A Study of In-Place Density Determinations For Base Courses and Soils

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The study reported here was undertaken to determine the amount of error inherent in several methods used by various organizations for measuring in-place density of base courses and soils. Four methods were studies: (a) sand-displacement, (b) water-balloon, (c) oil-displacement, and (d) drive cylinders. A laboratory procedure was devised for comparing the accuracy of the equipment under controlled conditions, and field tests were performed to compare the methods under field conditions.

Only the sand-displacement and water-balloon methods could be used in the laboratory tests. The test results indicated that the equipment could be arranged as follows in order of decreasing accuracy: sand-density cylinders, glass jar and cone, Washington Dens-O-Meter, glass jar and funnel, and Reinhart water-balloon. It was indicated that maximum variations from the actual density of about 1 lb per cu ft could be expected from the sand-density cylinders and 9 lb per cu ft from the Reinhart water-balloon.

Field tests bore out the laboratory tests, in general, but indicated that a little less accuracy could be expected under field conditions. The sand-density cylinders showed a maximum variation from the actual density of slightly less than 3 lb per cu ft; the other equipment showed slightly greater or no greater variations from the actual than the laboratory tests had indicated. The oil-displacement method was found to be generally unsatisfactory. Drive cylinders were considered satisfactory for moist clays and silts.

●IT is necessary to determine the in-place density of soils in almost all types of earthwork. Several methods have proved to be reasonably satisfactory for determining the in-place density of fine-grained materials, but many difficulties have been encountered in determining density of coarse materials, particularly those used as base courses in airfield and highway pavements. A study was undertaken at the Waterways Experiment Station to determine the amount of error inherent in certain apparatus and methods in general use and to examine the technique for using them in the field. This paper describes the methods used to evaluate the apparatus and test procedures and presents the results of the evaluations.

The study was conducted under the direction of the Chief of Engineers in connection with investigations of airfield pavements being accomplished for the U. S. Air Force. T. B. Pringle and F. B. Hennion of the Airfields Branch, Office of the Chief of Engineers, monitored the study. The field and laboratory work was accomplished by the Corps of Engineer's Flexible Pavement Branch, Waterways Experiment Station, Vicksburg, Miss., under the general supervision of W. J. Turnbull, C. R. Foster, and O. B. Ray, and was under the direct supervision of the author. A report entitled, "A Study of In-Place Density Determinations for Soils" was published by the Waterways Experiment Station in October 1955 which described the detailed study of each of the items in this investigation, except the Washington Dens-O-Meter which was tested subsequent to the publication of the report.

APPARATUS AND METHODS

Included in the investigation were density determinations using the following apparatus and methods:

1. Small water-balloon apparatus;
2. Washington Dens-O-Meter;

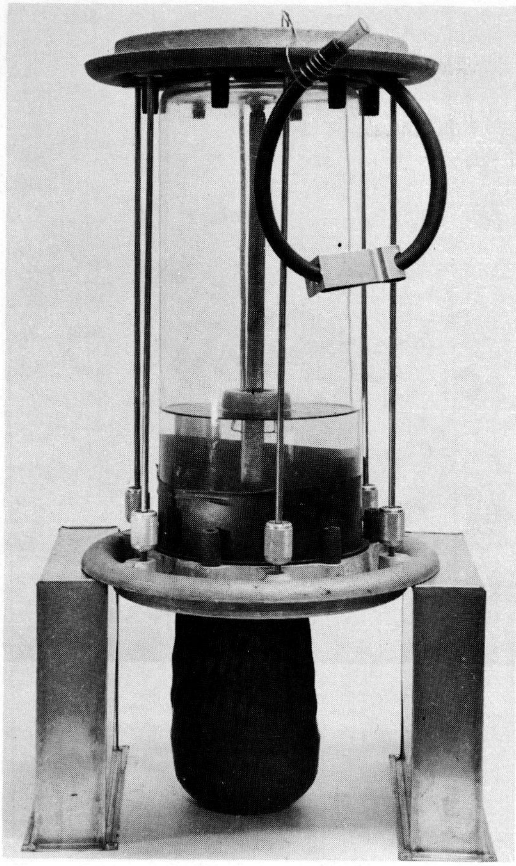


Figure 1. Small water balloon.

3. Glass jar and funnel;
4. Glass jar and cone;
5. 7-in. sand-density cylinder;
6. 10-in. sand-density cylinder;
7. Drive cylinders; and,
8. Oil-displacement method.

Items 1 through 6 were studied in the laboratory in the initial phase of the investigation. The second phase of the study consisted of field tests to investigate testing techniques and evaluate the apparatus and methods under field conditions. A brief description of each piece of apparatus or method is presented in the following paragraphs.

Small Water-Balloon. The water-balloon apparatus (Figure 1) consists of a glass cylinder which holds water, a rubber-membrane "balloon" attached to the cylinder, a scale graduated in cubic feet, and a rubber tube for applying air pressure. The diameter of the cylinder is about 8 in.; the height, 18 in.; and the length of the balloon, about 12 in. The surface of the ground may be "calibrated" with this apparatus to take into account the surface irregularities by making a determination on the area where the sample is to be taken before digging starts.

Washington Dens-O-Meter. This is another type of water-balloon device (Figure 2). Pressure is applied to the water by a piston which causes the balloon to fill the available space. The piston rod is calibrated in cubic feet. The original ground surface may be calibrated with this apparatus. Standard rings are used with the apparatus when calibrating the original ground surface so as to provide a volume about equal to that contemplated in the hole. This keeps the tension in the balloon about constant in all phases of the test.

Figure 2. Washington Dens-O-Meter.

Glass Jar and Funnel. This apparatus consists of a standard screw-top glass jar capped with a small funnel. No calibration of the ground surface can be made with this apparatus. The volume is determined by pouring sufficient calibrated sand from the jar, held at approximately a constant height, to fill the hole.

Glass Jar and Cone. This is also a sand-displacement type apparatus and is composed essentially of a 60-deg double-cone assembly fitted to a standard screw-top jar. The assembly consists of a bottom cone, 4. 75 in. in diameter at the

base; a ⅜-in. valve; and a top cone which is threaded for the screw-top jar. The surface of the ground may be calibrated with this apparatus.

Sand-Density Cylinders. These are sand-displacement type devices. Two sizes of cylinders were used; one is approximately 7 in. in diameter and 10 in. high, and the other is 10 in. in diameter and 10 in. high. A 7-in. diameter sand-density cylinder is shown in Figure 3. The identical cones have slopes of 45 deg and are joined at the apexes by a ¾-in. valve. The bottom cone fits into a recess in a metal plate which is placed over the area to be tested. The cylinder is made of Plexiglas and the cones are made of sheet metal. A transparent cylinder is considered highly desirable so that the movement of sand and condensation of moisture may be observed. By filling the cylinder with sand and weighing the filled cylinder, the sand can be calibrated before each test, which eliminates one possible source of error. The method of using the apparatus is the same as that of the glass jar and cone assembly. The sand-density cylinder and test procedure are slight modifications of those developed under the supervision of R. R. Proctor of the Department of Water and Power, Los Angeles, California.

Drive Cylinders. In this method, relatively undisturbed samples are obtained by driving short sections of 3-in. Shelby tubing into the ground with a special hammer. Their use is obviously limited to fine-grained materials.

Oil-Displacement Method. The volume of the hole from which a sample is taken is determined by filling with oil in the oil-displacement method. It is not practical to calibrate the original ground surface with this method.

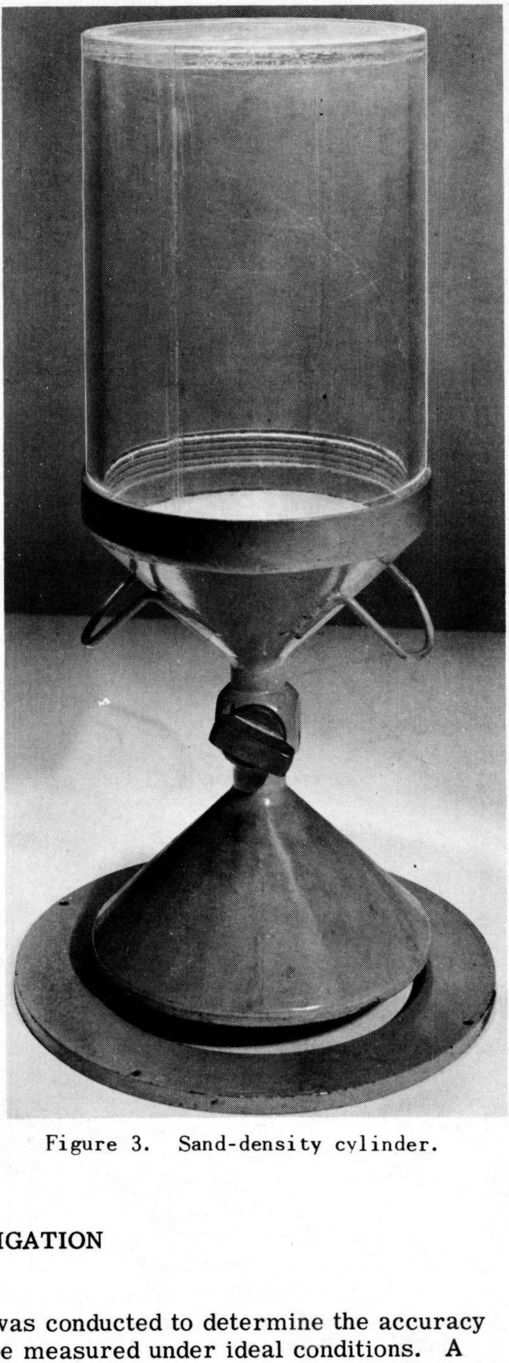


Figure 3. Sand-density cylinder.

THE INVESTIGATION

Laboratory Tests

Test Procedures. The laboratory phase was conducted to determine the accuracy with which the volume of a given hole could be measured under ideal conditions. A group of five holes, similar to those found in prototype conditions, was formed in concrete blocks. In addition, a cylindrical hole was cut in a large wooden block, and a 4-in. diameter compaction mold was used where possible. The sizes of the holes, textural description, and prototype simulated are given in Table 1. Figure 4 shows three of the holes used (Nos. 2, 3, and 4). The sides and bottoms of the holes were coated with a waterproofing material and the actual volumes of the holes were determined using water, except that the volume of hole 5 was computed from dimensional measurements.

TABLE 1

Hole No.	Approx. Hole Size: Diameter, in.	Approx. Hole Size: Depth, in.	Actual Volume, cu ft	Material and Texture Used in Forming Hole	Prototype Simulated
1	6.0	5.0	0.0550	Concrete, gritty	Sandy subgrade
2	7.0	6.0	0.0802	Concrete, smooth	Clay subgrade
3	6.0	6.0	0.0629	Concrete, very rough	Stone base
4	6.0	6.0	0.0683	Concrete, rough	Gravel base
5	4.0	4.5	0.0335	Steel compaction mold, smooth	None
6	4.6	5.0	0.0460	Wood, smooth	None
7	9.4	7.0	0.2990	Steel-lined concrete block, smooth	None

Volume measurements were made on these holes with as many pieces of apparatus as possible and by several technicians using each piece independently. The tabulation below indicates the apparatus used on each hole.

TABLE 2

Hole No.	Small Water Balloon	Washington Dens-O-Meter	Glass Jar and Funnel	Glass Jar and Cone	7-in. Sand-Density Cylinder	10-in. Sand-Density Cylinder
1	X		X		X	
2	X	X	X		X	X
3	X	X	X		X	
4	X	X	X		X	
5				X	X	
6				X	X	
7						X

The drive cylinder did not lend itself to laboratory testing. Also, the oil-displacement was not tested in the laboratory because this would merely be a duplication of the determination of the volumes of the holes with water.

Analysis of Data. Figure 5 illustrates the method of analysis used to compare the measured volumes of the holes with the actual volumes and also presents the results of tests with the small water-balloon apparatus. For purposes of analysis, a line has been drawn at 45 deg through the origin to indicate the locus of points at which the measured and actual volumes are equal. Points falling above the line represent determinations greater than the actual volume, while those falling below the line represent values less than the actual volume. The extreme variations of the measured volumes from the actual volumes within which 90 percent of the values fell were determined and expressed as a ratio of the measured to the actual volume. These values are shown on Figure 6 for all the apparatus tested in the laboratory. The maximum variation of the measured values from the actual in percentage of the actual volumes is summarized from Figure 6 in the following table. It is apparent that the greatest degree of accuracy was obtained

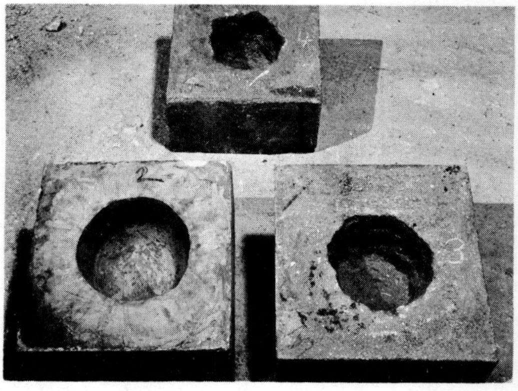


Figure 4. Concrete blocks containing holes 2, 3, and 4.

TABLE 3

Apparatus	Maximum Variation from Actual Volume Percent
Small water-balloon	7
Washington Dens-O-Meter	3
Glass jar and funnel	4
Glass jar and cone	2
7-in sand-density cylinder	1
10-in sand-density cylinder	1

in the laboratory with the sand-density cylinders. It is also noted on Figure 6 that the variations of the values obtained with the sand-density cylinders were about the same above and below the actual values. The variations of the values obtained with other apparatus were not distributed symmetrically about the actual value. This indicates that the average of a number of values obtained with the sand-density cylinders would probably fall near the actual value, whereas an average based on tests with other apparatus would probably fall away from the actual value.

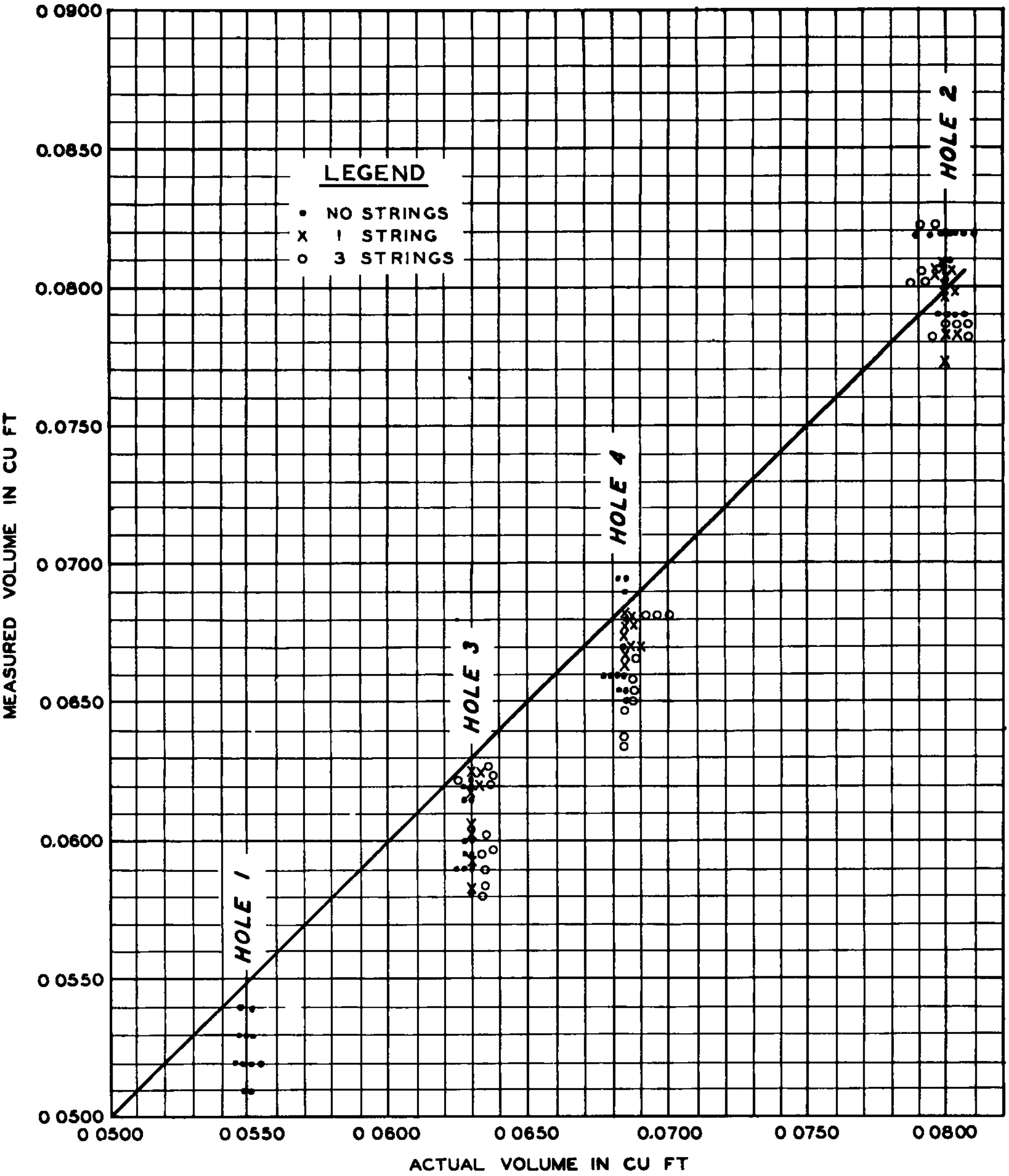


Figure 5. Volume measurements (water balloon).

Initial tests with the small water-balloon showed that the volumes measured were generally smaller than the actual volumes. Believing that pockets of entrapped air might be the cause of this, attempts were made to bleed this air from the pockets by placing small strings across the pockets. It is seen on Figure 5 that the use of strings appeared to bring the points closer to the actual volume in some cases.

Field Tests

Test Procedure (sand-density cylinder). Since it was found in the laboratory that the sand-density cylinder was the most accurate of the pieces of apparatus tested, the first program of field tests was performed with this apparatus to study techniques and later the results of tests with this apparatus were compared with those of other instruments. The study of techniques indicated that the cone should be placed on a metal plate recessed to fit the cone, and that the space under the inside of the plate should be filled with modeling clay. This procedure plus a calibration measurement of the surface made before the test hole was dug eliminated the obvious sources of error.

Comparison of Sand-Density Cylinder, Glass Jar and Funnel, and Drive Cylinders. Comparative tests were conducted in a lean clay which had been processed carefully

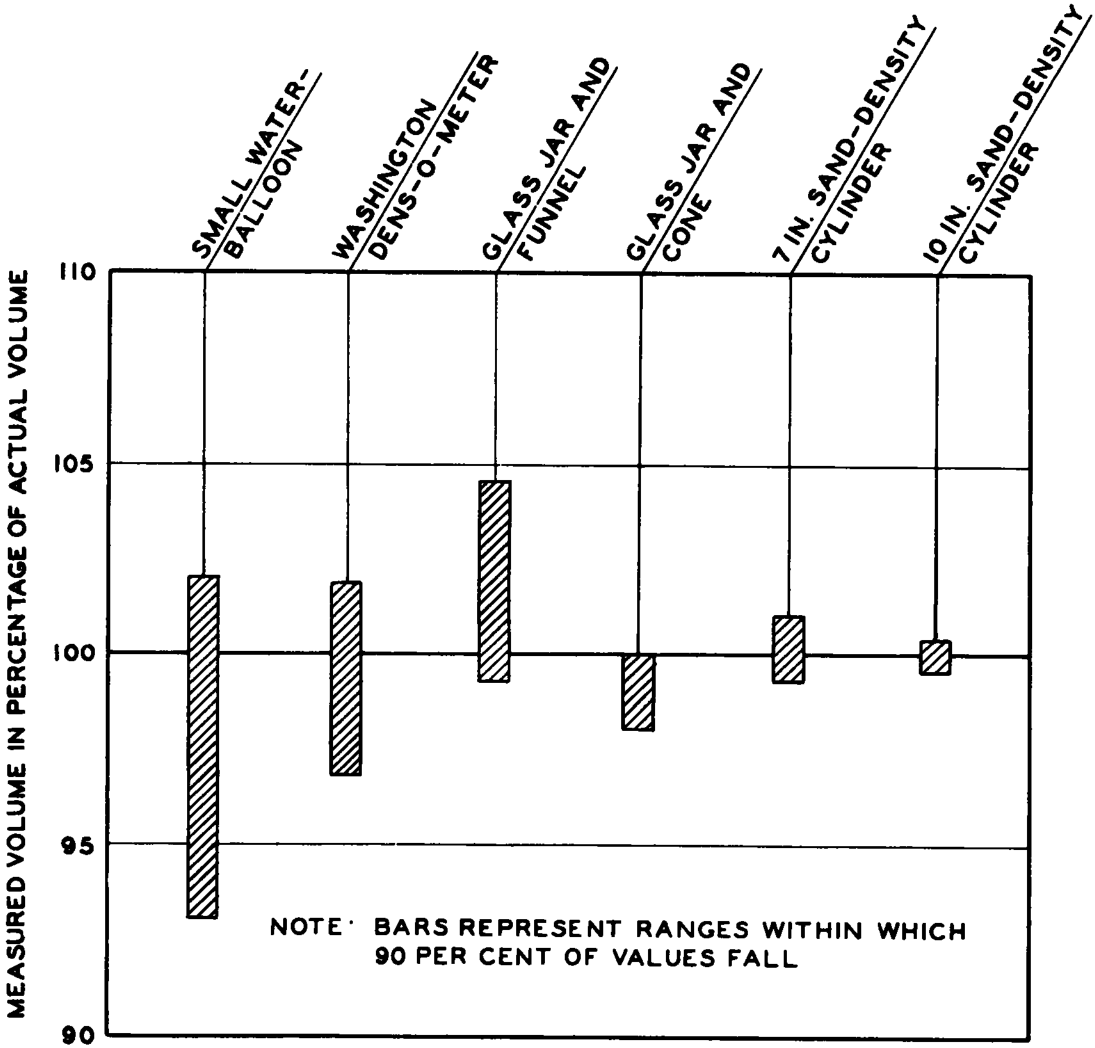
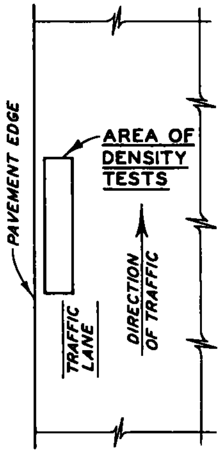


Figure 6. Comparison of accuracy of density apparatus.

	PAVEMENT EDGE / NO TRAFFIC	MODERATE OUTRIGGER TRAFFIC		INTENSE OUTRIGGER TRAFFIC	INTENSE OUTRIGGER AND LIGHT TRACTOR TRAFFIC	LIGHT OUTRIGGER AND TEST-WHEEL, AND INTENSE TRACTOR TRAFFIC
		LINE 1	LINE 2	LINE 3	LINE 4	LINE 5
ROW 1		137.5 Δ	141.1 O	144.9 □	140.9 Δ	147.1 O
ROW 2		138.5 O		140.2 Δ	138.8 O	143.8 O
ROW 3		139.6 □	143.1 Δ	144.3 O	147.1 O	145.2 O
ROW 4		139.7 Δ	147.1 O	142.6 □	146.1 O	150.5 Δ
ROW 5		141.7 O	143.9 □	149.4 Δ	146.5 O	157.6 O
ROW 6		143.2 □	140.6 Δ	148.7 O	147.4 O	154.4 O
ROW 7		143.3 Δ	146.8 O	146.7 □	152.5 Δ	156.3 O
ROW 8		144.6 O	153.2 □	153.5 Δ	153.2 O	153.3 O
ROW 9		150.5 □	148.3 Δ	153.3 O	154.3 O	155.7 O
ROW 10		150.9 Δ	153.0 O	155.0 □	154.6 O	154.5 O
ROW 11		152.7 O	151.5 □	153.9 Δ	154.0 O	155.0 Δ
ROW 12			149.4 Δ	154.3 O	143.9 O	154.0 O
ROW 13		145.7 Δ	148.0 O	158.8 □	158.1 Δ	156.2 O
ROW 14		139.8 O	152.2 □	151.8 Δ	151.4 O	156.7 O
ROW 15		147.6 □	148.1 Δ	149.1 O	145.5 O	151.4 O
ROW 16		141.9 Δ	148.5 O	152.0 □	141.5 O	140.8 Δ



LEGEND

□ GLASS JAR
O 7-IN. CYLINDER
Δ 10-IN CYLINDER

NOTE: FIGURES BESIDE TEST LOCATIONS ARE IN-PLACE DENSITY VALUES IN LB PER CU FT

LINES AND ROWS OF HOLES APPROXIMATELY 18 IN APART.

AREA OF DENSITY TESTS

Figure 7. In-place density tests (crushed limestone base course).

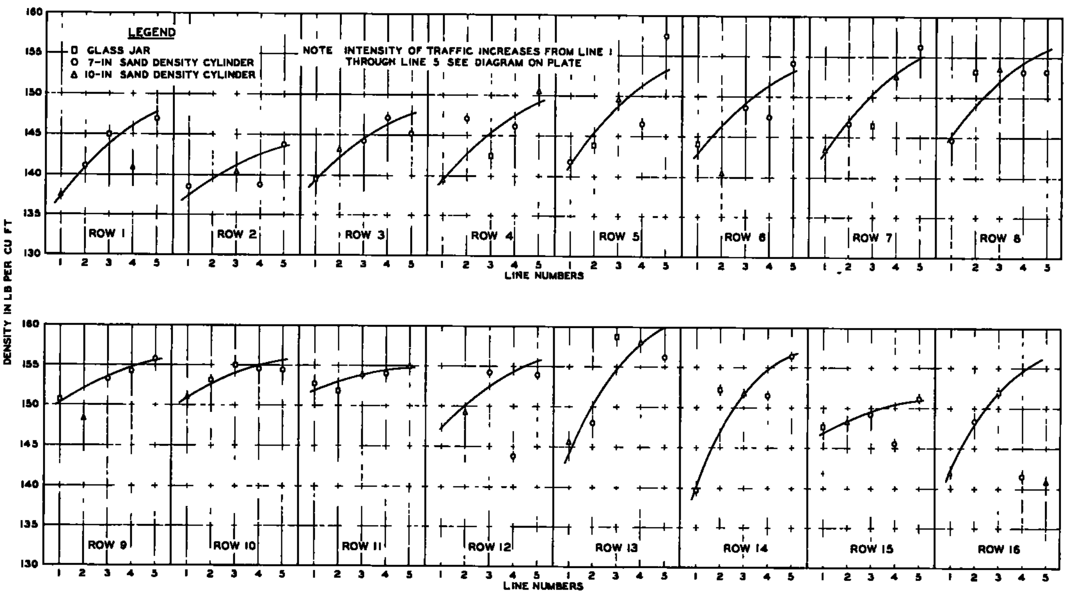


Figure 8. In-place density vs. location (crushed limestone).

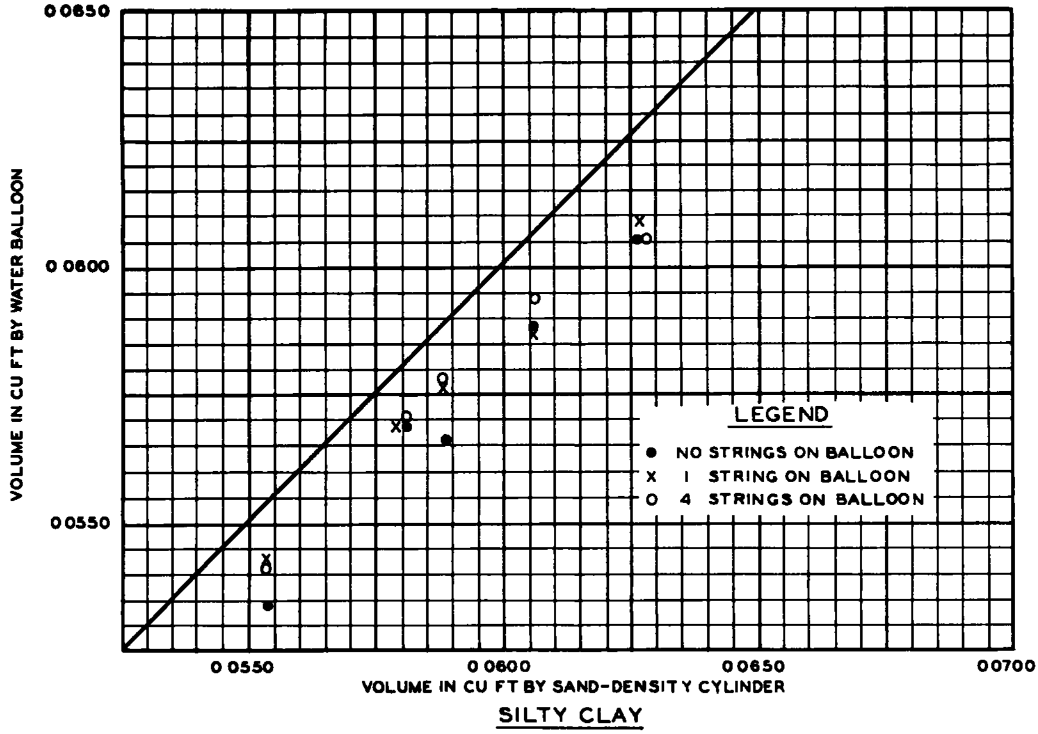
and compacted uniformly in an accelerated traffic test section. Results obtained with drive cylinders have been found to be reasonably accurate in clays.[1] Results of tests with sand-density cylinder in this material, glass jar and cone, and drive cylinders compared very favorably; the maximum difference in density determined by the three methods was 1.8 lb per cu ft over the area.

Comparison of Sand-Density Cylinders with Glass Jar and Cone. Tests with the 10- and 7-in. sand-density cylinders and the glass jar and cone were performed in the crushed-limestone base course of a flexible pavement test section. The maximum size of the material was 1½ in. The tests were performed in a grid pattern consisting of five lines and 16 rows as shown on Figure 7. The three pieces of apparatus were used at random over the area. Traffic increased in both intensity and load from line 1 to line 5. The test values obtained are shown on Figure 8, plotted against distance along the rows.

The density generally increased with the increase in compactive effort of traffic as shown by the curves on Figure 8. It is noted that 7 of the 16 points on line 4 varied considerably from the curves. Gradation determinations showed that the materials along line 4 were more coarsely graded than those along other lines, and examination of the section showed segregation of the aggregate at the base course construction joint on which line 4 fell. Several points at scattered locations on lines 2, 3, and 5 also lie away from the curve, and it is believed that they too represent significant differences in gradation. Deviations are probably a combination of experimental error and effect of gradation. Deviations of the points from the curves are summarized below by 1-lb-per-cu-ft groups. The exact amount of experimental error cannot be stated, but in the summation in Table 4, it is noted that there is a significant increase in the number of points in the 3- to 4-lb group as compared to the 2- to 3-lb group. On this basis, it is believed that the experimental error did not exceed about 3.0 lb per cu ft. On a volume basis, this is equivalent to about 2.5 percent error. The average experimental error was much less, since 75 percent of the samples showed less than 3-lb deviation from the curves.

Sand-Density Cylinders Versus Water-Balloon. A series of tests was performed on a test section of silty clay and one of crushed limestone with a maximum size of ¾ in.

[1] M.J. Hvorslev, "Subsurface Exploration and Sampling of Soils for Civil Engineering Purposes," p. 372, ff.



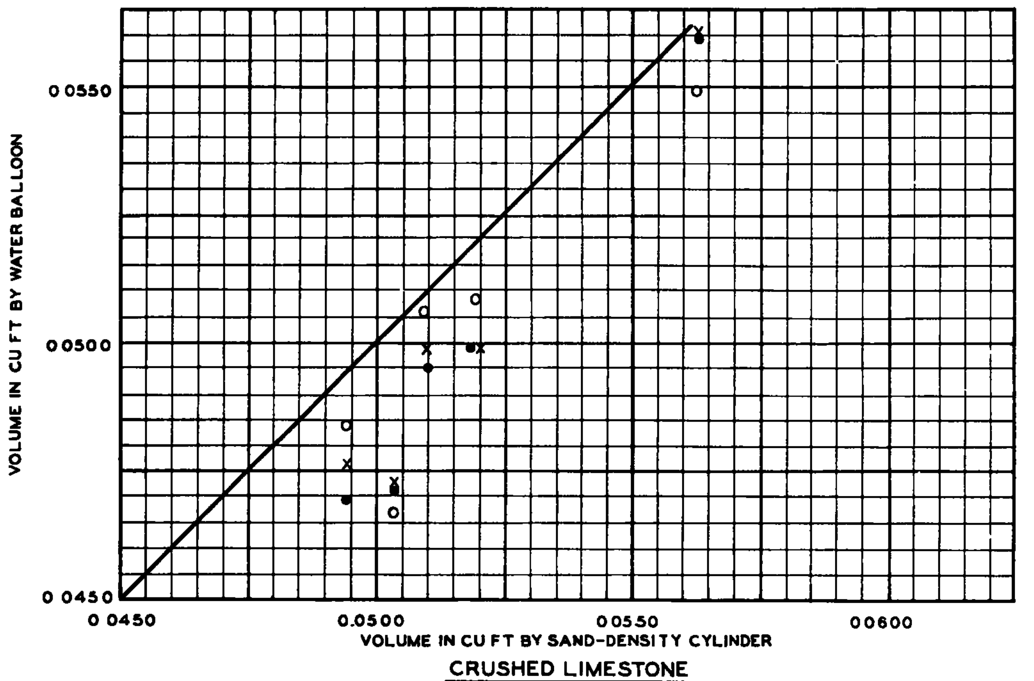


Figure 9. Comparison between water-balloon and 7-in. sand-density cylinder (in-place tests).

to compare the results of the water-balloon with those of the 7-in. sand-density apparatus and to check the feasibility of using strings to vent entrapped pockets of air in the water-balloon test. The results of the individual tests are shown on Figure 9. In all cases, the volumes determined by the water-balloon were less than those determined with the sand-density cylinder. Although the use of strings generally improved the results obtained with the water-balloon, the volumes obtained were still appreciably lower than those obtained with the sand-density cylinder. The water-balloon values ranged from 99.5 to 92.8 percent of the sand-density values. These represent differences in density of 1 to 9 lb per cu ft; the average in-place density of the silty clay was about 100 lb per cu ft and that of the crushed limestone was about 145 lb per cu ft. The only distinction found between tests in silty clay and limestone was that the results in the limestone were slightly more erratic.

TABLE 4

Deviation lb/cu ft	No in Group	Percent of Total
0.0 to 1 0	43	55
1 1 to 2 0	13	17
2.1 to 3 0	2	3
3.1 to 4 0	9	11
4 1 to 5.0	4	5
5 1 to 6.0	4	5
Above 6 0	3	4
Total	78	

Sand-Density Cylinder Versus Washington Dens-O-Meter. Density determinations were performed at a number of locations in a crushed-limestone base course with a maximum size of ¾ in. by measuring the volume of each hole with both the Washington Dens-O-Meter and the large sand-density cylinder. The volumes of the holes tested ranged from about 0.14 to about 0.17 cu ft. The volumes determined by the Washington Dens-O-Meter expressed as percentages of those determined by the sand-density cylinder ranged from 98.1 to 101.9. This represents a maximum difference in density values of 2.7 lb per cu ft in a material that had an average in-place density of about 152 lb per cu ft. The values measured by the Washington Dens-O-Meter ranged above and below those measured by the sand-density cylinder by approximately equal amounts. These differences are appreciably smaller than those found in the laboratory tests, and this is believed due to the larger volumes of holes tested in the field.

Oil-Displacement Method. The study of the oil-displacement method was performed in a dense-graded crushed-limestone base course with a maximum size of ¾ in. A total of 25 tests were performed using both sand-displacement and oil-displacement methods to determine the volumes of the holes. The holes were sprayed with a quick-drying lacquer to prevent loss of material during subsequent operations, and the volumes determined with the sand-density cylinder. The sand was then removed and the volumes determined with SAE 90-weight oil. The surface of the original ground was calibrated with the sand before the holes were dug, but this could not be done with the oil. Holes were filled with oil by pouring until the surface reached the average original ground surface elevation. The test results showed rather large differences in the volumes determined by the sand-displacement and the oil-displacement methods. The volumes determined by the oil-displacement method expressed as percentages of those determined by the sand-displacement method ranged from 90.0 to 112.9. About 70 percent of the volumes determined with oil were larger than those determined with sand. This indicates that in most cases either excessive leakage occurred, even though the holes were sprayed with lacquer, or the holes were overfilled with oil or both. Measurements of the elevation of the surface of the oil one minute from the time the hole was filled showed that appreciable amounts of leakage occurred after the hole was filled, and it is believed reasonable to assume that some leakage occurred during pouring. The moisture contents of the materials in these tests were low; additional tests in materials containing more moisture showed that no appreciable oil leakage occurred.

General. Observations during the digging of the holes in the crushed limestone showed that the walls of the holes were disturbed frequently unless considerable care was exercised. This disturbance always caused a decrease in the volume of the hole, which results in higher-than-actual density values.

SUMMARY

The results of the evaluations of the apparatus and methods may be summarized as follows:

1. The use of holes formed to simulate prototype conditions provides a laboratory method for evaluating the inherent accuracy of many pieces of testing apparatus.
2. Laboratory tests showed the apparatus to be accurate for determining the volumes of holes within the following tolerances:

Small water-balloon	7 percent
Washington Dens-O-Meter	3 "
Glass jar and funnel	4 "
Glass jar and cone	2 "
Sand-density cylinders	1 "

3. Field tests showed the accuracy of the sand-density cylinders to be within about 2.5 percent.
4. Care should be used to avoid disturbance to the walls when digging a hole.

Discussion

J.R. SALLBERG, Highway Physical Research Engineer, U.S. Bureau of Public Roads—The report by Mr. Redus on his study "to determine the amount of error inherent in certain apparatus and methods in general use..." for density determinations of base courses and soils is complete and leaves little room for discussion of the material presented. However the results of a somewhat similar study by the Division of Physical Research, Bureau of Public Roads, may help broaden the base for evaluating the accuracy of the various methods.

In-place density determinations of a dense-graded granular base were made using undisturbed samples, the oil-displacement method, and the sand-cone method. The average densities obtained were 133.5, 133.2, and 141.2 lb per cu ft, respectively. Because no oil leakage was observed and because the results obtained by the undisturbed sample method and the oil-displacement method checked each other so closely, it was concluded that under certain conditions of test the sand-cone method will result in excessively high densities.

TABLE 1

GRADATION ANALYSIS OF SAMPLES TAKEN FROM TEST AREA IN GRANULAR BASE

Sieve Size	Cumulative Percentage Passing Sieve			
	Sample 1-1	Sample 1-3	Sample 1-4	Sample 1-5
1½ in	100	100	100	100
1 in	99	99	100	99
¾ in	86	89	91	90
⅜ in	63	63	64	64
No 4	54	53	53	54
No 10	47	47	46	46
No 40	25	27	25	25
No 200	9	10	9	9

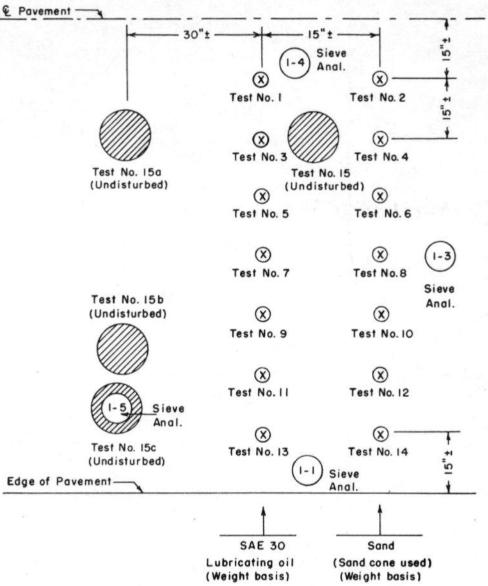
The relative locations of the tests in the study by the Bureau of Public Roads are shown in Figure 1, the gradation analyses in Table 1, and the results of the density tests in Table 2. Some details of the test procedures followed are given in the following.

To perform the tests, it was necessary to remove a 2-in. bituminous surfacing and the top ¾ in. or so of the base material into which the prime coat had penetrated (see Figure 2). It should be noted, in this connection, that the pictures here reproduced were taken at different locations, but over the same base. The resulting surface of the base was extremely rough and required special consideration in the testing procedures. The oil-datum ring was used with plaster of paris to establish a datum plane (Figure 3); then the sand-cone method, (Figure 4), was used to measure the volume between the datum plane and the surface of the base course, as tests had shown the sand-cone method suitable for measuring smooth-sided regular holes. The sand

TABLE 2

DRY DENSITY VALUES OBTAINED IN GRANULAR BASE

Undisturbed sample		Oil displacement		Sand-cone	
Test No	Dry density	Test No	Dry density	Test No	Dry density
	lb/cu ft		lb/cu ft		lb/cu ft
15	133 0	1	131 3	2	142 4
15a	131 7	3	132 2	4	141.3
15b	133 6	5	133 7	6	138.5
15c	135.5	7	133.9	8	140 7
		9	132 3	10	140 9
		11	134 6	12	142 6
		13	134.5	14	142 3
Avg	133.5		133 2		141.2



Note: Test holes approximately $4\frac{1}{2}$ inches in diameter and 12 inches deep.

Figure 1. Relative location of test holes in the granular base.

Figure 2. Leveling oil-datum ring.

was then removed and the hole excavated with considerable care; all the base course material was retained in a covered container for moisture content and dry weight determinations. The volume of the hole, to the top of the oil-datum ring, was then determined by either the sand-cone or the oil-displacement method. An undisturbed sample was obtained by digging a doughnut-shaped pit (Figure 5), leaving the center high and then trimming the center to the desired shape. The sample was progressively coated with paraffin as trimming continued from top to bottom. The volume of paraffin was computed from the weight of paraffin before and after coating.

The complicated routine described was necessary because of the very irregular surface and was intended to give each method a fair trial; it is not recommended as a standard construction inspection practice.

In addition to tests in the base material,

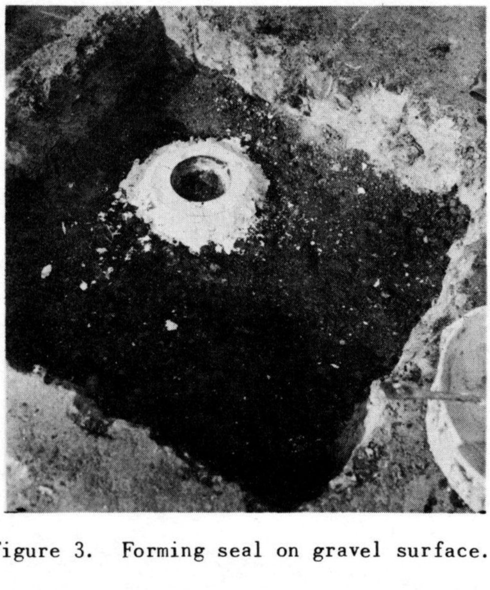


Figure 3. Forming seal on gravel surface.

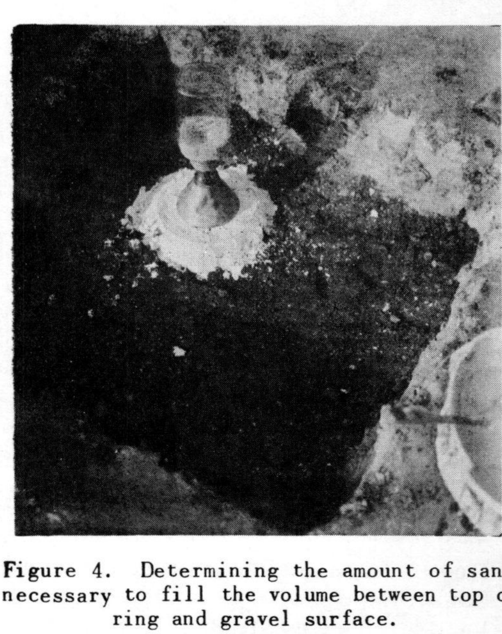


Figure 4. Determining the amount of sand necessary to fill the volume between top of ring and gravel surface.

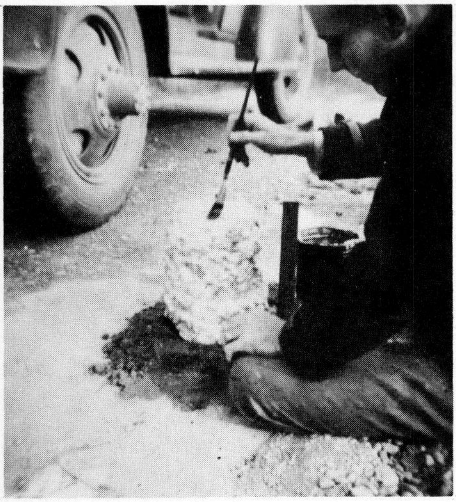


Figure 5. Undisturbed sample of gravel base course before removal (left) and after removal (right).

density determinations were made in the underlying clay embankment. Reasonable results were obtained by all methods—sand cone, SAE 30-weight oil, SC-2 cut-back asphalt, two different types of water pouch, and undisturbed sample.

The usefulness of the sand-cone method depends on how completely the sand fills the hole. This, in turn, seems to depend not only on the irregularities of the sides of the test hole due to rock projections and cavities left when rocks are pulled out, but also on the sandpaper-like roughness which may promote arching across those irregularities. This source of error can be reduced by increasing the diameter of the test hole.

H.W. HUMPHRES, Senior Materials Engineer, Washington State Highway Commission—The accuracy evaluation for the Washington Dens-O-Meter presented by Mr. Redus is in marked disagreement with the claims made in the original paper describ-

ing the unit[1], where it is stated that "results obtained with the Dens-O-Meter are of equal or greater accuracy than those obtainable by presently accepted standard field methods."

A re-check of the procedures and data used to establish those claims, and further tests duplicating in part the methods employed by Mr. Redus, lead to the conclusion that his tests did not evaluate properly the accuracy of the Dens-O-Meter. It is hoped that his data do not discourage the use of the Dens-O-Meter, as it is an excellent testing device.

The degree of error reported in the author's summary (3 percent) exceeds the original claims for accuracy by such a large amount that it was decided to try to duplicate the laboratory phase of Mr. Redus' tests to determine, if possible, the reasons for the discrepancies in results. Volume determinations were made on three "holes;" a smooth metal container (calibration "hat" for the large California sand-cone apparatus), a smooth hole in a concrete block, and a rough hole in a concrete block.

The surface of each concrete block was grouted with sand-cement slurry for a distance of 3 in. around the hole opening, and this surface was leveled as smoothly as possible to permit sealing the opening with a glass plate for making a precise determination of the hole volume with water. The inner surfaces of the pre-cast holes were sealed with shellac and their volumes determined by filling with water until total contact was made with the glass plate sealing the opening. Temperature correction factors were applied. The raised, smooth, level surfaces around the hole opening insured that the sand cone and Dens-O-Meter seated properly and in the same relative position each time.

For a normal density test using the Dens-O-Meter, an initial reading is made on the ground surface where the hole is to be dug, thus eliminating any possible error due to an uneven surface. In the laboratory, using pre-cast holes, this procedure is not possible, so the initial reading must be made on some flat surface that simulates the theoretical flat surface over the pre-cast hole. The potential for error due to this situation must be eliminated completely to duplicate actual field test conditions. It would be difficult to accomplish this without machine-finishing the surfaces; however, the degree of error can be minimized by taking the initial reading on a flat, circular ¾-in. plywood disk 3 in. larger in diameter than the opening in the Dens-O-Meter template. The flat, smooth, 3-in. wide raised surface around the test holes must be sufficiently smooth to insure a similar tight uniform seat on the test hole. This is very important, as large, false errors can result from an uneven surface on the test hole block or from poor seating of the template on a simulated flat surface. Even though extreme care is used a small error may still exist.

For comparative purposes volume determinations were made on the three test holes with the Dens-O-Meter and with a 12-in. California-type sand cone. Extreme care and experienced operators were used with the sand cone. With the Dens-O-Meter, seven different operators were used, four of whom had never operated the unit before. Results of these tests are summarized and shown graphically in Figure 1. For all three test holes the Dens-O-Meter gave more consistent readings than the sand cone, even though inexperienced operators were used, which confirms the previous Washington data. It should be noted that the accuracy obtained with the sand cone is in the same order as that obtained by Mr. Redus with the sand density cylinders.

It is apparent that the Dens-O- Meter balloons failed to fill completely the voids in the rough hole, although the maximum deviation from the true volume was less than 1 percent. This tendency is not consistent with field results. Field tests in granular base materials wherein the same rough test holes were checked with both the Dens-O-Meter and the sand cone showed very close agreement between the two instruments (within ± 1 percent), with the Dens-O-Meter generally indicating slightly larger hole volumes on the roughest holes. Extreme care must be used in the sand determination to obtain those close relationships, because external influences (such as traffic vibration and moisture) tend to induce considerable error in the results. Mr. Redus also

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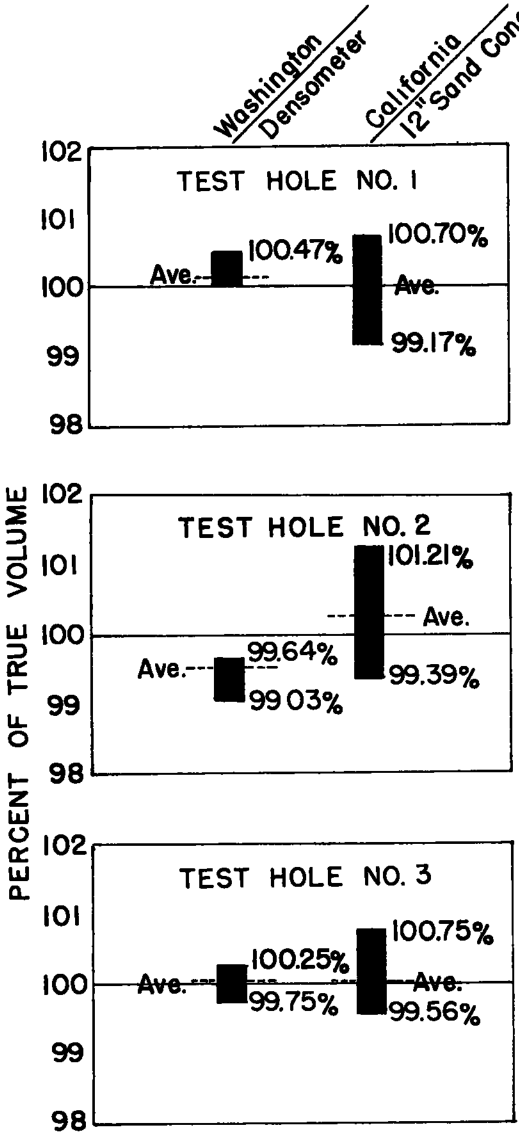
[1] "A New Method for Measuring In-Place Density of Soils and Granular Material," by C.E. Minor and H.W. Humphres, Highway Research Board Bulletin No. 93.

found that close agreement between the two methods could be obtained in the field, although his results show slightly greater variation (+ 1.9 percent).

The conflicting laboratory results are due to the fact that the rough hole in the concrete block is sealed watertight and does not duplicate field conditions except for shape. This is satisfactory for checking sand displacement-type instruments, but not for



	Densometer	Sand Cone
No. of Tests	12	12
Minimum Determined Volume	.0848	.0841
Maximum Determined Volume	.0852	.0854
Average Determined Volume	.0849	.0848
True Volume	0.0848 cu ft.	

	Densometer	Sand Cone
No. of Tests	12	12
Minimum Determined Volume	.0819	.0821
Maximum Determined Volume	.0823	.0836
Average Determined Volume	.0822	.0828
True Volume	0.0826 cu. ft.	

	Densometer	Sand Cone
No. of Tests	12	12
Minimum Determined Volume	0.1594	0.1591
Maximum Determined Volume	0.1602	0 1610
Average Determined Volume	0.15986	0 15983
True Volume	0.1598 cu. ft.	

TEST HOLE NO. 1 — Smooth hole in concrete block.

TEST HOLE NO. 2 — Rough hole in concrete block.

TEST HOLE NO. 3 — Metal container. (Calibrating hat for California Sand Cone with rounded bottom joint.)

Figure 1.

rubber-balloon-type units. Rough holes only occur in gravelly soils, the pervious nature of which permits the water-filled balloon to force out the air in the rough wall recesses. This cannot occur in the sealed hole in a concrete block, and thus this type of test cannot yield typical results.

Mr. Redus suggests that the closer agreement found in the field was due to using large test holes. This may account for part of the difference; however, the major factor causing the differences is believed to be his laboratory procedure, which induced errors that are automatically eliminated in normal field testing procedures.

The following conclusions are offered on the basis of a review of Mr. Redus' data, the previous Washington data, and the special test conducted for this discussion:

1. Mr. Redus' findings as to the accuracy of the Washington Dens-O-Meter are in error. This error is probably due to one or more of the following factors: (a) An uneven surface on the test blocks may have prevented a tight fit of the Dens-O-Meter template; (b) An uneven surface may have been used for obtaining the initial reading with the Dens-O-Meter; (c) The Dens-O-Meter may have functioned improperly due to entrapped air in the cylinder; and (d) Using data obtained from tests on rough, sealed holes in concrete blocks. These should not have been used because such holes do not duplicate field conditions.
2. Sealed rough holes in concrete blocks do not simulate field conditions and should not be used to evaluate the accuracy of rubber-balloon-type density apparatus.
3. Smooth containers of suitable shape, or smooth holes in concrete blocks shaped to duplicate field test holes in soils, can be used to evaluate both rubber-balloon and sand-displacement units, provided extreme care is taken to avoid introducing false error by the procedure used to make the simulated initial surface readings.
4. The accuracy reported in the original paper describing the Washington Dens-O-Meter is verified by the tests conducted herewith.

It seems pertinent to call attention to the fact that the Dens-O-Meter is not affected by external influences (such as vibration, moisture in the soil, wind, or rain), that calculations and weighings have been minimized to reduce chances of personal error, and that the unit need not be calibrated for each density—all of which tend to yield more accurate, more consistent, and more rapid results.

J.F. REDUS, Closure—As stated in the introduction, the purpose of this paper is to present a method for evaluating apparatus and procedures for determining in-place density of base courses and soils, and the methods are considered more important than the data for the specific pieces of apparatus.

It is possible that such an evaluation might show up an inherent inaccuracy in the sand-cone procedure used by Mr. Sallberg, wherein he obtained higher density with this method than with undisturbed-sample and oil-displacement methods. Also, it has been found that recalibration of the sand with each test can improve the accuracy in many instances. Any disturbance to an "undisturbed" sample would tend to relieve the stresses and increase the volume of the sample, thereby decreasing the density. It has been found that leakage of oil occurs sometimes during the filling of the hole which would not be detected after the hole is filled; this would tend to decrease the density of the sample. Nearly all possible errors with the sand-cone method tend to decrease the volume measurement and increase the density.

A plot of the density values versus lateral location of the tests performed by Mr. Sallberg is presented in Figure 10. It is assumed that the area sampled was in a 10-ft lane of a roadway subjected to normal traffic, which was inferred but not stated in the discussion. Under these conditions, two paths in the 10-ft lane would receive intensive traffic from vehicles, whereas the area on either side and between these paths would receive less traffic. These paths were found by measurements on several highly-traveled local and interstate highways in the vicinity of Vicksburg, Miss., to be about 2½ ft wide. One path lies 1 to 3½ ft from the centerline of the pavement, and the other lies 6 to 8½ ft from the centerline. These paths are indicated in Figure 10. The plot of density versus test location shows that there is considerable variation in density across the pavement width. The pattern determined by sand-displacement is in better

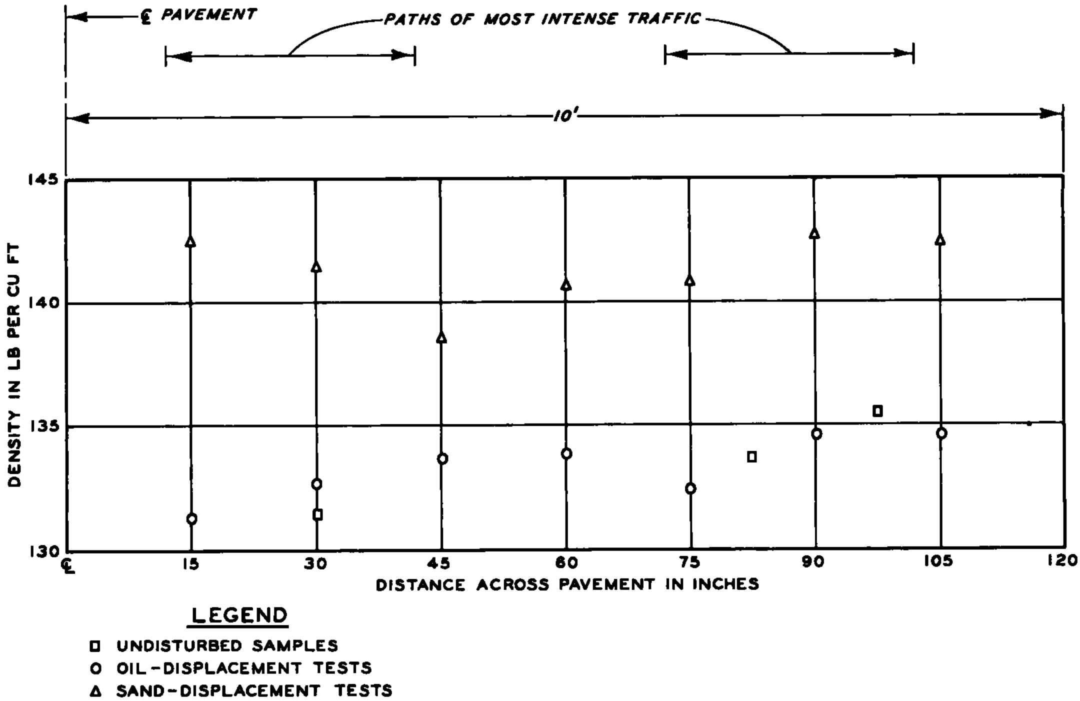


Figure 10. Density vs. distance highway base course.

agreement with the variation that would be expected than the pattern determined with the oil-displacement and undisturbed samples, even though, as previously pointed out the values determined by sand-displacement may be high.

It is agreed that larger samples tend to minimize certain errors, as suggested by Mr. Sallberg.

The data and discussion presented by Mr. Humphres tend to point up the contention that an evaluation of apparatus by the organization performing the work and under the existing operating conditions is necessary to determine the accuracy to be expected. It is certainly true that the Dens-O-Meter has many advantages, as stated by Mr. Humphres, in that external influences affect it but little, chances for personal error are minimized, and measurements can be made quickly and simply. Also, the blocks used may have trapped a little air. However, it is believed that users should assure themselves that the desired accuracy is being obtained by an evaluation such as that described in this paper.