HIGHWAY RESEARCH BOARD

Bulletin 319

Factors Influencing Compaction Test Results

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THE HUMPHRES METHOD FOR GRANULAR SOILS

The Humphres method (102) consists of establishing the maximum obtainable (that is, with current construction equipment) unit weight of a granular material for different percentages of fine aggregate (portion passing the No. 4 sieve). The method is intended for use with ballast, base course, and surfacing materials with specified gradations. The maximum unit weight curve developed, which relates maximum unit weight and percentage of fine aggregate, can be used by the compaction inspector to determine the proper "control" unit weight of material whose gradation fluctuates between fairly wide specification limits. To determine the proper "control" value, the inspector need only determine the percentage of fine aggregate in his sample and refer to the maximum unit weight curve for the material sampled.

To establish the maximum unit weight curve, for one material, the following 12 steps are necessary:

1. Oven-dry a representative sample of the granular material at 110 to 120 F.
2. Divide a sample into two parts: coarse aggregate, retained on No. 4 sieve; fine aggregate, passing No. 4 sieve.
3. Determine the maximum compacted dry unit weight of each part by using a combination of vibratory and static loading. (The vibratory spring load compactor unit is described in detail in HRB Bull. 159 (1957). Other methods of vibratory compaction (120) that yield comparable unit weights can also be used in determining maximum unit weight.) The maximum compacted dry unit weight of the fine aggregate is represented by γ_f^c ($\gamma_{fine}^{compacted}$) and the maximum compacted dry unit weight of the coarse aggregate by γ_c^c ($\gamma_{coarse}^{compacted}$).
4. Determine the loose dry unit weight of each part (γ_f^l; γ_c^l) by gently pouring each through an appropriately-sized funnel into a container of known volume, weighing, and calculating dry unit weight. The size of sample, pouring device, and volume of measure based on maximum particle size given in Table 27 may be used (121).
5. Determine the solid unit weight of each part (γ_f^s; γ_c^s). First determine the specific gravity of each (for fine aggregate, test ASTM D 854-52 or AASHO T 100-54; for coarse aggregate, apparent specific gravity ASTM C 124-42 or AASHO T 85-45), then multiply each specific gravity by 62.4.

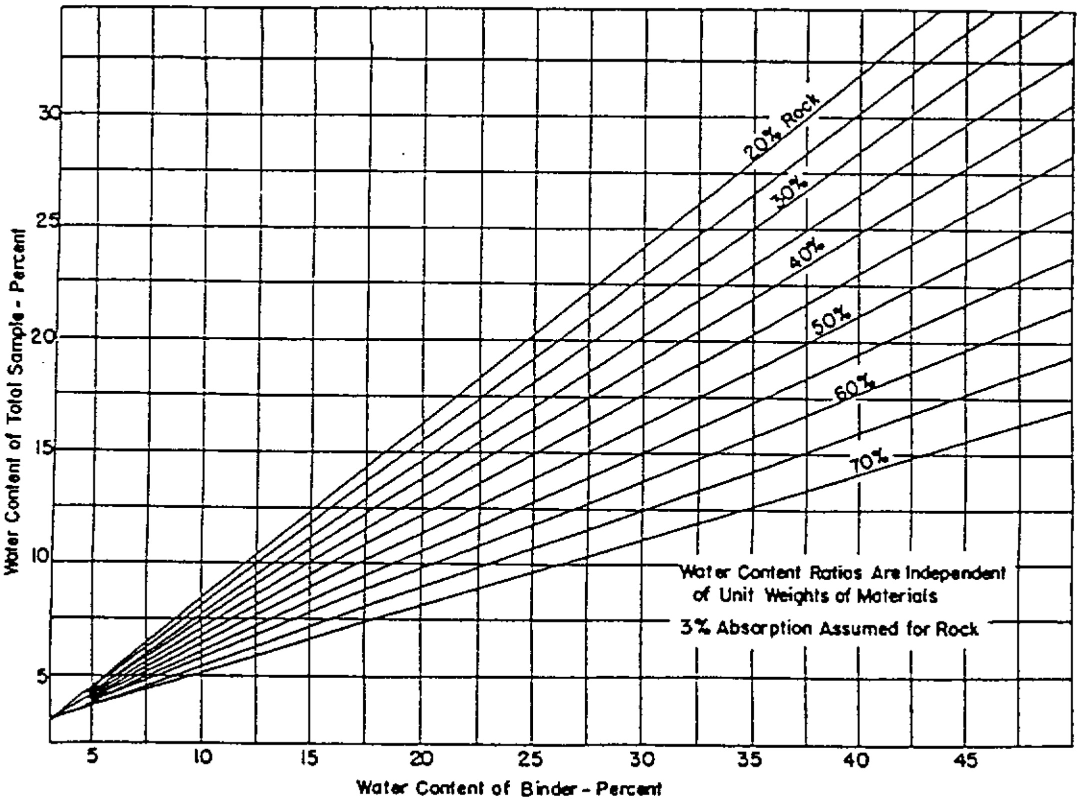

Figure 82. Chart for determining relation between water content of portion passing ¼-in. sieve and total sample (26).

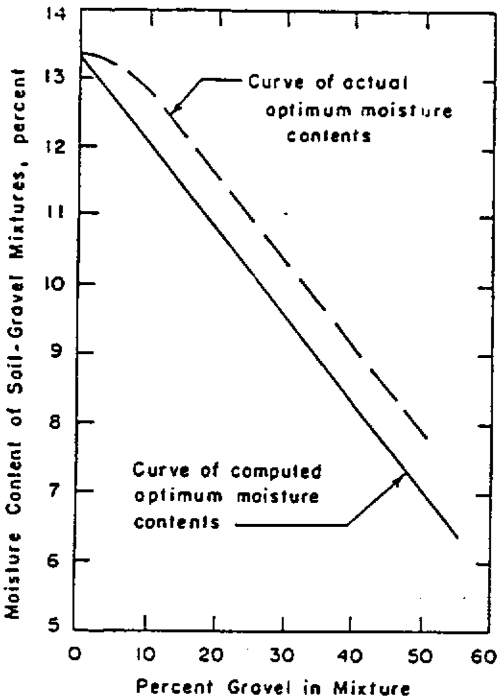

Figure 83. Effect of coarse aggregate (gravel) content on optimum moisture content (28).

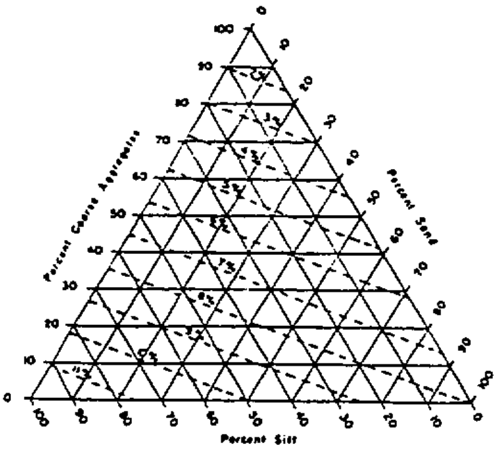

Figure 84. Triangular chart showing optimum moisture content of total material for various proportions of coarse aggregate, sand, and silt (58).

TABLE 27

Max. Size of Soil Particle (in.)	Size of Sample (lb)	Pouring Device	Volume of Measure (cu ft)
3	150	Shovel	1.0
1½	150	Scoop	0.5
¾	100	1½-in. spout	0.5
⅜	25	1-in. spout	0.1
¼	25	½-in. spout	0.1

6. Plot the three unit weights (loose, compacted, and solid) for the coarse aggregate and the fine aggregate on a chart (as in Fig. 85) relating unit weight to percentage of fine aggregate. The three unit weights for coarse aggregate are plotted on the left side of the chart on the zero percent vertical line. The three unit weights for the fine aggregate are plotted on the right side, on the 100 percent vertical line.

The data used in the example in Figure 85 are, as follows:

Coarse aggregate:

$\gamma_c{}^s = (2.73)(62.4) = 170.3$ pcf

$\gamma_c{}^c = 107$ pcf

$\gamma_c{}^l = 89$ pcf

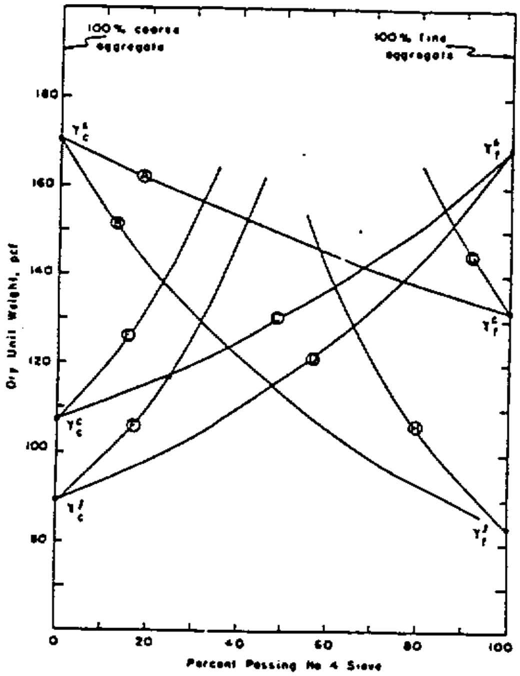

Figure 85. Sample theoretical curves for various combinations of coarse and fine aggregate and for solid, compacted, and loose unit weights (102).

Fine aggregate:

$$\gamma_f^s = (2.71)(62.4) = 169.0 \text{ pcf}$$
$$\gamma_f^c = 132 \text{ pcf}$$
$$\gamma_f^l = 84 \text{ pcf}$$

7. Determine sufficient points to plot each of the curves A, B, C, ...H, as shown in Figure 85, with the aid of the nomographs in Figures 86 and 87 or by using the following equations, and plot the curves. These curves will be used as guides in establishing the maximum unit weight curve. The equations for each curve, A through H, are as follows:

Curve A (theoretical unit weight formula)

$$\gamma_p = \frac{\gamma_c^s \ \gamma_f^s}{\left(\frac{p}{100}\right)\gamma_c^s + \left(\frac{1-p}{100}\right)\gamma_f^c}$$

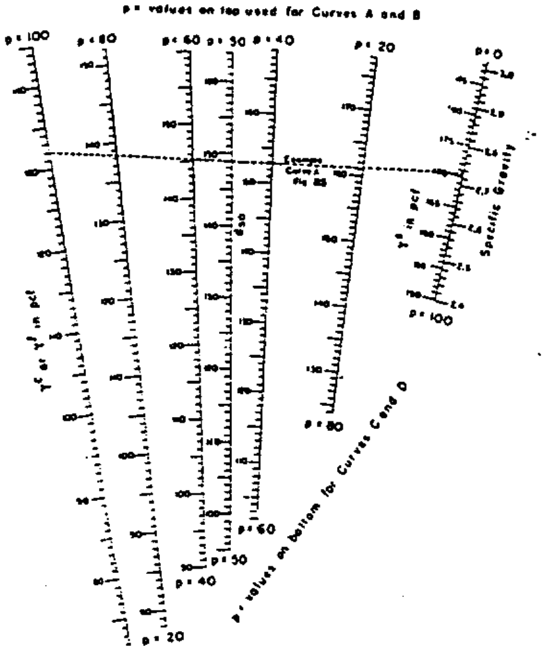

Figure 86. Nomograph for determining unit weight values (γ_p) for curve A, B, C, or D for different values of p, the percentage passing the No. 4 sieve (102).

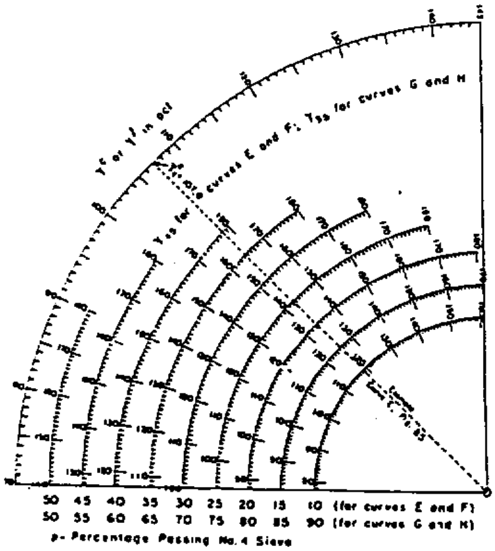

Figure 87. Nomograph for determining unit weight values (γ_p) for curve E, F, G, or H for different values of p, the percentage passing the No. 4 sieve (102).

in which

p = percentage of fine aggregate;

γ_p = unit weight of combination with p percent fine aggregate, pcf;

γ_c^s = solid unit weight of coarse aggregate, pcf; and

γ_f^c = compacted unit weight of fine aggregate, pcf.

For example, the ordinate (γ_p) on curve A (Fig. 85) for a given mixture (with 20 percent fine aggregate, $\gamma_c^s = 170$ pcf and $\gamma_f^c = 132$ pcf) is

$$\gamma_{20} = \frac{(170)\,(132)}{\left(\frac{20}{100}\right)(170) + \left(1 - \frac{20}{100}\right)(132)} = \frac{(170)\,(132)}{(0.2)\,(170) + (0.8)\,(132)}$$

$$\gamma_{20} = 160.8 \text{ pcf}$$

Curve B:

$$\gamma_p = \frac{\gamma_c^s\ \gamma_f^l}{\left(\frac{p}{100}\right)(\gamma_c^s) + \left(1 - \frac{p}{100}\right)\gamma_f^l}$$

Curve C:

$$\gamma_p = \frac{\gamma_c^c\ \gamma_f^s}{\left(\frac{p}{100}\right)\left(\gamma_c^c\right) + \left(1 - \frac{p}{100}\right)\left(\gamma_f^s\right)}$$

Curve D:

$$\gamma_p = \frac{\gamma_c^l\ \gamma_f^s}{\left(\frac{p}{100}\right)\left(\gamma_c^l\right) + \left(1 - \frac{p}{100}\right)\left(\gamma_f^s\right)}$$

Curve E:

$$\gamma_p = \frac{\gamma_c^c}{1 - \frac{p}{100}}$$

Curve F:

$$\gamma_p = \frac{\gamma_c^l}{1 - \frac{p}{100}}$$

Curve G:

$$\gamma_p = \frac{\gamma_f^c}{\frac{p}{100}}$$

Curve H:

$$\gamma_p = \frac{\gamma_f^l}{\frac{p}{100}}$$

8. Label intersections of the curves (as shown in Figure 88) as follows: Curves B and E intersect at point a, G and D at b, A and D at c, B and D at d, A and F at e, and C and H at f.

9. Calculate the coordinates of point r (Fig. 88) between points γ_c^c and e as shown in the following equation and plot point r.

$$p_r = 0.5\, p_e$$

$$\gamma_r = \frac{\gamma_c^c\ \gamma_e}{0.5\gamma_c^c + 0.5\gamma_e}$$

in which

p_r = percentage of fine aggregate in mixture represented by point r;
p_e = percentage of fine aggregate in mixture represented by point e;
γ_r = unit weight of mixture represented by point r, pcf;
γ_e = unit weight of mixture represented by point e, pcf; and
$\gamma_c{}^c$ = compacted unit weight of coarse aggregate, pcf.

If, for example, p_e = 41.5 percent γ_e = 152.0 pcf, and $\gamma_c{}^c$ = 107.0 pcf,

$$p_r = -(0.5)(41.5) = 20.75 \text{ percent}$$

$$\gamma_r = \frac{(107)(152)}{(0.5)(107) + (0.5)(152)} = \frac{16270}{53.7 + 76} = 125.6 \text{ pcf}$$

10. Draw a smooth curve from $\gamma_c{}^c$ through point r to e; label intersection with curve B, point o.

11. Draw straight lines ab and de and label their intersection point m; draw straight lines ac and df and label their intersection n.

12. Draw the maximum unit weight curve through $\gamma_c{}^c$, r, o, m, n, and $\gamma_f{}^c$ as shown in Figure 89.

This maximum unit weight curve shows how the maximum obtainable dry unit weight of a particular material varies with the percentage of fine aggregate in the mixture. In Figure 89 it can be seen that for the sample material, the maximum unit weight increases rapidly as the fine aggregate content increases from 0 to about 35

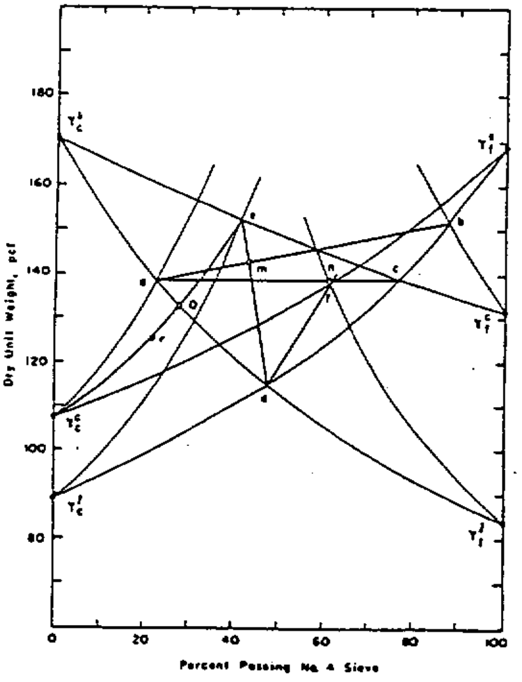

Figure 88. Determination of points (r, o, m, n) for maximum unit weight curve for mixtures of sample materials (102).

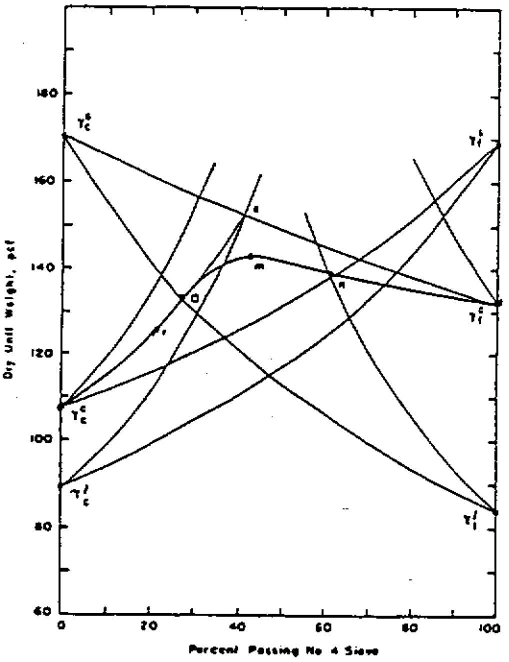

Figure 89. Derived maximum unit weight curve for mixtures of sample materials (102).

percent of the mixture. For the higher percentages of fine aggregate, fluctuations in gradation would have less effect on maximum unit weight.

The Humphres method is complex and lengthy, but has proved very useful in the State of Washington.

If several points on the Humphres maximum dry unit weight curve could be obtained by simply compacting several mixtures of coarse and fine aggregate, much time could be saved. James and Larew (133) investigated this possibility. They performed a series of impact compaction tests on two materials: a crushed limestone and a natural gravel. For each material, they first established the Humphres maximum unit weight curve. Then, they determined the compaction effort required to compact the fine aggregate (100 percent passing the No. 4 sieve) to the same unit weight as obtained in the Humphres method. Finally, they determined the maximum unit weight for each of several mixtures. The resulting maximum unit weight curve for the crushed limestone matched the Humphres curve very closely; the curve for the natural gravel generally fell below the Humphres curve. James and Larew concluded that the Humphres maximum unit weight curve represents a single level of compaction effort for some soil materials. It was also evident that a simple impact compaction test could not be used to duplicate the Humphres method for all soil-aggregate mixtures.