Investigation of Liquid Limit of Kamloops Silt by Soft-base Casagrande Apparatus and British Drop-Cone Penetrometer

by

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ABSTRACT

This study was to investigate the liquid limit of Kamloops silt using two world-wide popular testing apparatus: Casagrande device and British style Drop-Cone penetrometer. The testing with Casagrande device was conducted by a group of soil mechanics students in accordance with ASTM D423-61T (1961); the testing with British style Drop-Cone penetrometer was performed by two senior undergraduate engineering students in accordance with BS 1377 (1975). The liquid limit of Kamloops silt was found to be approximately 23%. The results obtained by both apparatus agreed to each other quite well, so these two testing methods can be alternative of each other. However, using Drop-Cone penetrometer required less experience of the operator and yielded results more easily and quickly than using Casagrande device. This paper also introduced the concept and the significance of Atterberg Limits, and summarized the development of Casagrande method by Arthur Casagrande and the evolution of Drop-Cone penetrating method.

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ACKNOWLEDGEMENT

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1.0 Introduction

1.1 Introduction

The liquid limit of fine-grained soil is the lowest water content when the soil-water mixture starts to behave like a viscous fluid and flows by its own weight (Nagaraj, 1993). It is a factor used in the classification of fine-grained soils, and it also relates to their engineering properties. Casagrande device and Drop-cone penetrometer are the two methods world-widely adopted in practice to determine the liquid limit of fine-grained soils. Since 1910s, engineers and scientists have performed both tests on numerous soil samples, and the results by both methods agree with each other in general.

This paper describes the process of determining the liquid limit of Kamloops Silts using a soft base Casagrande device and a British style Drop-cone penetrometer, and then compares the two methods in terms of the accuracy of results, ease of operation, and sources of errors.

1.2 Research Hypothesis

This paper is to evaluate the liquid limit of Kamloops Silts and to assess the consistency of the results obtained by both Casagrande Method and Drop-Cone Method.

2.0 Area Study

2.1 Geological History

Kamloops Silt Bluffs are distributed along the south bank of Thompson River, east of the City of Kamloops, British Columbia. Figure 1 shows the distribution of Kamloops Silt Bluffs which are alternatively named as Valleyview Silt Bluffs and Dallas Silt Bluffs and highlighted in green color. With the reference of NAD83 grid, the coordinates of the approximately 10-kilometer-long belt of silt bluffs are in Zone 10, 690000-701500 E, 5617000 N (NAD 83).

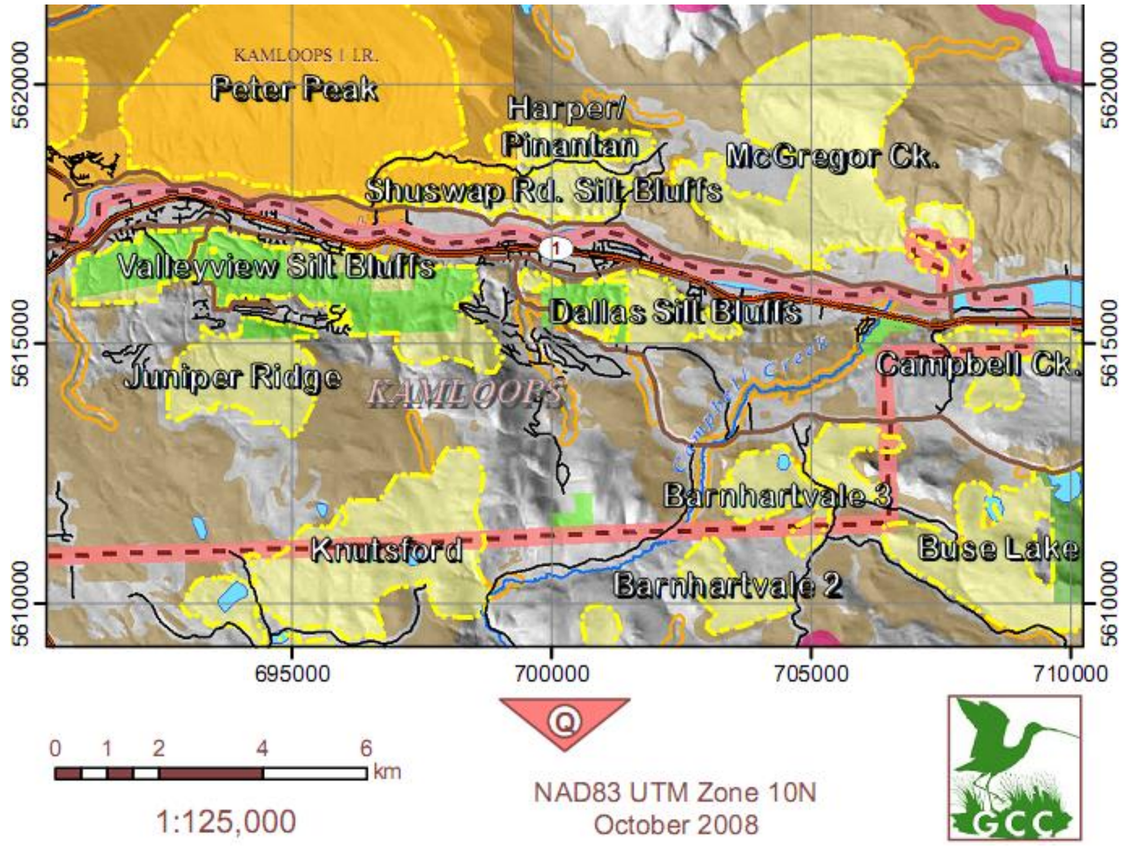

Figure 1: Map of Kamloops Silt Bluffs (GCC)

During the last deglaciation in late Wisconsinan (Roberts & Cummingham, 1992), in the process of ice receding, an ice tongue was trapped in Thompson Valley and was separated into eastern and western lobes that retreated apart each other. In the valley, lakes were formed by melted glaciers and enclosed by ice-dams. After these ice-dammed lakes were drained out, the glacial till was exposed. During the same period of time, maximum erosion, transportation, and deposition derived much of the lacustrine silts from the glacial till that was deposited on the uplands next to the Thompson Valley (Lum, 1979). The formation of Kamloops Silt Bluffs are presented in the photograph (Figure 2) and drawing (Figure 3) below.

Figure 2: Photograph of Kamloops Silt Bluffs (Roberts & Cummingham, 1992)

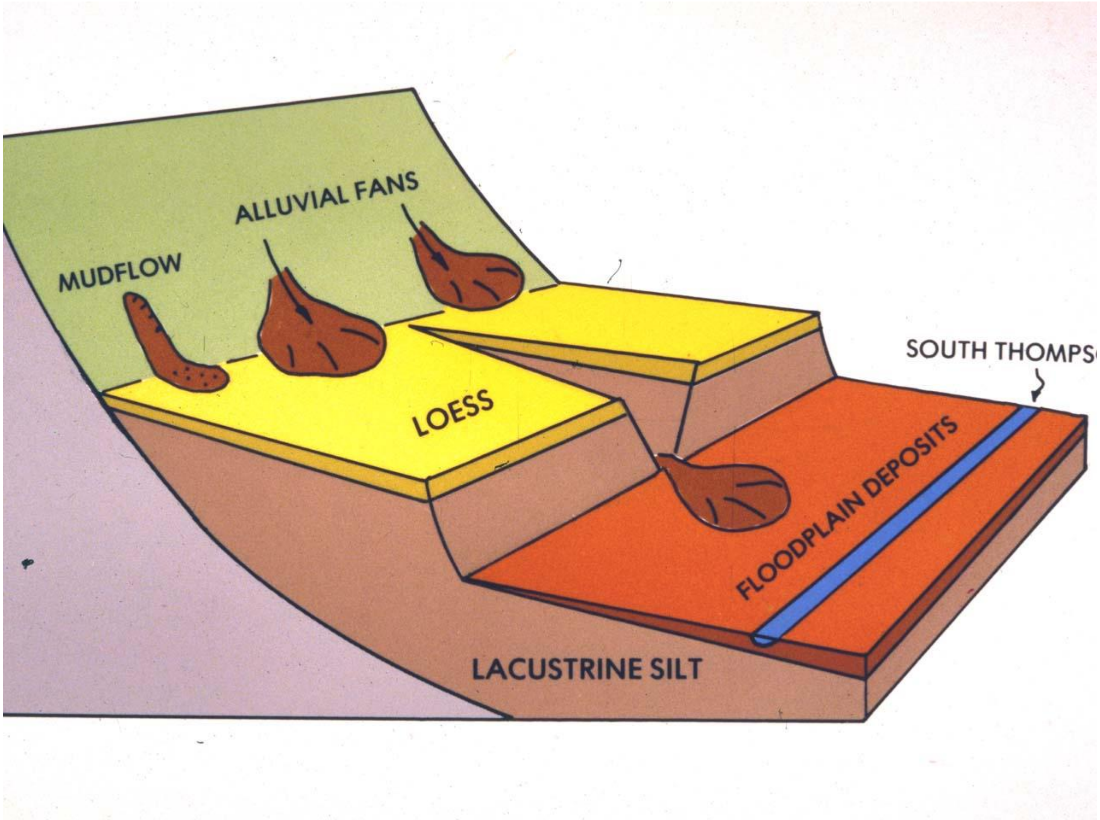

Figure 3: Illustrative Drawing of Stratigraphy of Kamloops Silt Bluffs (Roberts & Cummingham, 1992)

2.2 Current Climate at Kamloops

Kamloops, situated on the east side of the Rocky Mountains (rain shadow location), is in a semi-arid climate. The annual hours of sunshine are approximately 2000. The average annual precipitation is 256.5 mm, of which 174.8 mm is rainfall (BC Wildfire Management). The temperature changes significantly from season to season; the winter is usually mild and short, and the summer is prevailing hot and dry. According to the Department of Environment Canada, the mean temperature in January maintains around – 6.1 ℃ for most of time, with occasional colder period of – 29 ℃ and a historic extreme of – 38.3 ℃; the mean temperature in July stays about 20.8 ℃, with several days of 38 ℃ and a historic extreme of 41.7 ℃.

2.3 Description of Kamloops Silt

The soil sample was obtained from the Kamloops Silt Bluffs at Thompson River in Kamloops, British Columbia. A piece of uncrushed, air-dried soil sample exhibited light grey-beige colour, fair hardness, cohesiveness, and slight stratification. The crushed Kamloops silts were fine-grained inorganic soil with slight earthy smell.

Based on a sieve (#3) and hydrometer analysis performed by UBC undergraduate students under the supervision of professor and graduate students, Kamloops Silts consisted of about 4% of sand, 89% of silt, and 7% of clay. 10% of particles had sizes less than 0.0027mm; 60% of particles were smaller than 0.0092mm. By MIT classification, Kamloops silt was classified as uniform clayey silt (Lum, 1979).

A scanning electron microscope (Etec Autoscan Scanning Electron Microscope) study and a microprobe (Ortec Multichannel Analyser, Model 6200) study were also performed by Lum (1979) at the University of British Columbia campus. The mineralogy of soil particles were identified, such as mica, feldspar, and montmorillonite. Key elements were Si, Al, Fe, Ca, Mg, and Na, listed in the order of decreasing peak intensity observed in photomicrographs. Siliceous diatoms (a common species in freshwater lakes) scattered throughout the samples were also observed (Lum, 1979). This observation coincided with the theory that Kamloops silts were lacustrine silts exposed after ice-dammed lakes drained.

3.0 Literature Review

This section starts with an introduction to Atterberg Limits, followed by an invention of Arthur Casagrande. Next, a brief review of development of Drop-Cone method is presented.

3.1 Atterberg Limits

The Atterberg Limits are the measures of soil consistency that is defined as the "property of material which is manifested by its resistance to flow" (Jumikis, 1984). Consistency pertains to fine-grained (cohesive) soils only (Jumikis, 1984) and heavily depends on the water content of soil-water mixture, sometimes also referred as cohesion or plasticity. In soil mechanics, the term "plasticity" mostly means "the degree of plasticity" that is the ability of deformed soil to rearrange its particles without resulting in a noticeable volume change (Jumikis, 1984). The ability of rearranging soil particles and the resistance of soil to flow determines the shear strength of soil against external loading and directly influences the stability of slopes.

In 1911, Albert Atterberg, a famous Swedish chemist, reported his intensive research on the plasticity of fine-grained (cohesive) soil. He empirically set the limits of water content in soil as shrinkage limit (SL), plastic limit (PL), and liquid limit (LL), known collectively as Atterberg Limits, dividing the soil-water mixture into four phases as illustrated in Figure 4. Above liquid limit, soil-water mixture behaved like fluids; between plastic limit and liquid limit, the plastic soil-water mixture underwent continuous and permanent deformation without ruptures and exhibited certain level of shear strength that depended on the water content; below shrinkage limit (the least water content of saturated soil), the soil-water mixture was no longer saturated and no further volume decrease in the process of drying (Karol, 1955). In addition, cracks occurred when the solid-state soil-water mixture was deformed. Realistically, the transitions between phases were never abrupt but gradual (Nagaraj, 1993). Therefore, determination of Atterberg Limits to a precise point in the laboratory was virtually impossible. The acquisition of soil consistency testing results in the laboratory was empirically designed by the pioneers of soil mechanics.

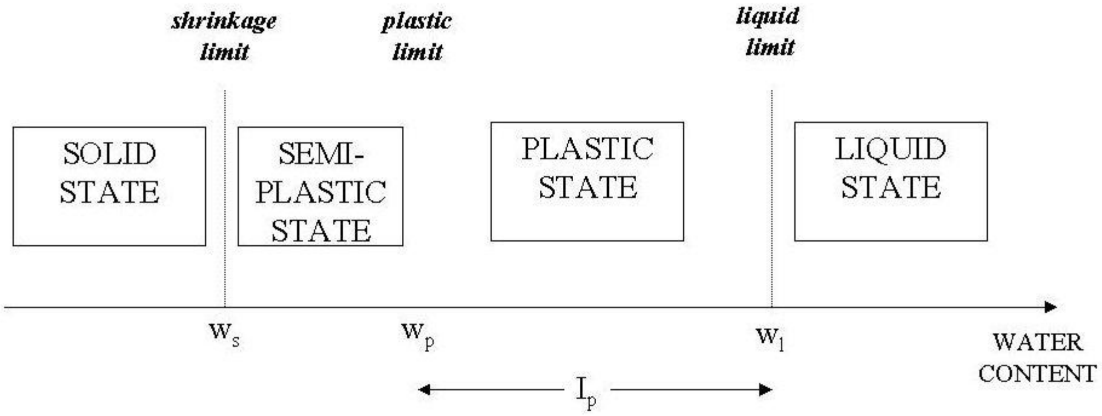

Figure 4: Four Phases of Soil-Water Mixture

Liquid limit is the focus of this paper. It is defined as the water content, expressed as a percentage of the weight of oven-dried soil, of the boundary between plastic phase and liquid phase. Liquid phase is usually seen as that the soil-water mixture is able to flow like a viscous fluid under its own weight. Exceeding the liquid limit, the soil-water mixture expands significantly in volume and exhibits no plasticity and no shear strength, which is vital factor controlling ground stability.

The importance of Atterberg Limits was not recognized until Terzaghi established the knowledge framework of soil mechanics and could see their potential application to classify fine-grained (cohesive) soils. The liquid limit was tested by 10 jarring blows with hands against a dish to just close the groove (Akroyd, 1957) and determined by operator's experience before Arthur Casagrande invented a mechanical device to test liquid limit with significant improvements in ease, accuracy, and repeatability.

3.2 An Invention of Arthur Casagrande

Arthur Casagrande (1902 – 1981) was a renowned civil engineer who was credited for numerous contributions to the advancement of soil mechanics. He was the Gordon McKay Professor of Soil Mechanics and Foundation Engineering Emeritus at Harvard University and served as the President of the International Society of Soil Mechanics and Foundation Engineering from 1961 to 1965. Casagrande was born in Austria in 1902 and immigrated to the United States in 1926, shortly after when he met Karl Terzaghi. While he worked as a private assistant of Karl Terzaghi at the Massachusetts Institute of Technology (MIT), Casagrande developed a mechanical liquid limit device (Figure 5) (Wilson, Seed, & Peck, 1984). Using this device to test the liquid limit of fine-grained soil became a standard practice in the United States, competing with Drop-Cone method that was popular in the rest of the world.

After thirty years of usage, Casagrande re-examined the device and testing procedures in 1958, and he realized some limitations of his method. He standardized the height of uplift and the hardness of rubber base; he re-designed the grooving tool that better cut the soil sample with low plasticity; he noticed the significance of the quality of soil sample prepared. A better thoroughly mixed and stabilized sample could yield a more accurate result. He found that the water content of samples that were oven-baked for over 24 hours is 3-6% higher than those were not well dried. Thus, a 24-hour baking time became a part of the standard testing procedures from then. He also revealed that the liquid limit test was closely related to a dynamic shear test which was stress controlled (without involving maximum stress) and strain dependent. Thus, he suggested that a simpler direct shear test or indirect shear test could be alternatives for testing liquid limit (Nagaraj, 1993).

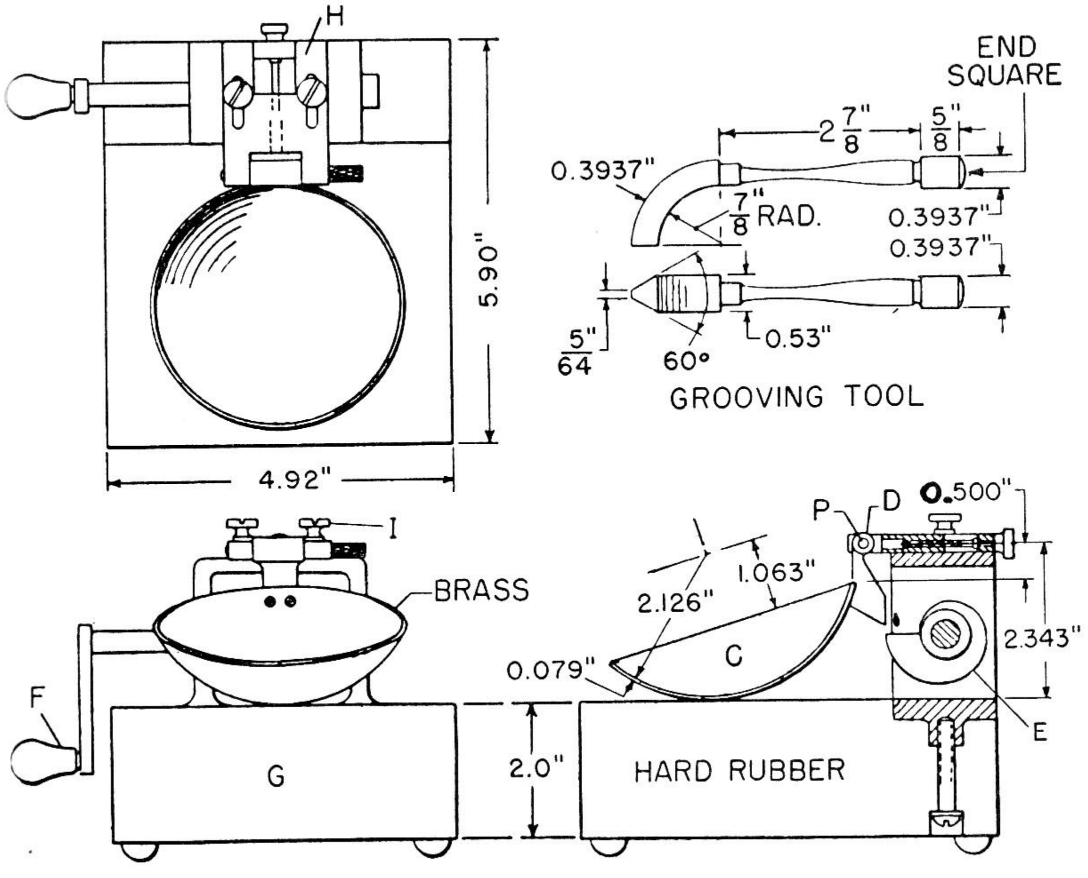

Figure 5: Schematic Drawing of Casagrande Liquid Limit Device (ASTM, 1958)

The accuracy of results was heavily dependent on the dimensions and the materials of apparatus. Thus, Casagrande specified the size of the brass cup, the new groove cutter, and the rubber base, as illustrated in Figure 5.

3.3 Drop-Cone Method

The method of using objects to penetrate into soil samples and to test shear strength was developed in Sweden in about the same period as when A. Casagrande proposed the means of determining the plasticity characteristics of fine-grained soils. Before a free falling cone was adopted, cylinder and ball were used to penetrate into soil samples to test the shear strength.

The basic mechanism of this method is to suspend a metal cone of specified apex angle and weight right above a leveled and smooth sample surface, then to release the cone an let it sink into the sample under its own weight. The depth of penetration (d) by the metal cone is related to the weight of cone (W) and the undrained shear strength (C_u) of soil sample. This relation is governed by the following equation:

$$\mathbf{C_u = k\frac{W}{d^2}}$$

where k is a constant for a cone of specified apex angle and weight.

A number of different styles of this device have been developed during its almost one-century-long application. The major differences are the apex angle and the mass of cone used. Typical apex angles include 30°, 60°, and 90°; the mass of cone varies from 10 grams to 400 grams. A British style Drop-Cone penetrometer utilizes a 35 mm long steel cone with apex angle of 30±1°. The mass of the steel cone and the sliding shaft is 80.00±0.05 g (BS1377, 1967).

In some area, this type of device is also named as “Fall-Cone” method. However, “Fall-Cone” penetrometer has been specifically referred to a soil shear strength testing device that utilizes a 60-gram cone with an apex angle of 60° (Campell, 1975).

Similarly, Drop-Cone penetrometer usually uses the 30 ° cone of 80 grams.

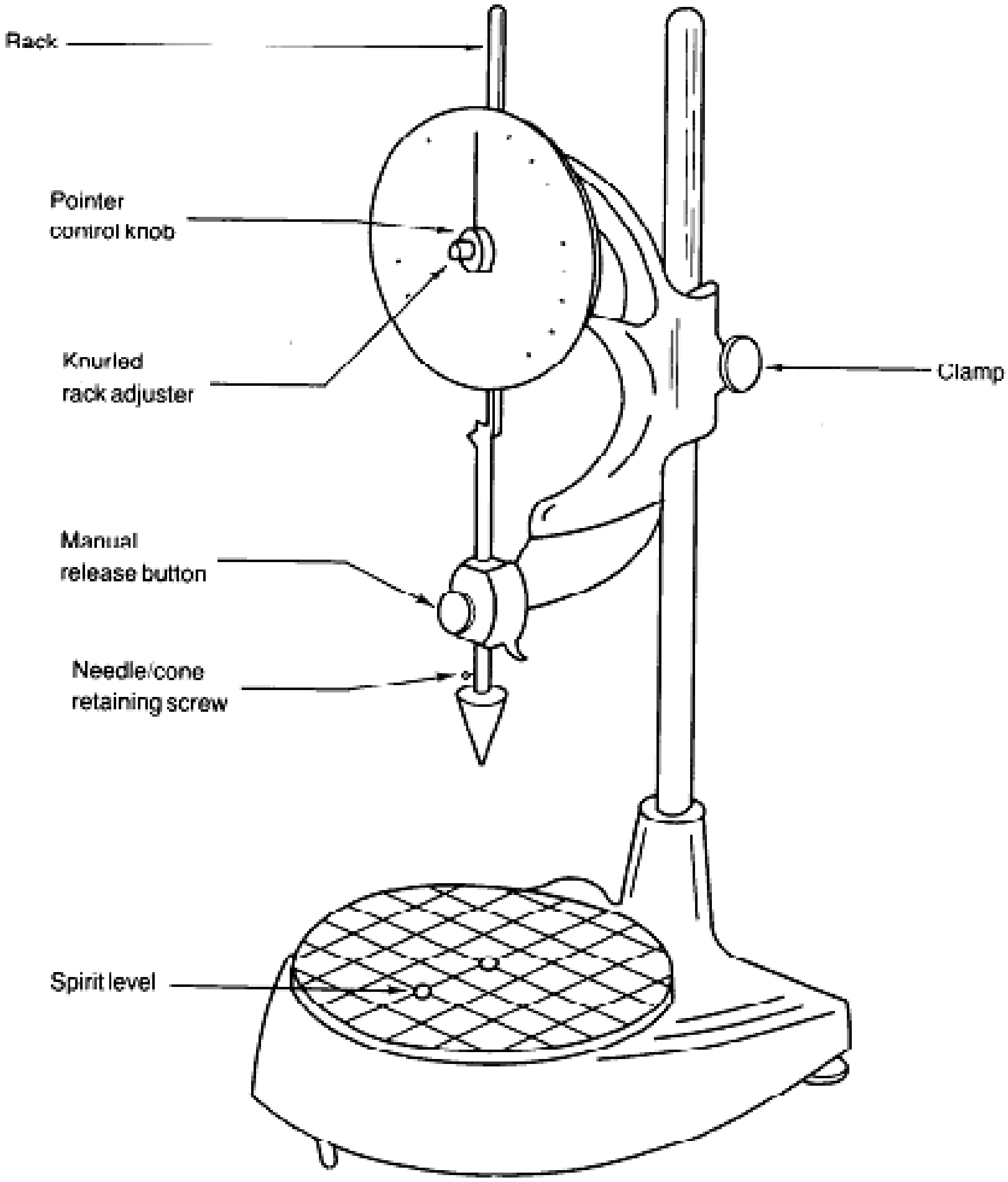

Figure 6: Sketch of British Style Drop-Cone Pentrometer

4.0 Testing Methods

Two standard methods of testing liquid limit of fine-grained soils are used: Casagrande method and Drop-Cone method. This chapter introduces the apparatus setup of both methods, illustrates the procedures of tests, and describes the process of acquiring results.

4.1 Casagrande Method

This section introduces the Casagrande method in terms of apparatus setup, procedures, and acquisition of results.

4.1.1 Apparatus Setup

A mechanical liquid limit device is consisted of the following parts:

- Brass Semi-spherical cup
- Cranking mechanism that lifts and drops the cup repeatedly
- Hard rubber base with footings

Other required apparatus include:

- Groove cutter
- Mixing bowl
- Spatula
- Syringe
- Glass plate
- Balance
- Tins and over

4.1.2 Testing Procedures

American Society for Testing and Materials (ASTM) is the regulatory body which publishes standard testing methods for engineering purposes. "Tentative Method of Test for Liquid Limit of Soil (ASTM D 423 – 61T)" gives the standard procedures of conducting tests using Casagrande device. The procedures are summarized in point form below:

- Fill the soil-water mixture into the brass cup like a soil cake with a level and smooth surface and a maximum depth of 1cm
- Cut an opening along the centerline of the soil cake with the groove cutter
- Crank to lift and drop the cup at the rate of two revolutions per second
- Count the number of blows and stop cranking immediately after the opening is just closed and the bottom of brass cup is no longer visible
- Take soil sample close to the grove and get the water content of the sample by oven-drying
- Repeated above procedures at least four times with soil-water mixture of different water contents.

4.1.3 Acquisition of Results

Arbitrarily defined by Casagrande, the liquid limit is the water content at which the two halves of soil cake flow together and cover the bottom of the groove for an half inch, when the cup is uplifted for 1 cm (0.3937 in.) and dropped for 25 times at a rate of two drops per second.

Having obtained the blow count and water content of each sample, one can plot these data on a semi-log graph that has the blow counts in algorithm scale on the horizontal axis. On the flow line (a best-fitted line) of these data points, the liquid limit will be the water content that corresponds to 25 blows.

4.2 Drop-Cone Method

A British style Drop-Cone Penetrometer (Figure 6) is used, so this section introduces the Drop-Cone method in terms of apparatus setup, procedures, and acquisition of results in accordance with British Standards (BS 1377: 1975).

4.2.1 Apparatus Setup

The key components of this apparatus include the metal cone, soil sample container, sliding shaft, and a gauge measuring penetration. The cone is made of stainless steel with an apex angle of $30 \pm 1°$ and a mass of 32.5 grams, with a sharp tip and polished surface. A weight of 50 grams is bound with the cone in order to comply with the standard mass of cone of 80 grams in British Standard 1377 (1975). The metal cup holding the soil sample is 60mm in diameter and 40mm in height. It has a flat base that is parallel to the rim. A gauge with precision of 0.1 mm is used to measure the depth of penetration; however, due to the imperfection of the gauge, a caliper is also used to check the accuracy of the penetration depth measured.

Other tools used are similar to the ones used in Casagrande method, such as mixing bowls, spatula, balance, glass plate, tins and oven.

4.2.2 Testing Procedures

According to BS 1377 (1975), the procedure of testing liquid limit of Kamloops

Silt with Drop-Cone method is summarized in point form below:

- Fill the soil-water mixture into the metal cup without trapping air bubbles
- Trim an even and smooth surface that is level with the rim of the cup
- Place the cone just touching the surface at the center
- Release the cone to penetrate into the soil sample under gravity for 5 seconds
- Measure the depth of penetration
- Take soil sample near the center for evaluating water content
- Repeat above procedures at least five times with the soil-water mixtures of different water contents.

4.2.3 Acquisition of Results

The liquid limit corresponds to the intersection of the calibration line and the best-fitted line for the plot of penetration depth against the water content. The calibration line is defined by a penetration of 20.5mm at a water content of 25%, a penetration of 21mm at a water content of 40%, a penetration of 22mm at a water content of 72%, and a penetration of 23mm at a water content of 100%.

5.0 Results

This chapter summarizes the results and comments on variation and validation of data, for both methods. The results include the average value, the standard deviation, and the maximum and minimum values of liquid limits.

5.1 Casagrande Method

The Casagrande testing was performed by the students taking the soil mechanics (CIVL 210) at UBC. Under the supervision of Dr. Fannin and graduate students, the testing was carried out in accordance to the standard procedures regulated by American Society for Testing and Materials (ASTM D 423 – 61T). Each group, consisted of four students, produced one set of data by repeating the test four times and evaluating water contents of four samples.

Within a set of data, each of the water contents was represented by a sampling point. A linear trendline was produced using Microsoft Excel, illustrating an estimated linear relation among four sampling points. Every set of data yielded a single value of liquid limit of Kamloops silt at the water content that corresponded to 25 blow counts. In total, thirty nine sets of data were retrieved and plotted in Figure 7 below.

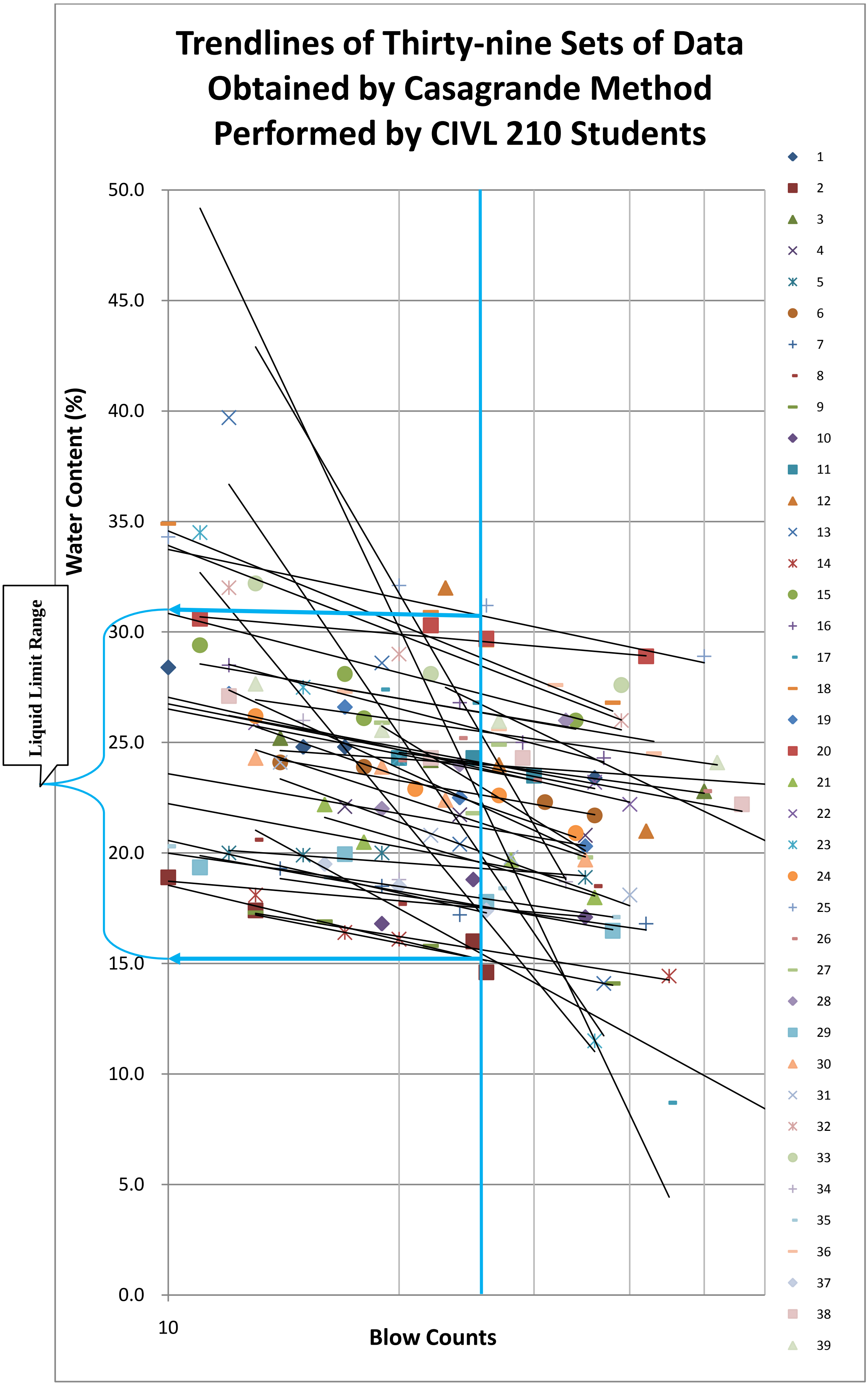

Figure 7: Trendlines of Thirty-nine Sets of Data Obtained by Casagrande Method

The liquid limit obtained by Casagrande method ranges from 15.3% to 31.5%, with an average of 23.2% and a standard deviation of 4.5%. The distribution of liquid limit is illustrated by a histogram (Figure 8) below.

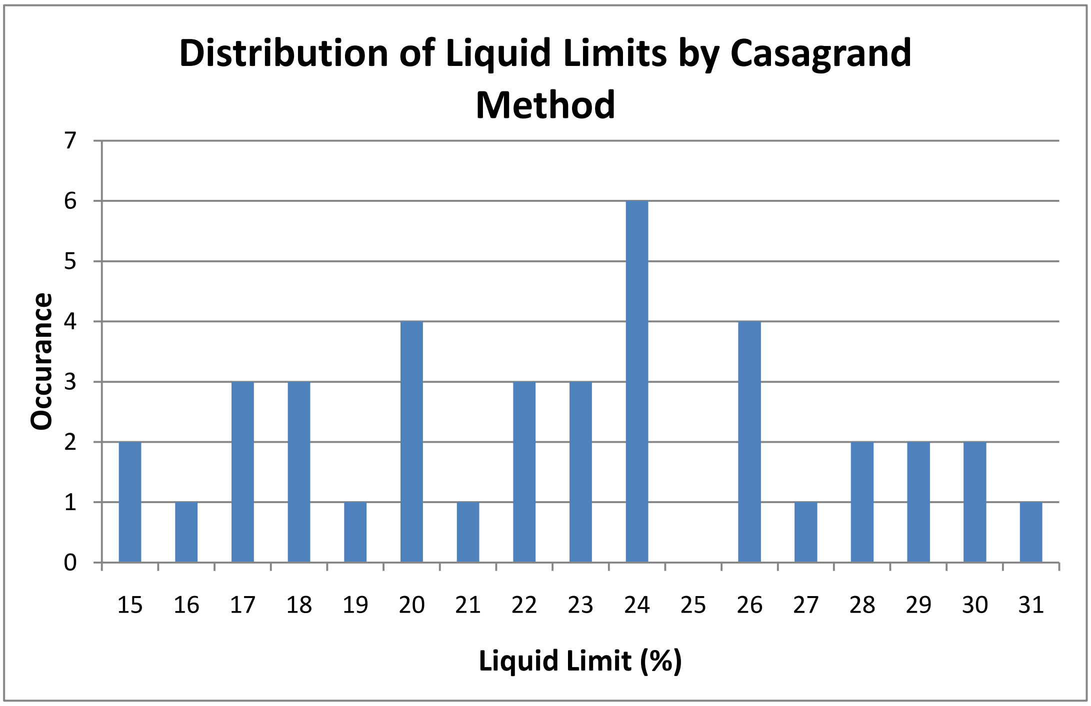

Figure 8: Distribution of Liquid Limits of Kamloops Silt Obtained by Casagrande Method

5.2 Drop-Cone Method

The Drop-Cone testing was conducted thirty times by two operators, each of whom independently conducted fifteen tests. Testing procedures were in accordance with British Standards (BS 1377); however, a 50-gram weight was added to the cone and sliding shaft in order to achieve enough penetration depth. Besides this modification, the rest of the test strictly followed the standards. A Drop-Cone test started with the soil-water mixture that resulted in about 15 mm penetration and proceeded with increasing water content. For each test, the testing procedures were repeated five times, with five different water contents sampled.

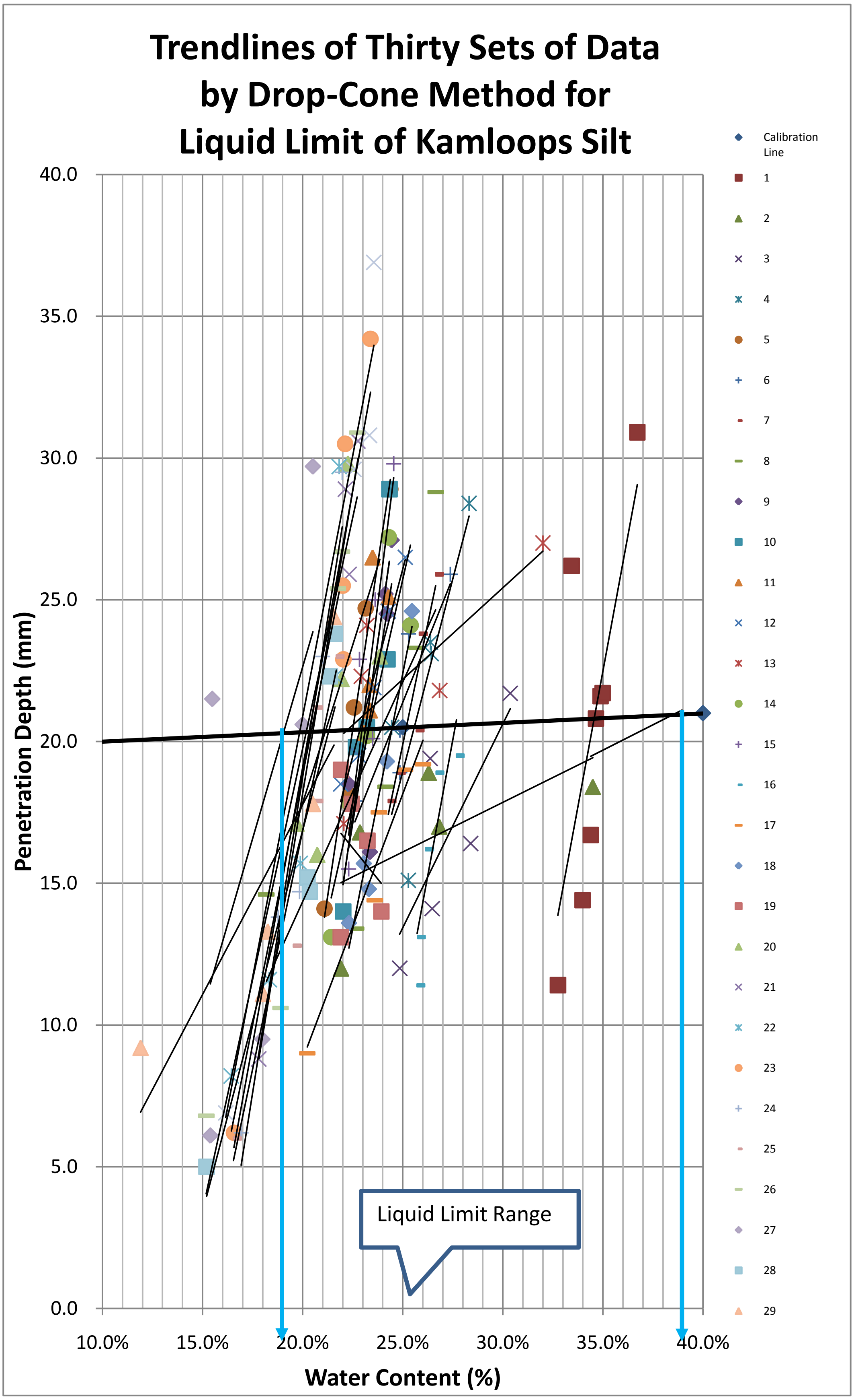

Figure 9: Trendlines of Thirty Sets of Data Obtained by Drop-Cone Method for Liquid Limit of Kamloops Silt

Every test produced one set of data, each of which consisted of five sampling points corresponding to five different water contents. A trendline was plotted using Microsoft Excel, revealing a linear relationship among the sampling points. The intersection of the trend line and the calibration line (defined in section 4.2.3) corresponded to the value of liquid limit. In Fiugre 9, thirty of these trendlines were plotted, and the range of liquid limits obtained by Drop-Cone method was also highlighted by blue colour arrows. However, due to system errors and human errors, there was one trendline was dipping in an opposite direction; consequently, it gave an untruthful liquid limit. Most of the remaining trendlines were almost parallel and closely distributed. This phenomenon indicated that the variation of results was insignificant, thus, the quality of data was acceptable.

The liquid limits by Drop-Cone method ranged from 17.9% to 38.9%, with an average of 23.9% and a standard deviation of 4.7%. The distribution of liquid limit is illustrated by a histogram (Figure 10) below.

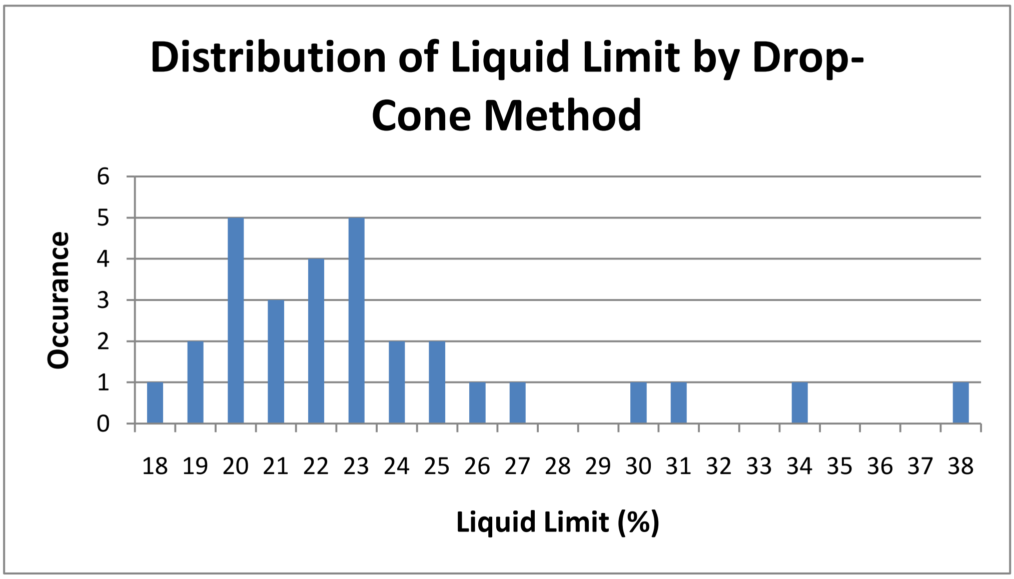

Figure 10: Distribution of Liquid Limit of Kamloops Silt Obtained by Drop-Cone Method

6.0 Conclusion

6.1 Liquid limit of Kamloops Silt

The average liquid limit obtained by both Casagrande method and Drop-Cone method is about 23%, which is much lower than the liquid limit of 31.1% reported by Lum (1979). Possible reasons for the difference in two reported liquid limits include: incomplete drying of soil samples by Lum (1979), imperfection of gauge measuring penetration in this study, and different sampling location resulting in different composition and mineralogy of soil samples.

6.2 Agreement of Results by Casagrande Method and Drop-Cone Method

The mean liquid limit found by Casagrande method is 23.2%; the mean liquid limit found by Drop-Cone method is 23.9%. The neglectable difference can lead to a conclusion that is Casagrande method and Drop-Cone method would yield very similar results of liquid limit for low plasticity soils, such as Kamloops Silt, and the tow methods can be alternatives for each other.

Although both methods tend to yield similar results, Drop-Cone method is easier to operate and gives a more accurate result with less effort than Casagrande method because penetration takes only a few seconds and does not require operator's experience to judge the optimal end point of test. Using Casagrande method, the operator must be experienced to judge the moment when the central groove is closed by soil for about half inch; meanwhile, the operator must count the number of blows while observing the closure of groove.

7.0 Recommendations for Further Work

It is possible that the liquid limit of Kamloops silt depends on the sampling location that would result in different mineralogy of samples. In order to thoroughly investigate the liquid limit of Kamloops silt, additional samples ought to be taken from different parts of the Kamloops silt bluffs.

The mechanical gauge that reads the penetration depth produces unacceptable level of errors and does not work properly sometimes. It is recommended to replace the mechanical gauge with electronic one. Not only does the electronic gauge more quickly produces an accurate reading than the mechanical one, but also it would eliminate human errors such as reading the measurements mistakenly.

The Drop-Cone penetration test yields a liquid limit of Kamloops silt, utilizing a 30° steel cone. It would be necessary to test the same sample with cones of other apex angels, such as 60°. If the same result was produced, it would be concluded that the Drop-Cone penetration test is reliable and its result is credible.

Appendix A: Data of Drop-Cone Penetration Test

Test	Mass of Tine	Mass of Tin + Wet Soil	Mass of Tin + Dry Soil	Mass of Water	Water Content	Penetration
	(g)	(g)	(g)	(g)	(%)	(mm)
1	21. 0	59. 1	49. 7	9. 4	32. 8%	11. 4
	20. 9	48. 5	41. 5	7. 0	34. 0%	14. 4
	20. 9	58. 8	49. 1	9. 7	34. 4%	16. 7
	20. 8	68. 6	56. 3	12. 3	34. 6%	20. 8
	21. 0	64. 5	53. 6	10. 9	33. 4%	26. 2
	20. 8	49. 8	42. 3	7. 5	34. 9%	21. 6
	21. 0	61. 9	51. 3	10. 6	35. 0%	21. 7
	21. 0	73. 5	59. 4	14. 1	36. 7%	30. 9
2	14. 3	23. 2	21. 6	1. 6	21. 9%	12. 0
	14. 5	54. 8	47. 3	7. 5	22. 9%	16. 8
	14. 4	55. 7	47. 1	8. 6	26. 3%	18. 9
	14. 5	50. 9	43. 2	7. 7	26. 8%	17. 0
	14. 4	41. 3	34. 4	6. 9	34. 5%	18. 4
3	14. 2	34. 8	30. 7	4. 1	24. 8%	12. 0
	14. 3	35. 8	31. 3	4. 5	26. 5%	14. 1
	14. 4	48. 9	41. 7	7. 2	26. 4%	19. 4
	14. 4	45. 6	38. 7	6. 9	28. 4%	16. 4
	14. 5	49. 7	41. 5	8. 2	30. 4%	21. 7
4	14. 5	36. 8	32. 3	4. 5	25. 3%	15. 1
	14. 3	36. 7	32. 3	4. 4	24. 4%	20. 5
	14. 2	53. 0	44. 9	8. 1	26. 4%	23. 5
	14. 4	67. 5	56. 4	11. 1	26. 4%	23. 1
	14. 4	50. 2	42. 3	7. 9	28. 3%	28. 4
5	14. 4	32. 2	29. 1	3. 1	21. 1%	14. 1
	14. 5	34. 2	30. 6	3. 6	22. 4%	18. 1
	14. 4	38. 3	33. 9	4. 4	22. 6%	21. 2
	14. 3	40. 9	35. 9	5. 0	23. 1%	24. 7
	14. 3	39. 3	34. 4	4. 9	24. 4%	28. 9
6	14. 3	32. 2	28. 9	3. 3	22. 6%	17. 9
	14. 5	36. 6	32. 2	4. 4	24. 9%	18. 9
	14. 3	36. 9	32. 4	4. 5	24. 9%	20. 4
	14. 3	36. 1	31. 7	4. 4	25. 3%	23. 8
	14. 6	37. 4	32. 5	4. 9	27. 4%	25. 9
7	14. 3	35. 8	31. 6	4. 2	24. 3%	17. 9
	14. 6	38. 3	33. 6	4. 7	24. 7%	18. 9
	14. 3	42. 2	36. 5	5. 7	25. 7%	20. 4
	14. 5	52. 0	44. 3	7. 7	25. 8%	23. 8
	14. 4	45. 3	38. 8	6. 5	26. 6%	25. 9

Data of Drop-Cone Penetration Test

Test	Mass of Tine	Mass of Tin + Wet Soil	Mass of Tin + Dry Soil	Mass of Water	Water Content	Penetration
	(g)	(g)	(g)	(g)	(%)	(mm)
8	14.3	32.7	29.3	3.4	22.7%	13.4
	14.5	32.7	29.9	2.8	18.2%	14.6
	14.4	43.2	37.6	5.6	24.1%	18.4
	14.4	54.6	46.4	8.2	25.6%	23.3
	14.4	49.1	41.8	7.3	26.6%	28.8
9	14.3	31.2	28.0	3.2	23.4%	16.1
	14.5	33.7	30.2	3.5	22.3%	18.5
	14.4	33.9	30.1	3.8	24.2%	24.5
	14.3	35.9	31.7	4.2	24.1%	25.2
	14.7	42.7	37.2	5.5	24.4%	27.1
10	14.3	48.1	42.0	6.1	22.0%	14.0
	14.5	32.9	29.5	3.4	22.7%	19.8
	14.4	36.7	32.5	4.2	23.2%	20.5
	14.5	43.2	37.6	5.6	24.2%	22.9
	14.4	47.1	40.7	6.4	24.3%	28.9
11	14.3	31.9	28.6	3.3	23.1%	20.3
	14.5	35.1	31.2	3.9	23.4%	21.1
	14.4	38.7	34.1	4.6	23.4%	22.0
	14.4	34.9	31.0	3.9	23.5%	26.5
	14.5	40.6	35.5	5.1	24.3%	25.1
12	14.2	30.9	27.9	3.0	21.9%	18.5
	14.3	38.0	33.6	4.4	22.8%	19.5
	14.4	42.2	36.9	5.3	23.6%	21.9
	14.3	35.8	31.6	4.2	24.3%	24.6
	14.6	40.0	34.9	5.1	25.1%	26.5
13	14.4	38.2	33.9	4.3	22.1%	17.1
	14.3	38.4	33.3	5.1	26.8%	21.8
	14.4	33.7	30.1	3.6	22.9%	22.3
	14.4	36.7	32.5	4.2	23.2%	24.1
	14.3	44.0	36.8	7.2	32.0%	27.0
14	14.4	31.4	28.4	3.0	21.4%	13.1
	14.3	35.1	31.3	3.8	22.4%	17.8
	14.4	35.1	31.2	3.9	23.2%	20.2
	14.4	38.6	33.7	4.9	25.4%	24.1
	14.3	45.5	39.4	6.1	24.3%	27.2
15	14.4	31.4	28.3	3.1	22.3%	15.5
	14.4	39.1	34.4	4.7	23.5%	20.1
	14.3	42.8	37.5	5.3	22.8%	22.9
	14.3	38.9	34.2	4.7	23.6%	25.0
	14.4	55.5	47.4	8.1	24.5%	29.8

Data of Drop-Cone Penetration Test

Test	Mass of Tine	Mass of Tin + Wet Soil	Mass of Tin + Dry Soil	Mass of Water	Water Content	Penetration
	(g)	(g)	(g)	(g)	(%)	(mm)
16	14.5	32.1	28.5	3.6	25.7%	11.4
	14.3	39.7	34.5	5.2	25.7%	13.1
	14.3	41.8	36.1	5.7	26.1%	16.2
	14.3	54.2	45.8	8.4	26.7%	18.9
	14.3	42.9	36.7	6.2	27.7%	19.5
17	14.5	35.3	31.8	3.5	20.2%	9.0
	14.5	43.3	37.8	5.5	23.6%	14.4
	14.3	40.3	35.3	5.0	23.8%	17.5
	14.3	41.7	36.2	5.5	25.1%	19.0
	14.3	42.4	36.6	5.8	26.0%	19.2
18	14.4	46.2	40.4	5.8	22.3%	13.6
	14.3	39.7	34.9	4.8	23.3%	14.8
	14.4	52.3	45.2	7.1	23.1%	15.7
	14.4	45.7	39.6	6.1	24.2%	19.3
	14.3	55.2	46.9	8.3	25.5%	24.6
19	14.5	49.0	42.8	6.2	21.9%	13.1
	14.3	44.9	39.4	5.5	21.9%	19.0
	14.3	44.3	38.8	5.5	22.4%	17.8
	14.3	57.8	49.6	8.2	23.2%	16.5
	14.2	43.2	37.6	5.6	23.9%	14.0
20	14.4	34.2	30.8	3.4	20.7%	16.0
	14.5	30.3	27.7	2.6	19.7%	17.1
	14.4	44.0	38.3	5.7	23.8%	23.0
	14.3	43.2	38.0	5.2	21.9%	22.2
	13.3	53.4	46.1	7.3	22.3%	29.8
21	14.4	31.6	29.0	2.6	17.8%	8.8
	14.3	40.6	35.8	4.8	22.3%	25.9
	14.4	43.1	37.9	5.2	22.1%	28.9
	14.4	50.0	43.4	6.6	22.8%	30.6
22	14.2	39.0	35.5	3.5	16.4%	8.2
	14.4	35.7	32.4	3.3	18.3%	11.6
	14.4	34.3	31.0	3.3	19.9%	15.7
	14.4	39.7	35.2	4.5	21.6%	22.3
	14.2	51.6	44.9	6.7	21.8%	29.7
23	14.4	34.8	31.9	2.9	16.6%	6.2
	14.4	36.0	32.1	3.9	22.0%	22.9
	14.4	38.8	34.4	4.4	22.0%	25.5
	14.3	39.7	35.1	4.6	22.1%	30.5
	14.3	44.9	39.1	5.8	23.4%	34.2

Data of Drop-Cone Penetration Test

Test	Mass of Tine	Mass of Tin + Wet Soil	Mass of Tin + Dry Soil	Mass of Water	Water Content	Penetration
	(g)	(g)	(g)	(g)	(%)	(mm)
24	14.5	51.8	46.4	5.4	16.9%	6.2
	14.3	37.7	34.0	3.7	18.8%	13.8
	14.3	45.1	40.0	5.1	19.8%	14.7
	14.3	40.8	36.2	4.6	21.0%	23.0
	14.4	53.8	46.7	7.1	22.0%	29.5
25	14.3	30.5	28.2	2.3	16.5%	6.0
	14.4	24.8	23.1	1.7	19.5%	12.8
	14.3	33.6	30.3	3.3	20.6%	17.9
	14.2	34.1	30.7	3.4	20.6%	21.2
	14.2	41.7	36.8	4.9	21.7%	23.0
26	14.4	36.4	33.5	2.9	15.2%	6.8
	14.2	24.9	23.2	1.7	18.9%	10.6
	14.2	40.5	35.8	4.7	21.8%	25.4
	14.2	35.3	31.5	3.8	22.0%	26.7
	14.3	38.6	34.1	4.5	22.7%	30.9
27	14.4	23.4	22.2	1.2	15.4%	6.1
	14.2	30.6	28.1	2.5	18.0%	9.5
	14.4	34.8	31.4	3.4	20.0%	20.6
	14.4	32.3	29.9	2.4	15.5%	21.5
	14.4	37.9	33.9	4.0	20.5%	29.7
28	14.2	28.6	26.7	1.9	15.2%	5.0
	14.4	24.5	22.8	1.7	20.2%	15.2
	14.3	27.9	25.6	2.3	20.4%	14.7
	14.2	39.2	34.8	4.4	21.4%	22.3
	14.2	41.2	36.4	4.8	21.6%	23.8
29	14.4	23.8	22.8	1.0	11.9%	9.2
	14.3	27.4	25.4	2.0	18.0%	11.1
	14.2	27.8	25.7	2.1	18.3%	13.3
	14.3	33.1	29.9	3.2	20.5%	17.8
	14.4	39.2	34.8	4.4	21.6%	24.4
30	14.2	25.7	24.1	1.6	16.2%	6.9
	14.4	34.5	30.8	3.7	22.6%	29.6
	14.4	36.6	32.4	4.2	23.3%	30.8
	14.4	44.3	38.6	5.7	23.6%	36.9

Appendix B: Data of Casagrande Test

Test	Natural Water Content	Blow Counts	Water Content	Liquid Limit	Plastic Limit
	(%)		(%)	(%)	(%)
1	1.6	36	23.4	24.0	21.7
		17	24.8		
		15	24.8		
		10	28.4		
2	3.5	26	14.6	15.3	14.7
		25	16.0		
		13	17.4		
		10	18.9		
3	2.3	80	23.3	24.1	21.2
		50	22.8		
		22	24.2		
		14	25.2		
4	2.1	35	20.8	22.0	18.8
		24	21.7		
		17	22.1		
		7	25.2		
5	3.5	35	18.9	19.3	17.9
		19	20.0		
		15	19.9		
		12	20.0		
6	4.5	36	21.7	22.8	24.0
		31	22.3		
		18	23.9		
		14	24.1		
7	3.5	42	16.8	17.9	15.9
		24	17.2		
		19	18.5		
		14	19.3		
8	3.4	69	6.2	22.0	18.8
		36	18.5		
		20	17.7		
		13	20.6		
9	3.3	38	14.1	15.7	18.4
		22	15.8		
		16	16.9		
		13	17.3		

Data of Casagrande Test

Test	Natural Water Content (%)	Blow Counts	Water Content (%)	Liquid Limit (%)	Plastic Limit (%)
10	1.6	35	17.1	17.6	15.1
		25	18.8		
		19	16.8		
		8	19.5		
11	3.2	30	23.5	24.2	20.0
		25	24.3		
		20	24.3		
		9	27.1		
12	2.0	70	21.0	29.0	20.0
		42	21.0		
		27	24.0		
		23	32.0		
13	2.8	37	14.1	22.0	18.6
		24	20.4		
		19	28.6		
		12	39.7		
14	3.1	45	14.4	15.9	16.1
		20	16.1		
		17	16.4		
		13	18.1		
15	7.7	34	26.0	26.5	21.3
		18	26.1		
		17	28.1		
		11	29.4		
16	3.0	37	24.3	26.1	20.3
		29	25.0		
		24	26.8		
		12	28.5		
17	2.0	45	8.7	30.0	26.0
		25	26.8		
		19	27.4		
		11	60.1		
18	4.5	38	26.8	30.2	25.6
		26	29.4		
		22	30.9		
		10	34.9		
19	4.4	35	20.3	23.2	19.8
		24	22.5		
		17	26.6		
		12	27.2		

Data of Casagrande Test

Test	Natural Water Content (%)	Blow Counts	Water Content (%)	Liquid Limit (%)	Plastic Limit (%)
20	3.1	42	28.9	29.8	22.9
		26	29.7		
		22	30.3		
		11	30.6		
21	1.0	36	18.0	19.4	22.0
		28	19.7		
		18	20.5		
		16	22.2		
22	2.6	40	22.2	24.3	17.6
		36	23.2		
		13	25.9		
		9	28.1		
23	2.4	36	11.5	18.0	27.4
		20	24.3		
		15	27.5		
		11	34.5		
24	3.7	34	20.9	22.7	19.5
		27	22.6		
		21	22.9		
		13	26.2		
25	2.3	50	28.9	31.3	25.3
		26	31.2		
		20	32.1		
		10	34.3		
26	2.3	50	22.8	24.1	21.3
		30	23.3		
		20	24.2		
		24	25.2		
27	2.0	35	19.8	23.5	23.2
		27	24.9		
		25	21.8		
		19	25.9		
28	3.0	33	26.0	22.0	22.0
		24	24.0		
		19	22.0		
		13	55.0		
29	2.7	38	16.5	18.5	17.2
		26	17.8		
		17	20.0		
		11	19.4		

Data of Casagrande Test

Test	Natural Water Content (%)	Blow Counts	Water Content (%)	Liquid Limit (%)	Plastic Limit (%)
30	2.5	35	19.7	22.0	21.4
		23	22.4		
		19	23.9		
		13	24.3		
31	1.7	40	18.1	20.6	16.7
		28	19.8		
		22	20.8		
		14	24.1		
32	2.5	39	26.0		
		20	29.0		
		12	32.0		
		5	34.0		
33	2.9	39	27.6	26.0	31.0
		22	28.1		
		13	32.2		
		8	38.1		
34	3.2	33	18.7	24.7	19.0
		20	18.8		
		15	26.0		
		8	20.9		
35	3.6	38	17.1	18.2	15.2
		27	18.4		
		16	18.9		
		10	20.3		
36	2.9	43	24.5	26.0	5.4
		32	27.6		
		27	25.6		
		17	27.3		
37	2.6	26	17.4	18.8	21.2
		20	18.5		
		16	19.5		
		8	21.4		
38	3.2	56	22.2	24.5	17.9
		29	24.3		
		22	24.3		
		12	27.1		
39	2.4	52	24.1	23.6	22.7
		27	26.0		
		19	25.6		
		13	27.7		

Appendix C: Sample Calculation for Water Content

For Example: Drop-Cone Penetration Test #1, 1st Sample

Known:

Mass of Tin = 21.0 g

Mass of Tin and Wet Soil = 59.1 g

Mass of Tin and Dry Soil = 49.7 g

Calculation:

Mass of Dry Soil = Mass of Tin and Dry Soil – Mass of Tin

= 49.7 g – 21.0 g

= 28.7 g

Mass of Water = Mass of Tin and Wet Soil – Mass of Tin and Dry Soil

= 59.1 g – 49.7 g

= 9.4 g

$$\text{Water Content} = \frac{\text{Mass of Water}}{\text{Mass of Dry Soil}} \times 100\%$$

$$= \frac{9.4\text{ g}}{28.7\text{ g}} \times 100\%$$

$$\approx \mathbf{32.8\ \%}$$

So, the water content of the first sample of Drop-Cone Penetration Test #1 is approximately 32.8%.

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