A COMPARISON OF METHODS FOR DETERMINING THE VOLUME-WEIGHT OF SOILS[1]

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INTRODUCTION

Since some of the soils of New Mexico are extremely variable in texture, structure, and stratification, they present many problems to the investigator who tries to determine their volume-weights.[2] Because of these varying conditions, several of the common methods used in making volume-weight determinations can not be depended upon to give satisfactory results. Therefore, experimental work was undertaken to determine the most suitable method for use under these conditions. The paraffin-immersion method,[3] being impractical here, was not considered in these tests. Comparisons were made between the 1-foot cylinder method, the rubber-tube method,[4] the viscous-fluid method,[5] the improved soil-tube method,[6] and a revised sand method.[7]

EQUIPMENT AND PROCEDURE

The cylinder used in the tests with the 1-foot cylinder method was made from a piece of large water pipe. (Fig. 1.) A section 13.25 inches in length was remodeled in a machine shop so that the inside diameter was 3.61 inches and the cylinder was uniform and smooth throughout.

Approximately one thirty-second inch was cut away from the outside of the cylinder from the top to within 1 inch of the lower end. From 1 inch downward the cylinder was beveled to a cutting edge, thus making it flush with the inside diameter and leaving a small flange on the outside to reduce friction. A driving plug was cut from a solid piece of material so that it was about 1.25 inches in thickness and of the same diameter as the outside of the cylinder. A seat about 0.2 inch in depth (it should have been deeper, so the plug would have remained in position better) was cut out on the lower side of the plug so that it seated snugly on top of and partially inside of

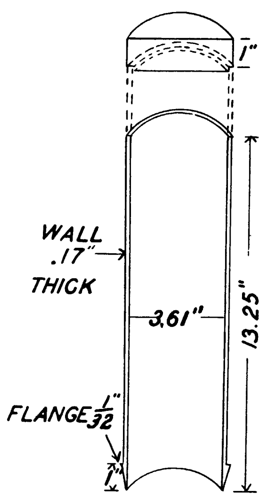

Figure 1.—Longitudinal section of cylinder and driving plug, with the approximate dimensions, used in the 1-foot cylinder method of soil volume-weight determination

[1] Received for publication Jan. 13, 1931; issued June, 1931.

[2] The volume-weight, or apparent specific gravity, of a soil is a figure which represents the ratio between the weight of a given volume of undisturbed water-free soil and the weight of an equal volume of water.

[3] Shaw, C. F. A method for determining the volume weight of soil in field condition. Jour. Amer. Soc. Agron. 9: 38–42. 1917.

[4] Israelsen, O. W. Studies on capacities of soils for irrigation water, and on a new method of determining volume weights. Jour. Agr. Research 13: 28. 1918.

[5] Beckett, S. H. The use of highly viscous fluids in the determination of volume-weight of soils. Soil Sci. 25: 481–483. 1928.

[6] Veihmeyer, F. J. An improved soil-sampling tube. Soil Sci. 27: 147. 1929.

[7] Frear, W., and Erb, E. S., Excavation method for determining the apparent specific gravity of soils. Jour. Assoc. Off. Agr. Chem. 4: 10. 1920.

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the cylinder. Owing to the use of this plug, the cylinder was not damaged by driving with a 2-pound hammer.

The rubber tube used in these trials was 61 inches in length and slightly more than 1.5 inches in diameter. Rubber bandages, such as are commonly used by the medical profession, were made up into a tube of the desired dimensions by a local tire vulcanizer. This rubber seems to have been slightly stiff for this purpose. From a specific-gravity test on the rubber, it was found that 86 ml. of water were displaced by the tube.

The oil used with the viscous-fluid method is commonly known as "600 W." (Preliminary tests were made with a heavy road oil, but it penetrated so rapidly into the sandy strata that an accurate measurement could not be secured.) The volumes were obtained by weighing the oil used for each hole. This weight was multiplied by 1.1287 as a correction factor, which was obtained by dividing 100 by 88.6 to get the correct volume. A test on the oil showed that 100 ml. weighed 88.6 gm.

The tube used with the improved soil-tube method was like the one described by Veihmeyer. He stated that this tube was used with satisfactory results in making volume-weight determintions.

When the sand method was used the volume of the hole was determined by measuring volumetrically the sand required to fill the hole which had been previously drilled with an auger. The sand was obtained from a gravel pit and screened. Only the particles which would pass through a 2-mm. sieve and which were retained on a 1-mm. sieve were used. Tests with various sized particles showed that this size gave the most consistent results, so far as pouring and compaction were concerned. As a preliminary test an old corroded water pipe, which was sufficiently rough to resemble the wall of a hole in the soil, about 1.5 inches in diameter and 5 feet in length, was placed upright and filled with the sand, which was poured continuously from a 500-ml. graduated cylinder through a funnel with an opening of about three-eighths of an inch. The same funnel was used to fill the cylinder with sand. An effort was made to pour the sand into the cylinder in a continuous and uniform stream until it was almost full. The remaining portion was filled by hand, extreme care being used to prevent jarring, as the least blow would have caused the sand to settle. Repeated trials showed that the milliliters of sand used in filling the pipe multiplied by 0.9501 gave the correct volume, within reasonable limits, which had been previously determined with water. However, this factor was not used in making volume-weight calculations, because it was thought that the inside of the pipe was not exactly like the holes in the soil, so far as roughness was concerned. The factors used in the tests were calculated from the field work, that is, the total dry weight of the samples was divided by the average volume weight, as determined by the cylinder method, and this figure was divided by the total cubic centimeters of sand; the resulting figure was the correction factor. The number of cubic centimeters of sand for each sample was then multiplied by this factor to secure the volume weights of each sample.

The auger employed in making the holes when the rubber-tube method, the viscous-fluid method, and the sand method were used was made of a 1.5-inch wood bit welded to about 5 feet of ½-inch water pipe with a T joint at the top and with 8-inch pieces of pipe for a handle.

The soil in which tests were made was extremely variable in structure and texture and is classed as Gila clay adobe.[8] The surface soil for a depth of 18 to 20 inches was a clay adobe. Below this was a 4-inch layer of silty fine sand; then a layer about 6 inches in thickness composed of an intermingling of sand, silt, and adobe. Next was a 1-inch layer of fine tight clay, and then about 30 inches of material varying from adobe with accumulations of sand at the top to clean medium sand at the bottom. The change in texture from the top to the bottom of this layer was gradual.

To facilitate the making of these tests a trench was dug 2.5 feet wide, 6 feet deep, and about 20 feet long. Ten groups of tests were made along one side of this trench, all of which were included in an area about 18 feet long and 2.5 feet wide. Ten tests were made with the cylinder, 20 with the soil tube, 20 with sand, 20 with oil, and 20 with the rubber tube. The holes used for sand were first used for the

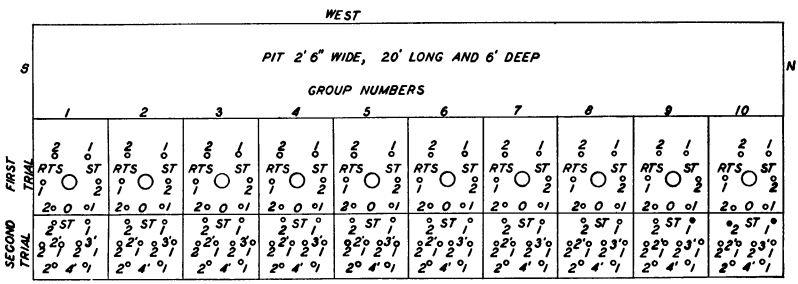

FIGURE 2.—Arrangement of pit, groups, and holes used in both trials. The sand method was used on the last two rows. See text for explanation

rubber-tube method. Figure 2 shows the arrangement of groups, holes, and pit.

The pit was dug so that as little soil as possible would be disturbed in taking the samples for the cylinder method. A large number of samples were taken in a very small area and theoretically there should have been very little difference in the soils from different groups. In the center of each group and about 18 inches from the edge of the pit a place was marked for the cylinder-method sample. On the east side of each group two holes were marked O for the oil method. On the northwest side two holes were marked ST for the soil-tube method, and on the southwest side two were marked RTS for the rubber-tube and sand methods. The holes in each group were from 4 to 6 inches apart and about 6 inches from the hole used for the cylinder method. The oil holes were placed on the far side from the pit so that the oil could be drained out after the cylinder-method sample had been taken and then used for the next set of holes. In doing this a small amount of sand accumulated in the oil, which probably changed its specific gravity and resulted in a lower volume-weight figure. However, this practice did not affect the spread of the results, since both the highest and lowest volume-weight figures were obtained from holes in which new oil was used.

The holes for the oil method, sand method, and rubber tube method were all made with the auger described above. The holes for the soil tube method were made with the improved soil tube. No

[8] NELSON, J. W., and HOLMES, L. C. SOIL SURVEY OF MESILLA VALLEY, NEW MEXICO-TEXAS. U. S. Dept. Agr., Bur. Soils Field Oper. 1912, Rpt. 14: 2011-2045, illus. 1915.

attempt was made to take any of these samples in foot sections. The soil tube was inserted in each hole from three to five times in taking the entire sample. When the cylinder method was used the samples were taken in 1-foot sections and the five weights totaled with the five volumes in making the volume-weight calculations. An attempt was made to take all samples for all methods to a depth of 60 inches, but with the cylinder method a slightly greater depth was obtained, although not enough to affect the results. The holes for the oil, soil tube, sand, and rubber-tube methods were made first, then the cylinder for the cylinder method was driven down 1 foot and excavated with a pick, chisel, saw, and shovel. It was found that very little if any compaction resulted from the use of the cylinder. Standard level marks were established with a stake about 2 feet from these holes, so that accurate measurements could be made on the depth of each sample. All of the soil taken from each hole was dried at about 105° C. and volume-weight calculations were made after the necessary correction factors had been applied. Table 1 shows the volume weights obtained by the different methods.

EXPERIMENTAL DATA

The results obtained by the cylinder method are more uniform and consistent than those obtained by the other methods and it is believed that they are accurate and reliable; therefore, they are used as the standard by which the results from the other methods are compared with it as a standard.

TABLE 1.—*Individual soil volume-weight determinations made by different methods*

[First group of tests]

Group No.	Hole No.	Soil volume weight as determined by method indicated					
		Cylinder	Sand	Improved soil tube		Rubber tube	Viscous fluid
				First trial	Second trial		
1	1	1.45	1.48	1.28	1.33	1.35	1.05
1	2		1.48	1.38	1.38	1.39	1.86
2	1	1.45	1.26	1.44	1.40	1.20	1.19
2	2		1.36	1.43	1.38	1.29	1.05
3	1	1.42	1.51	1.43	1.42	1.40	1.33
3	2		1.49	1.38	1.39	1.37	1.23
4	1	1.45	1.40	1.39	1.39	1.35	1.32
4	2		1.45	1.30	1.37	1.38	1.25
5	1	1.45	1.46	1.43	1.42	1.39	1.26
5	2		1.47	1.41	1.40	1.38	1.21
6	1	1.44	1.45	1.35	1.40	1.36	1.27
6	2		1.40	1.42	1.41	1.40	1.31
7	1	1.42	1.45	1.37	1.28	1.37	1.26
7	2		1.48	1.23	1.17	1.30	1.29
8	1	1.41	1.39	1.36	1.34	1.30	1.30
8	2		1.44	1.35	1.34	1.33	1.24
9	1	1.39	1.42	1.33	1.38	1.34	1.28
9	2		1.43	1.38	1.35	1.35	1.28
10	1	1.39	1.38	1.38	1.32	1.29	1.31
10	2		1.44	1.36	1.34	1.36	1.31
Average		1.43±0.005	1.43±0.008	1.37±0.008	1.36±0.008	1.34±0.007	1.28±0.023

These tests were located, unavoidably, at right angles to and a short distance from a row of young shade trees. In making these determinations it was noticed that the roots increased in number from the first to the last group, and it is probable that the decrease shown in the volume weights for the cylinder method is due to this factor. However, this condition was not so noticeable where the other methods were used, probably because the smaller instruments had a tendency to spread the roots rather than cut them off. Also a little more variation might have been secured if 20 determinations had been made instead of 10.

The determinations by the sand method, because of the correction factor used, gave the same average result as the cylinder method, but more variation was in evidence. The results obtained by the improved soil-tube method, shown in the fifth and sixth columns of Table 1, are about as variable as those obtained by the sand method, but are lower than those secured both by the cylinder and the sand methods. The results from the improved soil-tube method, shown in the fifth column, were secured from the first trial. The variation is about the same as for the sand method, but the average volume weight is lower than for the cylinder method. In order to check these data a second test was made, the results of which are shown in the sixth column. The average results for the second trial were practically the same as for the first and the variation was practically the same. This method is convenient and rapid, and it is probable that were the results multiplied by 1.0476, an accurate value would be secured. The results from the rubber-tube method were about the same as for the improved soil-tube method, but lower than for the cylinder method, and showed considerably more variation. Apparently a correction factor should be used in connection with this method to secure reliable results. The viscous-fluid method (where 600 W. oil was used) gave a low average volume weight with considerable variation in the individual determinations, and for this reason can not be recommended for use under such conditions as prevailed in these experiments.

Only half as many determinations were made by the cylinder method as by the others, and it would hardly be proper to compare 10 cylinder-method tests with 20 for the other methods. It was for this reason that Table 2 was prepared. Section A of this table shows the average volume weights, standard deviation, coefficient of variation, highest volume weight, lowest volume weight, and spread for all determinations for the various methods. Section B shows the same comparisons as section A, except that a summary of data from holes numbered 1 is used. In section C a summary of data from holes numbered 2 from all except the cylinder method was used. The first column of figures in the three sections of this table is the same, as duplicate holes were not used in connection with this method. A glance at section A shows that the cylinder method gave more satisfactory results than the others and that the viscous-fluid method gave the least reliable results. In section B, where only 10 determinations for each method were considered, the cylinder method also appears reliable and satisfactory, as compared with the other methods. The viscous-fluid method appears to be the least reliable, since the average volume-weight figure is very low and the spread, standard deviation, and coefficient of variation are all higher than for the other methods. The sand method, the improved soil-tube method, and the rubber-tube method are about the same so far as standard deviation and coefficient of variation are concerned.

The sand method presents more spread in the data than either of the other two in this section. In section C the same comparisons are made. The sand method is found to present less spread than the improved soil-tube method and it also shows a very small coefficient of variation. The viscous-fluid method appears to be very unsatisfactory in this section, because of the lack of consistency in the data.

TABLE 2.—*Comparisons of results obtained in soil determinations using various volume-weight methods*

SECTION A

	Values [a] given by the method indicated					
	3.61-inch cylinder	Sand	Improved soil tube		Rubber tube	Viscous fluid
			First trial	Second trial		
Trials, number	10	20	20	20	20	20
Average volume weights	1.43±0.005	1.43±0.008	1.37±0.008	1.36±0.008	1.34±0.007	1.28±0.023
Standard deviation	.0235	.0557	.0529	.0566	.0480	.1529
Coefficient of variation, per cent	1.64	3.90	3.86	4.16	3.58	11.95
Highest volume weight	1.45	1.51	1.44	1.42	1.40	1.86
Lowest volume weight	1.39	1.26	1.23	1.17	1.20	1.05
Spread	.06	.25	.21	.25	.20	.81

SECTION B

Trials, number	10 (No. 1)	10 (No. 1)	10 (No. 1)	10 (No. 1)	10 (No. 1)	10 (No. 1)
Average volume weights	1.43±0.005	1.42±0.010	1.38±0.010	1.37±0.010	1.34±0.012	1.26±0.017
Standard deviation	.0235	.0469	.0480	.0447	.0557	.0787
Coefficient of variation, per cent	1.64	3.30	3.48	3.26	4.16	6.25
Highest volume weight	1.45	1.51	1.44	1.42	1.40	1.33
Lowest volume weight	1.39	1.26	1.28	1.28	1.20	1.05
Spread	.06	.25	.16	.14	.20	.28

SECTION C

Trials, number	10 (No. 1)	10 (No. 2)	10 (No. 2)	10 (No. 2)	10 (No. 2)	10 (No. 2)
Average volume weights	1.43±0.005	1.44±0.006	1.36±0.012	1.35±0.014	1.36±0.008	1.30±0.042
Standard deviation	.0235	.0265	.0574	.0648	.0361	.1990
Coefficient of variation, per cent	1.64	1.84	4.22	4.80	2.65	15.31
Highest volume weight	1.45	1.49	1.43	1.41	1.40	1.86
Lowest volume weight	1.39	1.36	1.23	1.17	1.29	1.05
Spread	.06	.13	.20	.24	.11	.81

[a] Formula used:

Standard deviation, $SD=\sqrt{\frac{\Sigma d^2}{n}}$

Coefficient of variation, $CV=\frac{SD\times 100}{m}$. d=deviation; n=number of items; m=mean.

Probable error of mean$=\frac{0.6745\times SD}{\sqrt{n}}$

A comparison of the three sections of this table indicates that there is little, if any, difference between the improved soil-tube method, the sand method, and the rubber-tube method so far as consistency of the data is concerned; and apparently a correction factor should be applied, to secure correct results, where any one of these methods is used. Since sections B and C show some differences in the results from duplicate sets of holes, it appears that at least 10 determinations should be made on soils of this type to obtain reliable results.

After the tests described above were finished and the calculations made, it was thought wise to make further experiments with the sand method. Apparently this method is as accurate and reliable as any except the cylinder method, and it can be used in places where the improved soil-tube method is not practical. Therefore, additional tests for 2, 3, and 4 feet were made in order to determine the correction factor for these depths.

A comparison of the results from all tests with the sand and cylinder methods for the same depths is presented in Table 3. The correction factors shown were computed in the same manner as the correction factor described above. The factors for depths of 3, 4, and 5 feet are about the same, but the one for the first 2 feet is a little large, for no apparent reason.

TABLE 3.—*Individual soil volume-weight determinations made by cylinder and sand methods at various depths*

[Second group of tests]

Group No.	Hole No.	Volume weights, for—							
		First 2 feet by—		First 3 feet by—		First 4 feet by—		First 5 feet by— [a]	
		Cylinder method	Sand method	Cylinder method	Sand method	Cylinder method	Sand method	Cylinder method	Sand method
1	1	1.46	1.41	1.48	1.48	1.45	1.39	1.45	1.48
1	2		1.45		1.39		1.38		1.48
2	1	1.43	1.55	1.44	1.48	1.44	1.43	1.45	1.26
2	2		1.50		1.29		1.44		1.36
3	1	1.44	1.49	1.44	1.54	1.41	1.49	1.42	1.51
3	2		1.49		1.41		1.47		1.49
4	1	1.45	1.37	1.46	1.49	1.45	1.48	1.45	1.40
4	2		1.34		1.48		1.51		1.45
5	1	1.43	1.40	1.43	1.52	1.43	1.33	1.45	1.46
5	2		1.48		1.44		1.44		1.47
6	1	1.42	1.47	1.43	1.50	1.43	1.46	1.44	1.45
6	2		1.37		1.42		1.39		1.40
7	1	1.40	1.26	1.40	1.46	1.40	1.32	1.42	1.45
7	2		1.31		1.45		1.50		1.48
8	1	1.37	1.42	1.38	1.29	1.39	1.37	1.41	1.39
8	2		1.45		1.34		1.36		1.44
9	1	1.36	1.44	1.37	1.29	1.37	1.34	1.39	1.42
9	2		1.28		1.31		1.37		1.43
10	1	1.30	1.35	1.33	1.38	1.36	1.37	1.39	1.38
10	2		1.40		1.44		1.36		1.44
Average		1.41 ±0.010	[b]1.41 ±0.011	1.42 ±0.009	[b]1.42 ±0.012	1.41 ±0.007	[b]1.41 ±0.009	1.43 ±0.005	[b]1.43 ±0.008

[a] The figures in these two columns were taken from Table 1.
[b] The correction factor for the sand method is 0.9195 for the first 2 feet, 0.8800 for the first 3 feet, 0.8744 for the first 4 feet, and 0.8763 for the first 5 feet.

Comparisons of these data on the basis of 10 tests each are shown in Table 4 and divided into three sections as in Table 2. Table 4 shows that the results obtained by the cylinder method are more consistent than those obtained by the sand method. However, the results with the sand method in this trial are consistent with those in the first. Apparently this method can be used with a fair degree of accuracy for at least 5 feet in depth.

TABLE 4.—*Comparisons between results obtained in soil volume-weight determinations for different depths, using the cylinder and sand methods*

	Values for the—							
	First 2 feet by—		First 3 feet by—		First 4 feet by—		First 5 feet by—	
	Cylinder method	Sand method	Cylinder method	Sand method	Cylinder method	Sand method	Cylinder method	Sand method
SECTION A								
Trials, number	10	20	10	20	10	20	10	20
Average volume weight	1.41 ±0.010	1.41 ±0.011	1.42 ±0.009	1.42 ±0.012	1.41 ±0.007	1.41 ±0.009	1.43 ±0.005	1.43 ±0.008
Standard deviation	.0471	.0755	.0434	.0781	.0308	.0583	.0235	.0557
Coefficient of variation, per cent	3.34	5.35	3.06	5.50	2.18	4.13	1.64	3.90
Highest volume weight	1.46	1.55	1.48	1.54	1.45	1.51	1.45	1.51
Lowest volume weight	1.30	1.26	1.33	1.29	1.36	1.32	1.39	1.26
Spread	.16	.29	.15	.25	.09	.19	.06	.25
SECTION B								
Trials, number	10 (No. 1)	10 (No. 1)	10 (No. 1)	10 (No. 1)	10 (No. 1)	10 (No. 1)	10 (No. 1)	10 (No. 1)
Average volume weight	1.41 ±0.010	1.42 ±0.016	1.42 ±0.009	1.44 ±0.018	1.41 ±0.007	1.40 ±0.013	1.43 ±0.005	1.42 ±0.010
Standard deviation	.0471	.0762	.0434	.0866	.0308	.0600	.0235	.0469
Coefficient of variation, per cent	3.34	5.37	3.06	6.01	2.18	4.29	1.64	3.30
Highest volume weight	1.46	1.55	1.48	1.54	1.45	1.49	1.45	1.51
Lowest volume weight	1.30	1.26	1.33	1.29	1.36	1.32	1.39	1.26
Spread	.16	.29	.15	.25	.09	.17	.06	.25
SECTION C								
Trials, number	10 (No. 1)	10 (No. 2)	10 (No. 1)	10 (No. 2)	10 (No. 1)	10 (No. 2)	10 (No. 1)	10 (No. 2)
Average volume weight	1.41 ±0.010	1.41 ±0.016	1.42 ±0.009	1.40 ±0.013	1.41 ±0.007	1.42 ±0.012	1.43 ±0.005	1.44 ±0.006
Standard deviation	.0471	.0748	.0434	.0600	.0308	.0548	.0235	.0265
Coefficient of variation, per cent	3.34	5.30	3.06	4.29	2.18	3.86	1.64	1.84
Highest volume weight	1.46	1.50	1.48	1.48	1.45	1.51	1.45	1.49
Lowest volume weight	1.30	1.28	1.33	1.29	1.36	1.36	1.39	1.36
Spread	.16	.22	.15	.19	.09	.15	.06	.13

SUMMARY

This paper reports a comparative study of five different methods of determining soil-volume weights. These tests were made on Gila clay adobe to a depth of 5 feet, and the conclusions are based on the study of only this particular soil.

Ten determinations were made with the cylinder method, 20 with the viscous-fluid method, 20 with the rubber-tube method, 40 with the improved soil-tube method, and 80 with the sand method. In all, 170 determinations were made in an area about 20 by 2½ feet.

The cylinder method gave reliable and satisfactory results.

The viscous fluid method gave such variable results that it can not be recommended for such conditions as prevailed in these experiments.

The sand, rubber-tube, and improved soil-tube methods rank about the same so far as the variability of the results is concerned. To secure accurate results with these methods, a correction factor should be used.