**Test Procedure for**

# PARTICLE SIZE ANALYSIS OF SOILS

## TxDOT Designation: Tex-110-E

***Effective Date: August 1999***

## 1. SCOPE

1.1 This method covers the quantitative determination of the distribution of particle sizes in soils. The distribution of particle sizes larger than 75 µm (No. 200) is determined by sieving, while the distribution of particle sizes smaller than 75 µm is determined by a sedimentation process, using a hydrometer to secure the necessary data.

1.2 If hydrometer analysis is not required, but a determination of material passing the 75 µm (No. 200) sieve is desired, refer to Tex-401-A for low Plasticity Index (PI) materials or Tex-111-E for clay materials.

1.3 The values given in parentheses (if provided) are not standard and may not be exact mathematical conversions. Use each system of units separately. Combining values from the two systems may result in nonconformance with the standard.

# PART I—SIEVE ANALYSIS OF MATERIAL RETAINED ON THE 425 µM (NO. 40) SIEVE

## 2. SCOPE

2.1 Part I details the necessary steps for sieve analysis of material retained on the 425 µm (No. 40) sieve.

## 3. APPARATUS

3.1 *Drying oven*, maintained at 110 ± 5°C (230 ± 9°F).

3.2 *Mechanical sieve shaker*.

3.3 *Balance*, Class G2 in accordance with Tex-901-K, minimum capacity of 15 kg (33 lb.)

3.4 *Sample splitter, quartering machine, or quartering cloth.*

3.5 *Standard U.S. sieves*, meeting the requirements of Tex-907-K.

3.6 *Pans.*

## 4. SAMPLES

4.1 The mass of sample should be sufficient for particle size analysis. The minimum amount required of material retained on the 425 μm (No. 40) sieve depends on the maximum particle size. The size should not be less than the amount shown in Table 1. When the nominal maximum size is between sizes shown, use next larger minimum mass.

**Table 1—Mass Requirement for Sieve Analysis**

| Nominal Maximum Size | Approximate Minimum Mass |
|---|---|
| 9.5 mm (3/8 in.) | 0.5 kg (1 lb.) |
| 25 mm (1 in.) | 2 kg (4 lb.) |
| 37.5 mm (1-1/2 in.) | 4 kg (8 lb.) |
| 50 mm (2 in.) | 5 kg (10 lb.) |
| 75 mm (3 in.) | 6 kg (12 lb.) |

**Note 1**—The size of the portion passing the 425 μm (No. 40) sieve should be:

- for the hydrometer test, approximately 100 g for sandy soil and approximately 50 g for silty or clayey soils.
- for hygroscopic moisture determination, at least 10 g.

## 5. PROCEDURE

5.1 Prepare a sample of material for analysis in accordance with Tex-101-E, Method A). Record the mass of the material passing the 425 μm (No. 40) sieve (soil binder) as $W_S$ under Section 6.

5.2 Obtain all sieve sizes required by the material specification. Stack sieves in descending order with the sieve having the largest opening on top and a pan on the bottom.

5.3 Pour the plus (+) 425 μm (No. 40) portion of the sample into the sieves. Use a mechanical shaker and shake the sieves for five minutes.

5.4 After shaking, remove the top sieve from the stack without losing any of the retained material. Over a clean pan, hand sieve until not more than one percent, by weight, of the material retained on the sieve continues to pass through the sieve. Combine any material passing the sieve with the material retained on the next smallest size sieve.

5.5 Weigh the portion retained on the first sieve and record the mass as $W_1$ under Section 6. Repeat Section 5.4 for the next largest sieve size and then add the material retained to the portion retained on the first sieve and record the combined weight as $W_2$ under Section 6. Continue hand sieving and recording the combined masses, as $W_3$, $W_4$, etc., until all sieving is complete.

## 6. CALCULATIONS

6.1 Calculate the total mass of the sample:

$$W_T = W_S + W$$

Where:

$W_T$ = total mass of sample, g

$W_S$ = mass of material passing the 425 µm (No. 40) sieve, g

$W$ = cumulative mass of smallest sieve size, g.

6.2 Calculate cumulative percent retained for each sieve:

$$Cumulative\ \%\ Retained\ \ first\ sieve = 100 \bullet W_1 / W_T$$

$$Cumulative\ \%\ Retained\ second\ sieve = 100 \bullet W_2 / W_T\ ,etc.$$

6.3 Calculate individual percent retained for each sieve by subtracting the cumulative percent retained of one sieve size larger from the cumulative percent retained of the sieve size:

$$Individual\ \%\ Retained = Cum.\%\ of\ W_2 - Cum.\%\ of\ W_1\ ,\ etc.$$

Plot the cumulative percent retained, from above, versus the sieve size, on Tx110.xlsm, "Cumulative Mechanical Analysis" tab or on semi-logarithmic paper.

**Table 2—Sieve Analysis Calculations**

| Sieve Size | Cumulative Weight Retained (g) | Cumulative Percent Retained | Individual Percent Retained |
|---|---|---|---|
| 12.5 mm (1/2 in.) | 108.4 | 2.8 | 2.8 |
| 9.5 mm (3/8 in.) | 412.5 | 10.8 | 8.0 |
| 4.75 mm (No. 4) | 2285.0 | 59.6 | 48.8 |
| 2.36 mm (No. 8) | 3523.0 | 91.9 | 32.3 |
| Total – including minus (-) 425 µm (No. 40) material | 3832.0 | 100 | |

## 7. TEST REPORT

7.1 Report the individual percent retained on each sieve to the nearest whole number.

# PART II—HYDROMETER ANALYSIS OF SOILS PASSING 425 μM (NO. 40) SIEVE

## 8. SCOPE

8.1 This part describes the analysis of soils passing the 425 μm (No. 40) sieve using a hydrometer.

## 9. APPARATUS

9.1 *Balance*, Class G1 in accordance with Tex-901-K, minimum capacity of 200 g.

9.2 *Stirring apparatus*, either a mechanical stirring device or an air dispersion device, as shown in Figure 1.

9.3 *Hydrometer,* graduated in grams per liter, Type 151 H or 152 H, as shown in Figure 3.

9.4 *Sedimentation cylinder*, a glass hydrometer cylinder approximately 457 mm (18 in.) in height and 63.5 mm (2.5 in.) in diameter, graduated for a volume of 1000 mL, as shown in Figure 2.

9.5 *Mercury thermometer*, range of 0–104°C (1–220°F), accurate to 0.5°C (1°F).

9.6 *Standard U.S. sieves*, meeting the requirements of Tex-907-K in the following sizes:

- 75 mm (3 in.)
- 50 mm (2 in.)
- 25 mm (1 in.)
- 9.5 mm (3/8 in.)
- 4.75 mm (No. 4)
- 2 mm (No. 10)
- 425 μm ( No. 40)
- 75 μm (No. 200).

9.7 *Oven*, maintained at 110 ± 5°C (230 ± 9°F).

9.8 *Evaporating dishes.*

9.9 *Water bath, or constant temperature room.*

9.10 *Timing device,* with a second hand.

9.11 *Beaker*, 250 mL (7.5 oz.)

**Figure 1—**Mechanical Stirring Device

**Figure 2—**Air Dispersion Device

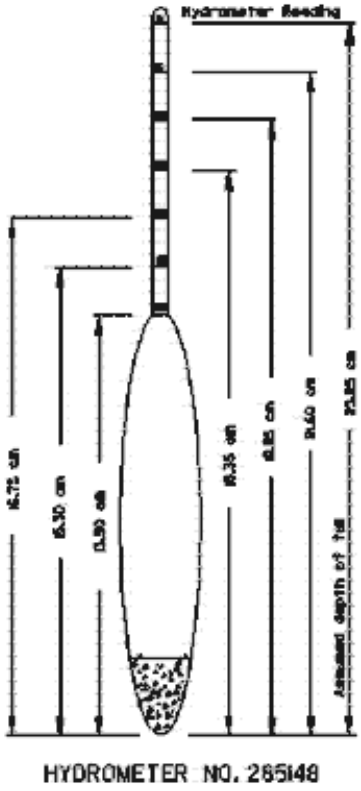


**Figure 3**—Hydrometer with Dimensions

## 10. MATERIAL

10.1 *Dispersing agent*, a solution of sodium hexametaphosphate in distilled or demineralized water, at the rate of 40 g of sodium hexametaphosphate per liter of solution.

10.1.1 Solution of this salt, if acidic, should be slowly reverted or hydrolyzed back to the orthophosphate form with a resultant decrease in dispersing action.

10.1.2 Solutions should be prepared frequently (at least once a month) or adjusted to pH of 8 or 9 by means of sodium carbonate.

10.1.3 Bottles containing solutions should have the date of preparation marked on them.

10.2 *Distilled or demineralized water*.

10.3 *Source of compressed air*, if air dispersion device is used.

## 11. DETERMINING COMPOSITE CORRECTION FOR HYDROMETER READING

11.1 Equations for percentages of soil remaining in suspension, as given in Section 13 are based on the use of distilled or demineralized water.

11.2 A dispersing agent is used in the water, however, and the specific gravity of the resulting liquid is appreciably greater than that of distilled or demineralized water.

11.3 The manufacturer calibrates the soil hydrometers at 20°C (68°F), and variations in temperature from this standard temperature produce inaccuracies in the actual hydrometer readings. The amount of the inaccuracy increases as the variation from the standard temperature increases.

11.4 The manufacturer graduates hydrometers to be read at the bottom of the meniscus formed by the liquid on the stem. Since it is not possible to secure readings of soil suspensions at the bottom of the meniscus, readings must be taken at the top and a correction applied.

11.5 The net amount of the corrections for the three items enumerated is designated as the composite correction, and may be determined experimentally.

11.6 For convenience, a graph or table of composite corrections for a series of one-degree temperature differences for the range of expected test temperatures may be prepared and used as needed. Measurement of the composite corrections may be made at two temperatures spanning the range of expected test temperatures, and corrections for the intermediate temperatures calculated assuming a straight-line relationship between the two observed values.

11.7 Prepare 1000 mL (30 fl. oz.) of liquid composed of distilled water and dispersing agent in the same proportion as will prevail in the sedimentation (hydrometer) test.

11.8 Place the liquid in a sedimentation cylinder and the cylinder in the constant-temperature water bath, set for one of the two temperatures to be used.

11.9 When the temperature of the liquid becomes constant, insert the hydrometer at the top of the meniscus formed on the stem. For hydrometer 151 H the composite correction is the different between this reading and one; for hydrometer 152 H it is the difference between the reading and zero.

11.10 Bring the liquid and the hydrometer to the other temperature to be used, and secure the composite correction as before.

## 12. PROCEDURE

12.1 *Hydrometer Analysis:*

12.1.1 Use soil binder prepared in Part I, or prepare the soil binder in accordance with Tex-101-E if Part I was not used. Record the mass of the air-dried sample as $W_A$ under Section 13.

12.1.2 Determine the hygroscopic moisture of the soil binder in accordance with Tex-103-E. Record the percent hygroscopic moisture as $P_H$ under Section 13.

12.1.3 Determine the specific gravity of the soil binder in accordance with Tex-108-E.

12.1.4 Use a sample splitter to obtain 50 g (for silty or clayed soils) or 100 g (for sandy soil) of soil binder to the nearest 0.01 g. Place the sample in a 250 mL beaker or in the hydrometer cylinder if the dispersion tube is available. Add approximately 125 mL of the sodium hexametaphosphate solution and cover with distilled water. Stir the soil thoroughly and then allow to soak for at least 12 hours.

12.1.5 After the soaking period, disperse the soil with the stirring device or a soil dispersion tube as follows:

12.1.5.1 *Stirring Device:*

12.1.5.1.1 Wash the soil into the dispersion cup and add distilled water until the cup is slightly more than half-full.

12.1.5.1.2 Disperse the contents for a period of 1 minute in the mechanical stirring device.

12.1.5.1.3 After dispersion, transfer the soil slurry to the hydrometer cylinder and add sufficient distilled water (having the same temperature as the water bath) to bring the level of the water to the 1000 mL mark on the cylinder.

12.1.5.1.4 Place the cylinder in the constant temperature water bath.

12.1.5.2 *Soil Dispersion Tube:*

12.1.5.2.1 Add about 300 mL of distilled water to the soaked sample and carefully place the dispersion tube into the hydrometer cylinder.

12.1.5.2.2 Adjust the air pressure by means of the valve and disperse the soil.

12.1.5.2.3 Disperse the soil-water mixture using an air pressure of 152 kPa (20 psi).

12.1.5.2.4 Disperse soils with a Plasticity Index (PI) of 5 or less for 5 minutes; soils with a PI between 6 and 20 for 10 minutes; and soils with a PI greater than 20 for 15 minutes.

12.1.5.2.5 Soils containing large percentage of mica need be dispersed for 60 seconds only.

12.1.5.2.6 Wash the soil from the dispersion tube into cylinder and add sufficient amount of distilled water to bring the level of the water to the 1000 mL mark before placing into the constant temperature bath.

12.1.6 When the soil suspension reaches the temperature of the bath, remove the graduate and thoroughly shake its contents for one minute, using the palm of the hand or a stopper over the open end of the cylinder. Mix the contents of the cylinder by alternately turning the cylinder upside-down, then right side up and by loosening any material remaining on the bottom while in the inverted position.

12.1.7 At the conclusion of this shaking, place the hydrometer cylinder on the table, immediately lower the hydrometer into the suspension and record the time. Read the hydrometer at the peak of the meniscus formed on the stem to the nearest 0.5 g per liter at the end of two minutes from the time the graduate was set on the table. Remove the hydrometer and carefully place the cylinder with contents into the constant temperature

bath. Obtain hydrometer readings at time intervals of 5, 15, 30, 60, 250, and 1440 minutes after the beginning of sedimentation. About 15 seconds before the time of each reading, slowly and carefully lower the hydrometer into the soil suspension and read the hydrometer after it has come to rest. After each reading, remove the hydrometer from the cylinder in such a manner as to cause as little disturbance as possible. Determine and record the temperature of the suspension each time a hydrometer reading is taken. Record data on work card, to the nearest 0.1%.

12.2 *Fine Sieve Analysis:*

12.2.1 At the conclusion of the final hydrometer reading, pour the soil suspension onto a 75 µm (No. 200) sieve and rinse the retained particles with tap water until the wash water is clear.

12.2.2 Flush any material retained on the 75 µm (No. 200) sieve to an evaporating dish and dry to a constant mass at a temperature of 110 ± 5°C (230 ± 9°F.) No water should be decanted from the evaporating dish to avoid loss of material; after the material has settled and the water is clear, carefully decant water from the evaporating dish avoiding any loss of material. A sieve analysis is made using the 425 µm (No. 40) and 75 µm (No. 200) sieves, and such other sieves as may be required by the material under test.

## 13. CALCULATIONS

13.1 Calculate the percentage of hygroscopic moisture to the nearest 0.001 percent:

$$P_H = 100 \bullet (W_{Air\ Dry} - W_{Ovenr\ Dry}) / W_{Ovenr\ Dry}$$

Where:

$W_{Air\ Dry}$ = mass of air-dry soil for hygroscopic moisture test, g

$W_{Ovenr\ Dry}$ = mass of oven-dry soil for hygroscopic moisture test, g.

13.2 Calculate the mass of oven-dry soil sample for the hydrometer test:

$$W_O = 100 \bullet W_A / (100 + P_H)$$

Where:

$W_O$ = mass of oven-dry soil sample for the hydrometer test

$P_H$ = percent hygroscopic moisture

$W_A$ = mass of air-dry sample for the hydrometer test.

13.3 Calculate the percent soil binder in the total sample:

$$P_B = 100 \bullet W_S / W_T$$

Where:

$P_B$ = percent soil binder in the total sample

$W_S$ = mass of material passing the 425 μm (No. 40) sieve, g

$W_T$ = total mass of the sample, g (as calculated in Part I).

13.4 Calculate the percentage of the total original material that is retained on any given fine sieve analysis sieves:

$$\%\ of\ \ Original\ Retained = P_B \cdot W_1 / W_B + (100 - P_B), etc.$$

Where:

$P_B$ = percent soil binder in the total sample

$W_B$ = mass of oven-dry soil sample for the hydrometer test, g

$W_1$ = mass of portion retained on the first sieve from fine sieve analysis, g.

13.5 Calculate the percentage of soil in suspension:

$$P_S = (P_B \cdot R \cdot a / W_O)$$

Where:

$P_S$ = percentage of soil binder in suspension

$P_B$ = percent soil binder in the total sample

$R$ = corrected hydrometer reading

$a$ = constant depending on the density of the suspension and varies with the specific gravity of the soil (Gr.), (shown in Table 3)

$W_O$ = mass of oven-dry soil sample for the hydrometer test.

**Table 3—Constant a**

| Specific Gravity, Gr. | Constant, a |
|---|---|
| 2.95 | 0.94 |
| 2.90 | 0.95 |
| 2.85 | 0.96 |
| 2.80 | 0.97 |
| 2.75 | 0.98 |
| 2.70 | 0.99 |
| 2.65 | 1.00 |
| 2.60 | 1.01 |
| 2.55 | 1.02 |
| 2.50 | 1.03 |
| 2.45 | 1.05 |

13.6 Calculate the maximum diameter, d, of the particles in suspension, corresponding to the percentages indicated by a given hydrometer reading, using modified Stoke's Law:

$$d = (K / 1000) \bullet (L / T)^{1/2}$$

Where:

*L* = distance from the surface of the suspension is being level at which the density of the suspension is being measured, cm. For a given hydrometer and sedimentation cylinder, the values vary according to the hydrometer readings. These values of distance L, known as the effective depth, are given in Table 4.

*T* = an interval of time from beginning of sedimentation to the taking of the reading, minutes (2, 5, 15, 30, 60, 250, and 1440 min.)

*K* = a constant depending on the temperature of the suspension and the specific gravity of the soil particles. Values of K for a range of temperatures and specific gravities are given in Table 5. The value of K does not change for a series of readings constituting a test, while values of L and T do vary.

**Table 4—Effective Depth, L**

| Actual Hydrometer reading | Effective Depth, L, cm | Actual Hydrometer reading | Effective Depth, L, cm |
|---|---|---|---|
| 0 | 16.3 | 31 | 11.2 |
| 1 | 16.1 | 32 | 11.1 |
| 2 | 16.0 | 33 | 10.9 |
| 3 | 15.8 | 34 | 10.7 |
| 4 | 15.6 | 35 | 10.6 |
| 5 | 15.5 | 36 | 10.4 |
| 6 | 15.3 | 37 | 10.2 |
| 7 | 15.2 | 38 | 10.1 |
| 8 | 15.0 | 39 | 9.9 |
| 9 | 14.8 | 40 | 9.7 |
| 10 | 14.7 | 41 | 9.6 |
| 11 | 14.5 | 42 | 9.4 |
| 12 | 14.3 | 43 | 9.2 |
| 13 | 14.2 | 44 | 9.1 |
| 14 | 14.0 | 45 | 8.9 |
| 15 | 13.8 | 46 | 8.8 |
| 16 | 13.7 | 47 | 8.6 |
| 17 | 13.5 | 48 | 8.4 |
| 18 | 13.3 | 49 | 8.3 |
| 19 | 13.2 | 50 | 8.1 |
| 20 | 13.0 | 51 | 7.9 |
| 21 | 12.9 | 52 | 7.8 |
| 22 | 12.7 | 53 | 7.6 |
| 23 | 12.5 | 54 | 7.4 |
| 24 | 12.4 | 55 | 7.3 |

**Table 4—Effective Depth, L**

| Actual Hydrometer reading | Effective Depth, L, cm | Actual Hydrometer reading | Effective Depth, L, cm |
|---|---|---|---|
| 25 | 12.2 | 56 | 7.1 |
| 26 | 12.0 | 57 | 7.0 |
| 27 | 11.9 | 58 | 6.8 |
| 28 | 11.7 | 59 | 6.6 |
| 29 | 11.5 | 60 | 6.5 |
| 30 | 11.4 | | |

**Table 5—Constant K**

| Temp | Specific Gravity of Soil Particles | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| °C | 2.45 | 2.50 | 2.55 | 2.60 | 2.65 | 2.70 | 2.75 | 2.80 | 2.85 |
| 16 | 15.10 | 15.05 | 14.81 | 14.57 | 14.35 | 14.14 | 13.94 | 13.74 | 13.56 |
| 17 | 15.11 | 14.86 | 14.62 | 14.39 | 14.17 | 13.96 | 13.76 | 13.56 | 13.38 |
| 18 | 14.92 | 14.67 | 14.43 | 14.21 | 13.99 | 13.78 | 13.59 | 13.39 | 13.21 |
| 19 | 14.74 | 14.49 | 14.25 | 14.03 | 13.82 | 13.61 | 13.42 | 13.23 | 13.05 |
| 20 | 14.56 | 14.31 | 14.08 | 13.86 | 13.65 | 13.44 | 13.25 | 13.07 | 12.89 |
| 21 | 14.38 | 14.14 | 13.91 | 13.69 | 13.48 | 13.28 | 13.09 | 12.91 | 12.73 |
| 22 | 14.21 | 13.97 | 13.74 | 13.53 | 13.32 | 13.12 | 12.94 | 12.76 | 12.58 |
| 23 | 14.04 | 13.81 | 13.58 | 13.37 | 13.17 | 12.97 | 12.79 | 12.61 | 12.43 |
| 24 | 13.88 | 13.65 | 13.42 | 13.21 | 13.01 | 12.82 | 12.64 | 12.46 | 12.29 |
| 25 | 13.72 | 13.49 | 13.27 | 13.06 | 12.86 | 12.67 | 12.49 | 12.32 | 12.15 |
| 26 | 13.57 | 13.34 | 13.12 | 12.91 | 12.72 | 12.53 | 12.35 | 12.18 | 12.01 |
| 27 | 13.42 | 13.19 | 12.97 | 12.77 | 12.58 | 12.39 | 12.21 | 12.04 | 11.88 |
| 28 | 13.27 | 13.04 | 12.83 | 12.64 | 12.44 | 12.25 | 12.08 | 11.91 | 11.75 |
| 29 | 13.12 | 12.90 | 12.69 | 12.49 | 12.30 | 12.12 | 11.95 | 11.78 | 11.62 |
| 30 | 12.98 | 12.76 | 12.56 | 12.36 | 12.17 | 11.99 | 11.82 | 11.65 | 11.49 |

## 14. TEST REPORT

14.1 Report the total percentages retained on each sieve, or the grain diameter to the nearest whole number, as follows:

14.1.1 Sieves, opening in millimeters (inches or sieve numbers):

- 75 mm (3 in.)
- 50 mm (2 in.)
- 25 mm (1 in.)
- 9.5 mm (3/8 in.)

- 4.75 mm (No. 4)
- 2.00 mm (No. 10)
- 425 µm (No. 40)
- 75 µm (No. 200).

14.1.2 Grain diameter:

- 0.02 mm
- 0.002 mm
- 0.001 mm.

**Note 2**—The sieve sizes listed above are suggested sizes only and may be specified only in part.

## 15. PLOTTING TEST RESULTS

15.1 The percentage of grains of different diameters is plotted on semi-logarithmic paper to obtain a grain size accumulation curve.

15.2 The data obtained from the hydrometer analysis are plotted as percent of material in suspension (percent passing) against corrected grain diameter in millimeters.

15.3 The data from the mechanical analysis are plotted as the percent retained against sieve size.

## 16. REPORT FORM

16.1 Tx110p2.xlsm, "Particle Size Analysis of Soil, Part II," is available to automate the calculation, plot, and report.