INTRODUCTION

Grain size analysis is widely used for the classification of soils and for specifications of soil for airfields, roads, earth dams, and other soil embankment construction. The standard grain size analysis test determines the relative proportions of different grain sizes contained in a given soil sample. The specific gravity of soil solids, which relates the density of soil solids to the density of water, is frequently used to solve for the various phase relationships in a soil block, including volume of solids, void ratio, porosity, and degree of saturation. The specific gravity is also required in the calculations of grain size during a hydrometer analysis.

MECHANICAL GRAIN SIZE ANALYSIS

Mechanical sieve analyses are commonly used to determine the relative distribution of soil particles greater than 0.075 mm, which corresponds to the opening size of a No. 200 sieve. This particle size is considered to be about the smallest individual particle that can be distinguished by the unaided human eye and represents the breakpoint between the macroscopic (+ 0.075 mm) and microscopic (- 0.075 mm) regions. A hydrometer analysis is required to determine the particle size distribution for that portion of the soil which passes through a No. 200 sieve. When both the mechanical and hydrometer methods are performed on the same soil, the analysis is said to be a combined analysis.

A sieve size analysis of soils containing relatively large particles is accomplished using a set of sieves of various opening sizes. A sieve consists of a metal ring, usually made of brass, with a wire mesh or screen on the bottom. Sieves are available in various dimensions with the most commonly used sieves being 2 inches deep and 8 inches in diameter. The sieve is given a number which corresponds to the number of square openings per linear inch of screen. For example, a No. 4 sieve has 4 square openings per inch, with each opening measuring 0.187 inches (4.75 mm). Sieves with larger openings than the No. 4 sieve are commonly designated by the opening size rather than the openings per inch, e.g. a 3/8" sieve.

A sieve analysis is accomplished using a stack of sieves, one on top of the other, sometimes referred to as a nest of sieves. The sieves are arranged with the sieve having the largest opening (smallest sieve number) on top progressing to the smallest opening size (largest sieve number) on the bottom. Specific sieves used to complete the nest are selected based on the soil type being analyzed and the intended results of the analysis. Oftentimes a U.S. standard sieve series is used, which indicates that each sieve in the
stack has openings approximately 1/2 as large as the sieve immediately above in the stack.
A lid is usually placed on top of the sieve stack to prevent spillage and a pan is placed
below the bottom sieve to catch any soil particles that pass through.

Prior to conducting the sieve analysis, each sieve should be cleaned of all soil particles and
inspected to ensure the mesh is undamaged. Particles which appear stuck in the sieve
screen should never be forced on through the mesh as this can damage the screen and
necessitate replacement. Particles caught in the screen should be removed by brushing
the underside of the screen with the proper brush (wire-bristled brush for coarse screens
and a hair brush for fine screens). Stubborn particles are best left in place rather than
being forced out. After cleaning, the mass of each sieve should be accurately determined
and recorded. It is also good practice to obtain and record the combined mass of the entire
sieve stack, including the pan.

A desired amount of dry soil is then prepared for analysis. Nodules or clumps of soil must
be broken down into their individual particles for the grain size analysis to be valid. This
may be accomplished using a soil processor and/or a ceramic mortar and rubber-tipped
pestle. After processing, the soil is poured into the top sieve on the stack and the
combined soil and sieve stack mass is obtained and recorded. The sieve stack is then
placed in a mechanical shaker which produces a principally horizontal shaking motion,
which is more efficient than a vertical shaking motion. A shaking period of 10 - 30 minutes
is usually specified, with longer periods being used for predominantly fine-grained soils.

After shaking, the sieves are carefully separated from the nest, one at a time beginning with
the uppermost sieve. Often the sieves fit tightly (and they properly should) and sudden,
unexpected separation could result in the contents being spilled and the whole test ruined.
For stubborn sieves, is may be helpful to twist a blade screw driver along the perimeter of
the seam to produce a slight separation which can aid in hand separation. The mass of
each separated sieve, including retained soil particles, should be accurately determined
and recorded. These values are then used in combination with the empty sieve masses to
determine the mass of soil particles retained on each sieve. To ensure minimal loss of soil
during testing, the combined mass of all retained soil is compared against the pre-sieve soil
mass and the % difference calculated. A difference exceeding 1% indicates significant soil
loss and a likely bias in the results.

Sequential calculations are then performed to determine the cumulative mass retained on
each sieve, the cumulative percent retained on each sieve, and the percent passing each
sieve. The final product of the sieve analysis, namely the cumulative percent passing each
sieve size by weight, is commonly presented in both tabular and graphical formats.
Table 1 provides example data for a mechanical sieve analysis conducted on a soil sample. Figure 1 provides a semi-log plot of this example data, which is the common method of presentation.

Table 1: Example Sieve Analysis Data

<table>
<thead>
<tr>
<th>Sample Jar No.</th>
<th>12</th>
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<tbody>
<tr>
<td>Sieve Stack Mass, g</td>
<td>3293.4 (A)</td>
</tr>
<tr>
<td>Sieve Stack + Soil Mass, g</td>
<td>3794.6 (B)</td>
</tr>
<tr>
<td>Pre-Sieve Soil Mass, g</td>
<td>501.2 (C = B - A)</td>
</tr>
<tr>
<td>Post-Sieve Soil Mass, g</td>
<td>499.6 ((\Sigma F))</td>
</tr>
<tr>
<td>% Difference</td>
<td>100*(C-(\Sigma F))/C = 0.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>US Standard Sieve #</th>
<th>Sieve Opening Size (mm)</th>
<th>Sieve Mass, g</th>
<th>Sieve+Soil Mass, g</th>
<th>Soil Mass Retained, g</th>
<th>Cumm Mass Retained, g</th>
<th>Cumm % Retained</th>
<th>Cumm % Passing</th>
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<td>632.5</td>
<td>633.8</td>
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<td>1.3</td>
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<td>479.4</td>
<td>94.0</td>
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<td>Pan</td>
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<td>Total</td>
<td></td>
<td>499.6</td>
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</tbody>
</table>

\(\Sigma F\) = 499.6

Figure 1: Example Grain-Size Distribution Curve
SPECIFIC GRAVITY OF SOIL SOLIDS

The specific gravity of a material represents the ratio of the mass of the material to the mass of an equal volume of distilled water at 4°C. Alternatively, the specific gravity may be defined as the ratio of the unit mass of the material (e.g., soil solids) to the unit mass of distilled water at 4°C (\(\gamma_w = 1\text{g/cc at 4°C}\)). When working with a soil block analysis, knowing the specific gravity of soil solids allows for the direct conversion from a known mass of solids to the absolute volume of the soil solids.

One method for determining the specific gravity of soil solids utilizes a volumetric flask with a known volume (e.g., 500 cc). The flask is inscribed with a fill line to allow for consistent measures. A modified displacement procedure uses three main data items for the calculations as follows:

\[
\begin{align*}
(A) &= \text{Mass of flask filled with distilled water} \\
(B) &= \text{Mass of dry soil added to the flask} \\
(C) &= \text{Mass of flask filled with water and soil}
\end{align*}
\]

If the above measures (A) and (C) are each made with the flask filled to the same level with distilled water at the same temperature, the mass of water displaced by soil solids is equal to:

\[
M_{\text{Water-Displaced}} = (D) = (A) + (B) - (C)
\]

If the water temperature in measurements (A) and (C) is the same, the specific gravity of soil solids is determined as:

\[
\text{Specific Gravity} = \frac{(B)}{(D)}
\]

If different water temperatures are used for measures (A) and (C), adjustments need to be made to eliminate bias.

During typical measurements, the water temperatures for measurements (A) and (C) are neither the same nor equal to 4°C. To account for these variations, the mass of the filled flask should be determined at two or more water temperatures. From this data, a graph and/or equation is developed to estimate the filled mass (A) at any intermediate temperature corresponding to the water temperature when filled with soil and water (C).

To illustrate the procedures described, assume you have a volumetric flask with a reference volume of 500 cc (= 500 ml) with an empty mass of 200.0 g. If this flask were filled to the reference mark with distilled water at 4°C (\(\gamma_w = 1\text{g/cc}\)), the filled mass (A) would be expected to be 700.0 g (200.0 g empty + 500.0 g water), as indicated in Figure 2a. Let’s assume further that you have a lead cube with an exact volume of 10 cc. We know that lead has a specific gravity of 11.34, so this cube would have a mass (B) of 113.4 g. If the cube was simply added to the filled flask without spillage, the combined mass would increase to 813.4
g and the water level would rise above the reference mark by 10cc (i.e., the cube volume), as indicated in Figure 2b. To lower the water level to the reference mark, as indicated in Figure 2c, one would need to remove 10 cc of water (leaving 490 cc) which would reduce the filled mass (C) to 803.4 g.

**Figure 2: Example Flask Measurements**

![Figure 2](image)

Using the presented equations:

\[
M_{\text{Water-Displaced}} = (D) = (A) + (B) - (C) = 700 \text{ g} + 113.4 \text{ g} - 803.4 \text{ g} = 10.0 \text{ g}
\]

Specific Gravity = \( \frac{(B)}{(D)} = \frac{113.4 \text{ g}}{10.0 \text{ g}} = 11.34 \)
Now assume the above measures were each made using distilled water with a temperature of 20°C and unit mass = 0.9982 g/cc. The following values would be expected:

\[(A) = 200.0 \text{ g} + 500\text{cc (0.9982 g/cc)} = 699.1 \text{ g}\]
\[(B) = 113.4 \text{ g}\]
\[(C) = 699.1 \text{ g} + 113.4 \text{ g} - 10\text{cc (0.9982 g/cc)} = 802.5 \text{ g}\]

Also, \[(C) = 200.0 \text{ g} + 113.4 \text{ g} + 490\text{cc (0.9982 g/cc)} = 802.5 \text{ g}\]

Using the presented equations without modification:

\[M_{\text{Water-Displaced}} = (D) = (A) + (B) - (C) = 699.1 \text{ g} + 113.4 \text{ g} - 802.5 \text{ g} = 10.0 \text{ g}\]
\[\text{Specific Gravity} = (B) / (D) = 113.4 \text{ g} / 10.0 \text{ g} = 11.34\]

Now let's repeat the above measures, this time using distilled water with a temperature of 10°C and unit mass = 0.9997 g/cc. The following values would be expected:

\[(A) = 200.0 \text{ g} + 500\text{cc (0.9997 g/cc)} = 699.9 \text{ g}\]
\[(B) = 113.4 \text{ g}\]
\[(C) = 699.9 \text{ g} + 113.4 \text{ g} - 10\text{cc (0.9997 g/cc)} = 803.3 \text{ g}\]

Also, \[(C) = 200.0 \text{ g} + 113.4 \text{ g} + 490\text{cc (0.9997 g/cc)} = 803.3 \text{ g}\]

Using the presented equations without modification:

\[M_{\text{Water-Displaced}} = (D) = (A) + (B) - (C) = 699.9 \text{ g} + 113.4 \text{ g} - 803.3 \text{ g} = 10.0 \text{ g}\]
\[\text{Specific Gravity} = (B) / (D) = 113.4 \text{ g} / 10.0 \text{ g} = 11.34\]

As shown by the two examples above, as long as the water temperature remains constant, the calculated specific gravity is unaffected by the specific water temperature used during measurements.
Now let’s assume the flask measures (A) and (C) were made using distilled water at different temperatures, say 20°C ($\gamma_w=0.9982\text{g/cc}$) and 30°C ($\gamma_w=0.9957\text{g/cc}$), respectively. The following values would be expected:

\[
\begin{align*}
(A) &= 200.0 \text{ g} + 500\text{cc} (0.9982 \text{ g/cc}) = 699.1 \text{ g} \\
(B) &= 113.4 \text{ g} \\
(C) &= 200.0 \text{ g} + 113.4 \text{ g} + 490\text{cc} (0.9957 \text{ g/cc}) = 801.3 \text{ g}
\end{align*}
\]

Using the presented equations without modification:

\[
\begin{align*}
M_{\text{Water-Displaced}} &= (D) = (A) + (B) - (C) = 699.1 \text{ g} + 113.4 \text{ g} - 801.3 \text{ g} = 11.2 \text{ g} \\
\text{Specific Gravity} &= (B) / (D) = 113.4 \text{ g} / 11.2 \text{ g} = 10.13
\end{align*}
\]

As shown, the calculated specific gravity is significantly affected by the variable water temperatures used during measurements when no adjustments are made.

To account for variable water temperatures, assume the following reference measures were recorded for the mass of the filled flask at two different water temperatures:

\[
\begin{align*}
\text{Filled Mass at } 20^\circ\text{C} &= 699.1 \text{ g} \\
\text{Filled Mass at } 40^\circ\text{C} &= 696.1 \text{ g}
\end{align*}
\]

Figure 3 provides a plot of the reference data and the equation for the trend line.

**Figure 3: Example Flask Calibration Plot**

![Figure 3: Example Flask Calibration Plot](image)
Using the equation of the trend line, the mass of the filled flask (A) can be estimated at the 30°C water temperature used for measure (C) as:

\[(A) = 702.1 - 0.15(30) = 697.6 \text{ g}\]

Using this estimated value for (A) results in:

\[M \text{ Water-Displaced} = (D) = (A) + (B) - (C) = 697.6 \text{ g} + 113.4 \text{ g} - 801.3 \text{ g} = 9.7 \text{ g}\]

\[\text{Specific Gravity} = (B) / (D) = 113.4 \text{ g} / 9.7 \text{ g} = 11.69\]

As shown, the calculated specific gravity is still affected by the variable water temperatures used during measurements, even after adjustments are made.

The reason for the above error is the inherent assumption of a linear variation in the unit weight of water versus temperature within the measurement range of 20 – 40 °C, as indicated in Figure 3. In reality, the variation is nonlinear, as shown by the additional data in Figure 4. To better account for this non-linear variation, one must either use more mass-temperature data pairs, as shown in Figure 5, or reduce the range of temperatures used during calibration, as shown in Figure 6.

**Figure 4: Example Flask Calibration Plot with Additional Data Pairs**
Figure 5: Example Flask Calibration Plot with Additional Data Pairs

![Figure 5: Example Flask Calibration Plot with Additional Data Pairs](image)

\[ y = -0.0031x^2 + 0.0386x + 699.59 \]

Figure 6: Example Flask Calibration Plot with Limited Temperature Range

![Figure 6: Example Flask Calibration Plot with Limited Temperature Range](image)

\[ y = -0.15x + 702.35 \]
Using the equation of the curve in Figure 5, the mass of the filled flask (A) can be estimated at the 30°C water temperature used for measure (C) as:

\[(A) = 699.59 + 0.0386(30) - 0.0031(30)^2 = 698.0 \text{ g}\]

Using this revised estimate for (A) results in:

\[M_{\text{Water-Displaced}} = (D) = (A) + (B) - (C) = 698.0 \text{ g} + 113.4 \text{ g} - 801.3 \text{ g} = 10.1 \text{ g}\]

Specific Gravity = \(\frac{B}{D}\) = \(\frac{113.4 \text{ g}}{10.1 \text{ g}}\) = 11.23

Using the equation of the trend line in Figure 6, the mass of the filled flask (A) can be estimated at the 30°C water temperature used for measure (C) as:

\[(A) = 702.35 - 0.15(30) = 697.9 \text{ g}\]

Using this revised estimate for (A) results in:

\[M_{\text{Water-Displaced}} = (D) = (A) + (B) - (C) = 697.9 \text{ g} + 113.4 \text{ g} - 801.3 \text{ g} = 10.1 \text{ g}\]

Specific Gravity = \(\frac{B}{D}\) = \(\frac{113.4 \text{ g}}{10.0 \text{ g}}\) = 11.34

As indicated by the above, significantly better agreement can be achieved by using either more calibration data pairs or a tighter temperature range. Note that in all cases, the calculated filled mass (A) is shown to the nearest 0.1g, which is the assumed resolution of the actual scale measurements.
OBJECTIVE: To obtain data necessary for the classification of a soil sample.

EQUIPMENT: A set of sieves (3/8", Nos. 4, 10, 16, 40, 100, 200 and Pan), brushes for cleaning sieves, balance, sieve shaker, volumetric flask, vacuum pump, balance, thermometer, swabs, distilled water, warm water bath.

ASTM REF: D 421, D 422, D 854-91

TEXT REF: Sections 1.3, 1.4, 1.5, 1.6, 2.1, 2.2

Part I. MECHANICAL SIEVE ANALYSIS (Data Sheet 1)

1. Clean the pan and each sieve to be used with the cleaning brush. Record separately the mass of the pan and each clean sieve to the nearest 0.1 g. Stack the sieves together by placing the pan on the table and then nesting the sieve with the smallest opening size into the pan. Repeat this process with the remaining sieves making sure that after the stack is completed, the opening size of the sieves consistently increases from bottom to top. Record the combined mass of the pan and all sieves to the nearest 0.1 g.

2. Select a clean sample jar and record the jar number.

3. Obtain a representative 500 g sample of the air-dried soil. Break up any large soil clods by hand. Pulverize the soil using the soil processor.

4. Pour the pulverized soil over the top sieve of the stack and record the weight of the sieve stack + soil to the nearest 0.1 g. Place the entire stack into the sieve shaker, cover, and shake for not less than 5 minutes.

5. Carefully separate the top sieve from the stack, taking care not to lose any soil particles from this top sieve nor from the remaining sieves in the stack. Record the combined mass of the sieve with its retained soil to the nearest 0.1 g. Repeat this process with the remaining sieves and the pan.

6. Discard all soil particles retained on the 3/8", No. 4, and No. 10 sieves. Carefully clean these three sieves and return to the cabinet.

7. Carefully place all soil particles remaining on the Nos. 16, 40, 100, 200 and pan into the sample jar. Carefully clean all sieves of soil particles, placing dislodged particles into the sample jar.
Part II. SPECIFIC GRAVITY OF SOIL SOLIDS (Data Sheet 2)

1. Thoroughly clean and dry a volumetric flask having a capacity of at least 200 ml. Record the mass of the dry flask to the nearest 0.1g.

2. Fill the flask with distilled water at approximately room temperature (bottom of meniscus tangent to mark on neck). Dry the outside of the flask and blot any water from the inside of the neck above the meniscus using a long handled swab.

3. Record the mass of the filled flask + water to the nearest 0.1g and the water temperature to the nearest 0.1°C.

4. Pour off approximately 1/3 of the water in the flask and warm the remaining water approximately 10°C by immersing the flask in a warm water bath. Using distilled water at room temperature, bring the water level in the flask up to the reference mark as in Step 2 and record the mass of the filled flask + water to the nearest 0.1g. Agitate the flask to ensure a uniform water temperature and record the water temperature to the nearest 0.1°C.

5. Pour off sufficient distilled water so that the flask bulb is approximately 1/3 full. Record the mass of the partially filled flask to the nearest 0.1 g.

6. Place approximately 25 g of soil from the sample jar into the flask. Record the mass of the partially filled flask + soil to the nearest 0.1 g.

7. Add distilled water to wash down any soil particles clinging to the inside of the neck and to fill the flask to slightly above that required to cover the soil. Agitate the flask slightly to ensure that all soil particles are dispersed. Remove any entrapped air by applying a vacuum (not exceeding 100 mm Hg) to the flask for approximately 5 min. Check air removal by filling the bottle to the base of the neck and re-applying the vacuum.

8. Fill flask with distilled water (bottom of meniscus tangent to mark on neck). Dry the outside of the flask and blot any water from the inside of the neck above the meniscus using a long handled swab.

9. Record the mass of the completely filled flask + soil to the nearest 0.1g and the water temperature to the nearest 0.1°C.

10. Pour off all water and soil and thoroughly clean and dry the flask.
CALCULATIONS:

1. Using the data provided, complete Data Sheet 1, indicating the individual % retained, cumulative % retained, and % passing for each sieve.

2. Use these results from (1) to prepare a hand drawn plot of the grain-size distribution curve on the semi-log chart provided (% Passing vs Grain Size) for the four soil samples provided.

3. Use the flask calibration data provided to prepare a plot illustrating a linear relationship between the weight of the filled flask vs. water temperature. Use the collected data to develop an equation to predict mass of the filled flask at any intermediate water temperature.

4. Complete Data Sheet 2 calculations to determine the specific gravity of soil solids, \( G_S \).
CEEN 3160 - Geotechnical Engineering - Laboratory Session 1
Mechanical Sieve Analysis and Specific Gravity of Soil Solids

DATA SHEET 1 - MECHANICAL SIEVE ANALYSIS

<table>
<thead>
<tr>
<th>Sample Jar No.</th>
<th>Sieve Stack Mass, g</th>
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<thead>
<tr>
<th>Sieve Stack + Soil Mass, g</th>
<th>Pre-Sieve Soil Mass, g</th>
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<table>
<thead>
<tr>
<th>Post-Sieve Soil Mass, g</th>
<th>% Difference</th>
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<table>
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<tr>
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<th>Sieve Opening Size, mm</th>
<th>Sieve Mass, g</th>
<th>Sieve + Soil Mass, g</th>
<th>Individual Soil Mass Retained, g</th>
<th>Cumulative Soil Mass Retained, g</th>
<th>Cumulative % Retained</th>
<th>% Passing</th>
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<tbody>
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### DATA SHEET 2 - SPECIFIC GRAVITY OF SOIL SOLIDS

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<tr>
<td>Reference Volume of Flask, cc</td>
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<tr>
<td>Mass of Dry Flask, g</td>
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<tr>
<td>Mass of Filled Flask + Water at Initial Temperature, g</td>
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<td>Initial Water Temperature, °C</td>
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<thead>
<tr>
<th>Specific Gravity Test Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of Partially Filled Flask + Water, g</td>
</tr>
<tr>
<td>Mass of Partially Filled Flask + Water + Soil, g</td>
</tr>
<tr>
<td>Mass of Filled Flask + Water + Soil, g</td>
</tr>
<tr>
<td>Test Water Temperature, °C</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Calculations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of Filled Flask + Water at Test Temperature, g (^{(1)})</td>
</tr>
<tr>
<td>Mass of Soil, g</td>
</tr>
<tr>
<td>Mass of Water Displaced, g</td>
</tr>
<tr>
<td>Specific Gravity of Soil Solids</td>
</tr>
</tbody>
</table>

\(^{(1)}\) Mass of filled flask determined from equation derived from flask calibration data