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Slope Stabilization of Stormwater Retention Basin (SRB) 6-7
Geotechnical Investigation and Stability Assessment

Prepared for:
Andrew Ziegler, P. Eng.
Project Engineer - Land Drainage and Flood Protection Branch
City of Winnipeg
1199 Pacific Avenue
Winnipeg, Manitoba
R3E 3S8

Project Number: 0015 035 00

Date: April 6, 2021

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Revision History

Revision No.	Project Engineer	Issue Date	Description
0	RB	October 22, 2020	Preliminary Design Report
1	RB	December 23, 2020	Revised Preliminary Design Report
2	RB	April 6, 2021	Revised Preliminary Design Report

Authorization Signatures

Prepared By:

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April 6/21

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Geotechnical Engineer

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ENGINEERS
GEOSCIENTISTS
MANITOBA
Certificate of Authorization
TREK GEOTECHNICAL INC.
No. 4877 Date: April 6, 2021

Table of Contents

List of Tables

List of Figures

List of Appendices

April 6, 2021 Our File No. 0015 035 00

Andrew Ziegler, P. Eng.
Project Engineer, Land Drainage and Flood Protection Branch
City of Winnipeg
1199 Pacific Avenue
Winnipeg, Manitoba
R3E 3S8

RE: Slope Stabilization of Stormwater Retention Basin (SRB) 6-7
Geotechnical Investigation and Stability Assessment

TREK Geotechnical Inc. is pleased to submit a revised preliminary design report for the geotechnical investigation and slope stability assessment for the above noted project. Changes to this report have been made in response to a request by Andrew Ziegler, P.Eng. of the City of Winnipeg, in an email dated February 24, 2021. The changes include an updated cost estimate that incorporates the cost to reconstruct the segment of the pedestrian pathway that lies along the extents of the stabilization works.

Please contact the undersigned should you have any questions.

Sincerely,

TREK Geotechnical Inc.
Per:

Ryan Belbas, M.Sc., P. Eng.
Geotechnical Engineer

Encl.

1.0 Introduction

This report summarizes the results of the geotechnical investigation performed by TREK Geotechnical Inc. (TREK) to address a slope instability that occurred along a segment of Stormwater Retention Basin 6-7 (SRB 6-7) in the Winnipeg neighborhood of Waverley Heights. The terms of reference for the work are included in our proposal to Mr. Andrew Ziegler, P.Eng. of the City of Winnipeg Land Drainage and Flood Protection Branch (the City) dated February 26, 2020. The scope of work for this assignment includes a visual assessment of the existing site conditions, a sub-surface investigation, a topographic survey, instrumentation monitoring, a slope stability analysis and the provision of preliminary design recommendations for slope stabilization and an associated Class 3 construction cost estimate.

2.0 Background

A slope instability was observed by the City along a segment of the east bank of SRB 6-7 during the week of October 14, 2019. The instability extended along the bank adjacent to and downslope of the pedestrian path between the properties of 94 and 106 Syracuse Crescent. The instability occurred after an exceptionally wet fall with a total precipitation of approximately 170 mm in September and early October. Winnipeg also experienced an unprecedented storm on October 10 and 11with over 35 cm of snow, sleet and rain. The SRB water level at the time of failure is estimated to have been at about EL. 229.3 m which is approximately 0.8 m lower than the 25-year design level of 230.124 m.

3.0 Field Program

3.1 Site Conditions

A site reconnaissance was completed by TREK on January 11 and July 31, 2020 during the sub-surface investigation. The east bank is approximately 4 m high (relative to the basin floor) with an overall slope angle of about 5.5H:1V (Horizontal:Vertical). A plan view of the failure area is shown in Figure 01. The failure is approximately 55 m long defined by discontinuous head scarps up to 0.5 m high near its centre. Numerous smaller intermediate scarps on the bank downslope of the head scarp are visible but there was no visual evidence of a toe bulge above the water line. Photo 01 shows the slope failure and additional site photos are attached in Appendix A.

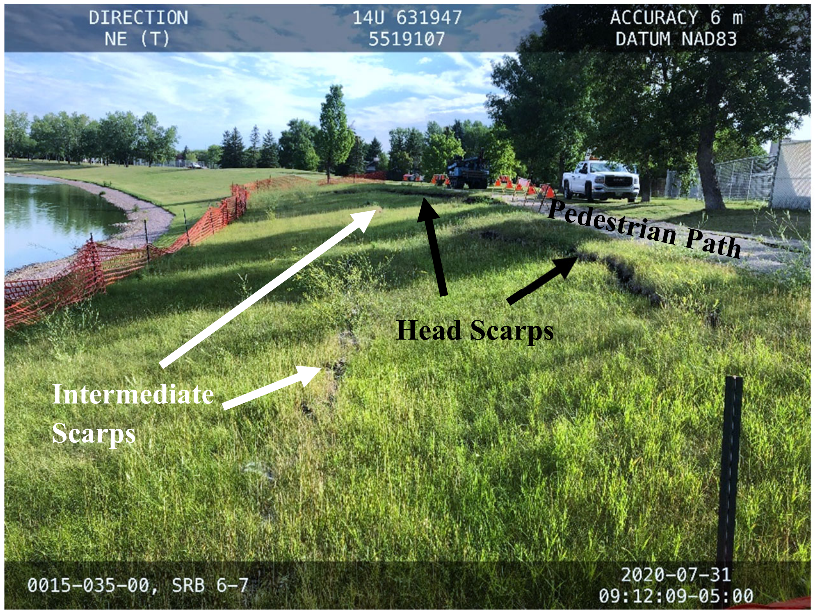


Photo 01. Looking northeast at the instability

3.2 Site Survey

A topographic survey was performed on July 31, 2020 by Wanless Geo-Point Solutions Inc. Site features and elevation contours generated from the survey are shown on Figure 01 and a cross-section (Cross-Section A) through the zone of instability is shown on Figure 02.

3.3 Sub-surface Investigation

A sub-surface investigation was performed on July 31, 2020 under the supervision of TREK personnel to determine the soil stratigraphy and groundwater conditions at the site. Test hole (TH) 20-01 was drilled to 12.2 m below ground surface at the location shown on Figure 01 using a track-mounted geotechnical rig equipped with 125 mm diameter solid stem augers. Inclinometer casing was installed in the test hole to facilitate slope movement monitoring. The casing terminates at ground surface where a flush-mount protective casing was installed.

Sub-surface soils observed during drilling were visually classified based on the Unified Soil Classification System (USCS). Samples retrieved during drilling included disturbed auger cutting samples and relatively undisturbed Shelby tube samples. All samples retrieved during drilling were transported to TREK's testing laboratory in Winnipeg, Manitoba. Laboratory testing consisted of moisture content measurements on all samples. Bulk unit weight measurements, Atterberg limits, grain-size analysis, and unconfined compression testing was also completed on select Shelby tube samples. Laboratory testing results are included in Appendix B.

3.3.1 Soil Stratigraphy and Groundwater Conditions

A brief description of the soil stratigraphy and groundwater conditions encountered during drilling is provided in the following sections. Interpretations of this information for the purposes of design should refer to the detailed information provided on the attached test hole log. The soil stratigraphy consists of

0.3 m of organic clay topsoil overlying silty clay. The silty clay is moist, of high plasticity and stiff becoming firm with depth. The clay is weathered with a blocky structure within 3.5 m of ground surface. Soft zones were encountered between 2.6 and 3.4 m and between 7 and 9 m. Squeezing of the test hole occurred within the upper soft zone.

3.3.2 Groundwater Conditions

Groundwater seepage was not observed during drilling, however, observations made during drilling are short-term and should not be considered reflective of (static) groundwater levels at the site which would require monitoring over an extended period to determine. It is important to recognize that groundwater conditions may vary seasonally, annually, or as a result of construction activities.

3.3.3 Slope Movement Monitoring

The slope inclinometer was monitored twice after installation, with the most recent monitoring event on September 16, 2020. No measurable slope movements are evident in the results to date (Appendix C).

4.0 Slope Stability Analysis

4.1 Numerical Analysis

A slope stability analysis was carried out to evaluate the existing instability and identify appropriate stabilization measures. The analyses were performed under assumed short and long-term groundwater levels (GWLs) with respective target factors of safety (FS) of 1.3 and 1.5.

4.1.1 Numerical Model Description

The stability analysis was conducted using a limit-equilibrium slope stability model (Slope/W) from the GeoStudio 2016 software package (Geo-Slope International Ltd.). The slope stability model used the Morgenstern-Price method of slices with the half-sine inter-slice force function to calculate factors of safety, and slip surfaces were identified using a grid and radius slip surface method. A static piezometric line was used to represent GWLs and SRB water levels. Cross-section A was used for the stability analysis.

4.1.2 Failure Mechanism

Preliminary analysis indicated that the failure is relatively shallow and likely confined to the upper portion of the slope (within the upper 4 m). Within this zone, low operating shear strengths can be expected. A sensitivity analysis carried out using two groundwater levels (GWLs) and soil strengths showed that it is plausible that soil cohesion within this zone may have reduced to 0 kPa at the time of failure, likely under a near-saturated bank condition after significant rainfall events in September and October of 2019. As background, weathering is known to occur within about 3 m of ground surface in Winnipeg clays due to climatic cycles of freeze-thaw and wetting-drying resulting in the formation of structural discontinuities (i.e. cracks and fissures) which alter the intact soil structure. These discontinuities may lead to a loss of effective cohesion over time and thus a reduction in the overall shear strength of clay deposits under low normal stress (i.e. clay within the shallow zone of weathering). This phenomenon is common with cut slopes in clay soils (Kjartanson, 1978). Cracks and fissures also increase the permeability of the clay and promote infiltration of surface run-off and precipitation which can lead to the development of critical groundwater conditions. Groundwater infiltration can also increase the water content of the clay within this zone and create a fully softened (normally consolidated) state. It is unknown if discharge of pool water from the adjacent properties contributed to the problem.

4.1.3 Soil Properties

The strength properties assigned to the underlying silty clay are considered typical for Winnipeg clays along slopes which have experienced large strains (i.e. fully softened). Table 01 summarizes the soil units (including construction materials) and strength properties used in the analysis which are based on the stratigraphy encountered during drilling, our experience, and the results of the back analysis described in Section 4.1.5. The unit weight and friction angle assigned to the composite soil are based on an average of the weathered clay and 100 mm down crushed limestone.

Table 01. Soil Properties used in Stability Modeling

Soil Description	Unit Weight (kN/m^3)	Cohesion (kPa)	Friction Angle (degrees)
Weathered Clay	17.3	0	17.0[1]
Clay	17.3	5.0	17.0
Composite Soil (Rockfill Ribs and Clay)	19.0[2]	0	31.0[2]

[1] *Derived from Back Analysis*
[2] *1:1 ratio of granular fill and weathered clay*

4.1.4 Groundwater and SRB Water Levels

A GWL within the upper bank, at approximately Elev. 230.5 m, was used to represent the normal (long-term) condition and a GWL at approximately Elev. 232.0 m was used to represent the high (short-term) GWL associated with a near-saturated condition. The normal GWL is assumed to transition from the top of the bank to a basin water elevation of 228.9 m. The GWL for the short-term condition was assumed to be at a higher elevation near the ground surface to a basin water elevation of 229.3 m

4.1.5 Back-Analysis

A back-analysis was completed to determine probable soil strengths and groundwater conditions at the time of failure. The following applied conditions/criteria:

- Near-saturated bank at the time of failure,
- Shallow slip (failure) surface within the upper 4 m,

- Entry point of slip surface coincides with the observed head scarps, and
- FS ~ 1.0 for the critical slip surface.

The computer output D-1 (Appendix D) shows the critical slip surface which extends to approximately 2 m below ground surface, exiting approximately 20 m downslope of the head scarps.

4.2 Stabilization Alternatives

A preliminary assessment of feasible stabilization measures included a shear key, a retaining wall with slope regrading (unloading), and rockfill ribs. A rockfill shear key at the mid to lower slope was ruled out because of potential continued movement upslope of the works and the potential for significant slope movements during construction. The retaining wall was also ruled out considering the significant construction costs associated with reconstruction (or relocation) of a portion of the pathway, guard rail, and significant alteration to bank geometry. Granular ribs were deemed the most appropriate stabilization measure in terms of cost, ease of construction, and limited disturbance/alteration to the existing greenspace.

Rockfill ribs are trenches excavated perpendicular to the slope at a regular spacing and backfilled with compacted granular fill. They provide mechanical stabilization of the lower, mid and upper bank areas and prevent potential re-saturation of the bank through internal drainage, lowering of the GWL within the stabilization zone. In this regard, ribs were numerically analyzed to determine the geometry required to achieve the design objective.

The soil mass within the stabilized zone was analyzed as a composite material consisting of a 1:1 ratio of 100 mm down crushed limestone to weathered clay with the strength properties indicated in Table 01. Various rib geometries were analyzed to determine a configuration meeting the design targets, as shown in the computer outputs D-2 and D-3 in Appendix D. The results of the stability analysis are summarized in Table 02. The recommended rib configuration is shown in Figure 03 and consists of 1.5 m wide ribs, with 1.5 m clear spacing between the ribs, excavated from the outside edge of the head scarp to about EL. 229.4 m and graded at 3% to EL. 229.0 m at the toe of the ribs about 15 m downslope. The 1.5 m spacing is considered necessary to achieve the desired groundwater drawdown effect between ribs and increased shear strength.

Table 02. Slope Stability Analysis Results

Stability Case	GWL and SRB Water Level	Slip Surface	Target FS	Calculated FS	Figure No. (Appendix D)
Back Analysis	Short-Term	Representative of Actual Conditions	1.0	0.99	D-1
Rockfill Ribs	Short-Term	Global	1.3	1.72	D-2
		Critical		1.37	
	Long-Term	Global	1.5	1.71	D-3
		Critical		1.49	

5.0 Cost Estimate

A Class C cost estimate (-20% to +30%) of the proposed rockfill ribs based on unit costs for similar stabilization projects is provided in Table 03. As requested by the City, the estimated cost to reconstruct the pedestrian pathway along the extent of the stabilization works is included in the cost estimate.

Table 03. Class 'C' Cost Estimate – Rockfill Ribs and Pedestrian Pathway Reconstruction

Item Description	Unit	Estimated Quantity	Unit Price	Estimated Cost
Mobilization and Demobilization	Lump Sum	1	$25,000.00	$25,000.00
Site Access and Development	Lump Sum	1	$10,000.00	$10,000.00
Supply and Placement of Granular Fill	tonnes	100	$90.00	$9,000.00
Supply, Placement, and Compaction of Rockfill	tonnes	650	$80.00	$52,000.00
Supply and Placement of Geotextile	m^2	110	$10.00	$1,100.00
Supply and Placement of Field Stone	tonnes	90	$35.00	$3,150.00
Removal and Disposal of Existing Asphaltic Concrete Pavement and Granular Base Course	m^2	130	$50.00	$6,500.00
Supply, Placement and Compaction of Granular Base Course	m^3	50	$65.00	$3,250.00
Construction of Asphaltic Concrete Pavement	tonnes	15	$190.00	$2,850.00
Grading and Supply and Placement of Topsoil and Seed	m^2	700	$20.00	$14,000.00
Supply and Placement of Erosion Control Blanket	m^2	700	$7.00	$4,900.00
Engineering Support During Construction	Time and Materials			$16,000
SUB-TOTAL				$131,750
Contingency (-20% to +30%)				-$26,350 to +$39,525
TOTAL				$105,400 to $171,275

We have included estimated allowances for engineering support during construction and post-construction services; however, these should be confirmed based on an engineering services proposal for the scope of the subsequent assignments. We have not included any contingencies, however, we can assist the City in developing appropriate contingencies, if required.

The cost estimate is for the construction of eighteen granular ribs and reconstruction of the pedestrian pathway within the segment of the stabilization works. If funding is available, the City may wish to consider adding ribs to the south end of the works where the slope steepens to reduce the likelihood of future extensions of the failure area. The estimated unit cost per additional rib is $5,000 to $6,000 assuming they are constructed as part of the stabilization works. A Tender could be written to include additional rib construction in the schedule of prices but left as incremental work to be carried out at the discretion of the Owner (Scope Change).

6.0 Closure

The geotechnical information provided in this report is in accordance with current engineering principles and practices (Standard of Practice). The findings of this report were based on information provided (field investigation and laboratory testing). Soil conditions are natural deposits that can be highly variable across a site. If sub-surface conditions are different than the conditions previously encountered on-site or those presented here, we should be notified to adjust our findings if necessary.

All information provided in this report is subject to our standard terms and conditions for engineering services, a copy of which is provided to each of our clients with the original scope of work or standard engineering services agreement. If these conditions are not attached, and you are not already in possession of such terms and conditions, contact our office and you will be promptly provided with a copy.

This report has been prepared by TREK Geotechnical Inc. (the Consultant) for the exclusive use of the City of Winnipeg (the Client) and their agents for the work product presented in the report. Any findings or recommendations provided in this report are not to be used or relied upon by any third parties, except as agreed to in writing by the Client and Consultant prior to use.

Figures

KEY PLAN
NTS

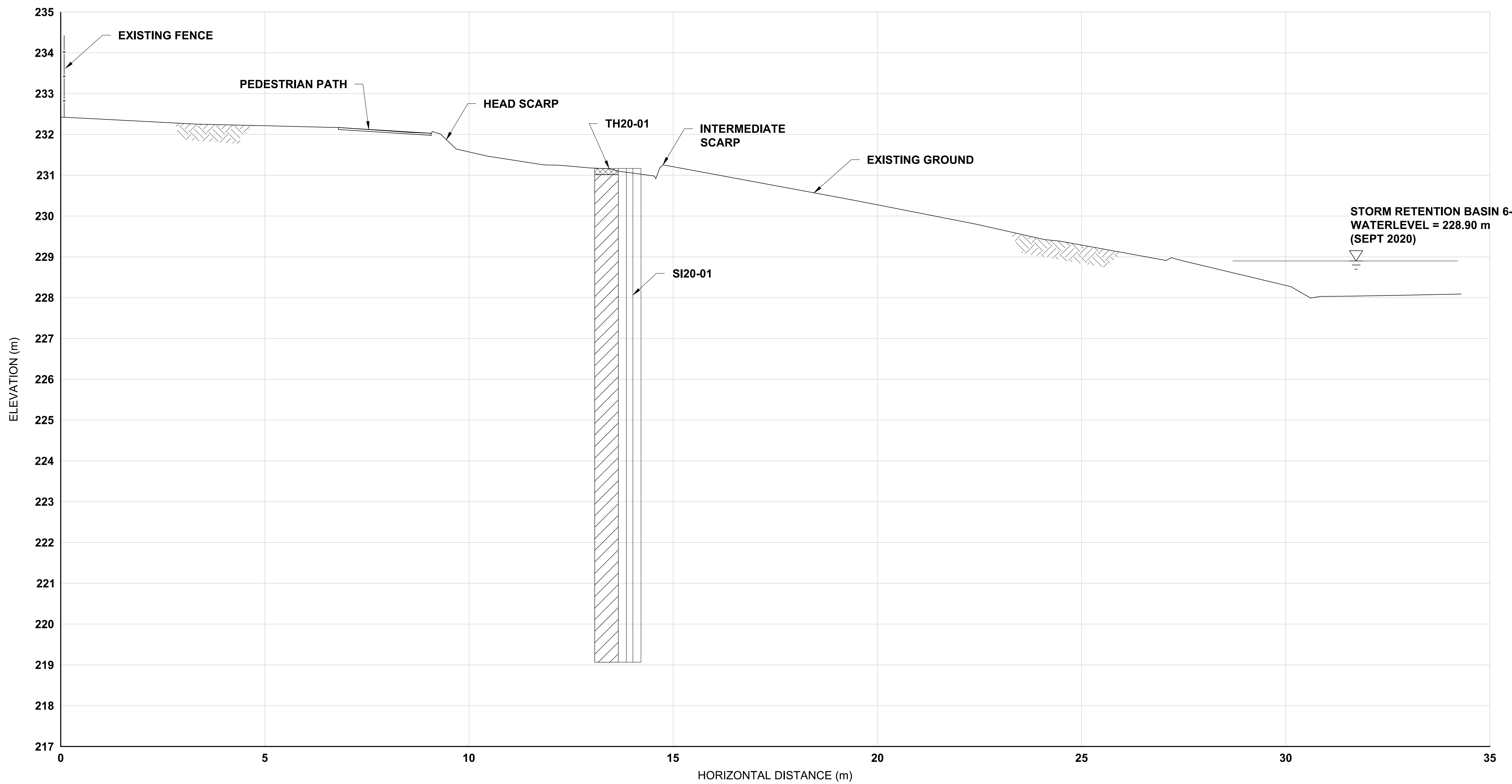
0 2.5 5 7.5 10 12.5 m
SCALE = 1 : 250 (279 mm x 432 mm)

LEGEND:
- TEST HOLE (TREK, 2020)
- TREE
- FENCE

NOTES:
1. AIR PHOTO TAKEN FROM GOOGLE EARTH (2020)
2. SURVEY COMPLETED BY WANLESS GEO-POINT SOLUTIONS INC. ON JULY 31, 2020
3. CONTOURS AT 0.25 m INTERVALS

Figure 01
Existing Site Conditions
Site Plan

Z:\Projects\0015 City of Winnipeg\0015 035 00 Slope Stabilization at SRB 6-7\3 Survey and Dwg\3.4 CAD\3.4.3 Working Folder\0115_035_00_SRB_A_CJH.dwg, 2020-12-21 12:38:06 PM
ANSI full bleed B (11.00 x 17.00 Inches)



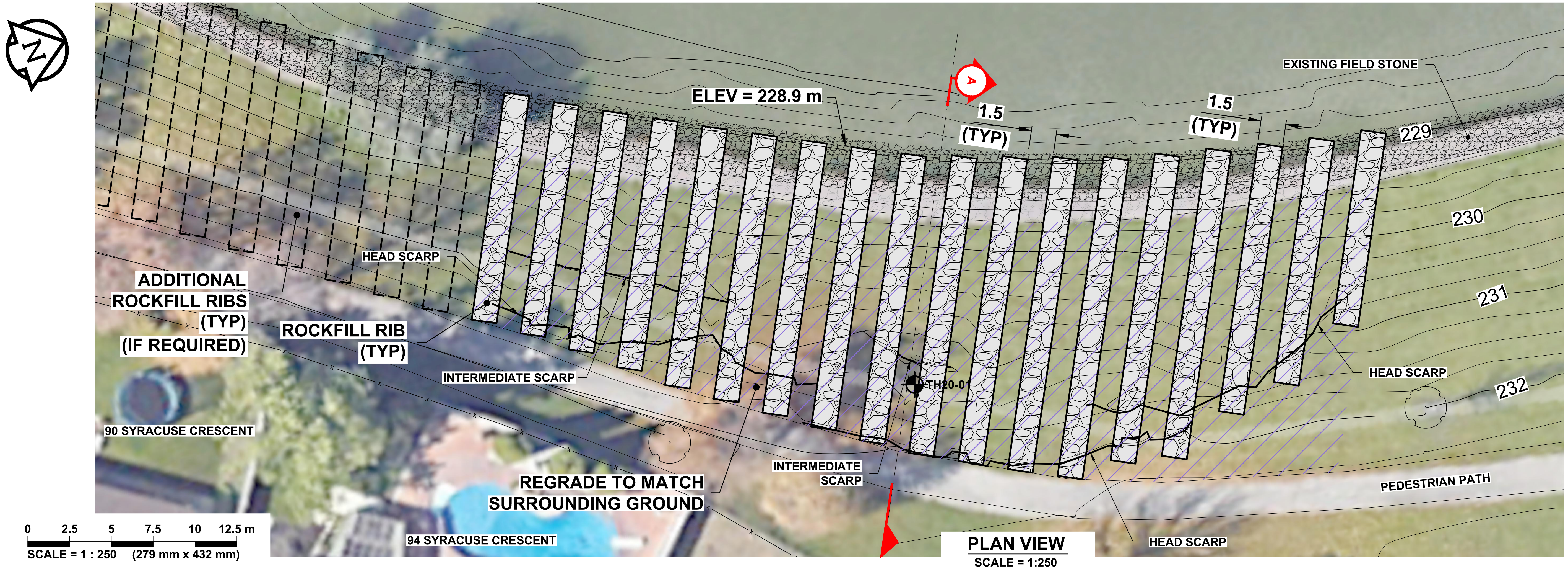
A 01 CROSS SECTION
SCALE = 1:100

0 1 2 3 4 5 m
SCALE = 1 : 100 (279 mm x 432 mm)

LEGEND:
- TEST HOLE (TREK, 2020)
- CLAY
- ORGANIC CLAY

NOTES:
1. AIR PHOTO TAKEN FROM GOOGLE EARTH (2020)
2. SURVEY COMPLETED BY WANLESS GEOPOINT SOLUTIONS INC. ON JULY 31, 2020

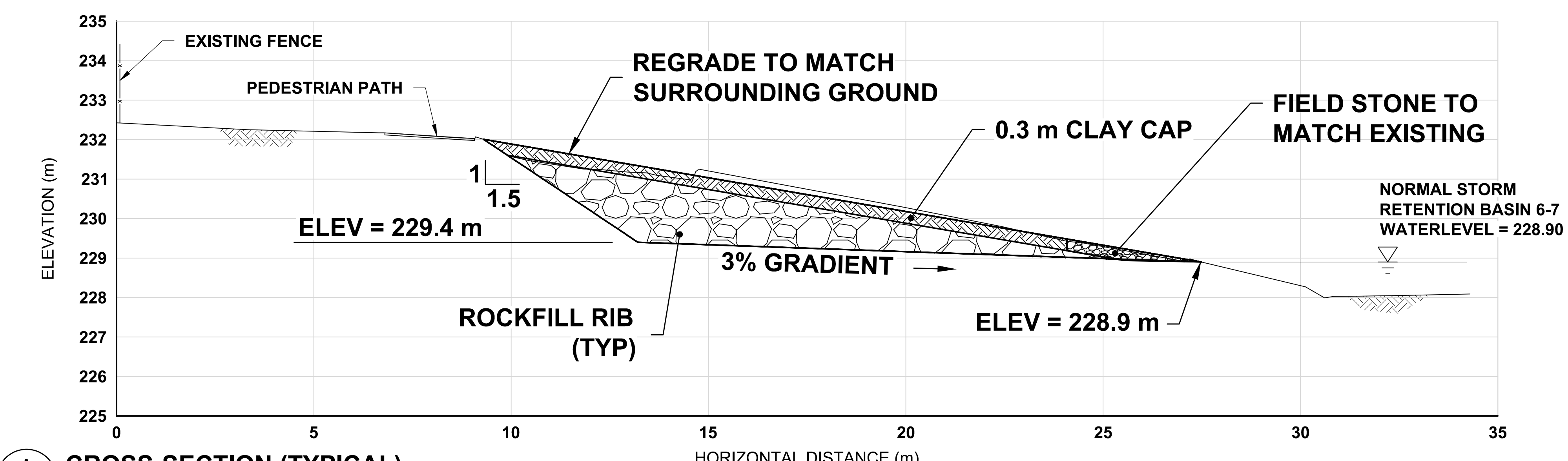
Figure 02
Existing Site Conditions
Cross Section A



PLAN VIEW
SCALE = 1:250

LEGEND:

- ROCKFILL RIB
- REGRADE TO MATCH SURROUNDING GROUND
- FIELD STONE
- FENCE



0 2 4 6 8 m
SCALE = 1 : 150 (279 mm x 432 mm)

A
-
CROSS-SECTION (TYPICAL)
SCALE = 1:150

NOTES:

1. AIR PHOTO TAKEN FROM GOOGLE EARTH (2020)
2. SURVEY COMPLETED BY WANLESS GEO-POINT SOLUTIONS INC. ON JULY 31, 2020
3. CONTOURS AT 0.25 m INTERVALS

Figure 03
Proposed Stabilization
Plan and Profile

ANSI full bleed B (11.00 x 17.00 Inches)
Z:\Projects\0015 City of Winnipeg\0015 035 00 Slope Stabilization at SRB 6-7\3 Survey and Dwg\3.4 CAD\3.4.3 Working Folder\0115_035_00_SRB_A_CJH.dwg, 2020-12-21 12:38:19 PM

Test Hole Logs

EXPLANATION OF FIELD AND LABORATORY TESTING

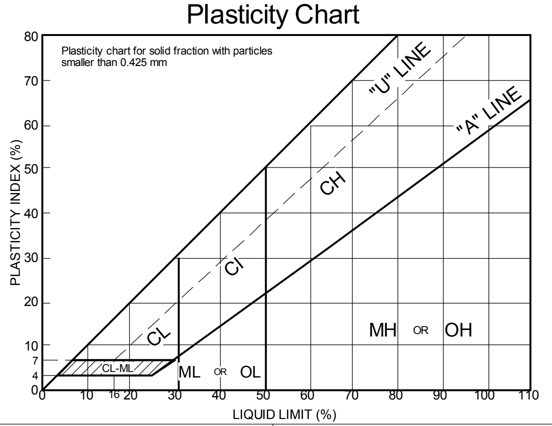
TREK GEOTECHNICAL

GENERAL NOTES

1. Classifications are based on the United Soil Classification System and include consistency, moisture, and color. Field descriptions have been modified to reflect results of laboratory tests where deemed appropriate.
2. Descriptions on these test hole logs apply only at the specific test hole locations and at the time the test holes were drilled. Variability of soil and groundwater conditions may exist between test hole locations.
3. When the following classification terms are used in this report or test hole logs, the primary and secondary soil fractions may be visually estimated.

Major Divisions			USCS Classi-fication	Symbols	Typical Names	Laboratory Classification Criteria		
Coarse-Grained soils (More than half the material is larger than No. 200 sieve size)	Gravels (More than half of coarse fraction is larger than 4.75 mm)	Clean gravel (Little or no fines)	GW		Well-graded gravels, gravel-sand mixtures, little or no fines	Determine percentages of sand and gravel from grain size curve, depending on percentage of fines (fraction smaller than No. 200 sieve) coarse-grained soils are classified as follows: Less than 5 percent....... GW, GP, SW, SP More than 12 percent....... GM, GC, SM, SC 6 to 12 percent...... Borderline case4s requiring dual symbols*	$C_U = \frac{D_{60}}{D_{10}}$ greater than 4; $C_C = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3	
			GP		Poorly-graded gravels, gravel-sand mixtures, little or no fines		Not meeting all gradation requirements for GW	
		Gravel with fines (Appreciable amount of fines)	GM		Silty gravels, gravel-sand-silt mixtures		Atterberg limits below "A" line or P.I. less than 4	Above "A" line with P.I. between 4 and 7 are border-line cases requiring use of dual symbols
			GC		Clayey gravels, gravel-sand-silt mixtures		Atterberg limits above "A" line or P.I. greater than 7	
	Sands (More than half of coarse fraction is smaller than 4.75 mm)	Clean sands (Little or no fines)	SW		Well-graded sands, gravelly sands, little or no fines		$C_U = \frac{D_{60}}{D_{10}}$ greater than 6; $C_C = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3	
			SP		Poorly-graded sands, gravelly sands, little or no fines		Not meeting all gradation requirements for SW	
		Sands with fines (Appreciable amount of fines)	SM		Silty sands, sand-silt mixtures		Atterberg limits below "A" line or P.I. less than 4	Above "A" line with P.I. between 4 and 7 are border-line cases requiring use of dual symbols
			SC		Clayey sands, sand-clay mixtures		Atterberg limits above "A" line or P.I. greater than 7	
Fine-Grained soils (More than half the material is smaller than No. 200 sieve size)	Silts and Clays (Liquid limit less than 50)		ML		Inorganic silts and very fine sands, rock floor, silty or clayey fine sands or clayey silts with slight plasticity	Plasticity Chart		
			CL		Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays			
			OL		Organic silts and organic silty clays of low plasticity			
	Silts and Clays (Liquid limit greater than 50)		MH		Inorganic silts, micaceous or distomaceous fine sandy or silty soils, organic silts			
			CH		Inorganic clays of high plasticity, fat clays			
			OH		Organic clays of medium to high plasticity, organic silts			
	Highly Organic Soils		Pt		Peat and other highly organic soils	Von Post Classification Limit	Strong colour or odour, and often fibrous texture	

Plasticity Chart



Material		Particle Size mm	Particle Size ASTM Sieve sizes
Sand	Coarse	2.00 to 4.75	#10 to #4
	Medium	0.425 to 2.00	#40 to #10
	Fine	0.075 to 0.425	#200 to #40
Silt or Clay		< 0.075	< #200

Material		Particle Size mm	Particle Size ASTM Sieve Sizes
Boulders		> 300	> 12 in.
Cobbles		75 to 300	3 in. to 12 in.
Gravel	Coarse	19 to 75	3/4 in. to 3 in.
	Fine	4.75 to 19	#4 to 3/4 in.

* Borderline classifications used for soils possessing characteristics of two groups are designated by combinations of groups symbols. For example; GW-GC, well-graded gravel-sand mixture with clay binder.

Other Symbol Types

	Asphalt		Bedrock (undifferentiated)		Cobbles
	Concrete		Limestone Bedrock		Boulders and Cobbles
	Fill		Cemented Shale		Silt Till
			Non-Cemented Shale		Clay Till

EXPLANATION OF FIELD AND LABORATORY TESTING

LEGEND OF ABBREVIATIONS AND SYMBOLS

LL - Liquid Limit (%)
PL - Plastic Limit (%)
PI - Plasticity Index (%)
MC - Moisture Content (%)
SPT - Standard Penetration Test
RQD - Rock Quality Designation
Qu - Unconfined Compression
Su - Undrained Shear Strength
VW - Vibrating Wire Piezometer
SI - Slope Inclinometer

▽ Water Level at Time of Drilling

▼ Water Level at End of Drilling

▼ Water Level After Drilling as Indicated on Test Hole Logs

FRACTION OF SECONDARY SOIL CONSTITUENTS ARE BASED ON THE FOLLOWING TERMINOLOGY

TERM	EXAMPLES	PERCENTAGE
and	and CLAY	35 to 50 percent
"y" or "ey"	clayey, silty	20 to 35 percent
some	some silt	10 to 20 percent
trace	trace gravel	1 to 10 percent

TERMS DESCRIBING CONSISTENCY OR COMPACTION CONDITION

The Standard Penetration Test blow count (N) of a non-cohesive soil can be related to compactness condition as follows:

Descriptive Terms	SPT (N) (Blows/300 mm)
Very loose	< 4
Loose	4 to 10
Compact	10 to 30
Dense	30 to 50
Very dense	> 50

The Standard Penetration Test blow count (N) of a cohesive soil can be related to its consistency as follows:

Descriptive Terms	SPT (N) (Blows/300 mm)
Very soft	< 2
Soft	2 to 4
Firm	4 to 8
Stiff	8 to 15
Very stiff	15 to 30
Hard	> 30

The undrained shear strength (Su) of a cohesive soil can be related to its consistency as follows:

Descriptive Terms	Undrained Shear Strength (kPa)
Very soft	< 12
Soft	12 to 25
Firm	25 to 50
Stiff	50 to 100
Very stiff	100 to 200
Hard	> 200

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Sub-Surface Log

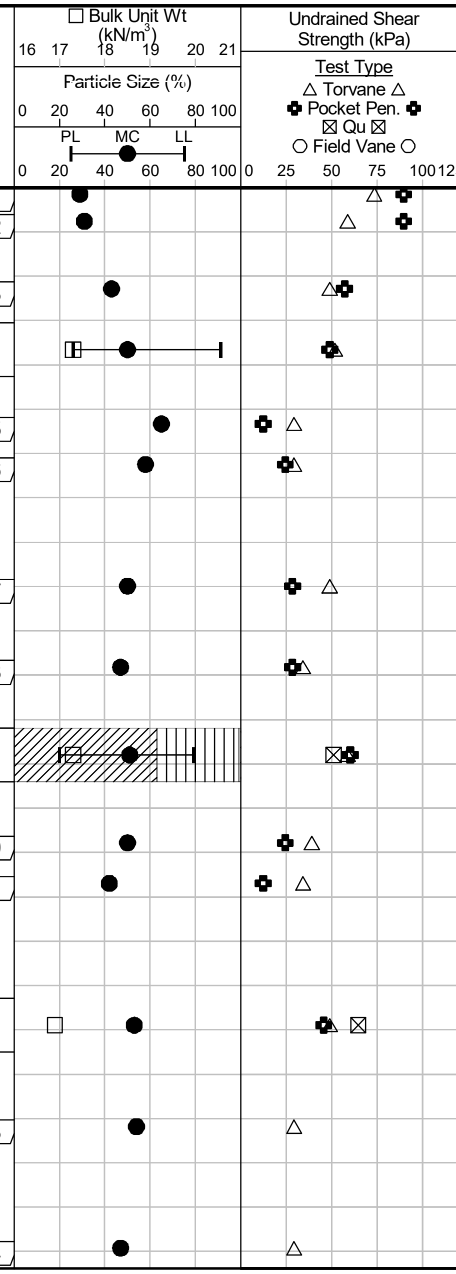
Client: City of Winnipeg
Project Number: 0015-035-00
Project Name: Slope Stabilization at SRB 6-7
Location: UTM N-5519133.943, E-631966.084
Contractor: Maple Leaf Drilling Ltd.
Ground Elevation: 231.17 m
Method: 125 mm Solid Stem Auger, Acker MP5-T Track Mount
Date Drilled: 31 July 2020

Sample Type: Grab (G) | Shelby Tube (T) | Split Spoon (SS) | Split Barrel (SB) | Core (C)

Particle Size Legend: Fines | Clay | Silt | Sand | Gravel | Cobbles | Boulders

Backfill Legend: Bentonite | Cement | Drill Cuttings | Filter Pack Sand | Grout | Slough

Elevation (m)	Depth (m)	MATERIAL DESCRIPTION	Sample Type	Sample Number
230.9		ORGANIC CLAY - silty, trace silt inclusions (diam. < 20 mm), trace gravel (diam. < 10 mm), blackish grey, moist, stiff, high plasticity	Grab	G01, G02
		CLAY - silty, trace silt inclusions (diam. < 15 mm), trace gravel (diam. < 5 mm) - brownish grey - moist, stiff - high plasticity - weathered and blocky to 3.4 m	Grab	G03
	2	- light brown, firm below 1.2 m.	Shelby Tube	T04
		- soft below 2.6 m.	Grab	G05
	3		Grab	G06
		- firm below 3.4 m.		
	4	- trace sulphate precipitates (diam. < 10 mm) at 4.3 m.	Grab	G07
	5		Grab	G08
	6		Shelby Tube	T09
	7	- trace sulphate precipitates (diam. < 20 mm) at 6.9 m.	Grab	G10
	8	- grey below 7.8 m.	Grab	G11
		- trace silt inclusions (diam. < 30 mm) below 8.2 m.		
	9	- trace gravel (diam. < 30 mm) at 8.8 m.	Shelby Tube	T12
	10			
	11		Grab	G13
219.0	12		Grab	G14



END OF TEST HOLE AT 12.2 m IN CLAY.
Notes:
1) No seepage observed.
2) Sloughing observed below 2.6 m.
3) Test hole open to 2.6 m below ground surface immediately after drilling.
4) SI20-01 installed in the test hole to 12.2 m depth below ground surface.
5) Test hole location provided by Wanless Geo-Point Solutions Inc.

Logged By: Jashandeep Singh Bhullar **Reviewed By:** Ken Skaftfeld **Project Engineer:** Ryan Belbas

Looking northeast at the instability from toe of bank

Looking northeast at the instability from top of bank

Looking southwest at the instability from top of bank after completion of drilling

Appendix B

Laboratory Testing Results

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Moisture Content Report
ASTM D2216-10

Project No. 0015-035-00
Client City of Winnipeg
Project Slope Stabilization at SRB 6-7

Sample Date 31-Jul-20
Test Date 04-Aug-20
Technician BMH

Test Hole	TH20-01	TH20-01	TH20-01	TH20-01	TH20-01	TH20-01
Depth (m)	0.0 - 0.2	0.3 - 0.5	1.1 - 1.2	2.6 - 2.7	3.0 - 3.2	4.4 - 4.6
Sample #	G01	G02	G03	G05	G06	G07
Tare ID	K1	Z16	N62	AB18	E93	Z135
Mass of tare	8.4	8.8	8.5	6.7	8.5	8.4
Mass wet + tare	252.7	231.0	169.8	149.8	132.3	213.2
Mass dry + tare	197.7	178.1	121.7	93.6	86.7	145.1
Mass water	55.0	52.9	48.1	56.2	45.6	68.1
Mass dry soil	189.3	169.3	113.2	86.9	78.2	136.7
Moisture %	29.1%	31.2%	42.5%	64.7%	58.3%	49.8%

Test Hole	TH20-01	TH20-01	TH20-01	TH20-01	TH20-01	
Depth (m)	5.3 - 5.5	7.3 - 7.5	7.8 - 7.9	10.5 - 10.7	11.9 - 12.0	
Sample #	G08	G10	G11	G13	G14	
Tare ID	P15	W35	AC29	H90	H36	
Mass of tare	8.5	8.5	6.7	8.5	8.5	
Mass wet + tare	204.5	144.3	167.4	158.2	148.8	
Mass dry + tare	141.5	99.3	120.2	106.0	103.6	
Mass water	63.0	45.0	47.2	52.2	45.2	
Mass dry soil	133.0	90.8	113.5	97.5	95.1	
Moisture %	47.4%	49.6%	41.6%	53.5%	47.5%	

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Atterberg Limits
ASTM D4318-10e1

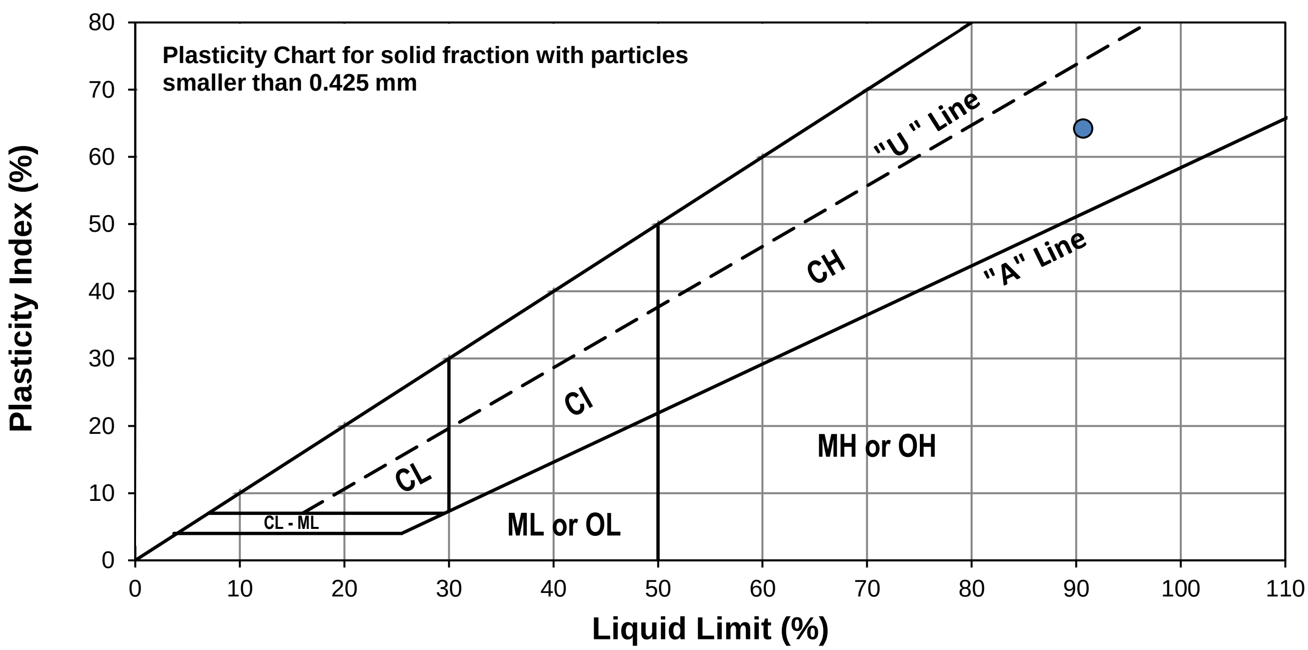
CERTIFIED BY CCIL Canadian Council of Independent Laboratories
For specific tests as listed on www.ccil.com

Project No.	0015-035-00
Client	City of Winnipeg
Project	Slope Stabilization at SRB 6-7
Test Hole	TH20-01
Sample #	T04
Depth (m)	1.5 - 2.1
Sample Date	31-Jul-20
Test Date	06-Aug-20
Technician	BMH

Liquid Limit	91
Plastic Limit	26
Plasticity Index	64

Liquid Limit

Trial #	**1**	**2**	**3**		
Number of Blows (N)	17	26	32		
Mass Wet Soil + Tare (g)	24.069	22.274	22.908		
Mass Dry Soil + Tare (g)	19.312	18.441	18.800		
Mass Tare (g)	14.195	14.195	14.200		
Mass Water (g)	4.757	3.833	4.108		
Mass Dry Soil (g)	5.117	4.246	4.600		
Moisture Content (%)	92.965	90.273	89.304		



Plastic Limit

Trial #	**1**	**2**	**3**	**4**	**5**
Mass Tare (g)	14.202	14.125			
Mass Wet Soil + Tare (g)	20.641	20.000			
Mass Dry Soil + Tare (g)	19.295	18.771			
Mass Water (g)	1.346	1.229			
Mass Dry Soil (g)	5.093	4.646			
Moisture Content (%)	26.428	26.453			

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Atterberg Limits
ASTM D4318-10e1

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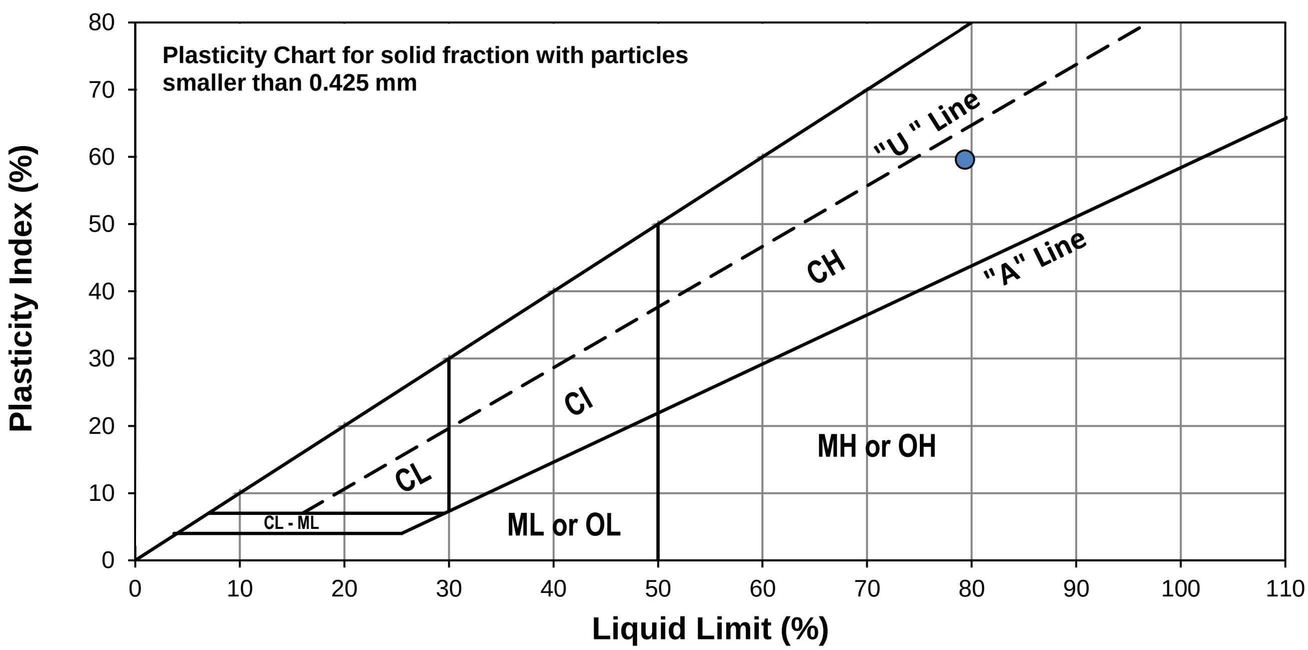
For specific tests as listed on www.ccil.com

Project No.	0015-035-00
Client	City of Winnipeg
Project	Slope Stabilization at SRB 6-7
Test Hole	TH20-01
Sample #	T09
Depth (m)	6.1 - 6.7
Sample Date	31-Jul-20
Test Date	06-Aug-20
Technician	AB

Liquid Limit	79
Plastic Limit	20
Plasticity Index	60

Liquid Limit

Trial #	**1**	**2**	**3**		
Number of Blows (N)	16	26	34		
Mass Wet Soil + Tare (g)	20.427	20.099	21.177		
Mass Dry Soil + Tare (g)	17.697	17.452	18.181		
Mass Tare (g)	14.399	14.117	14.277		
Mass Water (g)	2.730	2.647	2.996		
Mass Dry Soil (g)	3.298	3.335	3.904		
Moisture Content (%)	82.777	79.370	76.742		



Plastic Limit

Trial #	**1**	**2**	**3**	**4**	**5**
Mass Tare (g)	14.078	14.097			
Mass Wet Soil + Tare (g)	20.231	20.386			
Mass Dry Soil + Tare (g)	19.219	19.342			
Mass Water (g)	1.012	1.044			
Mass Dry Soil (g)	5.141	5.245			
Moisture Content (%)	19.685	19.905			

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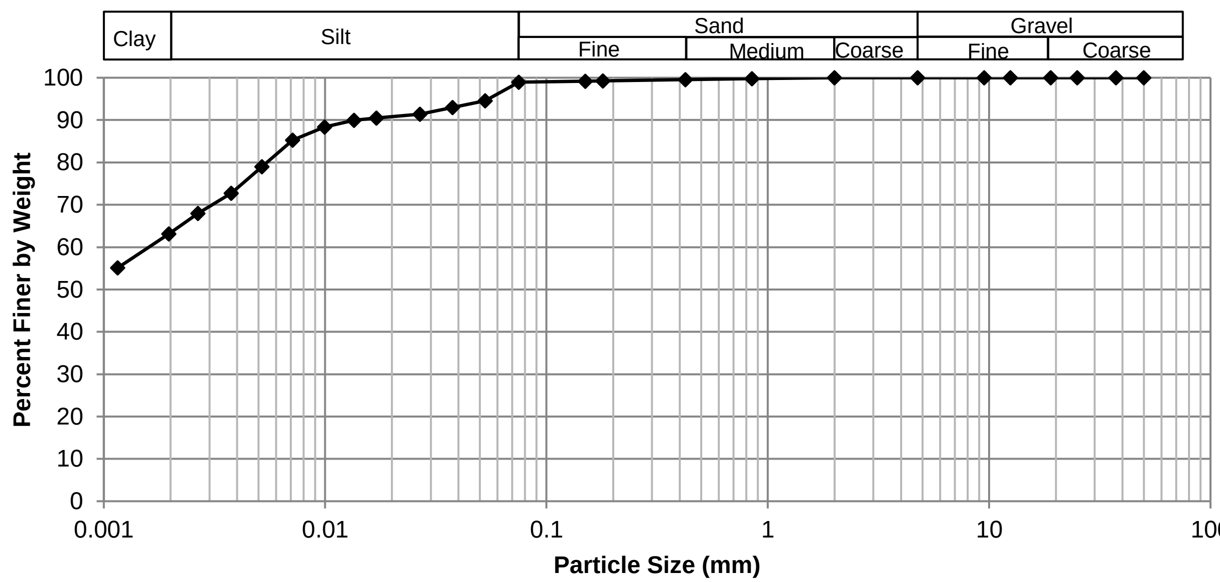
Grain Size Analysis (Hydrometer Method)
AASHTO T 88

Project No.	0015-035-00
Client	City of Winnipeg
Project	Slope Stabilization at SRB 6-7
Test Hole	TH20-01
Sample #	T09
Depth (m)	6.1 - 6.7
Sample Date	31-Jul-20
Test Date	6-Aug-20
Technician	NS

Gravel	0.0%
Sand	1.0%
Silt	35.6%
Clay	63.4%

Particle Size Distribution Curve



Gravel		Sand		Silt and Clay	
Particle Size (mm)	**Percent Passing**	**Particle Size (mm)**	**Percent Passing**	**Particle Size (mm)**	**Percent Passing**
50.0	100.00	4.75	100.00	0.0750	98.97
37.5	100.00	2.00	100.00	0.0529	94.55
25.0	100.00	0.850	99.78	0.0377	92.98
19.0	100.00	0.425	99.58	0.0269	91.42
12.5	100.00	0.180	99.27	0.0171	90.48
9.50	100.00	0.150	99.18	0.0135	89.93
4.75	100.00	0.075	98.97	0.0099	88.37
				0.0071	85.24
				0.0052	78.99
				0.0038	72.73
				0.0027	67.97
				0.0020	63.13
				0.0012	55.12

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Shelby Tube Visual

Project No.	0015-035-00
Client	City of Winnipeg
Project	Slope Stabilization at SRB 6-7
Test Hole	TH20-01
Sample #	T04
Depth (m)	1.5 - 2.1
Sample Date	31-Jul-20
Test Date	04-Aug-20
Technician	BMH

Tube Extraction

Recovery (mm) 670 (overpush)

Bottom - 2.2 m — 2.15 m — 2.10 m — 1.97 m — **Top - 1.5 m**

Toss	PP TV Moisture Content Visual Atterberg Limits	Bulk	Toss (Slough Material)
30 mm	40 mm	130 mm	470 mm

Visual Classification

Material	Clay
Composition	silty
trace silt inclusions (<10 mm diam.)	
Color	mottled brown and grey
Moisture	moist
Consistency	stiff
Plasticity	high plasticity
Structure	blocky
Gradation	

Torvane

Reading	0.53
Vane Size (s,m,l)	m
Undrained Shear Strength (kPa)	52.0

Pocket Penetrometer

Reading	**1**	1.00
	2	1.10
	3	1.00
	Average	1.03
Undrained Shear Strength (kPa)		50.7

Moisture Content

Tare ID	F17
Mass tare (g)	8.7
Mass wet + tare (g)	446.9
Mass dry + tare (g)	301.2
Moisture %	49.8%

Unit Weight

Bulk Weight (g)		730.8
Length (mm)	**1**	108.80
	2	108.32
	3	108.53
	4	108.23
Average Length (m)		0.108
Diam. (mm)	**1**	70.21
	2	69.25
	3	69.93
	4	69.47
Average Diameter (m)		0.070
Volume (m^3)		4.14E-04
Bulk Unit Weight (kN/m^3)		17.3
Bulk Unit Weight (pcf)		110.2
Dry Unit Weight (kN/m^3)		11.6
Dry Unit Weight (pcf)		73.6

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Shelby Tube Visual

Project No.	0015-035-00
Client	City of Winnipeg
Project	Slope Stabilization at SRB 6-7

Test Hole	TH20-01
Sample #	T09
Depth (m)	6.1 - 6.7
Sample Date	31-Jul-20
Test Date	04-Aug-20
Technician	BMH

Tube Extraction

Recovery (mm) 680 (overpush)

Bottom - 6.8 m	6.74 m	6.57 m	6.42 m	6.27 m **Top - 6.1 m**
Toss	Bulk Qu	Visual PP TV Moisture Content Atterberg Limits	Keep	Toss
40 mm	170 mm	150 mm	150 mm	170mm

Visual Classification

Material	Clay
Composition	silty
trace silt inclusions (<10 mm diam.)	
Color	brown and grey
Moisture	moist
Consistency	stiff
Plasticity	high plasticity
Structure	
Gradation	

Torvane

Reading	0.60
Vane Size (s,m,l)	m
Undrained Shear Strength (kPa)	58.8

Pocket Penetrometer

Reading	**1**	1.20
	2	1.30
	3	1.20
	Average	1.23
Undrained Shear Strength (kPa)		60.5

Moisture Content

Tare ID	Z01
Mass tare (g)	8.5
Mass wet + tare (g)	411.2
Mass dry + tare (g)	275
Moisture %	51.1%

Unit Weight

Bulk Weight (g)		1113.1
Length (mm)	**1**	153.05
	2	153.02
	3	153.61
	4	152.67
Average Length (m)		0.153
Diam. (mm)	**1**	72.73
	2	72.93
	3	72.14
	4	71.72
Average Diameter (m)		0.072
Volume (m^3)		6.30E-04
Bulk Unit Weight (kN/m^3)		17.3
Bulk Unit Weight (pcf)		110.3
Dry Unit Weight (kN/m^3)		11.5
Dry Unit Weight (pcf)		73.0

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Unconfined Compressive Strength
ASTM D2166

Project No.	0015-035-00
Client	City of Winnipeg
Project	Slope Stabilization at SRB 6-7

Test Hole	TH20-01
Sample #	T09
Depth (m)	6.1 - 6.7
Sample Date	31-Jul-20
Test Date	4-Aug-20
Technician	BMH

Unconfined Strength

	kPa	ksf
Max q_u	102.4	2.1
Max S_u	51.2	1.1

Specimen Data

Description Clay - silty, trace silt inclusions (<10 mm diam.), brown and grey, moist, stiff, high plasticity,

Length	153.1	(mm)	**Moisture %**	51%	
Diameter	72.4	(mm)	**Bulk Unit Wt.**	17.3	(kN/m^3)
L/D Ratio	2.1		**Dry Unit Wt.**	11.5	(kN/m^3)
Initial Area	0.00411	(m^2)	**Liquid Limit**	79	
Load Rate	1.00	(%/min)	**Plastic Limit**	20	
			Plasticity Index	59	

Undrained Shear Strength Tests

Torvane

Reading	Undrained Shear Strength	
tsf	**kPa**	**ksf**
0.60	58.8	1.23
Vane Size		
m		

Pocket Penetrometer

	Reading	Undrained Shear Strength	
	tsf	**kPa**	**ksf**
	1.20	58.9	1.23
	1.30	63.8	1.33
	1.20	58.9	1.23
Average	**1.23**	**60.5**	**1.26**

Failure Geometry

Sketch:

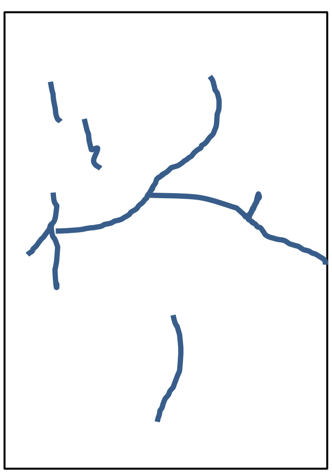

Photo:

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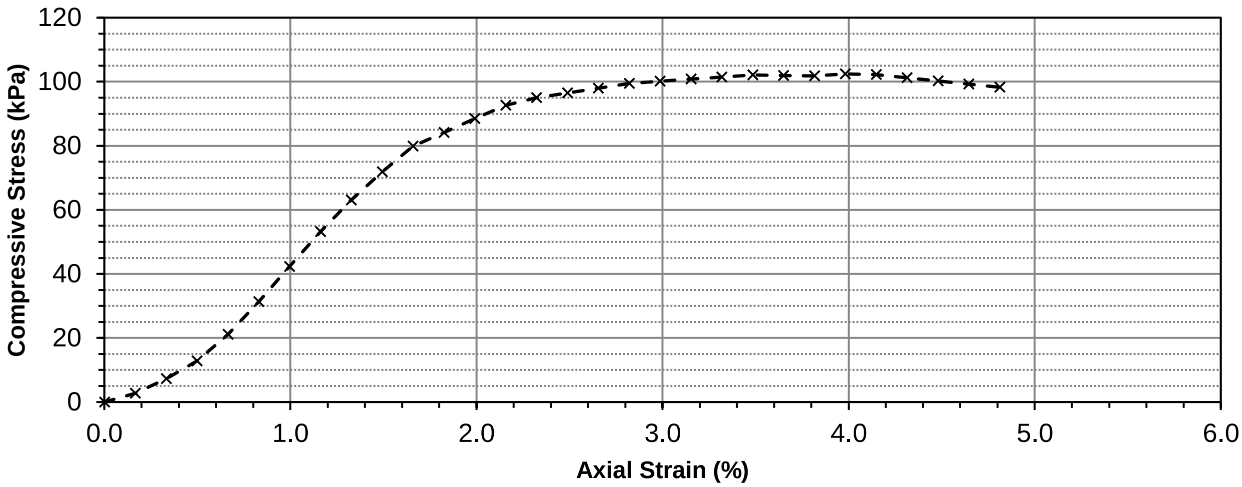
Unconfined Compressive Strength
ASTM D2166

Project No. 0015-035-00
Client City of Winnipeg
Project Slope Stabilization at SRB 6-7

Unconfined Compression Test Graph



Unconfined Compression Test Data

Deformation Dial Reading	Load Ring Dial Reading	Deflection (mm)	Axial Strain (%)	Corrected Area (m^2)	Axial Load (N)	Compressive Stress, q_u (kPa)	Shear Stress, S_u (kPa)
0	0	0.0000	0.00	0.004115	0.0	0.00	0.00
10	3	0.2540	0.17	0.004121	11.1	2.69	1.34
20	8	0.5080	0.33	0.004128	30.2	7.32	3.66
30	14	0.7620	0.50	0.004135	53.2	12.86	6.43
40	23	1.0160	0.66	0.004142	87.6	21.16	10.58
50	34	1.2700	0.83	0.004149	129.8	31.27	15.64
60	46	1.5240	1.00	0.004156	175.7	42.27	21.14
70	58	1.7780	1.16	0.004163	221.2	53.14	26.57
80	69	2.0320	1.33	0.004170	262.7	63.01	31.50
90	79	2.2860	1.49	0.004177	300.4	71.91	35.95
100	88	2.5400	1.66	0.004184	334.0	79.83	39.92
110	93	2.7940	1.83	0.004191	352.7	84.16	42.08
120	98	3.0480	1.99	0.004198	371.4	88.47	44.24
130	103	3.3020	2.16	0.004205	389.5	92.62	46.31
140	106	3.5560	2.32	0.004212	400.1	94.98	47.49
150	108	3.8100	2.49	0.004220	407.2	96.49	48.25
160	110	4.0640	2.65	0.004227	414.2	98.00	49.00
170	112	4.3180	2.82	0.004234	421.3	99.50	49.75
180	113	4.5720	2.99	0.004241	424.8	100.16	50.08
190	114	4.8260	3.15	0.004249	428.3	100.82	50.41
200	115	5.0800	3.32	0.004256	431.9	101.48	50.74
210	116	5.3340	3.48	0.004263	435.4	102.13	51.07
220	116	5.5880	3.65	0.004270	435.4	101.96	50.98
230	116	5.8420	3.82	0.004278	435.4	101.78	50.89

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Unconfined Compressive Strength
ASTM D2166

Project No. 0015-035-00
Client City of Winnipeg
Project Slope Stabilization at SRB 6-7

Unconfined Compression Test Data (cont'd)

Deformation Dial Reading	Load Ring Dial Reading	Deflection (mm)	Axial Strain (%)	Corrected Area (m^2)	Axial Load (N)	Compressive Stress, q_u (kPa)	Shear Stress, S_u (kPa)
240	117	6.0960	3.98	0.004285	438.9	102.43	51.22
250	117	6.3500	4.15	0.004293	438.9	102.25	51.13
260	116	6.6040	4.31	0.004300	435.4	101.26	50.63
270	115	6.8580	4.48	0.004308	431.9	100.26	50.13
280	114	7.1120	4.65	0.004315	428.3	99.27	49.63
290	113	7.3660	4.81	0.004323	424.8	98.28	49.14

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Shelby Tube Visual

Project No.	0015-035-00
Client	City of Winnipeg
Project	Slope Stabilization at SRB 6-7

Test Hole	TH20-01
Sample #	T12
Depth (m)	9.1 - 9.8
Sample Date	31-Jul-20
Test Date	04-Aug-20
Technician	BMH

Tube Extraction

Recovery (mm) 720 (overpush)

Bottom - 9.9 m	9.75 m	9.7 m	9.54 m	9.37 m	Top - 9.1 m
Toss	Visual PP TV Moisture Content	Bulk Qu	Keep	Toss	
60 mm	50 mm	160 mm	180 mm	270mm	

Visual Classification

Material	Clay
Composition	silty
trace silt inclusions (<20 mm diam.)	
Color	dark grey
Moisture	moist
Consistency	firm to stiff
Plasticity	high plasticity
Structure	-
Gradation	

Torvane

Reading	0.50
Vane Size (s,m,l)	m
Undrained Shear Strength (kPa)	49.0

Pocket Penetrometer

Reading	**1**	0.90
	2	1.00
	3	0.90
	Average	0.93
Undrained Shear Strength (kPa)		45.8

Moisture Content

Tare ID	AB19
Mass tare (g)	6.7
Mass wet + tare (g)	242
Mass dry + tare (g)	160.6
Moisture %	52.9%

Unit Weight

Bulk Weight (g)		1067.7
Length (mm)	**1**	152.57
	2	152.53
	3	152.53
	4	153.34
Average Length (m)		0.153
Diam. (mm)	**1**	72.39
	2	71.25
	3	71.69
	4	72.16
Average Diameter (m)		0.072
Volume (m^3)		6.20E-04
Bulk Unit Weight (kN/m^3)		16.9
Bulk Unit Weight (pcf)		107.6
Dry Unit Weight (kN/m^3)		11.1
Dry Unit Weight (pcf)		70.4

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Unconfined Compressive Strength
ASTM D2166

Project No.	0015-035-00
Client	City of Winnipeg
Project	Slope Stabilization at SRB 6-7

Test Hole	TH20-01
Sample #	T12
Depth (m)	9.1 - 9.8
Sample Date	31-Jul-20
Test Date	4-Aug-20
Technician	BMH

Unconfined Strength

	kPa	ksf
Max q_u	129.5	2.7
Max S_u	64.7	1.4

Specimen Data

Description Clay - silty, trace silt inclusions (<20 mm diam.), dark grey, moist, firm to stiff, high plasticity

Length	152.7	(mm)	**Moisture %**	53%	
Diameter	71.9	(mm)	**Bulk Unit Wt.**	16.9	(kN/m^3)
L/D Ratio	2.1		**Dry Unit Wt.**	11.1	(kN/m^3)
Initial Area	0.00406	(m^2)	**Liquid Limit**	-	
Load Rate	1.00	(%/min)	**Plastic Limit**	-	
			Plasticity Index	-	

Undrained Shear Strength Tests

Torvane

Reading	**Undrained Shear Strength**	
tsf	**kPa**	**ksf**
0.50	49.0	1.02
Vane Size		
m		

Pocket Penetrometer

	Reading	**Undrained Shear Strength**	
	tsf	**kPa**	**ksf**
	0.90	44.1	0.92
	1.00	49.1	1.02
	0.90	44.1	0.92
Average	**0.93**	**45.8**	**0.96**

Failure Geometry

Sketch:

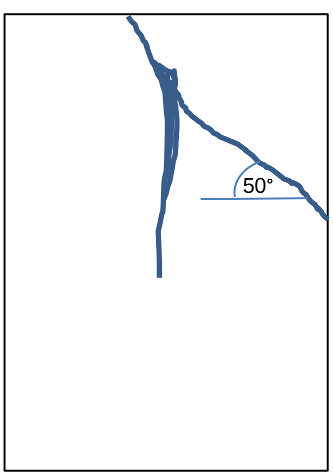

Photo:

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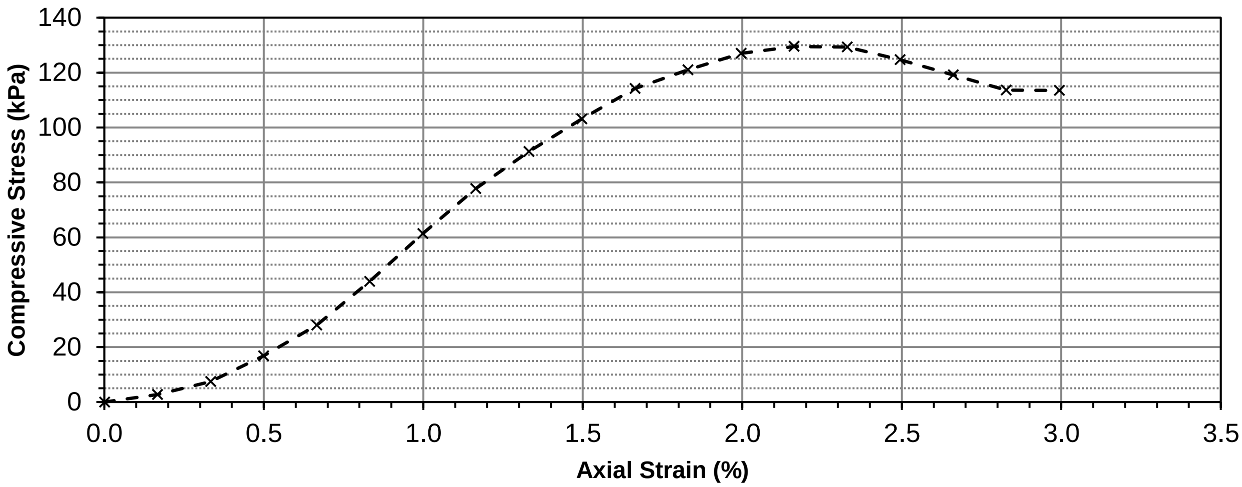
Unconfined Compressive Strength
ASTM D2166

Project No. 0015-035-00
Client City of Winnipeg
Project Slope Stabilization at SRB 6-7

Unconfined Compression Test Graph



Unconfined Compression Test Data

Deformation Dial Reading	Load Ring Dial Reading	Deflection (mm)	Axial Strain (%)	Corrected Area (m^2)	Axial Load (N)	Compressive Stress, q_u (kPa)	Shear Stress, S_u (kPa)
0	0	0.0000	0.00	0.004057	0.0	0.00	0.00
10	3	0.2540	0.17	0.004064	11.1	2.73	1.36
20	8	0.5080	0.33	0.004071	30.2	7.42	3.71
30	18	0.7620	0.50	0.004077	68.5	16.80	8.40
40	30	1.0160	0.67	0.004084	114.4	28.02	14.01
50	47	1.2700	0.83	0.004091	179.5	43.88	21.94
60	66	1.5240	1.00	0.004098	251.4	61.35	30.68
70	84	1.7780	1.16	0.004105	319.1	77.73	38.86
80	99	2.0320	1.33	0.004112	375.2	91.24	45.62
90	113	2.2860	1.50	0.004119	424.8	103.14	51.57
100	126	2.5400	1.66	0.004126	470.9	114.13	57.07
110	134	2.7940	1.83	0.004133	500.2	121.04	60.52
120	141	3.0480	2.00	0.004140	525.9	127.04	63.52
130	144	3.3020	2.16	0.004147	536.9	129.47	64.74
140	144	3.5560	2.33	0.004154	536.9	129.25	64.63
150	139	3.8100	2.49	0.004161	518.6	124.63	62.31
160	133	4.0640	2.66	0.004168	496.5	119.13	59.57
170	127	4.3180	2.83	0.004175	474.5	113.66	56.83
180	127	4.5720	2.99	0.004182	474.5	113.46	56.73

Appendix A

Site Photos

Looking northeast at the instability from toe of bank

Looking northeast at the instability from top of bank

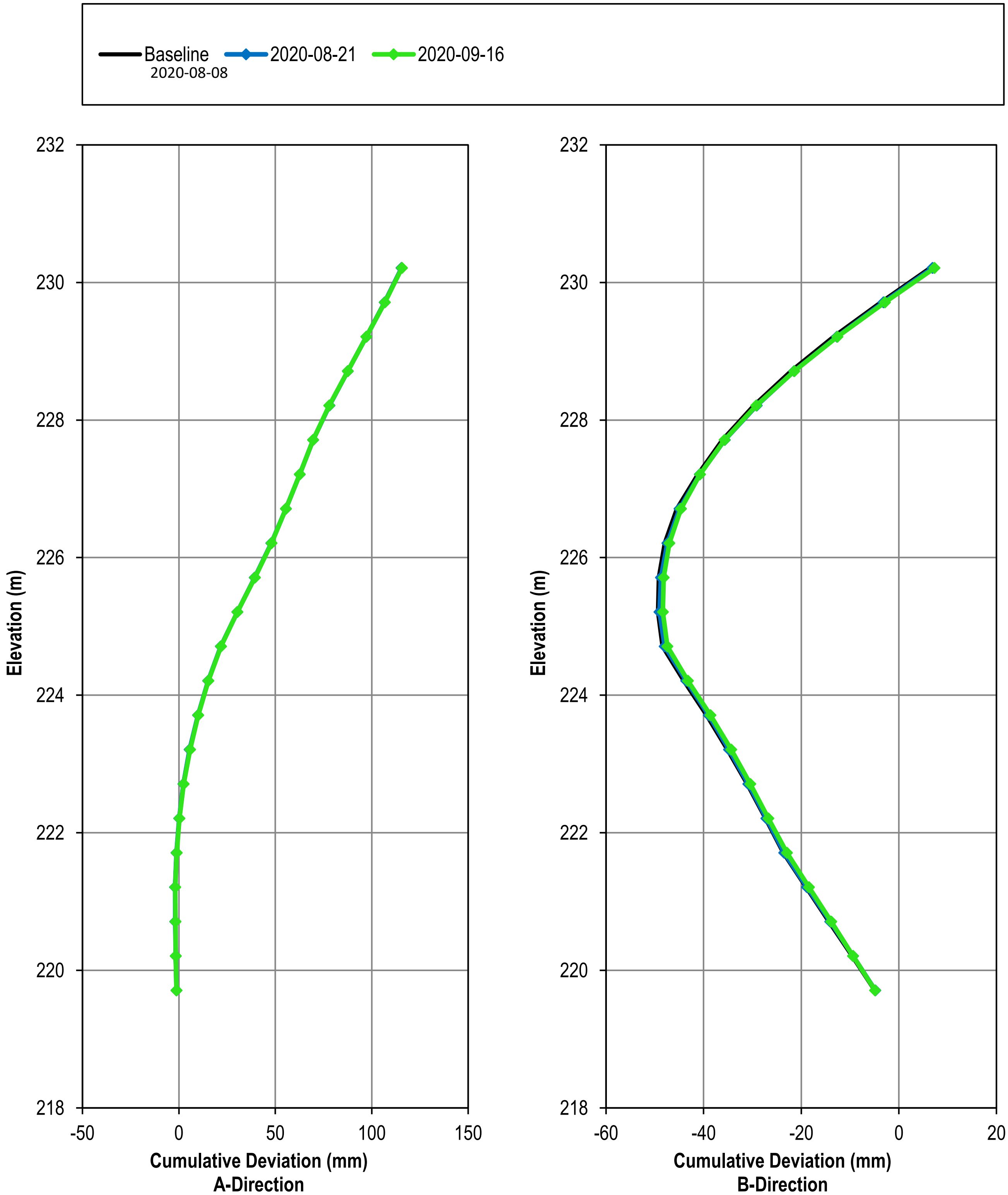
Looking southwest at the instability from top of bank after completion of drilling

Appendix C

Slope Inclinometer Monitoring Results

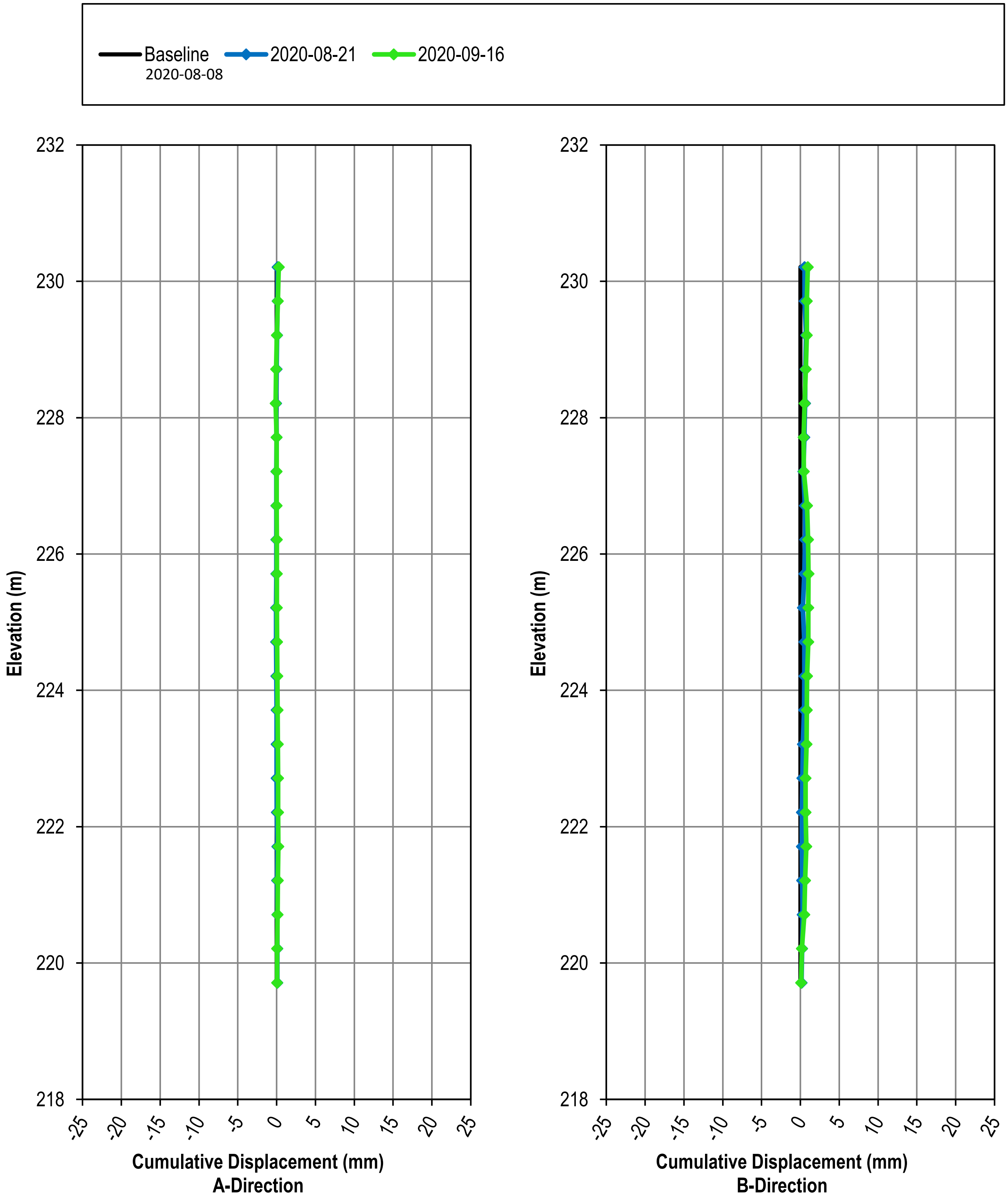
SLOPE INCLINOMETER DATA PLOTS

SI20-01



SLOPE INCLINOMETER DATA PLOTS

SI20-01



SLOPE INCLINOMETER DATA PLOTS

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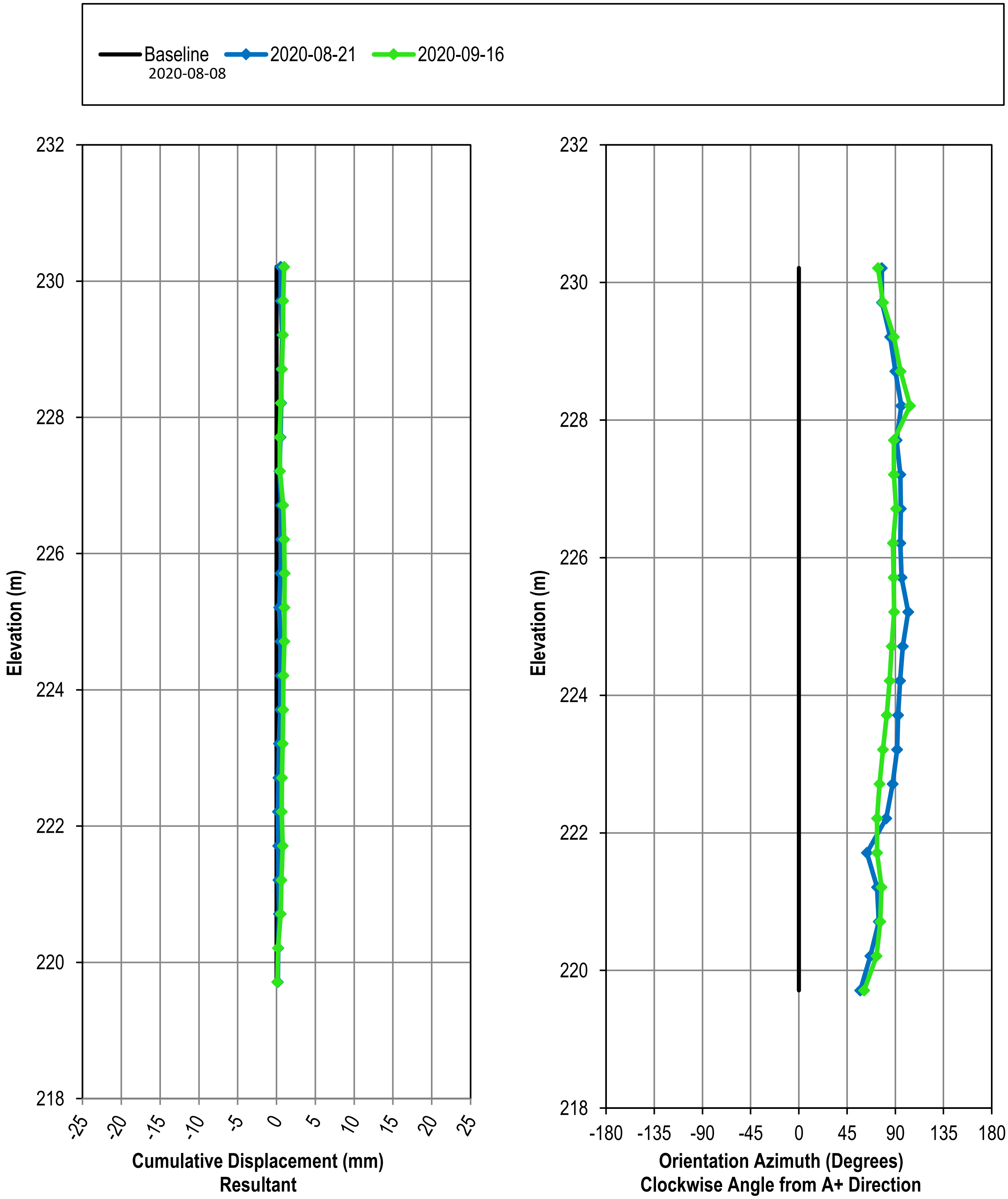

SLOPE INCLINOMETER DATA PLOTS

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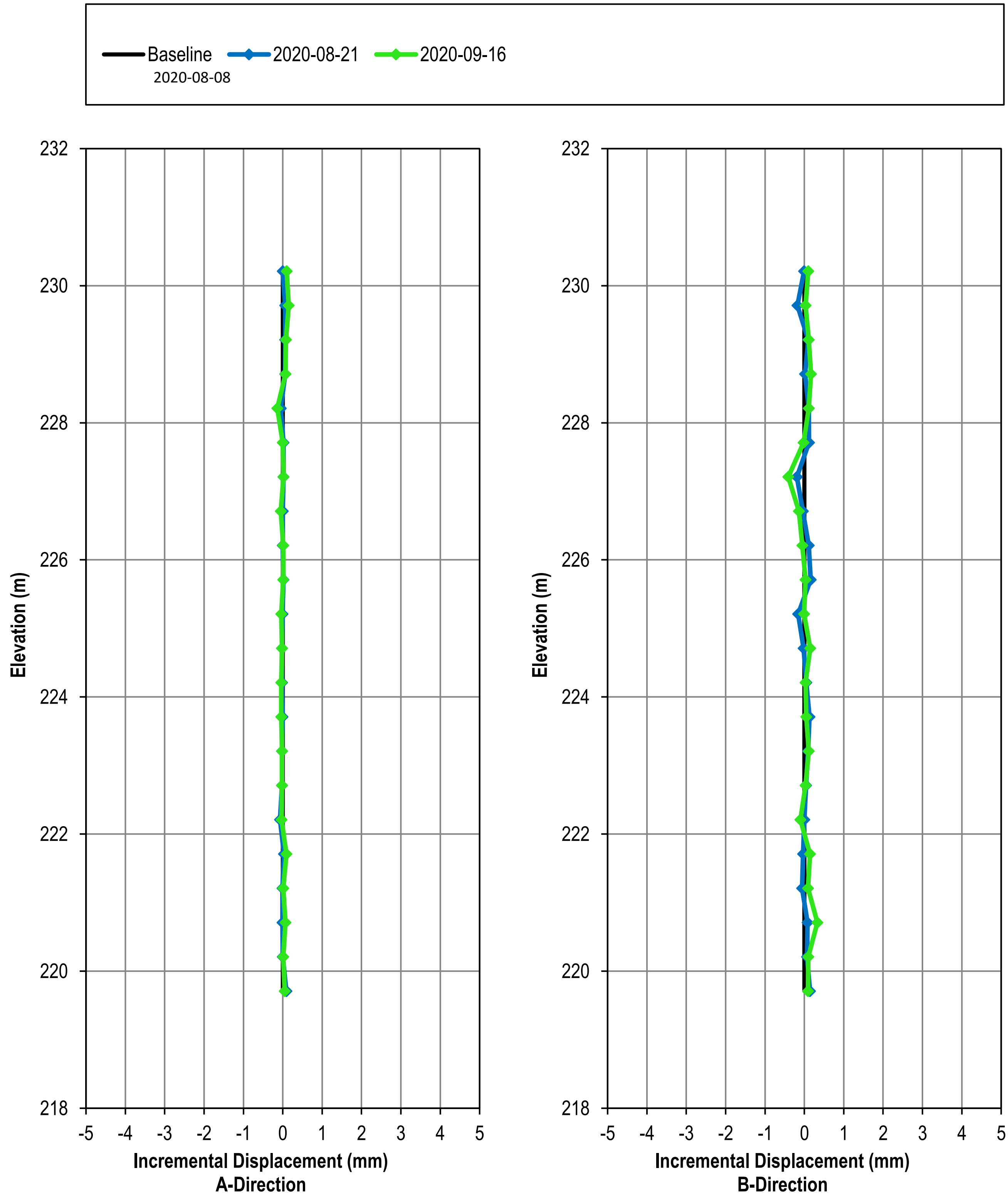
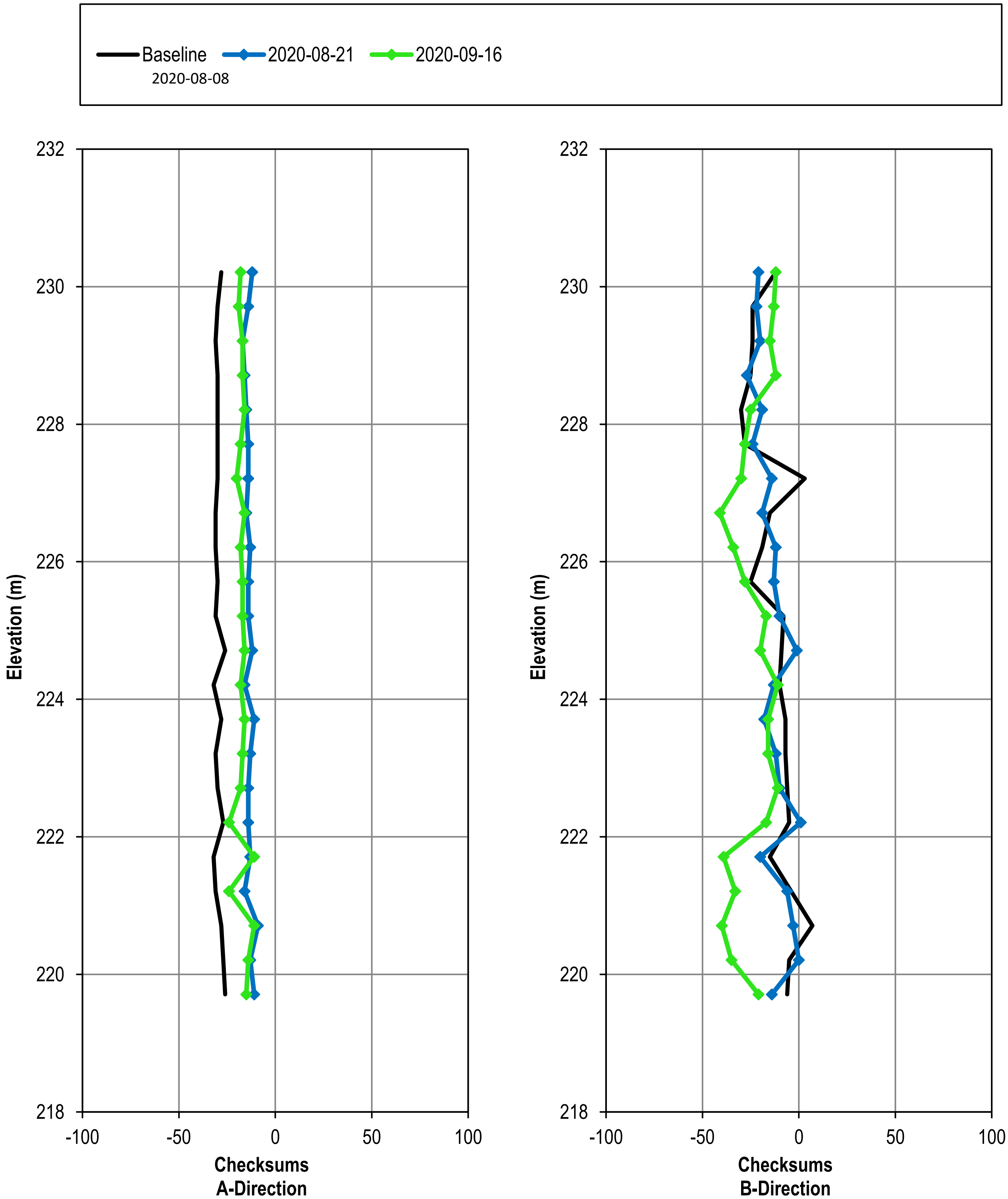


SLOPE INCLINOMETER DATA PLOTS

SI20-01



Appendix D

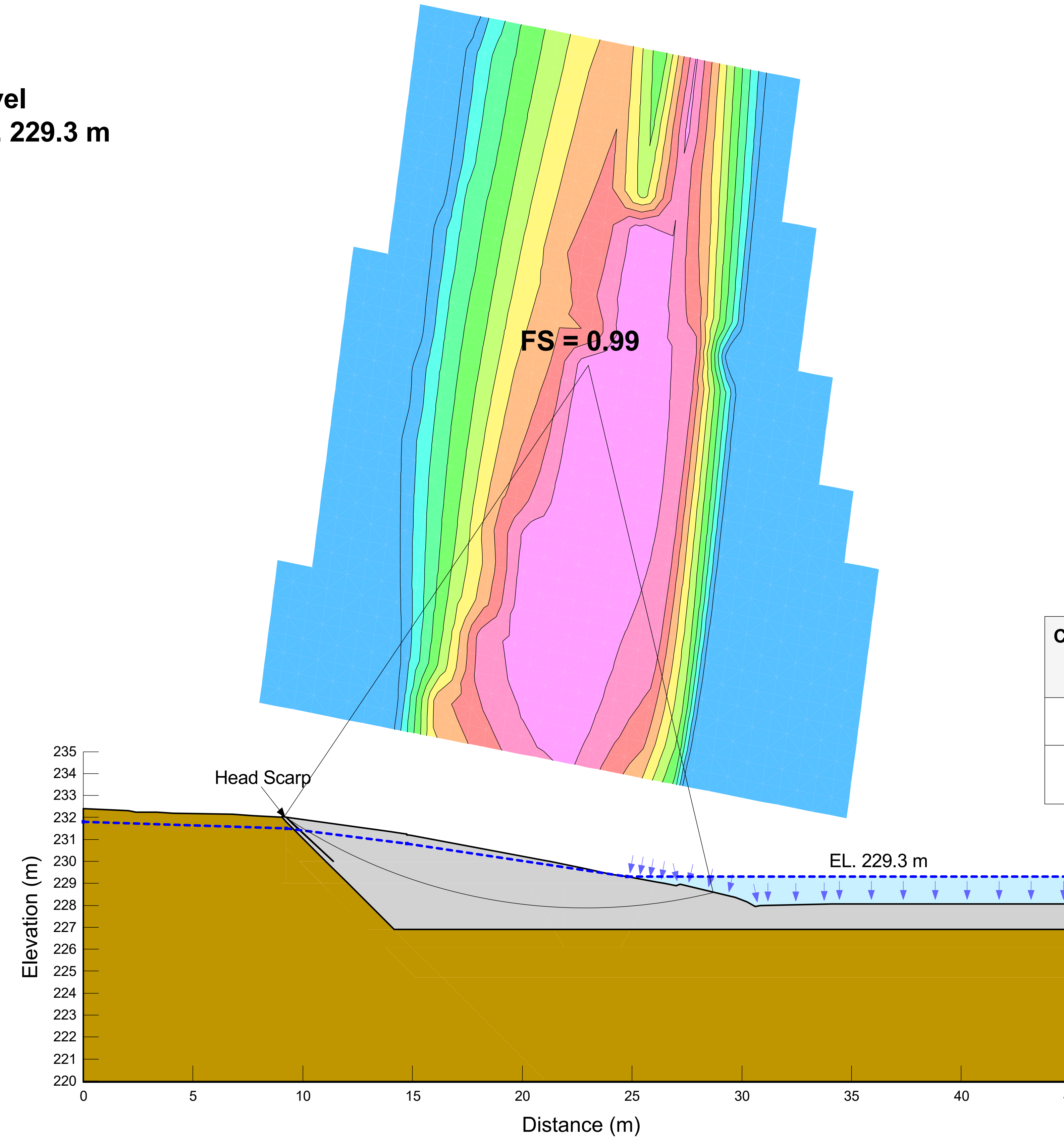
Slope Stability Analysis Results

Tabloid (279mm x 432mm)

SAVED: 16/10/2020 1:51:19 PM

SCALE: 1:231 (279mm x 432mm)

Back Analysis
High Groundwater Level
SRB Water Level = EL. 229.3 m

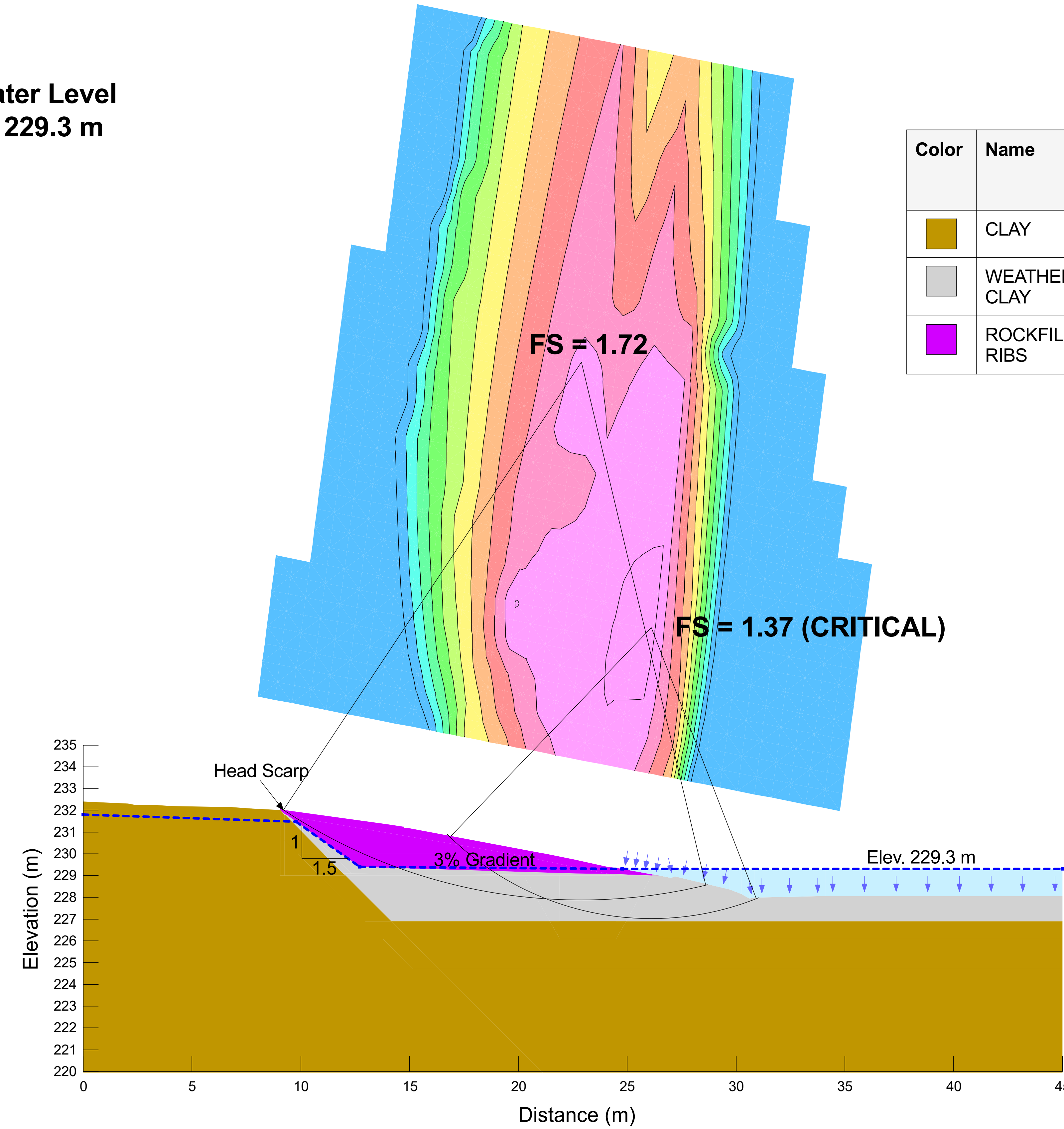


Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	CLAY	17.3	5	17
	WEATHERED CLAY	17.3	0	17

FILE PATH: Z:\Projects\0015 City of Winnipeg\0015 035 00 Slope Stabilization at SRB 6-7\2 Design\2.7 Modelling\Revision 1 PD Analyses\M001_1_A_RB - Back Analysis.gsz

Rockfill Ribs
High GWL and SRB Water Level
SRB Water Level = EL. 229.3 m

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	CLAY	17.3	5	17
	WEATHERED CLAY	17.3	0	17
	ROCKFILL RIBS	19	0	31



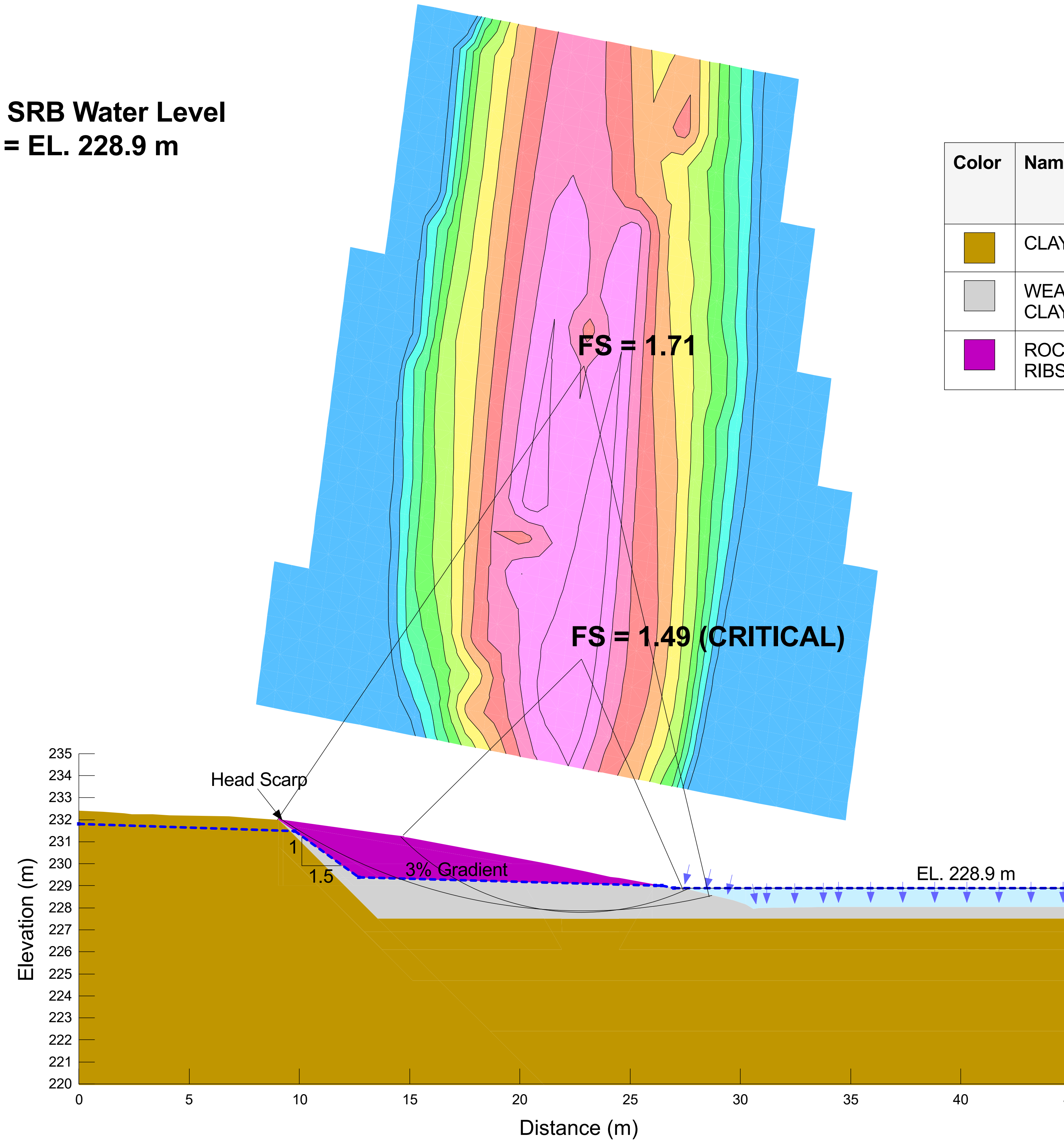
Tabloid (279mm x 432mm)

SAVED: 20/12/2020 9:43:58 AM

SCALE: 1:231 (279mm x 432mm)

Rockfill Ribs
Normal GWL and SRB Water Level
SRB Water Level = EL. 228.9 m

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
(gold)	CLAY	17.3	5	17
(grey)	WEATHERED CLAY	17.3	0	17
(magenta)	ROCKFILL RIBS	19	0	31



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