Screenings from the Soil Research Lab

IOWA ENGINEERING EXPERIMENT STATION
IOWA STATE UNIVERSITY OF SCIENCE AND TECHNOLOGY
AMES, IOWA

Nov. - Dec., 1959
Vol. 3, No. 6

PARTICLE SIGHS AND GRADATION

Nothing is so fundamental to a soils man as particle size, unless it be God, women, or the day the paycheck arrives. Particle size grasps at the fundament until a man wants to preach, cry, kick, roll, and pray thanks for Mechanical Analysis, which is what one does to measure particle size. One good mechanical analysis will tell more than 17 expert opinions, primarily because any expert opinion in excess of one means argument.[1]

It was with the advent of the slingshot that particle size took on something like scientific precision. The slingshot was much used for warfare, love, and the like. For example, a smooth stone carefully slung could effect a romance about as well as four fingers of gin, hence the popular expression "to get stoned."[2]

Unfortunately women soon got romantic monetary notions about the kinds of stones thrown and ultimately attentions were misdirected to exemplary facts of carats, cut, and blue-white brilliance. These more ridiculous aspects of romantic stone-throwing have survived to today, sans slingshot. I'll thank you dear to return my ring.

Shifting, sifting soils

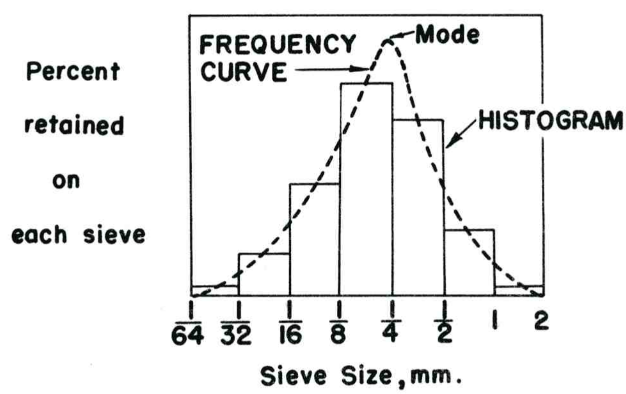
To return to the grosser aspects of our subject, the happiest way to measure soil particles quickly is to pass the soil through a sieve. Particles smaller than the holes pass through and particles larger than the holes do not, which is something we could use on our bank account but with no holes at all.

[1]Third General Law of Humanitarianism, from the Guidebook for Martian Visitors (forthcoming): "In Earthman the ear is located unsuitably close to the mouth, so that each creature hears its own voice louder than any other. One voice thus usually circumscribes the extreme boundaries of agreement. One plus one equals war--without they whisper in each other's ears, and that only delays the conflict."

[2]Soused, looped, blasted, plowed, pickled, soaked, knee-walking, tight, embalmed, drunk.

Just as one measurement does not make a beauty contest, one sieve does not supply much information on a soil. Usually a stack, or nest, of sieves is used, successive sieves being finer downward through the stack. Soil is put in the top and the stack is given a prolonged shake on a mechanical shaker. Then the sieves are separated and the contents of each emptied and weighed.

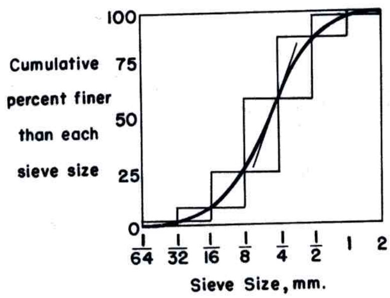
Sieve analysis data can be plotted directly as a bar graph called a histogram. The narrower the bars the more accurate the graph becomes, but the more sieves required, and there is a practical limit. Therefore histograms are sometimes "smoothed" by eye to give a "frequency curve" (below), which is a more true representation of actual sizes present in a soil.



Cumulative curves

Our final bit of introductory programing concerns the cumulative curve, which has a rather corpulent sound suggestive of middle age. A cumulative curve is a kind of fingerprint of a soil or sediment, and an experienced soils man can look at such a curve and tell you what the soil is and what it is good for, and perhaps where it was and how it got there.

Return to Table of Contents



Cumulative curve plotted from same data as the histogram (note bars). Mathematically, the frequency curve is the derivative of the cumulative curve. Modes are at points of maximum slope.

Because of the grace, clarity and usefulness of cumulative curves, many professions use them, not only for soils but for anything with varying particle size. To prevent one profession or group from gaining too much from work of another, each has its own way of plotting the data.

Geologists, for example, plot curves upside down and backwards, which may account for some of their peculiarities.[3] Soil physicists plot theirs upside down. Other cumulative curves can be properly read only with aid of a mirror, and this within the civil engineering profession! There is a great need for translation, or as an alternative we will be glad to arbitrate and let others do it our way.[4]

Please pass the logarithms

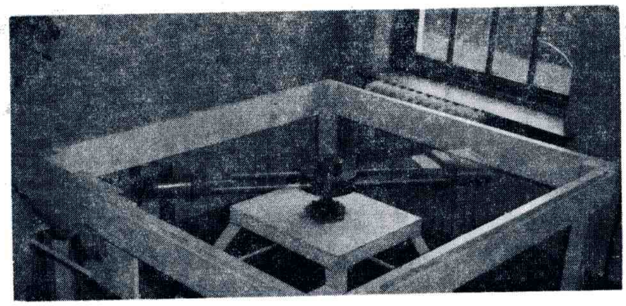
For reasons both aesthetic and practical, particle sizes are almost universally plotted on a geometric or logarithmic scale. Note in the graphs the sizes do not read right to left 2 mm, 1 mm, 0, but read 2 mm, 1 mm, $\frac{1}{2}$ mm, $\frac{1}{4}$ mm, etc. They have not a constant interval but a constant ratio. (Alternately the logarithms of these sizes would have a constant interval.)

One reason for this added complexity is that smoother and more symmetrical curves are a natural result, and where lives a man whose eye is unpersuaded by life's natural symmetries? Also there is a matter of convenience and keeping a graph on the paper, when particle sizes in a single soil may vary from ionic on up to boulders.

In line with this, most of the several standard sieve series have successive sieves with a constant hole size ratio of the second root or fourth root of two. For example, if one reads every fourth sieve in the U.S. Sieve Series, the openings in millimeters are 4.0, 2.0, 1.0, 0.5, 0.25, 0.125, 0.063, and 0.037. To keep things blithe and inconsistent, sieves in the U.S. Series above 6.35 mm ($\frac{1}{4}$ inch) are designated in inches. However, they may be selected to continue a ratio of the fourth root of two.

[3]Earthworms, indeed! (Science, 130: 3383: 1162)

[4]Third General Law again.[1]

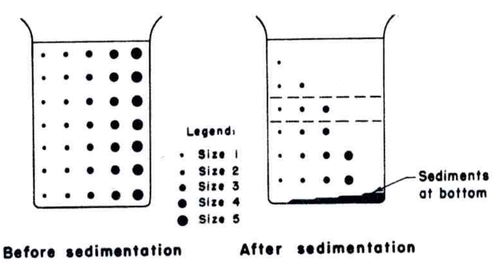


Tom McGee of the Iowa State U. Dept. of Ceramic Engineering revs up a long-arm centrifuge. Very small particles settle by gravity so slowly that centrifugal acceleration is substituted for g in the Stokes' equation. This particular apparatus is adapted to hydrometer analysis.

Dept. of clouded waters

Sieve analysis is fine as far as it goes, or to spin a pun, it is coarse as far as it goes, but for soils it does not go fine enough. The finest sieves commonly available are 325 mesh, which means 325 wires woven to the inch to give openings about 0.054 mm across. Such a sieve is fine enough to hold water unless agitated. Yet a goodly portion of soil, namely silt and clay, goes through.

To measure amounts and sizes of silt and clay one uses an ingenious means reminiscent of poorly stirred bean soup. Just as the beans tend to settle out and arrive in the bowl of the lucky



last person, usually the cook, so do soil grains settle from muddy water, the largest grains first.

Stokes' Law

To further illustrate, a man leaping from an airplane will reach a terminal velocity of only a few hundred miles per hour[5] due to drag from the air. Similarly particles settling in a fluid reach a velocity which is constant and calculable. For this we thank the brilliant English mathematician G. G. Stokes, who in 1851 said:

"$F = 6\pi rnv$."

[5]It can be very terminal.

Return to Table of Contents

The equation gives viscous drag on a sphere moving in a fluid. If the sphere is a soil grain settling from water, force down must equal force up, or pull of gravity must equal viscous drag.

$$F = \frac{4}{3}\pi r^3 g\ (G-G_1) = 6\pi r n v.$$

Solving for v, we get

$$v = \frac{2}{9}\frac{(G-G_1)\ g r^2}{n}.$$

where: v = cm/sec
G = specific gravity of the particle (2.65 for quartz)
G_1 = specific gravity of the liquid (1.0 for water)
r = radius of the particle, cm
n = viscosity of the liquid, poise
g = acceleration due to gravity, cm/sec^2

Translation

Perhaps you are one of the poetic beat for whom mathematics holds no charm. Then be assured that eventually you, too, will know what we're talking about--just as soon as we find out.

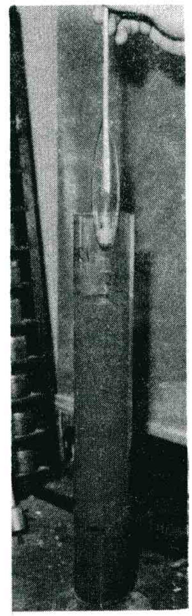
The gist of Stokes' Law is that particles half the size of a reference particle settle one-fourth as fast. Furthermore you don't even need the reference grain because settlement distances can be calculated with handbook numbers and by looking at the clock on the wall. The Law holds well for spherical particles finer than 0.1 mm. Admittedly very few soil grains are spherical, so we rationalize by speaking of "sedimentation radius" or some such.

Application

A column of water thus performs like a stack of sieves, except that soil is not put in the top but is stirred throughout. Then to measure, say, the percent of the soil finer than 0.005 mm (5 microns) one measures the amount of soil remaining in suspension at the calculated time and depth of settlement of 5 micron material. That is, at this time and depth only particles 5 microns and smaller can remain higher in the suspension. Ideally one should remove a layer, as indicated in the before-and-after sketches on the preceding page.

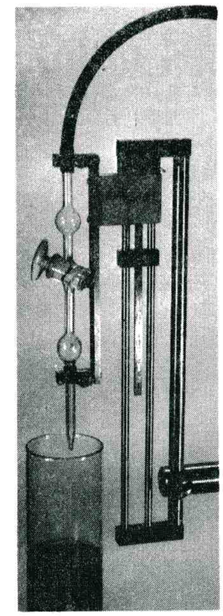
Gimmicks

The most direct method for measuring the amount of soil remaining in suspension at a specific depth and time is to extract some of the suspension with a pipette, dry the extract, and weigh it.



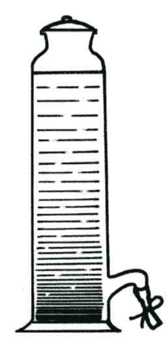
Hydrometer poised and ready for the plunge.

Pipette poised and ready to stab.



Let us assume the starting concentration of the suspension was 10 gm of soil per liter, and the pipette sample contains only 3 gm of soil per liter. Then 30% of the sample is finer than the size being measured. Pipette analysis is one of the most accurate methods and holds mighty sway in the U.S.D.A.

A similar method with a tricky idea for extraction is the Atterberg cylinder, suggested in 1914 and still widely used in Europe. Samples of suspensions are periodically drawn out the side. Calculations are the same.



A third method which requires more calculation but less work is to measure suspension concentrations with a hydrometer such as used to test anti-freeze, urine, or wine. The hydrometer can be read directly in grams of soil per liter of suspension, which saves the trouble of sampling, drying and weighing. On the other hand the depth the hydrometer sinks depends on the amount of soil remaining in suspension, so the exact size being measured must be calculated for each reading. Calculation is speeded with tables and graphs. The hydrometer method is standard in engineering laboratories.

Any sedimentation analysis requires careful control of the temperature to prevent thermal overturning of the suspension, and give some control on the viscosity, n.

DISPERSION

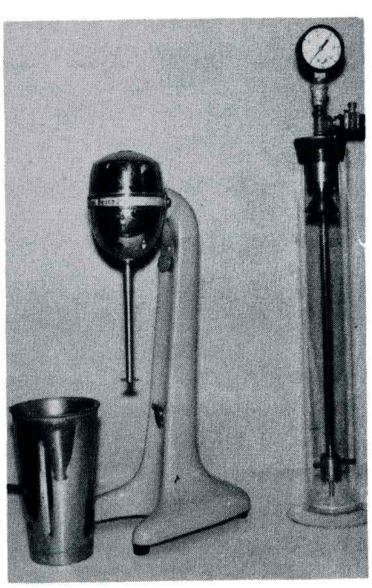
Crowds, particularly resentful crowds, can be very un-nice people, and dispersion of the crowd becomes necessary or grandma may throw a rock through somebody's window or find herself superintending a lynching.

Soil particles must also be dispersed, for they are hopelessly gregarious and like to gang up. Dispersion is both mechanical and chemical, like night sticks and tear gas.

Agitation

Machines for stirring include first the end-over-end shaker, in which bottles containing soil and water are tumbled end-over-end for a number of hours. This is one of the oldest and gentlest methods, still widely used in agronomy, geology, ceramic engineering, and cocktail parties. It is also the slowest.

George Buoyoucous, the American soil scientist who suggested the hydrometer to measure particle size, also suggested use of a high speed malted milk mixer to reduce stirring time to a few minutes. Soil engineers have adopted the high speed stirrer, primarily because they are fond of malted milks, but also because of the saving in time. Recurrent objections are that grain separation is sometimes incomplete, and prolonged stirring to attain proper separation causes breaking and wearing of primary soil grains. Tests at Iowa State showed these difficulties can be avoided with use of a rubber stirring paddle instead of the conventional metal tip.

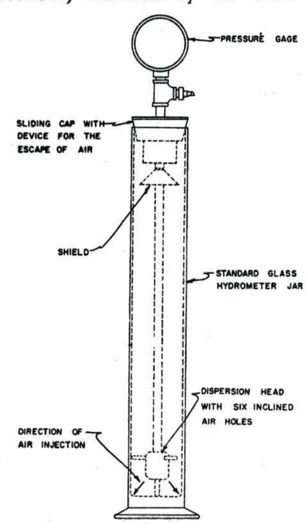


Two mechanical analysis stirrers. Although the air-jet apparatus, at right, offers some advantages, it imparts an odd flavor to the chocolate malts.

From agitation we go to vibration, and in Europe 50 cycle magnetic vibratory stirrers are used. The comparable machine gun for this technique is the ultrasonic vibrator, which separates soil grains with inaudible high-pitched sound waves that make a dog howl. This apparatus is electronic, expensive, and not standardized, but gives superior cleaning of grains for such purposes as microscopic analysis.

Wind

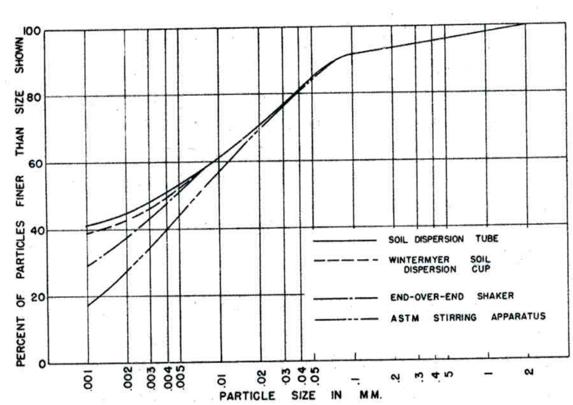
A third class of stirring devices uses compressed air, and here we most graciously acknowledge invention of a new, inexpensive air-jet device unconditionally guaranteed far superior to anything else you have ever seen anytime anywhere, with less tars and nicotine and absolutely no ties with cancer, senility or athlete's foot.[6]



The Soil Dispersion Tube blows and swirls air like underwater gaseous trepidations in a bathtub, lifting and erupting the soil-water suspension with great fervor but keeping it in the jar. The principal advantage is that stirring is done directly in the sedimentation jar, saving time and transfer. Other advantages are good dispersion without degradation, and reasonably low cost.

Chemicals

For good dispersion or sweet laundry one had best add a little water softener, because otherwise excess calcium in the soil may cause sudden settlement. In soil dispersions, clay



Cumulative curves for one soil, a California clay, dispersed four different ways. The air-jet dispersed the clay best (top curve). Similar tests on washed sands proved that the air-jet causes least degradation or wearing down of primary grains.

[6]The hard sell.

Return to Table of Contents

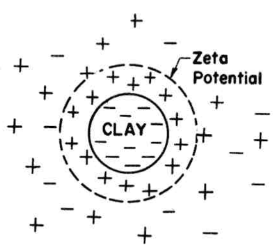
Screenings
from the Soil Research Lab

Nov. - Dec., 1959
Vol. 3, No. 6

particles carry an electrical charge causing them to join together in feathery wisps or flocculi resembling bits of wool and reminding one to dust under the bed. The flocculated clay settles out and leaves the suspension clear and potable, and worthless for measurement of particle size.

To prevent flocculation one must change the effective electrical charge, or zeta potential, of the clay. Zeta potential is measured by noting the migration rate of clay particles in an electrical field; it is ordinarily negative. If it is negative enough, clay particles repel one another and remain dispersed. If it is not negative enough, odds are that a few loose-living individuals will become positive, and positives and negatives will attract and settle down.

When a clay particle moves in suspension it carries with it a diffuse layer of hydrated ions which can do much to the zeta potential. Small, nicely charged cations such as calcium^{++} love to crowd in, make things less negative and cause flocculation. In contrast, sodium ions are monovalent and carry a big, bulky water hull; they crowd in poorly and leave the clay pessimistically negative and repulsive to strangers.

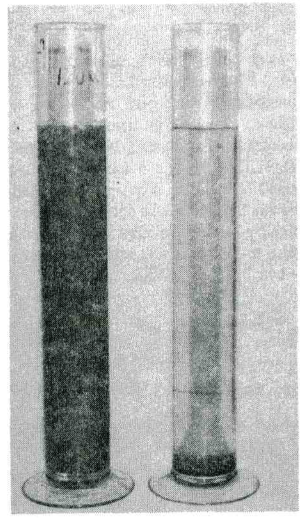


<u>Dispersing agents</u>

Sodium salts are good clay dispersing agents, but as with children, steaks, and candy bars, some are better than others. This is because clay, with characteristic weak character, has a preference for calcium or other polyvalent ions and tends to ignore sodium. Therefore we play rich father and force the desired alliance by tempting away calcium and tying it up in an insoluble reaction product.

Presently the dispersing agent gaining wide adoption is sodium metaphosphate, for which this laboratory must modestly accept some measure of credit. Previously sodium hydroxide, sodium oxalate, and sodium silicate were most popular. The dispersion results from a <u>cation exchange</u>, which reaction may be written

$$\underset{\text{Flocculated}}{Ca[Clay]} + 2NaPO_3 \rightarrow \underset{\text{Dispersed}}{Na_2[Clay]} + \underset{\text{Precipitate.}}{Ca(PO_3)_2\downarrow}$$

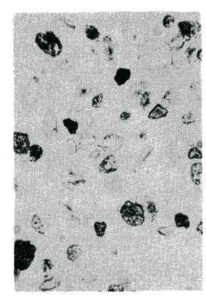


Which twin has the phony? Cylinder on the left contains clay dispersed in water and allowed to settle 12 hours. Cylinder on the right contains clay once dispersed in water but with no dispersing agent. The clay flocculated and settled out.

MAKING THE GRADES

Gravel, sand, silt, and clay are size grades in soils, and a single soil will contain varying percentages of each, the only requirement being that they add up to 100. Sometimes coarser grades--pebbles, cobbles, and boulders are defined, but for now let's delve into the first four.

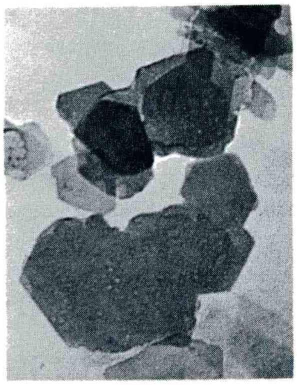
Gravel (at left, × 1/10) is usually well rounded due to vigorous banging in transport. Sand (not shown) is less well rounded and is mainly discrete mineral grains such as quartz and feldspar. Silt (right, × 100) is microscopic and more angular. For clay, turn the page.



One of the early grading schemes still widely used was devised by Udden at Augustana College in 1898, and later modified by Wentworth. Udden suggested a geometric interval based on a root of 2, which later became the basis for the Tyler Sieve Series. The gravel-sand break is at 2 mm, the sand-silt at 1/16 mm, and silt-clay at 1/256 mm. These breaks are currently favored by geologists.

Pedological ideas were forthrightly expressed by Atterberg in 1905, who also used a logarithmic interval but preferred to avoid fractions. Atterberg drew the boundaries at 2 mm, 0.02 mm, and 0.002 mm. Atterberg was first to suggest that size grades represent natural boundaries: sand differs from gravel by holding some capillary water, silt is microscopic, and suspended clay vibrates due to molecular bombardment.

Return to Table of Contents



Clay contains a distinctive group of minerals which resemble mica, but hold water like a sponge and carry a negative electrical charge. Individual grains are so small their shapes can be seen only by electron microscopy. These grains are of the mineral kaolinite (china clay), × 46,750.

The U.S. Bureau of Soils modified the Atterberg system to make use of U.S. Standard Sieves, and the sand-silt boundary was moved to 0.05 mm to coincide with the No. 270 sieve. The silt-clay boundary was moved to 0.005 mm to better fit an eyepiece calibration in one of their microscopes.

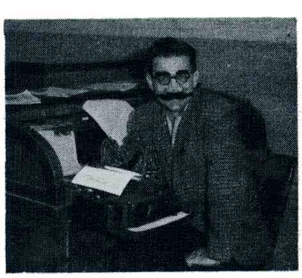
Finally soil engineers got into the swim by adopting the U.S. Bureau of Soils system, but changing the sand-silt boundary to the No. 200 sieve (0.074 mm) because the No. 270 was too delicate for engineers to handle safely.

Next the U.S. Department of Agriculture moved back to the old Atterberg definition of clay, 2 microns rather than 5 microns, because 2 more accurately described the break in characteristic mineralogy.

Therefore currently there is some small disagreement on proper definitions of sand, silt, and clay. In the U.S., soil engineers break their bread at 200, 64, and 5 microns; soil scientists at 200, 50, and 2 microns; and geologists at 200, 62.5, and 3.91. Or to summarize, see footnote 1.

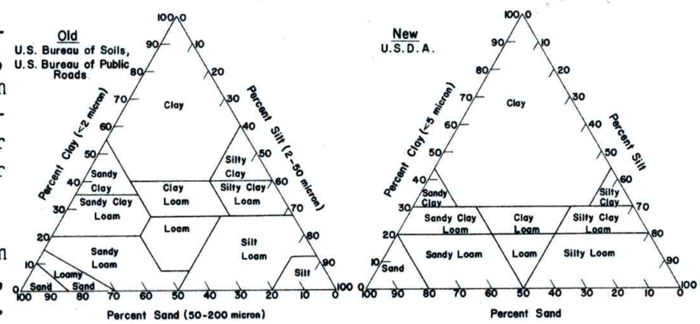
TEXTURE

Now that the soil has been adequately taken apart and graded, it can be mentally re-assembled and denoted by <u>texture</u>. Texture originally meant feel, but now it means particle size because feel is unscientific. Kiss me baby; I'm a gravel.



Ye Olde Editor and the rest of the happy flock extend their best wishes for a Merry Christmas and a Happy and Spirited New Year, as well as Happy Birthday, Joyous Thanksgiving, Amicable Valentine, and Pleasant and Virtuous Lent.

The soil textural chart (below) devised by the U.S. Bureau of soils has been widely adopted by engineers, with no allowance for the different sand-silt boundary definitions. The triangle has since been modified by the U.S.D.A. in keeping with their change in the definition of clay. To read the triangle, enter the percents sand, silt, and clay on the appropriate scales and follow in the directions of the external hash marks to where the lines cross. This will tell you whether a soil is a loam, silt loam, silty clay loam, etc. Without a triangle it is just plain dirt.



ACKNOWLEDGMENTS AND REFERENCES

Studies of dispersing agents were started under Project HR-1 of the Iowa Highway Research Board and continued to completion under Project 300 of the Iowa Engineering Experiment Station, along with development of the air-jet apparatus. Results of these studies are reported in a series of reprints in our Engineering Report 21 by D. T. Davidson, T. Y. Chu, et. al., 1954-1955.

The air-jet dispersion apparatus is manufactured and sold by Testlab Corporation, 3398 North Milwaukee Ave., Chicago 41, under a patent owned and licensed by the Iowa State University Research Foundation.

The electron photomicrograph, above, is by the Zentrallabor f. angew. Übermikroskopie, University of Bonn. Peerless sieving technique, p. 1, is dramatized by Arthur Dahl, Research Associate and graduate student in soil engineering and geology.

Standard engineering methods for mechanical analysis are presented in "Procedures for Testing Soils," published by the A.S.T.M., 1916 Race St., Philadelphia, 1958. More recent developments are included in A.S.T.M. "Symposium on Particle Size Measurement," Spec. Tech. Publ. 234, 1958.

RLH

Return to Table of Contents