When trying to figure out Borrow Pit Problems you need to understand a few things.

1. Water can be added or removed from soil
2. The MASS of the SOLIDS CAN NOT be changed
3. Need to know phase relationships in soil…which I will show you next

**Phase relationship in Soil**

This represents the soil that you take from a borrow pit. It is made up of AIR, WATER, and SOLIDS.

So if you separated the soil into its components it would look like this. It is referred to as a Soil Phase Diagram.


- **Volume**
  - $V_a = \text{Volume Air}$
  - $V_w = \text{Volume Water}$
  - $V_s = \text{Volume Solid}$

- **Mass**
  - $M_a = 0$
  - $M_w = \text{Mass Water}$
  - $M_s = \text{Mass Solid}$

$V_t = \text{Volume Total} = V_a + V_w + V_s$

$M_t = \text{Mass Total} = M_w + M_s$
**EARTHWORK CONSTRUCTION AND LAYOUT**
***BORROW PIT VOLUMES***

**Basic Terms/Formulas to know – Soil Phase relationship**

Specific Gravity = the density of the solids divided by the density of Water

Moisture Content = Mass of Water divided by the Mass of Solids

Void Ratio = Volume of Voids divided by the Volume of Solids

Porosity = Volume of Voids divided by the Total Volume,

Higher porosity = higher permeability

| Density of Water $\gamma_{\text{water}} = M_w/V_w$ | Specific Gravity $G_s = \gamma_{\text{solids}}/\gamma_{\text{water}}$ |
| English Units = 62.42 pounds per CF (pcf) | $= M_s/(V_s \cdot \gamma_{\text{water}})$ |
| SI Units = 1,000 g/liter = 1,000 kg/m$^3$ |

| Moisture Content (w) = $M_w/M_s$ | Porosity (n) = $V_v/V_t$ |
| $V_v = \text{Volume of Voids} = V_w + V_a$ |
| $V_t = \text{Total Volume} = V_s + V_w + V_a$ |

| Degree of Saturation (S) = $V_w/V_v$ | Void Ratio (e) = $V_v/V_s$ |
| $V_w = \text{Volume of Water}$ |
| $V_v = \text{Total Volume of Voids}$ |
| $V_s = \text{Volume of Solid}$ |

| Total or Wet Density of Soil ($\gamma_{\text{wet}}$) = $M/V$ | Dry Density of Soil ($\gamma_{\text{dry}}$) = $M_s/V$ |
| $M = M_w + M_s$ |
| $V = V_w + V_s + V_a$ |
| $V = V_w + V_s + V_a$ |

| Density of Solids = $M_s/V_s$ | |

**Relationships to know**

| Dry Density of Soil ($\gamma_{\text{dry}}$) = $\gamma_{\text{wet}}/(1+w)$ | Specific Gravity = $S \cdot e = G_s \cdot w$ |
| $\gamma_{\text{dry}} = (\gamma_{\text{water}} \cdot G_s)/(1+(w/S)\cdot G_s)$ |
| $\gamma_{\text{dry}} = (\gamma_{\text{water}} \cdot G_s)/(1+e)$ |

| Total or Wet Density of Soil ($\gamma_{\text{wet}}$) = $\gamma_{\text{wet}} = ((\gamma_{\text{water}} \cdot G_s(1+w))/(1+e)$ | Porosity (n) = $e/(1+e)$ |

| Void Ratio (e) = $n/(1-n)$ | |
Load and Shrinkage Factors

**BORROW PIT VOLUMES**

1.0 BCY

\[ V_B \]

1.25 LCY

\[ V_L = V_B (1 + \text{Swell}) \]

.90 CCY

\[ V_C = V_B (1 - \text{Shrinkage}) \]

\[ V_C = V_B \times \text{SWELL FACTOR (or Load factor)} \]

\[ V_L = V_B \times \text{SHRINKAGE FACTOR} \]

\[ V_C = V_B \times \text{SHRINKAGE FACTOR} \]

DL = Dry Loose Unit Weight (\( \gamma_{DL} \))

DC = Dry Compacted Unit Weight (\( \gamma_{DC} \))

DB = Dry Bank Unit Weight (\( \gamma_{DB} \))

\[ \text{Swell} = \frac{\text{DB} - \text{DL}}{\text{DL}} = \frac{\gamma_{DB} - \gamma_{DL}}{\gamma_{DL}} \]

\[ \text{Shrinkage} = \frac{\text{DC} - \text{DB}}{\text{DL}} \]

\[ \text{Swell} \% = \frac{\text{DB} - \text{DL}}{\text{DL}} \times 100 \]

\[ \text{Shrinkage} \% = \frac{\text{DC} - \text{DB}}{\text{DL}} \times 100 \]

**Important Volume Change Relationships:**

In excavation, 1+Swell is called “Swell Factor”

\[ V_L = V_C \frac{1 + \text{Swell}}{1 - \text{Shrinkage}} \]

\[ V_B = \frac{V_C}{1 - \text{Shrinkage}} \]
Another important concept to know is the Borrow Pit Method in order to calculate the volume of the borrow pit. It is also called the unit-area method.

The Volume is determined based on a predetermined grid pattern. The site is divided into equal squares of sides 20, 50, or a 100 ft. Elevations are then measured at the corners of the grid, which are given titles that correspond to the coordinates of the corner in the grid, e.g., 3-D, 4-A, ...

Then for simplicity of calculations, the points are connected to the corners.

Volume by borrow-pit method

\[ V = \sum (h_{i,j}) \frac{A}{4 \times 27} \]

Where:

- \( h_{i,j} \) = the corner height in row I, column j and \( n \) = the number of full squares to which that height is common.
Question #1: After surveying a borrow pit, the surveyor produced the following borrow pit grid below. If you consider 0.0, the elevation that you can cut to. What is the total cut volume (cy) available?

![Borrow Pit Grid]

- **A**: 2.4 feet
- **B**: 3.5 feet
- **C**: 2.8 feet
- **D**: 3.3 feet
- **E**: 2.1 feet
- **F**: 3.1 feet
- **G**: 2.4 feet
- **H**: 20 feet
- **I**: 20 feet
- **J**: 20 feet
- **K**: 20 feet
- **L**: 20 feet
- **M**: 20 feet

a. 250 cy  
 b. 232 cy  
 c. 201 cy  
 d. 343 cy

Question #2: 120cy of bank soil is excavated and stockpiled before being trucked and then compacted. The soil has a swell of 25% and a shrinkage of 15%. What is the final volume of the compacted soil?

- **a**: 68 cy  
- **b**: 102 cy  
- **c**: 150 cy  
- **d**: 128 cy
Question #3. A 10 ft wide, 500 ft long, 2 ft thick road is being constructed. The soil density after compaction was found to be 112.1 pcf at an optimum moisture content of 10.5%. The soil from the borrow pit has a total density of 105pcf and a moisture content of 8.5%.

What is the total volume(cf) of soil that needs to be hauled from the borrow pit?

a. 45,395 cf  
b. 12,856 cf  
c. 11,584 cf  
d. 5,260 cf

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Question #4. Soil borings at a proposed Borrow Pit indicate that the soil is primarily a sandy clay. Cores taken of the soil in the pit indicates an average dry density of 88pcf at a moisture content of 22%.

The volume of the contained soil in the fill when constructed is 20,000 cy.

Based on the average results of a Standard Proctor compaction test the soil will be compacted to a density of 95 pcf at a moisture content of 25%.

Dump trucks with a capacity of 15cy will be used to transport the soil from the borrow pit to the proposed road bed.

1. Assuming that the soil in the dump truck has a dry density of 69 pcf at a moisture content of 22% estimate the number of loads that will be necessary.

2. Compute the volume of the hole at the borrow pit after the soil is removed

a. 68 trucks  a. 36,568 cy  
b. 12,856 trucks b. 21,591 cy  
c. 658 trucks  c. 24,564 cy  
d. 1,836 trucks  d. 19,836 cy
**EARTHWORK CONSTRUCTION AND LAYOUT**

**BORROW PIT VOLUMES**

Answer #1:

Step 1: Setup a chart to get the volume under each square; Then sum up all the volumes.

<table>
<thead>
<tr>
<th>Grid</th>
<th>Area (sf)</th>
<th>Average depth (ft)</th>
<th>Volume (cf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>400</td>
<td>$(2.4+3.5+2.8+3.3)/4 = 3.0$</td>
<td>1200</td>
</tr>
<tr>
<td>B</td>
<td>200</td>
<td>$(3.5+3.3+2.1)/3 = 2.97$</td>
<td>594</td>
</tr>
<tr>
<td>C</td>
<td>400</td>
<td>$(2.8+3.3+3.2+3.1)/4 = 3.1$</td>
<td>1240</td>
</tr>
<tr>
<td>D</td>
<td>400</td>
<td>$(3.3+2.1+3.1+2.4)/4 = 2.7$</td>
<td>1080</td>
</tr>
<tr>
<td>E</td>
<td>400</td>
<td>$(2.1+1.8+2.4+1.6)/4 = 1.98$</td>
<td>792</td>
</tr>
<tr>
<td>F</td>
<td>200</td>
<td>$(3.1+2.4+2.8)/3 = 2.77$</td>
<td>554</td>
</tr>
<tr>
<td>G</td>
<td>400</td>
<td>$(2.4+2.8+1.6+1.3)/4 = 2.0$</td>
<td>800</td>
</tr>
</tbody>
</table>

$V_{total} = 6260$cf

Step 2: Find Volume in Cubic yards

$\Rightarrow V_{total} = 6260 \text{ cf} / (27\text{cf/cy}) = 232 \text{ cy}$
Answer #2:

The shrinkage factor is taken with respect to the bank volume condition.
- so, $V_{\text{compacted fill}} = (1-.15)(120\text{cy}) = 102\text{cy}$

For your information the swell is taken with respect to the bank volume condition too.
- so, $V_{\text{stockpile}} = (1+.25)(120\text{cy}) = 150\text{cy}$
Answer #3:

Step 1: Find the mass of solids ($M_s$) required for the controlled fill:
- Volume of Compacted soil = (500ft)(10ft)(2ft) = 10,000 cf
- dry density of the compacted soil is given = 112.1 pcf
- using Dry Density of Soil ($\gamma_{dry}$) = $M_s/V = 112.1$pcf = $M_s/10,000$cf, so $M_s = 1,121,000$ lbs

Step 2: Find total volume of soil that needs to be hauled from the borrow pit:
- using Moisture Content ($w$) = $M_w/M_s$, .085 = $M_w/1,121,000$lbs = $M_w = 95,285$ lbs
- Total Mass at borrow pit = 1,121,000lbs + 95,285lbs = 1,216,285 lbs
- using Total or Wet Density of Soil ($\gamma_{wet}$) = $M/V = 105$pcf = 1,216,285 lbs/V, $V = 11,583.7$ cf

FYI ----to figure out the Mass of water in compacted soil
- Moisture content in compacted soil given at 10.5% = .105
- using Moisture Content ($w$) = $M_w/M_s$, .105 = $M_w/1,121,000$lbs = $M_w = 117,705$ lbs
Answer #4:

Step 1: Find the mass of solids ($M_s$) required for the controlled fill:
- Volume of Compacted soil = 20,000 cy * 27cf/cy = 540,000 cf
- dry density of the compacted soil is given = 95 pcf
- using Dry Density of Soil ($\gamma_{dry}$) = $M_s/V = 95$ pcf = $M_s/540,000$ cf, so $M_s = 51,300,000$ lbs

Step 2: Find the # of Trucks required to haul Soil.
- $M_s = 51,300,000$ lbs, and the dry density of the soil to be hauled is 69 pcf
- so, $51,300,000$ lbs/69pcf = 743,478 cf / 27cf/cy = 27,536 cy
- so the number of trucks needed is 27,536cy/15cy/truck = 1836 trucks

Step 3: Find the Volume at the borrow pit
- dry density of the compacted soil is given = 88 pcf
- ($\gamma_{dry}$) = $M_s/V$, $88pcf = 51,300,000$ lbs/V, V = $51,300,000lbs/88pcf = 582,955cf$
- convert to cy, $582,955cf/(27cf/cy) = 21,591cy$