internal temperature rise of 8 deg C above ambient due to 100% powered-on duty, and e) a benign ambient environment typical of geotechnical instrumentation. MTBF will increase for more typical duty cycles (not powered on 100% of the time). At higher temperatures, MTBF will decrease (e.g. by ~half at 52 deg C). MTBF is based on “MIL-HDBK-217F Notice 2” performed by, ALD/SoHaR.

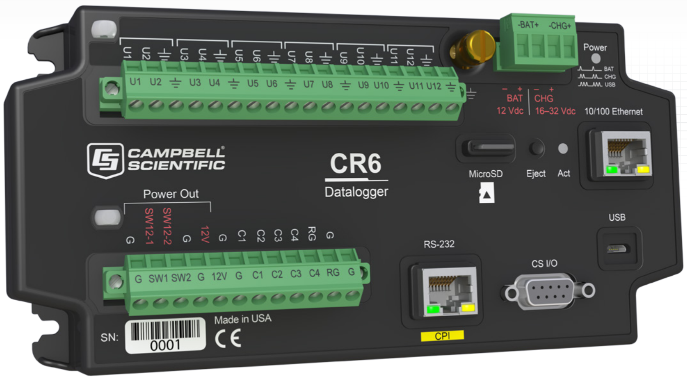
CAMPBELL SCIENTIFIC
WHEN MEASUREMENTS MATTER

CR6 Series

Measurement and Control Datalogger

One Datalogger, Countless Applications

Featuring advanced vibrating-wire technology



Overview

The CR6-series measurement and control datalogger is a powerful core component for your data-acquisition system. We combined the best features of all our dataloggers and added faster communications, low power requirements, built in USB, compact size, and improved analog input accuracy and resolution. The CR6 series also introduces our new universal (U) terminal—an ingenious way for allowing virtually any sensor (analog, digital, or smart) to be connected to any U terminal. This is also our first multipurpose datalogger capable of doing static vibrating-wire measurements.

Benefits and Features

- Powerfully versatile, multi-tool of data acquisition
- U terminals configurable to what you want them to be: analog or digital, input, or output
- Static vibrating wire measurements using our patented spectral analysis
- Surge and over-voltage protection on all terminals
- Flexible power input from solar panel, dc power supply, 12 V battery, USB
- Onboard communication via Ethernet 10/100
- Wiring made easy through removable terminal block
- MicroSD card drive for extended memory requirements
- Serial sensors support with RS-232 and RS-485 native
- CPI for hosting Campbell high speed sensors and distributed modules (CDM)
- Programmable with CRBasic or SCWin program generator, completely PakBus compatible
- Shared operating system (OS) with the popular CRBasic CR1000 and CR3000 dataloggers

Specifications

- **CPU:** 32 bit with hardware FPU, running at 100 MHz
- **Internal Memory:** 4 MB SRAM for data storage, 6 MB flash for OS, 1 MB serial flash (CPU) for program files
- **MicroSD Drive** for extended data storage up to 16 GB
- **Clock Accuracy:** ±3 min per year, optional GPS correction to 10 µs
- **USB micro B** for direct connection to PC (limited power source during configuration), 2.0 full speed, 12 Mbps
- **10/100 Ethernet RJ45** for LAN connection
- **CS I/O port** for connection to Campbell Scientific modems and displays
- **CPI port** for terminal expansion using Campbell Distributed modules (CDM)
- **Battery terminal pair** for regulated 12 V power input or rechargeable 12 V VRLA for UPS mode
- **Charge terminal pair** for 16 to 32 V from dc power converter or 12 or 24 V solar panel
- **Two switched 12 V terminals** for powering sensors or communication devices, 1100 mA @ 20°C
- **Continuous 12 V terminal**

Specifications Continued

Twelve Universal (U) Terminals: U terminals are software configurable for analog or digital functions

- Analog functions consist of:
  - Analog inputs: 12 single-ended or 6 differential with ±5000 mV, ±1000 mV, ±200 mV ranges 24 bit ADC
  - Analog outputs: ±2.5 V or ±2.5 mA ranges for bridge measurements 12 bit DAC
  - Static frequency-analyzed vibrating wire: terminal pair both excites to 12 V p-p and 100 Hz to 6.5 kHz and reads vibrating-wire transducers using our patented spectral-analysis technology (VSPEC™)
  - Thermistor: completion resistor internal 5 kΩ
  - Period average: up to 200 kHz, amplitude dependent
  - Low level ac: 1 Hz to 20 kHz, amplitude dependent
- Digital I/O functions consist of 5 V or 3.3 V logic levels for:
  - General status/control
  - Voltage source: 5 V, 3.3 V, 20 mA @ 3.5 V
  - Timer I/O
  - Switched closure (150 Hz) or high frequency counter (1 MHz)
  - Pulse width modulation
  - Interrupts
  - SDI-12 and SDM
  - Serial asynchronous communication Tx/Rx pairs

Four control (C) Terminals: C terminals are software configurable for digital functions

- Digital I/O functions consist of 5 or 3.3 V logic levels for:
  - General status/control
  - Voltage source 5 V, 3.3 V: 11 mA @ 3.5 V
  - Timer I/O
  - Switched closure (150 Hz) or high frequency counter (1 MHz)
  - Pulse width modulation
  - Interrupts
  - SDI-12 and SDM
  - RS-232/RS-485: half or full duplex, Tx/Rx pairs

Best Analog Accuracy: ±(0.04% of reading + 2 μV), 0° to 40°C

Best Effective Resolution: 50 nV (±200 mV range, differential measurement, input reversal, 5 Hz f_{N1})

Weight: 0.42 kg (0.92 lb)

Dimensions: 20.3 x 10.2 x 6.1 cm (8.0 x 4.0 x 2.4 in)

Programmable Terminals

Twelve U terminals and four C terminals are programmable for the following functions.

Analog Input Function	C1	C2	C3	C4	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10	U11	U12	Max
Single Ended					✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	12
Differential					H	L	H	L	H	L	H	L	H	L	H	L	6
Period Average					✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	12
Vibrating Wire					✓		✓		✓		✓		✓		✓		6
Thermistor					✓		✓		✓		✓		✓		✓		6
Analog Output Function	**C1**	**C2**	**C3**	**C4**	**U1**	**U2**	**U3**	**U4**	**U5**	**U6**	**U7**	**U8**	**U9**	**U10**	**U11**	**U12**	**Max**
Switched-Voltage Excitation					✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	12
Switched-Current Excitation					✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	12
Digital I/O Function	**C1**	**C2**	**C3**	**C4**	**U1**	**U2**	**U3**	**U4**	**U5**	**U6**	**U7**	**U8**	**U9**	**U10**	**U11**	**U12**	**Max**
RS-232	Tx	Rx	Tx	Rx													2
RS-485 (Half Duplex)	Tx-	Tx+	Rx-	Rx+													2
RS-485 (Full Duplex)	Tx	Rx	Tx	Rx													1
RS-232 TTL	Tx	Rx	Tx	Rx	Tx	Rx	Tx	Rx	Tx	Rx	Tx	Rx	Tx	Rx	Tx	Rx	8
SDI-12	✓		✓		✓		✓		✓		✓		✓		✓		8
SDM	DATA	CLK	ENABLE		DATA	CLK	ENABLE		DATA	CLK	ENABLE		DATA	CLK	ENABLE		1
General I/O Pair	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	16
5 V or 3.3 V Source	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	16
Pulse-Width Modulation	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	16
Timer I/O	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	16
Interrupt	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	16
Pulse Counting Function	**C1**	**C2**	**C3**	**C4**	**U1**	**U2**	**U3**	**U4**	**U5**	**U6**	**U7**	**U8**	**U9**	**U10**	**U11**	**U12**	**Max**
Switch Closure	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	16
High Frequency	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	16
Low Level AC						✓		✓		✓		✓		✓		✓	6

Terminal Pair Use Examples

1. If U1 is programmed for analog input or output, its associated pair, U2, may only be used as an analog input or output.
2. If U6 is programmed as a low level ac pulse connection, its associated pair, U5, may only be used for digital I/O or pulse counting.

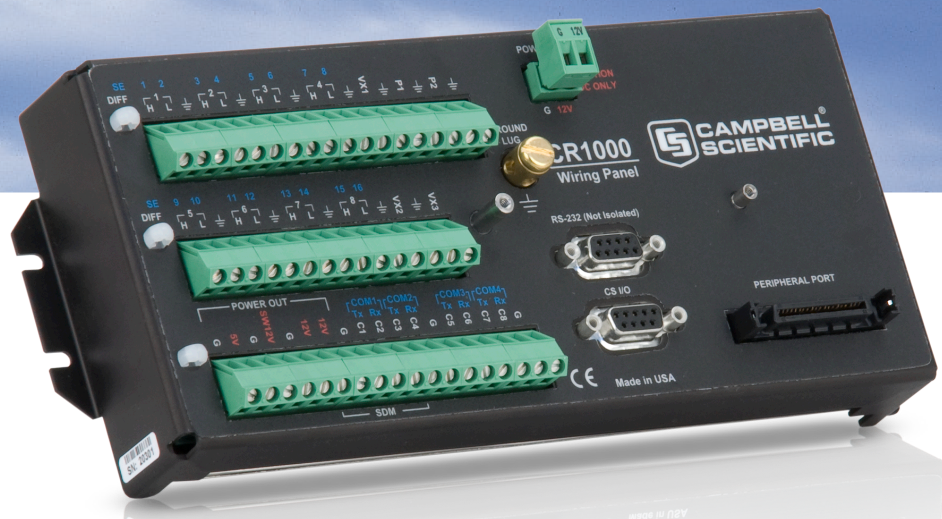
COMPONENT

CAMPBELL SCIENTIFIC
WHEN MEASUREMENTS MATTER

CR1000

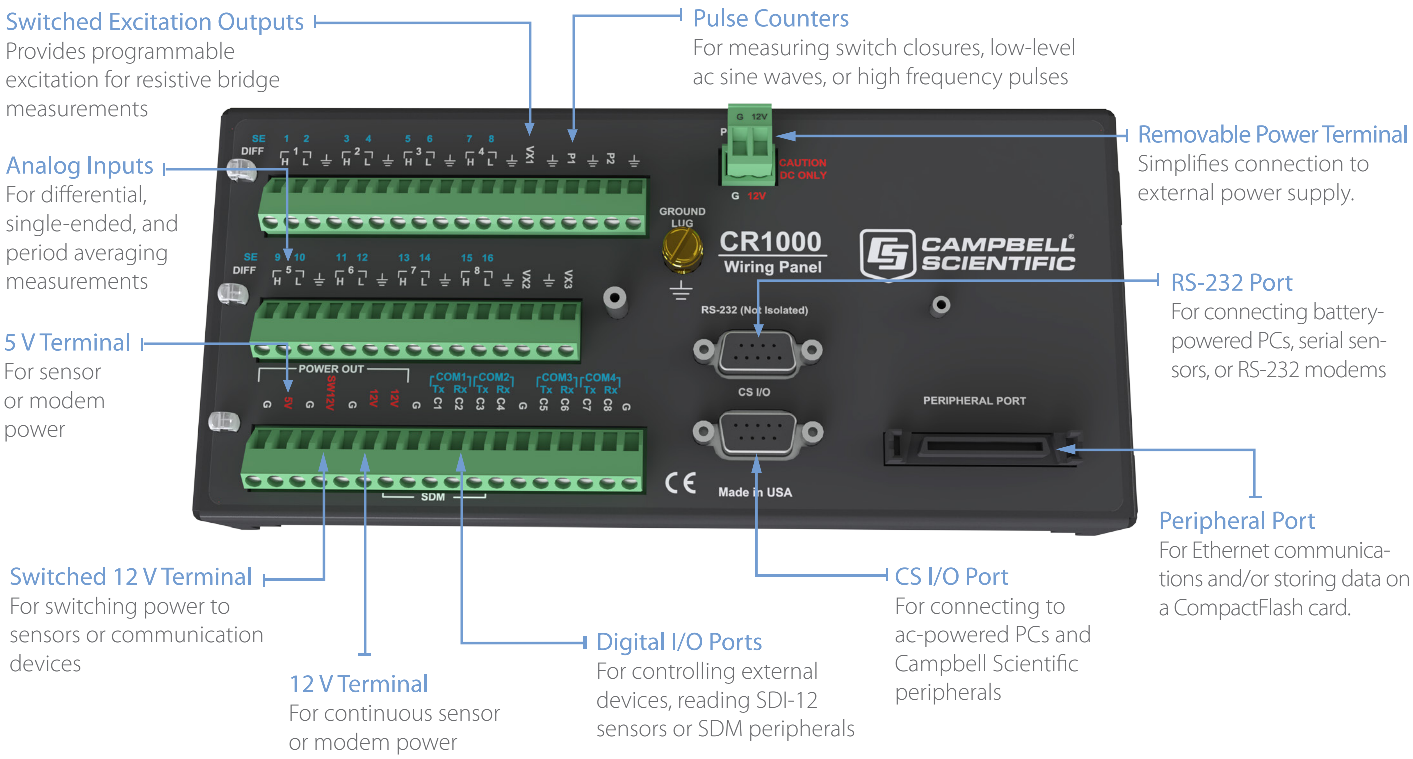
Measurement and Control Datalogger

Rugged, Reliable, and Ready for any Application



CR1000 Measurement and Control Datalogger

The CR1000 provides precision measurement capabilities in a rugged, battery-operated package. It consists of a measurement and control module and a wiring panel. Standard operating range is -25° to +50°C; an optional extended range of -55° to +85°C is available.



Benefits and Features

- 4 MB memory*
- Program execution rate of up to 100 Hz
- CS I/O and RS-232 serial ports
- 13-bit analog to digital conversions
- 16-bit H8S Renesas Microcontroller with 32-bit internal CPU architecture
- Temperature compensated real-time clock
- Background system calibration for accurate measurements over time and temperature changes
- Single DAC used for excitation and measurements to give ratio metric measurements
- Gas Discharge Tube (GDT) protected inputs
- Battery-backed SRAM memory and clock ensuring data, programs, and accurate time are maintained while the CR1000 is disconnected from its main power source
- Serial communications with serial sensors and devices supported via I/O port pairs
- PakBus®, Modbus, DNP3, TCP/IP, FTP, and SMTP protocols supported

Measurement and Control Module

The module measures sensors, drives direct communications and telecommunications, reduces data, controls external devices, and stores data and programs in on-board, non-volatile storage. The electronics are RF shielded and glitch protected by the sealed, stainless steel canister. A battery-backed clock assures accurate timekeeping. The module can simultaneously provide measurement and communication functions. The on-board, BASIC-like programming language supports data processing and analysis routines.

Wiring Panel

The CR1000WP is a black, anodized aluminum wiring panel that is compatible with all CR1000 modules. The wiring panel includes switchable 12 V, redistributed analog grounds (dispersed among analog channels rather than grouped), unpluggable terminal block for 12 V connections, gas-tube spark gaps, and 12 V supply on pin 8 to power our COM-series phone modems and other peripherals. The control module easily disconnects from the wiring panel allowing field replacement without rewiring the sensors. A description of the wiring panel's input/output channels follows.

**Originally, the standard CR1000 had 2 MB of data/program storage, and an optional version, the CR1000-4M, had 4 MB of memory. In September 2007, the standard CR1000 started having 4 MB of memory, making the CR1000-4M obsolete. Dataloggers that have a module with a serial number greater than or equal to 11832 will have a 4 MB memory. The 4 MB dataloggers will also have a sticker on the canister stating "4M Memory".*

Analog Inputs
Eight differential (16 single-ended) channels measure voltage levels. Resolution on the most sensitive range is 0.67 µV.

Pulse Counters
Two pulse channels can count pulses from high level (5 V square wave), switch closure, or low level AC signals.

Switched Voltage Excitations
Three outputs provide precision excitation voltages for resistive bridge measurements.

Digital I/O Ports
Eight ports are provided for frequency measurements, digital control, and triggering. Three of these ports can also be used to measure SDM devices. The I/O ports can be paired as transmit and receive. Each pair has 0 to 5 V UART hardware that allows serial communications with serial sensors and devices. An RS-232-to-logic level converter may be required in some cases.

CS I/O Port
AC-powered PCs and many communication peripherals connect with the CR1000 via this port. Connection to an AC-powered PC requires either an SC32B or SC-USB interface. These interfaces isolate the PC's electrical system from the datalogger, thereby protecting against ground loops, normal static discharge, and noise.

RS-232 Port
This non-isolated port is for connecting a battery-powered laptop, serial sensor, or RS-232 modem. Because of ground loop potential on some measurements (e.g., low level single-ended measurements), AC-powered PCs should use the CS I/O port instead of the RS-232 port (see above).

Peripheral Port
One 40-pin port interfaces with the NL116 Ethernet Interface and CompactFlash Module, the NL121 Ethernet Interface, or the CFM100 CompactFlash® Module.

Switched 12 Volt
This terminal provides unregulated 12 V that can be switched on and off under program control.

Storage Capacity
The CR1000 has 2 MB of flash memory for the Operating System, and 4 MB of battery-backed SRAM for CPU usage, program storage, and data storage. Data is stored in a table format. The storage capacity of the CR1000 can be increased by using a CompactFlash card.

Enclosure/Stack Bracket
A CR1000 housed in a weather-resistant enclosure can collect data under extremely harsh conditions. The 31551 and 31143 stack brackets allow a peripheral to be placed under the mounting bracket, thus conserving space. The 31143 is hinged, allowing easy access to the lower component during wiring or during maintenance.

Communication Protocols
The CR1000 supports the PakBus, Modbus, DNP3, TCP/IP, FTP, and SMTP communication protocols. With the PakBus protocol, networks have the distributed routing intelligence to continually evaluate links. Continually evaluating links optimizes delivery times and, in the case of delivery failure, allows automatic switch over to a configured backup route.

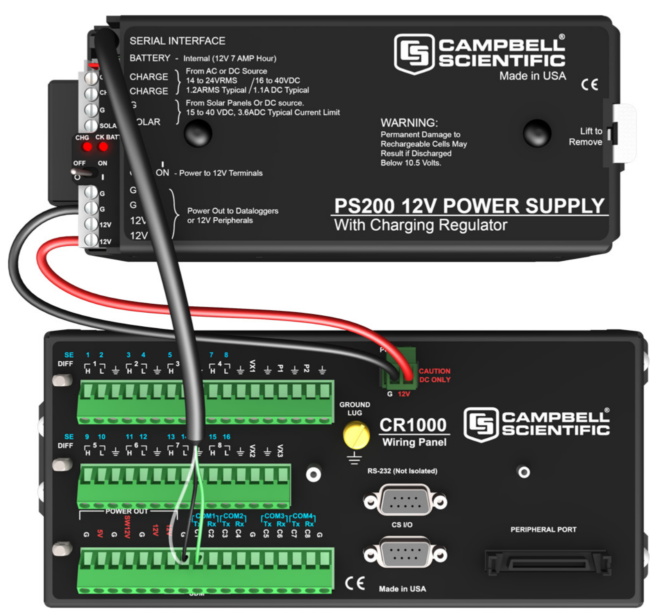
The Modbus RTU protocol supports both floating point and long formats. The datalogger can act as a slave and/or master.

The DNP3 protocol supports only long data formats. The dataloggers are level 2 slave compliant, with some of the operations found in a level 3 implementation.

The TCP/IP, FTP, and SMTP protocols provide TCP/IP functionality when the CR1000 is used in conjunction with an NL240, NL201, NL116, or NL121. Refer to the CR1000 manual for more information.

Power Supplies
Typically, the CR1000 is powered with a PS200, PS150, or BPALK. The PS200 and PS150 provide a 7 Ah sealed rechargeable battery that should be connected to a charging source (either a power converter or solar panel). The BPALK consists of eight non-rechargeable D-cell alkaline batteries with a 7.5 Ah rating at 20°C.

Also available are the BP7, BP12, and BP24 battery, which provide nominal ratings of 7, 12, and 24 Ah, respectively. The BP7 is typically used instead of the PS150 or PS200 when the battery needs to be mounted under the 31143 Hinged Stack Bracket. The BP12 and BP24 batteries are for powering systems that have higher current drain equipment such as satellite transmitters. The BP7, BP12, and BP24 should be connected to a regulated charging source (e.g., a CH200 or CH150 connected to a unregulated solar panel or power converter).



The PS200 (above) and CH200 can monitor charge input voltage, battery voltage, on-board temperature, battery current, and load current.

Communication Options

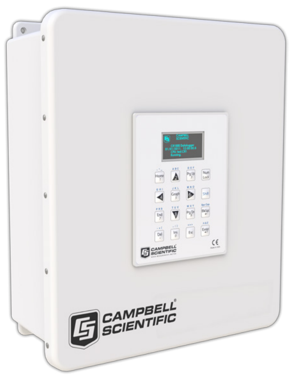
To determine the best option for an application, consider the accessibility of the site, availability of services (e.g., cellular phone or satellite coverage), quantity of data to collect, and desired time between data-collection sessions. Some communication options can be combined—increasing the flexibility, convenience, and reliability of the communications.

Keyboard Display

The CR1000KD can be used to program the CR1000, manually initiate data transfer, and display data. The CR1000KD displays 8 lines by 21 characters (64 by 128 pixels) and has a 16-character keyboard. Custom menus are supported allowing customers to set up choices within the datalogger program that can be initiated by a simple toggle or pick list. One CR1000KD can be carried station to station in a CR1000 network.

Mountable Displays

The CD100 and CD295 can be mounted in an enclosure lid. The CD100 has the same functionality and operation as the CD1000KD, allowing both data entry and display without opening the enclosure. The CD295 displays real-time data only.



The CD100 has a vacuum flourescent display for responsive use through a very wide operating temperature range.

iOS Devices and Android Devices

An iOS device or Android device can communicate with the datalogger or connect to the LoggerNet network using Apps available, at no charge, from the Apple Store or Google Play.

Direct Links

AC-powered PCs connect with the datalogger's CS I/O port using an SC32B or SC-USB interface. These interfaces provide optical isolation. A battery-powered laptop can be attached to the CR1000's RS-232 port via an RS-232 cable—no interface required.

External Data Storage Devices

A CFM100 or NL116 module can store the CR1000's data on an industrial-grade CompactFlash (CF) card. The CR1000 can also store data on an SC115 2 GB Flash Memory Drive.

Short Haul Modems

The SRM-5A RAD Short Haul Modem supports communications between the CR1000 and a PC using a four-wire unconditioned line (two twisted pairs).

Multidrop Interface

The MD485 intelligent RS-485 interface permits a PC to address and communicate with one or more dataloggers over the CABLE2TP two-twisted pair cable. Distances up to 4000 feet are supported.

Internet and IP Networks

Campbell Scientific offers several interfaces that enable the CR1000 to communicate with a PC using TCP/IP.

Radios

Radio frequency (RF) communications are supported using narrowband UHF, narrowband VHF, spread spectrum, or meteor burst radios. Line-of-sight is required for all of our RF options.

Satellite Transmitters

The CR1000 can transmit data using the Argos, Iridium, Inmarsat BGAN, GOES, or Meteosat satellite systems. Satellite telemetry offers an alternative for remote locations where phone lines or RF systems are impractical.

Telephone Networks

The CR1000 can communicate with a PC using landlines or cellular transceivers. A voice synthesized modem enables anyone to call the CR1000 via phone and receive a verbal report of real-time site conditions.

In Virginia, our RF500M Narrowband Radio Modem provides time- and event-driven ALERT data transmission.

Channel Expansion

4-Channel Low Level AC Module

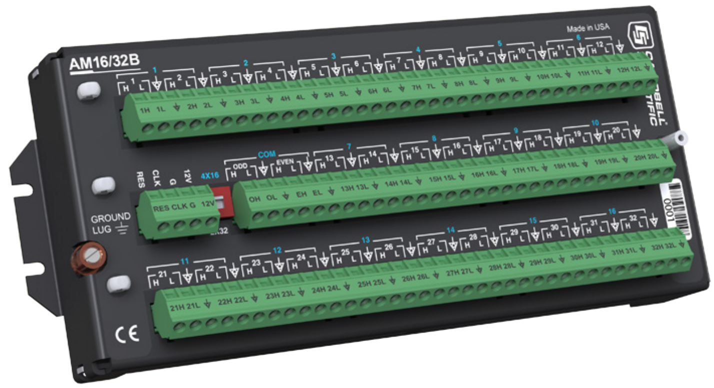
The LLAC4 is a small peripheral device that allows customers to increase the number of available low-level ac inputs by using control ports. This module is often used to measure up to four anemometers, and is especially useful for wind profiling applications.

Synchronous Devices for Measurement (SDMs)

SDMs are addressable peripherals that expand the datalogger's measurement and control capabilities. For example, SDMs are available to add control ports, analog outputs, pulse count channels, interval timers, or even a CANbus interface to the system. Multiple SDMs, in any combination, can be connected to one datalogger.

Multiplexers

Multiplexers increase the number of sensors that can be measured by a CR1000 by sequentially connecting each sensor to the datalogger. Several multiplexers can be controlled by a single CR1000.



The CR1000 is compatible with the AM16/32B (shown above) and AM25T multiplexers.

Software

Starter Software

Our easy-to-use starter software is intended for first time users or applications that don't require sophisticated communications or datalogger program editing. SCWin Short Cut generates straight-forward datalogger programs in four easy steps. PC200W allows customers to transfer a program to, or retrieve data from a CR1000 via a direct communications link.

At www.campbellsci.com/downloads, the starter software can be downloaded at no charge. Our Resource DVD also provides this software as well as PDF versions of our brochures and manuals.

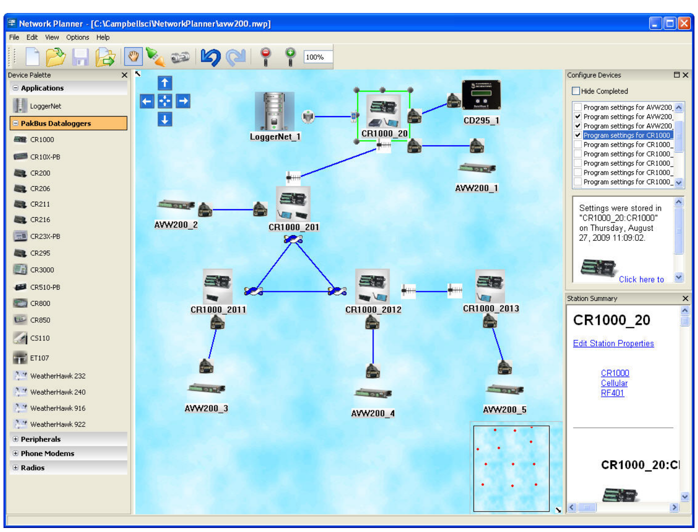
Datalogger Support Software

Our datalogger support software packages provide more capabilities than our starter software. These software packages contains program editing, communications, and display tools that can support an entire datalogger network.

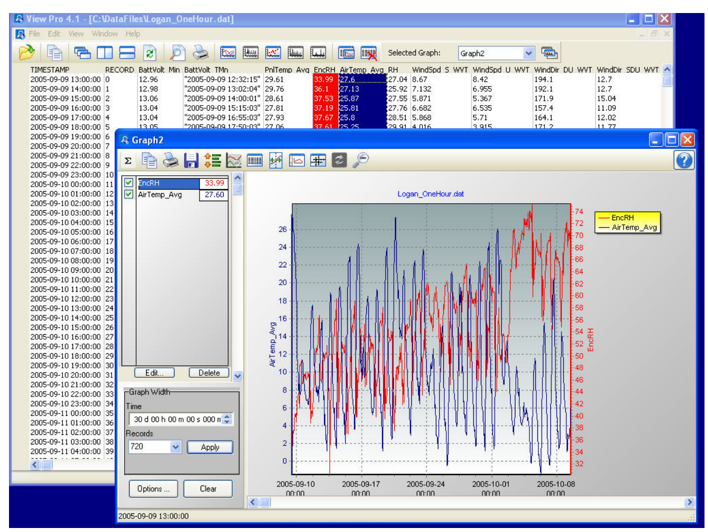
PC400, our mid-level software, supports a variety of telemetry options, manual data collection, and data display. For programming, it includes both Short Cut and the CRBasic program editor. PC400 does not support combined communication options (e.g., phone-to-RF), PakBus® routing, and scheduled data collection.

RTDAQ is an ideal solution for industrial and real-time users desiring to use reliable data collection software over a single telecommunications medium, and who do not rely on scheduled data collection. RTDAQ's strength lies in its ability to handle the display of high speed data.

LoggerNet is Campbell Scientific's full-featured datalogger support software. It is referred to as "full-featured" because it provides a way to accomplish almost all the tasks you'll need to complete when using a datalogger. LoggerNet supports combined communication options (e.g., phone-to-RF) and scheduled data collection.



The Network Planner, included in LoggerNet 4 or higher, generates device settings and configures the LoggerNet network map for PakBus networks.



Both LoggerNet and RTDAQ use View Pro to display historical data in a tabular or graphical format.

Applications

The measurement precision, flexibility, long-term reliability, and economical price of the CR1000 make it ideal for scientific, commercial, and industrial applications.

Meteorology

The CR1000 is used in long-term climatological monitoring, meteorological research, and routine weather measurement applications.

Our rugged, reliable weather station measures meteorological conditions at St. Mary's Lake, Glacier National Park, MT.

Sensors the CR1000 can measure include:

- cup, propeller, and sonic anemometers
- tipping bucket rain gages
- wind vanes
- pyranometers
- ultrasonic ranging sensor
- thermistors, RTDs, and thermocouples
- barometers
- RH probes
- Cooled mirror hygrometers

Agriculture and Agricultural Research

The versatility of the CR1000 allows measurement of agricultural processes and equipment in applications such as:

- plant water research
- canopy energy balance
- plant pathology
- machinery performance
- frost prediction
- crop management decisions
- food processing/storage
- integrated pest management
- irrigation scheduling

This vitaculture site in Australia integrates meteorological, soil, and crop measurements.

Wind Profiling

Our data acquisition systems can monitor conditions at wind assessment sites, at producing wind farms, and along transmission lines. The CR1000 makes and records measurements, controls electrical devices, and can function as PLCs or RTUs. Because the datalogger has its own power supply (batteries, solar panels), it can continue to measure and store data and perform control during power outages. Typical sensors for wind assessment applications include, but are not limited to:

- cup, propeller, and sonic anemometers (up to 10 anemometers can be measured by using two LLAC4 peripherals)
- wind vanes
- thermistors, RTDs, and thermocouples
- barometers
- pyranometers

For turbine performance applications, the CR1000 monitors electrical current, voltage, wattage, stress, and torque.

Photo courtesy npower renewables

A Campbell Scientific system monitors an offshore wind farm in North Wales.

Soil Moisture

The CR1000 are compatible with the following soil moisture measurement technologies:

- **Soil moisture blocks** are inexpensive sensors that estimate soil water potential.
- **Matric water potential sensors** also estimate soil water potential but are more durable than soil moisture blocks.
- **Time-Domain Reflectometry Systems (TDR)** use a reflectometer controlled by the datalogger to accurately measure soil water content. Multiplexers allow sequential measurement of a large number of probes by one reflectometer.
- **Self-contained water content reflectometers** are sensors that emit and measure a TDR pulse.
- **Tensiometers** measure the soil pore pressure of irrigated soils and calculate soil moisture.

Air Quality

The CR1000 can monitor and control gas analyzers, particle samplers, and visibility sensors. The datalogger can also automatically control calibration sequences and compute conditional averages that exclude invalid data (e.g., data recorded during power failures or calibration intervals).

Road Weather/RWIS

Our fully NTCIP-compliant Environmental Sensor Stations (ESS) are robust, reliable weather stations used for road weather/RWIS applications. A typical ESS includes a tower, CR1000, two road sensors, remote communication hardware, and sensors that measure wind speed and direction, air temperature, humidity, barometric pressure, solar radiation, and precipitation.

Water Resources/Aquaculture

Our CR1000 is well-suited to remote, unattended monitoring of hydrologic conditions. Most hydrologic sensors, including SDI-12 probes, interface directly to the CR1000.

Typical hydrologic measurements:

- **Water level** is monitored with incremental shaft encoders, double bubblers, ultrasonic ranging sensors, resistance tapes, strain gage pressure transducers, or vibrating wire pressure transducers. Vibrating wire transducers require an CDM-VW300-series, AVW200-series or another vibrating wire interface.
- **Well draw-down tests** use a pressure transducer measured at logarithmic intervals or at a rate based on incremental changes in water level.
- **Ionic conductivity measurements** use one of the switched excitation ports from the datalogger.
- **Samplers** are controlled by the CR1000 as a function of time, water quality, or water level.
- **Alarm and pump actuation** are controlled through digital I/O ports that operate external relay drivers

A turbidity sensor was installed in a tributary of the Cedar River watershed to monitor water quality conditions for Seattle, Washington.

Vehicle Testing

This versatile, rugged datalogger is ideally suited for testing cold and hot temperature, high altitude, off-highway, and cross-country performance. The CR1000 is compatible with our SDM-CAN interface and GPS16X-HVS receiver.

Vehicle monitoring includes not only passenger cars, but airplanes, locomotives, helicopters, tractors, buses, heavy trucks, drilling rigs, race cars, and motorcycles.

The CR1000 can measure:

- **Suspension**—strut pressure, spring force, travel, mounting point stress, deflection, ride.
- **Fuel system**—line and tank pressure, flow, temperature, injection timing.
- **Comfort control**—ambient and supply air temperature, solar radiation, fan speed, ac on and off, refrigerant pressures, time-to-comfort, blower current.
- **Brakes**—line pressure, pedal pressure and travel, ABS, line and pad temperature.
- **Engine**—pressure, temperature, crank position, RPM, time-to-start, oil pump cavitation.
- **General vehicle**—chassis monitoring, road noise, vehicle position and speed, steering, air bag, hot/cold soaks, wind tunnels, traction, CANbus, wiper speed and current, vehicle electrical loads.

Other Applications

- Eddy covariance systems
- Wireless sensor/datalogger networks
- Fire weather
- Geotechnical
- Mesonet systems
- Avalanche forecasting, snow science, polar, high altitude
- Historic preservation

CR1000 Specifications

Electrical specifications are valid over a -25° to +50°C, non-condensing environment, unless otherwise specified. Recalibration recommended every three years. Critical specifications and system configuration should be confirmed with Campbell Scientific before purchase.

PROGRAM EXECUTION RATE
10 ms to one day @ 10 ms increments

ANALOG INPUTS (SE1-SE16 or DIFF1-DIFF8)
8 differential (DF) or 16 single-ended (SE) individually configuredinput channels. Channel expansion provided by optional analog multiplexers.

RANGES and RESOLUTION: Basic resolution (Basic Res) is the A/D resolution of a single A/D conversion. A DF measurement with input reversal has better (finer) resolution than Basic Res.

Range (mV)[1]	DF Res (µV)[2]	Basic Res (µV)
±5000	667	1333
±2500	333	667
±250	33.3	66.7
±25	3.33	6.7
±7.5	1.0	2.0
±2.5	0.33	0.67

[1]Range overhead of ~9% on all ranges guarantees that full-scale values will not cause over range.
[2]Resolution of DF measurements with input reversal.

ACCURACY[3]:
±(0.06% of reading + offset), 0° to 40°C
±(0.12% of reading + offset), -25° to 50°C
±(0.18% of reading + offset), -55° to 85°C (-XT option only)

[3]Accuracy does not include the sensor and measurement noise. Offsets are defined as:
Offset for DF w/input reversal = 1.5•Basic Res + 1.0 µV
Offset for DF w/o input reversal = 3•Basic Res + 2.0 µV
Offset for SE = 3·Basic Res + 3.0 µV

ANALOG MEASUREMENT SPEED:

Integration Type/Code	Integration Time	Settling Time	Total Time[4] SE w/ No Rev	Total Time[4] DF w/ Input Rev
250	250 µs	3 ms	~1 ms	~12 ms
60 Hz[5]	16.67 ms	3 ms	~20 ms	~40 ms
50 Hz[5]	20.00 ms	3 ms	~25 ms	~50 ms

[4]Includes 250 µs for conversion to engineering units.
[5]AC line noise filter.

INPUT NOISE VOLTAGE: For DF measurements with input reversal on ±2.5 mV input range (digital resolution dominates for higher ranges).
250 µs Integration: 0.34 µV RMS
50/60 Hz Integration: 0.19 µV RMS

INPUT LIMITS: ±5 Vdc

DC COMMON MODE REJECTION: >100 dB

NORMAL MODE REJECTION: 70 dB @ 60 Hz when using 60 Hz rejection

INPUT VOLTAGE RANGE W/O MEASUREMENT CORRUPTION: ±8.6 Vdc max.

SUSTAINED INPUT VOLTAGE W/O DAMAGE: ±16 Vdc max.

INPUT CURRENT: ±1 nA typical, ±6 nA max. @ 50°C; ±90 nA @ 85°C

INPUT RESISTANCE: 20 GΩ typical

ACCURACY OF BUILT-IN REFERENCE JUNCTION THERMISTOR (for thermocouple measurements):
±0.3°C, -25° to 50°C
±0.8°C, -55° to 85°C (-XT option only)

ANALOG OUTPUTS (VX1-VX3)
3 switched voltage, sequentially active only during measurement.

RANGE AND RESOLUTION:

Channel	Range	Resolution	Current Source/Sink
(VX 1–3)	±2.5 Vdc	0.67 mV	±25 mA

ANALOG OUTPUT ACCURACY (VX):
±(0.06% of setting + 0.8 mV), 0° to 40°C
±(0.12% of setting + 0.8 mV), -25° to 50°C
±(0.18% of setting + 0.8 mV), -55° to 85°C (-XT only)

VX FREQUENCY SWEEP FUNCTION: Switched outputs provide a programmable swept frequency, 0 to 2500 mv square waves for exciting vibrating wire transducers.

PERIOD AVERAGE
Any of the 16 SE analog inputs can be used for period averaging. Accuracy is ±(0.01% of reading + resolution), where resolution is 136 ns divided by the specified number of cycles to be measured.

INPUT AMPLITUDE AND FREQUENCY:

Voltage Gain	Input Range (±mV)	Signal (peak to peak) Min. (mV)[6]	Signal (peak to peak) Max (V)[7]	Min Pulse Width (µV)	Max[8] Freq (kHz)
1	250	500	10	2.5	200
10	25	10	2	10	50
33	7.5	5	2	62	8
100	2.5	2	2	100	5

[6]Signal centered around Threshold (see PeriodAvg() instruction).
[7]With signal centered at the datalogger ground.
[8]The maximum frequency = 1/(twice minimum pulse width) for 50% of duty cycle signals.

RATIOMETRIC MEASUREMENTS
MEASUREMENT TYPES: Provides ratiometric resistance measurements using voltage excitation. 3 switched voltage excitation outputs are available for measurement of 4- and 6-wire full bridges, and 2-, 3-, and 4-wire half bridges. Optional excitation polarity reversal minimizes dc errors.

RATIOMETRIC MEASUREMENT ACCURACY:[9,10,11]
±(0.04% of Voltage Measurement + Offset)

[9]Accuracy specification assumes excitation reversal for excitation voltages < 1000 mV. Assumption does not include bridge resistor errors and sensor and measurement noise.
[10]Estimated accuracy, ΔX (where X is value returned from the measurement with Multiplier = 1, Offset = 0):
BrHalf() instruction: $\Delta X = \Delta V_1/V_X$
BrFull() instruction $\Delta X = 1000 \cdot \Delta V_1/V_X$, expressed as $mV \cdot V^{-1}$.
ΔV^{-1} is calculated from the ratiometric measurement accuracy. See Resistance Measurements Section in the manual for more information.
[11]Offsets are defined as:
Offset for DIFF w/input reversal = 1.5•Basic Res + 1.0 µV
Offset for DIFF w/o input reversal = 3•Basic Res + 2.0 µV
Offset for SE = 3•Basic Res + 3.0 µV
Excitation reversal reduces offsets by a factor of two.

PULSE COUNTERS (P1-P2)
2 inputs individually selectable for switch closure, high frequency pulse, or low-level ac. Independent 24-bit counters for each input.

MAXIMUM COUNTS PER SCAN: 16.7×10^6

SWITCH CLOSURE MODE:
Minimum Switch Closed Time: 5 ms
Minimum Switch Open Time: 6 ms
Max. Bounce Time: 1 ms open w/o being counted

HIGH-FREQUENCY PULSE MODE:
Maximum Input Frequency: 250 kHz
Maximum Input Voltage: ±20 V
Voltage Thresholds: Count upon transition from below 0.9 V to above 2.2 V after input filter with 1.2 µs time constant.

LOW-LEVEL AC MODE: Internal ac coupling removes ac offsets up to ±0.5 Vdc.
Input Hysteresis: 12 mV RMS @ 1 Hz
Maximum ac Input Voltage: ±20 V
Minimum ac Input Voltage:

Sine Wave (mV RMS)	Range(Hz)
20	1.0 to 20
200	0.5 to 200
2000	0.3 to 10,000
5000	0.3 to 20,000

DIGITAL I/O PORTS (C1-C8)
8 ports software selectable, as binary inputs or control outputs. Provide on/off, pulse width modulation, edge timing, subroutine interrupts / wake up, switch closure pulse counting, high frequency pulse counting, asynchronous communications (UARTs), and SDI-12 communications. SDM communications are also supported.

LOW FREQUENCY MODE MAX: <1 kHz
HIGH-FREQUENCY MODE MAX: 400 kHz
SWITCH-CLOSURE FREQUENCY MAX: 150 Hz
EDGE TIMING RESOLUTION: 540 ns
OUTPUT VOLTAGES (no load): high 5.0 V ±0.1 V; low <0.1
OUTPUT RESISTANCE: 330 Ω
INPUT STATE: high 3.8 to 16 V; low -8.0 to 1.2 V
INPUT HYSTERESIS: 1.4 V
INPUT RESISTANCE: 100 kΩ with inputs <6.2 Vdc
0.220 kΩ with inputs ≥6.2 Vdc
SERIAL DEVICE/RS-232 SUPPORT: 0 TO 5 Vdc UART

SWITCHED 12 VDC (SW-12)
1 independent 12 Vdc unregulated source is switched on and off under program control. Thermal fuse hold current = 900 mA at 20°C, 650 mA at 50°C, 360 mA at 85°C.

EU DECLARATION OF CONFORMITY
https://s.campbellsci.com/documents/us/compliance/eudoc_cr1000-series.pdf
https://s.campbellsci.com/documents/us/compliance/eudoc_cr1000kd.pdf

COMMUNICATIONS
RS-232 PORTS:
DCE 9-pin: (not electrically isolated) for computer connection or connection of modems not manufactured by Campbell Scientific.
COM1 to COM4: 4 independent Tx/Rx pairs on control ports (non-isolated); 0 to 5 Vdc UART
Baud Rates: selectable from 300 bps to 115.2 kbps.
Default Format: 8 data bits; 1 stop bits; no parity
Optional Formats: 7 data bits; 2 stop bits; odd, even parity

CS I/O PORT: Interface with telecommunications peripherals manufactured by Campbell Scientific.

SDI-12: Digital control ports C1, C3, C5, and C7 are individually configured and meet SDI-12 Standard v 1.3 for datalogger mode. Up to 10 SDI-12 sensors are supported per port.

PERIPHERAL PORT: 40-pin interface for attaching CompactFlash or Ethernet peripherals

PROTOCOLS SUPPORTED: PakBus, AES-128 Encrypted PakBus, Modbus, DNP3, FTP, HTTP, HTML, POP3, PPP, SMTP, Telnet, NTCIP, NTP, SDI-12, SDM, TLS.

SYSTEM
PROCESSOR: Renesas H8S 2322 (16-bit CPU with 32-bit internal core running at 7.3 MHz)

MEMORY: 2 MB of flash for operating system; 4 MB of battery-backed SRAM for CPU usage and final data storage; 512 kB flash disk (CPU) for program files.

REAL-TIME CLOCK ACCURACY: ±3 min. per year. Correction via GPS optional.

REAL-TIME CLOCK RESOLUTION: 10 ms

SYSTEM POWER REQUIREMENTS
VOLTAGE: 9.6 to 16 Vdc

INTERNAL BATTERIES: 1200 mAh lithium battery for clock and SRAM backup that typically provides three years of backup

EXTERNAL BATTERIES: Optional 12 Vdc nominal alkaline and rechargeable available. Power connection is reverse polarity protected.

TYPICAL CURRENT DRAIN at 12 Vdc:
Sleep Mode: < 1 mA
1 Hz Sample Rate (1 fast SE measurement): 1 mA
100 Hz Sample Rate (1 fast SE measurement): 6 mA
100 Hz Sample Rate (1 fast SE measurement w/RS-232 communication): 20 mA
Active external keyboard display adds 7 mA (100 mA with backlight on).

PHYSICAL
DIMENSIONS: 23.9 x 10.2 x 6.1 cm (9.4 x 4 x 2.4 in); additional clearance required for cables and leads.

MASS/WEIGHT: 1 kg / 2.1 lb

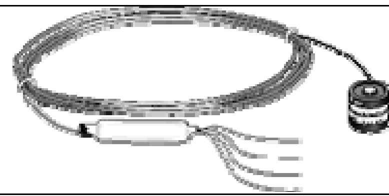
WARRANTY
3 years against defects in materials and workmanship.

Manual for Measurements with Campbell Scientific Dataloggers

Parts needed:
Power:

Small 12V battery	Terminals, wires, and power adapter for CR1000 datalogger

Datalogger and Sensors:

	
CR1000 Datalogger. **Handle with care!**	Licor 200SZ Pyranometer with 100 Ohm Resistor
USB 2 Serial Cable	More sensors as needed

Mounts, tools (Voltmeter, flat head screwdriver, wires, adjustable wrench, as needed)

Prepare and test program:
Thoroughly testing a datalogger program in the lab is crucial to a successful deployment. Using the LoggerNet - CRBasic software, we can edit the datalogger program and instructions for each sensor. Some of the instructions for basic sensors can be determined using the Short Cut Tool on the LoggerNet program menu, for others we have to manually write or search for the instructions online (see table).

Sensors	T107_C	CS215	Li200X	IRR-P	DavisWind	NR-lite	Soilheatflux
Shortcuts	Yes	Yes	Yes	No	No	Yes	yes

To test the program use the compile option in the CRBasic window, which will indicate some (but not all) errors. The program is now ready to be transferred to the datalogger for data collection.

Wiring:
Connect each sensor to the datalogger (CR1000) using the wiring instruction found in the wiring section at the end of the datalogger program. It is very important to confirm the correct datalogger ports, when wiring the sensors. Tighten each screw to avoid accidential disconnecting which would result in a loss of data.

Sensor specific mounting requirements:

- Air temperature and humidity sensors must be placed in radiation shield and should be at z= 2m

- Solar radiation sensors should be level and unobstructed by building, tripod, or sensor, shadows etc. This can usually be avoided by pointing them to the south side of the tripod. Sensor-specific calibration constant must be entered in datalogger program.
- Wind sensor should be mounted as high as possible
- Infrared radiometer for surface temperature (IRR-P) must be pointing to the roof (or the area of interest). Sensor-specific calibration constant must be entered in datalogger program.
- Rain gauge should be level on the ground or on a post away from the tower.

Confirming Proper Operation:

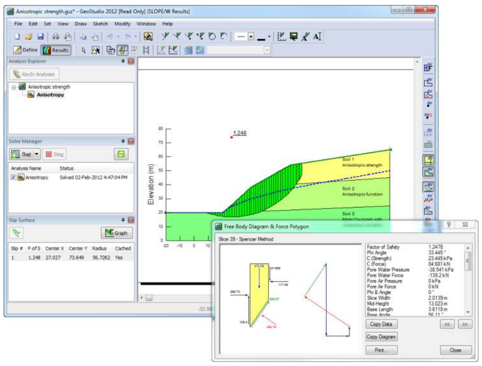
In order to confirm the proper operation of the program and all the sensors, connect the computer to the datalogger using a serial cable, click on 'connect' button from the menu. Check the connection first then load the program to the datalogger. Check the instantaneous readings for all the sensors by clicking on the 'Numeric' in the data displays window. For trouble shooting check the wiring and the ports you choose in your datalogger program for each sensor.

Possible reasons for failed connection Computer – Datalogger:

- **Datalogger does not have power:** check voltage across the wires going into the datalogger power connector. If U < 11.8 V exchange and charge battery. Confirm polarity of wires.
- **Incorrect COM port:** Go to Loggernet – Setup window. Go to 'ComPort' and click on the pull-down menu in Hardware – Com Port Connection. Set another COM port in the pull down menu and try to reconnect in the Loggernet – Connect window. If all these COM ports file check the COM port assigned to the USB 2 Serial cable in Windows – Settigns – Control Panel – Adminstrative Tools – Computer MAnagemetn – Device Manager – Ports
-

SLOPE/W™ 2012

Slope stability analysis.



Typical Applications

SLOPE/W can model almost any stability problem, including:

- Natural earth and rock slopes
- Sloping excavations
- Earth embankments
- Open-pit high walls
- Anchored retaining structures
- Berms at the toe of a slope
- Surcharges at the top of a slope
- Earth reinforcement, including soil nails and geofabrics
- Seismic and earthquake loading
- Tension cracks
- Partial and total submergence
- Line load at any point
- Unsaturated soil behavior
- plus many more!

Comprehensive and Powerful

SLOPE/W is the leading CAD software product for computing the factor of safety of earth and rock slopes. SLOPE/W can effectively analyze both simple and complex problems for a variety of slip surface shapes, pore-water pressure conditions, soil properties, analysis methods and loading conditions.

Using limit equilibrium, SLOPE/W can model heterogeneous soil types, complex stratigraphic and slip surface geometry, and variable pore-water pressure conditions using a large selection of soil models. Analyses can be performed using deterministic or probabilistic input parameters. Stresses computed by a finite element stress analysis may be used in addition to the limit equilibrium computations for the most complete slope stability analysis available.

With this comprehensive range of features, SLOPE/W can be used to analyze almost any slope stability problem you will encounter in your geotechnical, civil, and mining engineering projects.

Easy to Use

Defining a Stability Problem
Beginning an analysis is as simple as defining the geometry by drawing regions and lines that identify soil layers, or by importing a DXF™ file. Then choose an analysis method, specify soil properties and pore-water pressures, define reinforcement loads, and create trial slip surfaces.

Viewing the Results
Once you have solved your stability problem, SLOPE/W offers many tools for viewing the results. Display the minimum slip surface and factor of safety, or view each one individually. View detailed information about any slip surface, including the total sliding mass, a free body diagram and a force polygon showing the forces acting on each slice. Contour the factors of safety, or show plots of computed parameters. Then prepare the results for your report by adding labels, axes, and pictures, or export the results into other applications such as Microsoft® Excel® for further analysis.

Integrated with Other Applications

Use pore-water pressures from SEEP/W, SIGMA/W, QUAKE/W or VADOSE/W
Using finite element computed pore-water pressures in SLOPE/W makes it possible to deal with highly irregular saturated/unsaturated conditions or transient pore-water pressure conditions in a stability analysis. For example, you can analyze changes in stability as the pore-water pressure changes with time.

Use stresses from SIGMA/W or QUAKE/W
Using finite element computed stresses in SLOPE/W allows you to conduct a stability analysis in addition to a static deformation or dynamic earthquake analysis. For example, you can compute the minimum factor of safety that will be reached during an earthquake, or you can find the resulting permanent deformation, if any, using a Newmark-type procedure.

Requirements

- Microsoft® Windows® 8, Windows® 7, Windows Vista®, or Windows® XP with SP 3
- Intel® Pentium® 4 or better, or AMD Opteron™ or Athlon™ 64 or better (GeoStudio is optimized for multi-core Intel processors)
- 100 MB hard disk space
- 1024x768 screen resolution
- Microsoft® .NET 4.0 is required for Add-Ins
- An Internet connection is required to activate or renew a license

GeoStudio®

One Model. One Tool. Many Analyses.

SLOPE/W is part of GeoStudio, an integrated tool containing GEO-SLOPE's leading suite of geotechnical modeling software products: SLOPE/W, SEEP/W, SIGMA/W, QUAKE/W, TEMP/W, CTRAN/W, AIR/W and VADOSE/W. Using GeoStudio means you can run all of these products in one environment, creating one model that is shared among all products.

For example, geometry and material properties created in one product are immediately available in all other products. Sharing the data lets you run several analyses on the same problem. You can use the results from one analysis in another, or import files created by previous versions of the software.

Features

- Limit equilibrium methods include Morgenstern-Price, GLE, Spencer, Bishop, Ordinary, Janbu, and more
- Soil strength models include Mohr-Coulomb, Spatial Mohr-Coulomb, Bilinear, Undrained (Phi=0), anisotropic strength, shear/normal function, and many types of strength functions
- Specify many types of interslice shear-normal force functions
- Pore-water pressure options include Ru coefficients, piezometric lines, pressure contours, a grid of values, spatial functions, or finite-element computed heads or pressures
- Define potential slip surfaces by a grid of centers and radius lines, blocks of slip surface points, entry and exit ranges, fully specified shapes, or automatic
- Use probabilistic soil properties, line loads, and piezometric lines
- Transient stability analyses
- plus many more!

Formulation

SLOPE/W is formulated in terms of moment and force equilibrium factor of safety equations. For example, the Morgenstern-Price method satisfies both force and moment equilibrium. This general formulation makes it easy to compute the factor of safety for a variety of methods and to readily understand the relationships and differences among all the methods.

SLOPE/W can use finite element computed stresses from SIGMA/W or QUAKE/W to calculate a stability factor by computing both total shear resistance and mobilized shear stress along the entire slip surface. SLOPE/W then computes a local stability factor for each slice.

Probabilistic analysis can be performed by using normal distribution functions to vary soil properties and loading conditions. Using a Monte Carlo approach, SLOPE/W computes the probability of failure in addition to the conventional factor of safety.

Join a growing network

By acquiring GEO-SLOPE software, you are joining a group located in more than 100 countries, including practising engineers, university professors, regulators, researchers and students. You can be assured that we will support and continue to enhance the software's engineering capabilities, making it even more powerful and easy to use.

Get help when you need it

When you need assistance with your model, we have helpful services available. Attend one of our workshops, or communicate directly with our experienced numerical modeling professionals. We'll help you to create better models and to gain confidence in your results.

Try out SLOPE/W now!

Experience SLOPE/W for yourself today! Simply visit www.geo-slope.com/downloads/ to download the free evaluation software.

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