Debris Flow Early Warning System
Final Report

Prepared for: Colorado Water Conservation Board; Watershed Restoration Program
Attn: Chris Sturm
June 24, 2022

Boulder Watershed Collective (previous fiscal agent: Four Mile Fire Protection District)
Grant Amount: $20, 600
Prepared by: Maya MacHamer

THE BOULDER WATERSHED COLLECTIVE

Introduction

Debris flows are a poorly-understood hazard that are exacerbated by wildfires. Landslides and debris flows have affected numerous Colorado communities since 2020 associated with post wildfire rain events. These events can be severe like the Black Hollow debris flow in the Poudre River watershed in 2021. It is expected that this hazard will become more frequent as high severity wildfire continues to effect Colorado watersheds.

Geologic hazards such as debris flows and landslides are difficult emergencies to manage and recover from. Debris flows are not commonly experienced, difficult to predict and can cause multiple hazards such as structural collapse, hazardous materials, infrastructure failures, fires, mass casualty and fatalities. Response to these emergencies often include difficult operational coordination when the incident occurs, resource scarcity and access issues. Evacuating downslope, at risk communities prior to the disaster is the best way to minimize impact. The question emergency managers are faced with is where and when to initiate public warnings and what messaging should be included. The Debris Flow Early Warning System project integrates science and the human element. It is a data collection, utilization and communication project that strives to provide a new, innovative way of transmitting soil saturation and rain gage data in real time to be effectively used by emergency managers through public warning systems.

Improved prediction of debris flows and early alerts that provide time for downstream communities to evacuate, has the potential to reduce risk and transform fire and flood recovery strategies for emergency managers. An early warning system for debris flows, if successful, could be utilized state-wide.

The Boulder Watershed Collective (BWC) engaged the Colorado Geological Survey (CGS) to assist with debris flow modeling in 2016 as part of flood recovery efforts in Fourmile Canyon in Boulder County. Debris flows occurred in Fourmile Canyon in 2011 and 2013 associated with the Fourmile Fire (2010) burn scar. A better understanding of local debris flow hazards was part of the holistic watershed recovery process pursued by BWC and partners. Conversations throughout the debris flow modeling project led to the development of a pilot project for a debris flow early warning system using the Ingram Gulch watershed, where the debris flows occurred, as the pilot site.

After the 2020 fire season, the project was expanded, and two additional monitoring stations were installed in the Calwood burn scar. Calwood provided an opportunity to evaluate a new burn scar and collect data in a location with different soil types.

As a community, we have a reasonable understanding of where debris flows may occur and on-going research suggests that it is a combination of soil moisture and rainfall intensity that triggers the event to occur. In order to both understand and anticipate when conditions will reach the thresholds wherein a debris flow could initiate, monitoring both rainfall and soil conditions is paramount.

Background

CGS engaged debris flow experts at the Colorado School of Mines to assist with developing the debris flow monitoring and warning system. Dr. Ning Lu and Dr. Alexandra Wayllace have worked on multiple debris flow monitoring sites across the country and have the skills to analyze soil and precipitation data to help develop storm thresholds which could be used to inform warning system alerts.

Numerous data sources were evaluated prior to selecting the monitoring sites at Ingram Gulch. These data were also used to inform decisions on which instrumentation should be installed for monitoring. Evaluations of slope, geology, precipitation, previous storm footprints, values at risk and soil characterization occurred. At Calwood, the USGS Burn Area Emergency Report (BAER) was used to determine high priority monitoring locations where high probability of debris flows was indicated and there were downstream values at risk. Lidar was also used to inform monitoring location decisions.

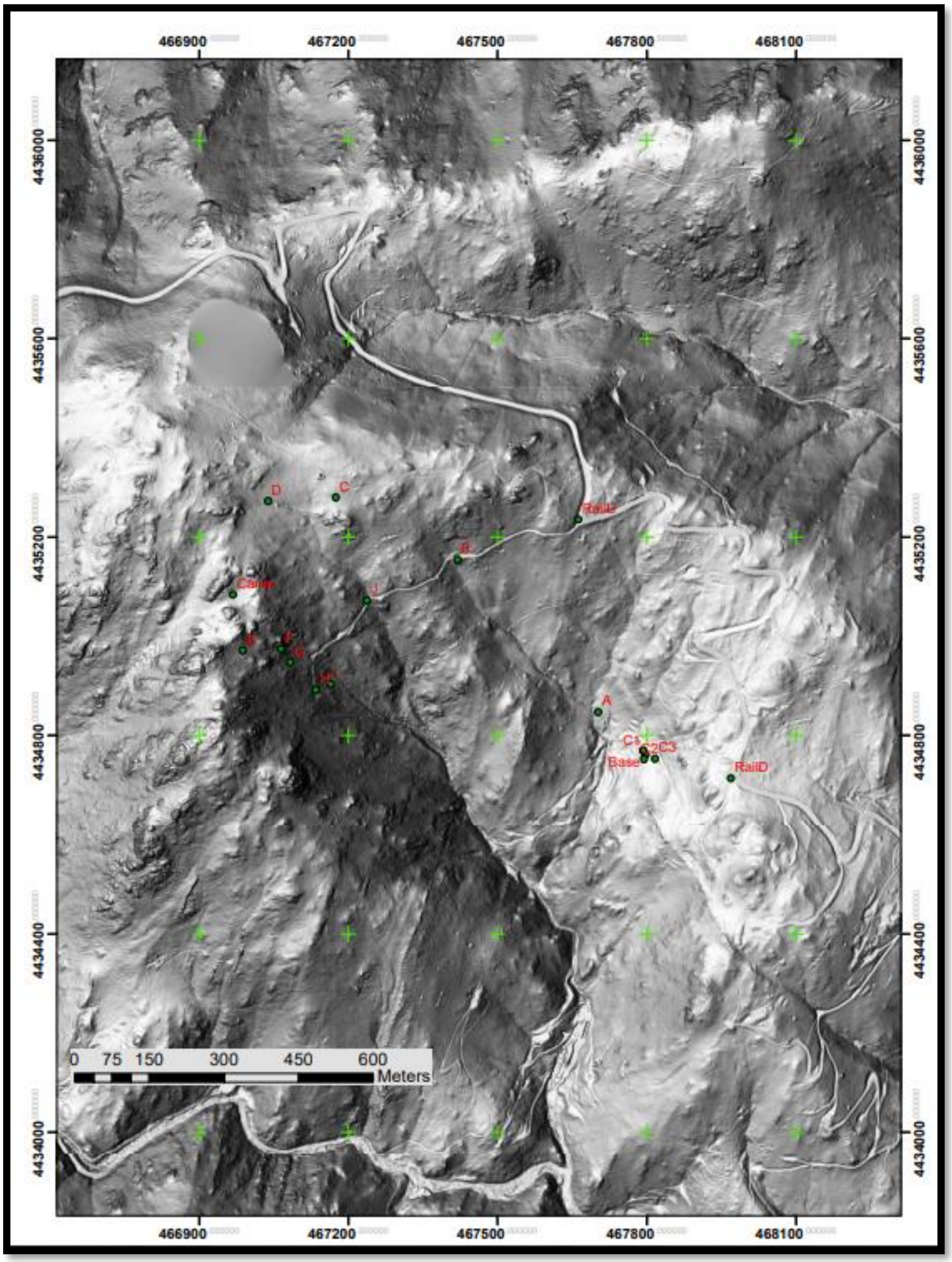


Figure 1: Lidar of Ingram Gulch with proposed monitoring locations and/or soil sample locations indicated.

The ultimate goal of this project is to improve community safety, preparedness and response to future geologic hazards. The primary short-term objective is to provide real-time rain, soil moisture, and soil strength measurements for the purpose of developing data thresholds for warnings and evacuation alerts. These data will inform the Boulder County Office of Disaster Management, Parks and Open Space, and first responders of imminent debris flow threats in the Calwood burn area. The run-out path at Ingram Gulch is short between where a debris flow may initiate and where it would impact homes. There would likely not be enough time to evacuate homes in the case of imminent threat. However, with accurate thresholds, there would be enough time to warn downstream communities that weather conditions are creating the likelihood of a serious potential threat. These differentiations are some of the alert threshold decisions that still need to be integrated with available data.

The available data from each monitoring station can be read directly from the Zentra Cloud web interface (example readings from the system that is deployed in Ingram Gulch in Fourmile Canyon are shown in the Results section) and via an app that is accessible from a phone in the field. Seven monitoring sites were installed in Ingram Gulch (see Fig 1). Installed sites are at points A, C, D, E, F, H & I. Two sites were installed at Calwood. The site above the Mountain Ridge Subdivision is a rain gauge only. All the sites were selected, after careful analysis, because they have experienced debris flows and remain unstable or are at risk of future debris flows.

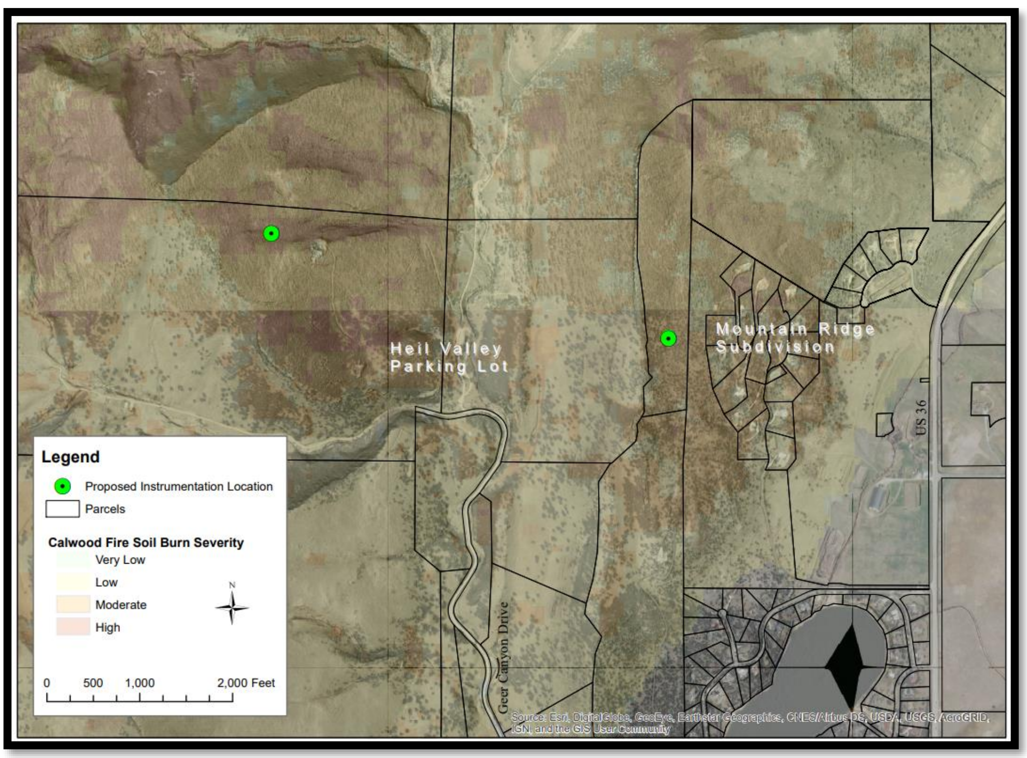


Figure 2: Monitoring sites within the Calwood burn scar.

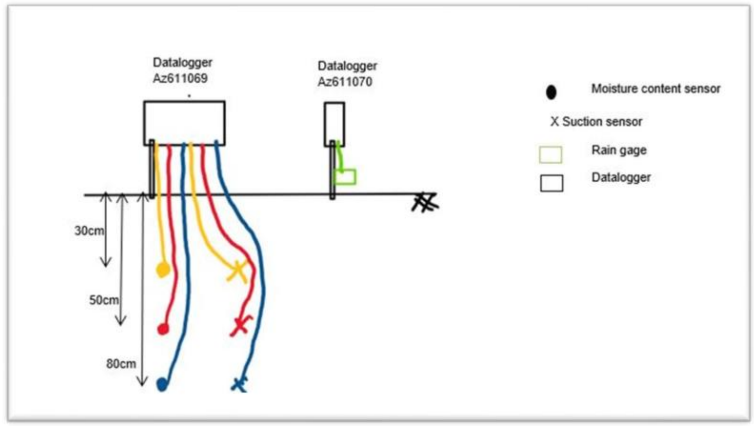
Methods

After data analysis occurred for site selection all monitoring equipment was purchased with Community Development Block Grant funding provided by a grant through the Colorado Department of Local Affairs. All costs associated with project development, research, technical assistance and consulting provided by the CGS and the School of Mines was donated (in-kind) from CGS. CWCB funds were used to support BWC staffing for coordination between partners, equipment installation, development of an educational storymap and other participation in the project.

Two soil sampling events occurred prior to equipment installation. Samples were collected and analyzed by both the Natural Resource Conservation Service and at the School of Mines laboratories. The soil results assisted in selecting appropriate monitoring equipment for installation. A soil pit was dug by hand at each site and soil was collected from each soil horizon. The following soil properties were measured, which are necessary to properly calibrate the sensors before installation: specific gravity, moisture content, Atterberg limits (liquid limit, plasticity index), absorption, clay content and particle size distribution. The soil results assisted in selecting appropriate monitoring equipment for installation.

Figure 3: Example of soil horizons

Monitoring equipment was installed at seven sites in Ingram Gulch and two sites at Calwood. Equipment includes: a) One Rain gauge (ECRN-100) to measure precipitation; connected to a solar powered datalogger. b) Tensiometers (TEROS 32) to measure matric suction in kPa; connected to solar powered dataloggers. c) Three volumetric water content sensors (EC-5); connected to datalogger. As shown in Figure 5 below, a pair of volumetric water content – suction sensors are installed at three depths: 30cm (yellow, ports 1 and 4), 50cm (red, ports 2 and 5), and 80cm (blue, ports 3 and 6). No sensors were installed deeper than 80 cm because at that point most of the hillslope material is likely to consist of larger rocks. Holes were excavated by hand. After equipment is installed, all removed material was backfilled to bury the equipment. The logged data is uploaded every 15 minutes and then sent via a 5G data transmitter to off-site computers and posted to the cloud.



Detail of connections to datalogger (Figure 4), Schematic of subsurface instrumentation (Figure 5)

All equipment was calibrated at the School of Mines lab prior to installation. The moisture content sensors were calibrated by preparing controlled volumetric water content samples using soil that was obtained at the site. The specified resolution is 0.03m3/m3. The tensiometers were saturated with distilled, de-aired water. They were installed at an angle of 10 – 80 degrees, have a range of -85 to +50kPa with a resolution of 0.0012kPa. The sensors must be re-saturated in the field if air enters the system (at suctions > 70kPa). The rain gage was also tested in the lab. All sensors were tested using the "Zentra Utility" application: (https://www.metergroup.com/de/environment/downloads/?download_category=software).

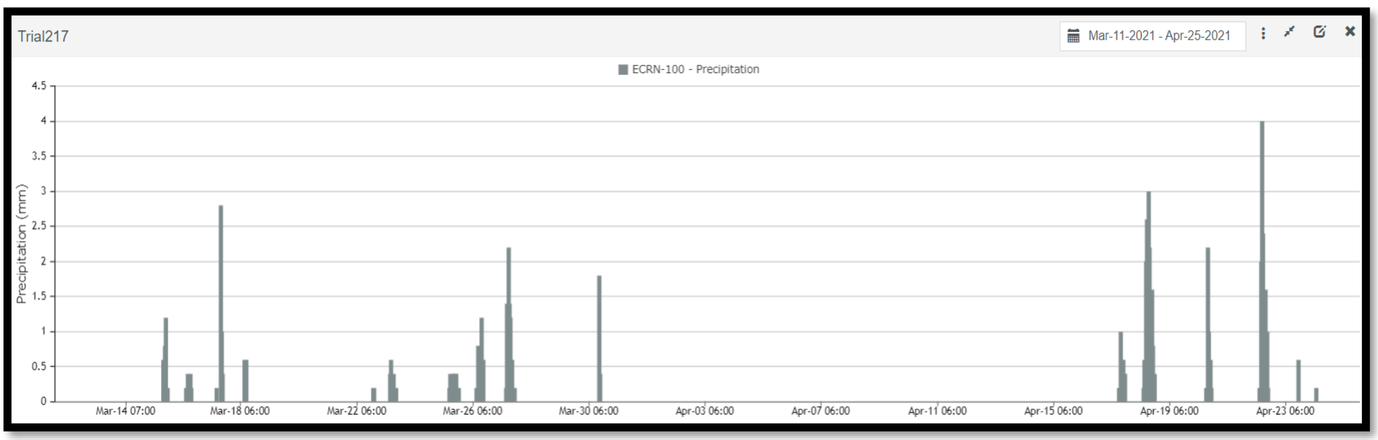
Results

This is an ongoing project. At this stage, results include installation of nine monitoring stations in Ingram Gulch and Calwood which each are able to transmit data in real time. The data feeds directly into the Boulder County Advanced Warning System modeling and notification system as rainfall gauge locations and as points of calibration for the calculated and assumed infiltration and soil moisture components for the physical hydrologic modeling that drives that advanced warning system (VFlo). This Advanced Warning system is what is used in the Boulder County emergency operations center during storm events. The ultimate goal of the comprehensive project is to be able to provide 10 to 15 minutes of warning to individuals in debris flow paths that are going to

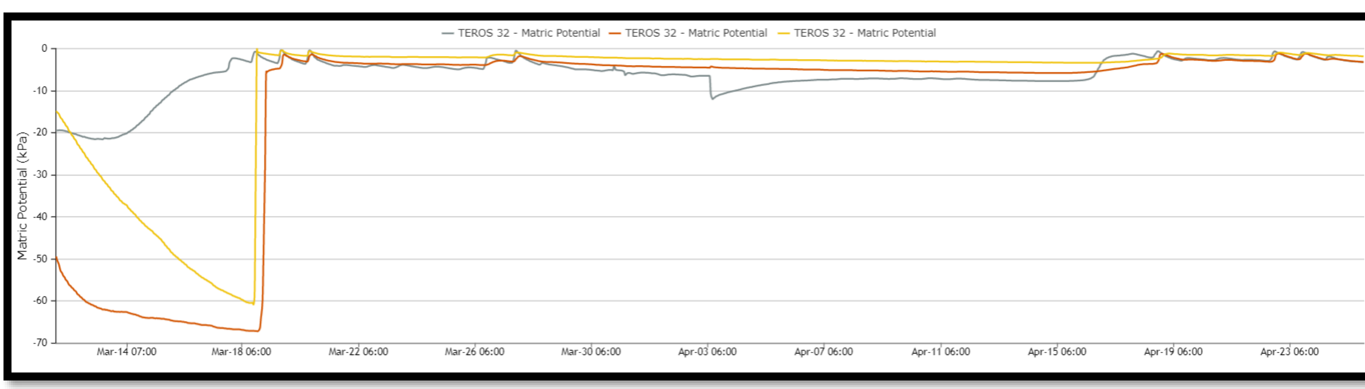
Figure 6: Monitoring station with rain gauge and data loggers visible.

slide, which will allow them to evacuate and ultimately save lives. The data can be accessed and used to field verify and inform National Weather Service and the Boulder County Advance Warning system alerts.

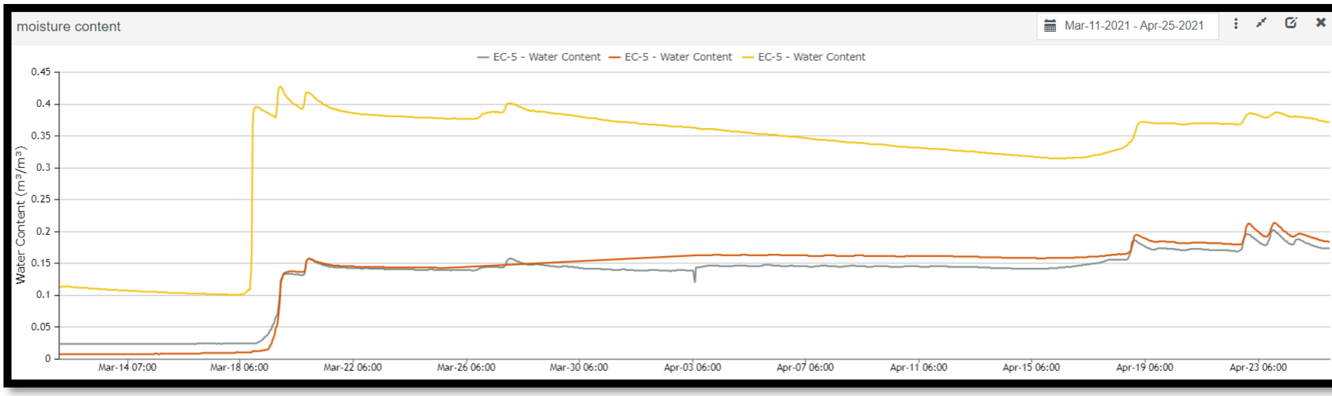
The figures below represent an example of data obtained from March 11 to April 25, 2021. Note that there was significant snow at the site on March 13-14. As the snow melts, moisture content increases and suction decreases. The moisture content sensor at z=50cm was disconnected on March 20 and reconnected on April 3. These data are available for each monitoring site. The data is remotely available through Zentra Cloud. While the soil is too dry during some months of the year (and air breaks in the tensiometers), the relevant soil behavior for slope stability is captured when water starts infiltrating into the soil. Colorado School of Mines is analyzing data in a calibrated model used for debris-flow (shallow landslide) prediction. The model synthesizes results by simulating stress and two-dimensional flow in a variably saturated cross-section and is based in numerical synthesis that is validated (calibrated) with the active field monitoring of soil suction and moisture content data. Once there is sufficient field data which has been modeled, preliminary warning system thresholds can be developed and tested. It is estimated that one to two years of data is required to make well informed threshold ranges for alerts.



(a)



(b)



(c)

Figure 6. (a) Precipitation vs. time, (b) Matric potential vs. time, (c) volumetric moisture content vs. time.

Conclusions and Discussion

There have been many challenges and lessons learned with this project. Generally, the entire project has taken much longer than expected. The project has been an attempt to integrate academic research and emergency management needs. While this objective remains extremely important, it has been more difficult than expected to merge differing priorities and timeframes, especially when faced with limited capacity caused by covid and natural disasters.

Since we began this project there have been several major debris flows which have caused loss of life in Larimer County and severe infrastructure, economic and natural resource impacts in Garfield County. These events have reaffirmed that while our progress has been slow, the need for a debris flow early warning system is critical. For this reason, BWC, CGS, Colorado School of Mines and Boulder County will continue to build off of the existing data sets and work toward creating data thresholds for different levels of alerts (awareness, warning, evacuation). Additionally, BWC will continue to speak with other agencies pursuing similar work to share data/resources, coordinate when appropriate and ensure that efforts are not duplicated.

The following points are lessons learned from equipment installation which may be helpful for future similar projects.

1. Installation of equipment is time consuming and often difficult. The sites that are advantageous for debris flow monitoring are typically steep, often difficult to access and may be hazardous post-wildfire. Digging holes deep enough for multiple levels of soil monitoring is arduous work. The current monitoring system needs adjustment to be useful for “quick deployment” in a post wildfire environment where debris flows may be imminent and data is needed quickly.
2. The tensiometers should be insulated with bubble wrap or other material after installation to keep the small rubber tubing from melting together during hot weather.
3. When soils are extremely dry and have increased suction potential equipment maintenance may need to occur to reintroduce water into the tensiometer tubing. This should be integrated into a maintenance plan. A small syringe with 10cc’s of distilled water is sufficient to re-wet the system.

4. The Zentra Cloud system upgraded from 3G to 5G. This change eliminated the ability of data to be uploaded to the cloud without physical replacement of SIM cards. Although data was still being collected and stored, this was an unanticipated equipment maintenance need.
5. The tensiometers we chose are produced in Germany. Long delivery times should be expected.

Future work: A video interview with a couple who survived a debris flow that impacted their home as they slept during the 2013 flood event will be added to the Debris Flow Story Map. When completed, the story map will be distributed to partners to share with their networks ad an educational tool.

Potential future research areas include using LIDAR to monitoring surface deformation to strengthen forecasting based on subsurface data and InSAR to monitoring surface and near surface moisture content (calibrated to field soil data monitoring). These tasks are not currently funded, but will be considered in the future.

Actual Expense Budget

Agency	Task	CWRP Funds	Match Amount
CWRP Grant	Staffing/storymap	$20,664	
CDBG	Equipment Purchase		$48,413
CGS	Technical Support		$100,000
Boulder County	Calwood Equipment		$7,724
TOTAL		**$20,664**	**$156,137**

Appendix

This Section focuses on any additional information that would benefit the understanding of the plan/ project. This can include photos (before and after), site maps, design drawings, metadata, measurement data used in calculations, survey data, model data, etc. used or generated throughout plan/ project implementation.

- Instrumentation List
- Ingram Gulch Pre-installation soil characterization data.
- Draft public webpage on the Colorado Geological Survey website with links to real time data for each monitoring site at Ingram Gulch: HTTP://www.cwayllace.com/cgs
- Draft story map created by Watershed Science and Design to be used as a public education tool to improve understanding of landslide and debris flow hazards: https://storymaps.arcgis.com/stories/7bc324cad46d47d9ad15d12d750132a2

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QUOTE

METER

METER Group, Inc. USA
2365 NE Hopkins Court, Pullman, WA99163
T 509.332.2756 F 509.332.5158
E info@metergroup.com W metergroup.com

Created Date	11/24/2020
Quote Number	00019467

Address Information

Bill To Name		Ship To Name	mes
Bill To		Ship To	
Contact Name		Ship Via	
Phone			
Email			

Terms

Expiration Date		Pay Terms	Net 30 Days
Prepared By			

Quantity	Product Code	Description	Sales Price	Total Price
1.00	0132040	TEROS 32 Tensiometer, total length 40 cm syringe refilling, refill tubes length 15 cm 4.7 m cable and stereo plug cable gland with bend protection	$388.00	$388.00
1.00	0132080	TEROS 32 Tensiometer, total length 80 cm syringe refilling, refill tubes length 15 cm 4.3 m cable and stereo plug cable gland with bend protection	$403.00	$403.00
1.00	0132120	TEROS 32 Tensiometer, total length 120 cm syringe refilling, refill tubes length 15 cm 3.9 m cable and stereo plug cable gland with bend protection	$418.00	$418.00
1.00	0152	UMS refill syringe BS60 for Tensiometers with external refilling, volume 60 ml, with faucet	$18.00	$18.00
3.00	40593-S	EC-5 Soil Moisture Sensor, 5m Cable, Stereo connector for use with METER loggers	$125.00	$375.00
1.00	40799	ECRN-100 High Res Rain Gauge (.2 mm), 5m Cable, Stereo connector for use with METER loggers	$400.00	$400.00
2.00	40897	ZL6 Cellular Data Logger, for use worldwide on 3G cellular networks using H-1 SIM, allows access to data via Internet, for use with all METER sensors, self-enclosed, solar charging, batteries included	$650.00	$1,300.00
2.00	50097	ZENTRA Cloud 2020 Season Pass for METER Loggers	$90.00	$180.00
2.00	50109	ZENTRA Cloud 2021 Season Pass for all METER Loggers	$180.00	$360.00

Subtotal	$3,842.00
Total Price	$3,842.00
Tax	$0.00
Freight and Handling	$20.29
Grand Total	$3,862.29

This Quote is good for 30 days unless otherwise noted. All prices in U.S Dollars (USD) unless otherwise noted. Shipping charges, if not quoted, may be added to the final invoice. **All Custom Orders are final and non-refundable.**

Memo

To: Jonathan Lovekin

From: Alexandra Wayllace, Ning Lu

Date: February 19, 2021

Ref: Soil properties of samples from Ingram Gulch

1. Summary of results

Sample testing from 5 locations are summarized in Table 1:

Table 1 Soils classification summary

Code	D_{10} [mm]	D_{30} [mm]	D_{60} [mm]	% Gravel	% Sand	% fines	Comments
2020CO643202	0.20	0.70	2.55	19.28	80.54	0.18	
2020CO13205	0.17	0.41	1.40	9.00	90.39	0.60	North of "A"
2020CO13204	0.15	0.40	1.40	13.31	84.25	2.44	
2020CO643203	0.20	0.50	1.65	14.07	85.78	0.15	Close to J
2020CO643206	0.17	0.49	2.20	27.23	72.61	0.16	Close to F & G

Code	C_u	C_c	LL	PL	G_s	Soil Classification
2020CO643202	12.75	1.37	26.19%	NP	-	SW
2020CO13205	8.24	1.72	35.02%	NP	-	SW
2020CO13204	9.33	1.90	37.03%	NP	-	SW
2020CO643203	8.25	1.52	15.10%	NP	2.65	SW
2020CO643206	12.94	1.31	22.20%	NP	-	SW

2. Soil samples

Eighteen samples aggregated in 5 groups were provided (Table 2).

Table 2 Soils denomination and description

N	Sample Label	Sample Code
1	E 15-65	2020CO643202
2	E Bt	
3	#W9	2020CO13205
4	A O-15	2020CO643203
5	AB 18-50	
6	BC	
7	Bta	
8	Bt1	
9	A O-18	
10	H2	2020CO643206
11	H3	
12	H4	
13	H5	
14	#W2	2020CO13204
15	#W8-1	
16	2 (Atterberg)	
17	top	
18	bottom	

3. Water content

In-situ water content was taken for all the samples (Table 3). Detailed data provided in Appendix A.

Table 3 Water content summary

N	Sample Label	w
1	E 15-65	6.57%
2	E Bt	8.48%
3	#W9	6.20%
4	A O-15	8.89%
5	AB 18-50	7.64%
6	BC	11.17%
7	Bta	7.98%
8	Bt1	6.36%
9	A O-18	11.53%
10	H2	11.77%
11	H3	3.05%
12	H4	1.57%
13	H5	3.55%
14	#W2	6.26%
15	#W8-1	4.75%
16	2 (Atterberg)	5.81%
17	top	8.38%
18	bottom	5.05%

4. Grain size distribution

Appendices B to F show the results of the grain size analysis (dry sieve and hydrometer tests, ASTM D-422).

5. Atterberg limits

All the soil samples were found non-plastic. Liquid limit results (multi-point test) are summarized in Appendices B to F (ASTM D-4318).

6. Specific gravity

Tests for only one soil was performed. Since most of the material are coarse, the same G_s is assumed for the rest of the samples.

Appendix A

Water content

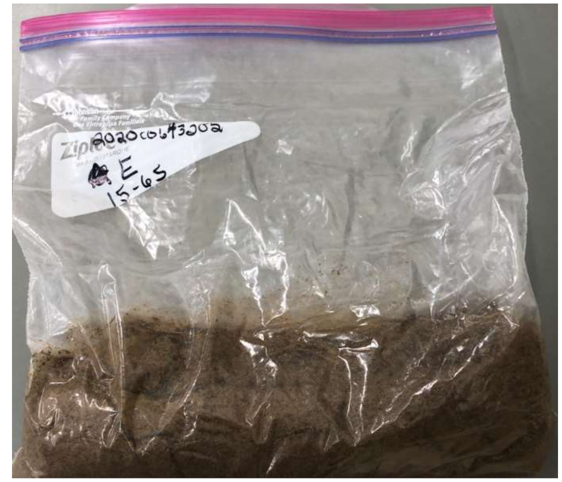
COLORADO SCHOOL OF MINES

PROFESSOR: Ph.D. Alexandra Wayllace
T.A.: Angel Rodrigo Angulo Calderon
PROJECT: Ingram Gulch

SOIL MECHANICS LABORATORY

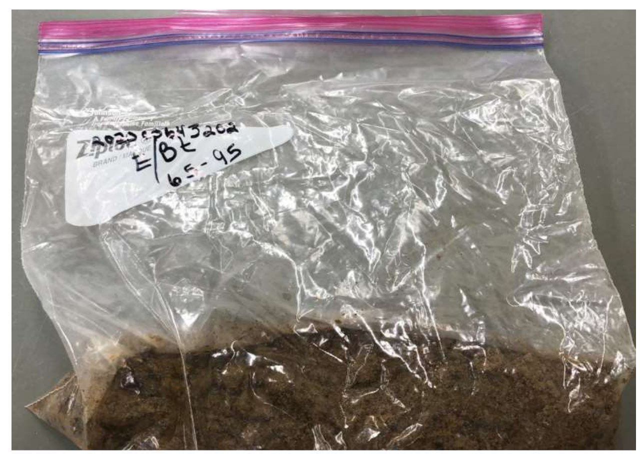
" WATER CONTENT"

Code		2020CO643202	
Denomination		E 15-65	
Date		-	
ITEM		**Test No.**	
	1	**2**	**3**
1. Can No.	C-1	C-2	C-3
2. Mass of can, M1 (g)	11.78	11.83	12.28
3. Mass of can + wet soil, M_2 (g)	42.62	41.83	46.01
4. Mass of can + dry soil, M_3 (g)	40.77	40.00	43.85
5. Mass of moisture, $M_2 - M_3$ (g)	1.85	1.83	2.16
6. Mass of dry soil, $M_3 - M_1$ (g)	28.99	28.17	31.57
7. Water content, w (%) = $((M_2 - M_3)/(M_3 - M_1)) \times 100$	6.38%	6.50%	6.84%
Average water content		**6.57%**	



Soil Sample Picture

Code		2020CO643202	
Denomination		E Bt	
Date		-	
ITEM		**Test No.**	
	1	**2**	**3**
1. Can No.	C-19	C-20	C-21
2. Mass of can, M1 (g)	12.19	12.67	11.60
3. Mass of can + wet soil, M_2 (g)	37.16	33.01	32.32
4. Mass of can + dry soil, M_3 (g)	35.28	31.42	30.64
5. Mass of moisture, $M_2 - M_3$ (g)	1.88	1.59	1.68
6. Mass of dry soil, $M_3 - M_1$ (g)	23.09	18.75	19.04
7. Water content, w (%) = $((M_2 - M_3)/(M_3 - M_1)) \times 100$	8.14%	8.48%	8.82%
Average water content		**8.48%**	



Soil Sample Picture

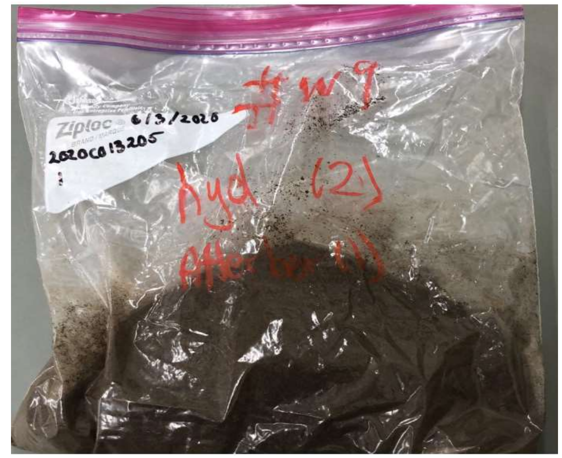
COLORADO SCHOOL OF MINES

SOIL MECHANICS LABORATORY

PROFESSOR: Ph.D. Alexandra Wayllace
T.A.: Angel Rodrigo Angulo Calderon
PROJECT: Ingram Gulch

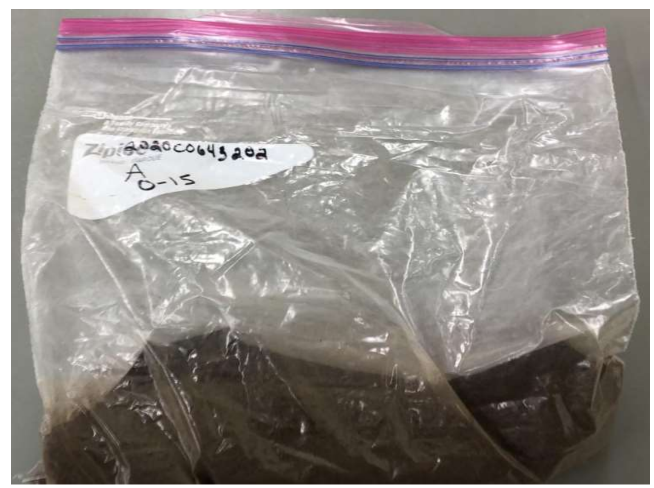
" WATER CONTENT"

Code	2020CO13205-1		
Denomination	#W9		
Date	3/6/2020		
ITEM	**Test No.**		
	1	**2**	**3**
1. Can No.	C-4	C-5	C-6
2. Mass of can, M1 (g)	12.37	12.06	12.05
3. Mass of can + wet soil, M_2 (g)	46.37	44.52	51.24
4. Mass of can + dry soil, M_3 (g)	44.60	42.56	48.79
5. Mass of moisture, $M_2 - M_3$ (g)	1.77	1.96	2.45
6. Mass of dry soil, $M_3 - M_1$ (g)	32.23	30.50	36.74
7. Water content, w (%) = $((M_2 - M_3)/(M_3 - M_1)) \times 100$	5.49%	6.43%	6.67%
Average water content	**6.20%**		



Soil Sample Picture

Code	2020CO643203		
Denomination	A O-15		
Date	-		
ITEM	**Test No.**		
	1	**2**	**3**
1. Can No.	C-10	C-11	C-12
2. Mass of can, M1 (g)	12.50	12.57	11.00
3. Mass of can + wet soil, M_2 (g)	35.54	35.89	36.45
4. Mass of can + dry soil, M_3 (g)	33.85	34.54	33.60
5. Mass of moisture, $M_2 - M_3$ (g)	1.69	1.35	2.85
6. Mass of dry soil, $M_3 - M_1$ (g)	21.35	21.97	22.60
7. Water content, w (%) = $((M_2 - M_3)/(M_3 - M_1)) \times 100$	7.92%	6.14%	12.61%
Average water content	**8.89%**		



Soil Sample Picture

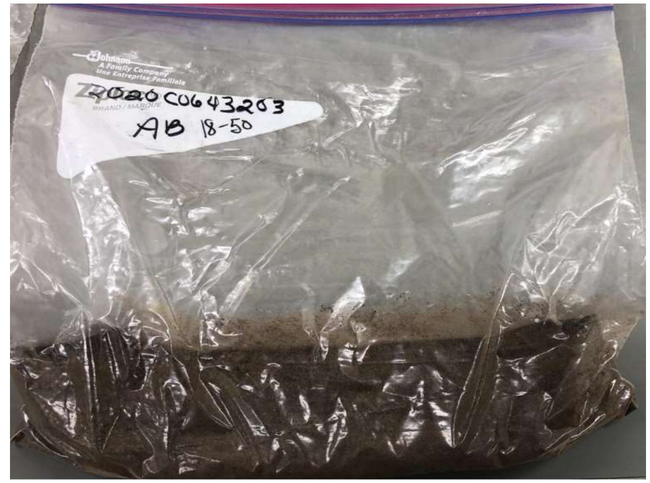
COLORADO SCHOOL OF MINES

SOIL MECHANICS LABORATORY

PROFESSOR: Ph.D. Alexandra Wayllace
T.A.: Angel Rodrigo Angulo Calderon
PROJECT: Ingram Gulch

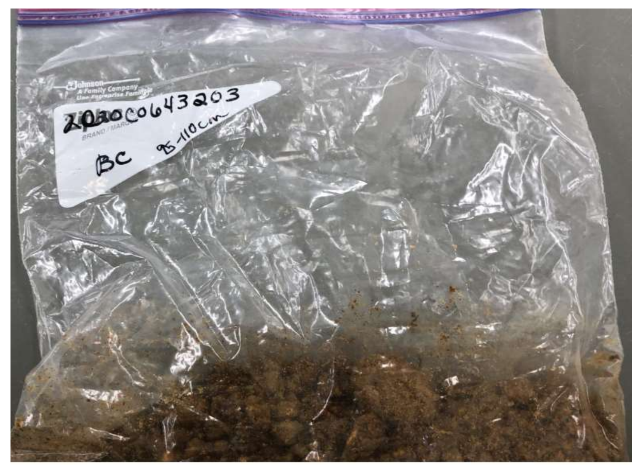
" WATER CONTENT"

Code		2020CO643203	
Denomination		AB 18-50	
Date		-	
ITEM		**Test No.**	
	1	**2**	**3**
1. Can No.	C-13	C-14	C-15
2. Mass of can, M1 (g)	12.40	12.16	12.36
3. Mass of can + wet soil, M_2 (g)	33.53	31.31	37.39
4. Mass of can + dry soil, M_3 (g)	31.95	29.93	35.74
5. Mass of moisture, M_2 - M_3 (g)	1.58	1.38	1.65
6. Mass of dry soil, M_3 - M_1 (g)	19.55	17.77	23.38
7. Water content, w (%) = $((M_2 - M_3)/(M_3 - M_1)) \times 100$	8.08%	7.77%	7.06%
Average water content		**7.64%**	



Soil Sample Picture

Code		2020CO643203	
Denomination		BC	
Date		-	
ITEM		**Test No.**	
	1	**2**	**3**
1. Can No.	C-16	c-17	c-18
2. Mass of can, M1 (g)	12.41	12.54	11.52
3. Mass of can + wet soil, M_2 (g)	32.99	35.28	35.78
4. Mass of can + dry soil, M_3 (g)	30.87	32.95	33.45
5. Mass of moisture, M_2 - M_3 (g)	2.12	2.33	2.33
6. Mass of dry soil, M_3 - M_1 (g)	18.46	20.41	21.93
7. Water content, w (%) = $((M_2 - M_3)/(M_3 - M_1)) \times 100$	11.48%	11.42%	10.62%
Average water content		**11.17%**	



Soil Sample Picture

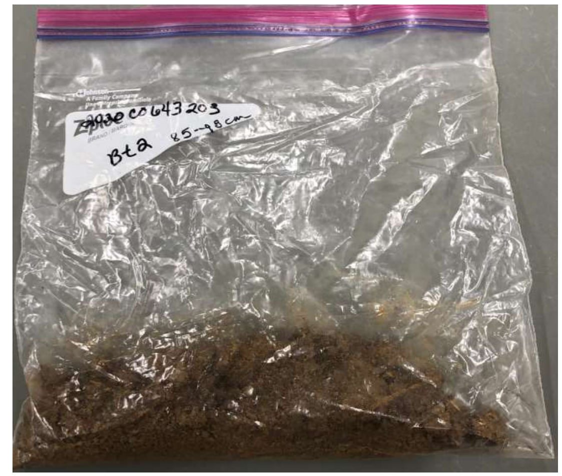
COLORADO SCHOOL OF MINES

PROFESSOR: Ph.D. Alexandra Wayllace
T.A.: Angel Rodrigo Angulo Calderon
PROJECT: Ingram Gulch

SOIL MECHANICS LABORATORY

" WATER CONTENT"

Code		2020CO643203	
Denomination		Bta	
Date		-	
ITEM		**Test No.**	
	1	**2**	**3**
1. Can No.	C-1		
2. Mass of can, M1 (g)	11.77		
3. Mass of can + wet soil, M_2 (g)	51.83		
4. Mass of can + dry soil, M_3 (g)	48.87		
5. Mass of moisture, M_2 - M_3 (g)	2.96		
6. Mass of dry soil, M_3 - M_1 (g)	37.10		
7. Water content, w (%) = ((M_2 - M_3)/(M_3 - M_1)) x 100	7.98%		
Average water content		**7.98%**	



Soil Sample Picture

Code		2020CO643203	
Denomination		Bt1	
Date		-	
ITEM		**Test No.**	
	1	**2**	**3**
1. Can No.	C-2		
2. Mass of can, M1 (g)	11.84		
3. Mass of can + wet soil, M_2 (g)	37.41		
4. Mass of can + dry soil, M_3 (g)	35.88		
5. Mass of moisture, M_2 - M_3 (g)	1.53		
6. Mass of dry soil, M_3 - M_1 (g)	24.04		
7. Water content, w (%) = ((M_2 - M_3)/(M_3 - M_1)) x 100	6.36%		
Average water content		**6.36%**	

Soil Sample Picture

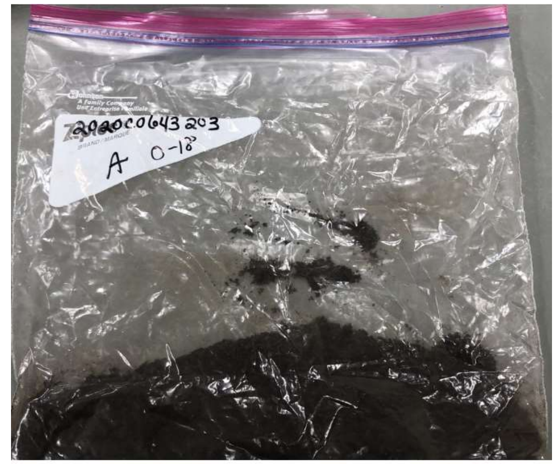
COLORADO SCHOOL OF MINES

SOIL MECHANICS LABORATORY

PROFESSOR: Ph.D. Alexandra Wayllace
T.A.: Angel Rodrigo Angulo Calderon
PROJECT: Ingram Gulch

" WATER CONTENT"

Code	2020CO643203		
Denomination	A O-18		
Date	-		
ITEM	**Test No. 1**	**2**	**3**
1. Can No.	C-4		
2. Mass of can, M1 (g)	12.34		
3. Mass of can + wet soil, M_2 (g)	31.49		
4. Mass of can + dry soil, M_3 (g)	29.51		
5. Mass of moisture, M_2 - M_3 (g)	1.98		
6. Mass of dry soil, M_3 - M_1 (g)	17.17		
7. Water content, w (%) = $((M_2 - M_3)/(M_3 - M_1)) \times 100$	11.53%		
Average water content	**11.53%**		



Soil Sample Picture

Code	2020CO643206		
Denomination	H2		
Date	6/26/20		
ITEM	**Test No. 1**	**2**	**3**
1. Can No.	C-5		
2. Mass of can, M1 (g)	12.02		
3. Mass of can + wet soil, M_2 (g)	27.31		
4. Mass of can + dry soil, M_3 (g)	25.70		
5. Mass of moisture, M_2 - M_3 (g)	1.61		
6. Mass of dry soil, M_3 - M_1 (g)	13.68		
7. Water content, w (%) = $((M_2 - M_3)/(M_3 - M_1)) \times 100$	11.77%		
Average water content	**11.77%**		

Soil Sample Picture

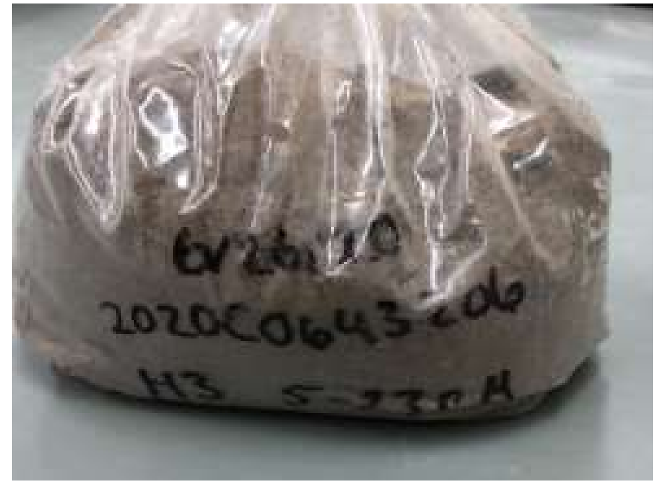
COLORADO SCHOOL OF MINES

SOIL MECHANICS LABORATORY

PROFESSOR: Ph.D. Alexandra Wayllace
T.A.: Angel Rodrigo Angulo Calderon
PROJECT: Ingram Gulch

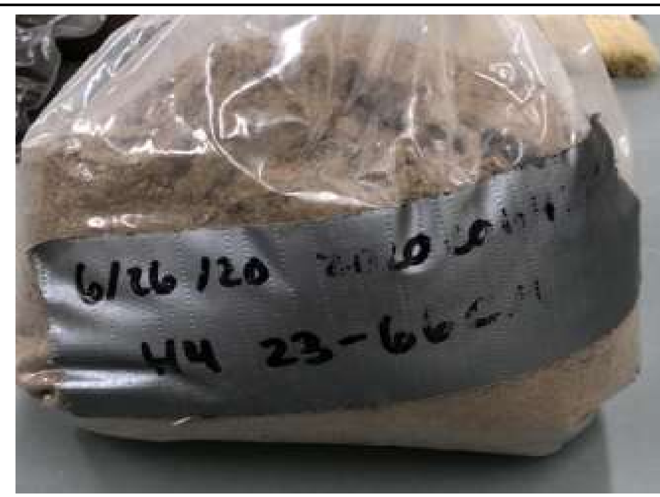
“ WATER CONTENT”

Code		2020co643206	
Denomination		H3	
Date		6/26/20	
ITEM		**Test No.**	
	1	**2**	**3**
1. Can No.	C-6		
2. Mass of can, M1 (g)	12.03		
3. Mass of can + wet soil, M_2 (g)	41.05		
4. Mass of can + dry soil, M_3 (g)	40.19		
5. Mass of moisture, M_2 - M_3 (g)	0.86		
6. Mass of dry soil, M_3 - M_1 (g)	28.16		
7. Water content, w (%) = $((M_2 - M_3)/(M_3 - M_1)) \times 100$	3.05%		
Average water content		**3.05%**	



Soil Sample Picture

Code		2020CO643206	
Denomination		H4	
Date		6-26-20	
ITEM		**Test No.**	
	1	**2**	**3**
1. Can No.	C-7		
2. Mass of can, M1 (g)	12.79		
3. Mass of can + wet soil, M_2 (g)	65.91		
4. Mass of can + dry soil, M_3 (g)	65.09		
5. Mass of moisture, M_2 - M_3 (g)	0.82		
6. Mass of dry soil, M_3 - M_1 (g)	52.30		
7. Water content, w (%) = $((M_2 - M_3)/(M_3 - M_1)) \times 100$	1.57%		
Average water content		**1.57%**	



Soil Sample Picture

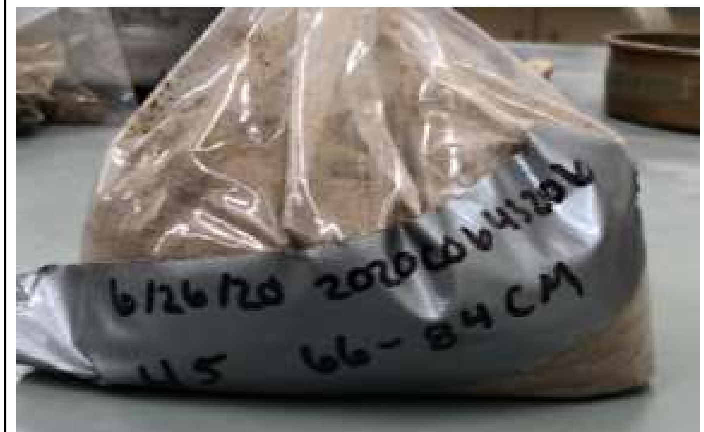
COLORADO SCHOOL OF MINES

PROFESSOR: Ph.D. Alexandra Wayllace
T.A.: Angel Rodrigo Angulo Calderon
PROJECT: Ingram Gulch

SOIL MECHANICS LABORATORY

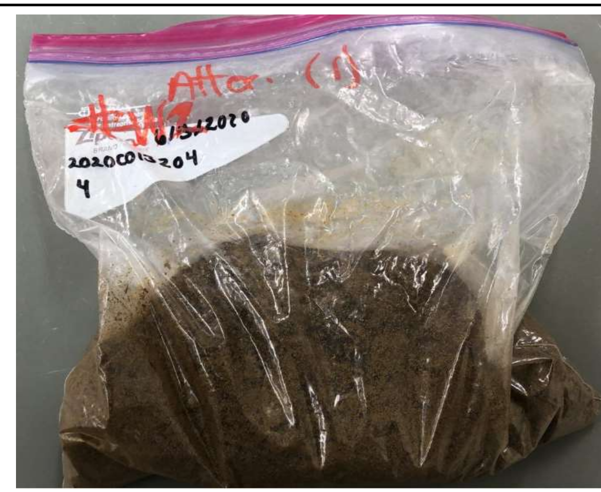
" WATER CONTENT"

Code		2020CO643206	
Denomination		H5	
Date		6-26-20	
ITEM		**Test No.**	
	1	**2**	**3**
1. Can No.	C8		
2. Mass of can, M1 (g)	11.60		
3. Mass of can + wet soil, M_2 (g)	64.70		
4. Mass of can + dry soil, M_3 (g)	62.88		
5. Mass of moisture, M_2 - M_3 (g)	1.82		
6. Mass of dry soil, M_3 - M_1 (g)	51.28		
7. Water content, w (%) = ((M_2 - M_3)/(M_3 - M_1)) x 100	3.55%		
Average water content		**3.55%**	



Soil Sample Picture

Code		2020CO13204	
Denomination		#W2	
Date		3/6/2020	
ITEM		**Test No.**	
	1	**2**	**3**
1. Can No.	C-7	C-8	C-9
2. Mass of can, M1 (g)	12.82	11.59	12.02
3. Mass of can + wet soil, M_2 (g)	49.27	61.33	56.97
4. Mass of can + dry soil, M_3 (g)	46.89	58.42	54.59
5. Mass of moisture, M_2 - M_3 (g)	2.38	2.91	2.38
6. Mass of dry soil, M_3 - M_1 (g)	34.07	46.83	42.57
7. Water content, w (%) = ((M_2 - M_3)/(M_3 - M_1)) x 100	6.99%	6.21%	5.59%
Average water content		**6.26%**	



Soil Sample Picture

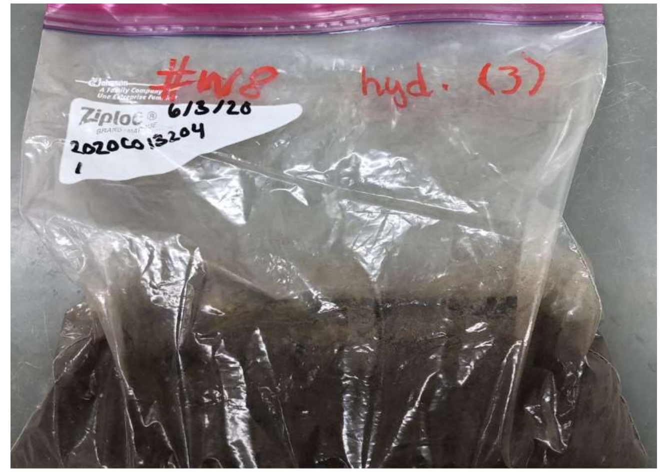
COLORADO SCHOOL OF MINES

PROFESSOR: Ph.D. Alexandra Wayllace
T.A.: Angel Rodrigo Angulo Calderon
PROJECT: Ingram Gulch

SOIL MECHANICS LABORATORY

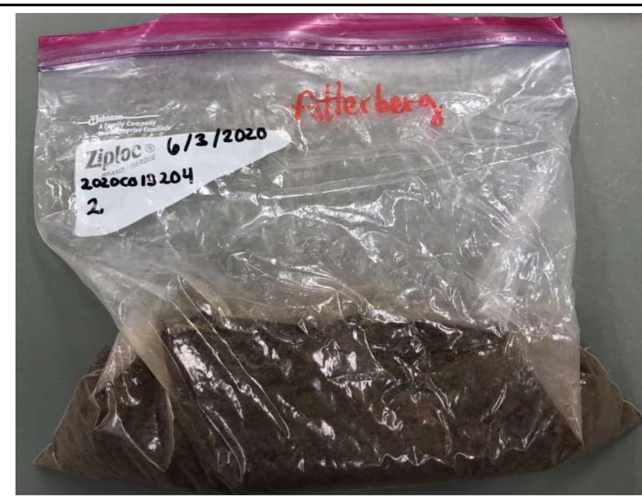
" WATER CONTENT"

Code		2020co13204	
Denomination		#W8-1	
Date		-	
ITEM		**Test No.**	
	1	**2**	**3**
1. Can No.	C-22	C-23	C-24
2. Mass of can, M1 (g)	12.43	12.50	11.83
3. Mass of can + wet soil, M_2 (g)	39.49	34.36	39.30
4. Mass of can + dry soil, M_3 (g)	38.35	33.19	38.19
5. Mass of moisture, M_2 - M_3 (g)	1.14	1.17	1.11
6. Mass of dry soil, M_3 - M_1 (g)	25.92	20.69	26.36
7. Water content, w (%) = ((M_2 - M_3)/(M_3 - M_1)) x 100	4.40%	5.65%	4.21%
Average water content		**4.75%**	



Soil Sample Picture

Code		2020CO13204	
Denomination		2 (Atterberg)	
Date		3/6/2020	
ITEM		**Test No.**	
	1	**2**	**3**
1. Can No.	C-3		
2. Mass of can, M1 (g)	12.28		
3. Mass of can + wet soil, M_2 (g)	45.77		
4. Mass of can + dry soil, M_3 (g)	43.93		
5. Mass of moisture, M_2 - M_3 (g)	1.84		
6. Mass of dry soil, M_3 - M_1 (g)	31.65		
7. Water content, w (%) = ((M_2 - M_3)/(M_3 - M_1)) x 100	5.81%		
Average water content		**5.81%**	



Soil Sample Picture

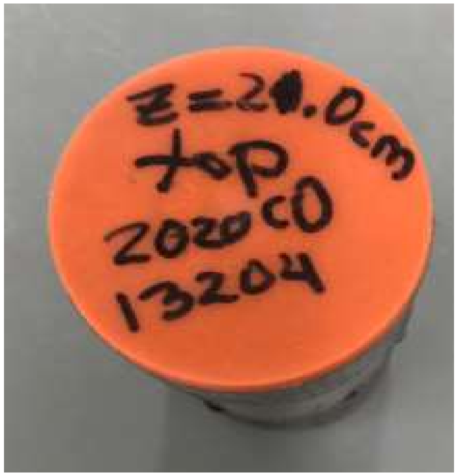
COLORADO SCHOOL OF MINES

PROFESSOR: Ph.D. Alexandra Wayllace
T.A.: Angel Rodrigo Angulo Calderon
PROJECT: Ingram Gulch

SOIL MECHANICS LABORATORY

" WATER CONTENT"

Code		2020CO13204	
Denomination		top	
Date		-	
ITEM	**Test No.**		
	1	**2**	**3**
1. Can No.	C-10		
2. Mass of can, M1 (g)	12.50		
3. Mass of can + wet soil, M_2 (g)	43.94		
4. Mass of can + dry soil, M_3 (g)	41.51		
5. Mass of moisture, M_2 - M_3 (g)	2.43		
6. Mass of dry soil, M_3 - M_1 (g)	29.01		
7. Water content, w (%) = $((M_2 - M_3)/(M_3 - M_1)) \times 100$	8.38%		
Average water content		**8.38%**	



Soil Sample Picture

Code		2020CO13204	
Denomination		bottom	
Date		-	
ITEM	**Test No.**		
	1	**2**	**3**
1. Can No.	C-9		
2. Mass of can, M1 (g)	12.02		
3. Mass of can + wet soil, M_2 (g)	55.10		
4. Mass of can + dry soil, M_3 (g)	53.03		
5. Mass of moisture, M_2 - M_3 (g)	2.07		
6. Mass of dry soil, M_3 - M_1 (g)	41.01		
7. Water content, w (%) = $((M_2 - M_3)/(M_3 - M_1)) \times 100$	5.05%		
Average water content		**5.05%**	

Soil Sample Picture

Appendix B

Sample 2020CO643202

COLORADO SCHOOL OF MINES

SOIL MECHANICS LABORATORY

PROFESSOR: PhD. Alexandra Wayllace
T.A.: Angel Rodrigo Angulo Calderon
TERM: Fall 2020

" SIEVE ANALYSIS"

SIEVE ANALYSIS

Description of soil **Ingram Gulch** .... Sample No. **2020CO643202**

Mass of dry specimen W= 406.9 $[g]$

Location **Boulder Landslide**..

Tested by **Angel Rodrigo Angulo Calderon**................................ Date **December 14th, 2020**

Sieve No.	Sieve opening (mm)	Mass of soil retained on each sieve, W_n (g)	Percent of mass retained on each sieve R_n	Cumulative percent retained $\sum R_n$	Percent finer $100-\sum R_n$
4	4.75	75.8	19.28	19.28	80.72
10	2	114.6	29.15	48.42	51.58
20	0.85	79.2	20.14	68.57	31.43
40	0.425	55.9	14.22	82.78	17.22
60	0.25	32.3	8.21	91.00	9.00
120	0.124	31.0	7.88	98.88	1.12
200	0.075	3.7	0.94	99.82	0.18
Pan		0.7			

$\sum W_n = W_1 =$ 393.2

Mass loss during sieve analysis = 3.37%

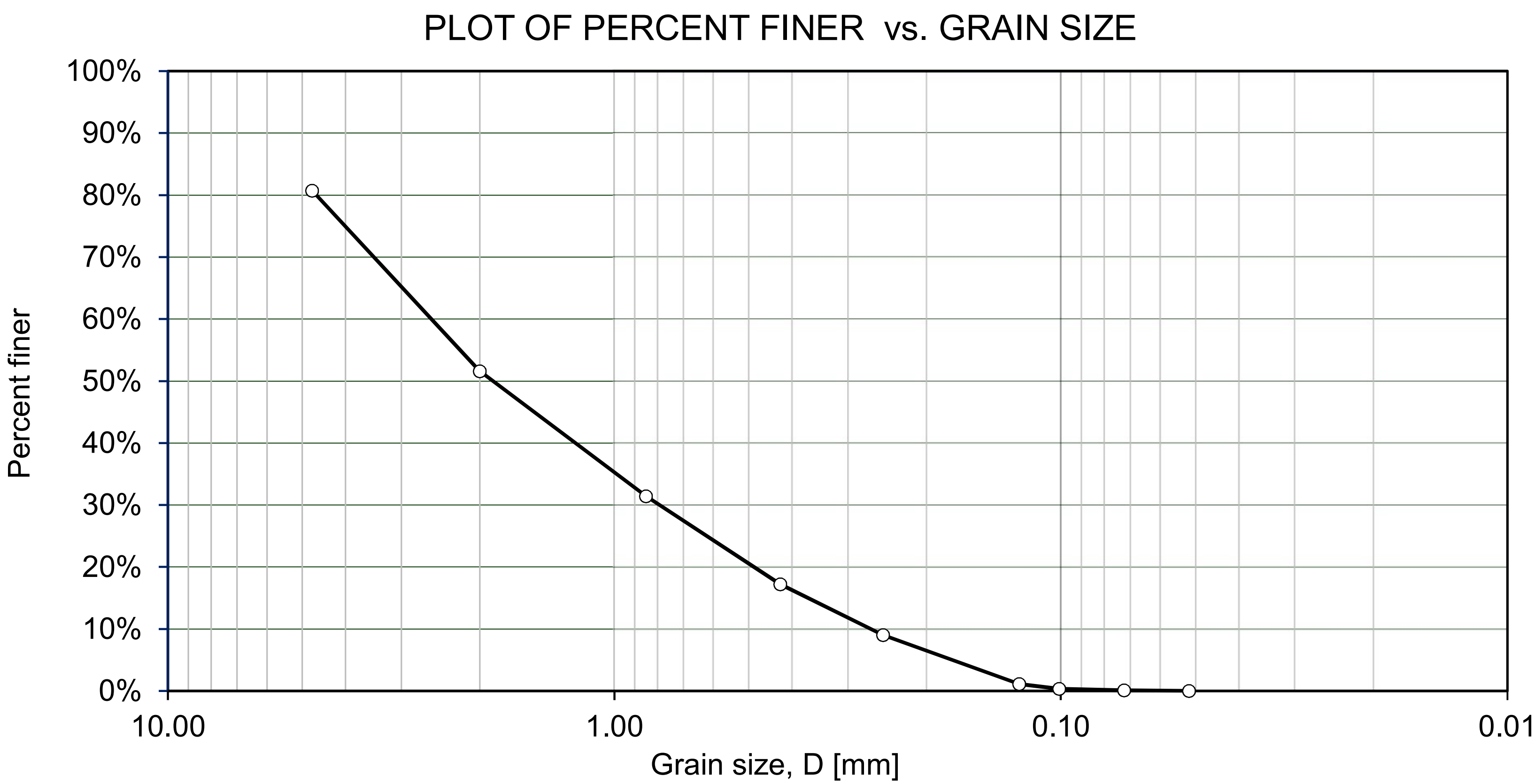
COLORADO SCHOOL OF MINES

SOIL MECHANICS LABORATORY

PROFESSOR: PhD. Alexandra Wayllace
T.A.: Angel Rodrigo Angulo Calderon
TERM: Fall 2020

" SIEVE ANALYSIS"

PLOT OF PERCENT FINER VS. GRAIN SIZE



COLORADO SCHOOL OF MINES

SOIL MECHANICS LABORATORY

PROFESSOR: PhD. Alexandra Wayllace
T.A.: Angel Rodrigo Angulo Calderon
TERM: Fall 2020

" SIEVE ANALYSIS"

SOIL CLASSIFICATION PARAMETERS

D [mm]	% Finer
4.7500	80.72%
2.0000	51.58%
0.8500	31.43%
0.4250	17.22%
0.2500	9.00%
0.1240	1.12%
0.1008	0.36%
0.0722	0.10%
0.0516	0.02%

D_{10} [mm]	=	0.20
D_{30} [mm]	=	0.70
D_{60} [mm]	=	2.55
C_u	=	12.75
C_c	=	1.37
% ret No. 200 =		99.82
% ret No. 4 =		19.28
% Gravel =		19.28
% Sand =		80.54
% Silt =		0.18
% Clay =		0.00
SW		

COLORADO SCHOOL OF MINES

SOIL MECHANICS LABORATORY

PROFESSOR: PhD. Alexandra Wayllace
T.A.: Angel Rodrigo Angulo Calderon
TERM: Fall 2020

"HYDROMETER TEST"

HYDROMETER ANALYSIS

Correction Factors		
Meniscus correction	F_m =	1
Zero correction	F_z =	1

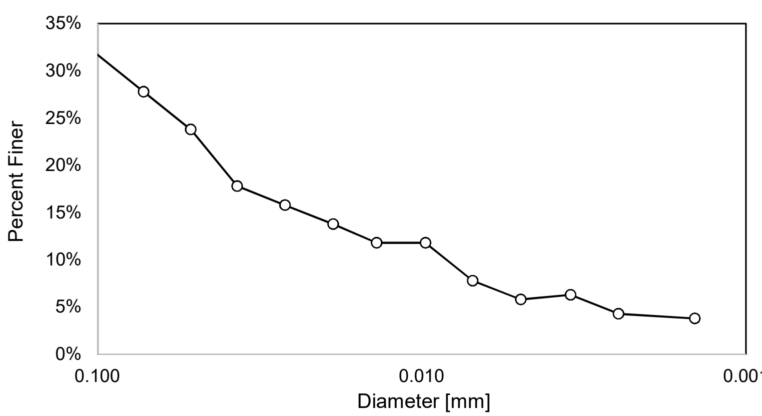
Soil Data		
Spec. gravity	G_s =	2.65
Soil mass	M_s [g]=	50
Viscosity	η (g*s/cm^2)=	9.11E-06

Hydrometer Data		
Length	L_2 [cm]=	14
Bulb volume	V_B [cm^3]=	67
Area	A_C [cm^2]=	27.8
	a =	1.00

(1) Time [min]	(2) Hydrometer Reading R	(3) Temperature [°C]	(4) R_{cp}	(5) Percent Finer ((a*R_{cp})/M_s)*100	(6) R_{cL}	(7) L [cm]	(8) A	(9) D [mm]	F_T	L_1 [cm]
0.25	17	19	15.90	31.80%	18	13.34	0.0138	0.1008	-0.1	7.5
0.5	15	19	13.9	27.80%	16	13.67	0.0138	0.0722	-0.1	7.9
1	13	19	11.9	23.80%	14	14.00	0.0138	0.0516	-0.1	8.2
2	10	19	8.9	17.80%	11	14.49	0.0138	0.0371	-0.1	8.7
4	9	19	7.9	15.80%	10	14.65	0.0138	0.0264	-0.1	8.9
8	8	19	6.9	13.80%	9	14.82	0.0138	0.0188	-0.1	9.0
15	7	19	5.9	11.80%	8	14.98	0.0138	0.0138	-0.1	9.2
30	7	19	5.9	11.80%	8	14.98	0.0138	0.0098	-0.1	9.2
60	5	19	3.9	7.80%	6	15.31	0.0138	0.0070	-0.1	9.5
120	4	19	2.9	5.80%	5	15.47	0.0138	0.0050	-0.1	9.7
240	4	20	3.15	6.30%	5	15.47	0.0137	0.0035	0.15	9.7
480	3	20	2.15	4.30%	4	15.64	0.0137	0.0025	0.15	9.8
1440	3	19	1.9	3.80%	4	15.64	0.0138	0.0014	-0.1	9.8

SAMPLE: 2020CO643202

Gradation curve only for hydrometry analysis only



COLORADO SCHOOL OF MINES | SOIL MECHANICS LABORATORY

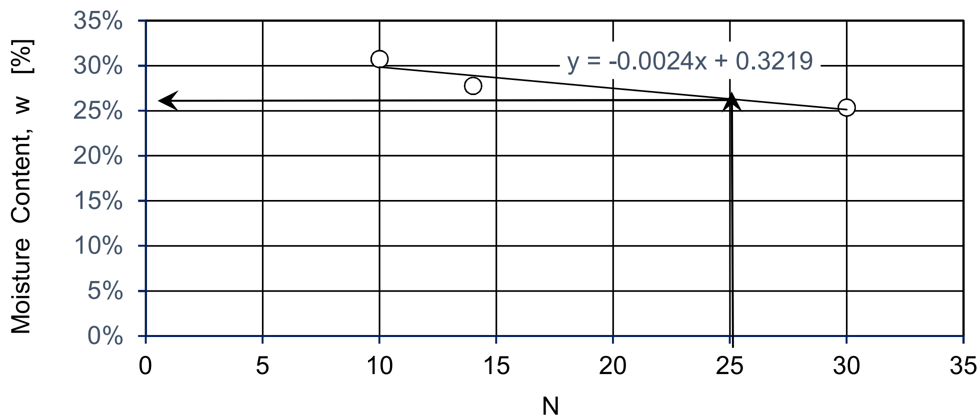
PROFESSOR: PhD. Alexandra Wayllace
T.A.: Angel Rodrigo Angulo Calderon
TERM: Fall 2020

LIQUID LIMIT TEST

LIQUID LIMIT TEST

Description of soil **Inram Gulch**…………………Sample No. **2020CO643202**……………………..…
Location **Boulder Landslide**……………………..………………………………..………...……………..
Tested by **Angel Rodrigo Angulo Calderon**…Date **December 14th, 2020** ……………………..

Item		Test No.		
		1	2	3
Can No.		1-1	1-2	1-3
Mass of can	W_1 $[g]$	11.91	11.83	12.14
Mass of can + we	W_2 $[g]$	18.88	19.33	19.2
Mass of can + dry	W_3 $[g]$	17.47	17.7	17.54
Mass of moisture	$W_2 - W_3$ $[g]$	1.41	1.63	1.66
Mass of dry soil	$W_3 - W_1$ $[g]$	5.56	5.87	5.4
Moisture content	$w\ [\%] = \frac{W_2 - W_3}{W_3 - W_1} * 100$	25.36%	27.77%	30.74%
Number of blows	N	30	14	10



			w=a*N+b				$\left(\frac{N}{25}\right)^{0,121}$
N=	25	a =	-0.0024	b=	0.3219		

Liquid limit = 26.19%

$N_1 =$ 20 $\rightarrow$ $w_1 =$ 27.39%
$N_2 =$ 30 $\rightarrow$ $w_2 =$ 24.99%

Flow index = 13.63%

$$F_1 = \frac{w_1\ [\%] - w_2\ [\%]}{logN_2 - logN_1}$$

Appendix C

Sample 2020CO13205

COLORADO SCHOOL OF MINES

SOIL MECHANICS LABORATORY

PROFESSOR: PhD. Alexandra Wayllace
T.A.: Angel Rodrigo Angulo Calderon
TERM: Fall 2020

" SIEVE ANALYSIS"

SIEVE ANALYSIS

Description of soil **Ingram Gulch** .... Sample No. **2020CO13205**

Mass of dry specimen W= 502.4 $[g]$

Location **Boulder Landslide**...

Tested by **Angel Rodrigo Angulo Calderon**................................... Date **December 14th, 2020**

Sieve No.	Sieve opening (mm)	Mass of soil retained on each sieve, W_n (g)	Percent of mass retained on each sieve R_n	Cumulative percent retained $\sum R_n$	Percent finer $100-\sum R_n$
4	4.75	44.7	9.00	9.00	91.00
10	2	86.6	17.44	26.44	73.56
20	0.85	125.7	25.31	51.75	48.25
40	0.425	88.4	17.80	69.55	30.45
60	0.25	75.0	15.10	84.66	15.34
120	0.124	50.4	10.15	94.80	5.20
200	0.075	22.8	4.59	99.40	0.60
Pan		3.0			

$\sum W_n = W_1 =$ 496.6

Mass loss during sieve analysis = 1.154%

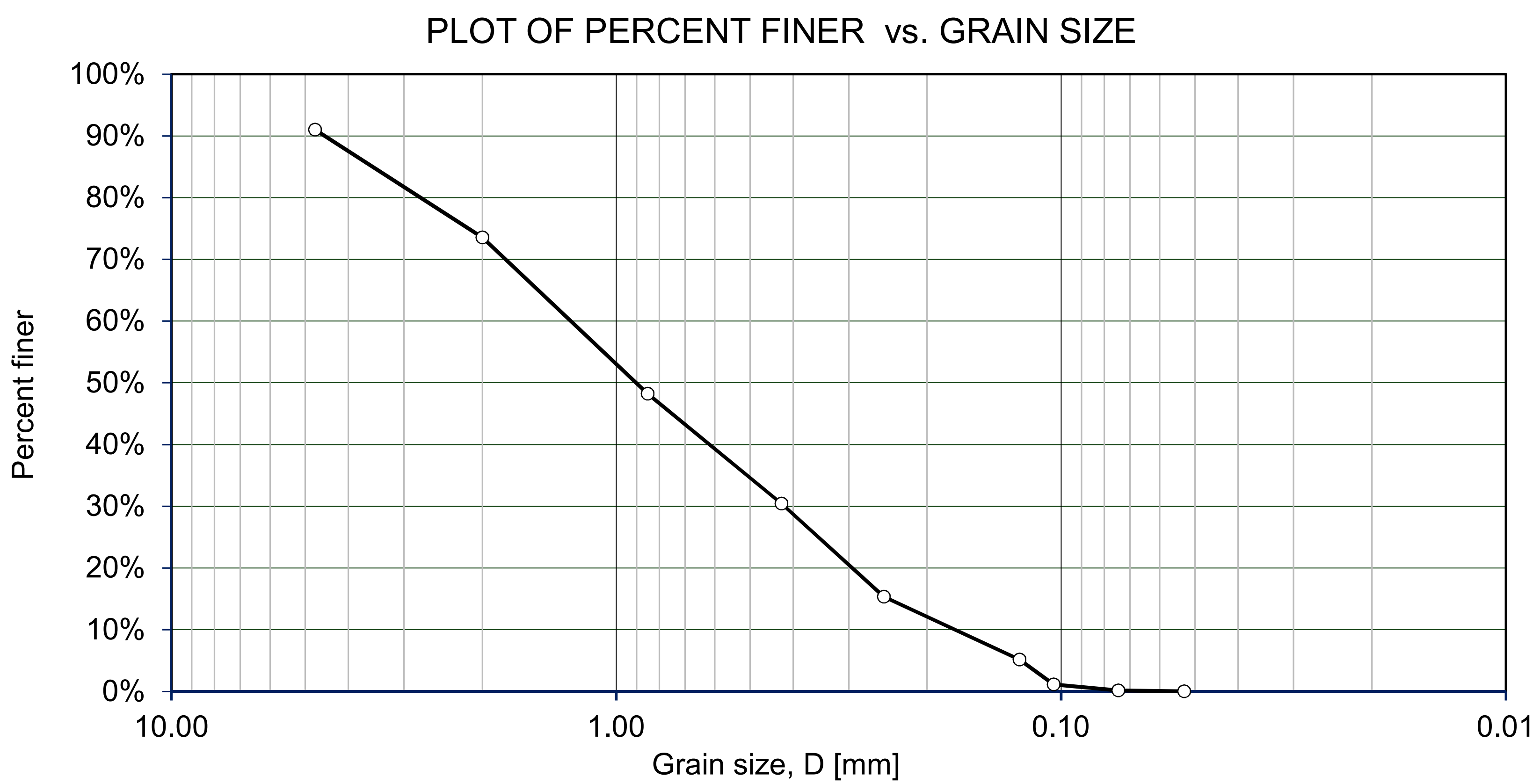
COLORADO SCHOOL OF MINES

PROFESSOR: PhD. Alexandra Wayllace
T.A.: Angel Rodrigo Angulo Calderon
TERM: Fall 2020

SOIL MECHANICS LABORATORY

" SIEVE ANALYSIS"

PLOT OF PERCENT FINER VS. GRAIN SIZE



COLORADO SCHOOL OF MINES

SOIL MECHANICS LABORATORY

PROFESSOR: PhD. Alexandra Wayllace
T.A.: Angel Rodrigo Angulo Calderon
TERM: Fall 2020

" SIEVE ANALYSIS"

SOIL CLASSIFICATION PARAMETERS

D [mm]	% Finer
4.7500	91.00%
2.0000	73.56%
0.8500	48.25%
0.4250	30.45%
0.2500	15.34%
0.1240	5.20%
0.1039	1.13%
0.0743	0.20%
0.0528	0.03%

D_{10} [mm]	=	0.17
D_{30} [mm]	=	0.41
D_{60} [mm]	=	1.40
C_u	=	8.24
C_c	=	1.72
% ret No. 200 =		99.40
% ret No. 4 =		9.00
% Gravel =		9.00
% Sand =		90.39
% Silt =		0.60
% Clay =		0.00
SW		

COLORADO SCHOOL OF MINES

PROFESSOR: PhD. Alexandra Wayllace
T.A.: Angel Rodrigo Angulo Calderon
TERM: Fall 2020

SOIL MECHANICS LABORATORY

"HYDROMETER TEST"

HYDROMETER ANALYSIS

Correction Factors		
Meniscus correction	F_m =	1
Zero correction	F_z =	1

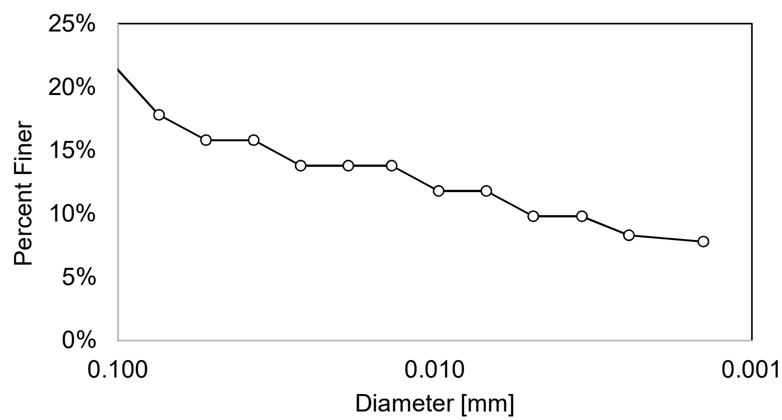
Soil Data		
Spec. gravity	G_s =	2.65
Soil mass	M_s [g]=	50
Viscosity	η (g*s/cm^2)=	9.11E-06

Hydrometer Data		
Length	L_2 [cm]=	14
Bulb volume	V_B [cm^3]=	67
Area	A_c [cm^2]=	27.8
	a =	1.00

(1) Time [min]	(2) Hydrometer Reading R	(3) Temperature [°C]	(4) R_{cp}	(5) Percent Finer ((a*R_{cp})/M_s)*100	(6) R_{cL}	(7) L [cm]	(8) A	(9) D [mm]	F_T	L_1 [cm]
0.25	12	19	10.90	21.80%	13	14.16	0.0138	0.1039	-0.1	8.4
0.5	10	19	8.9	17.80%	11	14.49	0.0138	0.0743	-0.1	8.7
1	9	19	7.9	15.80%	10	14.65	0.0138	0.0528	-0.1	8.9
2	9	19	7.9	15.80%	10	14.65	0.0138	0.0374	-0.1	8.9
4	8	19	6.9	13.80%	9	14.82	0.0138	0.0266	-0.1	9.0
8	8	19	6.9	13.80%	9	14.82	0.0138	0.0188	-0.1	9.0
15	8	19	6.9	13.80%	9	14.82	0.0138	0.0137	-0.1	9.0
30	7	19	5.9	11.80%	8	14.98	0.0138	0.0098	-0.1	9.2
60	7	19	5.9	11.80%	8	14.98	0.0138	0.0069	-0.1	9.2
120	6	19	4.9	9.80%	7	15.15	0.0138	0.0049	-0.1	9.4
240	6	19	4.9	9.80%	7	15.15	0.0137	0.0034	-0.1	9.4
480	5	20	4.15	8.30%	6	15.31	0.0137	0.0024	0.15	9.5
1440	5	19	3.9	7.80%	6	15.31	0.0138	0.0014	-0.1	9.5

SAMPLE: 2020CO13205

Gradation curve only for hydrometry analysis only



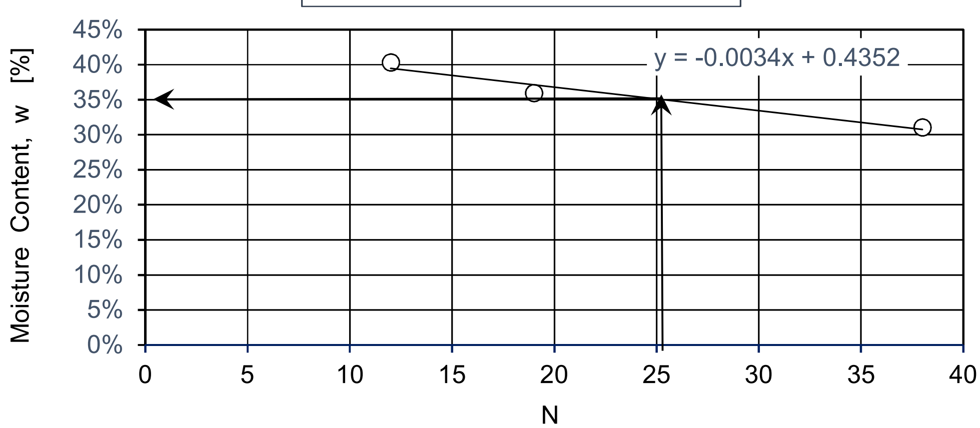
COLORADO SCHOOL OF MINES	SOIL MECHANICS LABORATORY
PROFESSOR: PhD. Alexandra Wayllace T.A.: Angel Rodrigo Angulo Calderon TERM: Fall 2020	LIQUID LIMIT TEST

LIQUID LIMIT TEST

Description of soil **Inram Gulch**…………………Sample No. **2020CO13205**……………………..…
Location **Boulder Landslide**…………………………………………………………………………………..
Tested by **Angel Rodrigo Angulo Calderon**…Date **December 14th, 2020** ……………………..

Item		Test No.		
		1	2	3
Can No.		II-1	II-2	II-3
Mass of can	W_1 $[g]$	16.31	12.51	12.81
Mass of can + we	W_2 $[g]$	40.45	30.88	31.39
Mass of can + dry	W_3 $[g]$	34.73	26.02	26.05
Mass of moisture	$W_2 - W_3$ $[g]$	5.72	4.86	5.34
Mass of dry soil	$W_3 - W_1$ $[g]$	18.42	13.51	13.24
Moisture content	$w\ [\%] = \frac{W_2 - W_3}{W_3 - W_1} * 100$	31.05%	35.97%	40.33%
Number of blows	N	38	19	12

LIQUID LIMIT TEST RESULTS



			w=a*N+b			
N=	25	a =	-0.0034	b=	0.4352	$\left(\frac{N}{25}\right)^{0,121}$

Liquid limit =	35.02%

$N_1 =$ 20 $\rightarrow$ $w_1 =$ 36.72%

$N_2 =$ 30 $\rightarrow$ $w_2 =$ 33.32%

Flow index = 19.31%

$$F_1 = \frac{w_1\ [\%] - w_2\ [\%]}{logN_2 - logN_1}$$

Appendix D

Sample 2020CO13204

COLORADO SCHOOL OF MINES

SOIL MECHANICS LABORATORY

PROFESSOR: PhD. Alexandra Wayllace
T.A.: Angel Rodrigo Angulo Calderon
TERM: Fall 2020

" SIEVE ANALYSIS"

SIEVE ANALYSIS

Description of soil **Ingram Gulch** .... Sample No. **2020CO13204**

Mass of dry specimen W= 508.6 $[g]$

Location **Boulder Landslide**..

Tested by **Angel Rodrigo Angulo Calderon**.................................. Date **December 14th, 2020**

Sieve No.	Sieve opening (mm)	Mass of soil retained on each sieve, W_n (g)	Percent of mass retained on each sieve R_n	Cumulative percent retained $\sum R_n$	Percent finer $100-\sum R_n$
4	4.75	67.7	13.40	13.40	86.60
10	2	83.5	16.52	29.92	70.08
20	0.85	104.8	20.74	50.66	49.34
40	0.425	92.0	18.21	68.87	31.13
60	0.25	61.9	12.25	81.12	18.88
120	0.124	57.4	11.36	92.48	7.52
200	0.075	28.9	5.72	98.20	1.80
Pan		9.1			

$\sum W_n = W_1 = 505.3$

Mass loss during sieve analysis = 0.649%

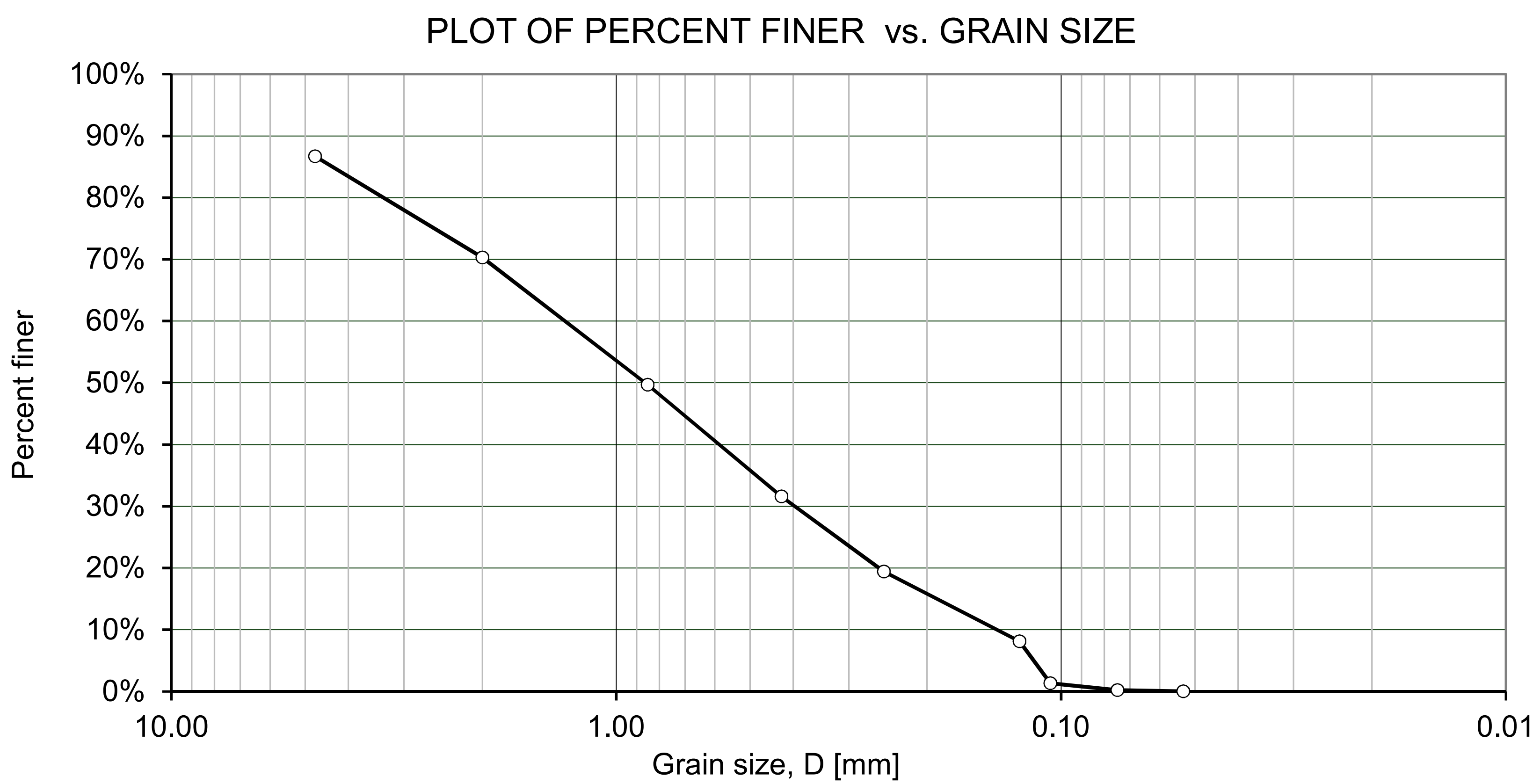
COLORADO SCHOOL OF MINES

SOIL MECHANICS LABORATORY

PROFESSOR: PhD. Alexandra Wayllace
T.A.: Angel Rodrigo Angulo Calderon
TERM: Fall 2020

" SIEVE ANALYSIS"

PLOT OF PERCENT FINER VS. GRAIN SIZE



COLORADO SCHOOL OF MINES

SOIL MECHANICS LABORATORY

PROFESSOR: PhD. Alexandra Wayllace
T.A.: Angel Rodrigo Angulo Calderon
TERM: Fall 2020

" SIEVE ANALYSIS"

SOIL CLASSIFICATION PARAMETERS

D [mm]	% Finer
4.7500	86.69%
2.0000	70.27%
0.8500	49.67%
0.4250	31.58%
0.2500	19.41%
0.1240	8.12%
0.1057	1.32%
0.0747	0.22%
0.0531	0.03%

D_{10} [mm]	=	0.15
D_{30} [mm]	=	0.40
D_{60} [mm]	=	1.40
C_u	=	9.33
C_c	=	1.90
% ret No. 200 =		98.20
% ret No. 4 =		13.40
% Gravel =		13.40
% Sand =		84.80
% Silt =		1.80
% Clay =		0.00
SW		

COLORADO SCHOOL OF MINES

PROFESSOR: PhD. Alexandra Wayllace
T.A.: Angel Rodrigo Angulo Calderon
TERM: Fall 2020

SOIL MECHANICS LABORATORY

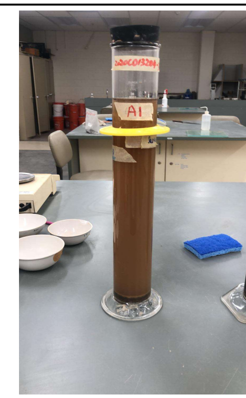
"HYDROMETER TEST"

HYDROMETER ANALYSIS

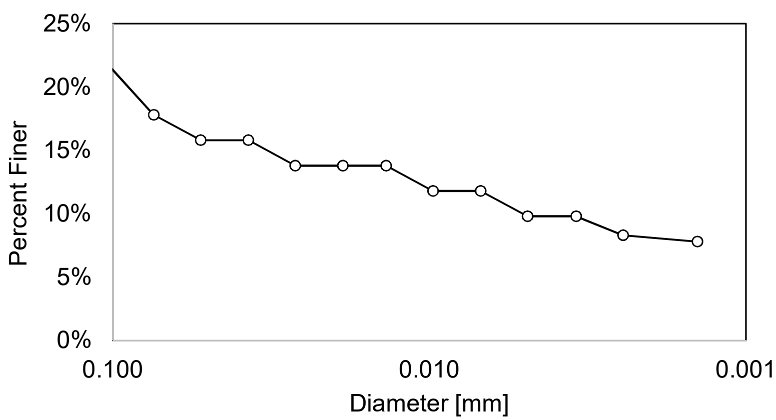
Correction Factors			Soil Data			Hydrometer Data		
Meniscus correction	F_m =	1	Spec. gravity	G_s =	2.65	Length	L_2 [cm]=	14
Zero correction	F_z =	1	Soil mass	M_s [g]=	50	Bulb volume	V_B [cm^3]=	67
			Viscosity	η (g*s/cm^2)=	9.11E-06	Area	A_c [cm^2]=	27.8
							a =	1.00

(1) Time [min]	(2) Hydrometer Reading R	(3) Temperature [°C]	(4) R_{cp}	(5) Percent Finer ((a*R_{cp})/M_s)*100	(6) R_{cL}	(7) L [cm]	(8) A	(9) D [mm]	F_T	L_1 [cm]
0.25	12	19	10.90	21.80%	13	14.16	0.0138	0.1039	-0.1	8.4
0.5	10	19	8.9	17.80%	11	14.49	0.0138	0.0743	-0.1	8.7
1	9	19	7.9	15.80%	10	14.65	0.0138	0.0528	-0.1	8.9
2	9	19	7.9	15.80%	10	14.65	0.0138	0.0374	-0.1	8.9
4	8	19	6.9	13.80%	9	14.82	0.0138	0.0266	-0.1	9.0
8	8	19	6.9	13.80%	9	14.82	0.0138	0.0188	-0.1	9.0
15	8	19	6.9	13.80%	9	14.82	0.0138	0.0137	-0.1	9.0
30	7	19	5.9	11.80%	8	14.98	0.0138	0.0098	-0.1	9.2
60	7	19	5.9	11.80%	8	14.98	0.0138	0.0069	-0.1	9.2
120	6	19	4.9	9.80%	7	15.15	0.0138	0.0049	-0.1	9.4
240	6	19	4.9	9.80%	7	15.15	0.0137	0.0034	-0.1	9.4
480	5	20	4.15	8.30%	6	15.31	0.0137	0.0024	0.15	9.5
1440	5	19	3.9	7.80%	6	15.31	0.0138	0.0014	-0.1	9.5

SAMPLE: 2020CO13204



Gradation curve only for hydrometry analysis only



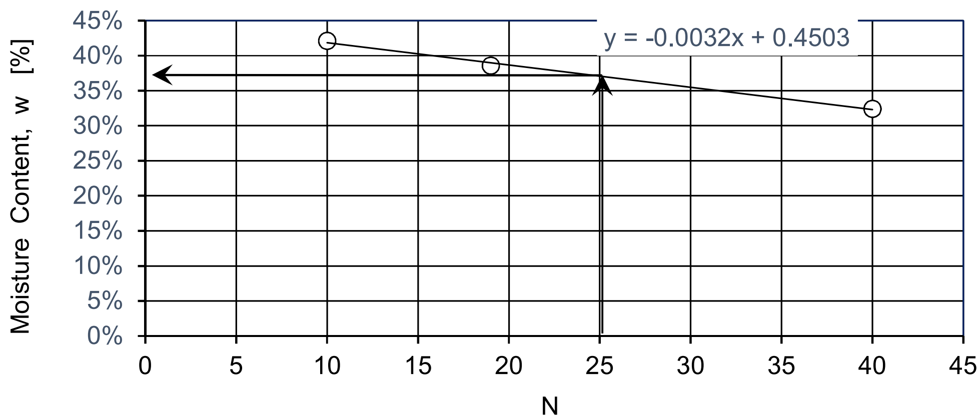
COLORADO SCHOOL OF MINES	SOIL MECHANICS LABORATORY
PROFESSOR: PhD. Alexandra Wayllace **T.A.:** Angel Rodrigo Angulo Calderon **TERM:** Fall 2020	LIQUID LIMIT TEST

LIQUID LIMIT TEST

Description of soil **Inram Gulch**…………………Sample No. **2020CO13204**………………………..…
Location **Boulder Landslide**……………………..………………………………..……….…..…………….
Tested by **Angel Rodrigo Angulo Calderon**…Date **December 14th, 2020** …………………….

Item	Test No. 1	Test No. 2	Test No. 3
Can No.	2-1	2-2	2-3
Mass of can W_1 $[g]$	11.66	12.44	11.82
Mass of can + we W_2 $[g]$	25.71	37.27	38.18
Mass of can + dry W_3 $[g]$	22.27	29.91	30.84
Mass of moisture $W_2 - W_3$ $[g]$	3.44	7.36	7.34
Mass of dry soil $W_3 - W_1$ $[g]$	10.61	17.47	19.02
Moisture content $w\ [\%] = \frac{W_2 - W_3}{W_3 - W_1} * 100$	32.42%	42.13%	38.59%
Number of blows N	40	10	19

LIQUID LIMIT TEST RESULTS



		w=a*N+b				
N=	25	a =	-0.0032	b=	0.4503	$\left(\frac{N}{25}\right)^{0,121}$

Liquid limit = 37.03%

$N_1 =$ 20 $\rightarrow$ $w_1 =$ 38.63%
$N_2 =$ 30 $\rightarrow$ $w_2 =$ 35.43%

Flow index = 18.17%

$$F_1 = \frac{w_1\ [\%] - w_2\ [\%]}{logN_2 - logN_1}$$

Appendix E

Sample 2020CO643203

COLORADO SCHOOL OF MINES

SOIL MECHANICS LABORATORY

PROFESSOR: PhD. Alexandra Wayllace
T.A.: Angel Rodrigo Angulo Calderon
TERM: Fall 2020

" SIEVE ANALYSIS"

SIEVE ANALYSIS

Description of soil **Ingram Gulch** .... Sample No. **2020CO643203**

Mass of dry specimen W= 461.2 $[g]$

Location **Boulder Landslide**..

Tested by **Angel Rodrigo Angulo Calderon**................................. Date **December 14th, 2020**

Sieve No.	Sieve opening (mm)	Mass of soil retained on each sieve, W_n (g)	Percent of mass retained on each sieve R_n	Cumulative percent retained $\sum R_n$	Percent finer $100-\sum R_n$
4	4.75	64.3	14.07	14.07	85.93
10	2	82.1	17.96	32.04	67.96
20	0.85	103.1	22.56	54.60	45.40
40	0.425	97.2	21.27	75.86	24.14
60	0.25	49.4	10.81	86.67	13.33
120	0.124	47.8	10.46	97.13	2.87
200	0.075	12.4	2.71	99.85	0.15
Pan		0.7			

$\sum W_n = W_1 =$ 457

Mass loss during sieve analysis = 0.911%

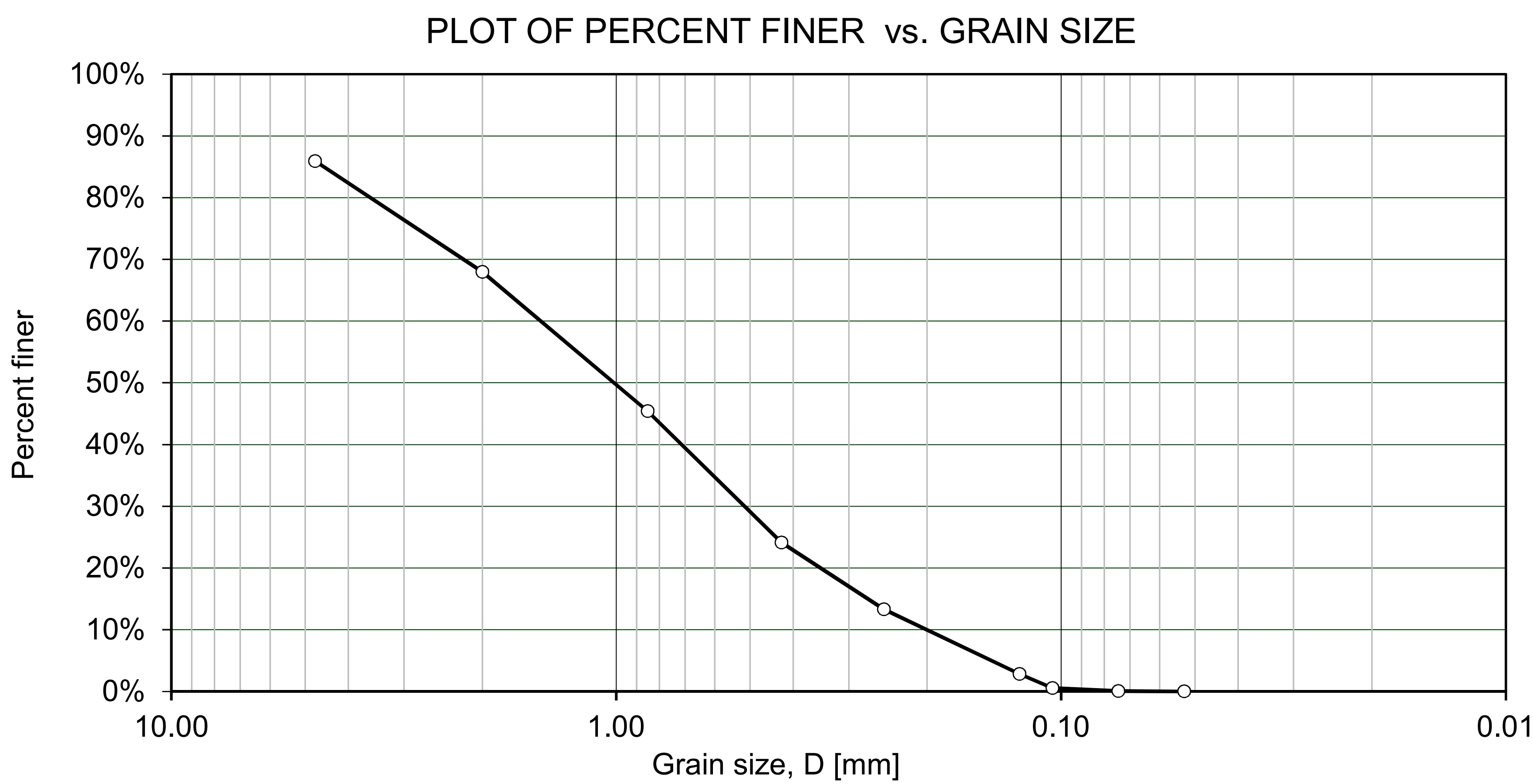
COLORADO SCHOOL OF MINES

SOIL MECHANICS LABORATORY

PROFESSOR: PhD. Alexandra Wayllace
T.A.: Angel Rodrigo Angulo Calderon
TERM: Fall 2020

" SIEVE ANALYSIS"

PLOT OF PERCENT FINER VS. GRAIN SIZE



COLORADO SCHOOL OF MINES

PROFESSOR: PhD. Alexandra Wayllace
T.A.: Angel Rodrigo Angulo Calderon
TERM: Fall 2020

SOIL MECHANICS LABORATORY

" SIEVE ANALYSIS"

SOIL CLASSIFICATION PARAMETERS

D [mm]	% Finer
4.7500	85.93%
2.0000	67.96%
0.8500	45.40%
0.4250	24.14%
0.2500	13.33%
0.1240	2.87%
0.1045	0.57%
0.0743	0.10%
0.0528	0.02%

D_{10} [mm]	=	0.20
D_{30} [mm]	=	0.50
D_{60} [mm]	=	1.65
C_u	=	8.25
C_c	=	1.52
% ret No. 200 =		99.85
% ret No. 4 =		14.07
% Gravel =		14.07
% Sand =		85.78
% Silt =		0.15
% Clay =		0.00
SW		

COLORADO SCHOOL OF MINES

PROFESSOR: PhD. Alexandra Wayllace
T.A.: Angel Rodrigo Angulo Calderon
TERM: Fall 2020

SOIL MECHANICS LABORATORY

"HYDROMETER TEST"

HYDROMETER ANALYSIS

Correction Factors		
Meniscus correction	F_m =	1
Zero correction	F_z =	1

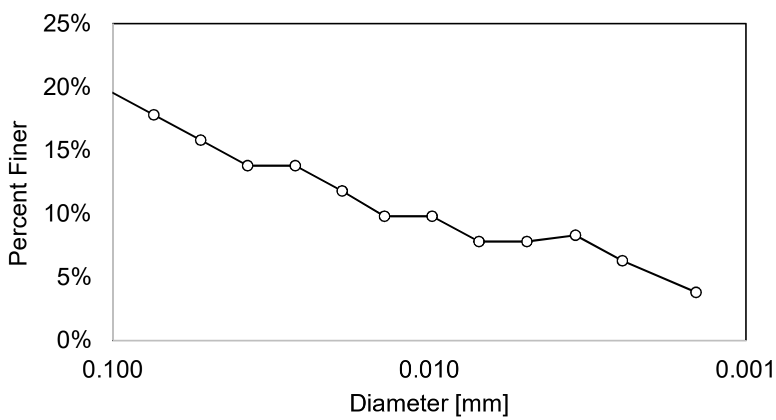
Soil Data		
Spec. gravity	G_s =	2.65
Soil mass	M_s [g]=	50
Viscosity	η (g*s/cm^2)=	9.11E-06

Hydrometer Data		
Length	L_2 [cm]=	14
Bulb volume	V_B [cm^3]=	67
Area	A_c [cm^2]=	27.8
	a =	1.00

SAMPLE: 2020CO643203

(1) Time [min]	(2) Hydrometer Reading R	(3) Temperature [°C]	(4) R_{cp}	(5) Percent Finer ((a*R_{cp})/M_s)*100	(6) R_{cL}	(7) L [cm]	(8) A	(9) D [mm]	F_T	L_1 [cm]
0.25	11	19	9.90	19.80%	12	14.33	0.0138	0.1045	-0.1	8.5
0.5	10	19	8.9	17.80%	11	14.49	0.0138	0.0743	-0.1	8.7
1	9	19	7.9	15.80%	10	14.65	0.0138	0.0528	-0.1	8.9
2	8	19	6.9	13.80%	9	14.82	0.0138	0.0376	-0.1	9.0
4	8	19	6.9	13.80%	9	14.82	0.0138	0.0266	-0.1	9.0
8	7	19	5.9	11.80%	8	14.98	0.0138	0.0189	-0.1	9.2
15	6	19	4.9	9.80%	7	15.15	0.0138	0.0139	-0.1	9.4
30	6	19	4.9	9.80%	7	15.15	0.0138	0.0098	-0.1	9.4
60	5	19	3.9	7.80%	6	15.31	0.0138	0.0070	-0.1	9.5
120	5	19	3.9	7.80%	6	15.31	0.0138	0.0049	-0.1	9.5
240	5	20	4.15	8.30%	6	15.31	0.0137	0.0035	0.15	9.5
480	4	20	3.15	6.30%	5	15.47	0.0137	0.0025	0.15	9.7
1440	3	19	1.9	3.80%	4	15.64	0.0138	0.0014	-0.1	9.8

Gradation curve only for hydrometry analysis only



COLORADO SCHOOL OF MINES | SOIL MECHANICS LABORATORY

PROFESSOR: PhD. Alexandra Wayllace
T.A.: Angel Rodrigo Angulo Calderon
TERM: Fall 2020

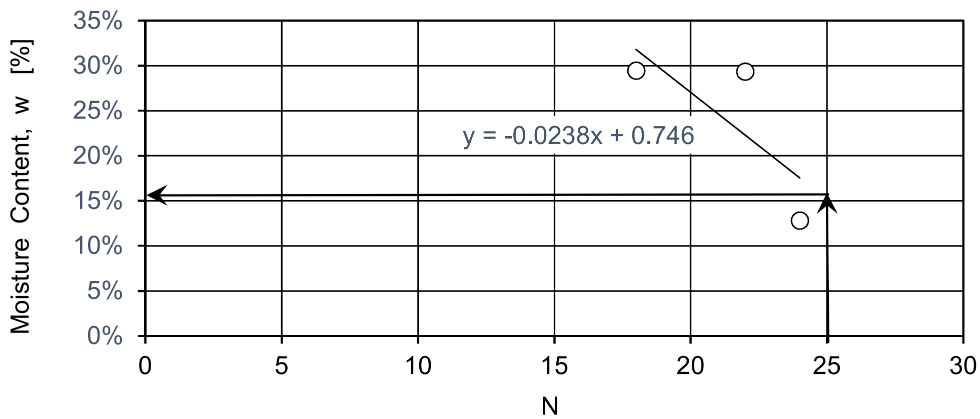
LIQUID LIMIT TEST

LIQUID LIMIT TEST

Description of soil **Inram Gulch**…………………Sample No. **2020CO643203**……………………..…
Location **Boulder Landslide**…………………..……………………………..………...……………..
Tested by **Angel Rodrigo Angulo Calderon**…Date **December 14th, 2020** ……………………..

Item		Test No.	
	1	2	3
Can No.	4-1	4-2	4-3
Mass of can W_1 $[g]$	12.95	12.64	11.9
Mass of can + we W_2 $[g]$	36.96	31.19	31.07
Mass of can + dry W_3 $[g]$	34.23	26.97	26.72
Mass of moisture $W_2 - W_3$ $[g]$	2.73	4.22	4.35
Mass of dry soil $W_3 - W_1$ $[g]$	21.28	14.33	14.82
Moisture content $w\ [\%] = \frac{W_2 - W_3}{W_3 - W_1} * 100$	12.83%	29.45%	29.35%
Number of blows N	24	18	22

LIQUID LIMIT TEST RESULTS



			w=a*N+b			
N=	25	a =	-0.0238	b=	0.746	$\left(\frac{N}{25}\right)^{0,121}$

Liquid limit = 15.10%

$N_1 =$ 20 $\rightarrow$ $w_1 =$ 27.00%
$N_2 =$ 30 $\rightarrow$ $w_2 =$ 3.20%

Flow index = 135.16%

$$F_1 = \frac{w_1\ [\%] - w_2\ [\%]}{logN_2 - logN_1}$$

Appendix F

Sample 2020CO643206

SIEVE ANALYSIS

Description of soil **Ingram Gulch** .... Sample No. **2020CO643206**

Mass of dry specimen W= 518.2 $[g]$

Location **Boulder Landslide**...

Tested by **Angel Rodrigo Angulo Calderon**................................. Date **December 14th, 2020**

Sieve No.	Sieve opening (mm)	Mass of soil retained on each sieve, W_n (g)	Percent of mass retained on each sieve R_n	Cumulative percent retained $\sum R_n$	Percent finer $100-\sum R_n$
4	4.75	135.2	27.23	27.23	72.77
10	2	78.8	15.87	43.09	56.91
20	0.85	70.1	14.12	57.21	42.79
40	0.425	94.6	19.05	76.26	23.74
60	0.25	48.7	9.81	86.07	13.93
120	0.124	53.3	10.73	96.80	3.20
200	0.075	15.1	3.04	99.84	0.16
Pan		0.8			

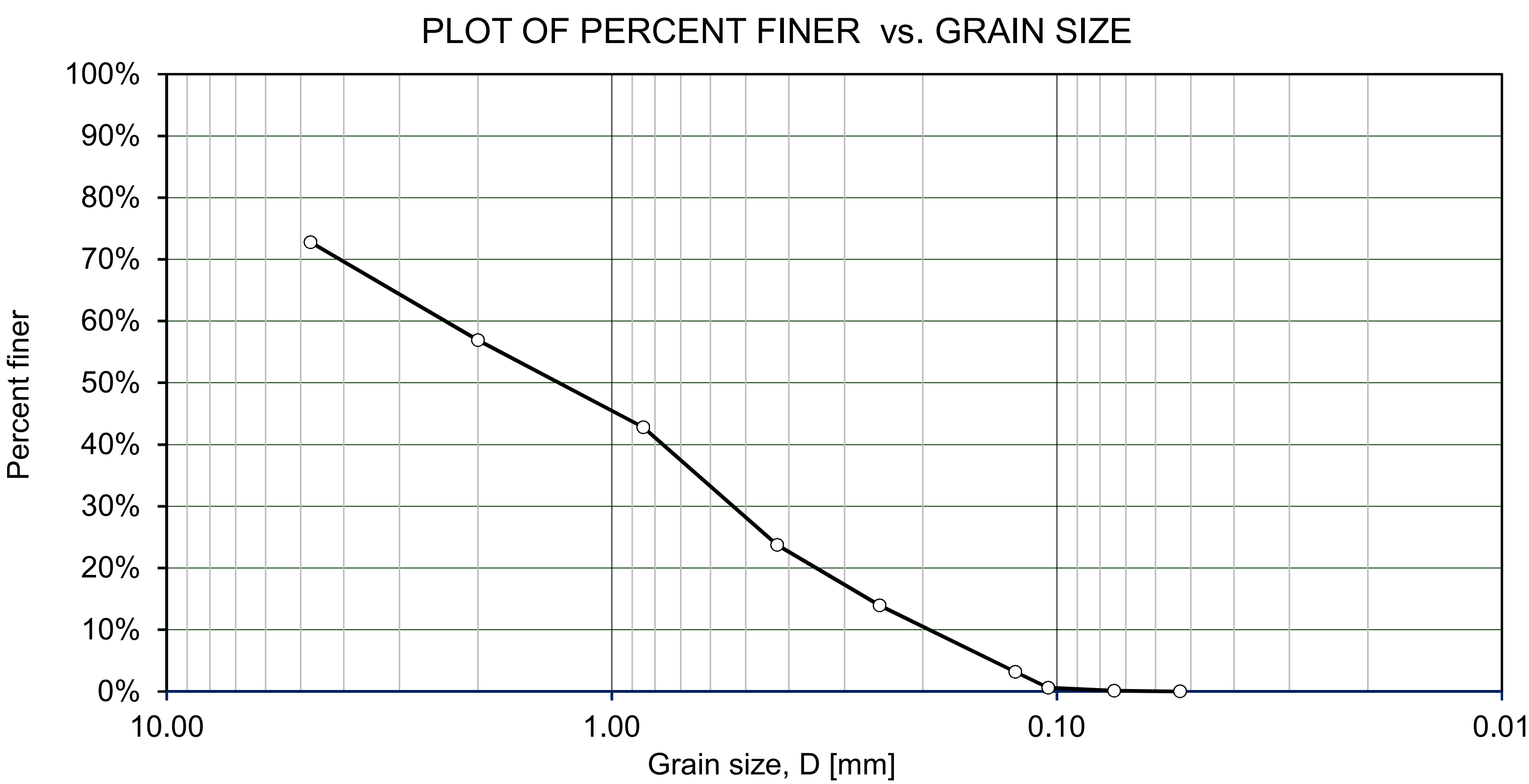
$\sum W_n = W_1 =$ 496.6

Mass loss during sieve analysis = 4.168%

PROFESSOR: PhD. Alexandra Wayllace
T.A.: Angel Rodrigo Angulo Calderon
TERM: Fall 2020

" SIEVE ANALYSIS"

PLOT OF PERCENT FINER VS. GRAIN SIZE



COLORADO SCHOOL OF MINES

SOIL MECHANICS LABORATORY

PROFESSOR: PhD. Alexandra Wayllace
T.A.: Angel Rodrigo Angulo Calderon
TERM: Fall 2020

" SIEVE ANALYSIS"

SOIL CLASSIFICATION PARAMETERS

D [mm]	% Finer
4.7500	72.77%
2.0000	56.91%
0.8500	42.79%
0.4250	23.74%
0.2500	13.93%
0.1240	3.20%
0.1045	0.63%
0.0743	0.11%
0.0528	0.02%

D_{10} [mm]	=	0.20
D_{30} [mm]	=	0.55
D_{60} [mm]	=	1.14
C_u	=	5.70
C_c	=	2.41
% ret No. 200 =		99.84
% ret No. 4 =		27.23
% Gravel =		27.23
% Sand =		72.61
% Silt =		0.16
% Clay =		0.00
SW		

COLORADO SCHOOL OF MINES

PROFESSOR: PhD. Alexandra Wayllace
T.A.: Angel Rodrigo Angulo Calderon
TERM: Fall 2020

SOIL MECHANICS LABORATORY

"HYDROMETER TEST"

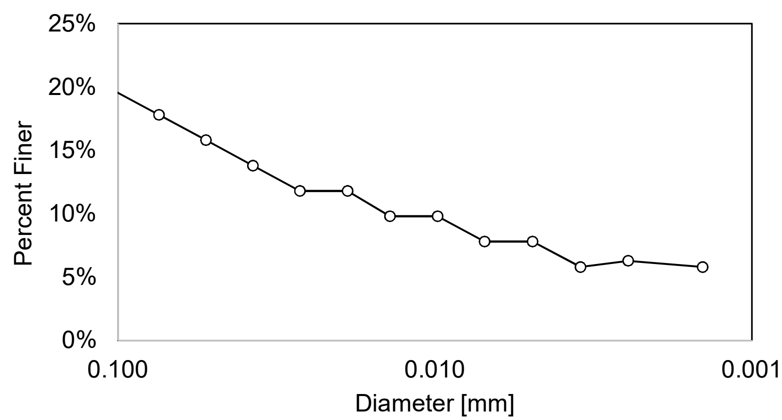
HYDROMETER ANALYSIS

Correction Factors			Soil Data			Hydrometer Data		
Meniscus correction	F_m =	1	Spec. gravity	G_s =	2.65	Length	L_2 [cm]=	14
Zero correction	F_z =	1	Soil mass	M_s [g]=	50	Bulb volume	V_B [cm^3]=	67
			Viscosity	η (g*s/cm^2)=	9.11E-06	Area	A_c [cm^2]=	27.8
							a =	1.00

(1) Time [min]	(2) Hydrometer Reading R	(3) Temperature [°C]	(4) R_{cp}	(5) Percent Finer $((a*R_{cp})/M_s)*100$	(6) R_{cL}	(7) L [cm]	(8) A	(9) D [mm]	F_T	L_1 [cm]
0.25	11	19	9.90	19.80%	12	14.33	0.0138	0.1045	-0.1	8.5
0.5	10	19	8.9	17.80%	11	14.49	0.0138	0.0743	-0.1	8.7
1	9	19	7.9	15.80%	10	14.65	0.0138	0.0528	-0.1	8.9
2	8	19	6.9	13.80%	9	14.82	0.0138	0.0376	-0.1	9.0
4	7	19	5.9	11.80%	8	14.98	0.0138	0.0267	-0.1	9.2
8	7	19	5.9	11.80%	8	14.98	0.0138	0.0189	-0.1	9.2
15	6	19	4.9	9.80%	7	15.15	0.0138	0.0139	-0.1	9.4
30	6	19	4.9	9.80%	7	15.15	0.0138	0.0098	-0.1	9.4
60	5	19	3.9	7.80%	6	15.31	0.0138	0.0070	-0.1	9.5
120	5	19	3.9	7.80%	6	15.31	0.0138	0.0049	-0.1	9.5
240	4	19	2.9	5.80%	5	15.47	0.0137	0.0035	-0.1	9.7
480	4	20	3.15	6.30%	5	15.47	0.0137	0.0025	0.15	9.7
1440	4	19	2.9	5.80%	5	15.47	0.0138	0.0014	-0.1	9.7

SAMPLE: 2020CO643206

Gradation curve only for hydrometry analysis only

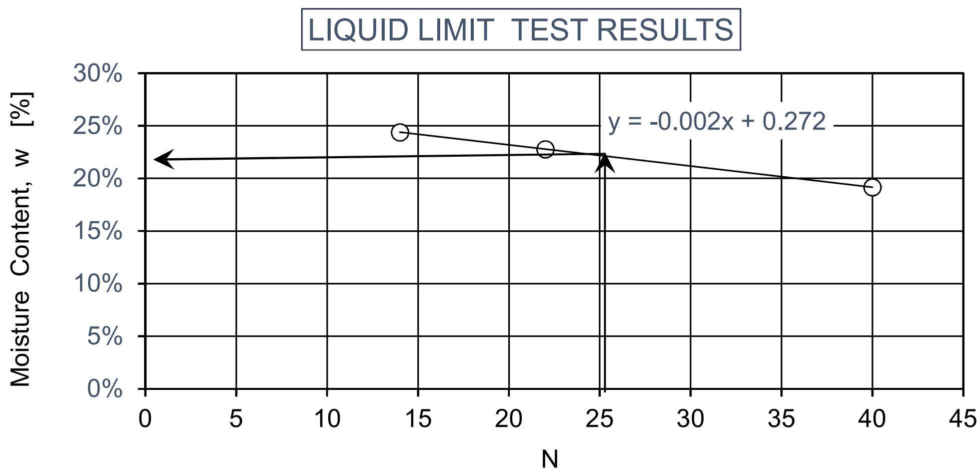


COLORADO SCHOOL OF MINES	SOIL MECHANICS LABORATORY
PROFESSOR: PhD. Alexandra Wayllace **T.A.:** Angel Rodrigo Angulo Calderon **TERM:** Fall 2020	LIQUID LIMIT TEST

LIQUID LIMIT TEST

Description of soil **Inram Gulch**…………………Sample No. **2020CO643206**…………………….…
Location **Boulder Landslide**…………………………………………………………………………..
Tested by **Angel Rodrigo Angulo Calderon**…Date **December 14th, 2020** …………………….

Item		Test No.	
	1	2	3
Can No.	V-1	V-2	V-3
Mass of can W_1 $[g]$	17.62	17.8	16.96
Mass of can + we W_2 $[g]$	35.66	36.07	43.64
Mass of can + dry W_3 $[g]$	32.76	32.68	38.41
Mass of moisture $W_2 - W_3$ $[g]$	2.9	3.39	5.23
Mass of dry soil $W_3 - W_1$ $[g]$	15.14	14.88	21.45
Moisture content $w\ [\%] = \frac{W_2 - W_3}{W_3 - W_1} * 100$	19.15%	22.78%	24.38%
Number of blows N	40	22	14



			w=a*N+b				
N=	25	a =	-0.002	b=	0.272		$\left(\frac{N}{25}\right)^{0,121}$

Liquid limit = 22.20%

$N_1 =$ 20 $\rightarrow$ $w_1 =$ 23.20%

$N_2 =$ 30 $\rightarrow$ $w_2 =$ 21.20%

Flow index = 11.36%

$$F_1 = \frac{w_1\ [\%] - w_2\ [\%]}{logN_2 - logN_1}$$