

Rubber-Balloon Apparatus for Measuring Densities of Soils in Place

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Determinations of in-place densities of soils are commonly accomplished in engineering practice by augering or digging a hole, weighing and determining the moisture content of the soil from the hole, and measuring the volume of the hole. The volume may be measured by the oil method, by the sand-cone method, or by using a rubber-balloon apparatus. The rubber-balloon method has been demonstrated to be accurate and is now widely accepted.

Various kinds of commercially available apparatus have been designed especially for measurements of densities of subgrades, bases, and compacted earth fills. These are limited to use on fairly level surfaces. Work in Iowa on natural soils showed a need for an apparatus which could be used either on level, sloping, or vertical faces. With such an apparatus, measurements could be made in roadcuts, in quarry faces, in borrow pits, in basement excavations, and in other like places deep in the soil section. Additional requirements for the design of the apparatus were that it be rugged enough to withstand rough field usage and light and compact enough for use by a man suspended from a rope over a roadcut or quarry wall. A new rubber-balloon apparatus was developed to meet these requirements. As a result of 2 years of use of the new apparatus in the United States and Alaska, various modifications and improvements have been made.

The paper describes the apparatus and presents representative test data.

● DURING the past several years, soils investigations by the Iowa Engineering Experiment Station have included in-place density measurements at a large number of locations in and out of the state. It was often desired to extend these measurements to depths of tens of feet in the soil materials and quarries and roadcuts became almost a necessary convenience. However, the common existing disturbed methods of density measurement, the oil, the sand-cone, and the rubber balloon methods (1, 2, 3, 4), are all adapted to measurements on a level surface. On a vertical face or a steeply sloping face, this required an undesirable amount of hand excavation; therefore a new apparatus was designed. The desirable features in the new apparatus were that it be equally adapted for use on level, sloping, or vertical faces and that it be light and handy enough to be operated by one person hanging on a rope swing.

A modified rubber-balloon apparatus was designed and constructed to meet these requirements. During the trial and development period of two years, many modifications have been made, and some rather unique features have been incorporated. The apparatus has been used and tried in various soils in the United States and Alaska. It is now used by the experiment station for all field density tests, including those on level surfaces.

DESCRIPTION

Figure 1 shows the Iowa balloon apparatus in use. The apparatus consists essentially of a folding template and a small balloon holder, the holder being connected by a $\frac{3}{8}$ -inch plastic hose to a 3-foot cylinder graduated in 0.001 cubic foot increments. The testing operation is as follows:

A smooth face is cut on the soil. The sample bag is put in place on the template and the template is pushed against the smoothed face, where it is held by pins projecting from the back of the template into the soil. With the hole in the template as a guide, a hole 4 inches in diameter and 4 to 6 inches deep is cut in the soil. On steep faces, all soil falls in the sample bag, and the bag can be removed and weighed immediately. On level or near level surfaces, the excavated soil is pushed away from the hole in the template; the balloon holder is fitted into this hole, and the volume of the excavation is measured.

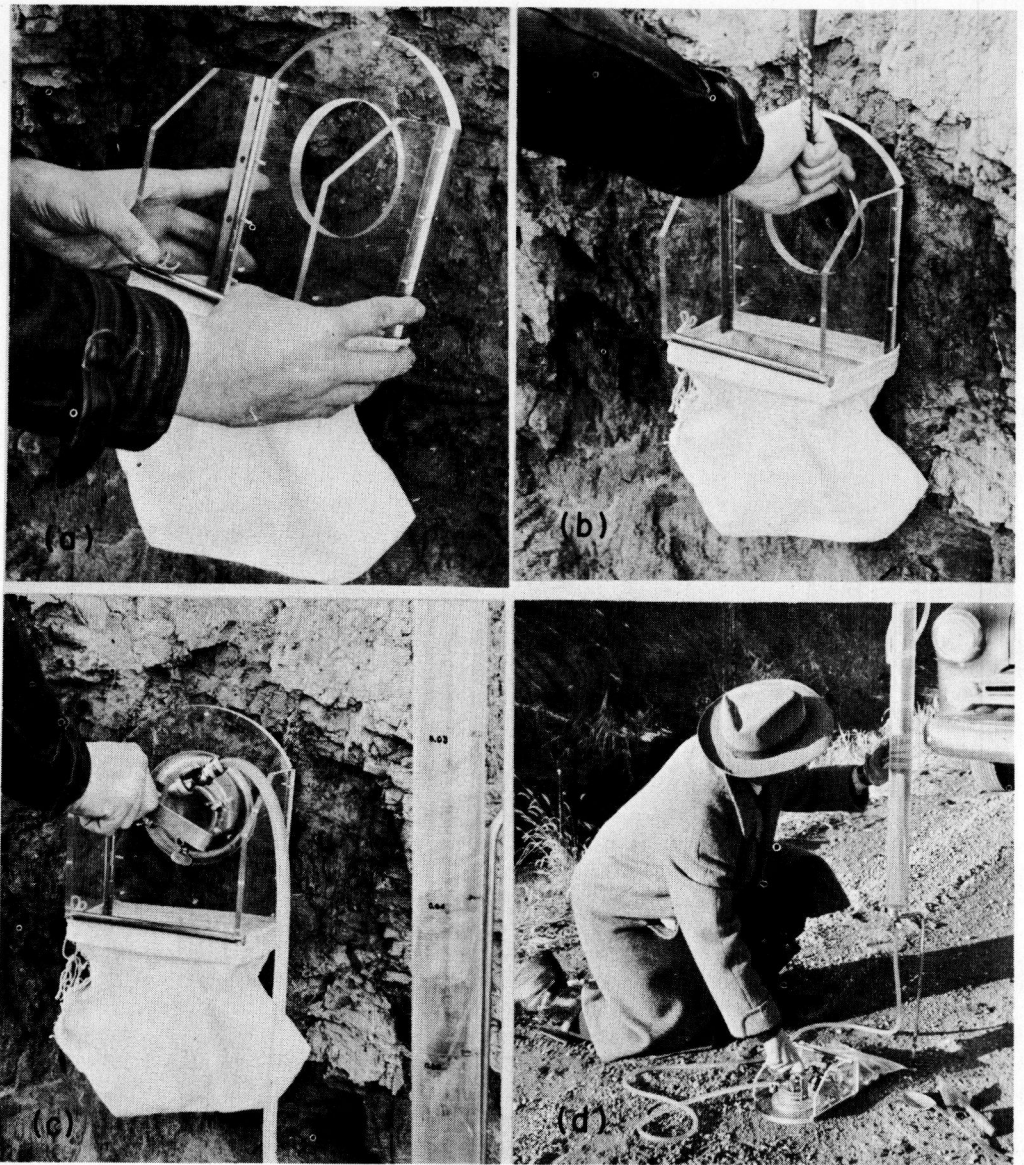


Figure 1. The Iowa field density apparatus in use. (a) The assembled template and sample bag are applied to a prepared flat surface. Pins hold the template in place (b) A hole is excavated through the template, and the soil falls into the sample bag. (c) The balloon holder fits into the template. It is held there while water pressure is applied from the calibrated cylinder (right). Volume readings are made from the water level in the cylinder. (d) Density measurements may also be made on a level surface. Here a plastic sample bag is used; the bag may be sealed for weight and moisture determinations in the laboratory.

One of the flow valves is turned off, the balloon is removed from the hole, and the sample bag is then removed and weighed. A moisture determination sample is taken from soil in the sample bag. Zero measurements are required for volume, the weight of the moisture can, and the weight of the sample bag. (A detailed procedure is given in Appendix A.)

UNIQUE FEATURES AND ADVANTAGES

Other features incorporated into the apparatus and believed to be advantageous are:

1. The graduated cylinder, balloon holder and template are all constructed of plexiglass—easy to see through but hard to break. Breaks can be repaired with common

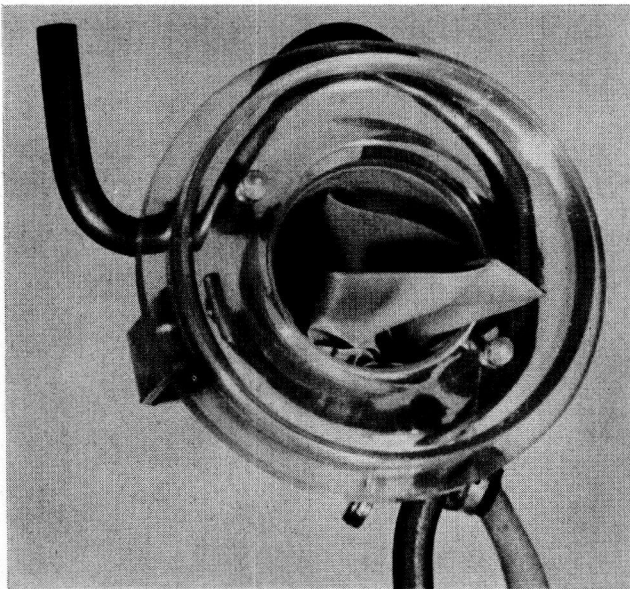
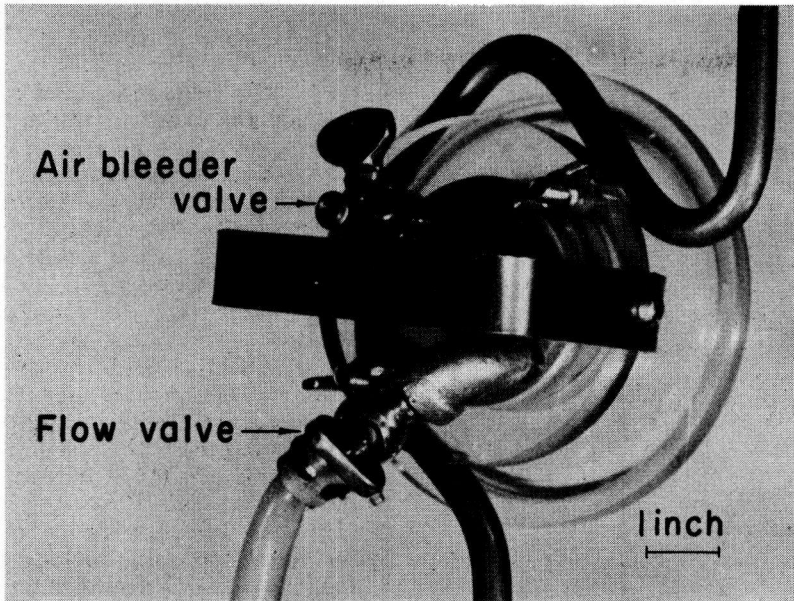


Figure 2. The balloon holder clipped into the steel cylinder support for carrying. In the lower photograph may be seen the concave rounded bottom of the balloon holder designed to minimize balloon breakage. The balloon is drawn inside of the holder as for a rapid zero reading.

household cements, most of which have a solvent effect on the plastic.

2. The balloon holder is concave and rounded on the bottom, minimizing balloon breakage (see Figure 2).

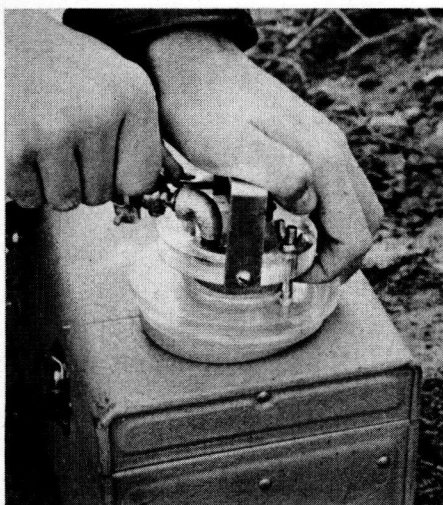


Figure 3. (a) For a rapid zero check, pressure is applied to draw the balloon up into the holder. A flow valve is turned, and the graduated cylinder is held vertically while the water level is read. (b) Normal method for making a zero reading. The rapid zero reading is calibrated to this reading.

balanced unit which can be lowered on a rope or carried in one hand (see Figure 4).

PRECAUTIONS AND DISADVANTAGES

1. Due to leaks or balloon changes, air may get into the balloon holder. To remove the air water is run into the balloon, the holder air valve is opened, and the air is forced out by squeezing the balloon. The water is then closed.

2. Reasonable care must be taken

3. Water flow is obtained by changing the head, so pumps or suction devices are unnecessary. For example, after running a test a flow valve is turned off, and the water is returned from the balloon to the cylinder by removing the balloon from the hole and holding it higher than the cylinder. The flow valves are opened, and the water flows back into the graduated cylinder.

4. A rapid check of the zero reading to determine effects of temperature changes during the day can be made by raising the balloon holder so that the water drains into the cylinder (see Figure 3a). The balloon is thus drawn up tightly inside of the balloon holder, giving a base point for a zero reading (see Figure 2). This reading must be calibrated to the normal zero reading obtained by inflating the balloon with the holder against a flat surface (see Figure 3b).

5. To secure complete inflation of the balloon inside the hole, pressure is applied by locating the cylinder above the balloon holder. If necessary, additional pressure can be applied by blowing into a hose connected to the top of the cylinder.

6. The apparatus uses ordinary toy balloons with the necks cut off. Balloons are replaced by dismantling the balloon holder with two thumb nuts. The balloon itself forms the gasket.

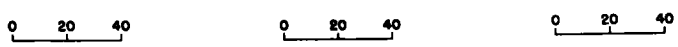
7. The apparatus clips together into a



Figure 4. Apparatus assembled for carrying. The balloon holder and loose hose fasten onto the graduated cylinder support, and (right) the folding template fits into the sample bag for carrying.

- during the test to prevent kinks in the hose. If there are no kinks, the plastic hose holds its shape well and does not expand appreciably with the pressures used, and the volume reading is not changed by moving the hose.
3. The sample bag must be shaken out and re-weighed prior to every test.
 4. The mouth of the sample bag may stretch so that it does not fit the template tightly. To correct this, the drawstring is drawn shorter and tied.
 5. The steel rod holding the graduated cylinder is forced into the ground in order to support the cylinder. (A foot rest is provided.)

Field moisture content, percent



In-place density (oven dry basis), lb./cu. ft.

Depth from surface, ft.

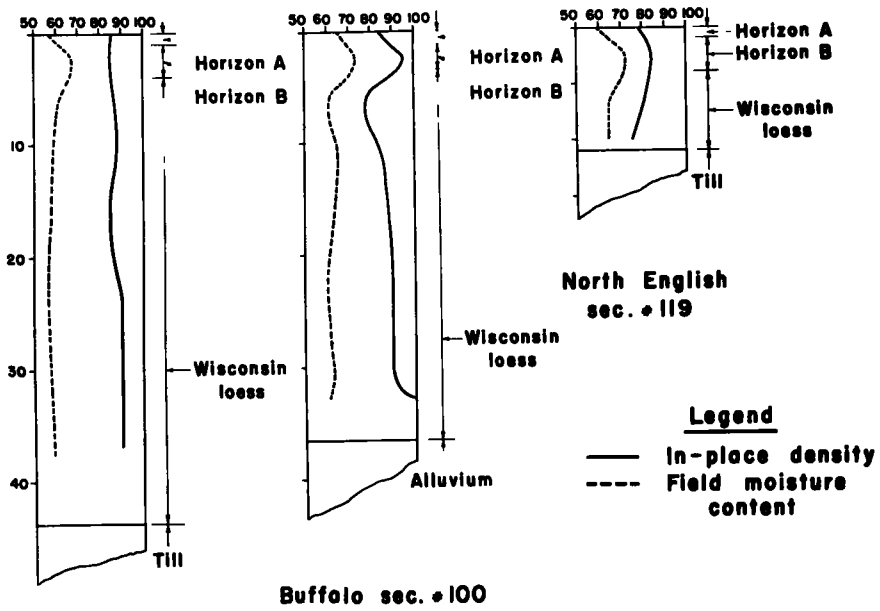


Figure 5. Depth field density relationships obtained with the Iowa apparatus. Measurements were made in roadcuts and quarries.

6. The overall length of the apparatus is about five feet, and care must be used to prevent breakage in transportation.
 7. The calibrated cylinder is two inches in internal diameter and has a capacity of 0.06 cubic foot. Therefore the maximum depth for a four inch hole in the soil is about 7½ inches. If desired, a larger cylinder could be used, but this size was found to be satisfactory for most soils, and superior from the standpoint of portability.
- Note 1: Tests are now being conducted with disposable polyethylene plastic sample bags. Since the plastic is waterproof, the bags can be sealed and returned to the laboratory for weighing and moisture content determinations. This would eliminate the need for transporting a rather delicate weighing mechanism into the field. The plastic bags will cost about ten cents apiece, and should be reusable several times.

APPLICATIONS OF THE APPARATUS

The new balloon apparatus, in addition to being used for ordinary borrow or compaction operations, may be used to determine densities through deep sections in soils. An example of the data obtained is presented in Figure 5. These data show that the in-place

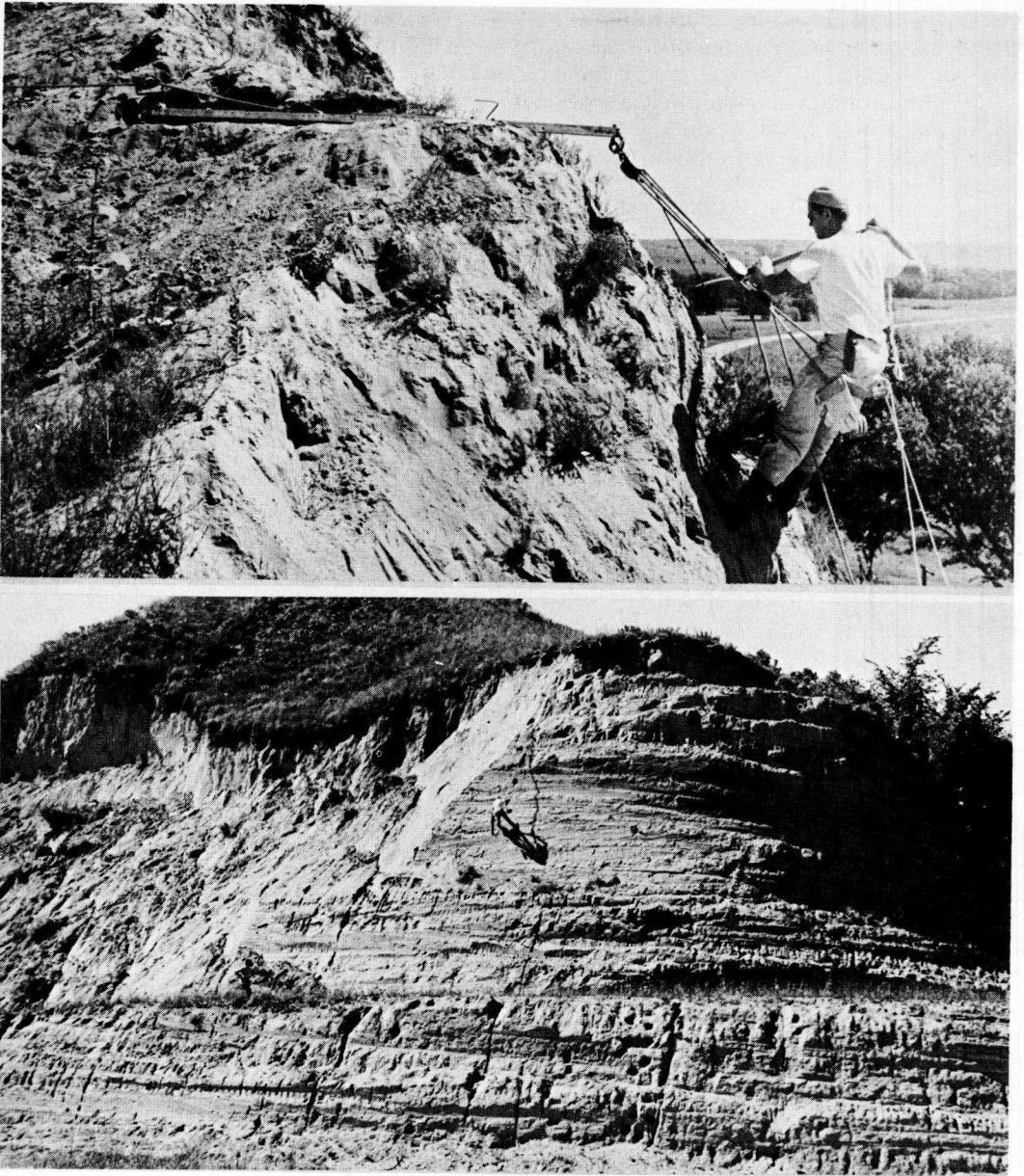


Figure 6. (a) A block-and-tackle apparatus for sampling and testing soils in deep cuts. A corkscrew-type soil anchor is used at the back of the two-piece aluminum beam. (b) Field densities on a deep cut.

density of loess gradually increases with increasing depth, probably due to the weight of the overlying material. Quite often there is also a large increase in loess density near the basal contact, probably due to mixing with the underlying material and to puddling by the water table.

Incidental to the development of the density apparatus, a rope swing was used in sampling and testing high, steep faces. The apparatus, pictured in Figure 6, consists of a board seat suspended by a $\frac{3}{8}$ -inch or $\frac{1}{2}$ -inch rope on a 3-to-1 block and tackle with the double block at the top. The top block is suspended from an eye at the end of a 6-foot collapsible aluminum beam. The beam was fabricated from 2-inch angles, and has a

bearing plate $1\frac{1}{2}$ feet back from the outer end. The other end is fastened to a cork-screw-type soil anchor. A safety rope is a convenient accessory in case of emergency.

ACKNOWLEDGEMENT

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References

1. Hank, R. J. Suggested method of test for density of material in place (rubber-balloon method). Procedures for Testing Soils, Am. Soc. Testing Materials, 1950, pp. 104-110.
2. Highway Research Board. Compaction of embankments, sub-grades and bases. Highway Research Board Bulletin 58, 1952, pp. 41-42, 55.
3. Minor, C. E., and Humphres, H. W. A new method for measuring in-place density of soils and granular material. Highway Research Board Bulletin 93, 1954.
4. Rainhart Company, Austin, Texas. Instructions for use of the Rainhart rubber balloon apparatus No. 171.
5. Allen, Harold. Classification of soils and control procedures used in construction of embankments. Public Roads, Vol. 22, No. 11, February, 1942, pp. 277.

Appendix A

Suggested Procedure for Use of Iowa Density Apparatus

APPARATUS

1. Iowa density apparatus, including calibrated cylinder, rubber balloon holder, template and sample bag.
2. Digging tools. A heavy kitchen spoon, hunting knife, chisel, prospector's pick, small pointed trowel, and a small flat shovel will be useful.
3. Tin cans with press tops for moisture tests. Four or eight ounce cans are satisfactory.
4. A balance of 3,000 gram capacity, accurate to 0.1 gram in the lower range.
5. A stove or oven for drying samples. The alcohol burning procedure is an alternative method for drying⁵.

TESTING

1. Prior to testing, an average zero volume reading is obtained by inflating the balloon with the holder pressed against a flat surface (see Figure 3b). The zero reading will ordinarily change only because of leaks or large temperature changes, but it should be checked occasionally. The check can be made by either repeating the zeroing operation or more conveniently by deflating the balloon so that it is drawn tightly back into the balloon holder. This is done by opening the flow valves and raising the holder four or five feet above the cylinder (see Figure 3a). The zero thus obtained must be corrected by adding to it the volume of the balloon holder. This volume can be determined by following the above procedure at the time of the initial zeroing and comparing the two zero readings.
2. The sample bag is shaken out and weighed prior to each test. To remove loose soil, the sample bag can be turned inside out, shaken and used that way in the next test.
3. The soil is shaved and smoothed off to a flat surface at the site of the test. The

area should be about a foot square and may be inclined. A shallow groove is scraped across the lower part of the area to make room for the seam of the sample bag.

4. The cylinder support is pushed into the ground near the test site to hold the cylinder vertical. The balloon holder is unclipped and set aside ready for use.

5. The folding template is removed from the sample bag and enough pins installed to hold it to the soil. Unless the soil is loose, three of the short pins, two at the top, will usually suffice.

6. The sample bag is placed on the folding template and the template braced open.

7. The assembled template is pushed against the soil face (see Figure 1a); the pins will be pushed into the soil and hold the template there. If the template does not fit solidly, it should be removed and the soil face trimmed. The plexiglass allows one to see irregular contacts.

8. The test hole is dug through the hole in the template, and the excavated soil placed in the sample bag or on the template (see Figure 1b). The hole should be smooth and approximately four to six inches deep.

9. (a) On steep slopes all excavated soil falls into the sample bag, and the bag can be removed and weighed immediately. (b) On level or near level surfaces the bag is left in place the soil is pushed away from the hole in the template, and the balloon holder installed (see Figure 1d). The flow valves are opened; the balloon fills with water and expands into the test hole. The balloon holder must be held down with a hand, knee or foot. Additional water pressure can be applied by either raising the cylinder or blowing in the cylinder air hose. As more pressure is applied, it should be noted if there is any increase in the reading. An increase would indicate that the balloon does not yet completely fill the hole, and the higher pressures are necessary. Caution must be used lest the balloon holder be lifted off the template. A 6-foot water head obtained by raising the cylinder will exert about 2.5 psi. pressure in the balloon, and the balloon holder must then be held down with a force of about 30 pounds.

10. When the balloon is inflated to a maximum inside the hole, one of the flow valves is turned off, and the balloon and holder are lifted from the hole and set aside. The volume can be read and recorded immediately or after the sample sack has been removed and weighed. If the operator is working alone, the latter procedure is advisable to reduce evaporation from the soil sample.

11. The template is lifted and the soil is brushed into the sample bag, which is then removed and weighed. A moisture can is filled with soil from the middle of the sample bag and the weight of the filled can is recorded. The soil in the can is later dried in an oven or by the alcohol burning method and the moisture content calculated.

12. The volume reading is estimated to 0.0001 cubic foot. The flow valves are opened and the balloon held above the cylinder so that the water flows back into the cylinder. The operation can be speeded up by squeezing the balloon.

13. All valves are closed and the apparatus either folded up or made ready for another test. Calculations of moisture content and dry density are illustrated in Appendix B.

SPECIAL PROCEDURES

14. Removing air from the system. This is seldom necessary unless there are leaks. The flow valves are opened and some water is allowed to run into the balloon. A flow valve is shut, the air valve on the balloon holder is opened, and the air is forced out by squeezing the balloon. It is necessary to re-zero after this operation.

15. Replacing a broken balloon. As much water as can be saved is run back into the cylinder, and more water added if necessary. Then the flow valves are closed and the balloon holder is disassembled by removing the two wing nuts. A new balloon is installed smoothly over the end of the holder tube and the holder reassembled. Air is removed (procedure 14), and the apparatus re-zeroed.

Ordinary round toy balloons are satisfactory for the test, although large sizes may be preferable. The neck is cut from the balloon at a point where it is somewhat smaller than the tube of the balloon holder.

16. Filling or adding water to the apparatus. If a water tap and small hose are available, water can be introduced at either the cylinder air valve or the balloon holder air valve.

In either case all valves are opened and the apparatus arranged to allow air to escape. If no hose or water pressure is available, the cylinder can be filled by removing the balloon and pouring water into the upturned balloon holder. The flow valves and the cylinder air valve must be open. The balloon is then replaced (Procedure 15), the air removed, and the apparatus re-zeroed.

Appendix B

SAMPLE DATA AND CALCULATION SHEET

Location: F1A-1, Fairbanks, Alaska.
 Material: Very dry, buff-colored friable silt.
 Compaction: None.
 Depth of Test: 2'7" to 2'11" (vertical roadcut)
 Hole: Final reading 0.0336 cu. ft.
 Zero reading 0.0171 cu. ft.
 Hole Volume 0.0165 cu. ft.

Moisture Content:

Wt. can + moist soil 149.8 gm.	Wt. can + dry soil 144.3 gm.
Wt. can + dry soil 144.3 gm.	Wt. can 30.0 gm.
Wt. moisture 5.5 gm.	Wt. dry soil 114.3 gm.

$$\text{Moisture Content} = \frac{5.5}{114.3} (100) = 4.8\%$$

Density:

Wt. sack + moist soil 729.5 gm.	
Wt. sack 40.6 gm.	
Wt. moist soil 688.9 gm.	

$$\text{Wt. dry soil} = \frac{688.9}{100 + 4.8} (100) = 657 \text{ gm.} = 1.45 \text{ lb.}$$

$$\text{Dry density} = \frac{1.45 \text{ lb.}}{0.0165 \text{ cu. ft.}} = 87.9 \text{ pct.}$$

Discussion

M.D. MORRIS, Eastern Representative, Soiltest, Inc. —Early in the abstract and later in the text, the authors state that . . . "the rubber balloon method has been demonstrated to be accurate . . .", it would be interesting to see some comparative results of a series of tests run simultaneously with this method, and say, with the sand cone method.

It would be of further interest to see some notes on comparative times per test on the series suggested above.

Although it incorporates the disadvantage of being opaque, the template, flaps and bag holder might be made of aluminum to reduce the weight and breakage factors. One always does not have the necessary repair cements with him in the field. Also, as the working surface of the template becomes scratched from use it too loses its transparent feature.

For operating in hard surfaces or on roads the spike end stand might be augmented by a sliding tripod stand of the same type used to support portable motion-picture screens.

The top hook might have welded to it a right angle spike to push into sideslopes to stable the apparatus while working suspended down vertical faces.

It is still not entirely clear how the apparatus is "zeroed-in" and how the level is maintained during tests on vertical faces while suspended to various elevations.

Granting that the space between the 0.001 readings will be lessened, it might prove economical, space, mobile and weight wise to use a shorter fluid reservoir of a larger diameter.

It would be of interest to know something of the balloon mortality rate considering rough spots not always removed from inside the hole or burrs on the template edges.

With this apparatus it is always necessary to carry an extra supply of water. Also, in very hot climates it might become necessary to make involved corrections to accommodate for temperature changes.

The observations regarding the expendable plastic bags could very well be most useful in many other phases of taking field samples for laboratory testing as well as density testing.