1302 PARTICLE SIZE ANALYSIS OF SOILS

AASHTO Designation T 88 (Mn/DOT Modified)

1302.1 SCOPE

This method describes a procedure for the quantitative determination of the distribution of particle sizes in soils.

The percentages of gravel and sand fractions in a representative soil sample are determined by shaking it through the required sieve sizes. The smaller size fractions, silt and clay both of which pass the 75μm (#200) sieve, are determined by hydrometer analysis. This involves measuring the settling velocity of these particles when the sample is thoroughly dispersed in a soil-water suspension. Since larger, heavier particles settle out of suspension more rapidly, the time rate of settlement provides a measure of the relative size of fine soil grains. Thus as the soil grains continue to settle with elapsed time, the gravity of the soil-water suspension becomes lighter.

A graduated hydrometer immersed in the suspension at increasing time intervals measures the change in gravity. By using the hydrometer readings so obtained in the proper formula, the percentages of silt and clay fractions in the soil sample can be calculated. Thus knowing the percentages of each grain size group in the sample, the soil can be assigned a definite textural classification dependent upon the various amounts of sand, silt and clay combined to form the soil mass.

1302.2 APPARATUS

A. Stirring apparatus - A mechanical stirring device consisting of an electric motor mounted to turn a shaft at a speed not less than 10,000 revolutions per minute without a load, with a replaceable stirring paddle made of metal, plastic or hard rubber and a dispersion cup. (For design of the complete stirring apparatus and dispersion cup see AASHTO T 88.)

B. Hydrometer - An ASTM hydrometer (#152H) conforming to the requirements of ASTM Specification E 100. For calibration of hydrometers see AASHTO T 88.

C. Sedimentation Cylinder - A glass cylinder approximately 460mm (18") high, 60mm (2 1/2") in diameter and marked for a volume of 1000ml. The inside diameter shall be such that the 1000ml mark is 360 ± 20mm (14 ± 1.0") from the bottom on the inside.

D. Thermometer - Accurate to 0.5 °C (1 °F).

E. Sieves - A series of sieves (4.75 and 2.00mm and 850, 425, 250, 150 and 75μm [#4, #10, #20, #40, #60, #100 and #200]) conforming to AASHTO M 92.

F. Water Bath - A water bath capable of maintaining a constant temperature in the range of 20 - 23.9 °C (68 - 75 °F) during the test. Other methods that can provide the required temperature control are acceptable.

G. Balance - An analytical balance conforming to AASHTO M 231 with an accuracy, sensitivity and readability of 0.01 gram.

H. Oven - A thermostatically controlled, drying oven capable of maintaining a temperature of 110 ± 5 °C (230 ± 9 °F) for drying the sieve analysis samples.

I. Beaker - A beaker of 250ml capacity or a pint mason jar.

J. Timing Device - A watch or clock with a sweep second hand.

1302.3 SAMPLE

A. A representative sample is obtained after splitting the sample on the 4.75mm and 2.00mm (#4 and #10) sieves as described in Section 1301.4 and 1301.6.

1. For sandy soils weigh up an approximate, 100g sample from the portion passing the 2.00mm (#10) sieve.

2. For silty or clayey soils weigh up an approximate, 50g sample from the portion passing the 2.00mm (#10) sieve.

1302.4 PROCEDURE

A. Hygroscopic Moisture

A hygroscopic moisture sample is taken when preparing the soil for testing. (See Section 1301.) Approximately a 10-15 gram sample portion of the fraction passing the 2.00mm (#10) sieve is used for the determination of the hygroscopic moisture. Weigh this sample to the nearest 0.01 gram, dry to a constant weight in an oven at a temperature of 110 ± 5 °C (230 ± 9 °F). Weigh to nearest 0.01 gram and record weight.

The weight of the air-dried sample (including the weight of the container) is recorded on the attached example as 25.71 grams. The weight of the oven-dried sample is recorded as 25.47 grams. The weight of the empty container is recorded as 14.34 grams. See Section 1302.7, Form #28293.

B. Dispersion of Soil Sample

1. The sample for the hydrometer test is weighed when preparing the soil for testing. This weight was entered on the attached example under "Weight of air-dried sample dispersed" as 50.0 grams.

2. A stock solution of dispersing agent shall be prepared using distilled or demineralized water at the rate of 40 grams of sodium hexametaphosphate per liter. Solutions should be adjusted to a pH of 8-9 by means of adding sodium carbonate (approximately 5 grams).

3. The sample (after weighing and being placed in a glass container) is covered with 125ml of stock solution, stirred thoroughly with a glass rod and allowed to soak for a minimum of 12 hours.

4. After the soaking period, the contents of the glass container shall be washed into a dispersion cup. Distilled or demineralized water shall be added until the cup is little more than half full and the contents dispersed for a period of one minute with the mechanical stirring apparatus.

C. Hydrometer Test

1. After dispersion, the mixture is transferred to the glass sedimentation cylinder and distilled or demineralized water added until the mixture is a volume of 1000ml. This mixture may be set in a water bath to attain a constant temperature or set aside in a room which has a constant temperature.

2. When the soil suspension attains the temperature of the bath or room, the sedimentation cylinder and its contents are thoroughly shaken for one minute using the palm of the hand or other approved stopper over the mouth of the cylinder. Alternately, turn the cylinder upside down and right side up for a period of one minute to complete this agitation. The number of turns should be approximately 60, counting the turn upside down and then right side up as 2 turns.

NOTE 1: The soil remaining in the bottom of the cylinder during the initial few turns should be loosened by vigorously shaking the cylinder while it's in the inverted position.

NOTE 2: At the conclusion of the shaking, turn the cylinder at an approximate 7.9 radian (45°) angle, swirl the solution inside so that any material trapped around the stopper is freed.

3. At the conclusion of this shaking, the time shall be recorded, the graduate placed in the water bath (if used) and readings taken with the hydrometer at intervals of 2, 5, 15, 30, 60, 250, and 1440 minutes after the beginning of the sedimentation. The time, temperature and hydrometer readings are recorded as shown on the example analysis. See Section 1302.7.

NOTE 3: The hydrometer is read at the top of the meniscus formed by the suspension around its stem and read to the nearest 0.5 gram per liter.

After each reading, the hydrometer is carefully removed from the soil suspension and placed with a spinning motion in a graduate of clean water. About 30 seconds before the time for a reading, it shall be taken from the clean water and **SLOWLY** immersed in the soil suspension to assure that the hydrometer comes to rest before the time of reading. The hydrometer should float freely and not touch the wall of the sedimentation cylinder.

NOTE 4: It is important to remove the hydrometer after each reading.

D. Sieve Analysis

1. At the conclusion of the final hydrometer readings, the entire sample in the sedimentation cylinder shall be washed, using a fine mist, over a 75μm (#200) sieve. The washing shall continue until the wash water is clear.

2. The fraction retained on the 75μm (#200) sieve shall be dried to a constant weight at 110 ± 5 °C (230 ± 9 °F) and a sieve analysis made using the following sieves: 850, 425, 250, 150 & 75μm (#20, #40, #60, #100, & #200). Continue sieving for a sufficient time period so that after completion not more than 0.5 percent by weight of total sample passes any sieve after one minute of continuous, hand sieving. (A period of 7 minutes has been found satisfactory.)

NOTE 5: Limit the quantity of material so that no more than 6kg/m^2 (4 grams per square inch) is retained on any sieve. For 75mm (3") diameter sieves, a maximum of 28 grams is permitted.

NOTE 6: Record results for the hydrometer test, hygroscopic moisture, sieve analysis and all calculations on Form# 28293.

1302.5 CALCULATIONS

A. Percentage of Hygroscopic Moisture (**PHM**)

1. The hygroscopic moisture shall be expressed as a percentage of the mass of oven dried soil and shall be determined as follows:

$$\textbf{\% PHM} = \frac{W-W_1}{W_1} \textbf{ X } 100$$

where:

W = weight of air-dried soil

W_1 = weight of oven-dried soil

These values are determined by subtracting the weight of the container from the recorded value of the air dried sample plus can, and the oven dried sample plus can as follows:

W **=** 25.71 **-** 14.34 **=** 11.37 grams

W_1 **=** 25.47 **-** 14.34 **=** 11.13 grams

Therefore:

$$\textbf{PHM} = \frac{11.37 - 11.13}{11.13} \textbf{ X } 100 \textbf{ = } 2.16\%$$

2. To correct the mass of the air-dried sample for hygroscopic moisture, the given value shall be multiplied by the Hygroscopic Correction Factor (HCF). The HCF is determined as follows:

$$\textbf{HCF} = \frac{100}{100 + \%\text{ of Hygroscopic Moisture (}\textbf{PHM}\text{)}}$$

Or in the example:

$$\textbf{HCF} = \frac{100}{100 + 2.16} = 0.979$$

The calculated values of the hygroscopic moisture and hygroscopic correction factor are recorded on the example analysis as 2.16 and 0.979 respectively. See Section 1302.7.

3. To correct the weight of the air-dried sample for hygroscopic moisture, the weight of the fraction passing the 2.00mm (#10) sieve shall be multiplied by the hygroscopic moisture correction factor (HCF). This factor is to be applied to the minus 4.75mm (#4) and minus 2.00mm (#10) fractions of the selected subsample.

In the example (See Section 1302.6, Medium Sieves) the following calculations are made:

Where:

A = The weight passing the 2.00mm (#10) sieve

B = The weight retained on the 2.00mm (#10) sieve

C = The HCF (Hygroscopic Correction Factor, from Section 1302.5A2)

The corrected weight of the fraction passing the 4.75mm (#4) sieve **=**

(A **+** B) **X** C or (1071.5 **+** 21.2) **X** 0.979 **=** 1069.7

The corrected weight of the fraction passing the 2.00mm (#10) sieve **=**

A **X** C or 1071.5 **X** 0.979 **=** 1049.0

4. To correct the weight of the air-dried sample used for the mechanical analysis, multiply the weight of the sample used by the HCF.

   From the example worksheet (See Section 1302.7), the following computation is made:

   Corrected weight of sample used for mechanical analysis:

   0.979 **X** 50.0 grams **=** 48.95 grams

B. Coarse Material

1. Calculate the percent passing the coarse sieves using the fraction weights recorded in the initial sample preparation (See Section 1301.4D). The Percent of Total Passing (PTP) shall be calculated as follows:

$$\textbf{PTP} = \frac{\text{Weight of material passing any sieve}}{\text{Total weight of sample}} \times 100$$

   In the example the following computations are used (See Section 1302.6):

$$\%\ \text{Passing 4.75mm (\#4) sieve} = \frac{14075.7}{14285.8} \times 100 = 98.5$$

   This value is recorded under "Mechanical Analysis", % of Total Passing - See Section 1302.7.

2. Calculate the percent passing the 2.00mm (#10) sieve using the corrected weights as calculated previously in Section 1302.5A3. In the example the following calculations are used:

$$\%\ \text{Passing 2.00mm (\#10) sieve} = \frac{1049.0}{1069.7} \times 100 = 98.1$$

   Multiply this value by the Percent of Total Sample passing the 4.75mm (#4) sieve. The result is the Total Percent Passing the 2.00mm (#10) sieve.

Using the values in the example the following calculation is made:

(98.1%) (98.5%) **=** 96.6%

This value is recorded under "Mechanical Analysis", % of Total Passing - See Section 1302.7.

C. Fine Sieve Analysis (FSA)

The Percent Passing each sieve (**P**) shall be calculated using the following formula:

$$P = \frac{X}{Y} (100Z)$$

When:

X = Accumulated weight of material passing any sieve.
Y = Total corrected dry weight of dispersed sample.
Z = Percent passing the 2.00mm (#10) sieve.

Using the values from the example (See Section 1302.7), a sample calculation is as follows:

$$\mathbf{P} = \frac{46.82}{48.95} (100) (.966) = 92.4\% \text{ passing the } 850\mu m \text{ (\#20) sieve}$$

D. Percent of Soil in Suspension (**PSS**)

1. Before the percent of soil remaining in suspension can be calculated, the hydrometer reading must be corrected for the following factors:

   a. The specific gravity of the dispersing agent and the distilled water - The formulas for the percent of soil remaining in suspension are based on the use of distilled water. A dispersing agent is used with the distilled water and the specific gravity of the resulting solution will be appreciably greater.

   b. The temperature of the solution - The soil hydrometer is calibrated to be read at 20 °C (68 °F). Variations from this standard temperature will result in inaccurate readings.

c. Apparent hydrometer readings - Hydrometers are graduated by the manufacturer to be read at the bottom of the meniscus, which is formed by the liquid on the stem. Since it is not possible to secure readings of soil suspension at the bottom of the meniscus, the readings must be taken at the top and a correction applied.

The correction for the above factors is designated as the "Determination of Composite Correction for Hydrometer Readings" and may be found in AASHTO T 88.

2. Hydrometer readings taken at temperatures other than 20 °C (68 °F) shall be corrected by applying the appropriate composite correction from the tables determined by calibration of the hydrometers in accordance with the requirements of AASHTO T 88. In the example analysis the correction factor is 4.9. The corrected reading for the two minute interval would be 22 - 4.9 = 17.1

NOTE 7: A table of correction factors should be prepared for the hydrometer in use. An example of this table is as follows:

CORRECTION FACTORS (CF) for HYDROMETER #

°C.	°F.	CF	°C.	°F.	CF	°C.	°F.	CF
19.4	67	7.1	22.2	72	6.1	25.0	77	4.9
20.0	68	6.9	22.8	73	5.8	25.6	78	4.7
20.6	69	6.7	23.3	74	5.6	26.1	79	4.5
21.1	70	6.5	23.9	75	5.4	26.7	80	4.3
21.7	71	6.3	24.4	76	5.2	27.2	81	4.1

3. The percentage of dispersed soil in suspension represented by different corrected hydrometer readings depends upon the amount and the specific gravity of the soil dispersed. The percentage of dispersed soil remaining in suspension shall be calculated as follows:

$$P = \frac{Ra}{W} X\ 100$$

Where:

P = Percentage of originally dispersed soil remaining in suspension.

R = Corrected hydrometer reading.

W = Corrected dry weight (in grams) of soil originally dispersed.

a = 1.0 when the specific gravity of the soil is 2.65. (See Table 1 of AASHTO T 88 for the value of "a" if the specific gravity is other than 2.65)

4. The percent of the total sample in suspension where Z = % passing the 2.00mm (#10) sieve equals:

$$\mathbf{P} = \frac{Z}{100}$$

Combining the above two formulas, yields the Total Percentage in Suspension (**TPS**) or the Percent Finer Than, as follows:

$$\mathbf{TPS} = \frac{Ra}{W} \mathbf{X} 100 \mathbf{X} \frac{Z}{100}$$

Using the values from the example and considering the two minute interval, a sample calculation is as follows:

$$\mathbf{TPS} = \frac{16.8 \mathbf{X} 1.0}{48.95} \mathbf{X} 100 \mathbf{X} \frac{96.6}{100} = 33.15\%$$

E. Diameter of Soil Particles in Suspension

The maximum grain diameter in suspension for assumed conditions and corresponding to the periods of sedimentation specified in this procedure are outlined in AASHTO T 88.

The corrected grain diameters are in tables available from the Mn/DOT Central Lab, Soils Lab. These corrections are based on AASHTO T 88.

F. Plotting (See Section 1302.8)

1. The accumulated percentages of grains of different diameters shall be plotted on semi- logarithmic paper to obtain a grain size accumulation curve such as that with the example analysis. From the hydrometer analysis, plot the corrected grain size versus the percent in suspension. To complete the curve, plot the sieve size (labeled at the top of the graph) versus the percent passing from the sieve analysis.

2. A soil classification shall be made by determining the percents of clay, silt, and sand present in the sample. The percent of clay corresponds to the particle size of 2μm as shown on the grain size accumulation curve. The percent of silt shall be determined by subtracting the percent of clay from the percent passing the 75μm (#200) sieve The percent of sand shall be determined by subtracting the percent passing the 75μm (#200) sieve from 100%. The calculations for the example for the example analysis are as follows:

% Clay **=** 16.4 (read from curve)

% Silt **=** % passing 75μm (#200) **-** % clay **=**
42.0 **-** 16.4 **=** 25.6

% Sand **=** 100 **-** % passing 75μm (#200) **=**
100 **-** 42.0 **=** 58.0

Knowing the percentages of each grain size group in the sample, the soil can be assigned a definite textural classification dependent upon the various amounts of sand, silt, and clay. The soil classification is found using the Triaxial Chart (See Section 1302.9). The Triaxial Chart defines the main soil classes in relation to their percentage of sand, silt, and clay. The sides of the triangle represent the zero % points and the angles represent the 100% points.

G. Report

The results of the complete mechanical analysis furnished by the combined sieve and hydrometer analysis shall be recorded as follows:

SIEVE SIZE (Metric)	SIEVE SIZE	PERCENT PASSING
19.0mm	3/4"	100
9.5mm	3/8"	99.4
4.75mm	#4	98.5
2.00mm	#10	96.6
850μm	#20	92.4
425μm	#40	85.1
250μm	#60	69.6
150μm	#100	54.1
75μm	#200	42.0

MATERIAL CLASSIFICATION	MATERIAL SIZE (Metric)	PERCENT
Gravel	>2mm	3.4
Coarse Sand	2mm - 425μm	11.5
Fine Sand	425 - 75μm	43.1
Silt	75 - 2μm	25.6
Clay	<2μm	16.4
Total % Silt & Clay (% Passing 75μm [#200] Sieve)		42.0

1302.6 EXAMPLE - GRADATION WORK SHEET

GRADATION WORK SHEET

Lab. No. *CO-SS99-001* Sieved by *J. SMITH* Date *1/1/99*

COARSE SIEVES

SIZE (mm)	WT. RETAINED	% of TOTAL PASSING
50		
25.0		
19.0	*0*	*100*
9.5	*82.1*	*99.4*
4.75	*128.0*	*98.5*
BOTTOM	*14075.7*	
TOTAL	*14285.8*	

MEDIUM SIEVES

		% of TOTAL PASSING
2.00	*21.2*	*96.6*
BOTTOM	*1071.5*	
TOTAL	*1092.7*	

1302.7 EXAMPLE - FORM #28293

NOTE 8: The lab number on this form is the old system and is not indicative of the system currently in use.

Mn/DOT 28293 (7-78)
(Formerly 24105)

LABORATORY NOTES ON SAMPLE OF SUBGRADE SOIL

Lab. No. SS. 93XXX Lab. Temporary No. ______ Date 1/1/93

Project # ______

MECHANICAL ANALYSIS

		% of Total passing
Total Wt. air dried sample	gms.	
Ret. on No. 4 sieve	gms.	98.5
Pass No. 4 – Ret. on No. 10	gms.	96.6
Pass No. 10	gms.	

HYDROMETER ANALYSIS – Fraction Passing No. 10

Hydrometer No. 152 H Wt. of air dried sample dispersed 50.0 gms.
Wt. corrected for Hygro. Moisture 48.95 gms.

Fraction	L.L.L.	
Passing # 40	P.I.	
% Silt		
% Clay		
Textural Class.		
AASHO Group		
Group Index		
Field Moisture %		
Max. Density		
Opt. Moisture		

TIME	INTVL (MIN)	TEMP	READ-ING	CORR.	COR'D RDG.	CORR. GR. SIZE	% IN SUSPEN.
START	9:05						
1							
2	9:07	77°	22	4.9	17.1	.0839	33.7
5	9:10		20	4.9	15.1	.0217	29.8
15	9:25		18	4.9	13.1	.0126	25.8
30	9:40		17	4.9	12.1	.0090	23.9
60	10:10		16	4.9	11.1	.0064	21.9
80	10:10						
250	1:15		14	4.9	9.1	.0031	17.9
24 hr	9:05	75°	13	5.4	7.6	.0013	15.0

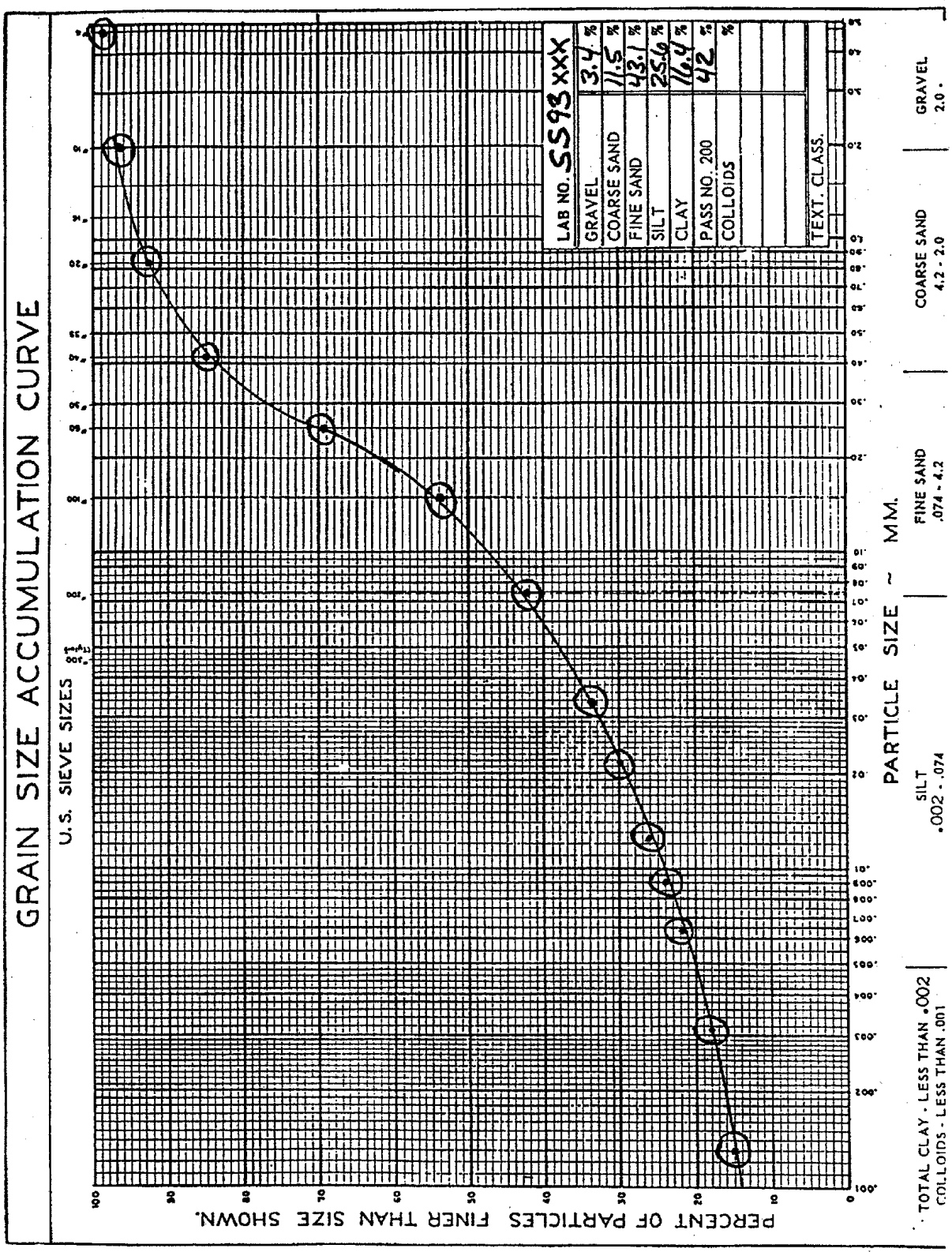
HYGROSCOPIC MOISTURE – Pass. No. 10

Air dried sample + can	25.71	gms.
Oven dried sample + can	25.47	gms.
Moisture loss	0.24	gms.
Tare wt. can	14.34	gms.
Oven dried soil	11.13	gms.
Hygroscopic moisture	2.16	%
Hygroscopic correction factor	0.979	

SIEVE ANALYSIS

			% Total Sample RET. PASS (PASS circled)
Pass No. 10–Ret. No. 20	2.13	gms.	92.4
Pass No. 20–Ret. No. 40	3.69	gms.	85.1
Pass No. 40–Ret. No. 60	7.84	gms.	69.6
Pass No. 60–Ret. No.100	7.83	gms.	54.1
Pass No.100–Ret. No.200	6.11	gms.	42.0
Pass No. 200		gms.	

1302.8 EXAMPLE – GRAIN SIZE ACCUMULATION CURVE



1302.9 EXAMPLE – TRIAXIAL CHART

The Triaxial Chart

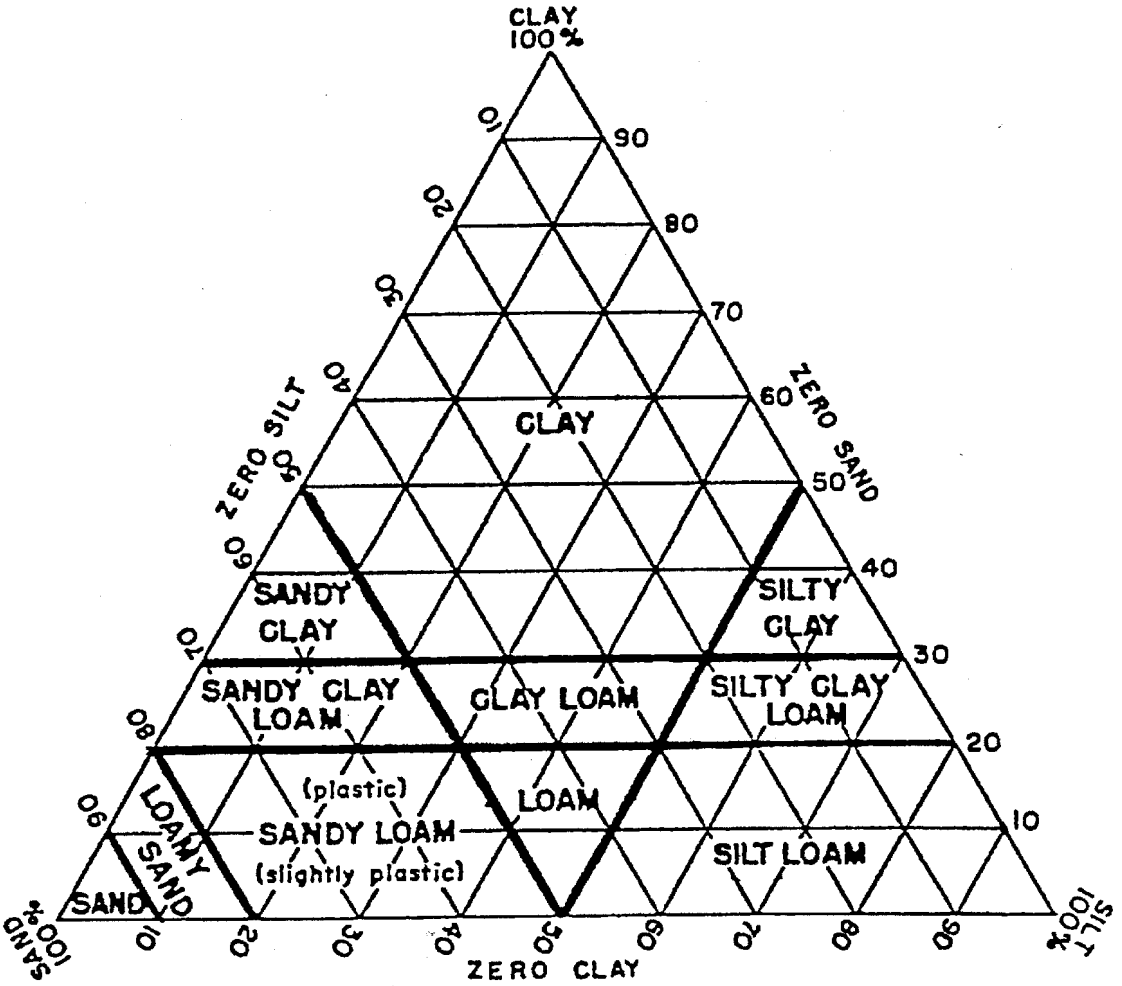


DIAGRAM SHOWING 11 OF THE MAIN SOIL CLASSES IN RELATION TO THEIR PERCENTAGE COMPOSITION OF SAND, SILT AND CLAY

SIZES OF SOIL SEPARATES

SAND..... Particle Diameter from 2.0mm to 75μm
SILT..... Particle Diameter from 75μm to 2μm
CLAY..... Particle Diameter below 2μm