New Rapid Test Method for Earthwork Compaction Control

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The quality control procedures for earthwork compaction used by New York State and many others have been to compare in-place density (measured by the sand-cone method) with maximum density (determined by a one-point compaction test and a family of moisture-density curves). This paper describes a new rapid test that uses all these concepts. A time saving is accomplished by a combination of equipment and computation improvements. Through use of a special slide rule, in-place density is obtained from the volume of a hole as measured by a sand replacement volumeter. Maximum densities, taken from the moisture-density curves and compiled in compaction control tables, can be compared with in-place densities without any calculations or interpolations. Moisture determinations are usually not required, and conversions from wet to dry density are never necessary. New York State is now using this system with a high degree of success.

The field test for earthwork compaction now most widely used takes $1\frac{1}{2}$ to $2\frac{1}{2}$ h. The number of tests that can be accomplished is thus severely limited, and the reportable results are delayed at a time when rapid substantiation of conformance is essential. Controls are generally in terms of dry density, which requires measurement of field moisture content even when moisture is not an explicit specification requirement. Testing personnel must perform many complex observations that are based in part on making rational engineering judgments and interpolations.

This new test method retains the fundamental elements of compaction control that have gained widespread recognition and acceptance but eliminates nonessential procedures having no quantitative application. Test procedures are simplified and judgment errors eliminated. The test is rapid, but control is not relaxed or compromised.

TEST PROCEDURES

The method consists of the following basic steps:

1. Measuring in-place wet density of soil in a layer just placed and compacted;
2. Determining the net weight of 944 cm^3 ($\frac{1}{30}$ ft^3) of soil after it is compacted in a mold in accordance with AASHTO Designation T-99, Method C (standard Proctor density);
3. Reading off the highest required and lowest allowable wet densities from compaction control tables specially designed for this test;
4. Determining whether the layer passes or fails by comparing the measured field wet density with the highest required and lowest allowable wet densities; and
5. In some cases, where the field wet density is between the highest required and the lowest allowable wet density, finding the moisture content to determine whether the layer passes or fails.

THEORY

Modern earthwork practices and equipment generally provide field densities exceeding the minimum specified. A new computational system, based on families of compaction control curves, now permits compaction testing in such cases without determination of moisture contents. For example, Figure 1 shows one set of control curves developed for New York State soils, specifically those identified as sands or as sands containing minor amounts of gravel and silt. For a laboratory dry density of 1810 kg/m^3 (113 lb/ft^3) and a moisture content of 6 percent, a point can be plotted on this graph. Through it a curve is drawn parallel and similar to the adjacent curves. The maximum dry density (1874 kg/m^3 or 117 lb/ft^3) is obtained from the point where this curve intercepts the locus of maximum density. Because moisture content for the laboratory and field dry densities is identical, the intersection of this moisture content value and the maximum dry density value is the point where field dry density would plot to be equivalent to maximum dry density. In Figure 1, this point is called field dry density required. Any point on this graph also represents a certain wet density that is the product of the dry density value and 1 plus the moisture content value. Points of equal wet density arrange in curves tending from the upper left to lower right.

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Figure 2 shows the relationship among the wet density curves, compaction control curves, and points as plotted in Figure 1. If the laboratory wet density (1922 kg/m^3 or 120 lb/ft^3) and the moisture content (6 percent) are known, Figure 2 can be used to determine the field wet density required (1986 kg/m^3 or 124 lb/ft^3) to obtain the maximum dry density.

Figure 3 shows that points of equal laboratory wet density (in this case, 1922 kg/m^3 or 120 lb/ft^3) and varying moisture contents develop different values for the maximum dry density and field wet density required. The range of varying moistures and these corresponding values can be limited as follows:

1. A 2 percent minimum limit for sand and for sands containing minor amounts of gravel and silt and a 4 per-

Figure 1. Compaction control curves.

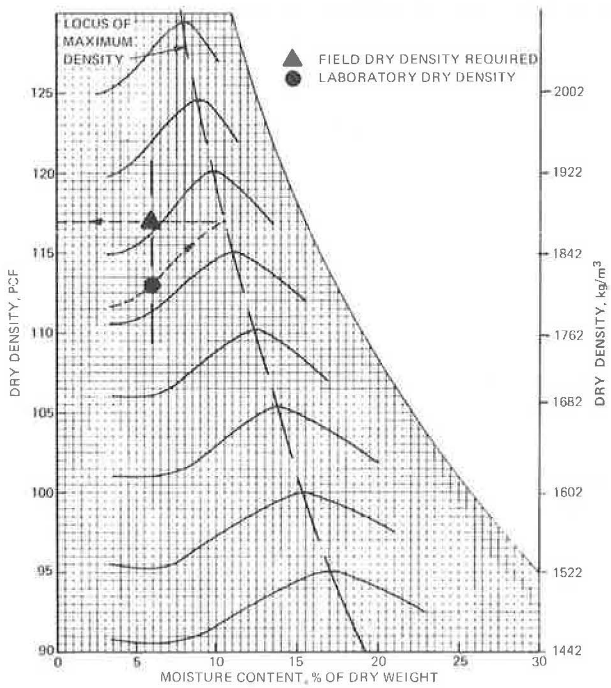


Figure 2. Field wet density required to obtain 100 percent maximum dry density.

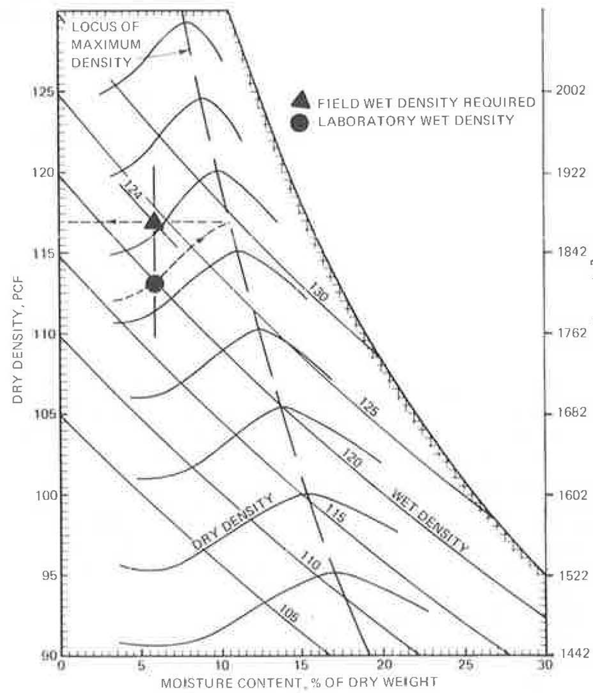


Figure 3. Field wet density required to obtain 100 percent maximum dry density for various moisture contents.

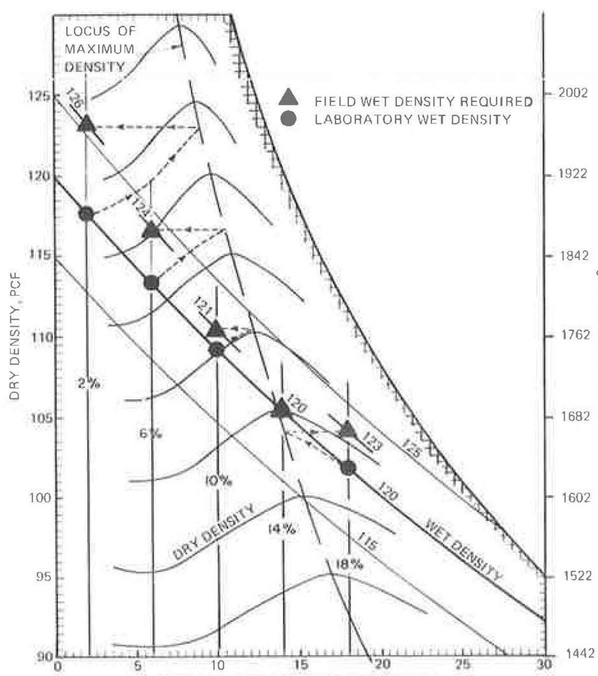
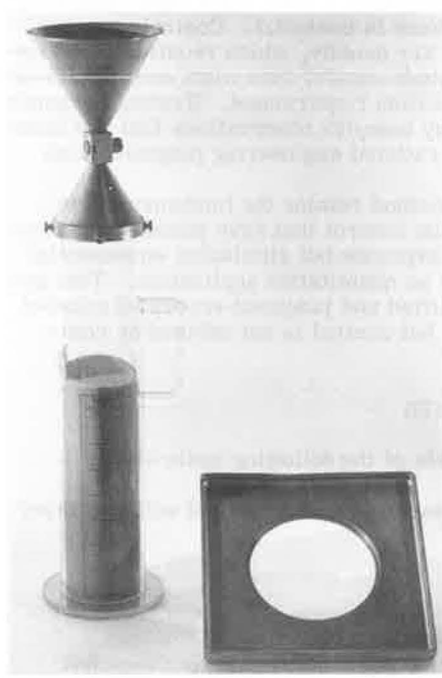


Figure 4. Sand replacement volumeter, including cone and base plate.



cent minimum limit for other soils. Usual embankment material will rarely be drier than these limits.

2. A maximum of +4 percent above optimum. Embankment materials with moisture approaching this limit will rut excessively and no compaction tests should be taken.

Within these limits, Figure 3 shows that the highest field wet density required (2018 kg/m^3 or 126 lb/ft^3) for a laboratory wet density of 1922 kg/m^3 (120 lb/ft^3) occurs at the minimum moisture content of 2 percent. Accordingly, if the measured field wet density is greater than the field wet density required at the 2 percent moisture content, the compaction test passes regardless of the actual moisture content of the soil.

As moisture content increases above 2 percent, the field wet density required to satisfy the specification requirements decreases until the lowest field wet density required (1922 kg/m^3 or 120 lb/ft^3) is reached. This is at the point where the wet density curve crosses the locus of maximum density (or optimum moisture). It then increases on the wet side of optimum moisture. This means that, if the measured field wet density is lower than the field wet density required at the optimum moisture content, the test fails regardless of the actual moisture content of the soil.

If the field wet density of the soil is between the highest and lowest field wet densities required, a moisture content determination is necessary to complete the test. From the known laboratory wet density and moisture content, the actual field wet density required can be obtained and compared with the measured field wet density for a pass-fail decision.

COMPACTION CONTROL TABLES

The field wet densities required to obtain a specified percentage of maximum dry density have been tabulated (Table 1) to eliminate the otherwise necessary computations and graphic interpolations. These tabulations thus replace the statewide compaction control curves, one of which was shown in Figure 1. They cover the full range of soil types and moisture contents normally encountered in earthwork construction in New York State. Similar tables can be developed to apply to any soil where moisture-density relationships are known.

NEW EQUIPMENT

Sand Replacement Volumeter

The sand replacement volumeter, a direct-reading apparatus (Figure 4), eliminates all weighings, corrections, and calculations usually associated with measuring the hole by the normal sand cone method. The apparatus is used as follows:

1. Fill the volumeter. Place the empty apparatus upright on a firm, level surface. Close the valve, and fill the cone with sand. Open the valve and fill the apparatus, keeping the cone at least half full of sand. Close the valve sharply, and empty the excess sand. Note that, as the volumeter is handled and transported, the sand will compact and the level within the volumeter will drop, but do not add sand. Measurement of the hole's volume is based on the loose volume of sand.
2. Fill the hole. Seat the apparatus on the base plate through which the hole was dug. Open the valve and, after the sand has stopped flowing, close the valve and remove the apparatus.
3. Read the volume. Hold the volumeter vertically with the cone end up. Invert it, and immediately return it to its original position. Gently shake the apparatus horizontally, just enough to level the sand. Read, average, and record the upper surface level of the sand, visible on the three vertical scales printed on the circumference of the volumeter.

When the simple techniques devised for this operation are used, the precision capability of the instrument has proved to be greater than the acceptable precision capability of the sand that may be used (±1 percent bulk density per AASHTO Designation T-191). Errors inherent in the normal sand cone method, due to the variability in unit weight of the sand caused by changes in moisture, gradation, and specific gravity, are eliminated. Measurements by this volumeter are easy, rapid, and (when compared under actual field conditions) more accurate than those by the older system.

Field Wet Density Calculator

A slide rule (Figure 5) is used to resolve the as-compacted density of the minus 19-mm (¾-in) fraction. Instructions are printed on the face of the slide rule. The limits set by the scales are designed to prevent errors that are outside the parameters of the test.

Fixed-Weight Containers

Weights of the moisture container and density cylinder have been standardized to simplify the test method further. With a container weight of 200 g (0.44 lb) and a moist soil weight of 500 g (1.1 lb), moisture content can be found from Table 2 by observing the total weight of the dry soil and container only. The fixed-density cylinder weight of 1814 g (4 lb) eliminates the need to compute laboratory wet density. The compaction control tables are arranged to find the required wet density from the total weight of the cylinder and soil.

Test Record Form

Figure 6 shows the complete procedure and some typical test results.

EVALUATION OF NEW METHOD

A new test method must exhibit real and significant benefits to be viable. To validate the new method, it was compared with the compaction control method previously used in New York State (Table 3). Test records from three major highway construction projects were selected to provide a large range of embankment materials, construction procedures, and manual testing techniques. The analysis included

1. Determining errors in computation and interpolations that are eliminated by the new method,
2. Finding the number of compaction tests in which moisture content determination would not have been required,
3. Estimating the time saved by using the new test method, and
4. Examining the simplification accomplished by this method.

Errors Eliminated

Of 1542 tests, 325 were found to have at least one error in computation or interpolation that would not have occurred if the new rapid test method had been used. For comparison purposes, a discrepancy that resulted in a value greater than ±1 percent from the true percentage

Table 1. Field wet densities required to obtain maximum dry density specified.

Weight of Cylinder and Soil (kg)	Maximum Density Specified (%)	Densities (kg/m^3) by Moisture Content Percentage														
		2	4	6	8	10	12	14	16	18	20	22	24	26	28	30
Sands or Sands Containing Minor Amounts of Gravel and Silt																
3.90	100	229.1	225.9	224.3	222.7	224.3										
	95	217.9	214.7	213.1	211.5	213.1										
	90	206.7	203.5	201.9	200.3	201.9										
3.86	100	224.3	222.7	219.5	216.3	219.5										
	95	213.1	211.5	208.3	205.1	208.3										
	90	201.9	200.3	197.0	193.8	197.0										
3.81	100	219.5	217.9	216.3	213.1	211.5	214.7									
	95	208.3	206.7	205.1	203.5	201.9	205.1									
	90	197.0	195.4	193.8	192.2	190.6	193.8									
3.76	100	214.7	213.1	211.5	209.9	206.7	208.7	209.9								
	95	205.1	203.5	201.9	200.3	197.0	198.6	200.3								
	90	193.8	192.2	190.6	189.0	185.8	187.4	189.0								
3.72	100	209.9	208.3	206.7	205.1	203.5	201.9	203.5	206.7							
	95	200.3	198.6	197.0	195.4	193.8	192.2	193.8	197.0							
	90	189.0	187.4	185.8	184.2	182.6	181.0	182.6	185.8							
3.67	100	206.7	205.1	203.5	200.3	198.6	197.0	197.0	200.3							
	95	197.0	195.4	193.8	190.6	189.0	187.4	187.4	190.6							
	90	185.8	184.2	182.6	179.4	179.4	177.8	177.8	181.0							
3.63	100	201.9	200.3	198.6	197.0	193.8	192.2	192.2	193.8	197.0						
	95	192.2	190.6	189.0	187.4	184.2	182.6	182.6	184.2	187.4						
	90	181.0	179.4	179.4	177.8	174.6	173.0	173.0	174.6	177.8						
3.58	100	195.4	195.4	193.8	192.2	190.6	189.0	187.4	189.0	189.0						
	95	185.8	185.8	184.2	182.6	181.0	179.4	177.8	179.4	179.4						
	90	176.2	176.2	174.6	173.0	171.4	169.8	168.2	169.8	169.8						
3.54	100	190.6	190.6	189.0	187.4	185.8	185.8	184.2	184.2	184.2	185.8					
	95	181.0	181.0	179.4	177.8	176.2	176.2	174.6	174.6	174.6	176.2					
	90	171.4	171.4	169.8	168.2	166.6	166.6	165.0	165.0	165.0	166.6					
3.49	100	185.8	185.8	185.8	184.2	182.6	181.0	179.4	177.8	177.8	179.4					
	95	176.2	176.2	176.2	174.6	174.6	173.0	171.4	169.8	169.8	171.4					
	90	166.6	166.6	166.6	165.0	165.0	163.4	161.8	160.2	160.2	161.8					
3.45	100	179.4	179.4	179.4	179.4	177.8	176.2	174.6	174.6	174.6	173.0					
	95	171.4	171.4	171.4	171.4	169.8	168.2	166.6	166.6	166.6	165.0					
	90	161.8	161.8	161.8	161.8	160.2	158.6	157.0	157.0	157.0	155.4					
3.40	100	174.6	174.6	174.6	174.6	173.0	171.4	169.8	169.8							
	95	166.6	166.6	166.6	166.6	165.0	163.4	161.8	161.8							
	90	157.0	157.0	157.0	157.0	155.4	153.8	152.2	152.2							
3.36	100	169.8	169.8	169.8	169.8	169.8										
	95	161.8	161.8	161.8	161.8	161.8										
	90	152.2	152.2	152.2	152.2	152.2										
3.31	100	166.6	166.6	166.6	166.6											
	95	158.6	158.6	158.6	158.6											
	90	150.6	150.6	150.6	150.6											
3.27	100	161.8	161.8	161.8												
	95	153.8	153.8	153.8												
	90	145.8	145.8	145.8												
Tills, Silts, Clays, and Well-Graded Gravels																
4.08	100		243.5	240.3	241.9											
	95		232.3	229.1	230.7											
	90		219.5	216.3	217.9											
4.04	100		240.3	235.5	235.7	241.9										
	95		229.1	224.3	224.3	230.7										
	90		216.3	211.5	211.5	217.9										
3.99	100		237.1	233.9	230.7	233.9										
	95		225.9	222.7	219.5	222.7										
	90		213.1	209.9	208.3	209.9										
3.95	100		233.9	230.7	227.5	225.9	232.3									
	95		222.7	219.5	216.3	214.7	217.9									
	90		209.9	208.3	205.1	203.5	206.7									
3.90	100		230.7	227.5	224.3	221.1	221.1	227.5								
	95		219.5	216.3	213.7	209.9	209.9	216.3								
	90		208.3	205.1	201.9	198.6	198.6	205.1								
3.86	100		227.5	224.3	221.1	217.9	216.3	217.9	222.7							
	95		216.3	213.1	209.9	206.7	205.1	206.7	211.5							
	90		205.1	201.9	198.6	195.4	193.8	195.4	200.3							
3.81	100		224.3	221.1	217.9	214.7	213.1	211.5	214.7	217.9						
	95		213.1	209.9	206.7	205.1	203.5	201.9	205.1	206.7						
	90		201.9	198.6	195.4	193.8	192.2	190.6	193.8	195.4						
3.76	100		221.1	217.9	213.1	211.5	208.7	206.7	206.7	208.3	213.1					
	95		209.3	206.7	203.5	201.9	198.6	197.0	197.0	198.6	203.5					
	90		198.6	195.4	192.2	190.6	187.4	185.8	185.8	187.4	192.2					
3.72	100		217.9	213.1	209.9	208.3	206.7	205.1	203.5	201.9	201.9	205.1	208.3			
	95		206.7	203.5	200.3	198.6	197.0	195.4	193.9	192.2	192.2	195.4	198.6			
	90		195.4	192.2	189.0	187.4	185.8	184.2	182.6	181.0	181.0	184.2	187.4			
3.67	100		216.3	211.5	208.3	205.1	203.5	200.3	198.6	198.6	197.0	197.0	198.6	201.9		
	95		205.1	201.9	198.6	195.4	193.8	190.6	189.0	189.0	187.4	187.4	189.0	192.2		
	90		193.8	190.6	187.4	185.8	182.6	181.0	179.4	179.4	177.8	177.8	179.4	181.0		
3.63	100		211.3	208.3	205.1	201.9	198.6	198.6	197.0	195.4	193.9	193.9	192.2	192.2	193.8	
	95		201.9	198.6	195.4	192.2	189.0	189.0	187.4	185.8	184.2	184.2	182.6	182.6	184.2	
	90		190.6	187.4	184.2	181.0	179.4	179.4	177.8	176.2	174.6	174.6	173.0	173.0	174.6	
3.58	100		208.3	203.5	201.9	198.6	197.0	195.4	193.8	192.2	192.2	190.6	190.6	189.0	189.0	187.4
	95		198.6	193.8	192.2	189.0	187.4	185.8	184.2	182.6	182.6	181.0	181.0	179.4	179.4	177.8
	90		187.4	182.6	181.0	179.4	177.8	176.2	174.6	173.0	173.0	171.4	171.4	169.8	169.8	168.2
3.54	100		203.5	200.3	198.6	195.4	192.2	192.2	190.6	189.0	189.0	187.4	185.8	185.8	184.2	184.2
	95		193.8	190.6	189.0	185.8	182.6	182.6	181.0	179.4	179.4	177.8	176.2	176.2	174.6	174.6
	90		182.6	181.0	179.4	176.2	173.0	173.0	170.4	169.8	169.8	168.2	166.6	166.6	165.0	165.0
3.49	100		200.3	197.0	195.4	192.2	190.6	189.0	187.4	187.4	185.8	184.2	182.6	182.6		
	95		190.6	187.4	185.8	182.6	181.0	179.4	177.8	177.8	176.2	174.6	174.6	174.6		
	90		179.4	177.8	176.2	173.0	171.4	169.8	168.2	168.2	166.6	165.0	165.0	165.0		
3.45	100		197.0	193.8	190.6	189.0	187.4	185.8	185.8	184.2	182.6	181.0	181.0			
	95		187.4	184.2	181.0	179.4	177.8	176.2	176.2	174.6	174.6	173.0	173.0			
	90		177.8	174.6	171.4	169.8	168.2	166.6	166.6	165.0	165.0	163.4	163.4			
3.40	100		192.2	190.6	187.4	185.8	184.2	182.6	181.0	181.0	179.4	177.8				
	95		182.6	181.0	177.8	176.2	174.6	174.6	173.0	173.0	171.4	169.8				
	90		173.0	171.4	168.2	166.6	165.0	165.0	163.4	163.4	161.8	160.2				
3.36	100		189.0	185.8	184.2	182.6	181.0	179.4	179.4	177.8	176.2	176.2				
	95		179.4	176.2	174.6	174.6	173.0	171.4	171.4	169.8	168.2	168.2				
	90		169.8	166.6	165.0	165.0	163.4	161.8	161.8	160.2	158.6	158.6				
3.31	100		185.8	182.6	179.4	177.8	176.2	176.2	174.6	174.6	174.6					
	95		176.2	174.6	171.4	169.8	168.2	168.2	166.6	166.6	166.6					
	90		166.6	165.0	161.8	160.2	158.6	158.6	157.0	157.0	157.0					
3.27	100		181.0	179.4	177.8	176.2	174.6	174.6	173.0	173.0						
	95		173.0	171.4	169.8	168.2	166.6	166.6	165.0	165.0						
	90		163.4	161.8	160.2	158.6	157.0	157.0	155.4	155.4						

Note: 1 kg = 2.2 lb; 1 kg/m^3 = 0.06 lb/ft^3.

of maximum density obtained was considered an error. Although only a small percentage of errors found would have affected a pass-fail decision, the high incidence of errors clearly shows the need to reduce the complexity of the older method.

Moisture Content Tests Virtually Eliminated

For project 1 (which appeared, in comparison with many other construction projects, to have particularly typical test results), 98 percent of the compaction tests taken would have required no moisture determinations had the newer method been used. This is significant in view of the extensive research that has been devoted to equipment improvements and time savings for moisture determinations, which now prove to be unnecessary.

Time Saved

A comparison of the time required by each method gave the following approximations.

1. The time necessary to travel to the test site, dig the hole, fill it with sand, and return to the soils laboratory varies considerably but is similar for both test methods.
2. Assuming a soil sample can be dried in about 45 min by the open flame method, the time necessary for a test result by the older method (after the inspector returns to the soils laboratory) is 1 h.
3. A test result using the new method, which does not require moisture content, can be obtained (after the inspector returns to the soils laboratory) in 10 min.

Figure 5. Field wet density calculator.

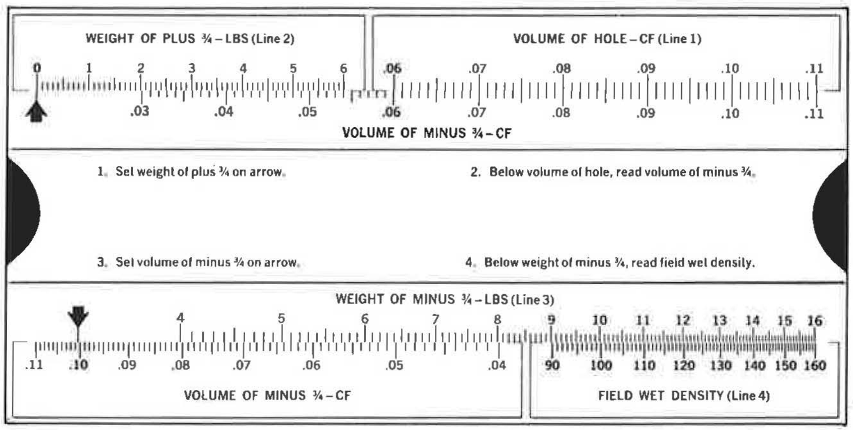


Table 2. Weight related to moisture content.

Dry Soil and Tare Weight[a] (g)	Moisture Content (%)	Dry Soil and Tare Weight[a] (g)	Moisture Content (%)
700	0	613	21
695	1	610	22
690	2	606	23
685	3	603	24
681	4	600	25
676	5	597	26
672	6	594	27
667	7	591	28
663	8	588	29
659	9	585	30
655	10	582	31
650	11	579	32
646	12	576	33
642	13	573	34
639	14	570	35
635	15	568	36
631	16	565	37
627	17	562	38
624	18	560	39
620	19	557	40
617	20		

Note: 1 g = 0.035 oz.
[a]Based on a 500-g moist sample and a 200-g container weight.

Table 3. Testing on three projects.

Total Tests	Project 1	Project 2	Project 3	Total
Observed	541	699	302	1542
With errors	70	112	143	325
Compared	471	587	159	1217
Not requiring moisture determination	461	438	136	1035

Figure 6. Compaction control data sheet with typical entries.

PIN	PROJECT					
COUNTY	CONTRACT NO.	INSPECTOR				
DATE OF TEST						
TEST NUMBER						
STATION OF TEST						
OFFSET						
TYPE AND WEIGHT OF COMPACTOR						
NUMBER OF PASSES PER LAYER						
SOIL TYPE (SAND) (TILL-SILT-CLAY-GRAVEL)	SAND		TILL		SILT	
DEPTH BELOW SUBGRADE SURFACE	4.0		6.0		1.0	
1 MEASURE VOLUME OF HOLE - CF	.072		.068		.082	
2 WEIGH PLUS 3/4 - LBS	1.51		2.32		0	
3 WEIGH MINUS 3/4 - LBS	7.40		6.68		9.83	
FROM CALCULATOR						
4 FIELD WET DENSITY	118		124		120	
5 WEIGH CYLINDER AND SOIL - LBS	7.9		8.3		8.1	
6 MAXIMUM DENSITY REQUIRED - %	90		90		95	
7 COMPACTION CONTROL TABLE NUMBER	A		B		B	
FROM TABLES						
8 HIGHEST FIELD WET DEN. REQUIRED	110		124		128	
9 LOWEST FIELD WET DEN. ALLOWED	105		116		117	
10 PASS (LINE 4 EQUAL OR GREATER THAN LINE 8)	✓		✓			
11 FAIL (LINE 4 LESS THAN LINE 9)						
12 RUN MOISTURE (USE 500 GRAM SAMPLE)					✓	
13 WEIGH DRY SOIL AND TARE - GRAMS					645	
FROM TABLES						
14 MOISTURE CONTENT - %					12	
15 FIELD WET DENSITY REQUIRED					121	
16 PASS (LINE 4 EQUAL OR GREATER THAN LINE 15)						
17 FAIL (LINE 4 LESS THAN LINE 15)					✓	

REMARKS:

Table 4. Comparison of old and new test methods.

Old Test Method		New Test Method	
Step	Weighing or Calculation	Step	Weighing or Calculation
Calibrate for Sand Density (about every 10 tests)			
Calibrate cone			
1	Weigh jar, sand, and cone (before)		
2	Weigh jar, sand, and cone (after)		
3	1 - 2 = weight of sand in cone		
Find weight of sand in container			
4	Weigh jar, sand, and cone (before)		
5	Weigh jar, sand, and cone (after)		
6	4 - 5 = weight of sand in cone and container		
7	3 = weight of sand in cone		
8	6 - 7 = weight of sand in container		
Find volume of container			
9	Weigh container filled with water		
10	Weigh container		
11	9 - 10 = weight of water to fill container		
12	11 ÷ 28.3 kg (weight of 0.028 m^3 of water) = volume of container		
Determine sand density			
13	8 ÷ 12 = density of sand		
Find Volume of Hole			
14	Weigh sand and cone (before)		
15	Weigh sand and cone (after)		
16	14 - 15 = weight of sand used		
17	3 = cone volume correction		
18	16 - 17 = net sand in hole		
19	Record sand calibration factor (step 13)		
20	18 ÷ 19 = net volume of hole	1	Record volume of hole by using volumeter
Find Density in the Field (minus 19-mm material)			
21	Weigh soil and tare	2	Weigh plus 19-mm material
22	Record weight of tare	3	Weigh minus 19-mm material
23	21 - 22 = weight of soil		
24	23 ÷ 20 = field wet density of total sample		
25	Weigh plus 19-mm material and tare		
26	Record tare weight		
27	25 - 26 = weight of plus 19-mm material		
28	(27 ÷ 23) × 100 = percentage of material (in total sample)		
29	Using 24 and 28 interpolate from control charts = field wet density of minus 19-mm material		
30	Weigh wet soil and tare		
31	Weigh dry soil and tare		
32	Record tare weight		
33	30 - 31 = weight of water		
34	31 - 32 = weight of dry soil		
35	(33 ÷ 34) × 100 = moisture content (percent)		
36	29 ÷ [1 + moisture content (percent)] = field dry density of minus 19-mm material	4	Record field wet density of minus 19-mm material by using slide rule (Figure 5)
Find Density in the Laboratory			
37	Weigh cylinder and soil	5	Weigh cylinder and soil
38	Record cylinder weight		
39	37 - 38 = net weight of soil		
40	39 × 1039 (cylinder capacity = 955 cm^3) = laboratory wet density		
41	40 ÷ [1 + moisture content (percent)] = laboratory dry density (Proctor)		
Analyze Test Results			
42	Use 35 and 41 to interpolate from control charts = maximum density (control)	6	Record percentage of maximum density required
43	Interpolate from control charts for optimum moisture content	7	Record highest wet density required (Table 1)
44	(36 ÷ 42) × 100 = percentage of maximum density obtained	8	Record lowest wet density allowed (Table 1)
45	Record percentage of minimum density required		

Note: 1 kg = 2.2 lb; 1 m^3 = 35.3 ft^3; 1 mm = 0.04 in; 1 cm^3 = 0.06 in^3.

The older method also requires additional time to calibrate the sand and more time to check the test results; therefore, the total time saved is estimated at more than 1 h. By saving 1 h per test (when moistures are not required), a total of 530 person-hours (98 percent × total number of tests) could have been saved for more productive use on project 1. Inasmuch as the contractor is sometimes delayed awaiting test results, the time saved by this method can also increase the productivity of his operations.

Simplification Accomplished

Data given in Table 4 demonstrate the reduction in steps required by this method. Test results by the older method depended on the accuracy of 45 separate entries, including 16 weighings and 21 calculations. Test results by the rapid method are dependent on the accuracy of eight entries, including three weighings and one calculation.

SUMMARY AND CONCLUSIONS

Instructions for this test method are uncomplicated and straightforward. Moisture content determinations for compaction control purposes are virtually eliminated. Examination of the steps required by the two methods clearly shows that the time necessary to perform a test has been reduced and that simplification of the test provides a corresponding reduction in the probability of errors.

Although the new equipment and procedures described in this paper were designed for this test, if desired they can be independently evaluated and incorporated into other test methods. The direct-reading volumeter is accurate and rapid; it is simple to operate, relatively maintenance-free, and inexpensive. The slide rule is specially designed to reduce the steps and errors now involved in determining field wet density corrected for ±19-mm (±$\frac{3}{4}$-in) material. Fixed-weight moisture containers and compaction cylinders contribute to the simplicity of the test. Development of the required wet density tables from moisture-density curves is a major evolution in quality control of earthwork construction.

This system of compaction control has been tried and proved by thousands of tests performed on various projects throughout New York State during the 1974, 1975, and 1976 construction seasons. The time-saving benefits of this procedure have been enthusiastically endorsed by project engineers and contractors alike.

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