The Cooper Union for the Advancement of Science and Art

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING
INTRODUCTION TO GEOTECHNICAL ENGINEERING LABORATORY

PART 1

SOIL SAMPLE PROPERTIES FROM MANALAPAN, NJ

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CE-331
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1 Overview

This report details the properties of a soil sample obtained from Manalapan, New Jersey. The experiments run and the results are to be used for consideration in the design of a flexible pavement project to be executed in the area. A summary of results is presented in the following table.

Specific Gravity at 20°C	2.714
AASHTO Classification	A-1-b (0)
USCS Classification	GP-GM
FAA Classification	E-5 (F1)
Coefficient of Gradation, C_c	0.075
Liquid Limit	26.84%
Plastic Limit	34.6%
Dry Unit Weight	96.13 pcf
Optimum Moisture Content	8.55%
Dry Unit Weight @ 75% Relative Density	110.7 g
Moisture Content @ 75% Relative Density	14.6%
CBR	32.24
Soaked CBR	20.94

Table 1: Overview

2 Experimental Results

2.1 Specific Gravity Determination

2.1.1 Overview

Determining the specific gravity of soil is important in geotechnical engineering. The specific gravity of any substance is defined as the ratio of its density to the density of water. In this experiment, the specific gravity is determined by comparing the weight of a given volume of soil to the weight of the same volume of water. This provides valuable information about the composition of the soil its sustainability for various engineering applications. To perform the experiment, a soil sample is collected and oven-dried to remove any excess moisture. Then, a known volume of the sample is weighed. The same volume of water is also weighed. The specific gravity is calculated by dividing the weight of the dry soil by the weight of the water.

2.1.2 Results

G_s at 20°C	2.714
G_s at 4°C	2.709

Table 2: Specific Gravities of Soil Sample at Various Temperatures

As seen in the table above, the specific gravity of the soil sample at 20 °C is 2.72. This means that at 20 °C, the density of the soil is 2.72 times the density of water. Additionally, the specific gravity of the soil sample at 4 °C is 2.71, meaning that at 4 °C, the density of the soil is 2.71 times the density of water. While this is a minor difference from 20 °C, it is still important to the experiment as the densities of both soil and water can vary at different temperatures.

2.2 Grain Size Distribution

2.2.1 Overview

In determining grain size distribution, the soil sample was run through a series of sieves to separate the fine and coarse fractions (gravel and sand), which for this series of experiments is defined to be passing No. 10 sieve and retained on No. 10 sieve, respectively. The sieves used for this analysis were: 1.500 in, 1.000 in, 0.750 in, 0.500 in, 0.375 in, No. 4, No. 10, No. 16, No. 30, No. 60, No. 100, and No. 200.

First, the entire quantity was separated by both No. 4 and No. 10 sieves into +No. 4, +No. 10, and -No. 10 fractions. The coarse fraction is all +No. 10 material (+No. 4 and -No. 4 +No. 10) and is worked through a nest of sieves comprised of: 1.5", 1.0", 3/4", 1/2", 3/8", No. 4, and No. 10 sieves. First, the +No. 4 material is worked through the sieves. Any material that passed through the No. 4 sieve was added to the portion of the sample that is -No. 4 +No. 10; any material that is found to be -No. 10 should be noted as a correction.

Once oven dried, the -No. 10 material is worked through a nest of sieves comprised of No. 16, No. 30, No. 60, No. 100, and No. 200. See Appendix for recorded weights of soils retained on each sieve.

A hydrometer analysis was performed on 75.02 grams (wet soil) of the fine fraction to which distilled water was added such that the soil was thoroughly wetted. The wetted soil was then mixed with 100 ml of dispersing agent, loosely covered and allowed to soak for at least 18 hours. This mixture was then transferred to a 1000 ml graduated cylinder, using a spatula and wash bottle as needed. A compressed air mechanical mixer was used to give further dispersion to the sample and mixed at a pressure of 25 psi. for an amount of time corresponding to the plastic index. After the mixing period, pressure was reduced to 1 psi. The mixer tube was unseated and lifted from the graduated cylinder at the same time as it was washed with distilled water to return any soil grains to the graduated cylinder. The graduate was then mixed to create a soil suspension of uniform density; a stirring rod was pumped vigorously for 40 seconds up and down through the entire depth of the suspension, then slowly pumped in the upper half of the suspension for 15 seconds, and finally moved slowly up through the suspension and withdrawn from the graduate for the last 5 seconds. The hydrometer was immediately inserted to a depth slightly below its floating depth and allowed to freely float to rest. Readings were taken at elapsed times of 1/2, 1, and 2 minutes, with the hydrometer remaining continuously in suspension for those two minutes. The hydrometer was then removed, dried, and reinserted to attain three reading at each time; the average of the 1/2, 1, and 2 minute readings was used as the data. Additional hydrometer readings at 4, 8, 15, and 30 minutes, as well as at 1, 2, 4, and 24 hours of elapsed time were recorded, as well as temperature at 2 minutes and all subsequent readings.

Upon the last hydrometer reading, the soil suspension was transferred to a No. 200 sieve, and washed with tap water until the water ran clear. Material retained on the sieve was dried in the oven. The hydrometer and 1000 ml graduated cylinder were calibrated as follows: cross sectional area of the graduate was found and recorded; the volume of the hydrometer bulb was found and recorded; the distance from the neck of the bulb to a calibration mark on the hydrometer stem was measured and recorded along with the corresponding hydrometer reading; the distance from the neck of the bulb to the tip is measured and recorded; the value of the meniscus correction was found and recorded; and the value of the density correction was found and recorded. Calibrated hydrometer readings can be found in the Appendix.

2.2.2 Results

When hydrometer readings are included in the grain size distribution analysis, as calculated in the provided spreadsheet, the table below describes the soil properties. If, however, a grain size distribution curve is produced according to mass retained on each sieve, those properties are also shown below.

Property	Standard	Using Retained Mass
Effective Size, D_{10} (mm)	0.51	4.75
D_{30} (mm)	0.2	15
Median Size, D_{50} (mm)	5	18
D_{60} (mm)	10.5	4.21
Uniformity Coefficient	205.88	4.21
Coefficient of Gradation	0.075	2.37
% Coarse Gravel	0	0
% Medium Gravel	45.055	80.66
% Fine Gravel	5.209	9.32
% Coarse Sand	0.133	0.738
% Medium Sand	0.4922	0.121
% Fine Sand	37.37	9.155
% Silt and Clay	11.74	0

Table 3: Grain Size Distribution Properties

In this table, coarse gravel is defined as soil of diameter greater than 38 mm, medium gravel is greater than 12.5mm, fine gravel greater than 4.75 mm. Coarse sand is greater than 1.18mm, medium sand greater than 0.6 mm, and fine sand greater than 0.075 mm. Silt and clay are defined as smaller than 0.075 mm.

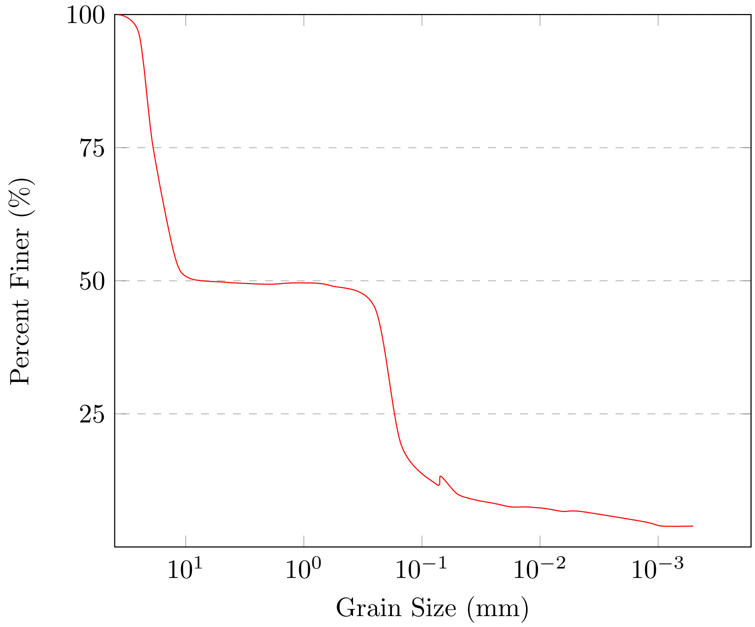

Figure 1: Grain Size Distribution - Logarithmic Scale

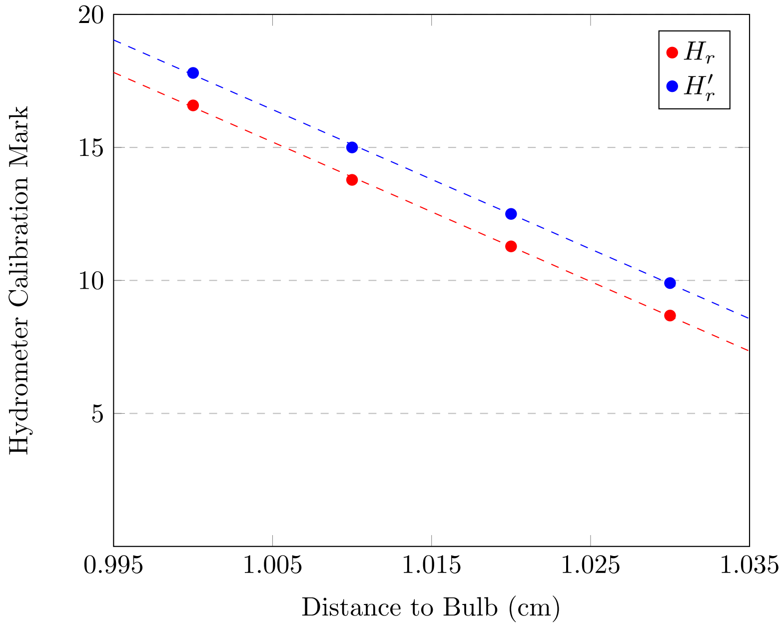

Figure 2: Hydrometer Calibration Graph

2.3 Atterberg Limits

2.3.1 Overview

This experiment was separated into two parts, both asynchronous from one another. The first part of this experiment was to identify the liquid limit of the soil by placing a sample within a grooving machine called a Casagrande grooving tool. First, place a sample within the bowl, making sure that the sample is compacted within the bowl. Once compacted, 'blow', or tap, the sample repeatedly at a constant pace until a clear grove has been created, around 1/2 inch in depth. Record the number of blows that it took to create the marking. After each trial, add either water or soil, depending on the moisture content of the current sample. If it is dry, add water. If it is wet, add more soil. Repeat this for a total of five times, making sure that the number of blows increase per trial and a sample has been collected to be weighted and dried in the oven. Dry all samples in a weighted evaporating dish and cover with a weighted watch glass.

The second part is focused on finding the plastic limit. Taking a sample of the given soil, continuously mix in water until an oval-shaped ball has been formed and the shape can be sustained. Once the soil has been kneaded to the preferred consistency, take a portion of the soil and begin rolling the soil out into a thin snake-like shape. If it breaks before reaching 1/8 inch in diameter, record the weight of the soil and place it in an oven to dehydrate. If it can sustain a snake-like shape with a diameter smaller than 1/8 inch, repeat the rolling process until it breaks before the size limit. Rerolling will draw out moisture, allowing the soil to reach its desired plasticity. Repeat this process two more times, for a total of three trials. As before, place all samples into a weighted evaporating dish, cover with a weighted watch glass, and heat in the oven.

Once all the samples have been dried out, place all samples into the desiccator to cool down without introducing new moisture into the samples. Once the samples are cool to the touch, record the weight of the samples.

2.3.2 Results

Liquid Limit	26.84%
Plastic Limit	34.6%
Flow Index	17.65
Liquid Index	1

Table 4: Atterberg Limits

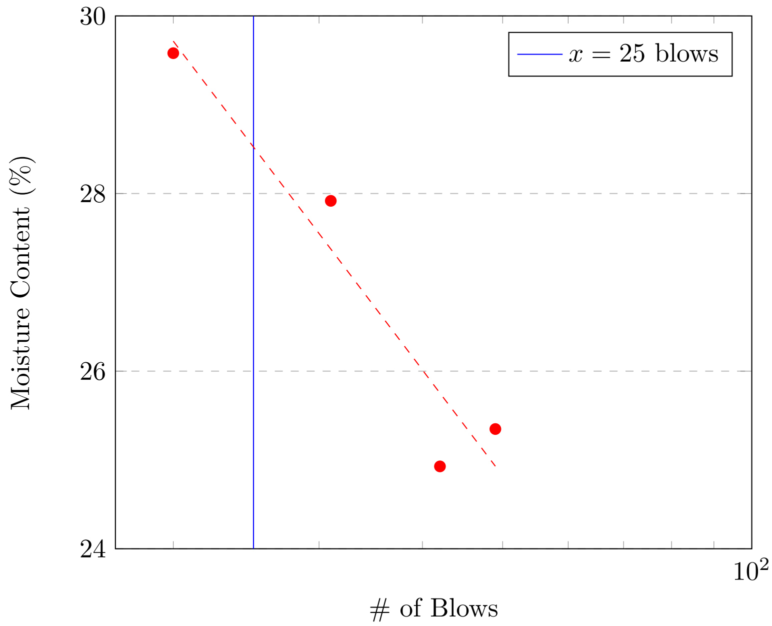

Figure 3: Flow Index

In the first experiment, results and data calculated the Liquid Limit to be 26.84, meaning that, starting with the sample, if the soil becomes 27% liquid, the sample will behave as a liquid more than a solid. This result was achieved during laboratory experiments, by using a Casagrande grooving tool, as well as precise measurements of the soil sample's weights, both wet and dry, as well as giving proper attention to the varying weights of the containers used.

Following the first experiment, the second experiment identified the Plastic Limit as 34.6. By using the Liquid Limit and subtracting it with the Plastic Limit, we obtained the Plastic Index, and this calculation resulted in a negative value. For Plastic Index, since it cannot be a negative value, when the resulted value is less than zero, Plastic Index equals zero. This makes this sample's degree of plasticity non-plastic. Furthermore, the Activity value of this sample is also zero, due to both the Plastic Index and amount of clay to be both zero.

For the Flow Index, we obtain a value of 17.65. Note, however, that the first data point was omitted from the calculations and graph, due to its obscure results, which deems it as an outlier. Referring to Figure (insert figure of Blows per water contents), we see that the first data is significantly lower than the graph's natural trendline. This is speculated to be human error, as familiarity and experience builds per trial, the first attempt would most likely hold the highest chances of mistakes.

For the Liquid Index, the results indicate a value of 1. This value dictates the ratio between plasticity and liquid. A value of 1 would indicate an even ratio, resulting in a non-plastic sample, due to any plasticity property not being able to activate and be of use.

2.4 Compaction Test

2.4.1 Overview

Soil compaction is the process of densifying soil by reducing the amount of air present in the soil. The soil compaction test completed in this experiment was the Standard Proctor Test. In the Standard Proctor Test, soil was compacted in a standard cylindrical mold having a volume of 1/30 cubic feet and a diameter of 4 inches. This mold was first weighed empty with an electronic balance to get its initial weight before filling it with two to three inches of soil taken from the -4 material. Once the mold was filled, it was placed in the compaction box to be uniformly hammered approximately 25 times with the compacting hammer. This hammer was also weighed prior to compacting and the height of the freefall blows was recorded in order to calculate the energy used in compaction.

After completing the first layer, another two layers are added by the same process of uniform hammer compacting, ensuring equal layer thickness and that the final compacted soil extends slightly over the rim of the mold. With the mold filled, the collar was carefully removed and the mold plus soil weight was recorded with the same electronic balance used previously. First centering a 1.375” diameter loading block on the soil sample surface, the soil sample was loaded into a compressing machine with a dial indicator to measure soil penetration as the sample is compressed. Compression load was applied at a strain rate of 0.06 in/min and the load at the time of 0.025, 0.05, 0.075, 0.1, 0.2, 0.3, 0.4 and 0.5 inches of penetration was recorded.

Once the compression loading process was complete, the soil was separated from the mold using a hydraulic sample extruder and reduced using a spatula until the center was exposed. From the center, a small sample was removed in order to be tested for moisture content and placed in a previously weighed crystallizing dish and watch glass. Finally, the dish and soil are weighed together before being placed in an oven to be dried. This process was repeated for 2 more trials using soil of increasing moisture content. In between trials, the moisture content of the soil is increased by uniformly spraying and mixing water into the tray containing the initially measured 3000 grams of -4 soil material. Once the soil samples taken from the cored compaction material were dried, their final weights were recorded in order to find moisture content.

2.4.2 Results

Optimum Moisture Content (%)	8.55
Maximum Density (lb/ft^3)	104.85
Minimum Density (lb/ft^3)	80.92
Dry Unit Weight at 75% Relative Density (g)	110.7
Moisture Content at 75%	14.6%
CBR Design Value	20.94

Table 5: Compaction Test Results

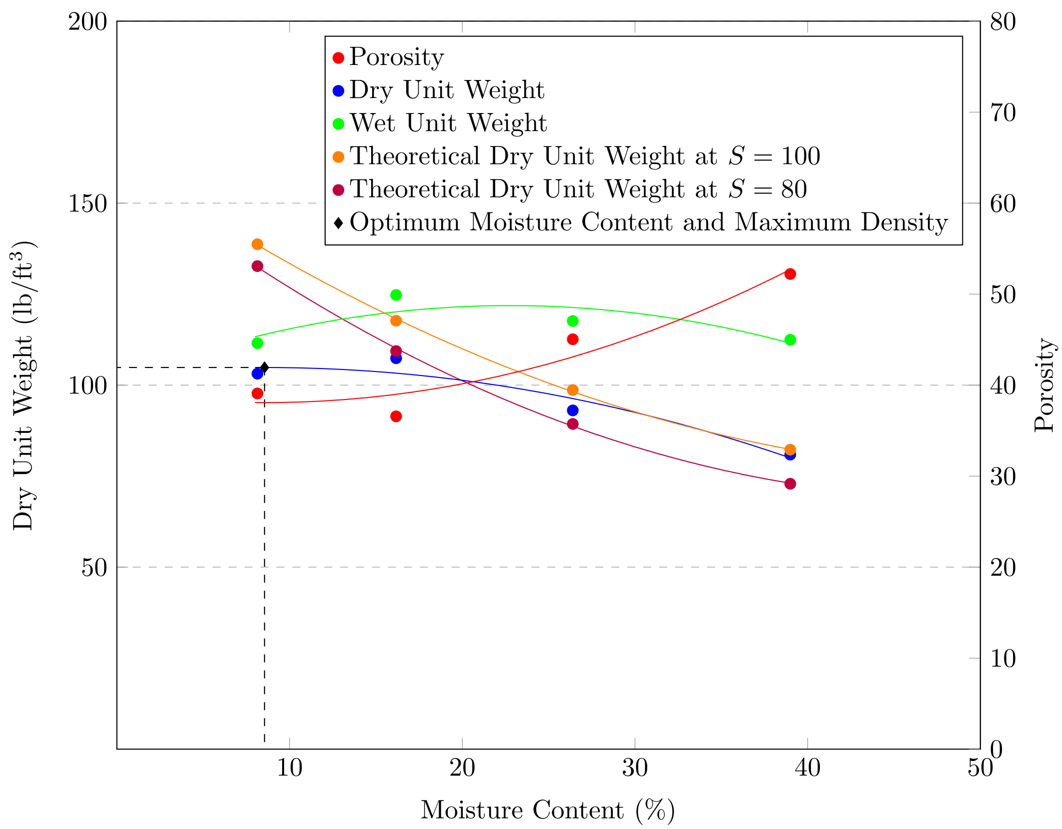

Figure 4: Standard Proctor Test Results

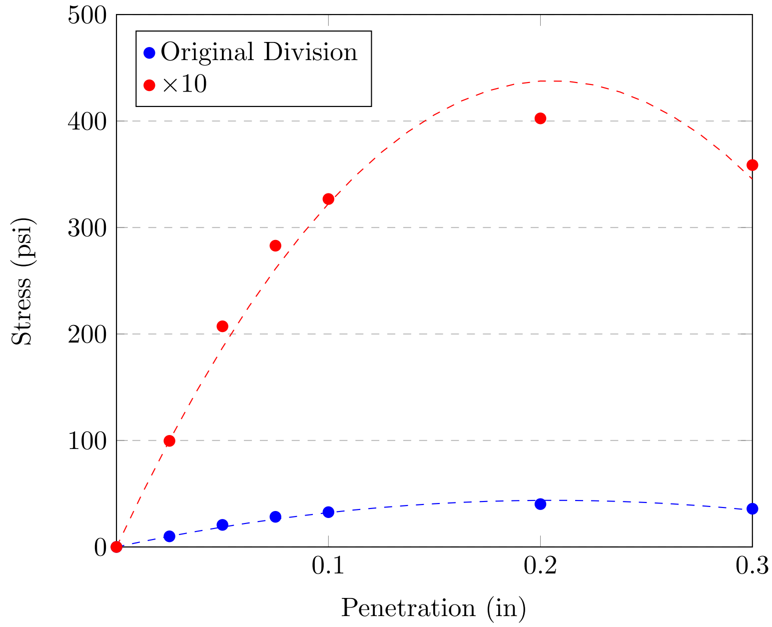

Figure 5: First Determination

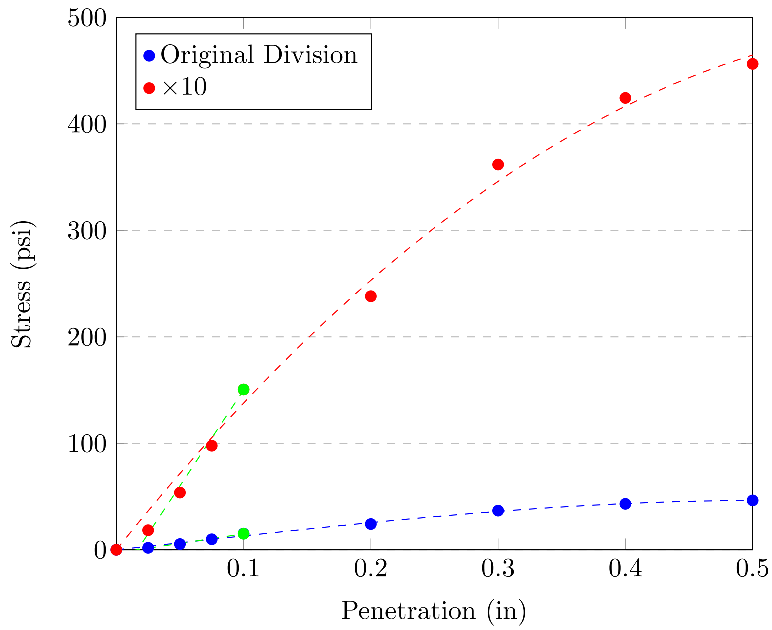

Figure 6: Second Determination

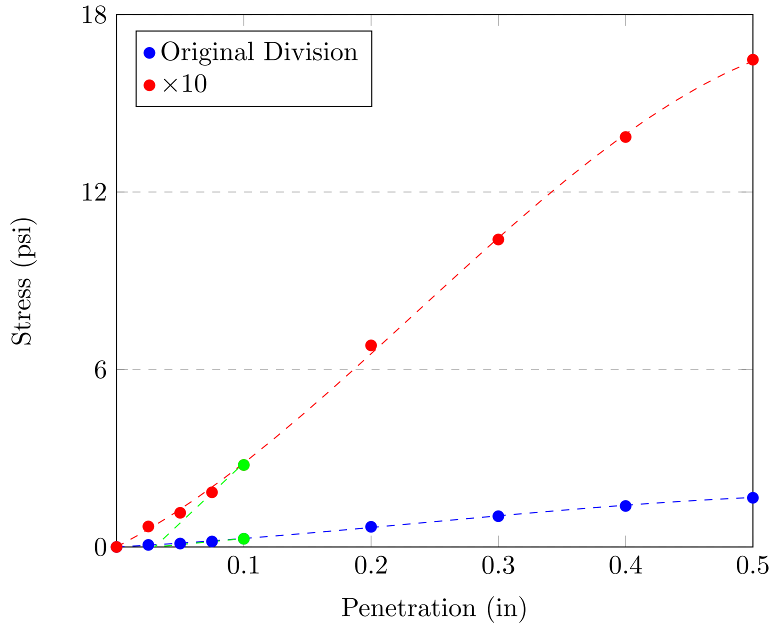

Figure 7: Third Determination

The California Bearing Ratio (CBR) can be determined from the plots of the compression load results by plotting stress versus penetration depth. The CBR value of a soil sample is one characteristic used to determine its overall strength as it is correlated to the penetration resistance of a soil. In this experiment, the soil sample analyzed yielded a CBR of approximately 20.94 which corresponds to expected values of more coarse soil. Depending on the soil composition, a CBR value in the range of 15 to 50 can be indicative of well graded soil. Having a higher CBR value also correlates to the smaller required thickness of the subgrade level in pavement design.

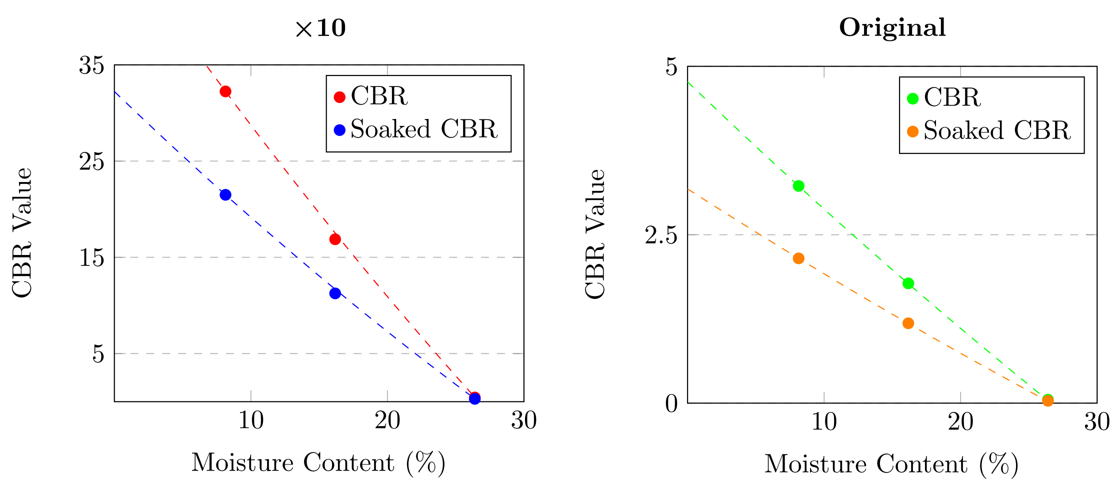

Figure 8: CBR and Soaked CBR vs. Moisture Content

3 Classifications

Soil generally consists of gravel, sand, silt, and clay. The predominant particle size usually dictates what the soil sample is called. Several organizations have developed particle-size classifications, as well as soil classification groups. Different soils with similar properties can be grouped together based on their engineering behavior. These Classification groups help to express the general characteristics of soils, without needing to develop a detailed description.

3.1 AASHTO

The American Association of State Highway and Transportation Officials, AASHTO, classifies soils into seven major groups. There are two main classifications, granular and fine, which are further divided based on the percent of soil either passing through or retained above number 10, 40, and 200 sieves. These sieves separate the particle sizes for gravel, sand, silt, and clay. In addition to grain size, AASHTO classification also considers plasticity through the soils' liquid limit and plastic index. The grain size percentages, liquid limit, and plastic index for our soil sample is as follows:

$$\%\text{ Passing No. } 10 = 49.34\% \quad \%\text{ Passing No. } 40 = 47.01\% \quad \%\text{ Passing No. } 200 = 11.74\%$$

$$LL = 26.8\% \quad PI = -7.77\%$$

These values are compared to the values present on the Classification of Highway Subgrade Materials chart to determine which group the soil best falls under. The AASHTO classification of the soil is $\boxed{\text{A-1-b (0)}}$. The group index for A-1-b classification is always 0.

3.2 USCS

The United Soil Classification System, USCS, classifies soils into two main groups: coarse-grained and fine-grained. Like AASHTO, for USCS, the percent of gravel, percent of sand, percent of silt and clay, liquid limit, and plasticity index are needed for proper classification. In addition to these values, the uniformity coefficient, and coefficient of gradation of the soil help with classification. Flow charts are used to determine the group symbol, group name, and description of a soil sample. Since 88.26% was retained above the No. 200 sieve (greater than 50%), the sample is coarse-grained. Since the percent finer for the No. 4 sieve is 47.01% (less than 50%), the sample falls under gravel. Because the plastic index is negative, it is effectively 0, indicating no plasticity. The plastic index of the A-line is compared to the actual value of the plastic index.

$$\text{A-line PI} = 0.73(26.8 - 20) = 4.96$$

The Plastic Index is less than the A-line Plastic Index, therefore the sample falls below the A-line and can fall under the group symbols ML or OL. Using the grain size percentages, it can be determined that 50.26% of the sample is gravel, and 38.00% is sand. Because the percentage of sand is less than that of gravel, the sample can be labeled ML, gravelly silt with sand. More than 50% of the sample is retained above both the No. 4 and No. 200 sieve. In addition, the Coefficient of gradation, C_u, is determined to be 254, and the uniformity coefficient, C_c, is 0.06. According to these values, the sample is GP-GM, poorly graded. The complete USCS Classification of the soil is $\boxed{\text{GP-GM, poorly graded gravel with silt and sand}}$.

3.3 FAA

The Federal Aviation Administration, FAA, has a separate method for classifying soils that is designed for airport pavement design. FAA subclasses depend depends on soil classification, and whether the pavement is rigid or flexible. These subgrades are based on the performance of soil under different conditions of drainage and frost. 'F' and 'R' denote "flexible" or "rigid", and drainage implies that the soil under the pavement does not retain water. The designations for frost depends on geographical conditions. FAA classification utilized sieve analysis, plastic index, and liquid limits like AASHTO and USCS.

For FAA, we look at the percent retained above the No. 10 sieve, 50.66%. In addition, we look at the percent finer than No. 10 but retained above No. 40, 3.65%, the percent finer than No. 40 but retained above No. 200, 41.25%, and the percent finer than No. 200 sieve, 11.74%. These values are compared to a chart defined by the FAA, so a subgroup could be determined. The group that this soil best falls under is E-5. In addition, because the percent passing through the No. 200 is less than 20%, we can say that this soil has good drainage. The FAA Classification for this soil sample, therefore, is $\boxed{\text{E-5 (F1) for flexible pavement, no frost}}$.

3.4 Overall

Overall soil descriptions are based on particle size and the percentage of the sample that falls within each classification of gravel, sand, silt, and clay. The AASHTO and USCS descriptions are shown below.

Grain Size Type	Percentage (AASHTO)	Percentage (USCS)
Gravel	50.66%	50.26%
Sand	37.60%	38%
Silt and Clay	11.74%	11.74%

Table 6: AASHTO and USCS Descriptions

For both AASHTO and USCS, clay is described as any particles less than 0.002 mm. In our experiment, we did not use a sieve smaller than No. 200. Therefore, we cannot determine, with certainty, what percent of our soil sample is clay using particle size analysis.

For FAA, silt and Clay are grouped into the same category. Note that the percentages for each type of grain size should add up to 100% of the soil sample. Having a value greater than or less than 100% is attributed to error in the completion of the sieve analysis. The FAA description is below.

Grain Size Type	Percentage
Gravel	50.66%
Coarse Sand	3.65%
Fine Sand	41.25%
Silt and Clay	11.74%

Table 7: FAA Description

4 Appendix

4.1 Data Sheets

Specific Gravity Deterimation
Members: JM, JS, EE, GR, SC
Group Number: 2
Date: 4/17/22

W_f	182.61	g
W_{fw} @ T_1	680.02	g
T_1	24	°C
W_{fws} @ T_x	726.24	g
T_x	26	°C
W_{fw} @ T_x	679.766	g
Weight of Beaker & Watchglass	481.21	g
Weight of Beaker, Watchglass, and Soil	554.74	g
W_s	73.53	g
γ_w @ T_1	0.99745	g/cm^3
γ_w @ T_x	0.99694	g/cm^3
γ_w @ 20 °C	0.99843	g/cm^3
γ_w @ 4 °C	1	g/cm^3
G_s @ T_x	2.71773	
G_s @ 20 °C	2.71367	
G_s @ 4 °C	2.70941	

Grain Size Distribution
Members: JM, JS, EE, GR, SC
Group Number: 2
Date: 4/17/22

546.3858108	cgfmax
49.73628393	pfmax

Table 1 - Moisture Content of Fine Fraction

Weight of Container and Wet Soil, g.	132.84	g
Weight of Container & Dry Soil, g.	131.96	g
Weight of Container, g.	82.83	g
Weight of Moisture, g.	0.88	g
Weight of Dry Soil, g.	49.13	g
Moisture Content, %.	1.791166294	%

Table 2 - Dry Weight of Course and Fine Fraction

Weight of Pan & Wet Fine Fraction, g.	928.9	g
Weight of Pan, g.	382.53	g
Weight of Wet Fine Fraction, g.	546.37	g
Moisture Content of Fine Fraction, %	1.791166294	%
Weight of Dry Fine Fraction, g.	536.7558108	g
Weight of Dish & Coarse Fraction, g.	1028.82	g
Weight of Dish, g.	472.43	g
Weight of Dry Coarse Fraction, g	556.39	g
Weight of Dry Coarse & Fine Fraction (w/correction), g.	1098.565811	g
- No. 10 Correction (if any)	5.42	

Table 3 - Dry Weight of Course and Fine Fraction

Sieve Number	Size Opening	Individual Grams Retained
1.5in	38	0
1in	25	38.46
3/4in	19	232.48
1/2in	12.5	224.02
3/8in	9.52	48.01
No. 4	4.75	9.21
No. 10	2	4.33
-	INPUT	INPUT

Cumulative Grams Finer	% Finer
1098.565811	100
1060.105811	96.49907182
827.6258108	75.336935
603.6058108	54.94489314
555.5958108	50.57464973
546.3858108	49.73628393
542.0558108	49.34213367
#VALUE!	#VALUE!

Table 4 - Sieve Analysis of Fine Fraction

Sieve Number	Size Opening (mm)	Cumulative Grains Retained
No. 16	1.18	0.2
No. 30	0.6	0.94
No. 60	0.25	7.27
No. 100	0.15	45.89
No. 200	0.075	57.12

Cumulative Grams Finer	% Finer	
	of No.10	of Whole
74.57		
73.83	99.73251304	49.60324586
67.5	98.74281129	49.11100498
28.88	90.276849	44.90034994
17.65	38.62511703	19.21069787
	23.60572422	11.74061002

Table 5 - Dry Weight of Hydrometer Sample

Weight of Dish and Wet Soil	299.46	g
Weight of Dish	224.44	g
Weight of Wet Soil	75.02	g
Moisture Content	0.33	
Weight of Dry Soil	74.77	g

Table 6 - Hydrometer Calibration

Type	INPUT	Number	INPUT
Specific Gravity	2.713673755	Height of Bulb, cm.	14.4
c_m	0.0002	c_d	0.0018
H (distance @ calibration mark)	2.7	@	1.03
	5.3	@	1.02
	7.8	@	1.01
	10.6	@	1
H'_r	9.9	@	1.03
	12.5	@	1.02
	15	@	1.01
	17.8	@	1
H_r	8.68	@	1.03
	11.28	@	1.02
	13.78	@	1.01
	16.58	@	1
Volume, cc.	68		
Area, cm^2	27.78		
D'ag't	INPUT		
Date	Elapsed Time (sec)	Time	Temp °C
2/14/2023	30	15:07	24
2/14/2023	60	15:08	24
2/14/2023	120	15:09	24
2/14/2023	240	15:11	23.5
2/14/2023	480	15:15	23
2/14/2023	900	15:23	23
2/14/2023	1800	15:38	24
2/14/2023	3600	16:08	24
2/14/2023	7200	17:08	24
44971	14400	-	-
2/15/2023	86400	-	25
2/16/2023	172800	-	26
2/21/2023	604800	14:10	24
INPUT	INPUT	INPUT	INPUT
R'_H	$R''_H = R'_H + c_m$	D (mm)	$R_H = R''_H$ +/- c_d
1.013	1.0132	0.06927113	1.0114
1.01	1.0102	0.050314693	1.0084
1.009	1.0092	0.035886461	1.0074
1.0085	1.0087	0.02461142	1.0069
1.008	1.0082	0.017589043	1.0064
1.008	1.0082	0.012845221	1.0064
1.0075	1.0077	0.00901386	1.0059
1.007	1.0072	0.006402531	1.0054
1.007	1.0072	0.004527273	1.0054
-	#VALUE!	#N/A	#VALUE!
1.005	1.0052	0.001314359	1.0034
1.004	1.0042	0.000926525	1.0024
1.0045	1.0047	0.000504918	1.0029
INPUT	#VALUE!	#N/A	#VALUE!
% Finer			
of No. 10	of Whole		
26.69178333	13.27550114		
20.05268047	9.973458096		
17.83964619	8.872777081		
16.47817884	8.195633815		
15.11671149	7.51849055		
15.11671149	7.51849055		
14.52009476	7.221755557		
13.41357762	6.67141505		
13.41357762	6.67141505		
#VALUE!	#VALUE!		
9.519579041	4.734684861		
7.882953914	3.920688341		
7.880991906	3.919712511		
#VALUE!	#VALUE!		

Atterburg Limit Test
Members: JM, JS, EE, GR, SC
Group Number: 2
Date: 4/17/22

LIQUID LIMIT

Trial Number	1	2	3	4	5
Weight of Container, g.	74.61	93.98	74.85	103.17	101.92
Weight of Container & Wet Soil, g.	88.91	99.85	80.44	111.79	110.92
Weight of Container & Dry Soil, g.	85.92	98.51	79.22	110.07	109.1
Weight of Moisture, g.	2.99	1.34	1.22	1.72	1.82
Weight of Dry Soil, g.	11.31	4.53	4.37	6.9	7.18
Moisture Content, %	26.43678	29.58057	27.91762	24.92754	25.34819
No. of Blows	13	20	31	42	49

PLASTIC LIMIT

Trial Number	1	2	3	4	5
Weight of Container, g.	67.83	84.14	99.71		
Weight of Container & Wet Soil, g.	89.19	114.64	141.46		
Weight of Container & Dry Soil, g.	85.12	110.37	125.16		
Weight of Moisture, g.	4.07	4.27	16.3		
Weight of Dry Soil, g.	17.29	26.23	25.45		
Moisture Content, %	23.53962	16.27907	64.04715		

Liquid Limit	26.84214
Plastic Limit	34.62195
Plastic Index	-7.77981
Flow Index	17.65097
Liquidity Index	1.052104
Activity	#DIV/0!

Compaction Test
Members: JM, JS, EE, GR, SC
Group Number: 2
Date: 4/17/22

INPUTS

Diameter of Mold	4	in
Depth of Mold	4.5	in
Volume of Mold	0.0327	ft^3
Weight of Mold and Base	4277.5	g
Weight of Hammer	5.5	lbs
Height of Fall of Hammer	12	in
No. of Layers	3	
No. of Blows per Layer	25	
Compaction Energy	151260.86	inlb/ft^3

	Specific Gravity	2.713673755		
Determination Number	1	2	3	4
Weight of Mold and Wet Soil, g.	5964	6164	6056	5978
Weight of Mold, g.	4277.5	4277.5	4277.5	4277.5
Weight of 1/30 ft3 Wet Soil, g.	1686.5	1886.5	1778.5	1700.5
Wet Unit Weight, pcf.	111.54	124.77	117.63	112.47
Weight of Container and Wet Soil, g.	194.8	223.72	256.27	148.8
Weight of Container and Dry Soil, g.	187.6	206.94	222.41	129.32
Weight of Moisture	7.2	16.78	33.86	19.48
Weight of Container, g.	99.13	103.16	94.14	79.36
Weight of Dry Soil, g.	88.47	103.78	128.27	49.96
Moisture Content, %	8.14	16.17	26.40	38.99
Dry Unit Weight, pcf.	103.15	107.40	93.06	80.92
Porosity, %	39.09	36.57	45.04	52.21
Dry Unit Weight (Theoretical) at S = 100%	138.70	117.69	98.66	82.28
Dry Unit Weight (Theoretical) at S = 80%	132.70	109.36	89.34	72.91

Determination No. 1

Load Ring Number: 155
DIA of Loading Block, in. 1.375

Penetration, in.	No. of Divisions	Load (lbs)	Stress (psi)
0	0	0	0
0.025	25	147.93	99.62331285
0.05	52	307.6944	207.2164907
0.075	71	420.1212	282.9302085
0.1	82	485.2104	326.7644661
0.2	101	597.6372	402.4781839
0.3	90	532.548	358.6439263
0.4	INPUT	#VALUE!	#VALUE!
0.5	INPUT	#VALUE!	#VALUE!

Determination No. 2

Load Ring Number: 17592
DIA of Loading Block, in. 1.375

Penetration, in.	No. of Divisions	Load (lbs)	Stress (psi)
0	0	0	0
0.025	13	27.3	18.38515812
0.05	38	79.8	53.74123143
0.075	70	145.122	97.73226801
0.1	108	223.5464	150.547103
0.2	171	353.5658	238.1085399
0.3	260	537.244	361.8064428
0.4	305	630.115	424.3503263
0.5	328	677.5824	456.3172001

4.2 Sample Calculations

4.2.1 Specific Gravity Determination

The specific gravity is calculated using *Equation 1*.

$$G_s = \frac{W_s}{W_{fw} + W_s - W_{fws}} \tag{1}$$

$$G_s = \frac{73.53 \text{ g}}{680.02 \text{ g} + 73.53 \text{ g} - 726.24 \text{ g}} = \boxed{2.72}$$

4.2.2 Grain Size Distribution

The soil fraction is calculated using *Equation 2*.

$$W_{\text{soil}} = W_{\text{container+soil}} - W_{\text{container}} \tag{2}$$

$$W_{\text{dry}} = 131.96 \text{ g} - 82.83 \text{ g} = \boxed{49.13 \text{ g}}$$

The weight of moisture is calculated using *Equation 3*.

$$W_{\text{Moisture}} = W_{\text{container+wet soil}} - W_{\text{container+dry soil}} \tag{3}$$

$$W_{\text{moisture}} = 132.84 \text{ g} - 131.96 \text{ g} = \boxed{0.88 \text{ g}}$$

The moisture content is calculated using *Equation 4*.

$$w = \frac{W_{\text{moist}}}{W_{\text{dry}}} \times 100 \tag{4}$$

$$w = \frac{0.88 \text{ g}}{49.13 \text{ g}} \times 100 = \boxed{1.79\%}$$

The weight of dry fine fraction is calculated using *Equation 5*.

$$W_{\text{dry fines}} = \frac{W_{\text{wet fines}}}{1 + \frac{w}{100}} \tag{5}$$

$$W_{\text{dry fines}} = \frac{546.37 \text{ g}}{1 + \frac{1.79\%}{100}} = \boxed{536.76 \text{ g}}$$

The weight of dry coarse and fine fraction is calculated using *Equation 6*.

$$W_{\text{coarse + fine dry}} = W_{\text{dry coarse}} + W_{\text{fine dry}} + (\text{-No. 10 Correction}) \tag{6}$$

$$W_{\text{coarse + fine dry}} = 556.39\text{ g} + 536.76\text{ g} + 5.42\text{ g} = \boxed{1098.57\text{ g}}$$

The cumulative grams finer is calculated using *Equation 7*.

$$\text{Cum. Grams Finer} = (\text{Grams Finer})_{i-1} - (\text{Grams Retained})_i \tag{7}$$

$$\text{Cum. Grams Finer (1 in.)} = 1098.57\text{ g} - 38.46\text{ g} = \boxed{1060.11\text{ g}}$$

The percent finer for the coarse and fine fraction is calculated using *Equation 8*.

$$\%_{\text{Finer}} = \frac{\text{Cum. Grams Finer}}{W_{\text{coarse + fine dry}}} \times 100 \tag{8}$$

$$\%_{\text{Finer (1 in.)}} = \frac{1060.11\text{ g}}{1098.57\text{ g}} \times 100 = \boxed{96.5\%}$$

The percent finer of the whole is calculated using *Equation 9*.

$$\%_{\text{Finer of Whole}} = \frac{\%_{\text{Finer No. 10}}}{100} \times \frac{pf_{\text{max}}}{100} \times 100 \tag{9}$$

$$\%_{\text{Finer of Whole (No. 16)}} = \frac{99.73}{100} \times \frac{49.74}{100} \times 100 = \boxed{49.6\%}$$

H'_r is calculated using *Equation 10*.

$$H'_r = H + \frac{\text{Bulb Height}}{2} \tag{10}$$

$$H'_r = 2.7 + \frac{14.4\text{ cm}}{2} = \boxed{9.9\text{ cm}}$$

H_r is calculated using *Equation 11*.

$$H_r = H'_r - \frac{\text{Volume}}{2 \times \text{ Area}} \tag{11}$$

$$H_r = 9.9 - \frac{68\text{ cm}^3}{2 \times 27.78\text{ cm}^2} = \boxed{8.68\text{ cm}}$$

R''_H is calculated using *Equation 12*.

$$R'_H + c_m \tag{12}$$

$$R''_H = 1.013 + 0.0002 = \boxed{1.0132}$$

$\underline{R_H}$ is calculated using *Equation 13*.

$$R''_H \pm c_d \tag{13}$$

$$R''_H = 1.013 \pm 0.0018 = \boxed{1.0114}$$

The <u>distance</u> is calculated using *Equation 14*.

$$D^2 = \frac{18\mu \times v}{\gamma_w - (\gamma_w + c_d)}$$

$$d = D^2 \times t \times \frac{G_s - (\gamma_w + c_d)}{18 \times \mu} \tag{14}$$

$$d = \frac{\left(\frac{0.069}{10}\right)^2 \times 30 \times (2.8 - (0.9982 + 0.0018))}{18 \times (1029 \times 10^{-8})} = \boxed{13.99 \text{ cm}}$$

The <u>uniformity coefficient</u> is calculated using *Equation 15*.

$$C_u = \frac{D_{60}}{D_{10}} \tag{15}$$

$$C_u = \frac{10.5}{0.51} = \boxed{205.88}$$

The <u>coefficient of gradation</u> is calculated using *Equation 16*.

$$C_c = \frac{D_{30}^2}{D_{60} \times D_{10}} \tag{16}$$

$$C_c = \frac{0.2^2}{10.5 \times 0.51} = \boxed{0.075}$$

The <u>percent soil type</u> is calculated two ways one using *Equation 17* and the alternative way using *Equation 18*.

$$\%_{\text{Soil Type}} = \%_{\text{Greater}} - \%_{\text{Finer}} \tag{17}$$

$$\%_{\text{Medium Gravel}} = 100\% - 54.94\% = \boxed{45.06\%}$$

$$\%_{\text{Soil Type}} = \sum [\%_{\text{retained on each sieve}}] \tag{18}$$

$$\%_{\text{Fine Sand}} = 1.03\% + 6.29\% + 1.83\% = \boxed{9.15\%}$$

4.2.3 Atterberg Limits

The moisture content is calculated using the equation below, with W_m being the weight of the moisture, W_d being the weight of the dry soil, and W_c being the weight of the container, as seen in *Equation 19.*

$$w = \frac{W_m}{W_d - W_c} \times 100 \tag{19}$$

$$w = \frac{2.99\%}{85.92\% - 74.61\%} \times 100 = \boxed{26.43\%}$$

The Liquid Limit is calculated by taking the sum of the water content and dividing it by the number of trials, as seen in *Equation 20.*

$$LL = \frac{\sum w}{w_n} \tag{20}$$

$$LL = \frac{24.44\% + 29.58\% + 27.92\% + 24.93\% + 25.35\%}{5} = \boxed{26.84\%}$$

The Plastic Limit is calculated similarly, as seen in *Equation 21.*

$$PL = \frac{\sum w}{w_n} \tag{21}$$

$$PL = \frac{23.54\% + 16.28\% + 64.05\%}{3} = \boxed{34.62\%}$$

The Plastic Index is calculated using *Equation 22.*

$$PI = LL - PL \tag{22}$$

$$PI = 26.84\% - 34.62\% = \boxed{-7.78\%}$$

The Flow Index is calculated using *Equation 23.* w and N represent the moisture content and number of blows respectively.

$$FI = \frac{w_1 - w_2}{\log\left(\frac{N_2}{N_1}\right)} \tag{23}$$

$$FI = \frac{26.43\% - 29.58\%}{\log\left(\frac{20}{13}\right)} = \boxed{17.65\%}$$

The Liquidity Index is calculated using *Equation 24.*

$$LI = \frac{w - PL}{PI} \tag{24}$$

$$LI = \frac{26.43\% - 34.62\%}{-7.78\%} = \boxed{1.05}$$

The Activity is calculated using *Equation 25*.

$$A = \frac{PI}{\%_{\text{Clay}}} \tag{25}$$

$$A = \frac{0\%}{0\%} = \boxed{\text{Undefined}}$$

4.2.4 Compaction Test

The dry weight at a specific relatvie density is calculated using *Equation 26*.

$$D_r = \frac{\frac{1}{\gamma_{dmin}} - \frac{1}{\gamma_d}}{\frac{1}{\gamma_{dmin}} - \frac{1}{\gamma_{dmax}}} \tag{26}$$

$$0.75 = \frac{\frac{1}{96.13} - \frac{1}{\gamma_d}}{\frac{1}{96.13} - \frac{1}{116.6}}$$

$$\gamma_d = \boxed{110.7}$$

The moisture content at a specific relative density is calculated using *Equation 27*.

$$w = \frac{\frac{sG_s\gamma_w}{\gamma_d - s}}{G_s} \times 100 \tag{27}$$

$$w = \frac{\frac{0.75\times2.71\times62.4}{110.71} - 0.75}{2.71} \times 100 = \boxed{14.6\%}$$

4.3 Soil Classifications

Soil group	Mechanical sieve analysis				Plasticity		Subgrade class			
	Gravel*	Material finer than No. 10 sieve			Liquid limit ω_L (%)	Plastic Index I_P	Good drainage**		Poor drainage**	
	% > No. 10	Coarse sand No. 10 > % > No. 40	Fine sand No. 40 > % > No. 200	Silt and clay % < No. 200			No frost	Severe frost	No frost	Severe frost
E-1	0 - 45	40^+	60^-	15^-	25^-	6^-	Fa Ra	Fa Ra	Fa Ra	Fa Ra
E-2	0 - 45	15^+	85^-	25^-	25^-	6^-	Fa Ra	Fa Ra	F1 Ra	F2 Ra
E-3	0 - 45	-	-	25^-	25^-	6^-	F1 Ra	F1 Ra	F2 Ra	F2 Ra
E-4	0 - 45	-	-	35^-	35^-	10^-	F1 Ra	F1 Ra	F2 Rb	F3 Rb
E-5	0 - 55	-	-	45^-	40^-	15^-	F1 Ra	F2 Rb	F3 Rb	F4 Rb
E-6	0 - 55	-	-	45^+	40^-	10^-	F2 Rb	F3 Rb	F4 Rb	F5 Rc
E-7	0 - 55	-	-	45^+	50^-	10 - 30	F3 Rb	F4 Rb	F5 Rb	F6 Rc
E-8	0 - 55	-	-	45^+	60^-	15 - 40	F4 Rb	F5 Rc	F6 Rc	F7 Rd
E-9	0 - 55	-	-	45^+	40^+	30^-	F5 Rc	F6 Rc	F7 Rc	F8 Rd
E-10	0 - 55	-	-	45^+	70^-	20 - 50	F5 Rc	F6 Rc	F7 Rc	F8 Rd
E-11	0 - 55	-	-	45^+	80^-	30^+	F6 Rd	F7 Rd	F8 Rd	F9 Re
E-12	0 - 55	-	-	45^+	80^+	-	F7 Rd	F8 Re	F9 Re	F10 Re
E-13	Peat and/or muck based on field examination						Not suitable for subgrade use			

** When the sample contains material coarser than No. 10 in amounts equal to or greater than the maximum limit shown in the table, a lower group classification may be allowed provided the coarse material is reasonably sound and well graded.*

*** A good draining soil is one with less than 20% passing the No. 200 sieve.*

Figure 9: FAA Classification Table

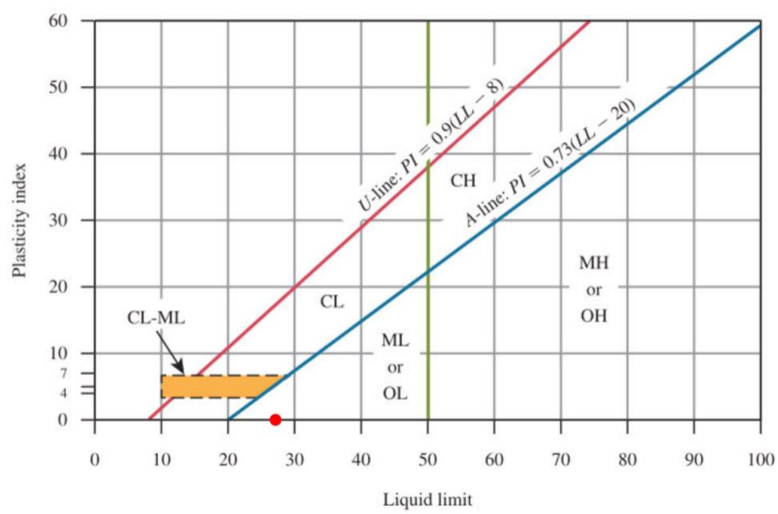

Figure 10: Plasticity Chart

General classification	Granular materials (35% or less of total sample passing No. 200)						
	A-1			A-2			
Group classification	A-1-a	A-1-b	A-3	A-2-4	A-2-5	A-2-6	A-2-7
Sieve analysis (percentage passing)							
No. 10	50 max.						
No. 40	30 max.	50 max.	51 min.				
No. 200	15 max.	25 max.	10 max.	35 max.	35 max.	35 max.	35 max.
Characteristics of fraction passing No. 40							
Liquid limit				40 max.	41 min.	40 max.	41 min.
Plasticity index	6 max.		NP	10 max.	10 max.	11 min.	11 min.
Usual types of significant constituent materials	Stone, fragments, gravel and sand		Fine sand	Silty or clayey gravel, and sand			
General subgrade rating	Excellent to good						

General classification	Silt-clay materials (more than 35% of total sample passing No. 200)			
Group classification	A-4	A-5	A-6	A-7 A-7-5[a] A-7-6[b]
Sieve analysis (percentage passing)				
No. 10				
No. 40				
No. 200	36 min.	36 min.	36 min.	36 min.
Characteristics of fraction passing No. 40				
Liquid limit	40 max.	41 min.	40 max.	41 min.
Plasticity index	10 max.	10 max.	11 min.	11 min.
Usual types of significant constituent materials	Silty soils		Clayey soils	
General subgrade rating	Fair to poor			

[a]For A-7-5, $PI \leq LL - 30$
[b]For A-7-6, $PI > LL - 30$

Figure 11: AASHTO Classification Table

Criteria for assigning group symbols			
Coarse-grained soils More than 50% retained on No. 200 sieve	**Gravels** More than 50% of coarse fraction retained on No. 4 sieve	Clean Gravels Less than 5% fines[a]	$C_u \geq 4$ and $1 \leq C_c \leq 3$[c] $C_u < 4$ and/or $C_c < 1$ or $C_c > 3$[c]
		Gravels with Fines More than 12% fines[a,d]	$PI < 4$ or plots below "A" line (Figure 5.2) $PI > 7$ and plots on or above "A" line (Figure 5.2)
	Sands 50% or more of coarse fraction passes No. 4 sieve	Clean Sands Less than 5% fines[b]	$C_u \geq 6$ and $1 \leq C_c \leq 3$[c] $C_u < 6$ and/or $C_c < 1$ or $C_c > 3$[c]
		Sands with Fines More than 12% fines[b,d]	$PI < 4$ or plots below "A" line (Figure 5.2) $PI > 7$ and plots on or above "A" line (Figure 5.2)
Fine-grained soils 50% or more passes No. 200 sieve	**Silts and clays** Liquid limit less than 50	Inorganic	$PI > 7$ and plots on or above "A" line (Figure 5.2)[e] $PI < 4$ or plots below "A" line (Figure 5.2)[e]
		Organic	$\frac{\text{Liquid limit—oven dried}}{\text{Liquid limit—not dried}} < 0.75$; see Figure 5.2; OL zone
	Silts and clays Liquid limit 50 or more	Inorganic	PI plots on or above "A" line (Figure 5.2) PI plots below "A" line (Figure 5.2)
		Organic	$\frac{\text{Liquid limit—oven dried}}{\text{Liquid limit—not dried}} < 0.75$; see Figure 5.2; OH zone
Highly organic soils	Primarily organic matter, dark in color, and organic odor		

[a]Gravels with 5 to 12% fine require dual symbols: GW-GM, GW-GC, GP-GM, GP-GC.
[b]Sands with 5 to 12% fines require dual symbols: SW-SM, SW-SC, SP-SM, SP-SC.
[c]$C_u = \frac{D_{60}}{D_{10}}$; $C_c = \frac{(D_{30})^2}{D_{60} \times D_{10}}$
[d]If $4 \leq PI \leq 7$ and plots in the hatched area in Figure 5.2, use dual symbol GC-GM or SC-SM.
[e]If $4 \leq PI \leq 7$ and plots in the hatched area in Figure 5.2, use dual symbol CL-ML.

Figure 12: USCS Classification Table

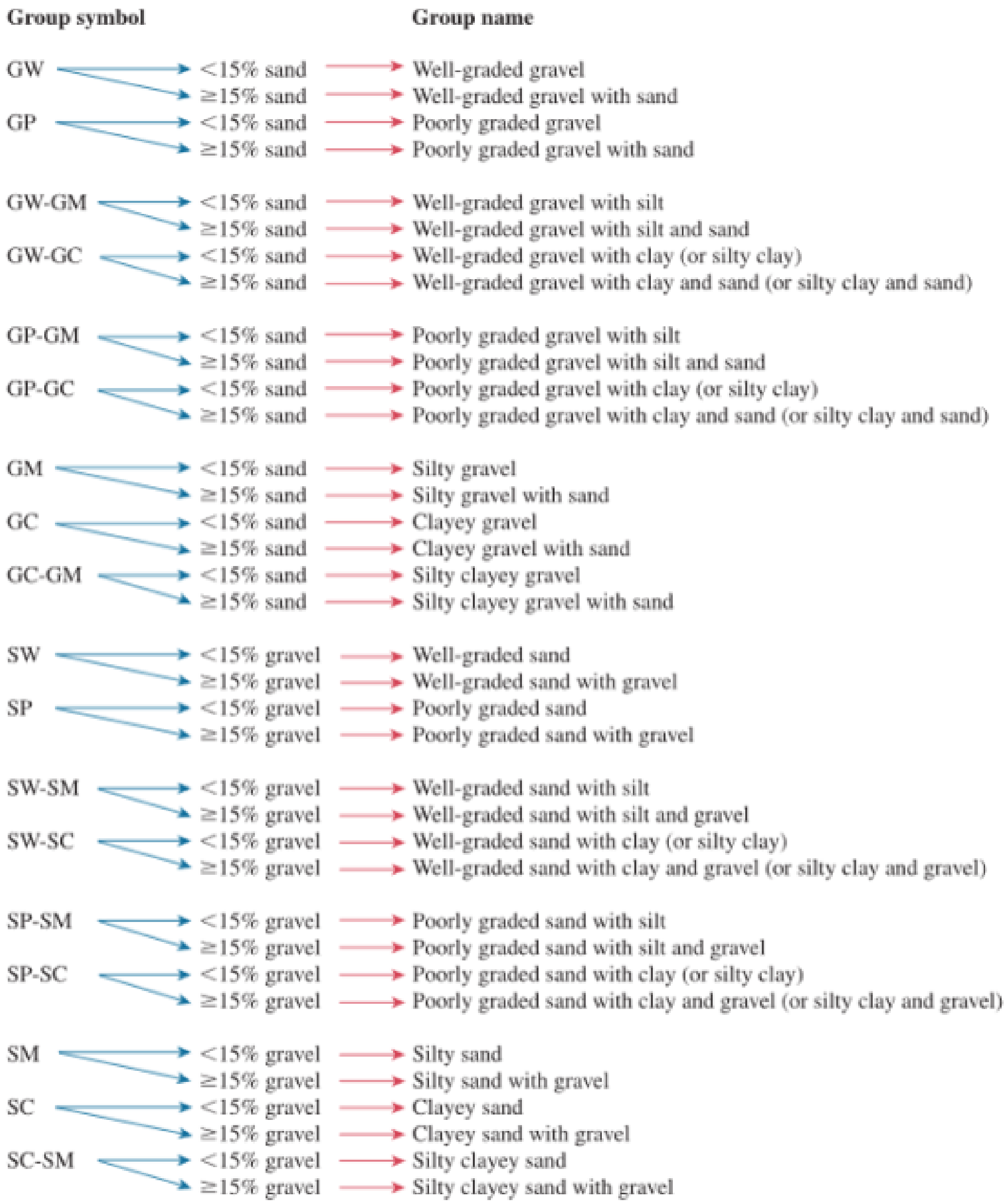

Figure 13: Flow Chart for Group Names

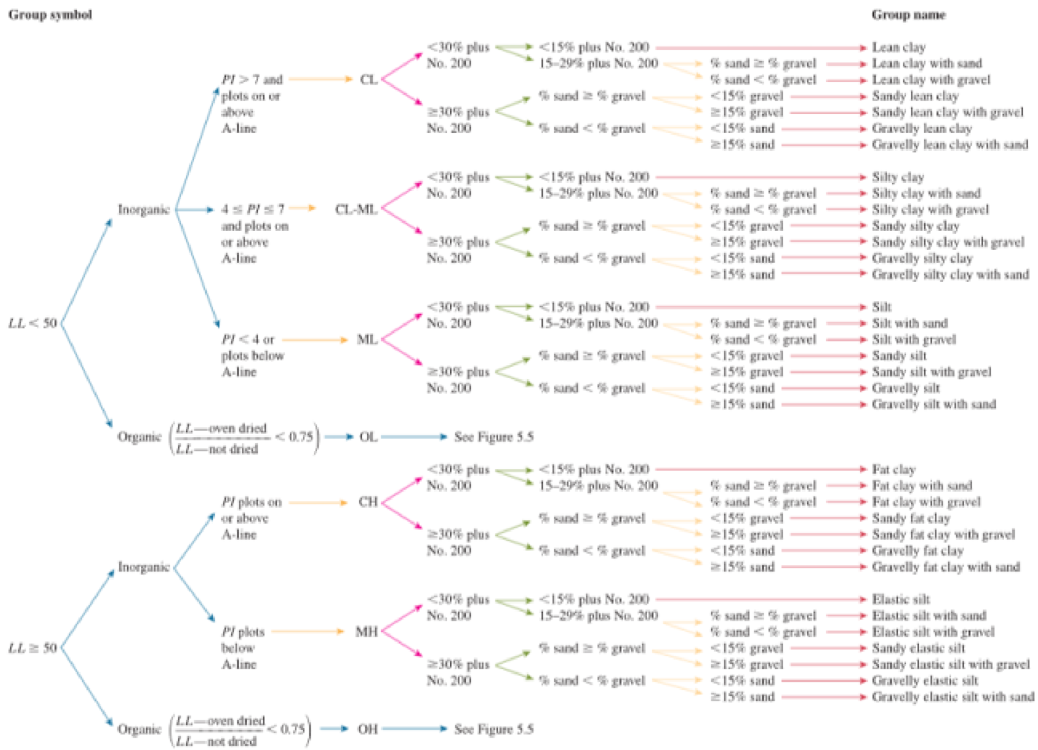

Figure 14: Flow Chart for Group Names of Inorganic Silty and Clayey Soils