

CRD-C 653-95

**Standard Test Method for Determination of  
Moisture-Density Relation of Soils\***

**1. Scope.**

This method is used for determining in the laboratory the relation between the moisture content of a soil and its density (oven-dried mass per ft<sup>3</sup>) when the soil is compacted as specified herein.

**2. Apparatus.**

2.1 *Cylinder mold.* A mold, 6 in. in diameter and 7 in. high, provided with a collar extension about 2 in. long and a detachable metal base plate. The mold-and-collar assembly should be constructed so that it can be fastened firmly to the detachable baseplate and can be used in California Bearing Ratio (CBR) tests. Figure 1 shows a satisfactory mold for moisture-density tests.

2.2 *Spacer disk.* A metal spacer disk, 5.94 in. in diameter and 2.5 in. thick, for use as a false bottom in the mold during compaction of the test specimen (see Figure 1).

2.3 *Compacting hammer or tamper.* A compacting tamper of the sliding-weight type, as shown in ASTM D 1557, having a 2-in.-diameter steel striking face, a 10-lb mass, and an 18-in. fall. The striking face and mass shall be so constructed that tamping blows can be applied adjacent to the sides of the mold. The maximum allowable mass of the assembled compaction hammer is 17.5 lb.

2.4 *Straightedge.* A steel straightedge, 12 in. long.

2.5 *Balances.* A balance or scale of 25-lb capacity sensitive to 0.01 lb (or equivalent metric balance), and a 200-g-capacity balance sensitive to 0.1 g.

2.6 *Drying oven.* A thermostatically controlled drying oven capable of maintaining temperature of 110 °C plus or minus 5 °C. (221 °F to 239 °F).

2.7 *Sieves.* A 4.75-mm (No. 4) sieve and a 19.0-mm (3/4-in.) sieve conforming to ASTM E 11.

2.8 *Mixing tools.* Miscellaneous tools such as mixing pan, spoon, trowel, spatula, or a mechanical de-

vice for thoroughly mixing the sample of soil with increments of water.

Note. It is convenient, but not essential, to have a mechanical device for removing the compacted soils from the mold. Such a device may consist of a closed, cylindrical sleeve slightly less than 6 in. in diameter, or a piston of like diameter actuated mechanically or by hydraulic or air pressure.

**3. Specimen.**

3.1 *Size of sample.* The amount of material required for the compaction test will vary with the kind, condition, and gradation of the material to be tested but will generally fall within the following limits:

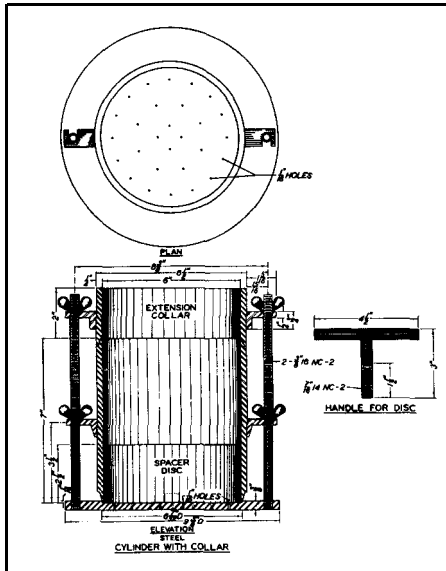


Figure 1. Cylinder mold assembly

\* Formerly MIL-STD-621A. Method 100, 22 December 1964.

- a. Fine-grained soils, 75 to 100 lb.
- b. Granular soils, 100 to 200 lb.

3.2 *Preparation of test specimen.* Dry the soil sample, as received from the field, until it becomes friable-under a trowel. Drying may be done in the air or by use of drying apparatus provided the temperature of the sample does not exceed to 60 °C. (140 °F). Break up the soil thoroughly but in such a manner as to avoid reducing the size of the individual particles. Granular soils, stone, or gravel containing particles larger than 3/4 in. must be processed by removing all material larger than 3.4 in. and replacing this with an equal percentage by weight of material passing the 3.4-m sieve and retained on the 4.75-mm (No. 4) sieve. The percentage of material finer than the 4.75-mm (No. 4) sieve thus remains constant.

3.3 *Mixing.* First, separate the sample into portions for each point desired on the compaction curve. Add the desired amount of mixing water for each compaction test specimen, mix well, place the material in a container, cover with an airtight cover, and allow to cure for 24 h. A shorter curing time may be used where tests show that shortening the curing time will not affect the results. Redetermine the moisture content if appreciable condensation forms on the wall of the container. Use a separate, fresh portion of material for each specimen; do not reuse any material.

#### 4. Procedure.

4.1 *Assembly of mold.* Clamp the 6-in.-diameter mold with detachable collar extension to the baseplate, and insert the spacer disk in the baseplate. Place a coarse filter paper on top of the disk.

4.2 *Compacting.* Place the mold on a concrete floor or pedestal during compaction. Place the soil in the mold in five layers of equal thickness (as nearly equal as practicable), with each layer receiving the specified compaction effort (number of blows of the tamper). The thickness of these layers should be such that after compaction the total thickness of the sample is not less than 4.6 in. nor more than 5.0 in.

Note: To assure conformance with the specified thickness, average total thickness may be determined by determining the mass of the trimmings (see below) and computing total thickness on the basis of wet density of trimmed sample.

After the specimen has been compacted, remove the collar from the mold, and carefully trim and smooth the compacted soil flush with the top of the cylinder. For cohesive materials, the moisture content tested shall

range from below to above the estimated optimum; for cohesionless materials, it shall range from air-dried to as high as practicable. Height of fall of the hammer (18 in.) must be controlled carefully and the blows distributed uniformly over the specimen.

4.3 *Compaction effort.* The following tabulation lists the compaction efforts commonly used in determining moisture-density relations and in preparing specimens for CBR tests. Other compacting efforts may be used for special purposes as required.

Compaction effort designation	Blows per layer	Compaction effort ft-lb/cu ft of compacted soil <sup>1</sup>
CE 55.....	55	55,000
CE 26.....	26	26,000
CE 12.....	12	12,000

<sup>1</sup>Based on a sample height, after compaction but before trimming, of 4.6 in., which will result in the maximum compaction effort within the allowable tolerance for total thickness.

Note: The compaction efforts designated CE 12 and CE 55 are approximately the same as those indicated in ASTM D 698 and D 1557, respectively, and AASHTO T 99 and T 180, respectively. There are some differences between the procedures specified for soil preparation by the CE method and those specified by the ASTM and AASHTO methods. The CE method also specifies sole use of the 10-lb sliding weight hammer with a 6-in.-diameter mold, while the ASTM and AASHTO methods allow use of 4-in.- and 6-in.-diameter molds with a 5.5-lb sleeve-type hammer being used for ASTM D 698 and AASHTO T 99 efforts and a 10-lb sleeve-type hammer being used for ASTM D 1557 and AASHTO T 180 efforts.

4.4 *Moisture content sample.* Detach the baseplate and remove the compacted specimen from the mold and slice it vertically through the center. Take a representative specimen of the material from each of the two parts and determine the water content of each (follow ASTM D 2216). The water content specimens shall weigh not less than 100 g. For granular soils, the entire compaction specimen may be used for the water content determination. In this case, the wet weight of specimen for use in computing water content should be redetermined after the specimen is extruded from the compaction mold because some loss of material may occur during transfer of the specimen.

5. Calculations.

The computation sheet, Figure 2, shows the step-by-step procedures for calculating the moisture content as well as both the wet and dry densities of the compacted soil specimen.

6. Moisture-Density Relation.

6.1 *Plotting.* Plot the dry densities in lb/ft<sup>3</sup> as ordinates and the corresponding moisture contents as abscissas. Figure 3 shows a typical plot of compaction results for the three designated compacting efforts. To aid in determining the validity of the compaction data, a semilog plot of maximum dry density versus compaction effort may be made as illustrated in Figure 3. This relation is usually a straight line when plotted as illustrated. Using the specific gravity of the material involved, a zero percent air voids curve can be plotted using data from Table 1. This relation to the moisture-density curves gives an idea of percent saturation for the compaction curves and provides a check on the validity of the wet side of the compaction curves.

6.2 *Optimum moisture content.* When the moisture-density relations have been determined for a soil and the results have been plotted as described in 6.1,

SOIL COMPACTION TEST					
PROJECT	ARDMORE AFB			DATE	9 JUNE 52
SAMPLE NO.	3245			JOB NO.	52181
INITIAL WATER CONTENT, $w_i$	= 4.5 %		AS MOULDED	BOARDED <input checked="" type="checkbox"/>	
5.5 BLDGS PER BACK OF		5	LAYERS	10	-18 NUMBER 10 -IN. DROP
Specimen	A	B	C	REMARKS	
Desired dry weight $M_d$	5000				
$1 + w_i$	1.045	1.	1.	Subgrade Material	
Soil weight $M_s$ (dry) = $M_d$	5225				
Soil tare $M_s$					
$V_s = V_w$					
Tare water content $w'$	6 %	%	%		
Add water, $M_w$ ( $w' - w_i$ )	75				
Mold No.	4				
Weight mold + soil $M$	14767				
Mold tare $M_m$	10742				
Less tare, $M - M_m = M_c$	4025				
Average water content $w$	5.3 %	%	%		
Mold constant $C$	0.0258	0.	0.		
Wet density, $M_w = M/V$	120.5				
Dry density, $m = 1 + w - d$	114.4				
WATER CONTENTS					
Tare	4	29			
Tare + wet soil	159.8	180.3			
Tare + dry soil	153.0	178.5			
Water $M_w$	6.8	7.8			
Tare	25.3	25.4			
Dry soil $M_s$	127.7	147.1			
Water content $w$	5.3 %	5.3 %	%	%	%
Densities in pounds per cubic foot. Weights in grams.					
TECHNICIAN	ACB	COMPUTED	JSH	CHECKED	TH

Figure 2. Computation sheet

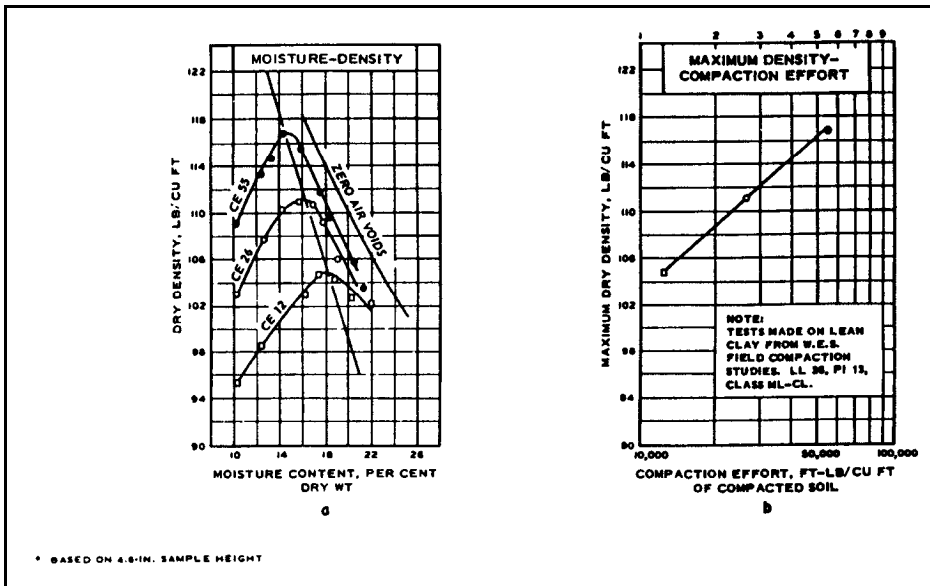


Figure 3. Typical plots of compaction test results

connect the plotted points with a smooth line. The moisture content corresponding to the peak of the curve is the optimum moisture content for the specific compaction effort. Report this value to the nearest 0.1 percent and indicate the compaction effort; e.g., CE 55 optimum moisture content equals 14.4 percent.

6.3 *Maximum dry density.* The dry weight in pounds per cubic foot of the soil at optimum moisture content is termed the maximum dry density for the specific compaction effort. Report this value to the nearest 0.1 lb/ft<sup>3</sup> and indicate the compaction effort; e.g., CE 55 maximum dry density equals 116.9 lb/ft<sup>3</sup>.

Table 1  
Data for Zero Air Voids Curve

Specific Gravity of Soil	Water Content, w, in Percent of Dry Weight for Dry Unit Weight, $\gamma_d$ , in Pounds per Cubic Foot of																			
	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	145
2.40	83.2	71.8	62.4	54.4	47.5	41.6	36.4	31.8	27.7	24.1	20.8	17.8	15.1	12.8	10.4	8.3	6.4	4.6	2.9	1.4
2.45	84.0	72.7	63.2	55.2	48.4	42.4	37.2	32.6	28.6	24.9	21.6	18.6	15.9	13.5	11.2	9.1	7.2	5.4	3.8	2.2
2.50	84.9	73.5	64.1	56.1	49.2	43.2	38.0	33.5	29.4	25.7	22.4	19.5	16.8	14.3	12.0	9.9	8.0	6.2	4.6	3.1
2.51	85.0	73.7	64.2	56.2	49.4	43.4	38.2	33.6	29.5	25.9	22.6	19.6	16.9	14.5	12.2	10.1	8.2	6.4	4.8	3.2
2.52	85.2	73.8	64.4	56.4	49.5	43.6	38.4	33.8	29.7	26.0	22.8	19.8	17.1	14.6	12.4	10.3	8.3	6.6	4.9	3.4
2.53	85.3	74.0	64.5	56.5	49.7	43.7	38.5	33.9	29.8	26.2	22.9	19.9	17.2	14.8	12.5	10.4	8.5	6.7	5.1	3.5
2.54	85.5	74.1	64.7	56.7	49.8	43.9	38.7	34.1	30.0	26.4	23.1	20.1	17.4	14.9	12.7	10.6	8.7	6.9	5.2	3.7
2.55	85.6	74.3	64.8	56.8	50.0	44.0	38.8	34.2	30.2	26.5	23.2	20.2	17.5	15.1	12.8	10.7	8.8	7.0	5.4	3.8
2.56	85.8	74.5	65.0	57.0	50.1	44.2	39.0	34.4	30.3	26.7	23.4	20.4	17.7	15.2	13.0	10.9	9.0	7.2	5.5	4.0
2.57	86.0	74.6	65.1	57.1	50.3	44.3	39.1	34.5	30.5	26.8	23.5	20.6	17.8	15.4	13.1	11.0	9.1	7.3	5.7	4.2
2.58	86.1	74.8	65.3	57.3	50.4	44.5	39.3	34.7	30.6	27.0	23.7	20.7	18.0	15.5	13.3	11.2	9.3	7.5	5.8	4.3
2.58	86.3	74.9	65.4	57.4	50.6	44.6	39.4	34.8	30.8	27.1	23.8	20.9	18.1	15.7	13.4	11.3	9.4	7.6	6.0	4.5
2.60	86.4	75.1	65.6	57.6	50.7	44.8	39.6	35.0	30.9	27.3	24.0	21.0	18.3	15.8	13.6	11.5	9.6	7.8	6.1	4.6
2.61	86.6	75.2	65.7	57.7	50.9	44.9	39.7	35.1	31.1	27.4	24.1	21.2	18.4	16.0	13.7	11.6	9.7	7.9	6.3	4.8
2.62	86.7	75.3	65.9	57.9	51.0	45.1	39.9	35.3	31.2	27.6	24.3	21.3	18.6	16.1	13.9	11.8	9.9	8.1	6.4	4.9
2.63	86.8	75.5	66.0	58.0	51.2	45.2	40.0	35.4	31.4	27.7	24.4	21.4	18.7	16.3	14.0	11.9	10.0	8.2	6.6	5.0
2.64	87.0	75.6	66.2	58.2	51.3	45.4	40.2	35.6	31.5	27.8	24.6	21.6	18.9	16.4	14.2	12.1	10.1	8.4	6.7	5.2
2.65	87.1	75.8	66.3	58.3	51.5	45.5	40.3	35.7	31.6	28.0	24.7	21.7	19.0	16.6	14.3	12.2	10.3	8.5	6.9	5.3
2.66	87.3	75.9	66.5	58.5	51.6	45.7	40.5	35.9	31.8	28.1	24.8	21.9	19.2	16.7	14.4	12.4	10.4	8.7	7.0	5.5
2.67	87.4	76.1	66.6	58.6	51.7	45.8	40.6	36.0	31.9	28.3	25.0	22.0	19.3	16.9	14.6	12.5	10.6	8.8	7.1	5.6
2.68	87.6	76.2	66.7	58.7	51.9	45.9	40.7	36.1	32.1	28.4	25.1	22.2	19.4	17.0	14.7	12.6	10.7	8.9	7.3	5.8
2.69	87.7	76.3	66.9	58.9	52.0	46.1	40.9	36.3	32.2	28.6	25.3	22.3	19.6	17.1	14.9	12.8	10.9	9.1	7.4	5.9
2.70	87.8	76.5	67.0	59.0	52.2	46.2	41.0	36.4	32.3	28.7	25.4	22.4	19.7	17.3	15.0	12.9	11.0	9.2	7.6	6.0
2.71	88.0	76.6	67.2	59.2	52.3	46.3	41.1	36.5	32.5	28.8	25.5	22.6	19.9	17.4	15.1	13.0	11.1	9.3	7.7	6.2
2.72	88.1	76.8	67.3	59.3	52.4	46.5	41.3	36.7	32.6	29.0	25.7	22.7	20.0	17.5	15.3	13.2	11.3	9.5	7.8	6.3
2.73	88.2	76.9	67.4	59.4	52.6	46.6	41.4	36.8	32.7	29.1	25.8	22.8	20.1	17.7	15.4	13.3	11.4	9.6	8.0	6.4
2.74	88.4	77.0	67.6	59.6	52.7	46.7	41.5	37.0	32.9	29.2	25.9	23.0	20.3	17.8	15.5	13.4	11.5	9.7	8.1	6.6
2.75	88.5	77.2	67.7	59.7	52.8	46.9	41.7	37.1	33.0	29.4	26.1	23.1	20.4	17.9	15.7	13.6	11.7	9.9	8.2	6.7
2.76	88.6	77.3	67.8	59.8	53.0	47.0	41.8	37.2	33.1	29.5	26.2	23.2	20.5	18.1	15.8	13.7	11.8	10.0	8.4	6.8
2.77	88.8	77.4	68.0	60.0	53.1	47.1	41.9	37.4	33.3	29.6	26.3	23.4	20.7	18.2	15.9	13.8	11.9	10.1	8.5	7.0
2.78	88.9	77.5	68.1	60.1	53.2	47.3	42.1	37.5	33.4	29.8	26.5	23.5	20.8	18.3	16.1	14.0	12.1	10.3	8.6	7.1
2.79	89.0	77.7	68.2	60.2	53.4	47.4	42.2	37.6	33.5	29.9	26.6	23.6	20.9	18.5	16.2	14.1	12.2	10.4	8.8	7.2
2.80	89.2	77.8	68.3	60.3	53.5	47.5	42.3	37.7	33.7	30.0	26.7	23.8	21.0	18.6	16.3	14.2	12.3	10.5	8.9	7.4
2.81	89.3	77.9	68.5	60.5	53.6	47.7	42.5	37.9	33.8	30.1	26.8	23.9	21.2	18.7	16.4	14.4	12.4	10.7	9.0	7.5
2.82	89.4	78.1	68.6	60.6	53.7	47.8	42.6	38.0	33.9	30.3	27.0	24.0	21.3	18.8	16.6	14.5	12.6	10.8	9.1	7.6
2.83	89.5	78.2	68.7	60.7	53.9	47.9	42.7	38.1	34.0	30.4	27.1	24.1	21.4	19.0	16.7	14.6	12.7	10.9	9.3	7.7
2.84	89.7	78.3	68.8	60.8	54.0	48.0	42.8	38.2	34.2	30.5	27.2	24.3	21.5	19.1	16.8	14.7	12.8	11.0	9.4	7.9
2.85	89.8	78.4	69.0	61.0	54.1	48.2	43.0	38.4	34.3	30.6	27.3	24.4	21.7	19.2	16.9	14.9	12.9	11.2	9.5	8.0
2.86	89.9	78.5	69.1	61.1	54.2	48.3	43.1	38.5	34.4	30.8	27.5	24.5	21.8	19.3	17.1	15.0	13.1	11.3	9.6	8.1
2.87	90.0	78.6	69.2	61.2	54.4	48.4	43.2	38.6	34.5	30.9	27.6	24.6	21.9	19.5	17.2	15.1	13.2	11.4	9.8	8.2
2.88	90.1	78.8	69.3	61.3	54.5	48.5	43.3	38.7	34.7	31.0	27.7	24.7	22.0	19.6	17.3	15.2	13.3	11.5	9.9	8.3
2.89	90.3	78.9	69.5	61.5	54.6	48.6	43.4	38.9	34.8	31.1	27.8	24.9	22.2	19.7	17.4	15.3	13.4	11.6	10.0	8.5
2.90	90.4	79.0	69.6	61.6	54.7	48.8	43.6	39.0	34.9	31.2	28.0	25.0	22.3	19.8	17.6	15.5	13.5	11.8	10.1	8.6
2.95	91.0	79.6	70.2	62.2	55.3	49.3	44.1	39.6	35.5	31.6	28.5	25.6	22.9	20.4	18.1	16.0	14.1	12.3	10.7	9.2
3.00	91.5	80.2	70.7	62.7	55.9	49.9	44.7	40.1	36.0	32.4	29.1	26.1	23.4	21.0	18.7	16.8	14.7	12.9	11.3	9.7
3.05	92.1	80.7	71.3	63.3	56.4	50.5	45.3	40.7	36.6	32.9	29.6	26.7	24.0	21.5	19.2	17.2	15.2	13.5	11.8	10.3
3.15	93.1	81.8	72.3	64.3	57.4	51.5	46.3	41.7	37.6	34.0	30.7	27.7	25.0	22.5	20.3	18.2	16.3	14.5	12.8	11.3

Note: Zero air voids curve equivalent to a degree of saturation, S, equal to 100 percent. Data for zero air voids curve computed from the following formula (using a  $\gamma_u$  value of 62.43):

$$S = 100\% = \frac{w}{\frac{\gamma_u}{\gamma_t} - 1}$$

The above equation may also be used to determine curves representing degrees of saturation other than 100 percent.