SOIL COMPOSITION BASICS

Soil is comprised of 3 Major Components

1. Soil Particles (S)
2. Water (W)
3. Air (A) (if not saturated)

Typical Soil Matrix
SOIL COMPOSITION BASICS

SOIL MATRIX

3 PHASE DIAGRAM

Figure 2-1. from FHWA NHI-06-088.
Soil Composition

Main Variables:
- \( V \) = Volume
- \( W \) = Weight
- \( m \) = Mass

Subscripts:
- \( a \) = air
- \( v \) = voids
- \( w \) = water
- \( s \) = solids
- \( t \) = total (or blank)

Examples:
- \( V_s \) = Volume of Soil
- \( V = V_t \) = Total Volume

Figure 2-1. from FHWA NHI-06-088.
**KEY RELATIONSHIPS:**

**VOLUME**

*Porosity (n) (given in decimal or %):*

\[
n = \frac{\text{Volume of Voids} (V_v)}{\text{Total Volume} (V_t)} = \frac{e}{1+e}
\]

*Void Ratio (e) (given in decimal):*

\[
e = \frac{\text{Volume of Voids} (V_v)}{\text{Volume of Solids} (V_s)}
\]

*Relative Density (given in %):*

\[
D_r = \frac{e_{\text{max}} - e}{e_{\text{max}} - e_{\text{min}}}
\]

**Figure 3.1.** Das FGE (2005).
**KEY RELATIONSHIPS:**

**RELATIVE DENSITY ($D_r$)**

Used as an indication of the in-situ denseness or looseness.

\[
D_r = \frac{e_{\text{max}} - e}{e_{\text{max}} - e_{\text{min}}}
\]

**Where:**

- $D_r$ = Relative Density (%)
- $e$ = In-situ Void Ratio
- $e_{\text{max}}$ = Maximum Void Ratio
- $e_{\text{min}}$ = Minimum Void Ratio

**Table 3.3.** Das FGE (2005).

<table>
<thead>
<tr>
<th>Relative Density ($D_r$) (%)</th>
<th>Description of Soil Deposit</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 15</td>
<td>Very Loose</td>
</tr>
<tr>
<td>15 – 50</td>
<td>Loose</td>
</tr>
<tr>
<td>50 – 70</td>
<td>Medium</td>
</tr>
<tr>
<td>70 – 85</td>
<td>Dense</td>
</tr>
<tr>
<td>85 - 100</td>
<td>Very Dense</td>
</tr>
</tbody>
</table>
KEY RELATIONSHIPS: WEIGHT-VOLUME

Moisture Content (w):

\[ w = \frac{W_w}{W_s} \]

Degree of Saturation (S) (%):

\[ S = \frac{V_w}{V_v} \times 100\% \]

Moist Unit Weight (γ or γt) (i.e. the soil “as is”):

\[ \gamma = \gamma_t = \frac{\text{Weight (W)}}{\text{Volume (V)}} = \frac{W_w + W_s}{V} \]
Key Relationships: Weight-Volume

Dry Unit Weight ($\gamma_d$) (i.e. no water):

$$\gamma_d = \frac{W_s}{V} = \frac{\gamma}{1 + w}$$

Specific Gravity of Solids ($G_s$):

$$G_s = \frac{\gamma_s}{\gamma_w}$$

For Clays and Silts, $2.6 < G_s < 2.9$
For Quartz Sands: $G_s \approx 2.65$

Saturated Unit Weight ($\gamma_{sat}$) (i.e. no air):

$$\gamma_{sat} = \frac{W_s + W_w}{V} = \frac{(G_s + e)\gamma_w}{1 + e}$$
**KEY RELATIONSHIPS:**

**INDEX PROPERTIES SUMMARY & APPLICATIONS**

<table>
<thead>
<tr>
<th>Property</th>
<th>Symbol</th>
<th>Units</th>
<th>Obtained via:</th>
<th>Comments &amp; Direct Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Porosity</td>
<td>$n$</td>
<td>Dim</td>
<td>Weight-Volume Relationships</td>
<td>Defines relative volume of voids to total soil volume.</td>
</tr>
<tr>
<td>Void Ratio</td>
<td>$e$</td>
<td>Dim</td>
<td>Weight-Volume Relationships</td>
<td>Volume Change Calculations (Consolidation)</td>
</tr>
<tr>
<td>Moisture Content</td>
<td>$w$</td>
<td>Dim</td>
<td>Measurement (D2216)</td>
<td>Classification and in weight-volume relations.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Compaction.</td>
</tr>
<tr>
<td>Total Unit Weight</td>
<td>$\gamma_t$</td>
<td>F/L$^3$</td>
<td>Weight-Volume Relationships or Measurement</td>
<td>Classification, Stress Computations, Compaction.</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>$G_s$</td>
<td>Dim</td>
<td>By Measurement (D854)</td>
<td>Volume computations.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Compaction.</td>
</tr>
</tbody>
</table>
# Key Relationships:

**Index Properties Summary & Applications**

**Table 3.1.** Das FGE (2005).

<table>
<thead>
<tr>
<th>Moist unit weight ($\gamma$)</th>
<th>Dry unit weight ($\gamma_d$)</th>
<th>Saturated unit weight ($\gamma_{sat}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Given</strong></td>
<td><strong>Relationship</strong></td>
<td><strong>Given</strong></td>
</tr>
<tr>
<td>$w$, $G_s$, $e$</td>
<td>$\frac{(1 + w)G_s\gamma_w}{1 + e}$</td>
<td>$\gamma$, $w$</td>
</tr>
<tr>
<td>$S$, $G_s$, $e$</td>
<td>$\frac{(G_s + Se)\gamma_w}{1 + e}$</td>
<td>$G_s$, $e$</td>
</tr>
<tr>
<td>$w$, $G_s$, $S$</td>
<td>$\frac{(1 + w)G_s\gamma_w}{1 + \frac{wG_s}{S}}$</td>
<td>$G_s$, $n$</td>
</tr>
<tr>
<td>$w$, $G_s$, $n$</td>
<td>$G_s\gamma_w(1 - n)(1 + w)$</td>
<td>$G_s$, $w$, $S$</td>
</tr>
<tr>
<td>$S$, $G_s$, $n$</td>
<td>$G_s\gamma_w(1 - n) + nS\gamma_w$</td>
<td>$e$, $w$, $S$</td>
</tr>
<tr>
<td>$\gamma_{sat}$, $e$</td>
<td>$\frac{e\gamma_w}{1 + e}$</td>
<td>$\gamma_d$, $e$</td>
</tr>
<tr>
<td>$\gamma_{sat}$, $n$</td>
<td>$\gamma_{sat} - n\gamma_w$</td>
<td>$\gamma_d$, $n$</td>
</tr>
<tr>
<td>$\gamma_{sat}$, $G_s$</td>
<td>$\frac{(\gamma_{sat} - \gamma_w)G_s}{(G_s - 1)}$</td>
<td>$\gamma_d$, $S$</td>
</tr>
<tr>
<td>$\gamma_d$, $w_{sat}$</td>
<td>$\gamma_d(1 + w_{sat})$</td>
<td></td>
</tr>
</tbody>
</table>
KEY EQUATION OF SOIL COMPOSITION

\[ Se = \omega G_s \]

Where:

- \( S \) = Degree of Saturation
- \( e \) = Void Ratio
- \( \omega \) = Moisture Content
- \( G_s \) = Specific Gravity of Solids

Figure 3.1. Das FGE (2005).
### Typical Soil Properties for Soils in a Natural State

*(After Table 3.2, Das FGE (2005)).*

<table>
<thead>
<tr>
<th>Soil</th>
<th>Void Ratio ($e$)</th>
<th>$w$ (%)</th>
<th>$\gamma_d$ (lb/ft³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loose Uniform Sand</td>
<td>0.8</td>
<td>30</td>
<td>92</td>
</tr>
<tr>
<td>Dense Uniform Sand</td>
<td>0.45</td>
<td>16</td>
<td>115</td>
</tr>
<tr>
<td>Loose Angular Silty Sand</td>
<td>0.65</td>
<td>25</td>
<td>102</td>
</tr>
<tr>
<td>Dense Angular Silty Sand</td>
<td>0.4</td>
<td>15</td>
<td>121</td>
</tr>
<tr>
<td>Stiff Clay</td>
<td>0.6</td>
<td>21</td>
<td>108</td>
</tr>
<tr>
<td>Soft Clay</td>
<td>0.9 - 1.4</td>
<td>30-50</td>
<td>73-93</td>
</tr>
<tr>
<td>Soft Organic Clay</td>
<td>2.5 – 3.2</td>
<td>90-120</td>
<td>38-51</td>
</tr>
<tr>
<td>Till</td>
<td>0.3</td>
<td>10</td>
<td>134</td>
</tr>
</tbody>
</table>