HOW DRY IS A DRY SOIL?

T. WILLIAM LAMBE, *Assistant Professor of Soil Mechanics, Massachusetts Institute of Technology*

SYNOPSIS

This paper discusses the effect of removal of water on the size of colloidal soil particles and how driving out water by heating to 105 C affects the relative amounts of adsorbed water and thus affects the particle size in different degrees in different soils Drying curves and values of specific gravity are shown for several temperatures ranging from room temperature to 190 C. for each of five soils The soils range in fineness from that of Ottawa sand to the very fine Mexico City clay. The paper also shows variations in different parts of the oven chamber for three different ovens of the non-heat-distributing and so called "constant temperature" type.

Since many of the standard laboratory tests of soil mechanics require the weight of soil in the dry state, it appears worthwhile to examine the term "dry". Most specifications define the dry weight of a soil as that weight which is obtained by heating the soil at 105 C until the weight reaches a constant value. The implication is that the water is a distinctly separate phase that is completely driven from the voids or pores of the soil mass while the soil particles remain unaltered in composition.

Mineralogists and soil chemists have shown that soils contain water which is influenced by forces from the soil grains and that this water can be removed from the soil by the application of the proper amount of heat [1] Thus two interesting questions are raised· Does heating to 105 C. drive off any of this non-free water? Is the method of drying a critical consideration in soil testing?

THEORETICAL CONSIDERATIONS

Nature of Soil Water—

One can picture the effective grain in a natural soil as consisting of the actual particle surrounded by a layer of attached water. The water that is far enough away from the soil particle not to be controlled by its forces is usually denoted "pore" or "free" water. Pore water is thus at liberty to move under the application of hydrostatic pressure and, therefore, is the water that flows under a dam or rises in subgrades due to capillarity, etc. There-

[1] For dehydration curves of 73 minerals, see "Some Standard Thermal Dehydration Curves of Minerals," by P. G Nutting, Geological Survey Professional Paper 19 7-E, U. S Dept of Interior, 1943

fore, when one attempts to get the weight of dry soil for engineering tests, he actually want the weight of the soil particle plus any attached or non-pore water.

The attached water can be water of hydration or water adsorbed on the particle itself A mineral which has the expending type of lattice, as do the montmorillonites, can take water within its lattice. All of this attached water is sometimes termed "adsorbed" water. Due to the colloidal size and the structure of the clay minerals, the attached water constitutes a considerably greater percentage of the soil mass in clays than in the larger grained soils such as sands or silts

Removal of Soil Water—

One should expect most of the free water in a soil to evaporate at room temperature if sufficient time were allowed. The rate of drying would, of course, depend, among other things, on the existing humidity. Drying in a desiccator or under an applied partial vacuum would increase the rate of drying and probably remove more of the water held within the soil capillaries.

The commonly accepted diffuse double-layer theory of colloidal particles in a suspension pictures the particle as surrounded by a layer of partially immobilized ions and water. The colloidal particle with its associated layer, or lyosphere, is termed the colloidal micelle. The addition of the proper amount of an electrolyte neutralizes the electrical charge, causing the micelles to form floccs and settle out of suspension. Due to the addition of electrolyte, the size of the lyosphere is decreased, thus making the effective size of the particle smaller. Therefore, it is seen that the effective size of

the colloidal particle is somewhat dependent on the nature of surrounding medium.

Is it reasonable to extend the above concept to the statement that the effective size of colloidal particles of an in-situ clay may be related to the pore water? For such soils, is it possible to remove pore water by drying and not change the effective size of the colloidal particle, since the drying would alter the concentration of any electrolyte in the system?

Thus, one should recognize that the use of 105 C. as a drying temperature is an arbitrary although convenient selection.

EXPERIMENTAL DATA

In Figure 1 are drying curves for five soils which are extremely different in their characteristics The curves were obtained by heating the soil specimens at each temperature in an oven until a constant weight was obtained.
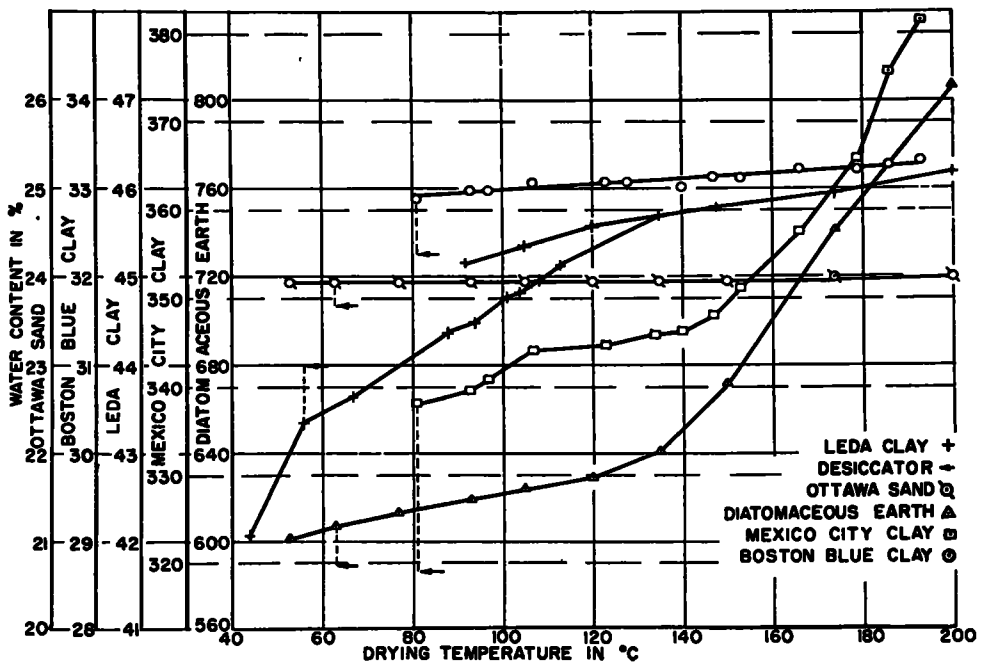

Figure 1. Drying Curves

The water adsorbed on the soil can, of course, be removed by the addition of enough energy in the form of heat. Soils having no free water give reactions in the differential thermal analyzer at temperatures less than 105 C thus indicating that adsorbed water is being driven off

From the preceding theoretical considerations one can conclude that the boundary between the free water and partially immobilized water on a soil particle may be far from definite In some soils it may be impossible to remove pore water and not disturb adsorbed water due to the altered equilibrium between the two. Also, heating to 105 C can remove adsorbed water which is an effective part of the particle.

Three to five days[2] were required to reach such equilibrium All soil samples were initially at their natural water content, except the Ottawa sand which was moistened prior to testing The points plotted in Figure 1 (also Figs 2 and 3) for the clays are the average for three separate specimens; only one specimen was used for the sand and diatomaceous earth. To reduce the heating time for equilibrium, small speciments (from 5 to 20 g. weight at 105 C) of clay and diatomaceous earth were used· an 85-g specimen of sand was used. To obtain some indication of extended desiccation

[2] Large specimens of some clays probably require many times the one day of heating commonly allowed to come to equilibrium.

effects, the Leda clay was dried at 113 C then stored in a standard desiccator over calcium chloride for 2½ months and finally redried These data are plotted in Figure 1. Also in Figure 1 the water contents of each soil obtained by desiccator drying are plotted.

In Figure 2 are shown drying curves for three clays dried under two conditions (1) at room temperature (21 to 26 C) in a standard

sists of silicaceous shells of diatoms which are not in the colloidal size range, but, because of their tremendous surface area, caused by their pores and striae, are colloidal in behavior. The diatomaceous earth specimen contained a small amount of organic matter in the form of hair-like roots Therefore, the pronounced slopes of the Mexico City clay and diatomaceous earth drying curves are not surprising
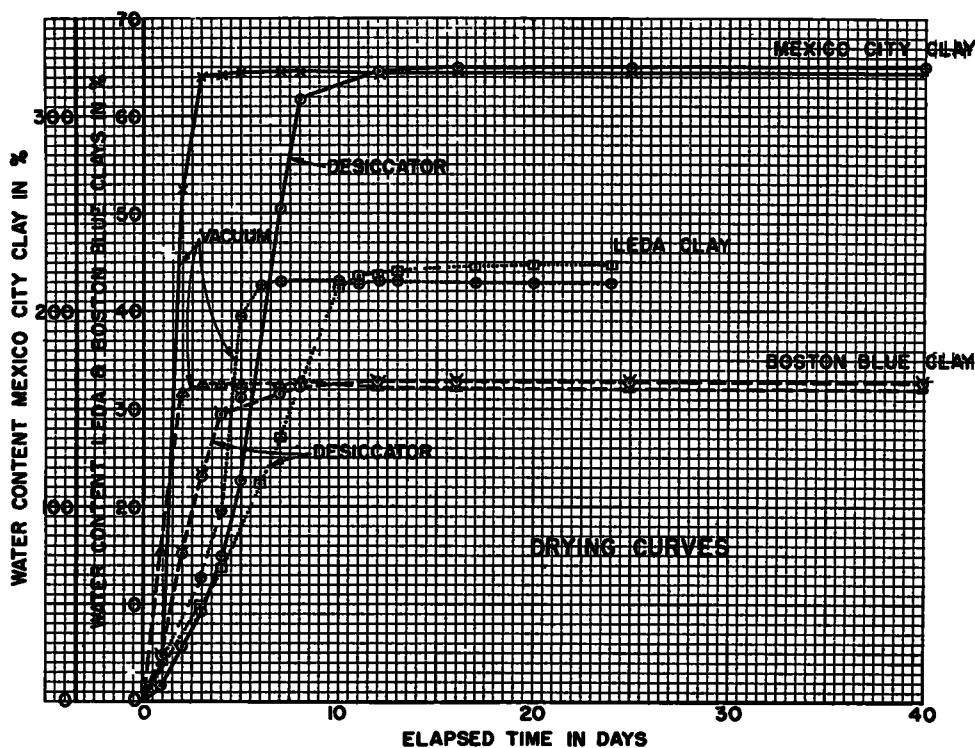

Figure 2

desiccator over calcium chloride and (2) in a desiccator at 30 to 37 C and under an applied vacuum of 74 cm Hg Figure 3 shows water pick-up curves for the two clays, Boston Blue Clay and Mexico City Clay, which exhibited the extremes of the clays.

Since the grains of Ottawa sand are neither colloidal nor the expanding lattice type, one should not expect the dry weight to depend much on the drying method. The expectation is proved correct by Figure 1 On the other hand, the Mexico City clay consists of the expanding montmorillonite clay particles which are colloidal Diatomaceous earth con-

Figure 2 shows that essentially the same water content is obtained by vacuum and desiccator drying. Drying curves such as those in Figure 2 depend, of course, on the size and shape of the specimen being dried. The long time required to dry a soil by such a method makes this procedure infeasible for normal soil testing, even though this procedure probably comes closer to removing only pore water than does 105 C. heating

The data plotted in Figure 3 were obtained partly to check the laboratory technique employed in securing the drying curves, i.e., remove the specimens from the oven, cool

in a desiccator for 30 minutes to an hour, then weigh. The desiccator was a standard one employing calcium chloride; the calcium chloride had been in use for approximately four months. The relative humidity in the room in which the samples were air dried varied from 50 to 60 percent. These curves suggest the interesting probability of some clays being better desiccants than calcium chloride, since they indicate that water was removed from the chloride.

of the oven chamber varied, as in a typical case, from 99.6 to 146.7 C., a variation of 47.1."[3] Figure 4 is a plot of temperature against height within three non heat-distributing ovens that were used in the M I.T. Soils Laboratory These data were obtained from observations on thermometers placed on shelves of the ovens "controlled "at 105 C

In view of the investigation of the Central Scientific Company and the data shown in Figure 4, one should expect probable tem-

Figure 3

Figures 1, 2 and 3 show that for some soils, e.g., sands, the procedure used for drying is not an important consideration. The antithesis can be true for other soils, such as clays and especially montmorillonitic clays. One may wonder if it is possible to obtain the weight of effective soil particles without the pore water. In order to obtain reproducible values of an arbitrarily defined dry weight, extreme care is required in the drying procedure.

EFFECT OF DRYING METHOD ON SOIL PROPERTIES

Oven Temperature Variation—

Few people realize the magnitude of temperature variation which exists in the commonly used "constant-temperature" oven. Central Scientific Company reports that carefully conducted tests on non heat-distributing ovens controlled to a temperature of 110 C revealed that "temperatures in different parts

Figure 4

peratures as high as 140 C and possible temperatures in excess of 190 C. near the heating

[3] P. 1598, Catalog J136, Central Scientific Company, Chicago, Illinois.

units of commonly used non heat-distributing ovens controlled at 105 C.; one should expect the center of the shelf near the control thermometer to be within a few degrees of 105 C. Temperatures at the corners of the oven as low as 90 C. seem reasonable. Therefore, in the following examples temperatures of 90, 105, 140 and 190 C. will be selected as ones which may be obtained at different locations in an ordinary drying[4] oven.

Effect on Soil Properties—

Any soil test or determination which requires the dry weight of a soil, will, of course, be affected by variation in this dry weight. The absolute magnitude of certain soil determinations, such as natural water content and Atterberg Limits are a function of the dry soil weight. The water content of a soil is, by definition, the water weight divided by dry soil weight. One can see that a drying method which drives off more water, gives a lower dry weight in addition to a higher water weight, and thus a higher water content. Figure 1 illustrates the effect that drying procedure can have on water content

The dry soil weight enters in more than once in such computations as void ratio and degree of saturation. The void ratio, e, defined as the volume of voids divided by the volume of dry soil grains can be found from,

$$e = \frac{GV\gamma_w}{W_s} - 1$$

in which,

V = volume of moist soil
W_s = weight of dry soil grains
G = specific gravity of soil grains
γ_w = unit weight of water.

A drying procedure which tends to give a low value of W_s, tends to give a high value for G; the two tendencies combine to make e too large.

The antithesis of this situation presents itself in the computation of the degree of saturation, S. The degree of saturation, defined as the volume of water divided by the volume of voids can be found from,

$$S = \frac{W_w}{\gamma_w V - \frac{W_s}{G}}$$

in which,

W_w = weight of water.

A drying procedure which would decrease W_s, would increase G and W_w. These effects tend to efface each other

The grain size analysis of a soil depends on the weight of dry soil grains used in the laboratory test and thus the exact distribution curve depends on the drying method employed For an extreme example, if the Mexico City clay whose drying curve is shown in Figure 1, were dried at 190 C. instead of 105 C., the percent finer values of its grain size distribution curve would be about 7 percent higher.

TABLE 1

	Specific Gravity By Different Drying Methods				
	Desiccator	90 C	105 C	140 C	190 C
Ottawa Sand	2 67	2 67	2.67	2 67	2 67
Diatomaceous Earth	1 91	1 99	2 00	2.06	2 56
Boston Blue Clay	2.76	2 78	2 78	2.78	2 79
Mexico City Clay	2 22	2 33	2.35	2 37	2 62
Leda Clay	2 74	2.75	2 77	2.80	2 82

The 7 percent is probably minor compared to the unsatisfied assumptions made in the analysis.

Since soil engineers attempt to compute the specific gravity with precision and since the specific gravity is a sensitive determination, soil dry weight variation is probaby the most serious in this determination In Table 1 specific gravity values for different drying conditions are given for the soils whose drying curves are given in Figure 1. This table shows that one should not expect consistent values of specific gravity in the ordinary oven unless some special control is employed

CONCLUSION

In an attempt to answer the question raised by the title of this paper, one finds that the dry weight of a soil is not a definite quantity Some mineralogists[5] use the weight of the soil heated to 700–900 C. as the dry

5 "Some Standard Thermal Dehydration Curves of Minerals," by P G Nutting, Geological Survey Professional Paper 19 7-E, U. S. Dept of Interior, 1943

weight; soil engineers have set the arbitrary, although convenient, definition of dry weight as that obtained at 105 C.

Drying to 105 C. removes some of the adsorbed water which is part of the effective soil grain. This effect is of more importance in soils whose grains are colloidal or expanding in behavior. Due to the removal of part of the soil particle, one tends to obtain natural water contents, Atterberg Limit values, void ratios and specific gravities that are too high.

The above error in absolute value of soil properties does not appear to be as important as the scatter one may obtain by not carefully maintaining the arbitrary standard drying procedure.

A STUDY OF BITUMINOUS-SOIL STABILIZATION BY METHODS OF PHYSICAL CHEMISTRY[1]

A. C. Andrews, *Kansas State College* and G. G. Noble, *State Highway Commission of Kansas*

SYNOPSIS

This report describes laboratory studies of several phases of bituminous-soil stabilization

The work described was carried out with two general aims in mind:

Phase 1 To develop laboratory tests that would permit evaluation of some of the physical, physical chemical and surface properties of the materials being studied

Phase 2. To make studies that would lead to the development of methods and (or) treatments which would allow bituminous stabilization of a wider range of soils than is practical at the present time

The two general phases of the work were carried out simultaneously so that information obtained as the work progressed could be utilized in later experiments

The first phase of the work was carried out by using techniques standard to physical chemistry but foreign to the field of bituminous-soil stabilization These techniques were used for the measurement of physio-chemical and surface properties of soils and asphalts The ability of soils and asphalt to imbibe and retain moisture was also examined

The second phase consisted of studying the effect of approximately 85 different substances added to soil-water-asphalt systems The effect of the additives was evaluated by obtaining the compressive strength of small briquettes before and after immersion in water.

The results are not conclusive; however valuable data were collected and are presented here to serve as a guide for future investigations

A study of the literature pertaining to soil stabilization in general reveals that the past ten years has been a period of rapid advancement in this field. This is also true in the more specialized field of bituminous stabilization.

Mills (1)[2] gives charts and tables showing the mileage of different types of stabilized roads constructed in the United States in the period 1925 to 1939 by State and Federal agencies. It is interesting to note the years in which the first 100 miles of road stabilized with various stabilizing agents were completed They are: 1931 for cutback asphalt, 1933 for chemical stabilization, 1935 for tar, and 1937 for portland cement and for asphalt emulsion. As a comparison, there were about 600 miles of soil-aggregate stabilization in 1929 and 4000 miles in 1936.

The bibliographies attached to articles on soil stabilization published in the last ten years are very revealing. They show that there has been a definite movement from "rule of thumb" methods to methods attempting to use all available knowledge in the fields of