ASSESSMENT OF ATTERBERG LIMITS USING SIEVE # 40 AND SIEVE #200

BY

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A thesis submitted in partial fulfilment of the requirement for the degree of

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In

Geotechnical Engineering

Supervisor

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THESIS ACCEPTANCE CERTIFICATE

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Signature :____________________________

Supervisor Dr. Badee Alshameri

Date:________________________________

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Date:________________________________

(Dean/Principal): _____________________

Date:_________________________________

DEDICATED

TO

MY BELOVED PARENTS

WHO GAVE ME A LOT OF SUPPORT

AND

ENCOURAGEMENT

ACKNOWLEDGEMENTS

I am very thankful to Almighty Allah, the most Merciful for bestowing upon me the dedication to complete this research work. Countless Salutations upon the Holy Prophet Hazrat Muhammad (S.A.W), the source of knowledge for the mankind. I express my deepest gratitude for the guidance of my supervisor, Dr. Badee Alshameri and thesis committee members Dr. Zain Maqsood and Dr. Abbas Haider who continuously and convincingly conveyed a spirit of hard work and steadfastness to complete the project. I am forever indebted to my Parents for their unconditional love, motivation and the endless patience. Their endless confidence in my abilities was the driving force throughout my life and this project would not have been possible without their trust and assurance. I would like to acknowledge the continuous guidance and supervision of my supervisor Dr. Badee Alshameri for his support and assistance. I would also like to thank my friend Muhammad Naqeeb Nawaz who have supported me in various aspects during this project. Special thanks to Mr. Muhammad Naqeeb Nawaz,

ABSTRACT

Casagrande plasticity chart (CPC) based on liquid limit (LL) and plasticity index (PI) is used for classifying fine-grained soils. Fine soil is defined as a material having a size less than 0.075 mm (passed sieve #200) in conformity with the unified soil classification system (USCS). The amount of fine sand in the material that passes through the #40 sieve is expected to be significant, which causes significant errors when estimating the soil's class or plasticity level. Therefore, 120 samples of clay soil were obtained from different districts in Pakistan, and they were subjected to rigorous testing. The findings demonstrate that Atterberg limits estimated using sieve # 200 passing material were greater than those calculated using sieve # 40 passing material, resulting in changes to the liquid limit and level of plasticity index in CPC. However, it takes a lot of time and effort to determine Atterberg limits using material from sieve # 200. In order to accurately determine the Atterberg limits based on sieve # 200, prediction models were developed employing artificial neural network (ANN) and regression (MLR) techniques.

Keywords: Atterberg limits, sieve # 40 and sieve # 200, Casagrande Plasticity Chart (CPC), artificial neural network (ANN).

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List of Abbreviations

PI = plasticity index

LL = Liquid Limit

PL = Plastic Limit

CPC = Casagrande Plasticity Chart

UCSC = unified soil classification system

AASHTO = American association of state highway transportation official

Pr = plastic ratio

CL = clay of low compressibility

CH = clay of high compressibility

ML = silt of low compressibility

MH = silt of high compressibility

ASTM = American Society for Testing and Materials

BS = British Standard

LR = Linear Regression

MLR = Multilinear Regression Analysis

ANN = Artificial Neural Network

Chapter 1. Introduction

1.1 Background

The word"clay" can be defined as a natural material containing fine-grained soils and are plastic at suitable moisture contents and will harden when desiccated (1,2). Clay is prevalent and wide-ranging material found on the Earth's surface, originating from the various rock classes that came into existence due to different natural and artificial processes, including biological, environmental, and mechanical operations. Therefore the soil is divided into groups based on their engineering characteristics but without detailed explanation (3).

Sieve analysis is mainly used to determine in percentage the amount of different particle sizes contained within a soil sample. A standard classification for the course and fine-grained soil includes a unified soil classification system (4), the American association of state and highway and transportation officials, and the British Standard (4–6). USCS defines gravel and sand as the materials retained on sieve No #4 (75mm to 4.75 mm), No #200 (0.075 mm), respectively, and below considered ultra-fine. Clay soil has a large specific surface than sand and, therefore, immense swelling potential. Thus, another parameter that could best describe soil behaviour is the plasticity of the soil. Plasticity is an essential property for classifying fine-grained soil (7), defined as a material's ability to be moulded to any shape without cracking (2). Casagrande's plasticity chart (4) separating Clay from silt by developing A-line. Clay located above and silt below the A-line. Therefore, clay denoted by C and silt M with L and H representing low and high compressibility (CL or CH, ML or MH). Based on CPC, the size of fines are determined by passing over sieve number 40 (0.425 mm), while USCS defines fines as those that have a size smaller than 0.075 mm.

Author Polidori tried to address the fine fraction (CF) effect on Casagrande's classification and proposed a new plasticity chart (8). He takes available data from the literature (9) of an artificial mixture of pure clay minerals. According to his classification a clay (C groups) which has a percentage equal to 50% or more clay content. The position of silt and change which is the controversial finding of the author (Activity: (10) due to the expandability of minerals when clay content is low)

The author Kim & Kim, 2018 (11) collected a sample in Korea. The objective was to implement the Casagrande and modified Polidori chart on the soil sample. However, the samples collected have low plasticity; therefore, their behaviour was not the same based on Polidori and Casagrande plasticity chart (4,8). Afolagboye LO (12) also carried his work to check the plasticity of laterite soil by passing them through sieve #40 and sieve #200. The same was recorded by Kayabali 2011 (13); as materials become delicate, specific surface areas increase, leading to an increase in LL and a change in the level of plasticity of the soil.

The various author tries to develop a unique plasticity chart which addresses all soil groups accurately. However, each author in precedent studies has an outstanding contribution to the knowledge of soil plasticity chart and has certain limitations. For example, USCS is based on sieve #40 (0.425 mm) Casagrand Plasticity chart address only the effect of particle size 0.075 mm to 0.425 mm. However, they did not address the impact of particle size less than 0.075 (0.002 mm).

Polidori (8) develops a chart for clay-based on sieve #40 (0.425 mm), which shows that the position of Clay and silt changed with references to the Casagrande plasticity chart. The limitation Polidori has taken some tables and data from the other studies which do not meet the percept of the author (14). Furthermore, the author uses only two pure clay samples as a base for classification. That must reflect the behaviour of the remaining soil because of plasticity parameters which are not valid. Secondly, the data do not follow linear relation with fine fraction <2 μm, and PI and LL relationships do not pass the origin.

Afolagboye and Kamil Kayabali (12,15)both observed a change in soil type and level plasticity. However, they did not address the actual position of soil on the plasticity chart.

Juhyun Kim & Dongwook Kim (11) The Sample collected has silt content more than Clay; secondly, the Sample collected from the location has no uniform soil sample wrt silt and sand. At the same time, the area of site data has low plasticity soil. Therefore, the same data has been taken for the plasticity classification of soil.

1.2 Problem Statement:

Precedent literature has limitations not to address an appropriate plasticity chart for natural clay soil. Most of the research has been carried on the plasticity chart based on sieve #40, which does not include the proper delicate materials. For example, from the Casagrande plasticity chart, they used only #40 and did not address the effect of fine (<0.075). Polidori has carried the same, but the author considers only artificial clay soil with two pure clay samples as a base for classification.

- In the light of literature, it can be concluded that there is a dire need to explore the effect of particle size on the Atterberg Limit and subsequent changes in CPC to propose possible modifications in CPC. In this study, the research study is comprised of two domains.
- First domain deals with the experimental work and possible modifications in CPC while the second domain focuses on the development of prediction models for the determination of Atterberg limits using sieve # 200 passing material.
- This research intends to address the correct location of Natural inorganic clay soil on a plasticity chart based on an assessment of Atterberg limits & materials passing sieve #40 (0.425 mm) and #200 (0.074 mm) in Pakistan

1.3 Aim and Objective

The Aim of the research is the “Assessment of Atterberg Limits Based on Sieve #40 and Sieve #200”. This aim can be achieved with the following objective

- To assess the effect of particle size on Atterberg limits based on sieve #40 and #200 passing soil material.
- The prediction models for the calculation of Atterberg limits based on sieve 200 passing material.
- To evaluation of the proposed prediction model by verifying with sensitivity and parametric studies

1.4 Research Scope:

To accomplish the set objective mentioned above, a research plan was organized, and the following was formulated.

- A detailed study of the previous literature has been conducted on the plasticity of inorganic clay soil and its categorization based on the plasticity chart. Review of the previous research articles worldwide to understand the methodologies adopted and procedures followed by them.
- To achieve the set goals natural inorganic soil sample from a different location in Pakistan was collected. The Sample sieved with both #40 and #200 and Atterberg limits were calculated.
- The Atterberg Limits was calculated using sieve #40 (0.425 mm) and #200 (0.074 mm) sieve respectively and observed change in soil class and level of plasticity.
- The ANN and MLR prediction models provide correlation and coefficient of determination that hold very strong (R = 0.99 and R2 = 0.98) in order to avoid misinterpretation and underestimation of the results using sieve number 40.

1.5 Expected Outcome:

- Details, on table studies of precedent literature about fine-grained soil and its plasticity potential, have been conducted, Study of the worldwide acceptable classification system of soil, its productivity as well as its limitation
- Sample collection of inorganic natural clay soil
  Eighty samples were collected from a different location, as mentioned in the methodology section for lab testing.
- Lab work and data calculation
- Analysis of result and discussion
- Conclusion
- Recommendation

Chapter 2. Literature Review

2.1 Introduction:

This section provides a short review of the plasticity chart, its development, and the factor affect the plasticity and contribution of different authors, the limitation of the existing plasticity chart and the proposed gap address by the author of this dissertation.

2.2 Understanding Clay and its urgency:

Clay is prevalent and wide-ranging material found on the earth's crust, originating from the various rock classes that came into existence due to different natural and artificial processes, including biological, environmental, and mechanical operations. The understanding of the clay mineral is vital due to its wide variety of applications in the field of ceramics (16), construction industry (17), healthcare system (18), civil engineering, and geotechnical engineering (19), the field of agriculture, and many more among them. Therefore, it is necessary to define the Clay according to its application. The word "clay" is defined as a natural material containing fine-grained soil having a plastic behavior at suitable moisture contents and will harden when desiccated (1,2). According to ASTM, materials that pass over sieve #200 (75-μm) possess plasticity within the moisture content range, revealing considerable strength when withered (20).

2.3 Classification of soil:

Therefore the soil is divided into groups based on their engineering characteristics but without detailed explanation (3). A standard classing for the course and fine-grained soil is a unified soil classification system (20), the Americain association of state and highway and transportation

Officials (21), and the British Standard. USCS defines gravel as the materials retained on sieve No #4 (75mm to 4.75 mm), sand retained on sieve No #200 (0.075 mm), and below considered ultra-fine. AASHTO system defines sand size between 2 to 0.06 mm, and silt defines as a size between 0.06 to 0.002 mm and <0.002 mm, is considered Clay (7). These classifications are used to address the particular class of soil and its behavior because fine and coarse-grained soil presences affect the ultimate functioning of the soil. Clay soil has a large specific surface than sand and, therefore, immense swelling potential. With the same particle size distribution, soil can have different physical behaviour; Casagrande concluded that particle size addresses necessary behaviour, but it does not necessarily indicate all soil's physical properties and functioning.

Particle size distribution	Grain Size (mm)			
Name of organization	Gravel	Sand	silt	Clay
Massachusetts Institute of Technology (MIT)	>2	2 to 0.06	0.06 to 0.002	<0.002
U.S. Department of Agriculture (USDA)	>2	2 to 0.05	0.05 to 0.002	<0.002
American Association of State Highway and Transportation Ofcials (AASHTO)	76.2 to 2	2 to 0.075	0.075 to 0.002	<0.002
Unied Soil Classication System (U.S. Army Corps of Engineers, U.S. Bureau of Reclamation, and American Society for Testing and Materials)	76.2 to 4.75	4.75 to 0.075		

2.4 Historical background of Plasticity chart and its development:

Therefore, parameter that could best describe soil behavior is the plasticity of the soil. Plasticity is an essential property for fine-grained soil, and also the parameter plasticity in Casagrande plasticity chart's fundamental parameter (7). Plasticity is the material's ability to deform to any other shape without cracking (2). the particle size affects the behavior and plasticity due to its clay mineralogy, chemical constitution, PH, cation capacity, crystallinity pore fluid's dielectric constant, and properties reveal more information about soil nature. But it is worth noting that USCS does not define the soil particle size as more delicate than that of sand, and they separate silt and 2clay-based on the plasticity chart (11)

The plasticity index (PI) can be is numerically difference between as a between liquid LL and PL. Casagrande's plasticity chart (Casagrande 1948) has LL at abscissa and PI at the ordinate, separating Clay from silt by developing A-line that obeys the equation PI = 0.73*(LL-20) clay is located above and silt below the A-line. Clay is denoted by C and silt M with L and H representing low and high compressibility (CL or CH, ML or MH). At the upper, most location U-line (PI = 0.9(LL-8) shows the upper limit for cohesionless soil. Casagrande's plasticity chart is based on material passing over sieve #40 (0.425 mm), but according to USCS that defines fines as a material having a size < 0.075 mm, but that chart is based on #40, which contains large-sized particles (silt, sand). Therefore, the presences of sand and silt in soil underestimate the engineering behaviour of soil. As LL and PL of materials passing #200 are more than #40 Materials and verified by (15), they found that plasticity and class of soil changed with particle size distribution on #200.

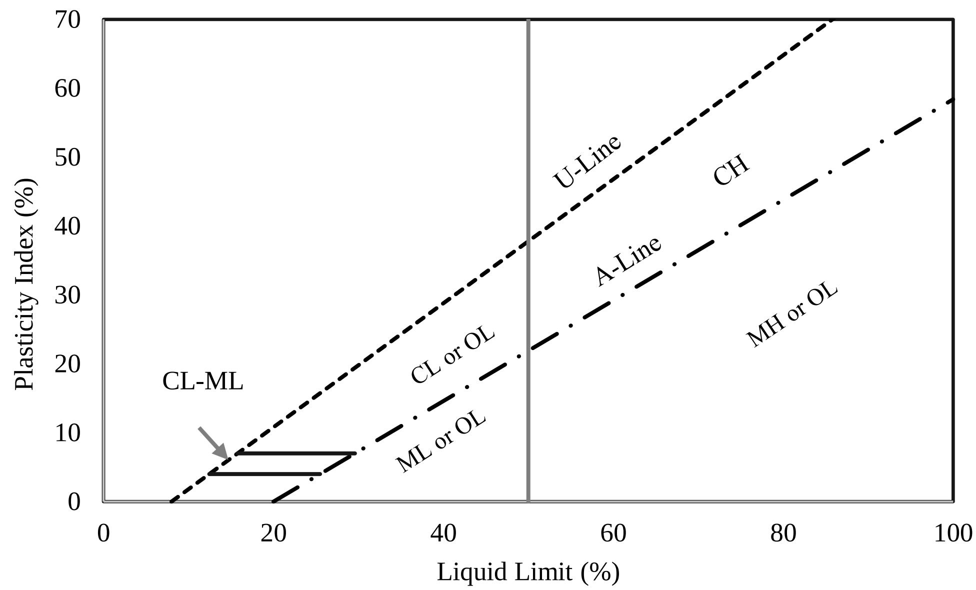

Figure 1 Plasticity Chart

Polidori (8) proposed a new plasticity chart by considering the fine fraction (CF) effect on Casagrande's classification. He takes an artificial mixture from literature which are Montmorillonite, Illite, and Kaolinite. The clay fraction was controlled by adding clean sand to the Sample with 100% CF. For the purposes, Polidori takes available data from the literature (9) and develops a chart contains PI and LL. Polidori called those samples clays (C groups) which has more than 50 % clay amount. At the same time, it was defined as silt if the percentage of fine-grained less than 50%. These results, 0.5C-line obtained (line responding to 50% clay) and Polidori, 2004, establishes a U-line that represents the line upper limit of plastic Clay with low clay content.

Moreover, the percentage of clay corresponding to 100% CF was taken as C-Line. The position of Clay on the proposed Polidori chart between C-Line and 0.5-line and silt located above 0.5-line. This chart completely changes the position of silt and Clay concerning the Casagrande plasticity chart. A composition of more significant silt and sand contents at the same LL shows an even higher plasticity index due to the expandability of minerals when clay content is low. The activity of clay soil, which Ratio of plasticity to clay fraction which has soil less than 2 μm (10), shows that increased plasticity if clay decrease.

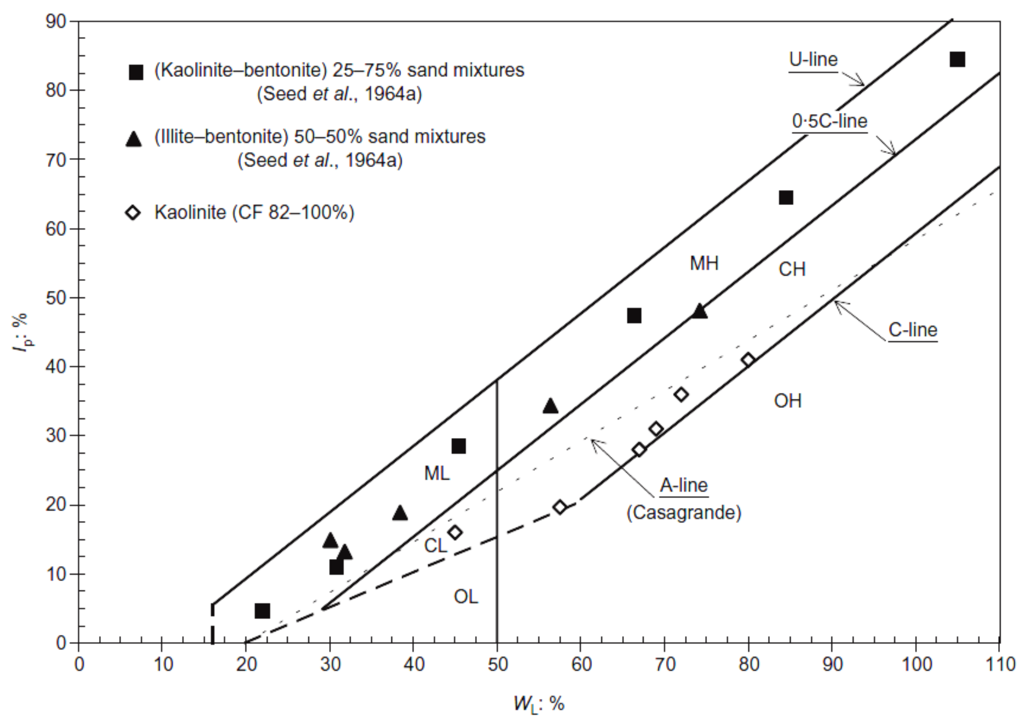

Figure 2 Proposal for a new plasticity chart

Kim & Kim (11) collected samples from four coastal sites in Korea. The predominant clay type were Illite, Kaolinite, and Chlorite. The for the most of cay was Illite. The objective was to implement the Casagrande and modified Polidori chart on the soil sample. Most of the soil is defined in clay soil (CL & CH) and above the A-line from the CPC, while the same soil is defined as silt (ML &MH) based on the Polidori chart. Adopting the same methodology as Polidori did Kim, 2018 develop a 0.3-line taking LL and PL linear relationship as a reference corresponding to 30% CF. based on experimental observation, they define soil as a clay corresponding to CF >30% and lies above C-line and below 0.3-line and silt is defined as a soil corresponding to CF<30% and lies above 0.3-line and below U-line.

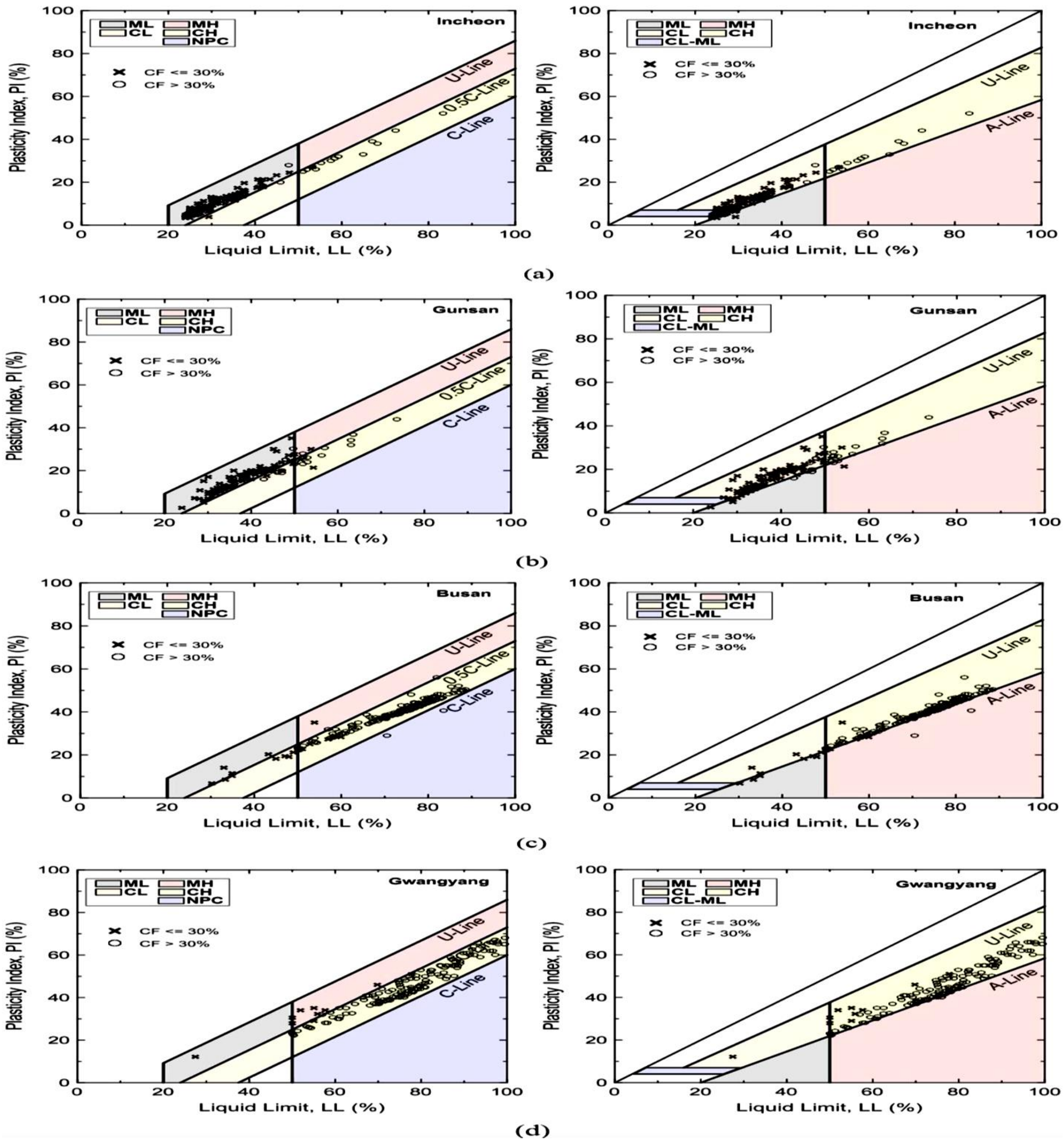

Figure 3 Proposed Plasticity chart by Kim et al.

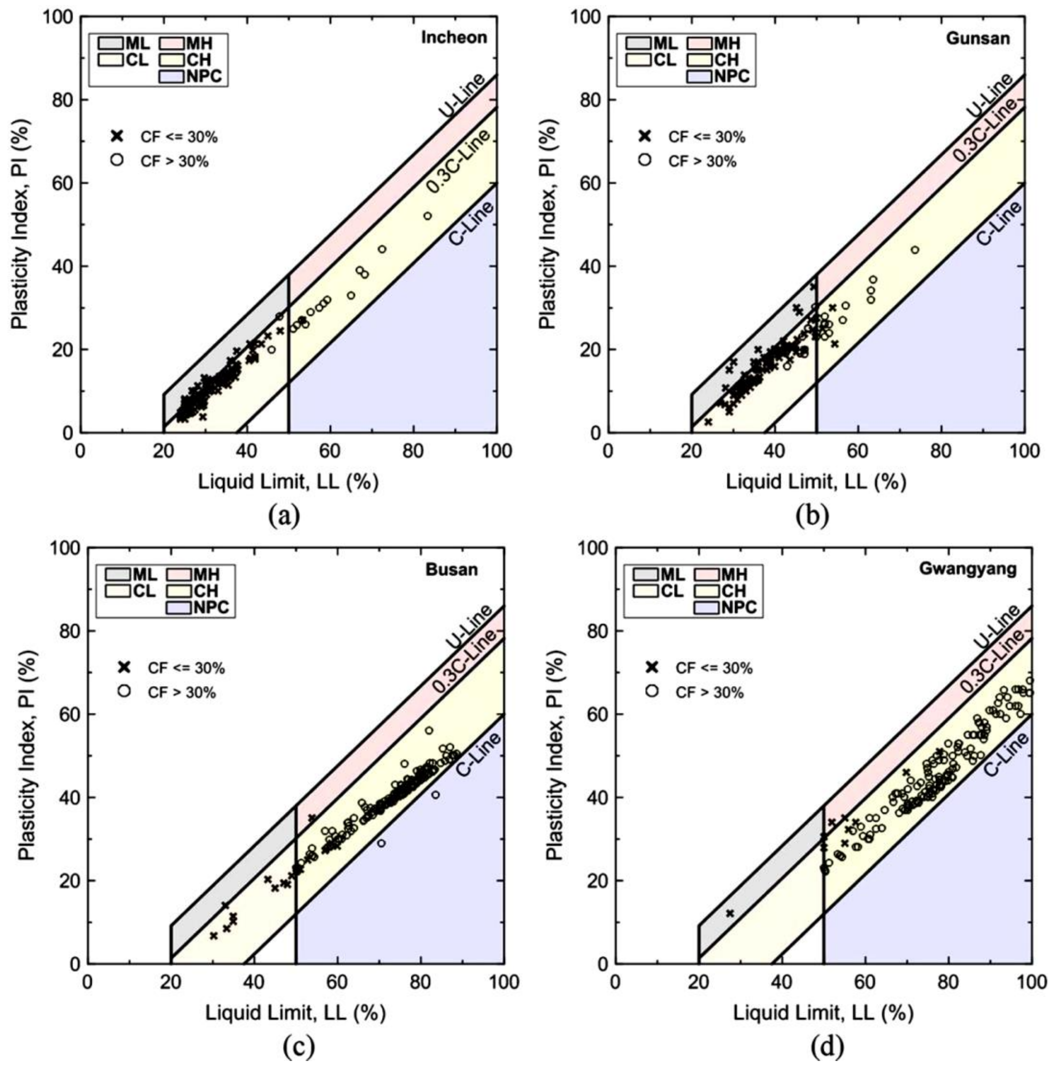

Figure 4 Results of Kim et al. Plasticity chart

Afolagboye LO (12) also carried his work to check the plasticity of laterite soil by passing them through sieve #40 and sieve #200. As materials become delicate, specific surface areas increase, leading to an increase in LL and a change in the level of PI of the soil. It is noted that a 5-10% increase occurs in LL (Between #40 to #200). Thus, a shift in plasticity occurs, which has been noted by Kayabali (13), which directly questions the USCS based on #40 sieve Moreover, materials were passing and distinguishing between Clay and silt based on the proposed plasticity chart. Also, the swell Index test found that the swelling potential of materials passes from # 200 more than materials passing over # 40. The author of the paper said

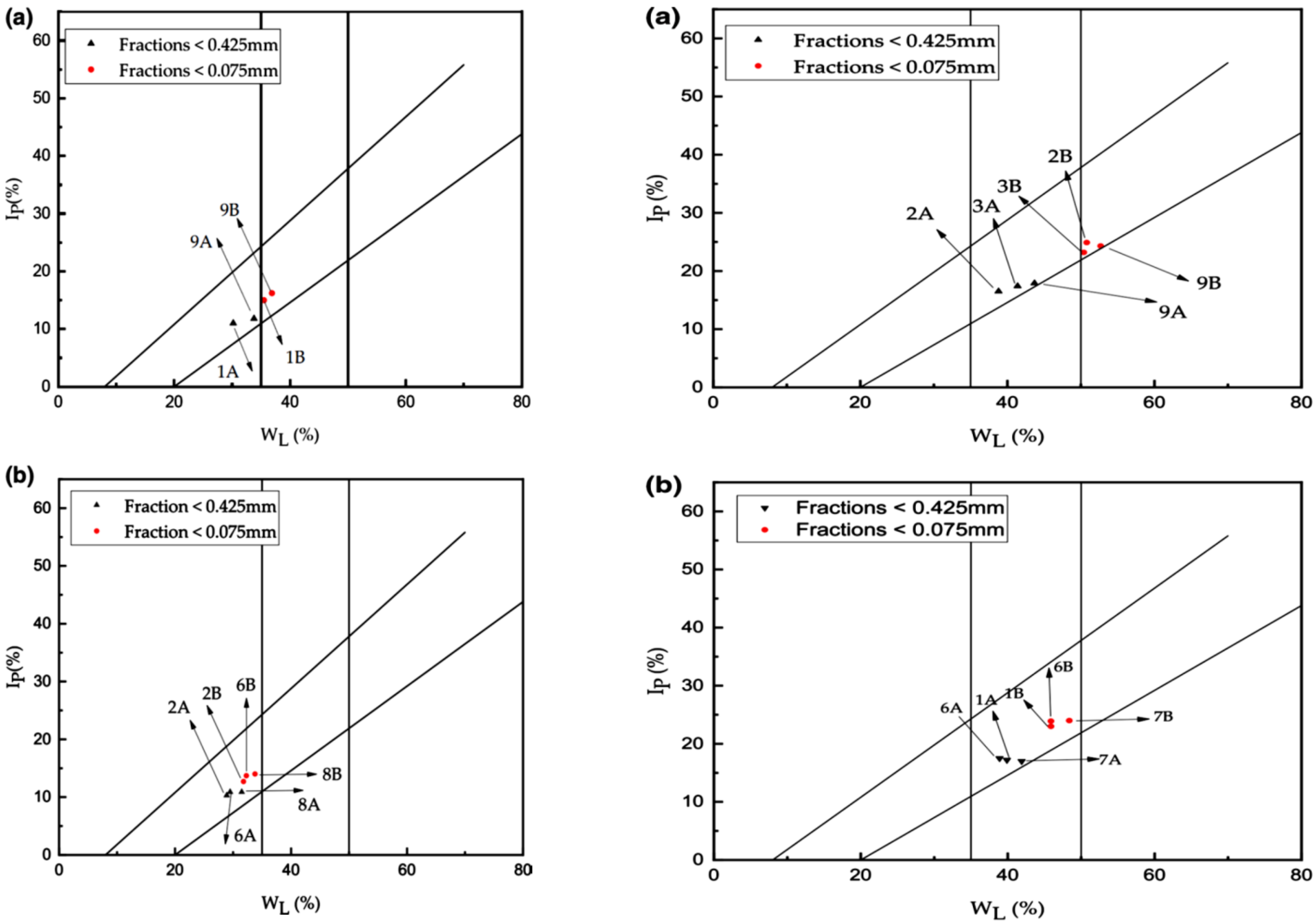

Figure 5 observation of Afolagboye LO

Using sieve #200 effect the USCS and changed the level of plasticity. Thus, taking soil is fine based on sieve #40 may lead to some severe geotechnical issues for the structure.

Plasticity has also been calculated from the flow index (I_F), and different soil has different flow characteristics. Defend on clay mineralogy and fine fraction. The relationship between moisture content and blows plotted and is a straight line which is called flow curve (7). The flow index is the moisture content versus $\log_{10}$ of the blows number plot and measures the rate at which moisture content increases that cause leading to decrease in shear strength of the soil is. A. Sridharan (22), given the relation of PI and I_F, is given by PI % = $4.12 I_F$ %. And for PI vs. fine fraction (I_{FC}) PI

%= $0.74I_{FC}$%. the author has used the standard rules and developed these equations, but he has not addressed fine fractions.

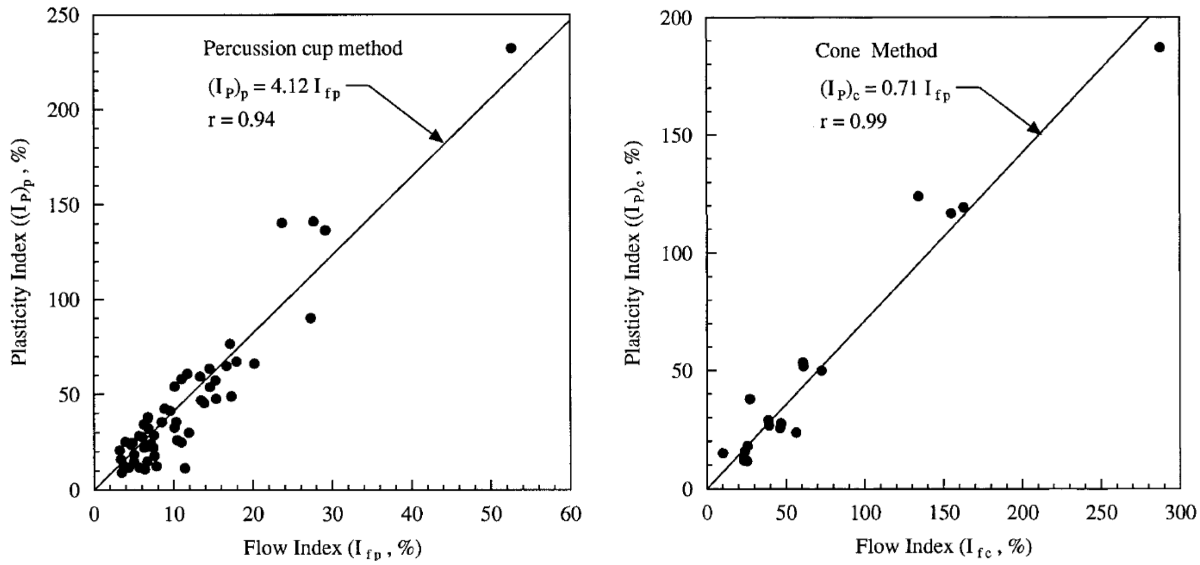

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figure 6: Percussion cup, cone method. A. Sridharan et al.

If we passed the same Sample from the #40 sieve well, we the same equation as above, or if we follow #200, thus for sieve #200 it needs to consider what will be the change in slope.

2.5 Indirect Approaches to address silt and clay-based on plasticity:

Several writers provide a chart to address the silt and clay location based on several literature characteristics. For instance, SAITO and MIK1 (23) create a chart based on Pr and LL and construct a measure called plastic ratio (Pr), which is the ratio of PI and LL (Pr = PI/LL). The A-Line rises hyperbolically when the PR is used, from a low Pr value of 0.3 to an upper limit of 2..

From this development, when LL changes, P_r will also be changed, and the higher the P_r, the more the soil cohesive. For the same P_r, the compressibility and volumetric variation will be more as LL is increasing. Moreover, the residual shear strength will be reduced as P_r and LL increase.

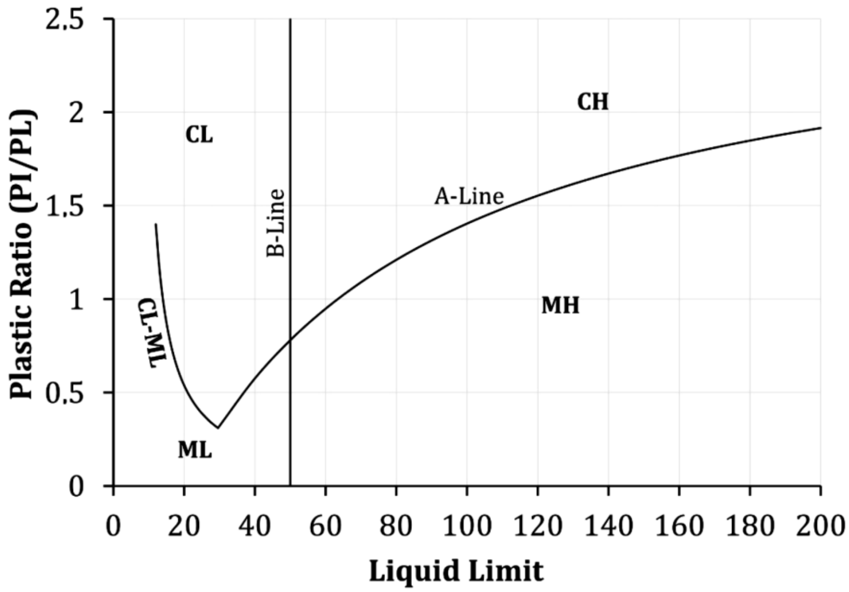


Figure 7 classification chart based on Pr

Based on this, P_r and LL criteria chart is developed which separating the silt, and clay byline which a parabolic line and at a point corresponding to LL = 50 has a B-line

Moreno-Maroto and Alonso-Azc´arate (24) classifications were developed a plasticity chart based on a new thread bending method to determine Plastic Limit (PL) and the variation in soil consistency. New parameters were developed from his work, the so-called bend-breaking limit (BL), and defined as the moisture content above which a 3-mm-diameter soil cylinder can bend completely without breaking. It was observed that BL and LL have a direct relation to any soil. Therefore, LL/BL>1.3 could be addressed as clays. When LL/BL value between 1 and 1.3, it has intermediate characteristics between Clay and silt. Based on the statistical analysis, the Ratio of BL and LL can be expressed in terms of the PI vs. LL chart in which the C-Line (PI = 0.4855 × LL) and the M-Line (PI = 0.3311 × LL), respectively. So that clays located above the C-Line, silts, and low plasticity soils lie below the M-Line.

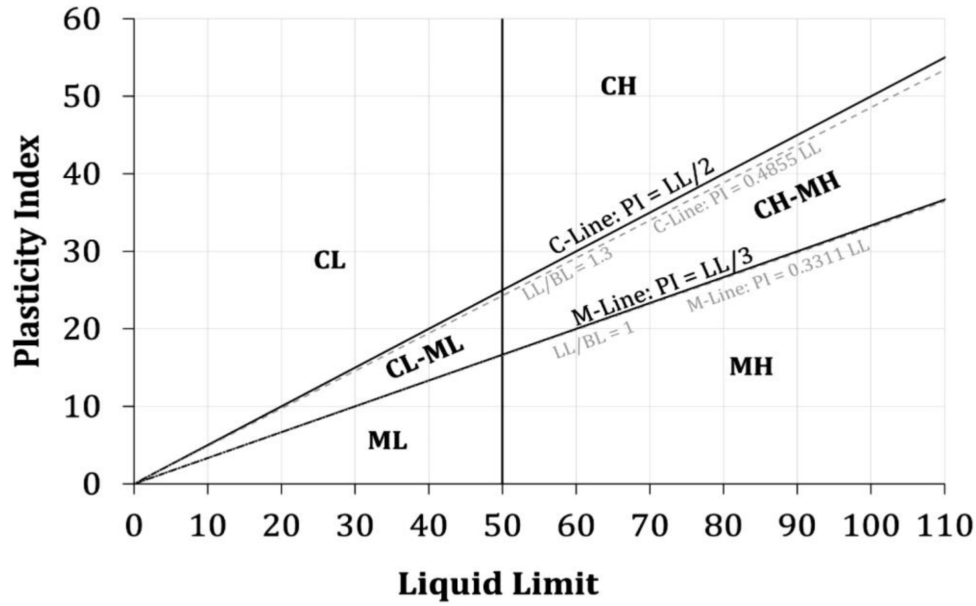


Figure 8 Classification charts for fine-grained soils developed by Moreno-Maroto and Alonso-Azc´arate (2017-18).

Moreno-Maroto and Alonso-Azc´arate (1) worked to address the soil behavior more accurately for that purpose; the toughness and Atterberg limit were correlated. The authors' aims were that toughness is the property that can best describe the soil behaviour and develop the equation which PI/LL = 0.0077 Tmax +0.3397. T_{max} is the Maximum Toughness, the toughness corresponding to the moisture content at the PL obtained by the Barnes thread-rolling apparatus. When the value of Tmax = 0 kJ/m3, then PI/LL=0.3397 indicates the upper limit for cohesionless soil. Also, the presence of Clay will have high toughness of 20 kJ/m3 when PI/LL = 0.4937 as a boundary between moderately or slightly clayey materials and actual clays results is based on the equation mentioned above. When this data is plotted in Moreno-Maroto, and Alonso-Azc´arate 2017 same plasticity chart was obtained.

Polidori 2009 (25) develop an activity chart that describes the activity of soil. The soil was divided into three classes: low activity, medium activity, and high activity. Referred to Polidori 2004 plasticity chart, activity can best describe the fine fraction in soil (PI=AC skempton). Two artificial soil Montmorilonite and kaolinite were used; one has high plasticity than the other one. The activity of both Samples was plotted in the Polidori plasticity chart. H-line and high activity by L-line represent the low activity. Based on the Polidori activity chart, sample A is classified as silt of high activity instead of silt with low plasticity. Sample B is represented with low activity instead of Clay with high plasticity.

2.6 The shortcoming of precedent studies:

A unified soil classification system USCS based on sieve #40 (0.425 mm) and they separate Clay and silt based on their plasticity chart. Casagrand Plasticity chart address only the effect of particle size 0.075 mm to 0.425 mm. However, they did not address the effect of particle size less than 0.075 (0.002 mm) and its effect on plasticity, activity, and the swelling potential of these soil.

Polidori (8) develops a chart for clay-based on sieve #40 (0.425 mm), which shows that the position of Clay and silt changed with references to the Casagrande plasticity chart. One limitation is that plasticity parameters do not follow linear relation with fine fraction <2 μm, and PI and LL relationships do not pass the origin. Polidori has taken some tables and data from the other studies that do not meet the percept of the author. It means that the author tries to address and calculate another parameter (Residual shear strength, shear resistance) of soil (26,27); Polidori takes the exact data for plasticity chart development. The author uses only two pure clay samples as a base for classification, and that must reflect the behavior of the remaining soil, which is not valid. Criteria for Separating Clay from silt is modified, and differentiate element was only Clay (Activity PI/<2 μm) (20).

Afolagboye and Kamil Kayabali (12,13) both observed a change in soil type and level plasticity. However, they did not address the actual position of soil on the plasticity chart.

Juhyun Kim & Dongwook Kim (11) The Sample collected was from coastal areas, which will have silt content more than Clay; secondly, the Sample collected from the location has no uniform soil sample wrt silt and sand. At the same time, the location of site data has low plasticity soil Taylor et al. (11). The same data has been taken for the plasticity classification of soil, so if the silt content is more in the soil, it will affect the ultimate behaviour of soil. They also quoted that the Polidori chart is also valid for the clay-silt of some sites, but the Polidori chart also has shortcomings.

Plasticity and flow index relationship has to be addressed that what is the effect of fine. Changing the fine amount, the response of flow cure, and the equation of PI vs. I_F changing or remaining the same. The author has used the standard rules and developed these equations, but he has not addressed fine fractions. If we passed the same Sample from the #40 sieve well, we the same equation as above, or if we follow #200, what will be the relationship between plasticity index and flow index?

In this research study, a plasticity chart will be developed based on natural inorganic fine clay materials passing over sieves #40 and #200. Eighty (80) Samples will be collected from Pakistan's northern and southeastern sides: Mardan, charsada, Peshawar, okara, Muzaffargarh. The Atterberg limits will be calculated, and fine-grained position and level plasticity soil will address corresponding to the Casagrande plasticity chart. The exact moment flow index will be checked based on sieve #40 and #200 passing materials to know the impact of fine-grained soil on the flow index. This is any deviation from the standard equation developed by A. Sridharan or remains the same.

Chapter 3. Methodology

This chapter describes the steps followed to achieve the intended objective of the research. After review of the literature of the past research and scholarly articles available regarding the topic of research, a comprehensive framework was prepared which included the details regarding the sample collection, conduct laboratory tests, Atterberg limits limit for plasticity calculation

3.1 Research framework

- This thesis was conducted to achieve the research goals of keeping economy of effort and resources and precision and accuracy in measurement. The salient points of the research framework are:
- Collection of soil samples from the location of Pakistan
- Conducting different lab test which includes,
    - Sieves analysis of soil samples (both #40 and #200)
    - Atterberg limits calculation (LL & PL)
    - Plasticity of soil pass #40 and #200
- Plasticity calculation from the Atterberg limits
- Developing correlation between sieve #40 and #200 passing materials
- Developing the plasticity chart based on sieve #40 and #200 and presenting the amount of shift in plasticity and change in class of soil

During the execution of the lab work, the following point should be considered with great care.

- Calibration of all types of equipment/tools/test apparatus before use
- Extreme care was exercised during the laboratory procedure and test.
- All activities and reports were documented to ensure accurate reporting of all facts and figure
- We are ensuring self-presence during the conduct of laboratory tests and procedures.
- Accuracies in measurement and scale were ensured by repeating the test if any ambiguity in results was found.

3.2 Test plan:

The core objective of the research is to develop a plasticity chart based on #40 and #200 and investigate the effect of fine-grained soil on plasticity. For this purpose, the following test was conducted.

- Sieve analysis using #40 and #200 sieve
- Liquid Limit test
- Plastic Limit test
- Hydrometer analysis
- Specific gravity

3.3 Flow Chart For Research Work:

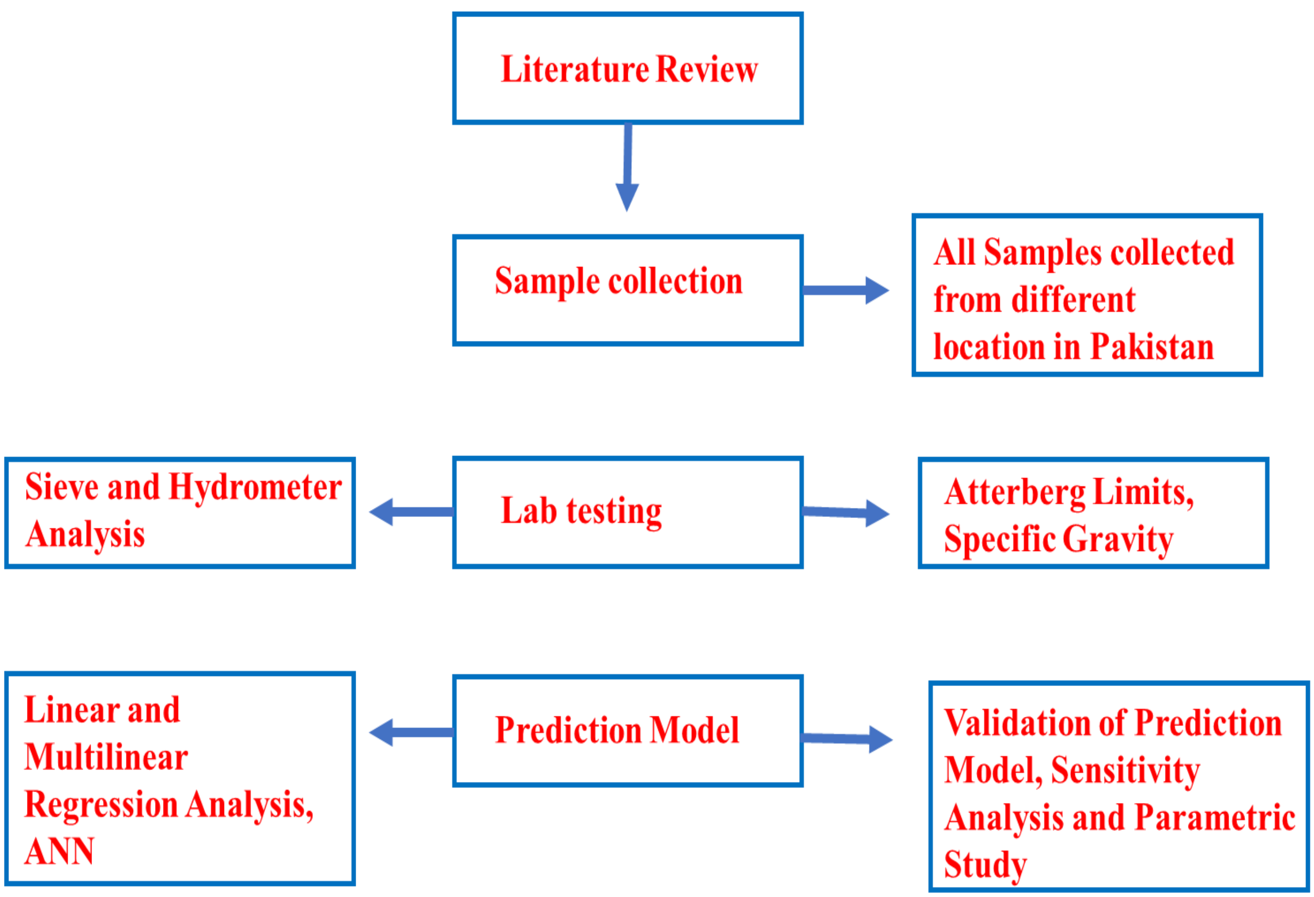


Figure 9: Research Methodology plan

3.4 Samples Collection:

Eighty samples are collected from different locations in Pakistan. More than 50 samples are collected from the northern side of Pakistan (Charsada, Mardan, Peshawar, Nowshera, swabi). Some samples are collected from federal areas of Pakistan Islamabad, and the rest of the samples are taken from other areas of pakistan. The coordinates of each sample have been noted with the store coordinator app from mobile to develop a map that shows the soil profile which is easily understandable from the map sheet. Maps represent the real world on a much smaller scale in this way using the GIS shapefile of Pakistan the northern and federal areas have been extracted and developed a map having the coordinates of each sample.

City name	Number of samples	Coordinates
Islamabad	13	33°43'47.08"N73° 5'32.10"E
Mardan	10	34°11'36.99"N72° 2'53.67"E
Takht bahi	10	34°17'9.56"N 71°55'35.30"E
Peshawar	10	33°59'33.26"N 71°31'25.29"E
Charsada	10	34°10'5.46"N 71°45'1.40"E
Nowshehra	10	34° 3'31.17"N71°46'4.45"E
Okara	2	30°48'49.63"N 73°27'11.99"E
Muzaffargarh	2	30° 4'24.99"N71°10'49.79"E
Bannu	3	32°59'27.33"N 70°38'44.04"E
Hangu	3	33°31'16.55"N71° 3'38.97"E
Lakki Marwat	3	32°36'49.23"N70°54'4.37"E
Sari Nourang	4	32°46'18.60"N70°46'41.43"E
Khar, Bajaur	3	34°43'48.12"N 71°31'19.42"E

Table 1: Coordinates noted with Store Coordinator App

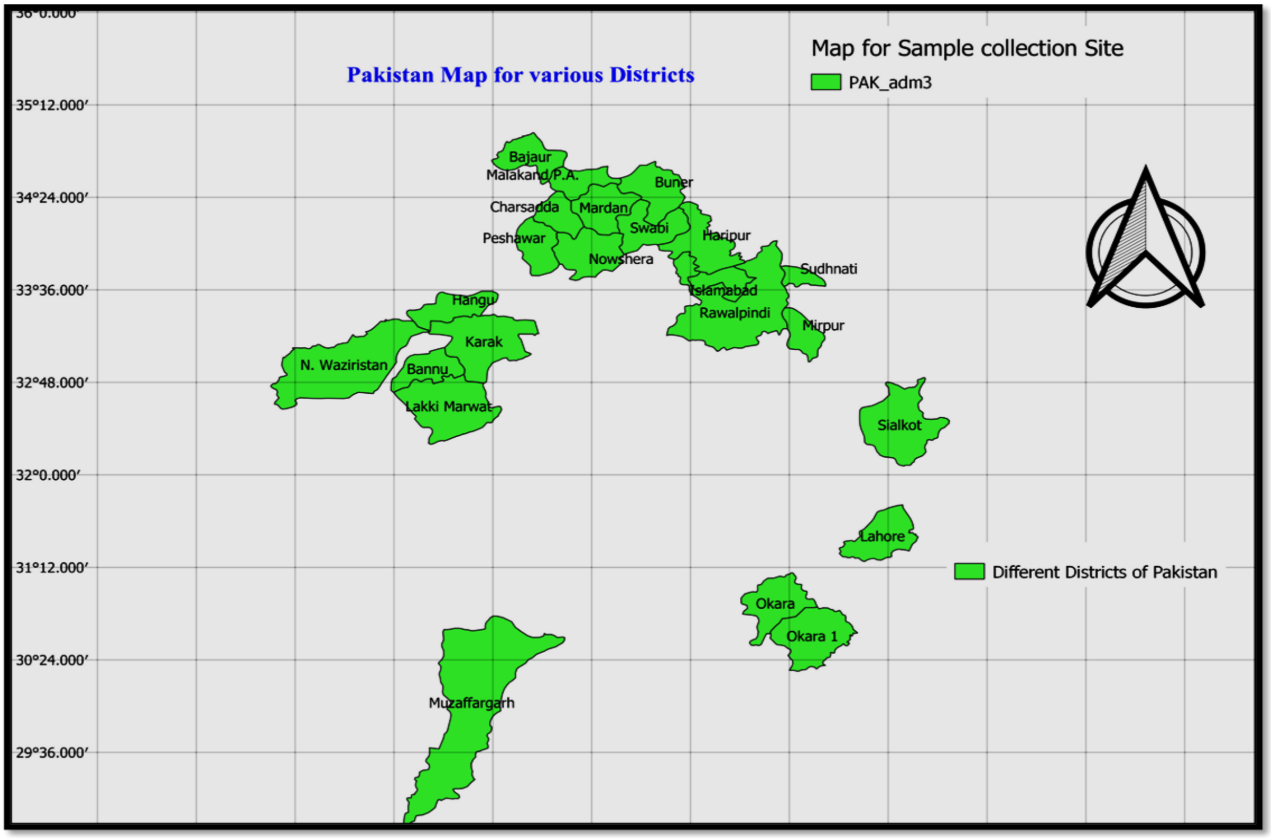


Figure 10 Map of Different Site for Samples Collection

3.5 Sieve analysis:

For lab work to conduct the various test, including the PL and LL test, the first sieve analysis is carried out of all samples. There are different sizes of sieve given in the table, but we are interested in only sieve #40 and Sieve #200. All the Sample is passed over sieve #40 and conduct all the relevant test then pass the same Sample from sieve #200 and repeat the tests. The size of sieve #40 is 0.425 mm, and #200 has 0.075 mm, respectively. The Standard used for sieve analysis is ASTM C136 (28). Samples are prepared according to the given code and then perform sieve analysis.

3.5.1 Preparation of Sample for sieve analysis:

For the sieve analysis the sample is the first oven dry and for 24 hours to remove all moisture content as shown in Figure 10.

Figure 11 Oven Dry the Samples

3.5.2 Pulverized the Samples before sieve analysis

The soil samples are first completely pulverized before the sieve analysis to get fine particles accurately. With the time clay particles are bound together make large particles or coarse sand, due to its cohesive nature, therefore, it needs to be pulverized. It is the isolation of particles grains from each other rather than the breaking up of individual particles

Figure 12 Pulverizing the Samples

3.5.3 Sieve analysis & its arrangement

The sieves are arranged in descending order according to the mesh size of the sieve. Sieve #4 (4.75 mm) at top and sieve #200 (0.075 mm) at the bottom of the arrangement.

Figure 13 Arrangement of sieve descending order according to Mesh sizes

The larger particles size of soil mass that is retained in each sieve was noted in a lab notebook and then calculate the accumulative mass. By proceeding with the calculation to find the percentage retained and percentage pass. Then develop the curve for particles size distribution.

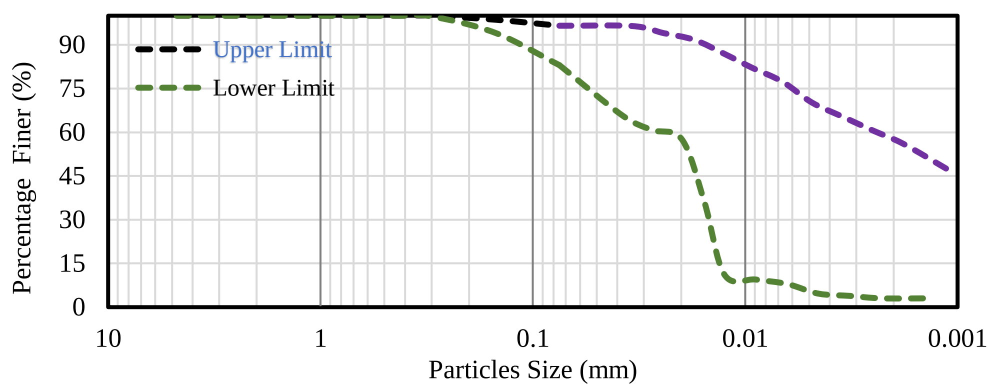


Figure 14 Lower and upper limits of percentage finer based on Hydrometer analysis of soil samples

3.6 Atterberg limits:

In the lab work, we are required to conduct the LL and PL test to calculate the Plasticity index. First, we determine the LL and PL for samples passed over sieve #40 and then the same for #200.

3.6.1 Atterberg Limits:

In Swedish scientist, Atterberg first determines the behavior of soil which changes with water content. As its logical increase, the amount of water in the soil it will lose its structure and shear strength will reduce and it does not behave like plastic, but it will flow like a liquid. Based on the investigation of Atterberg, he introduces some terminology when water content changes, the state of soil also changes.

According to Atterberg, the level of water at which soil changes its state from solid to semi-solid is called shrinkage limit. When water changes more and soil changes from semi-solid to plastic at this state, it is called a plastic state, as shown in the figure. After the plastic limit the level of water, which further cause variation in soil behavior, a state came which called the liquid limit of the soil at which soil has low shear strength due to a large amount of water and flow like a liquid

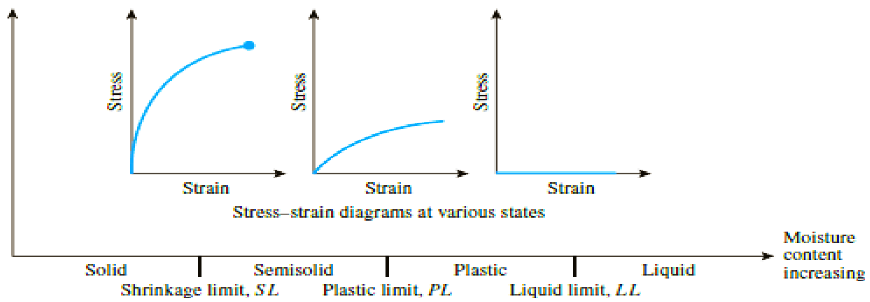


Figure 15 Atterberg Limits Das 2018

3.6.2 Liquid Limit (LL):

Liquid limit can be address as a moisture content at which it behaves as a liquid. Most commonly two method is used for LL calculation, Casagrande apparatus and fall cone penetrometer. In a Casagrande apparatus LL is Calculated by placing a sample in a standard cup and making a narrow groove. The cup is dropped till the standard separation combine the moisture in percentage then plotted against blow and MC corresponding to 25 blows are LL.

A groove is cut in the middle of the soil filled Casagrande cup using a conventional tool that is 2 millimeters (0.079 in) wide. The cup is dropped 10 mm onto a strong rubber base at a rate of 120 blows per minute, with each drop causing the groove to progressively close. It is noted how many strikes are necessary to seal the groove. The moisture level at which 25 drops from the cup cause the groove to narrow by more than 12.7 millimeters is known as the liquid limit (0.50 in). The test is conducted at the water content, and based on the test results, it is determined that it took 25 blows to close the groove. The liquid limit test is specified by ASTM Standard Test Method D 4318. The test method also allows for running the test at a single moisture content, where 20 to 30 blows are necessary to close the groove, and then applying a correction factor to get the liquid limit from the moisture content.

A standard weight and tip angle stainless steel cone is place so that it just touches a soil sample, based on the Fall cone analysis. For the cone to enter the soil, it must be released for a set amount of time, usually five seconds. There are several standards in use all around the world. The cone tip angle and cone mass are the two most significant distinctions. In soil, the liquid limit is the amount of water that allows the cone to penetrate a certain depth in a certain amount of time. The LL is tested at a different depth depending on the standard and method used. The BS 1377, for example, is one of the most well-known standards. According to the British standard, the LL is the amount of water in a soil at which an 80g, 30o cone penetrates 20mm. as maintaining a moisture corresponding to 20 mm penetration is difficult therefore number of test is conducted with for a variety of water volumes, and the results are interpolated.

The LL can be determined with the famous method fall cone method (BS1377) (29). As a result of this test, the liquid limit is calculated as the moisture content at which a cone with an apex angle of 30° and a weight of 0.78 N will penetrate a distance d = 20 mm within 5 seconds from point contact. The apparatus used for liquid limit determination in this thesis will be the fall cone method, as shown in the figure below.

The Sample is placed in the apparatus with given moisture content and allowed to penetrate the reading is noted after 5 sec. Due to difficulty in achieving the LL four test is performed at different moisture content, and the penetration depth is noted. A semilogarithmic graph is plotted between moisture content and depth, and water content corresponding to 20 mm depth is the LL.

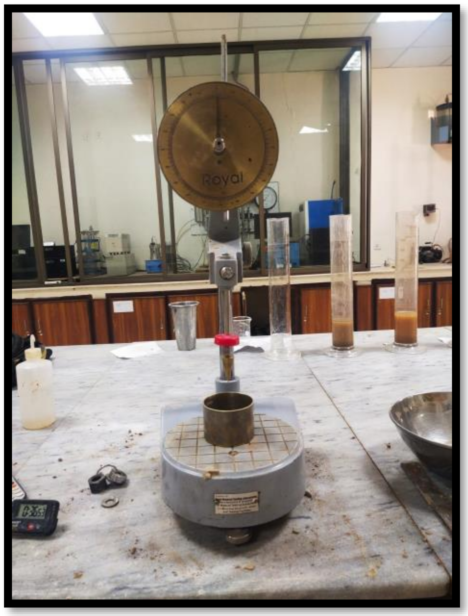


Figure 16 Fall Cone Penetrometer apparatus

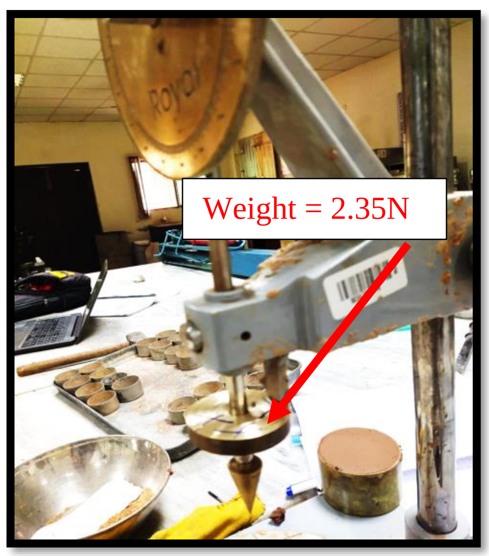
3.6.3 Plastic Limit (PL):

The PL can be obtained by rolling technique in which spacemen in rolled into a thread of diameter 0.125 inches at a given moisture content then it crumbles. Standard used to determine PL ASTM D-4318 (30) in which soil is rolled repeatedly into the ellipsoidal-sized soil mass by hand over a plate surface.

On a level, non-porous surface, a thread of fine dirt is spread out to determine the plastic limit (PL). The method is described in ASTM Standard D4318. This thread will maintain its shape down to a very tiny diameter if the soil is sufficiently wet for it to act plastically. The test can then be performed once the sample has been reshaped. The thread will start to separate at bigger diameters as the moisture content decreases due to evaporation.

Figure 17 PL Using Cone Penetrometer

However, PL can be determined by the fall cone method in which the same geometry apparatus used by changing the weight of hammer 2.35N. follow the same procedure was performed for liquid limit and carried out three or four tests with varying moisture content to calculate PL. As shown in the figure.



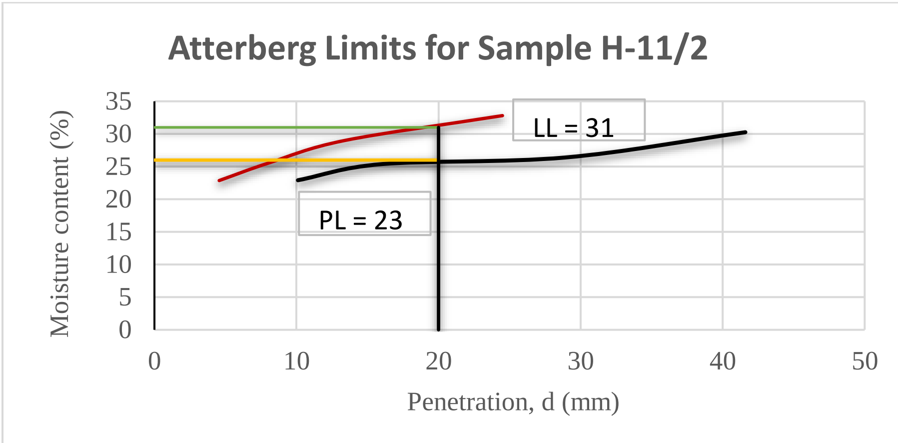


Figure 18 LL & PL by fall cone test

3.6.4 Plasticity Index:

The plasticity index (PI) is an indicator of a soil's more clay content. The plasticity index measures the total amount of the water soil can hold before it transfers to other state. The PI is the difference between the liquid and plastic limits. Clay soils have a high PI, it because of high clay content which have large specific are and thus lead to increase of PI while silty soils have a lower PI.

Plasticity (PI) can claim as the numerically difference between LL and PL.

$$PI = LL-PL$$

For this research, plasticity is a core parameter to define the goal of the gap of research and it will determine from different soil samples. Plasticity is an essential property for classifying fine-grained soil defined as a material's ability to be moulded to any shape without cracking. USCS has defined fine-grained soil base on plasticity.

The author Burmister (1949) (31) determines the different ranges for the soil which revealing that in a particular range of plasticity index what is the behaviour of soil.

PI	Description
0	Nonplastic
1_5	Slightly plastic
5_10	Low plasticity
10_20	Medium plasticity
20_40	High plasticity
>40	Very high plasticity

In this research, the plasticity of different soil samples is calculated, and it is addressed that it is low plastic or highly plastic. Moreover, soil plasticity is calculated based on materials passing over sieve #40 and #200 and soil plasticity is higher for materials passing #200 which we called in a shift in plasticity.

From the lab the following result has been achived upto now.

3.6.5 Hydrometer analysis

The fine content of soil that passes through sieve #200 is calculated using the hydrometer analysis of soil, also known as sedimentation analysis, based on Stokes' law. The velocity at which the grains settle out of suspension, all other factors being equal, is determined by the shape, weight, and size of the grains, according to Stokes law. When soil particles in soil water suspension have the same specific gravity, the coarser particles settle faster than the finer ones. The speed at which soil particles settle out of suspension from a liquid is used to calculate their size. The grain size distribution for soils finer than the 75m sieve (#200) is shown in the test results.

$$v = \frac{\rho s - \rho w}{18\eta} D^2$$

Where

v = velocity

ρs = density of soil particles

ρs = density of water

η = viscosity of water

D = diameter of soil particles

From Equation 1

$$D = \sqrt{\frac{18\eta v}{\rho s - \rho w}} = \sqrt{\frac{18\eta}{\rho s - \rho w}}\sqrt{\frac{L}{t}}$$

Where V = L/t

Also $\rho s = Gs\rho s$

Thus solving the above equation, we will get

$$D = \sqrt{\frac{18\eta}{(Gs-1)\rho w}}\sqrt{\frac{L}{t}}$$

Assume ρ_w to be approximately equal to 1 g/cm3, so that

$$D(mm) = \sqrt{\frac{L(cm)}{t(\min)}}$$

$$K = \sqrt{\frac{30\eta}{(Gs-1)}}$$

Note that the value of K is a function of Gs and η, which are dependent on the temperature of the test.

The hydrometer test is commonly performed in a sedimentation cylinder with 50 g of oven-dried material. The sedimentation cylinder has a height of 457 mm and a diameter of 63.5 mm. It is indicated for a capacity of 1000 ml. Sodium hexametaphosphate is commonly used to disperse flocculant soil. By adding distilled water, the amount of the scattered dirt suspension is raised to 1000 ml. The ASTM D152H (32).

The samples are first socked for a time with sodium hexametaphosphate to make a solution flocculate so that the particles in suspension are settled under gravity as shown in figure 19.

Figure 19: Samples Placed to Soaked Before starting of Testing

Then the cylindrical jar of 1000 ml is filled with water and makes full suspension of particles and allowed the hydrometer in a jar and start the reading in 1 minute, 2, 4, 8, 15, 30, 60, 120, 240, 480, 1440 minute. At each interval take the reading of temperature so that temperature correction is compensated at the net result as shown in figure 20.

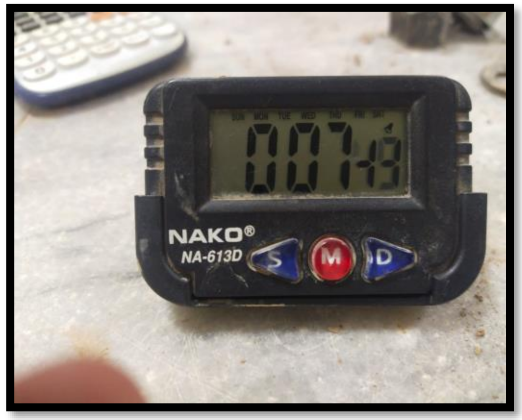
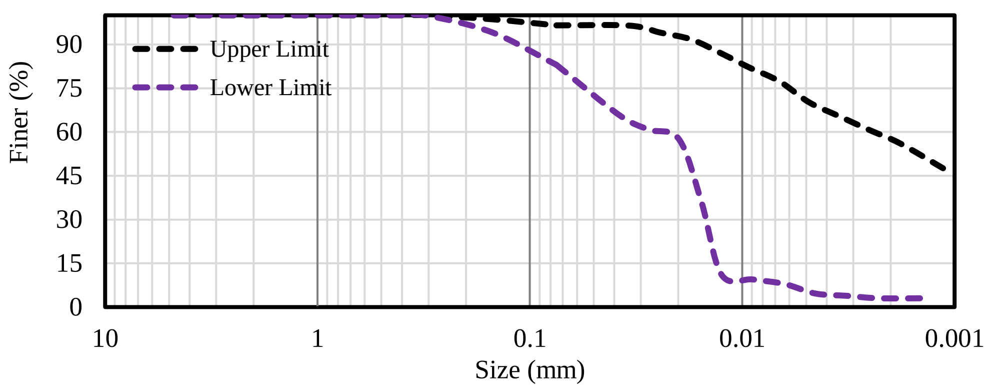


Figure 20: Hydrometer analysis of soil

Results:



3.6.6 Specific Gravity (Gs.)

Specific gravity (Gs) can be computed as the weight in air of a certain volume of soil particles at a particular temperature compared to the weight in air of an equivalent volume of distilled water at the same temperature. The specific gravity is critical for many computations, including calculating soil quality. It can be determined accurately in the laboratory by using a pycnometer meter or by density bottle method. G_S. Can be used for determination of fine soil through Hydrometer analysis and which the prime objective to determine Gs. Of the soil.

The procedure for specific gravity determination in this research is using density bottle method in which we first take empty clean bottle and weight and put the soil sample in that as shown in figure.

Figure 21 Preparation of Soil Samples for Testing

Take water in bottle containing soil and weight again (soil + water + bottle) and wight this.

Figure 22 Clean Empty bottle with soil sample

Use the hot plate the soil samples to de-aired and the called them and filled them with water upto the level.

Figure 23 Show Different Steps Followed During Specific Gravity Test

The weight of the flask, soil and water up to the marks is calculated and then flask is lean from soil and water and filled from water up to the and weight the weight of flask and water.

Chapter 4. Results and Discussion

Sieve analysis, Atterberg limits, hydrometer analysis, and specific gravity are all part of a laboratory examination for one hundred and twenty (120) soil samples. The majority of the samples gathered from the various sites were fine-grained dirt. The maximum and lower boundaries of the particle size distribution of soil samples used in the current investigation are shown in Figure 4. The upper and lower bounds of the particle distribution curves demonstrate that silt content ranges from 34% to 93%, whereas clay concentration ranges from 5% to 60%. All samples were subjected to hydrometer examination to determine the proportion of clay and silt. According to the test data, silt has a higher proportion than clay. According to experimental results, a few soil samples had a maximum ratio of 60% clay and 40% silt, while the remainder of the soil has a silt content of more than 50%, as shown in Figure 24..

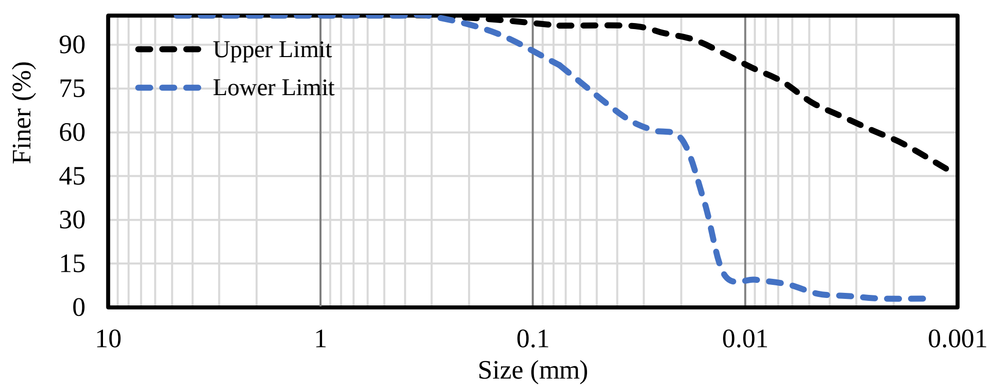


Figure 24 Sieve analysis

Figures 5 and 6 illustrate the findings of Atterberg limits derived from sieve # 40 and 200 passing material, respectively. The results show that the liquid limit achieved from sieve # 200 material is much larger than that obtained from sieve # 40 passing material due to smaller size particles having a higher water retaining capacity. (33). This suggests that the soil categorization based on CPC will be impacted by the Atterberg limitations discovered using sieve # 200 passing material. Figure 7's plot of the Atterberg limits data for soils passing through sieves #40 and #200 illustrates the shift in soil class and location of plasticity in CPC. In this investigation, it was discovered that there is a certain range at which the largest influence on the soil occurs, which in most cases results in a change in soil class and location of plasticity. When soil classification was carried out in accordance with USCS based on Atterberg limits determination utilising sieve 40 and 200 materials, Figure 8 illustrates the change in soil type and location of plasticity. For instance, the class of soil sample shifted from CL-ML to CL to lean clay according to CPC when the soils passing through sieve #40 had a plasticity index between 5 and 7. It is possible to switch the soil type from CL to MH or CL to CH if the liquid limit is higher than 45.

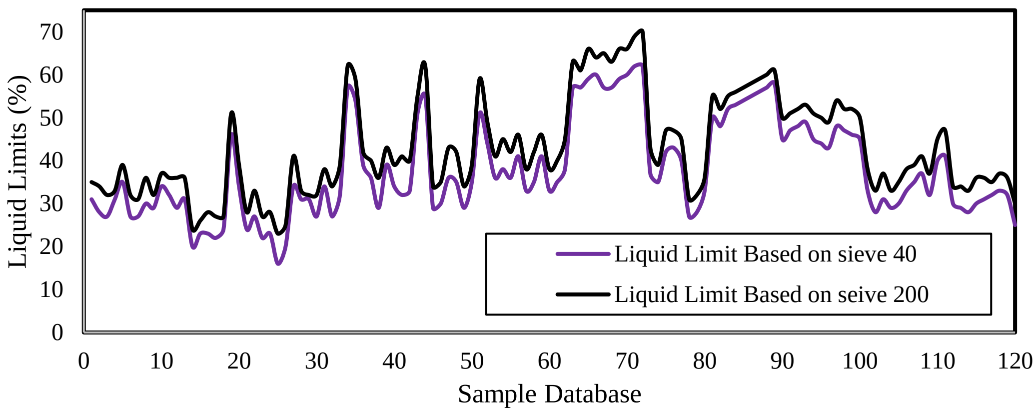


Figure 25 LL obtained using sieve # 40 and 200.

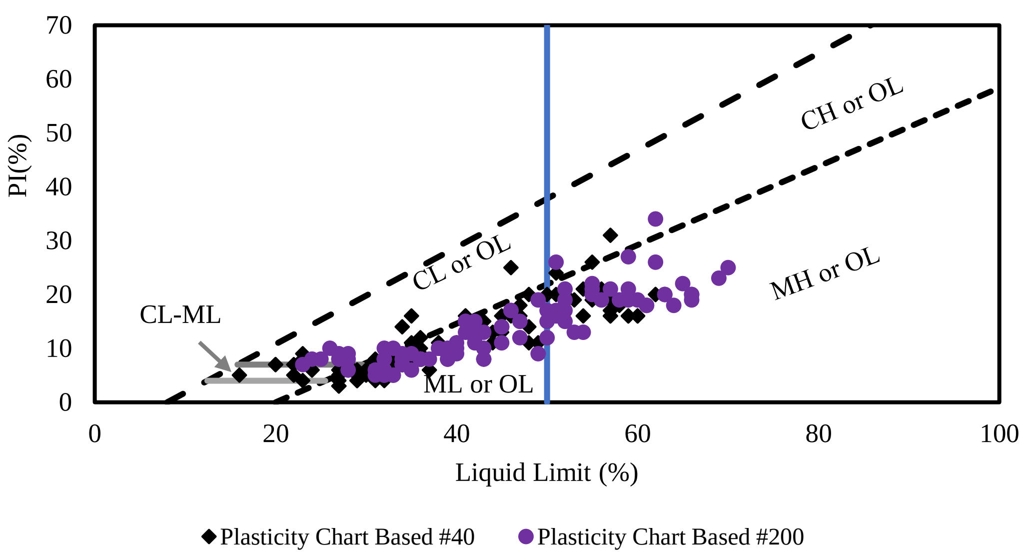


Figure 26 Plasticity chart

Since it takes a lot of time and effort to calculate the liquid limit using the material that passes through sieve # 200, It can take a long time and a lot of work for the material to pass through sieve

#200. Prediction models were created as a result to address these problems. The creation of prediction models for the identification of Atterberg limits is the subject of the study's subsequent parts..

4.1 Development of Prediction Models:

Particle size and gradation are expected to have an impact on how fine kind of soil is classified. The same idea, that categorization based on sieve # 40 passing material may lead to errors, has already been covered in the preceding sections. Moreover, it takes a lot of time and effort to calculate the liquid limit using sieve # 200 material. Prediction models were created using linear regression, multiple linear regression, and artificial neural network (ANN) approaches to take particle size into consideration when classifying soil.s

However, in this work, the Atterberg limit # 40, the clay content, the silt content, and the sand content (S) were selected as the most important and pertinent inputs for the creation of the prediction model.

$$(Atterberg\ Limit)_{200} = f\ (CL, ML, S, Atterberg\ Limit_{40}) \qquad \textbf{(1)}$$

CL(%) = clay content, ML(%) = silt content, S(%) = sand content, Atterberg limits(40) = are liquid limit (LL) and plastic limit (PL).

4.2 Linear Regression Model (LRM):

Based on sieve #40 and #200, the correlation is created to signify some kind of relationship between the Atterberg limits. Two variables are used in simple linear regression; one is the input variable and the other is the ouput variable. The value of the response variable (Y) can be represented as eq for a certain value of the input variable (x) (2).

$$Y = \alpha + \beta x + e \qquad (2)$$

Using experimental data between the LL200 and LL40 given by equations 1 and 2, a linear regression with a significant correlation coefficient was established, as illustrated in Figures 29 and 30. (R2). R2 values over 0.9 show a significant correlation between the independent and dependent variables.

$$LL_{200} = 1.0103x + 4.6073 \qquad (3)$$

$$PL_{200} = 0.9936x + 3.2782 \quad (4)$$

Where x = Atterberg limits based on sieve #40

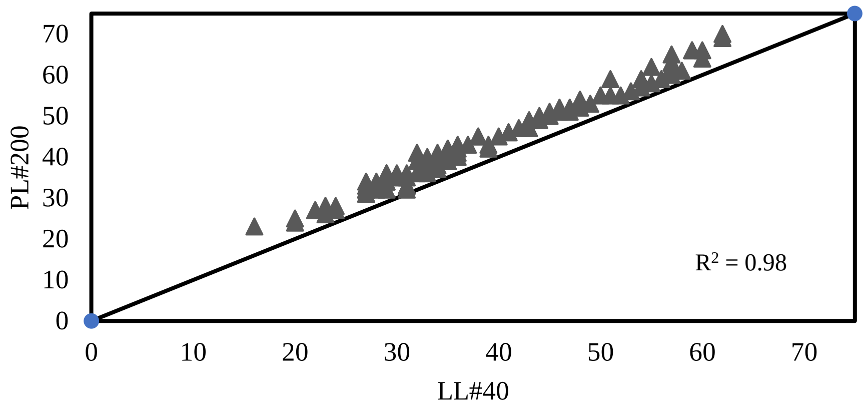


Figure 27 LL based on #40 and sieve #200

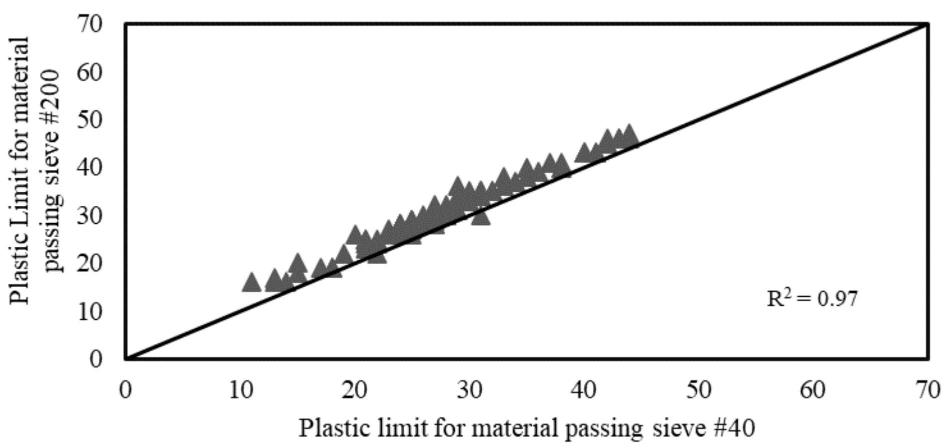


Figure 28 Plastic Limit Based on sieve #40 and sieve #200.

4.3 Multilinear Regression Model (MLR)

It is well knowledge that soil gradation and particle size have an impact on Atterberg limits. Consequently, a multiple linear regression model was created in order to accurately determine Atterberg limits (200). Because figuring out the liquid limit on passing sieve #200 takes a lot of time. For accurate calculation of Atterberg limits200, clay, silt, sand, and Atterberg limit(40) were used as independent variables. For the purpose of developing and testing the prediction model, Table.3 gives a basic statistical description of the inherent characteristics of soil. 120 soil samples were used to train the prediction model.

Table 2 Statistics of input for Validation of Atterberg limit$_{200}$ model

Predictors	Minimum	Maximum	Mean	Std. Deviation
Clay (%)	5	60	27.8	17.8
Silt (%)	34	93	66.2	18.7
Sand (%)	2	36	5.9	3.2
LL_{40} (%)	16	62	39.3	11.78
PL_{40} (%)	11	44	27.9	7.29

The MLR model was developed, and prediction equations for LL200 and PL200 can be established. General form for MLR is given as (5).

$$Y_i = \beta_0 + \beta_1 xi_1 + \beta_2 xi_2 + \cdots + \beta_p xi_p + e \qquad (5)$$

Multiple regression's initial presumption is that the connection between the independent variables (IVs) and the dependent variables can be described by a straight line (DVs). The distribution of residuals is specified by the assumption of normality. This presumption that the data near to zero reflects the best residual distribution may be confirmed by the histogram. When a prediction model is homoscedastic, the residual has a constant variance with respect to the values of the dependent variables (DVs).

As seen in Figures 31 and 32, the MLR model has met all of the major presumptions. The MLR model's inputs consist of clay, silt, sand, and LL40. The prediction equations for LL200 and PL200, respectively, are Eqs. (6) and (7)..

$$LL_{200} = 4.0 + 0.006\,ML + 0.039\,C + 0.9762\,LL40 + 0.076\,S \qquad (6)$$

$$PL_{200} = 3.5 - 0.001\,ML + 0.01\,C + 0.9751\,PL40 - 0.003\,S \qquad (7)$$

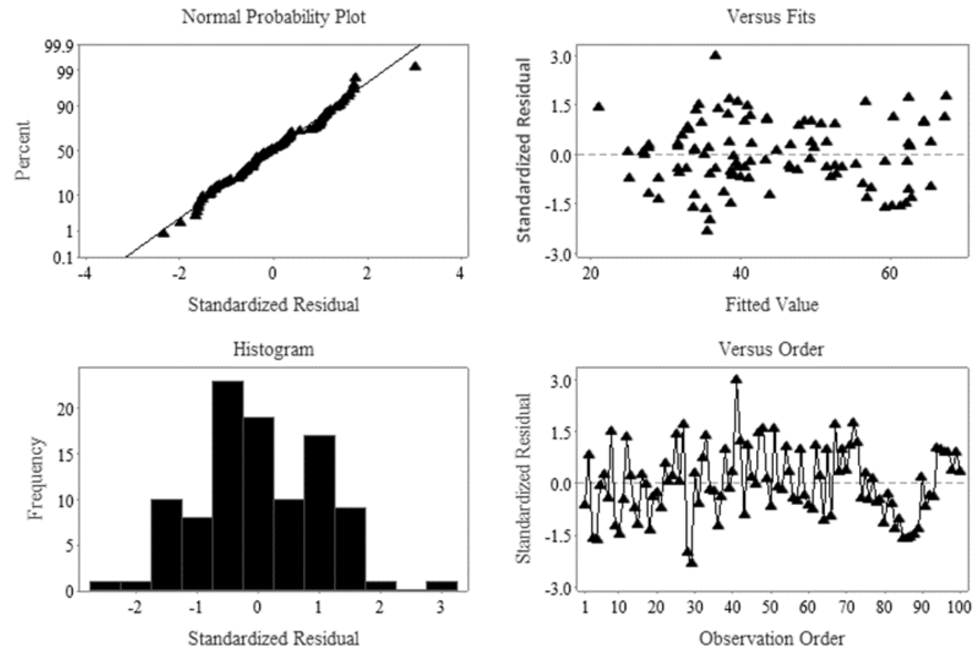


Figure 29 MLR analysis Assumption for predicting LL200

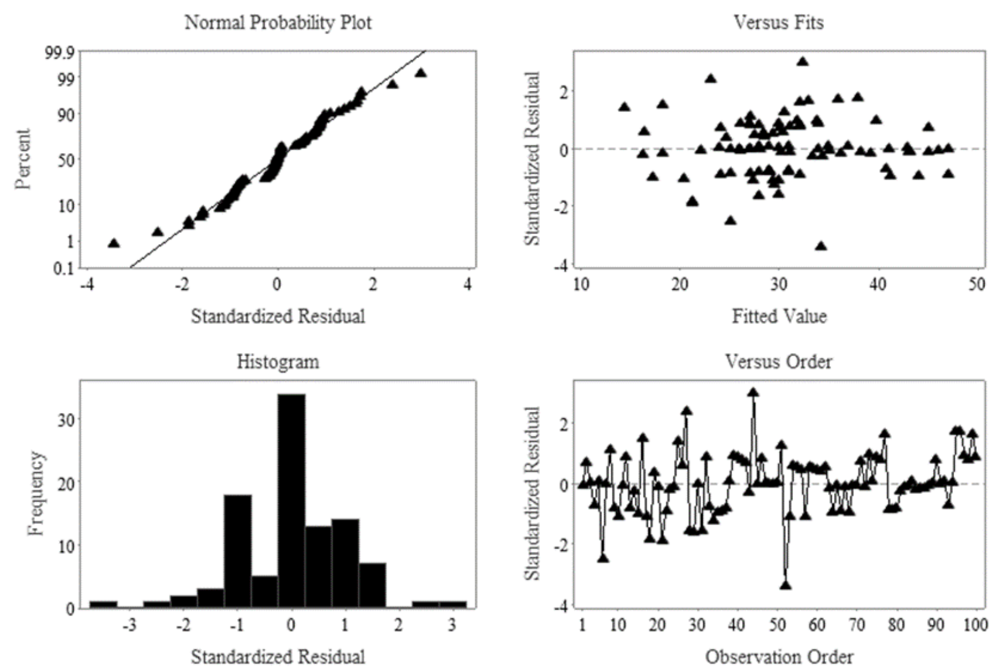


Figure 30 MLR analysis Assumption for predicting PL200

The interdependency of variables taken into consideration for modelling purposes is assessed in terms of correlation strength using the Pearson correlation approach (34). R values, which range from -1 to +1, are used to assess the correlation's strength. Values around 1 similarly indicate a high association (34). The Pearson correlation matrices for the independent input variables clay, silt, sand, LL40, and PL40, as well as the dependent output variables LL200 and PL200, are shown in Tables 4 and 5.

Table 3 correlation matrix for LL_{200}

	LL_{200} [%]
LL_{200} [%]	1.000
Silt [%]	-0.773
Sand [%]	-0.262
Clay [%]	0.799
LL_{40} [%]	0.992

Table 4 correlation matrix for PL200

	PL_{200} [%]
PL_{200} [%]	1.000
Silt [%]	-0.626
Sand [%]	-0.20
Clay [%]	0.643
PL_{40} [%]	0.986

4.4 Artificial Neural Model (ANN):

ANN is a popular artificial intelligence method for accurately predicting parameters and pattern recognition. Over the last few decades, ANN has grown in importance in the field of civil engineering (35,36). After examining a neuron's fundamental structure, we may look at ways to express its activities and functions in software. According to this, we create artificial neurons as basic mathematical operations, and three key variables—input signals, weights, and bias—decide their output (37). As indicated in Figure 34, the input signals are impulses that directly originate from nearby neurons, while the Weights, which each neuron provides a distinct weight to each input signal received, and the Bias values, which are unique to each neuron and contributed to the total output..

Using three input variables—liquid limits, plastic limits, and a plasticity index based on sieve # 40—an Artificial Neural Model (ANN) was created using MATLAB to forecast the same Atterberg limits for sieve # 200. (see Figure 34). Training, testing, and validation data samples are all taken into account by ANN networks. During training, the network is given training data, and depending on its mistakes, the network is modified. Network generalization is monitored using the validation, and training is halted when generalization slackens. Testing, however, has no bearing on training and provides a neutral evaluation of network performance both during and after training.

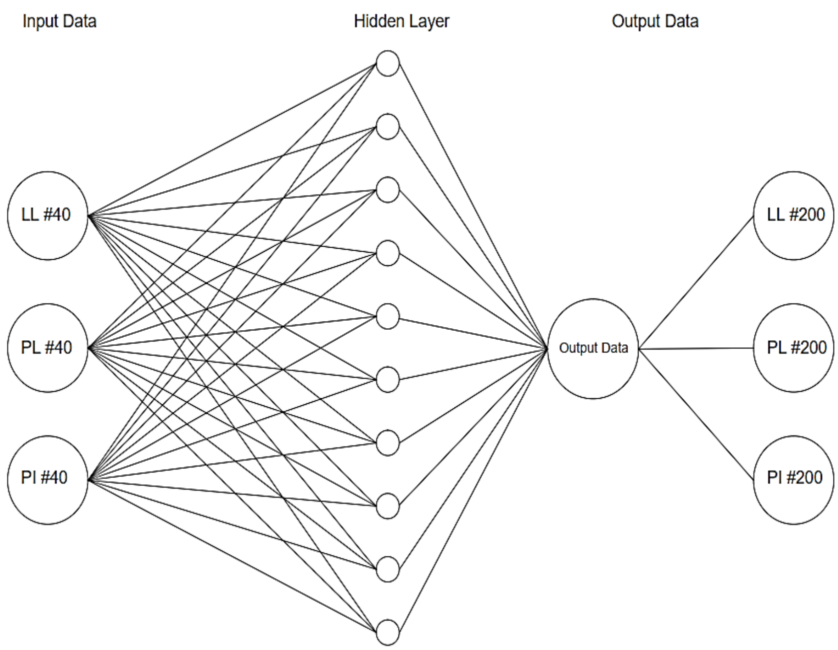


Figure 31 Artificial neural network (ANN) model configuration

The feed-forward background with two hidden layers each having 10 neurons serves as the foundation for the ANN model type. Data was randomly split into 100 samples, then neural fitting was used. 30% of the data is utilized for testing and validation and 70% of the samples are used for training. As indicated in Table 5 the correlation coefficient has been used to illustrate the performance of the ANN model. R values of 0.99 were found for training, validation, and testing, respectively, indicating that the ANN approach has good coherency and prediction capabilities..

Table 5 Performance of the proposed model

Parameter	Training	Validation	Testing	All Data
R	0.997	0.995	0.997	0.995

R Correlation Coefficient.

Figures 36 and 37 display the link between the experimental dataset and the anticipated dataset in terms of lower and upper limit errors.

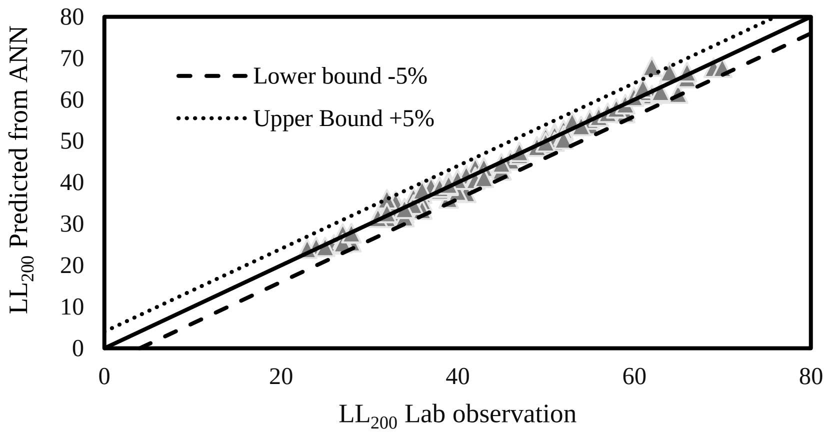


Figure 32 Lab observation and ANN Prediction Model for LL200

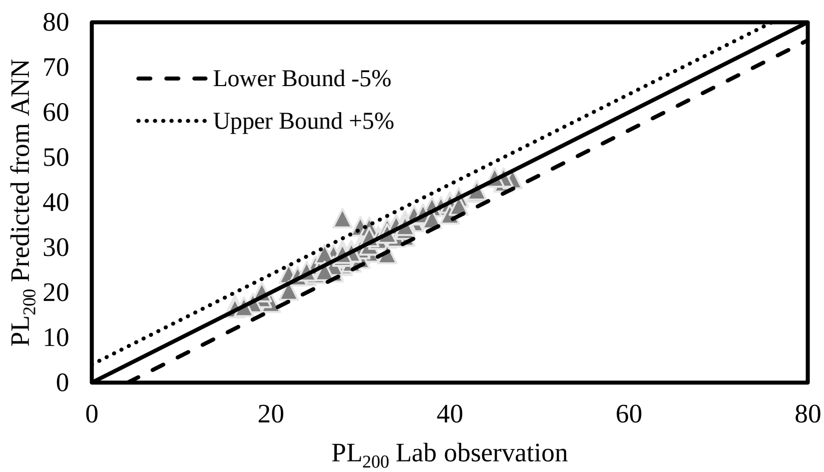


Figure 33 Error plots for ±5 % error bounds (a) LL200 (b) PL200

4.5 Sensitivity Analysis

sensitivity analysis (SA) and parametric studies use to verify the importance of prediction model and its accuracy. While parametric studies show the propensity of prediction models to rationalize the physical processes or not, sensitivity analysis shows the relevance of independent variables in the order of significance. Eqs. 5, (22, 23) were employed in this study's sensitivity analysis, with sensitivity values ranging from 0 to 1.

The results of the sensitivity analysis are shown in Figures 38 and 39. While fine content has a significant influence, which is consistent with the literature study, the Atterberg limits (LL40, PL40) based on sieve #40 soil are the most relevant and sensitive criteria for assessing the Atterberg limit (LL200, PL200) based on sieve #200. (10). Clay is regarded as the most sensitive soil attribute because when clay content rises, surface area and water holding capacity rise, leading to increasing Atterberg limits (1,10). Since direct measurement of LL200 and PL200 is time-consuming and impractical, the prediction model uses LL40 and PL40 as input parameters. As shown in table 4, the Pearson correlation also supports the notion that LL40 and PL40 are the most sensitive parameters for predicting LL200 and PL200. With sensitivity of 74% and 76% for LL40 and PL40, respectively, the Sand is a crucial parameter. Sand is still a key parameter even though its sensitivity is lower than that of other factors (33).

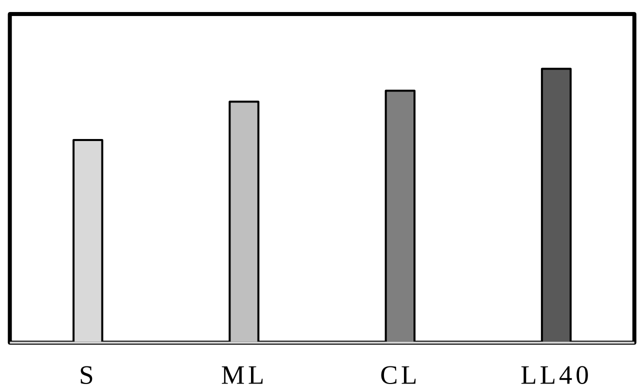


Figure 34 Order of sensitivity for LL200

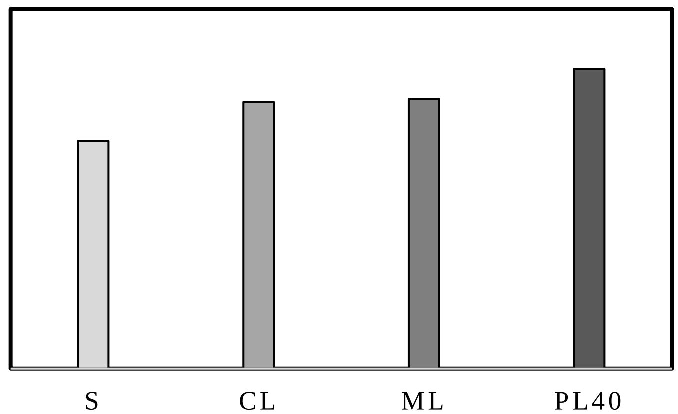
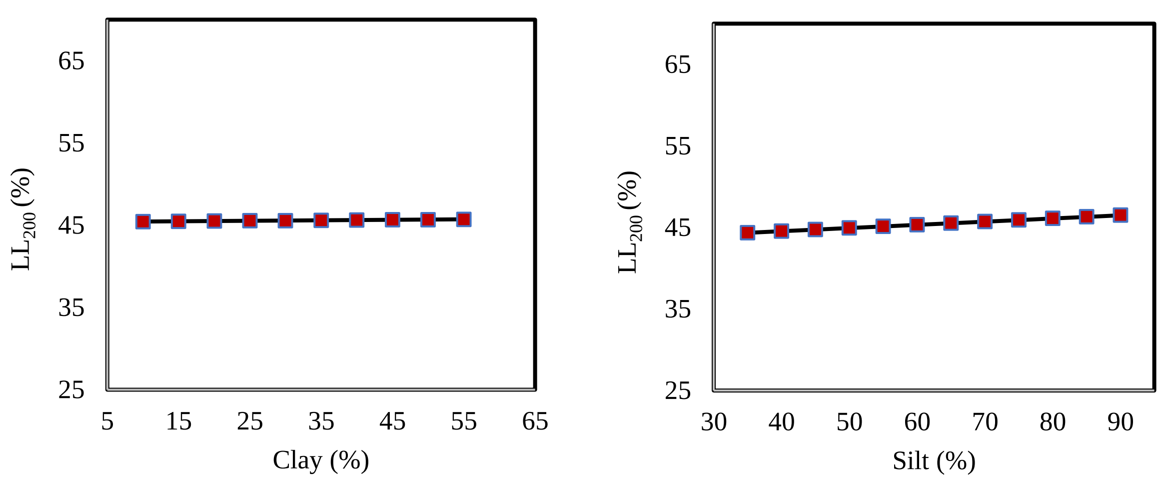


Figure 35 Order of sensitivity for PL200

Additionally, parametric analysis was done to determine whether the prediction models adequately described the physical process or whether it was only a correlation (38,39). Figure 20 presents the results of a parametric study on the variables employed in the Atterberg limit prediction model based on sieve # 200. In a parametric analysis, all predictor variables remain constant at their Average values while one input variable is modified around its average. The related outcome is then observed. In order to understand the physical operation of the predictor and the model, a connection is created. According to the findings, the Atterberg limits likewise rise as fine content rises, which is clearly described in the prior work. Similar to how sand mixes and silt concentration directly relate to Atterberg limitations.



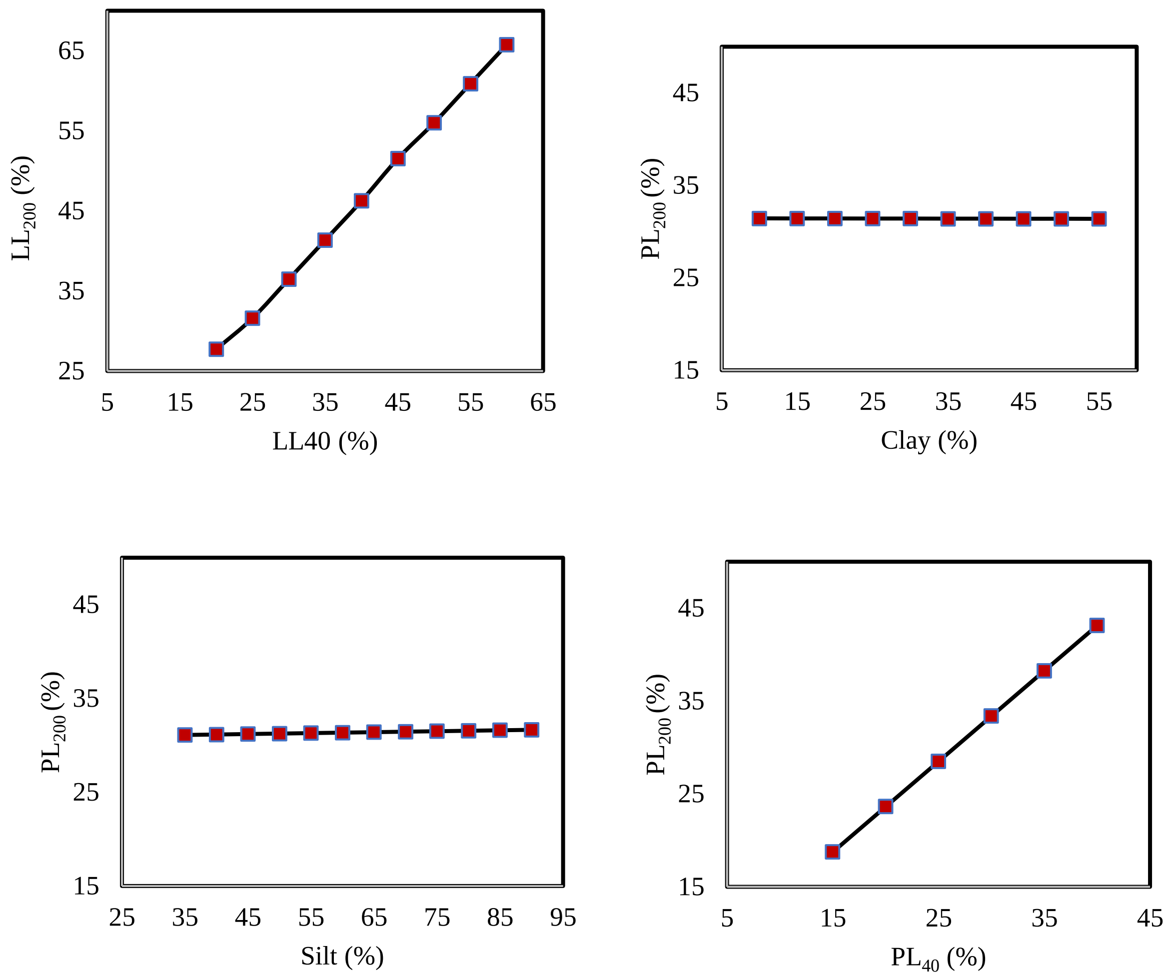


Figure 36 Parametric analysis

Chapter 5. Conclusion

The Sieve # 40 for the fine soil categorization served as the foundation for Casagrande's original development of the Casagrande Plasticity Chart (CPC). Soil with a coarse grain is present in the material passing through sieve #40. The real Atterberg limit of the soil and its location in terms of plasticity are therefore impacted by the coarse-grained material, which results in a shift in soil type. Fine soil, as described by the USC system, is material having a particle size of less than 0.075 mm. According to the lab studies, the liquid and plastic limits for material types # 200 are higher than those for material types # 40, which results in considerable changes to soil classes and plasticity levels. When utilizing the CSC for fine-grained soils, Atterberg limits must be established using material that passes sieve # 200 rather than material that passes sieve # 40 to support the USC system's definition of fine-grained soils. As seen from the data, there has been a change in the flexibility of the soil classes and levels, which can be dangerous for delicate buildings. Reliable findings were obtained by developing ANN models using the Atterberg limit40 as an input and the Atterberg limit200 as an output. In order to estimate the Atterberg limit200, linear and multilinear regression equations are built between the Atterberg limit40, clay, silt, and sand. To ensure more accurate predictions, a sensitivity and parametric analysis was used to validate the prediction models.

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