Moisture-Density Documentation of Calculations

This document details the calculations employed by the software to produce moisture-density test results. Units are omitted from the following sections for simplification: unless noted, all dimensions are in centimeters, weights are in grams and all calculations involving densities assume grams/cubic centimeter.

1 Test Point Calculations

1.1 Wet Density

$$\gamma_m = \frac{W_{wm} - W_m}{V_m} \tag{1.1}$$

Where:

γ_m = the soil wet density
W_{wm} = the weight of the compacted specimen and the mold
W_m = the weight of the mold
V_m = the volume of the mold

For the California Test Method 216 the equation used is:

$$\gamma_m = \frac{W_{wss}}{TR * 2.54 * A_m} \tag{1.2}$$

Where:

A_m = area of mold, in cms^2. This is a constant value of 41.5335 $cms.^2$.
TR = the tamper reading, *in inches*
W_{ws} = the wet weight of the soil

1.2 Moisture Content

Moisture content is calculated with the following formula:

$$MC = 100\% * \frac{W_{wt} - W_{dt}}{W_{dt} - W_t} \tag{1.3}$$

Where:

MC = the moisture content
W_{wt} = the weight of the moisture specimen with tare
W_{dt} = the weight of the dried specimen with tare
W_t = the weight of the container

1.2.1 Moisture Content Averaging

If the option to average two moisture values is chosen then the two moistures are determined and then averaged. If the weights for the second moisture determination are zero, then only the first moisture value is used.

1.3 Dry Density

$$\gamma_d = \frac{\gamma_m}{1 + \frac{WC}{100\%}} \tag{1.4}$$

Where:

γ_d = the soil dry density

2 Curve Equation

Internally, moisture-density curves are modeled using either a cubic spline or a third order regression curve. For either method, the optimum moisture content is located as being the highest point on the curve: this is normally the zero-point of the first derivative of the curve (for cubic spline curves the first derivitive of every curve knot is considered to create a set of local maxima, which is then searched to find the highest local maximum point). For curves that do not change slope (i.e. continually increase or decrease in moisture content), the software considers the test point with the highest moisture content to be the optimum moisture content point. (This does not strictly conform to the ASTM/AASHTO test specifications, both of which require test points on either side of the optimum moisture content.)

The maximum dry density is found by evaluating the curve model using the calculated optimum moisture result.

3 Oversize (Rock) Correction

3.1 ASTM D4718 Oversize Percentage

Past Geosystem Proctor implementations required that you manually calculate and enter the oversize moisture, then retrieved the oversize percentage from your sieve test results (or you could manually enter it). This option still exists, but for better compatibility with D4718, the software can be configured to calculate both values via the "coarse/fine dry mass ratio" procedure covered in §5.1.1- §5.1.3 of D4718-15:

$$MC_o = 100\% * \frac{W_{wto} - W_{dto}}{W_{dto} - W_{to}} \tag{1.5}$$

Where:

$\mathrm{MC_o}$ = the oversize moisture content

$\mathrm{W_{wto}}$ = the weight of the oversize moisture specimen with tare

$\mathrm{W_{dto}}$ = the weight of the dried oversize specimen with tare

$\mathrm{W_{to}}$ = the weight of the oversize moisture content container

$$MC_f = 100\% * \frac{W_{wtf} - W_{dtf}}{W_{dtf} - W_{tf}} \tag{1.6}$$

Where:

MC_f = the fines moisture content
W_{wtf} = the weight of the fines moisture specimen with tare
W_{dtf} = the weight of the dried fines specimen with tare
W_{tf} = the weight of the fines moisture content container

$$M_{do} = \frac{M_{mo}}{1 + \frac{MC_o}{100}} \tag{1.7}$$

Where:

M_{do} = dry mass of the oversize material
M_{mo} = moist mass of the oversize material (user-entered)

$$M_{df} = \frac{M_{mf}}{1 + \frac{MC_f}{100}} \tag{1.8}$$

Where:

M_{df} = dry mass of the fines fraction
M_{mf} = moist mass of the fines fraction (user-entered)

$$P_o = 100 * \frac{M_{do}}{M_{df} + M_{do}} \tag{1.9}$$

Where:

P_o = the percent of oversize material

3.2 ASTM D4718 Density Correction

Dry densities are corrected for removed oversize material by the ASTM D4718 method using the following equation:

$$\gamma_{dc} = \frac{\gamma_{df} * \gamma_{do}}{\frac{P_o}{100} * (\gamma_{df} - \gamma_{do}) + \gamma_{do}} \tag{1.10}$$

Where:

γ_{dc} = the corrected dry density
γ_{df} = the uncorrected dry density
γ_{do} = the bulk unit weight of the soil's oversize fraction (usually determined using the SSD specific gravity of the oversize material).
P_o = the percent of oversize material (user-entered or calculated per the coarse/fines mass ratio)

3.3 ASTM D4718 Moisture Correction

Moisture contents are corrected for removed oversize material by the ASTM D4718 method using the following equation:

$$MC_c = \frac{P_o}{100} * MC_o + (1 - \frac{P_o}{100}) * MC \tag{1.11}$$

Where:

MC_c = the corrected moisture content, in percent

MC = the uncorrected moisture content, in percent

MC_o = the moisture content of the oversize material, in percent (either user-entered, or calculated)

P_o = the percent of oversize material (user-entered or calculated)

3.4 AASHTO T 224 Density Correction

The current AASHTO T 224 correction specification (2010) is performed identically to the correction specified by ASTM D4718.

3.5 CT 216 Density Correction

Wet densities are corrected for removed oversize material by the California Test 216 method using the following equation:

$$\gamma_{dc} = \frac{1}{\frac{1 - \frac{P_o}{100}}{\gamma_{df}} + \frac{\frac{P_o}{100}}{Y * \gamma_{do}}} \tag{1.12}$$

Where:

γ_{dc} = the corrected dry density

γ_{df} = the uncorrected dry density

γ_{do} = the bulk unit weight of the soil's oversize fraction (usually determined using the SSD specific gravity of the oversize material).

Y = the coefficient of the + 19 mm. aggregate, as listed in § I of the standard

P_o = the percent of oversize material

⇒ The 2000 version of the CT 216 standard repeats an error present in earlier versions of the standard, in that it incorrectly uses $Y*\gamma_{df}$ instead of $Y*\gamma_{do}$ in the second part of the equation's denominator. Our attempts to contact the committee head responsible for the standard have been ignored.

4 Zero Air Voids Curve

The following equation is utilized when plotting a zero air voids (ZAV) curve:

$$\gamma_d = \frac{ZGS}{\frac{MC}{100} * ZGS + 1} \tag{1.13}$$

Where:

MC = the moisture content point (in percent) corresponding to a given point on the ZAV curve

γ_{d} = the density corresponding to MC on the ZAV curve

ZGS = the user's chosen ZAV curve specific gravity

