Relative density of soil test- Formula, Procedure, and Calculation

What is relative density of soil?

The most important soil aggregate property is relative density. The relative density of soil is used to describe the relative compactness of cohesionless soil and is generally described as very loose, loose, medium, dense, and very dense.

Relative density is the proportion of the difference between void ratios of cohesionless soil in its loose state and natural state to difference between the void ratio of loose state and densest states of soil. In another word, relative density is a function of void ratio and is expressed as:

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Relative density of soil formula

\[ D = \frac{(e_{\text{max}} - e)}{(e_{\text{max}} - e_{\text{min}})} \]

Where,
\( e_{\text{max}} = \text{maximum void ratio} \)

\( e_{\text{min}} = \text{minimum void ratio} \)

\( e = \text{soil at some void ratio} \)

When soil is very loose, \( e = e_{\text{max}} \) and \( D=0 \).

When soil is very dense, \( e = e_{\text{min}} \) and \( D=100\% \)

If we plot graph of \( e_{\text{max}}/e_{\text{min}} \) against \( D=0 \) and \( D=1 \), a curve is obtained as:

Range of relative density of soil:
<table>
<thead>
<tr>
<th>Degree of compaction</th>
<th>Very loose</th>
<th>Loose</th>
<th>Medium</th>
<th>Dense</th>
<th>Very dense</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative density D%</td>
<td>&lt;15</td>
<td>15-35</td>
<td>35-65</td>
<td>65-85</td>
<td>&gt;85</td>
</tr>
<tr>
<td>Standard penetration resistance (SPT)</td>
<td>0-4</td>
<td>4-10</td>
<td>10-30</td>
<td>30-50</td>
<td>&gt;50</td>
</tr>
<tr>
<td>Angle of internal friction</td>
<td>25-32</td>
<td>27-35</td>
<td>30-40</td>
<td>35-45</td>
<td>&gt;45</td>
</tr>
<tr>
<td>Range of moist unit weights (γt) KN/m²</td>
<td>11-16</td>
<td>14.5-18.5</td>
<td>17.5-21</td>
<td>18.5-22.5</td>
<td>21-24</td>
</tr>
</tbody>
</table>

**Important of relative density of soil:**

The relative density of soil is important for following reasons.

1. For compaction of coarse-grained sand and helps us in deciding the earth, the filling is required or not.
2. For evaluating the safe bearing capacity of sandy soils.
3. It helps in determining the strength.
4. To find out the compressibility and permeability of the soil as the soil with higher unit weights proposes higher strength and lower compressibility and permeabilities.
5. It helps us in determining the maximum and minimum densities of soil.
6. It helps to determine the closeness of soil solid in
soil relative to the void ratio.

**Relative density of soil formula derivation:**

Void ratio cannot be measured directly so the convenient way of measuring relative density is in term of dry weight which can be measured easily.

We know,

- Void ratio = $e = \frac{V_v}{V_s}$
- Dry density = $Y_d = G Y_w \times \left(1 + e\right)$

Therefore,

$$e = \left(\frac{G Y_w}{Y_d}\right) - 1$$

If $Y_{max}$, $Y_{min}$, $Y_d$ are the maximum dry unit weight in densest state, minimum dry unit weight in loosest state and dry unit weight in natural conditions, relative density can be expressed as:

$$D_r = \frac{\left(\frac{G \times e_w}{e_{min}} - 1\right) - \left(\frac{G \times e_w}{e_d} - 1\right)}{\left(\frac{G \times e_w}{e_{min}} - 1\right) - \left(\frac{G \times e_w}{e_{max}} - 1\right)}$$

$$D_r = \frac{e_{max}}{e_d} \times \frac{e_d - e_{min}}{e_{max} - e_{min}}$$

Thus, this equation is used for determining relative density of a deposit in natural state.
Method for finding relative density of soil:

Apparatus required

1. Cushioned steel vibrating deck having rpm 3600 of size 75*75cm
2. Two no’s of Cylindrical metallic moulds
3. 10 mm thick surcharge base plate
4. Surcharge weights of 140gm/sq.cm.
5. Sieves
6. Calibration bars
7. Mixing pan
8. Weighing scale

Procedure

The test is conducted in two phases i.e. preparation of sample and calibration

Preparation of sample

The sample of the soil that is to be taken depends on the maximum size of the particle in the soil as shown in the table below.
<table>
<thead>
<tr>
<th>Maximum size of the soil particle (mm)</th>
<th>Mass of soil sample required (kg)</th>
<th>Pouring device to be used for determining minimum density</th>
<th>Size of mould to be used (cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>75</td>
<td>45</td>
<td>Shovel or extra-large scoop</td>
<td>15000</td>
</tr>
<tr>
<td>37.5</td>
<td>12</td>
<td>Scoop</td>
<td>3000</td>
</tr>
<tr>
<td>19</td>
<td>12</td>
<td>Scoop</td>
<td>3000</td>
</tr>
<tr>
<td>9.50</td>
<td>12</td>
<td>Pouring device (25 mm dia spout)</td>
<td>3000</td>
</tr>
<tr>
<td>4.75</td>
<td>12</td>
<td>Pouring (12mm dia spout)</td>
<td>3000</td>
</tr>
</tbody>
</table>

- The soil sample is dried thermostatically in a controlled electrical oven at a temperature of 105° to 110°C.
- The sample is cooled down in a desiccator.
- The soil lumps are segregated without breaking individual particles
- The soil sample is then sieved according to the size.

**Calibration of mould**
The inner diameter of the mould at different depth using a bore gauge is measured and the average is measured.
- The mould is kept on the flat surface.
- The volume of the mould is noted.
- The mould is filled with distilled water till overflow takes place.
- Then weight of the water filling the mould is noted.
- The density of the water is found out from the laboratory.
- The volume of the mould is calculated.

Determination of Minimum density

Note the weight of the mould and mass. Soil having the particle having a size less than 9.50mm must be loosely placed in the mould and oven-dried soil must be used.

The spout should be used for pouring the soil in steady stream by adjusting the spout in such a way that the height of the freefall of soil is 25mm.

Rotate the pouring device in a spiral motion from the outside to center while pouring the soil in order to form a layer of soil in systematic thickness without segregation.

Fill the mould about 25mm above the top, level with top by forming one pass with steel linear edge. Should be very careful while pouring and trimming process to avoid jarring. Again, measure the mould and soil weight and mass and note it.
For the soil having the particle greater than 9.50mm, it should be done by using large scoop keeping close to and just above the surface of soil for making the material slide rather than fall into previously placed soil.

The mould should not be filled more than 25mm above the top and also the surface of the soil must be leveled by the help of a steel linear edge so that projection of the larger particles above the mould is almost balanced the greater voids in beneath the top of mould.

Now, measure the mould and soil weight and note it.

**Calculation:**

Mass of dry soil = W1 - W = Ms (g)

Where, W = initial weight of mould,

W1 = final weight of mould with levelled soil.

Volume of mould = V (cc)

\[ \gamma_{\min} = \frac{Ms}{V} \text{ (g/cc)} \]

\[ e_{\max} = \left( \frac{Gw}{\gamma_{\min}} \right) - 1 \]
Determination of Maximum density

Top of the mould should be assembled with guide sleeve and should tighten the clamp assemblies in order to make the inner surface of the walls of mould and sleeve in line. Now, the third clamp is loosened and removal of guide sleeve is done also the measurement of empty mould and mass is recorded.

Mix the mould thoroughly with oven dry soil as said in above and fill the mould for the determination of minimum density that will be used in this process.

Now, attach the guide sleeves to the mould and place the surcharge base plate on the surface of soil. Use the hoist to lower surcharge weight on the base plate, if using 1500 cm$^3$ mould.

Fix the vibrator deck in the mould for assembly and vibration should be done at minimum amplitude for 8 minutes.

Remove the surcharge weight and guide sleeves from the mould and check the dial gauge reading on the two side of surcharge bas plate and read the average of record. At last, note the weight of mould with soil and its mass.

Calculation:

Mass of dry soil=$W_2-W=M_{ss}$ (g)
Where,

\[ W = \text{weight of empty mould}, \]

\[ W_2 = \text{weight of mould with soil at last}. \]

Volume of mould = \( V \) (cc)

\[ \gamma_{\text{max}} = \frac{M_{\text{ss}}}{V} \text{ (g/cc)} \]

\[ e_{\text{max}} = \left( \frac{G \gamma_w}{\gamma_{\text{max}}} \right) - 1 \]

**Determination of relative density of soil:**

Mould with dry soil should be weighted and the volume of mould and weight of dry soil is noted.

The natural density of the soil is given by

\[ e = \left( \frac{G \gamma_w}{\gamma_d} \right) - 1 \]

since we know \( e_{\text{max}} \), \( e_{\text{min}} \) the relative density of the soil can be calculated as
Relative density=$\frac{(e_{\text{max}}-e)}{(e_{\text{max}}-e_{\text{min}})} \times 100$

More the relative density of the soil, more the soil mass will be denser.

**Precaution to be remembered:**

1. The sample should be completely oven-dried.
2. The reading should be taken very carefully.
3. Should be very attending while leveling the surface.
4. While pouring the soil, do it attentively without spreading the soil outside.
5. Sample of the soil should be taken correct one by checking the table according to particle size.

I hope this article remains helpful for you.

**Happy Learning – Civil Concept**

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