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USAGE MANUAL

for sampling and testing

LATERITE AND LATERITIC SOILS

and other problem soils

of

AFRICA

A.I.D.
Reference Center
Room 1656 NS

Prepared for

AGENCY FOR INTERNATIONAL DEVELOPMENT
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LYON ASSOCIATES, INC.
Baltimore, Maryland, U.S.A.

BUILDING & ROAD RESEARCH INSTITUTE,
Kumasi, Ghana

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INTRODUCTION

Soil testing is an important and integral part of highway design and construction. A thorough knowledge of the soils traversed by a highway alignment is mandatory in order to properly design the structural courses of the roadway. The knowledge is invariably acquired by field study and laboratory investigations. It is also necessary during construction to verify that the design is followed. The density, or degree of compaction is monitored through standard and relatively simple field tests. The quality of the imported material is periodically checked through simple laboratory tests on the "index" properties.

Most of the soil tests described in this manual are relatively simple and can be mastered with a few days practice. As in all laboratory testing, accuracy and reproducibility are important. All tests should be carefully performed with all measurements and calculations checked. With practice a testing routine can be evolved suitable for the work load at hand, where a variety of tests can be accurately completed each day.

Field laboratories are required for construction projects or on design projects when central testing laboratories are too distant to be conveniently used. Small regional laboratories have been set up in many countries in order to provide soils information on roads locally designed and also to perform the necessary tests to control construction. Mobile laboratories, often housed in trailers, are becoming increasingly popular for use in construction control, particularly in more remote areas.

Almost all testing required for simple roadway design or construction control can be performed in such laboratories. More complex tests, such as those used in determining some of the engineering properties, should be performed only in central laboratories with special equipment.

The purpose of this manual is to provide the basic details on: (1) identifying the various soils: (2) the laboratory equipment required to perform the tests; (3) exploration and sampling techniques for soils; and (4) laboratory test procedures. The format is straightforward and simple with many illustrations provided. This should make it easier for inexperienced engineers and technicians to use the manual in the field.

An introductory section is included on tropical soils. This has been excerpted from the Lyon Associates—BRRI final report on "Laterite, Lateritic Soils and Other Problem Soils of Africa" prepared for U. S. Agency for International Development. The brief descriptions of the soils are meant to furnish background on general properties, distribution and special treatment required of certain tropically weathered soils. More specific procedures to be employed in testing are also considered in the appropriate sections.

Field identification of soils is an important aspect of field work. A section is provided on the usual procedure of determining general soil types. Field sampling procedures are described including both disturbed and undisturbed samples.

All of the routine laboratory tests are completely described and suggested data sheets are shown. A list of recommended equipment for a field laboratory is also provided.

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Conversion Factors

In soil testing, it is frequently necessary to convert metric units to British units.

1 CU FT WATER WEIGHS 62.4 LB

1 GAL WATER WEIGHS 8.34 LB

MULTIPLY	BY	TO OBTAIN
CUBIC CENTIMETERS	.06102	CUBIC INCHES
CUBIC INCHES	16.39	CUBIC CENTIMETERS
CUBIC INCHES	.0005787	CUBIC FEET
CUBIC FEET	28,320	CUBIC CENTIMETERS
CUBIC FEET	1,728	CUBIC INCHES
CUBIC FEET	7.48	GALLONS
CENTIMETERS	10	MILLIMETERS
CENTIMETERS	.3937	INCHES
CENTIMETERS	.0328	FEET
FEET	30.48	CENTIMETERS
GALLONS	.1336	CUBIC FEET
GRAMS	.001	KILOGRAMS
GRAMS	.0022	POUNDS
INCHES	2.540	CENTIMETERS
INCHES	25.40	MILLIMETERS
KILOGRAMS	2.205	POUNDS
KILOGRAMS	1,000	GRAMS
KILOGRAMS PER SQUARE CENTIMETER	1.024	TONS PER SQUARE FOOT
MILLIMETERS	0.1	CENTIMETERS
MILLIMETERS	.03937	INCHES
POUNDS	453.6	GRAMS
POUNDS	.4536	KILOGRAMS
POUNDS PER SQUARE INCH	.072	TONS PER SQUARE FOOT
QUARTS	946.3	CUBIC CENTIMETERS
QUARTS	57.75	CUBIC INCHES
SQUARE CENTIMETERS	.1550	SQUARE INCHES
SQUARE INCHES	6.452	SQUARE CENTIMETERS

SOIL TERMINOLOGY AND SOIL IDENTIFICATION PROPERTIES

Each term used in soil work has specific meaning and application. Each soil test has specific meaning and application and indicates certain soil properties. Care in using correct terminology will do much to prevent confusion and misunderstanding.

Soil

Soil has been given scientific definitions by the agricultural engineer, the geologist, and others concerned with it. However, the highway engineer can consider as soil any earth material that he encounters in his work, except embedded rock and shale. Thus, soil will vary from clay to glacial gravel and talus.

The properties of soil will vary with its gradation, its moisture content, its vertical position in relation to the surface of the ground, and its geographical location.

Most soils were originally solid rock. Time and climate have broken the rock into progressively smaller particles. This can be shown in the laboratory by taking two or three pieces of calcareous gravel or stone, for example, and pulverizing them. First, sand-size particles can be made, then silt-size particles, and finally clay-size particles. However, as nature reduces rock into finer particles, chemical changes also take place; therefore, clay produced by nature over a period of many years will vary from clay-size material produced in a short time in the laboratory.

Soil Particle Sizes

The highway engineer has named the different particle sizes of soil and set definite limits for the size of each. By this naming and defining of sizes of soil particles, all soil tests are placed on a common ground for comparison. The amount of each size group of "soil separates" contained in a soil is one of the major tools used in judging, analyzing, and classifying a soil. There are slight differences in the way various agencies define the soil separates.

The amounts of each particle size group in a soil are determined by laboratory tests usually referred to as the mechanical analysis of a soil. The amounts of the gravel and sand fractions are determined by sieving; silt, clay, and colloid contents are determined by sedimentation tests. The distribution of particle sizes that compose a soil is called the gradation of the soil. The standard methods of tests prescribed by the American Association of State Highway Officials* and the American Society for Testing and Materials,** which include the hydrometer test for the fraction of the soil passing the No. 200 sieve, have been widely used in highway engineering. The mechanical-analysis method used by the U. S. Department of Agriculture† serves as a basis for the pedological system of classification.

Soil Texture

The amount of each soil separate contained in a soil mixture will determine its texture or feel. The textural terms used for various combinations of soil separates are defined by several agencies. The amount of each soil separate in the soil is determined by laboratory tests. These test results are then compared with the definitions of texture in use to determine the textural name.

With laboratory experience in testing and classifying the texture of a soil after its gradation is determined, it is possible to make approximations of texture by the feel of moist soil when rubbed and ribboned between the thumb and index finger.

The texture of soil is given to tell as much as possible about a soil in a few words. With texture given, approximations and estimates can be made of many properties of a soil, such as bearing value, water-holding capacity, liability to frost-heave, adaptability to soil-cement construction, etc.

To permit approximate textural classification, many practical short cuts can be devised to determine the amount of silt and clay in a soil. However, since the range in clay content for the textural groups is not large, accurate weighing of samples is needed, which requires some laboratory facilities.

Soil Color

The color of a soil varies with its moisture content. While it is standard practice to determine color of a soil in a moist condition, the moisture condition of the soil when color is determined must always be recorded. Color of mottled soils must be determined at their natural moisture contents because manipulation will blend and destroy individual colors. The apparent color of a soil, both wet and dry, is one of the tools used to locate different soils and to determine the limits of each soil horizon (layer). The individual horizons are defined under "Soil Profile."

Color indicates possible presence of certain compounds. Black to dark brown colors are indicative of organic matter. Reddish soils indicate the presence of iron oxides. Yellow and yellowish

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* AASHO T88

** ASTM D422

† Victor J. Kilmer and Lyle T. Alexander, "Methods of Making Mechanical Analyses of Soils," Soil Science, Vol. 68, July to December 1949, pages 15-24.

brown soils indicate presence of iron, perhaps hydrated iron, and are poorly drained; otherwise the iron would be in a different chemical form with a different color, perhaps redder. Greyish blue and grey and yellow mottled colors indicate poor drainage. White colors indicate presence of considerable silica or lime, or in some cases aluminum compounds.

Soil Structure

A moist or dry soil mass in its natural state tends to break into pieces of a rather definite shape resembling a geometric figure or some other material. Thus a soil may have a prismatic, block, granular, crumb, or floury structure. Structure is indicative of drainage characteristics and is one of the tools used to locate different soils and to determine the limits of soil horizons. Soil structure should not be confused with the structural (strength) characteristics of a soil.

Soil Profile

A vertical cross-section of soil layers constitutes the soil profile, which is composed of three major layers designated A, B and C horizons. The A and B horizons are layers that have been modified by weathering, while the C horizon is unaltered by soil-forming processes. (The D horizon, below the three soil layers, is the underlying material in its original condition of formation.)

A horizon: The original top layer of soil having the same color and texture throughout its depth. It is usually 10 to 12 in. thick but may range from 2 in. to 2 ft. Removing native cover of timber by lumbering operations or of grasses by farming may introduce erosion that removes this top layer as well as underlying layers. The A horizon is also referred to as the topsoil or surface soil when erosion has not taken place.

B horizon: The soil layer just below the A horizon that has about the same color and texture throughout its depth. It is usually 10 to 12 in. thick but may range from 4 in. to 8 ft. In regions of humid or semihumid climate, the B horizon is a zone of accumulation in the sense that colloidal material carried in suspension from overlying horizons has lodged in it. The B horizon is also referred to as the subsoil.

C horizon: The soil layer just below the B horizon having about the same color and texture throughout is depth. It is quite different from the B horizon. It may be of indefinite thickness and extend below any elevation of interest to the highway engineer. At the beginning of the soil profile development, the C horizon constituted the entire depth, but time, weather, and soil-forming processes have changed the top layers into A and B horizons described above. The C horizon (mother soil) may be clay, silt, sand, gravel, combinations of these soils, or stone.

The C horizon is also referred to as parent material or soil material.

D horizon: The layer of solid rock, gravel, sand, or clay underlying the C horizon. It is of indeterminate depth and is in its original condition of formation.

Soil Water

Moisture content: The amount of moisture (water) in a soil is always given as a percentage of the oven-dry weight of the soil. The percentage of moisture is determined by weighing the soil with the moisture in it, oven-drying the soil to constant weight at 110 deg. C. (230 deg. F.), and reweighing. The difference in weights gives the moisture loss. This figure divided by the oven-dry weight of the soil gives the percentage of moisture. This method of reporting moisture contents applies not only to the types of water occurring in soil, but also to all other moisture-content tests such as liquid limit, shrinkage limit, plastic limit, optimum moisture, etc., as hereafter described.

The soils engineer recognizes three different types of water or moisture in his soil work. The type and amount of water that may occur in a soil have a great influence on the soil's performance and value as a subgrade.

Gravitational water: Water free to move downward from the force of gravity. It is the water that will drain from a soil.

Capillary water: Water held in a soil by the capillaries (pores) in the soil. It is free water, but it can be removed from soil only after the water table is lowered or when evaporation takes place at a rate faster than the rate of capillary flow.

(NOTE: Both gravitational and capillary water are considered and spoken of as free water.)

Hygroscopic moisture (water): Water retained by soil after gravitational and capillary moisture are removed. It is held by each soil grain in the form of a very thin film and has both a physical and chemical affinity for the soil grain. Also, it is spoken of as the air-dry moisture content. This film is in equilibrium with the moisture content of the air and increases or decreases as the moisture content (humidity) of the air increases or decreases. The hygroscopic moisture content of a soil also varies with the grain size. As the grain size decreases, the hygroscopic moisture content increases.

	Organic debris lodged on the soil; usually absent on soils developed by grasses.	A_0	Organic debris.
The solum. (This portion includes the true soil developed by soil-building processes.)	Zone of eluviation.	A_1	A dark-colored horizon containing a relatively high content of organic matter but mixed with mineral matter. Thick in chernozem and very thin in podzol.
		A_2	A light-colored horizon, representing the region of maximum leaching (or reduction) where podzolized* or soladized.** The bleicherde of the podzol. Absent in chernozem,† brown,† sierozem,† and some other soils.
		A_3	Transitional to B but more like A than B. Sometimes absent.
	Zone of illuviation. (Exclusive of carbonates or sulphates as in chernozem, brown, and sierozem soils. In such soils this horizon is to be considered as essentially transitional between A and C.)	B_1	Transitional to B but more like B than A. Sometimes absent.
		B_2	A deeper-colored (usually) horizon representing the region of maximum illuviation where podzolized or soladized. The orstein of the podzol and the claypan of the soladized solonetz. In chernozem, brown, and sierozem soils, this region has a definite structural character, frequently prismatic, but does not have much if any illuvial materials; it represents a transition between A and C. Frequently absent in the intrazonal soils of the humid regions.
		B_3	Transitional to C.
	The parent material.	C	Parent material.
Any stratum underneath the parent material, such as hard rock or a layer of clay or sand, that is not parent material but may have significance to the overlying soil.		D	Underlying stratum.

*Process of water leaching downward through A and B horizons.
**Process of accumulating surface minerals through leaching upward, produced by evaporation in areas of low rainfall causing moisture movements to be toward the surface.
†Members of great soil groups (see Table 1).

A hypothetical soil profile having all the soil horizons.

TROPICALLY WEATHERED SOILS

Introduction

The engineering behavior of soils, whether formed under arctic, temperate or tropical conditions, is determined by certain physical characteristics designated as engineering properties. Once the engineer has ascertained which properties are the significant ones with respect to a particular type of construction at a particular site, he may at least in principle perform suitable tests to evaluate the properties quantitatively and may base his design on the findings. This fundamental procedure is at the root of all sound geotechnical design.

In practice, the apparently straightforward fundamental procedure can rarely be used without modification. Since determination of the engineering properties is usually expensive, index properties, simpler and cheaper to evaluate but indicative of the engineering characteristics, are investigated. On the basis of these investigations, materials having similar behaviors are classified into separate categories. Experience may then be organized and used as the basis for design in new localities or on new projects associated with soils of similar classification.

The consequences of tropical weathering have been of overriding significance in the formation of the soils of Equatorial Africa. Hence, no system of classification or no attempt to identify the significant engineering characteristics can succeed if not based on an appreciation of tropical weathering processes. These processes have been the subject of a vast amount of research and are described in an impressive body of literature.

Weathering*

Rocks when exposed at or near the earth's surface find themselves in a physical and chemical environment often quite different from that in which they were originally formed. The minerals which constitute the rocks may react chemically with the rainwater, groundwater, and dissolved solids and gases of the new near-surface environment to form new minerals which are more nearly in equilibrium with the surface conditions. Some materials may be carried away by solution in groundwater. The end result of these changes is to convert the upper portion of the rock into a residual debris more soil-like than rock-like in character and with chemical, mineralogical, and physical properties entirely different from those of the original rock.

The changes which take place in the rock by these near-surface processes are encompassed by the geological term weathering. One form of weathering, denoted as physical, includes the effects of such mechanical processes as abrasion, expansion, and contraction. Physical weathering produces end products consisting of angular blocks, cobbles, gravel, sand, silt, and even clay-sized rock flour. The mineral constituents of all these products are exactly those of the original rock. Chemical weathering, on the other hand, results in the decomposition of the rock and the formation of new minerals. The near-surface agents of weathering which enter into chemical reactions with the primary minerals of the rock include water, oxygen, carbon dioxide, and organic acids derived from vegetation. The various chemical processes include hydration, hydrolysis, solution, and carbonation. All of these may operate simultaneously, some more rapidly than others and some more effectively in the alteration of one mineral than another.

The chemical changes operating in the primary minerals of the rocks in temperate or semi-tropical zones tend to produce end-products consisting of clay minerals predominantly represented by kaolinite and occasionally by halloysite and by hydrated or anhydrous oxides of iron and aluminum. Quartz experiences slight solution but remains essentially unchanged, although it may undergo some comminution.

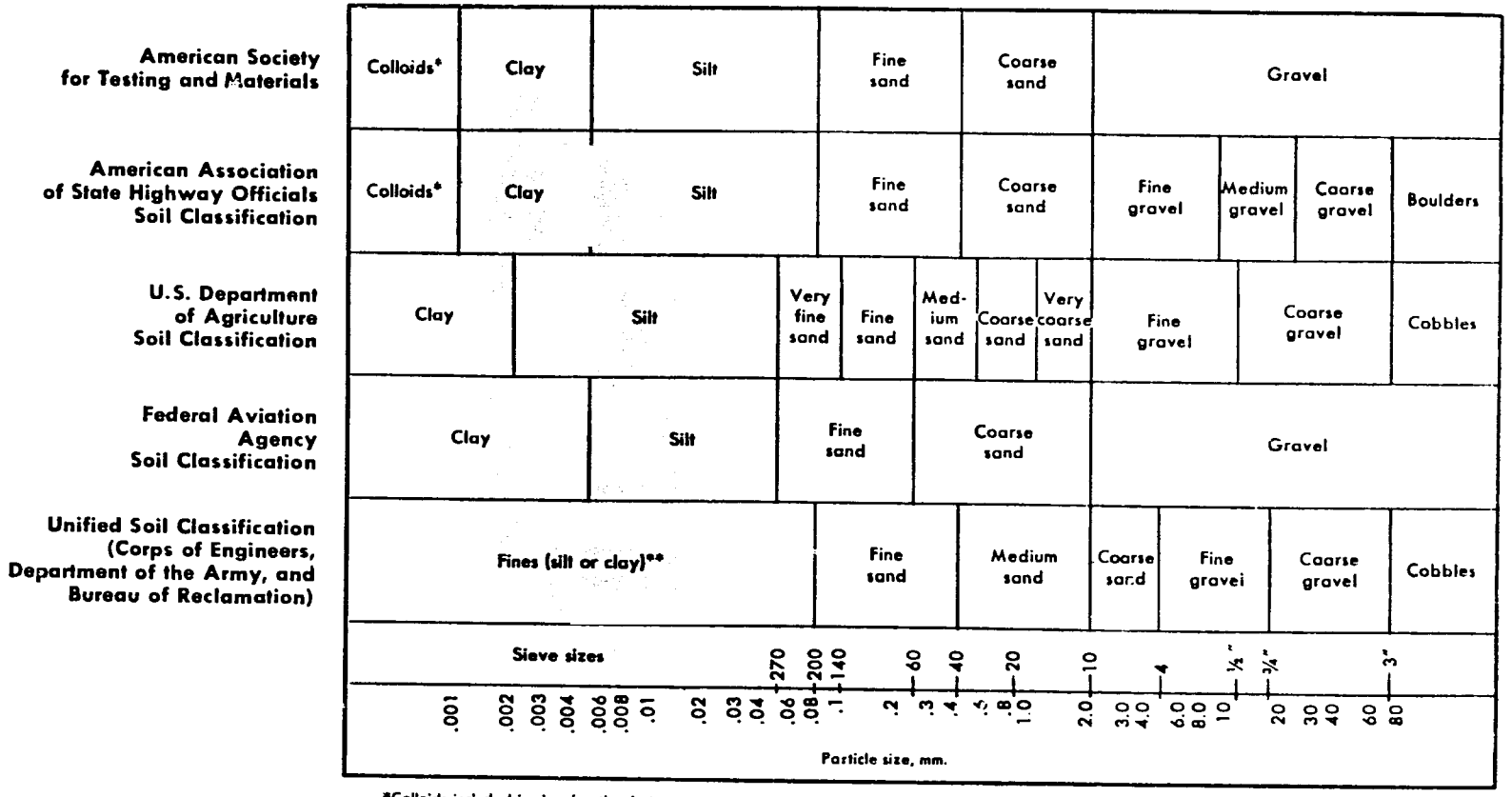
Chemical weathering is favored by warm humid climates, by the presence of vegetation, and by gentle slopes. Thus, tropical and subtropical regions of low relief with abundant rainfall and high temperature are the most susceptible to chemical alteration. Deep, strongly leached red, brown, and yellow profiles are manifestations of the effects of severe chemical weathering.

Under conditions favorable to tropical weathering, the weathering processes may be so intense and may continue so long that even the clay minerals, which are primarily hydrous aluminum silicates, are destroyed; in the continued weathering the silica is leached and the remainder consists merely of aluminum oxide such as gibbsite, or of hydrous iron oxide such as limonite or goethite derived from the iron. This process is known as laterization.

The extent to which a residual soil has been laterized may be measured by the ratio of silica, SiO_2, remaining in the soil (except for discrete pebbles of free quartz that may remain) to the amount of Fe_2O_3 and Al_2O_3 that has accumulated. The silica: sesquioxide ratio

$$\frac{SiO_2}{R_2O_3} = \frac{SiO_2}{Fe_2O_3 + Al_2O_3}$$

* This section is taken largely from P. Jiminez-Quionones, "The Compaction Characteristics of Tropically Weathered Soils", Ph.D. Thesis, University of Illinois, 1963, and from lectures by Prof. Don U. Deere in his regular courses at the University of Illinois and as condensed in guest lectures at Harvard University in 1968.



*Colloids included in clay fraction in test reports.
**The L.L. and P.I. of "Silt" plot below the "A" line on the plasticity chart, Table 4, and the L.L. and P.I. for "Clay" plot above the "A" line.

Soil-separate size limits of ASTM, AASHO, USDA, FAA, Corps of Engineers, and USBR.

has served as a basis for classification of residual soils. Ratios less than 1.33 have sometimes been considered indicative of true laterites, those between 1.33 and 200 of lateritic soils, and those greater than 2.00 of nonlateritic tropically weathered soils.

Determination of even the relatively simple silica: sesquioxide ratio requires a chemical analysis not likely to be available to the civil engineer. Furthermore, experience has indicated that the ratio is by no means a unique indicator of the index properties or engineering characteristics required by the engineer. Many other factors are of greater importance.

Profiles of Weathering

The alteration of rock by the processes of chemical weathering takes place progressively through a series of events and stages which result in a profile of weathering. Those who have worked with tropically weathered residual soils have noted the frequent occurrence of an upper clayey zone a few feet thick, underlain by a silty or sandy zone which, in turn, passes through a very irregular transition into weathered and finally into sound rock. The thickness of each member of the profile varies greatly from site to site because of the complexity of the interrelationships among the controlling soil-forming factors of rainfall, temperature, time, character of parent rock, topography and vegetation. Moreover, at a given site there may be great differences in the depth and thickness of the weathered rock within lateral distances of only a few feet. The differences arise because of differences in lithology, such as the presence of a dike or a contact, or because of differences in the degree of joining or extent of shearing. The latter features increase the permeability and the depth to which weathering can proceed.

Similar weathering profiles develop under similar conditions as reflected by the soil-forming factors mentioned above. Hence, a convenient means for regional description of soil properties for engineering purposes is the determination of the engineering characteristics of the various members or zones in typical profiles of weathering. Such investigations constitute a framework by means of which information and further experience can be coordinated.

Hydrated and Dehydrated Laterite

In continuously wet regions the end-products of the process of laterization are likely to be characterized by high natural water contents, high liquid limits, and irreversible changes upon drying. Inasmuch as limonite and goethite are hydrated oxides of iron, and gibbsite is a hydrated oxide of aluminum, drying alters the characteristics of the material markedly. The plasticity decreases and the grain-size increases such that much of the clay-sized material agglomerates to the size of silt. When dealing with such materials, the engineer may need to determine the index properties and the engineering properties on the basis of tests performed at the natural water content and again at various degrees of air drying in order to evaluate fully the range of properties associated with the physical conditions that may prevail on the job. Serious engineering and construction problems have arisen through failure to recognize materials likely to experience irreversible changes as a consequence of desiccation.

On the other hand, in regions subject to distinct wet and dry seasons, the products of laterization are likely to be characterized by low natural water contents, low plasticity, and the presence of concretions and cemented horizons. The alternate upward and downward movement of water causes concentration of the iron or of the alumina. Laboratory tests run from the natural water content or from the air-dried state lead to essentially the same results.

The difference in behavior of the hydrated and dehydrated forms of lateritic soils deserves attention because of the danger of being misled by reports in the literature in which the significance of the distinction may not be realized.

It was found during a recent study* that most of the tropically weathered soils of Africa can be

* "Laterite, Lateritic Soils and Other Problem Soils of Africa" by Lyon Associates, Inc. (Baltimore, Maryland U.S.A.) and Building and Road Research Institute (Kumasi, Ghana). Report for the U. S. Agency for International Development, Contract AID/csd-2164.

Properly designed, constructed and maintained, laterite can provide excellent, long-lasting roadway such as this typical example along the Tamale-Yapei, Ghana route.

Average Soil Properties, Ferrallitic, Ferrisols and Ferruginous

ATTERBERG LIMITS

	FERRALLITIC Ghana			FERRISOLS Ghana			FERRUGINOUS Ghana		
	LL	PL	PI	LL	PL	PI	LL	PL	PI
$\bar{x}$ (mean)	42	24	19	46	23	23	31	18	14
σ (standard deviation)	12	7	7	11	6	7	11	3	9
N (number of samples)	(41)	(41)	(41)	(46)	(46)	(46)	(47)	(47)	(47)

	Other Countries			Other Countries			Other Countries		
	LL	PL	PI	LL	PL	PI	LL	PL	PI
$\bar{x}$	47	24	23	55	29	27	33	12	15
σ	13	8	7	17	9	12	11	6	8
N	(35)	(35)	(35)	(12)	(12)	(12)	(32)	(32)	(32)

GRADATION

FERRALLITIC Ghana				FERRISOLS Ghana				FERRUGINOUS Ghana			
Sieve	$\bar{x}$	σ	N	Sieve	$\bar{x}$	σ	N	Sieve	$\bar{x}$	σ	N
1	99	2	(20)	1	95	9	(16)	1	99	2	(19)
3/4	96	6	(20)	3/4	94	10	(16)	3/4	98	3	(19)
1/2	92	10	(20)	1/2	90	12	(16)	1/2	96	5	(19)
3/8	86	14	(20)	3/8	86	14	(16)	3/8	93	8	(19)
4	70	19	(20)	4	73	21	(16)	4	75	16	(19)
10	54	22	(20)	10	52	29	(16)	10	51	19	(19)
40	46	18	(20)	40	40	23	(16)	40	46	22	(19)
200	34	16	(20)	200	37	20	(16)	200	30	16	(19)
2m	19	8	(20)	2m	25	16	(11)	2m	13	7	(15)

Other Countries				Other Countries				Other Countries			
Sieve	$\bar{x}$	σ	N	Sieve	$\bar{x}$	σ	N	Sieve	$\bar{x}$	σ	N
1	99	3	(36)	1	100	0	(13)	1	99	1	(35)
3/4	97	6	(36)	3/4	99	1	(13)	3/4	98	5	(35)
1/2	94	10	(36)	1/2	97	4	(13)	1/2	94	9	(35)
3/8	90	13	(36)	3/8	92	8	(13)	3/8	89	12	(35)
4	80	21	(36)	4	74	18	(13)	4	76	20	(35)
10	70	28	(36)	10	61	26	(13)	10	65	24	(35)
40	56	25	(36)	40	51	28	(13)	40	51	21	(35)
200	40	20	(36)	200	44	27	(13)	200	32	15	(35)
2m	26	14	(18)	2m	24	20	(13)	2m	16	8	(35)

AASHO MODIFIED COMPACTION—CBR

	FERRALLITIC Ghana			FERRISOLS Ghana			FERRUGINOUS Ghana		
	OMC	MDD	CBR	OMC	MDD	CBR	OMC	MDD	CBR
$\bar{x}$	12	129	46	14	122	42	10	133	75
σ	4	13	30	5	14	26	3	8	53
N	(38)	(38)	(33)	(43)	(43)	(39)	(40)	(40)	(40)

	Other Countries			Other Countries			Other Countries		
	OMC	MDD	CBR	OMC	MDD	CBR	OMC	MDD	CBR
$\bar{x}$	13	117	24	21	108	14	13	124	33
σ	4	9	17	7	14	11	4	11	23
N	(12)	(3)	(11)	(9)	(7)	(9)	(19)	(19)	(17)

Typical embankment demonstrates tendency of ferruginous material to cement itself into hard boulders (upper half) while deeper material, protected from weathering, remains moist and soft.

divided into three groups. These are ferruginous soils, ferrallitic soils and ferrisols Average soil properties are given on page 7.

Ferruginous soils occur in the more arid extremes for lateritic soils, in areas with pronounced dry seasons. They have formed over all rock types: igneous, metamorphic and sedimentary. Dehydration of the iron minerals and less abundant aluminum minerals has occurred in all except the soils which are sufficiently moist that seasonal dehydration does not occur. Ferruginous crusts are common which are hard and durable. The aluminum mineral gibbsite does not occur or is uncommon. Similarly halloysite or allophane do not occur. The absence of these minerals and the state of oxidation (dehydration) precludes significant changes of properties with air drying. The fact that these soils display lower Atterberg limits, higher densities and CBR values could all be explained by dehydration and aggregation. Hydrated minerals would be expected to display greater plasticity and liquid limits.

Ferrallitic soils occur in the humid extremes for lateritic soils and in areas with dense vegetation. These soils have also formed over all rock types. Gibbsite is a common clay material and other hydrated forms of alumina occur as well as hydrated iron minerals. Halloysite is fairly common over volcanic rocks and to a lesser extent over the relatively small bodies of basic intrusives found in West Africa. Changes in properties with drying occur due to hydrated halloysite (generally restricted to continually humid areas) and, to a lesser extent due to gibbsite. Crusts or hardpans are also relatively common. These have not been subjected to complete dehydration as have the crusts in ferruginous regions and consequently have not attained the hardness or durability. However, nodular concretion in relatively shallow horizons can be hard and as durable as those in ferruginous soils. Ferrallitic soils can also be expected to harden on exposure. Dehydration is normally prohibited by the dense vegetative cover, but with exposure this process is no longer prevented.

Ferrisols have formed over all types of rocks in intermediate to high rainfall areas where erosion has kept pace with profile development. Kaolinite predominates, but goethite also occurs. The degree of hydration of the clay materials is high, causing the properties to be similar to ferrallitic soils. Changes in properties with dehydration are considered minor when due to aggregation of the iron minerals, but can be significant in volcanic rocks when hydrated halloysite is a consituent.

Climate is the most important factor in the formation of the various soil groups. Parent material, vegetation, drainage conditions and time are also factors and these may cause local modifications within each soil group.

The average annual rainfall for each of the soil groups are as follows:

Ferruginous soils: 24-72 inches (600-800 mm)
Ferrallitic soils: 60- over 160 inches (1500-over 4000 mm)
Ferrisols: 50-110 inches (1250-2750 mm)

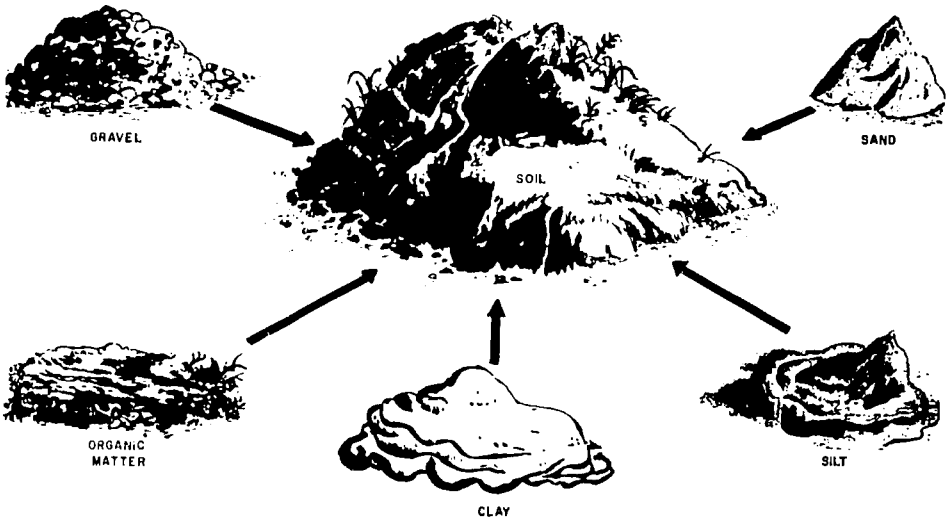
A general correlation exists among the various soil groups and vegetation in Africa. Generally, moist forests (rain forests) at low and medium altitudes cover ferrallitic soils while woodlands and savannahs (relatively moist types) cover the ferrisoils. Wooded and grass-covered steppes and savannahs cover the ferruginous soils.

One sub-group of ferrallitic soils display properties considerably different from all the other ferrallitic soils. This sub-group is the sandy ferrallitic soils. The causes of the abnormal sand content are the parent materials—either coastal sands or continental sandy sediments of the interior basins. These are in general restricted to thin strips along the coasts and to large parts of the Congo and Kalahari Basins. The parent materials for these soils are geologically young and contain a high percentage of resistant quartz. Climatic effects have not had sufficient time to chemically alter the constituents and dissolve much of the quartz.

FIELD IDENTIFICATION OF SOILS

Correct soil identification is required for proper soil control. Lack of time or facilities often makes detailed soil classification tests impossible in military construction. Ability to identify soils in the field by simple visual inspection and examination by hand is important, since vital decisions must often be based on field identification. Even when time and facilities permit laboratory tests, a field examination is made when the sample is taken to describe the soil properly.

CLASSIFICATION AND DESCRIPTION



Principal Soil Types

For identification and classification, all soils can be grouped into five basic types and various combinations: gravel, sand, silt, clay, and organic matter. Soils in nature seldom exist separately as basic types, but are found as composites. Field identification and classification depend on recognition of basic soil types and characteristics of composite soils.

General Description of Basic Types

Gravel consists of bulky mineral grains larger than about ¼ inch in diameter. Large pieces are called stones; pieces larger than about 10 inches are called boulders.

Sand consists of mineral grains varying from about ¼ inch to 0.002 inch (0.05 mm) in diameter.

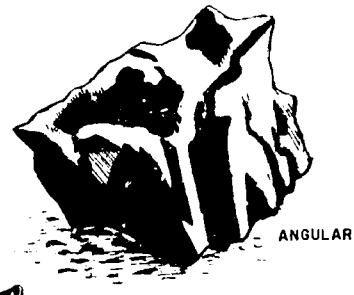
Silt consists of natural mineral grains smaller than 0.002 inch which lack plasticity and have little or no dry strength.

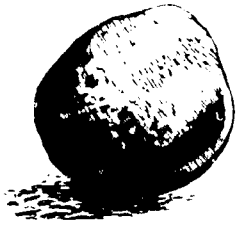
Clay contains colloidal scale-like particles which are the cause of plasticity. Plasticity and dry strength are affected by shape and mineral composition of the particles.

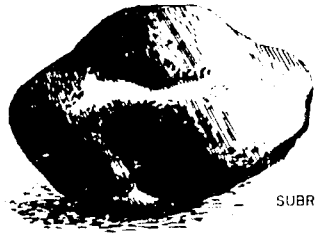
Organic matter consists either of partly decomposed vegetation as in peats, or of finely divided vegetable matter as in organic silts and organic clays

FIELD IDENTIFICATION TESTS

The following simple tests can be performed without equipment and are helpful in identifying soils. Do not make a decision on the basis of a single test. Use all applicable tests to identify soil.







Visual Inspection

Grain shape. Observe and classify the sand and gravel particles as to degree of angularity or roundness.

Grain size and gradation. Sand and gravel sizes are readily identified by visual inspection. Individual grains below the smallest sand size cannot be seen by the naked eye and must be identified by other tests.

For gradation of **coarse-grained soils,** spread a representative sample out on a flat surface and observe the distribution or uniformity of grain sizes.

For gradation of **fine-grained soils,** shake the sample in a jar of water and allow it to settle out. Approximate gradation is indicated by the separation of the particles in the jar from top to bottom. Silt remains in suspension for at least 1 minute; clay, 1 hour or more.

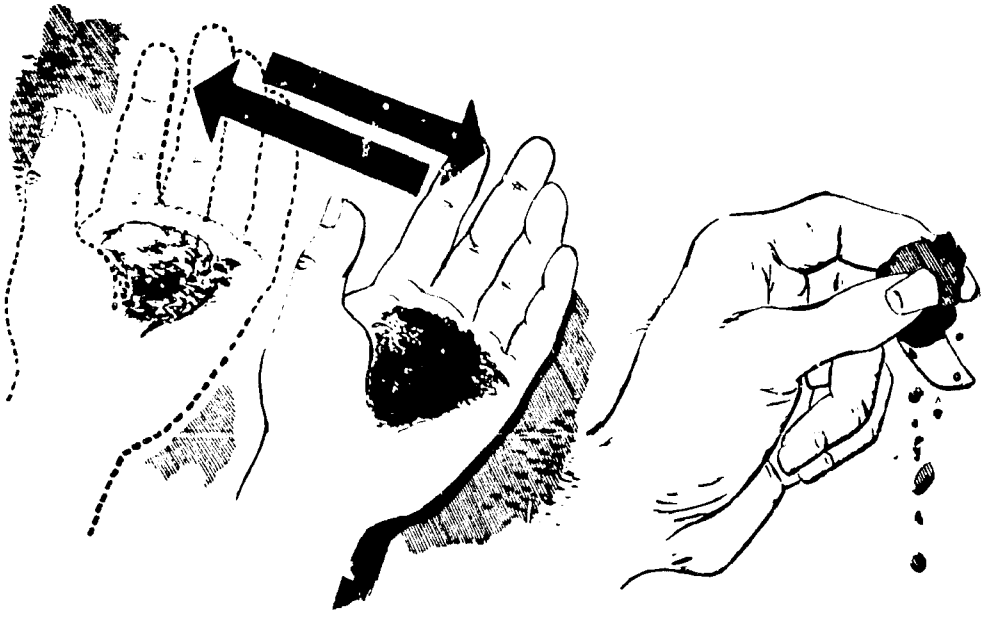
Shaking Test

The shaking test aids in the identity of fine-grained soils.

Prepare a pat of moist soil (try several pats with different moisture contents) and shake horizontally in the palm of the hand.

Observe if water comes to the surface of the sample, making it appear soft and glossy. Then squeeze the sample between the fingers, causing the moisture to disappear from the surface which changes from a shiny to a dull appearance. At the same time, the sample stiffens and finally crumbles under increasing finger pressure. Shake the broken pieces until they become livery and flow together again. Distinguish between slow, medium, and rapid reaction to the shaking test.

Rapid reaction indicates a lack of plasticity, such as is the case with a typical inorganic silt, a rock flour, or a very fine sand.



SHAKING THE MOIST SAMPLE

CRUMBLING DRY SAMPLE BETWEEN FINGERS

Slow reaction indicates a slightly plastic silt or silt clay.

No reaction indicates a clay or a peaty (organic) material.

Breaking Test

The breaking test may be used to determine the dry strength of a soil, which is a measure of its cohesiveness.

Allow a wet pat of the sample to dry and test its dry strength by crumbling with the fingers. Learn to distinguish between slight, medium, and high dry strength. Before drying sample, remove all coarse particles which would interfere with test.

Slight dry strength indicates an inorganic silt, a rock flour, or a silty sand. However, the sand feels gritty when sample is powdered.

Medium dry strength indicates a low to medium plastic inorganic clay. Considerable finger pressure is required to powder the sample.

High dry strength indicates a highly plastic, inorganic clay. The dried sample can be broken but cannot be powdered by finger pressure.

NOTE: Cohesion or high dry strength may be furnished by some cementing material such as calcium carbonate or iron oxide. For example, nonplastic lime rock or caral may develop high dry strength.

Plasticity Tests

Plasticity is the physical property of a fine-grained soil which allows it to be kneaded into a putty-like consistency at the proper moisture content

To test plasticity of a soil, prepare a moist pat and remove coarse particle. Start rolling it out with the palm of the hand on a flat surface into approximately ⅛-inch-diameter threads. Fold the

threads into a lump, roll out again, and repeat process until moisture loss causes the thread to crumble when rolled. The moisture content at this stage is called the plastic limit. Note the toughness of the threads as the plastic limit is reached and test to see if the crumbled pieces can be lumped together again.

Any soil that can be readily rolled into a thread without crumbling is plastic.

High-plasticity clay forms a tough thread which can be remolded into a lump below the plastic limit and deformed under high finger pressure without crumbling.

Medium-plasticity soil forms a medium tough thread, but the lump crumbles soon after the limit is reached.

Low-plasticity soil forms a weak thread that cannot be lumped together below the plastic limit. Plastic soils containing organic material or much mica form threads which are very soft and spongy.

Odor Test

Freshly sampled organic soils usually have a distinctive odor which aids in their identification. The odor can be made more apparent by heating a wet sample.

Acid Test

Drop a little hydrochloric acid on a piece of soil. A fizzing reaction indicates calcium carbonate.

Shine Test

Rub a dry or slightly moist sample with the finger nail or a knife blade. A shiny surface indicates a highly plastic clay; a dull surface indicates a silt or clay of low plasticity.

Slaking Test

The slaking test will aid in determining the suitability of lateritic soils for construction. If a ball of minus No. 40 sieve material submerged in water disintegrates slowly during a 24 hour submergence, it usually is suitable as a construction material. If time is available, the process of drying and soaking should be repeated to see if the sample changes significantly from cycle to cycle. If the ball disintegrates rapidly, it is not suitable for use.

LABORATORY SETUP

General Requirements

The following considerations are the most important in setting up any laboratory.

Torsion and triple-beam balances require a firm, level base free from vibration. They should not be set on the same table with other testing equipment and must be protected from air currents.

The gasoline stove and oven should be protected from air currents. The wind baffle is not effective when oven temperature must be carefully controlled.

Compaction equipment requires a firm foundation. A dirt or concrete floor is best; on wood floors, place equipment directly over a floor beam or joist.

Adequate lighting is required to read gages and balances.

Tap water is desirable. If not available, enough water must be stored in laboratory for washing, mixing, and soaking samples.

A desk for recording and computing results is desirable.

Storage space for samples is required.

Protection from wind, rain, and sun is required.

Semipermanent Laboratory

Efficient use of all the testing equipment requires a room about 8 feet wide and 14 feet long. By rearranging the equipment, buildings having different dimensions but approximately the same floor space can be used.

Use of Existing Buildings

The basement or first floor of an existing building is generally the most satisfactory for a laboratory because of the cool, damp air and solid floor. Compacting samples on an upper floor disturbs other occupants of the building unless the floors are solidly constructed.

Laboratory Hints

The following recommendations are made for semipermanent laboratories.

1. Keep a supply of tin cans, cardboard boxes, bags, and other containers on hand for obtaining and storing samples.
2. Prepare and keep a supply of data sheet forms in stock.
3. Number and match-mark all containers.
4. Weigh all containers acurately and record their weights either on a separate form or paint them on the containers.
5. Keep a supply of sealing materials, such as cellophane, waxed paper, and koroseal on hand for sealing samples.

EQUIPMENT

General. The laboratory soil testing equipment presented below are minimum requirements for a field semipermanent laboratory.

DESCRIPTION AND USE

Auger

Used for soil exploration and to obtain bag samples. Keep cutting edges sharp by filing. Clean and apply lard or engine oil to prevent rusting.

Auger Extension. Used to extend handle to dig holes to a depth greater than 4 feet. Tighten firmly with pipe wrenches before using.

Stove

Used for quick drying of samples. Burn nonleaded white gas for maximum operating efficiency and stove life. If leaded gas is used, provide adequate ventilation to avoid harmful effects from fumes. Follow operating instructions issued with stove.

Oven

Used with stove for drying samples more slowly.

Liquid-limit Device

Used in making the liquid-limit test. Keep all parts clean and check adjustment frequently.

NOTE: For accurate results, the base should be made of hard rubber. Some models in use may have wood bases, which should be replaced by hard rubber bases.

Torsion Balance

Used for weighings between 100 and 4,500 grams. Do not overload. Protect knife edges from damage and keep away from dust. Check adjustment daily and clean moving parts weekly when in frequent use. Never leave the balance with a weight on the pans, and never use the weights for any other purpose.

Triple-beam Balance

Used for weighing less than 200 grams. Give same care as torsion balance.

Portable Screen Set

For screening large samples. One size screen only can be used at a time. Screen is locked in position by the frame, cleat, locking plate, and handle. Protect wire screens from damage. Used for sieve analysis and for separating coarse material from fines in preparing samples for various tests. The fine sieves are fragile and must not be mistreated or overloaded. Always protect the fine sieves with a coarse sieve. Clean sieves after each analysis by brushing with paint brush. Repair punctured sieves by soldering.

The recommended sets of equipment include a number of testing sieves which are used to grade and determine the size of soil and aggregates used in construction. The normal size of sieve is 8 inches diameter. The sieve set includes a pan and cover.

California Bearing Ratio (CBR) Equipment

Used for CBR test. Keep unpainted metal parts clean and coated with oil to prevent rusting when not in use.

Sampling Collar. For taking undisturbed samples.

Compaction Mold with Collar and Base. For compacting samples before testing.

Dial Extensometer or Dial Indicator. Used for accurate measurements of swell and penetration. This is a precision instrument and should be kept in a protected place when not in use. Do not oil. Treat it like a watch.

Hydraulic Jack. Used to apply load for penetration test. To raise jack, turn release valve in base firmly to right, then pump handle. To

lower jack, turn release valve slowly to left. A can of oil is provided for filling jack through oil-level filler plug on side. Do not use brake or shock-absorber fluid as this will damage jack. Check jack calibration occasionally by weights.

Compaction Equipment

The tamper and guide are shown at the top of the photo. On the left is a disassembled Soiltest 1/30 cubic foot standard compaction mold. On the right is the CBR mold. These molds and tampers are used to make optimum moisture content and compaction tests. Keep the tamper and guide clean so tamper falls freely. Holes at bottom of guide must be kept open to permit air to escape on the downward stroke.

Miscellaneous Tools

Hacksaw Blades. For obtaining and trimming undisturbed soil samples.

Paint Brushes. For cleaning sieves and pans, and to coat samples with paraffin. Keep clean and dry.

Chisel. For general utility.

Files. For sharpening augers and other tools.

Butcher Knife. For trimming soil samples.

Pliers. For general utility.

12-inch Steel Rule. For accurate laboratory measurements. Graduated in 16ths, 32ds, and 64ths of an inch.

72-inch Steel Tape. For accurate field measurements. Graduated in 16ths and 32ds of an inch.

Screwdrivers. For general utility and adjustment of equipment.

Spatula. For mixing and trimming soil samples.

Spoon. For digging and for mixing soil samples.

Steel Straightedge. For checking ends of trimmed samples and general utility.

Trowel. For mixing, digging, trimming, and quartering samples.

Crescent-type Wrench. For adjusting CBR loading frame and general utility.

Pipe Wrench. For screwing on auger extensions and for general utility.

Miscellaneous Supplies

Paraffin. Used in coating samples to prevent loss of moisture. Care must be taken when heating over an open flame since it is highly inflammable. Do not continue to heat melted paraffin as it may become overheated and burn the brushes.

China-marking Pencils. For marking shipping tags and laboratory equipment. Marks are not affected by heat or moisture.

General Utility

Notebook
Gummed labels
Semilogarithmic paper
Shipping tags
Memorandum pads
Cross-section paper
Lead pencils
Towels, Twine

Miscellaneous Equipment

Sample Bags. For taking, transporting, and storing samples. The small sample bags are 10 inches by 18 inches and hold about 20 pounds of soil. The large sample bags are 17 inches by 32 inches and hold about 100 pounds of soil. After use with wet clays, turn inside out and scrape with straightedge or spatula. Then dry and beat against hard, smooth surface until clean. When bags become soiled, turn inside out. Wash occasionally in warm soapy water.

Metal Boxes. Used as containers for making moisture-content tests. The small boxes hold about 4 ounces and the large boxes about 8 ounces. Number each box and lid and record tare weights to save time.

Buckets. For general utility and for soaking CBR samples.

100-cc Graduate. Used for measuring liquids. Keep clean and usable.

Quartering Canvas. Keep clean and dry.

Battery Filler. Used for adding small quantities of water when mixing soils.

Split Molds. For compacting samples of remolded clay for compression or other tests.

Can Opener. For removing tops from cans to be used for sampling.

Saucepans. For drying and mixing samples and general utility.

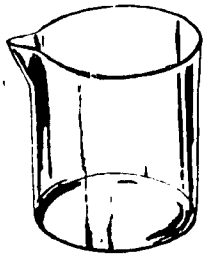
Thermometer. For determining temperature of drying oven.

Stopwatch. For determining rate of load penetration in CBR test. It should be cared for as any other watch.

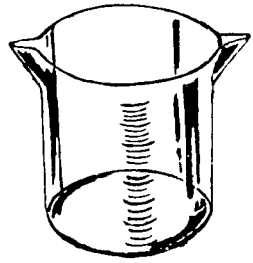
SUPPLEMENTAL EQUIPMENT

When using the set in semipermanent laboratories, it is desirable to supplement the set with equipment sometimes available from depot stock and with equipment improvised from local materials. Suggestions for supplemental equipment are illustrated below.

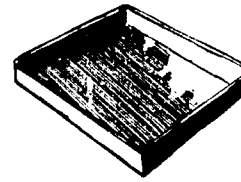
Equipment from Depot Stock



600 ML GLASS BEAKER

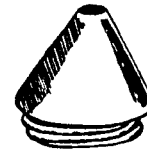


32-OZ GALSS GRADUATE

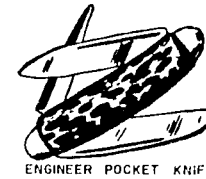


SHEET-METAL PAN

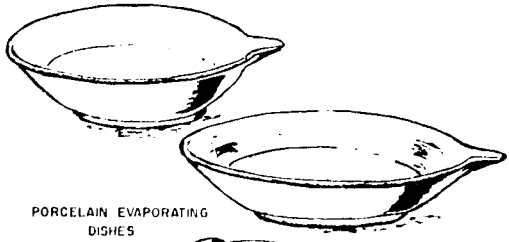
400ML PORCELAIN MORTAR AND PESTLE



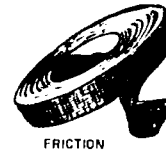
PYCNOMETE TOP
(to fit 1-quart mason jar)



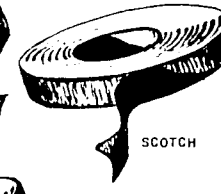
ENGINEER POCKET KNIFE
(for trmming samples and general use)



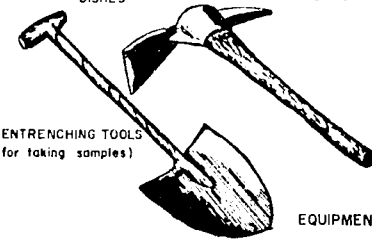
PORCELAIN EVAPORATING DISHES



FRICTION



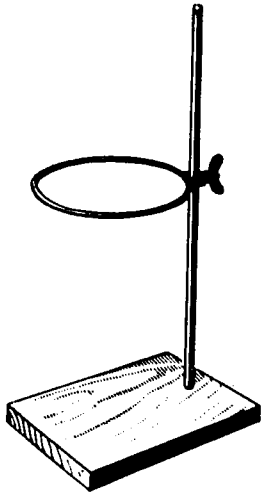
SCOTCH



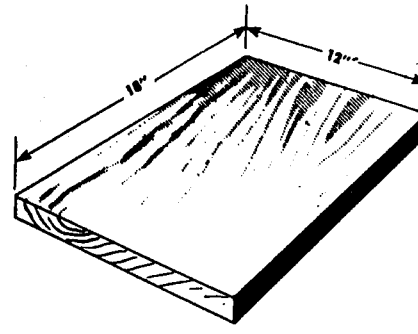
ENTRENCHING TOOLS
(for taking samples)

RUBBERIZED SEALING TAPES
(for sealing moisture-content and undisturbed samples)

EQUIPMENT FROM DEPOT STOCK



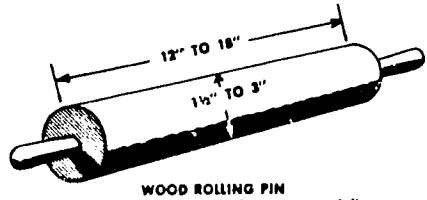
RING SUPPORT AND BASE



FLAT HARDWOOD BOARD
(for breaking up material)

Improvised Equipment

RUBBER-COVERED PESTLE
(for pulverizing fine material)



WOOD ROLLING PIN
(for breaking up lumps of coarse material)

SOIL EXPLORATION AND SAMPLING

GENERAL

Types of soils to be sampled, number of samples to be taken, and where and how the samples will be taken is decided by the engineer in charge of soil exploration.

TYPES OF SAMPLES

Bag Samples

Bag samples are taken by shovel, auger, or any other convenient hand tool and placed in bags without attempting to keep the soil in an undisturbed condition.

Bag samples are used for:
- Mechanical Analysis (page 34)
- Plasticity Test (page 28)
- Optimum-moisture-content Test (page 27)
- Laboratory compacted CBR Test (page 48)

Moisture-content Samples

To determine natural moisture content of soil, samples are taken in the field and placed in a container which is sealed to prevent loss of moisture by evaporation.

Undisturbed Samples

An undisturbed sample is soil that is cut, removed, and packed with the least possible disturbance. Undisturbed samples are used for:

1. Determining density (unit weight) in the laboratory (page 40).
2. Investigating strength of undisturbed soils in the laboratory by CBR (page 48).
3. Shipping to other laboratories for special examination or testing.

LOCATING, RECORDING, AND NUMBERING SAMPLES

It is the responsibility of the engineer in charge of soil exploration to see that:

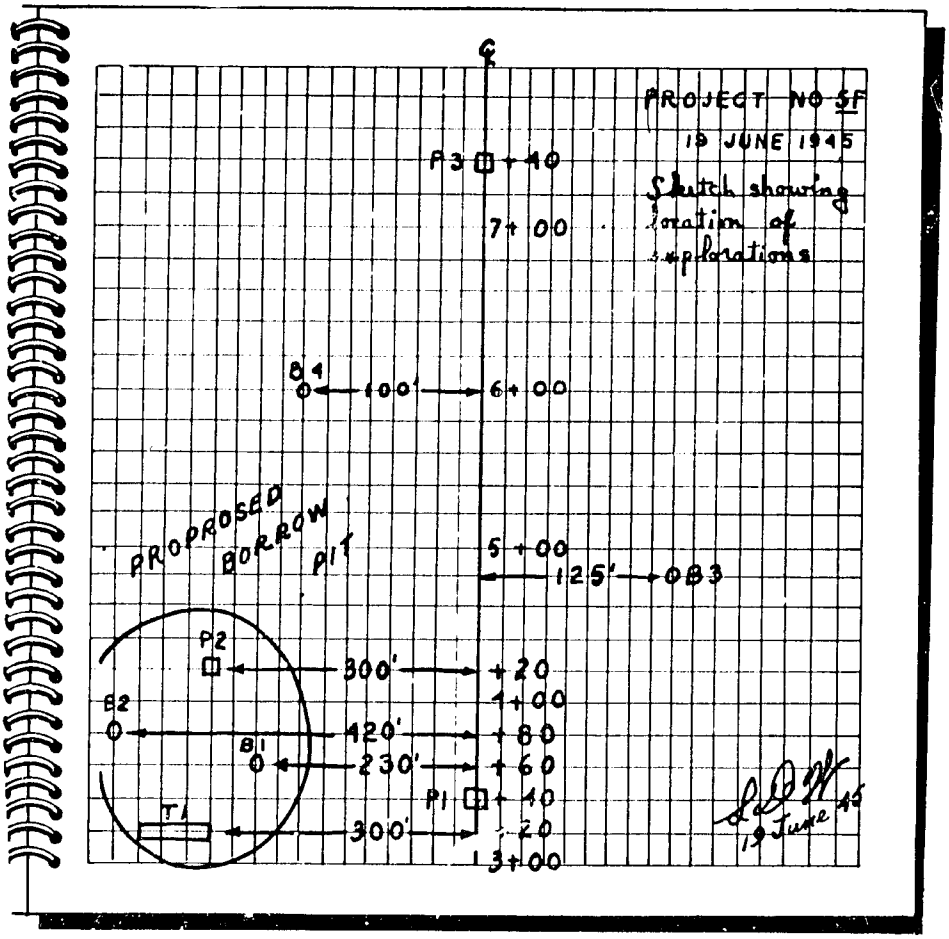
1. Each test pit, boring, or other exploratory excavation is properly surveyed, numbered, and recorded.
2. A log is kept of each test hole.
3. Each sample is properly numbered, tagged, and prepared for shipment.

Survey

Each test pit, boring, or other exploratory excavation is located by measuring or pacing right-angle offsets from the center line of the road or airstrip. Its location, type, and identification is plotted on a map or sketch in the notebook.

TYPE	ABBREVIATION	SYMBOL
PIT	P	□
BORING	B	○
TRENCH	T	▭

A uniform system of symbols should be used for platting exploratory excavations. The symbols shown above are common.


PROJECT NO SF
19 JUNE 1945
Sketch showing location of explorations
℄
P3
+40
7+00
B4
100'
6+00
PROPROSED BORROW PIT
5+00
125'
OB3
P2
300'
+20
4+00
B2
120'
+80
B1
230'
+60
P1
+40
T1
300'
+20
3+00
19 June 45

Log

A detailed log is kept in the notebook of each exploratory excavation.

Logs must be complete and contain all information which might be of value in interpreting the test results and in plotting the soil profiles.

Numbering Samples

Each sample is identified by the following information:

A project number consisting of a number, an abbreviation, or a symbol. For example, SF might be used for Smith Field.

An excavation number which corresponds to the number of the exploratory excavation. For example, P3 would mean that the sample was obtained from pit No. 3.

A sample number which is the number of the sample in the order in which it was obtained from each location. If the sample consists of more than one bag, the total number of bags comprising the sample must also be recorded.

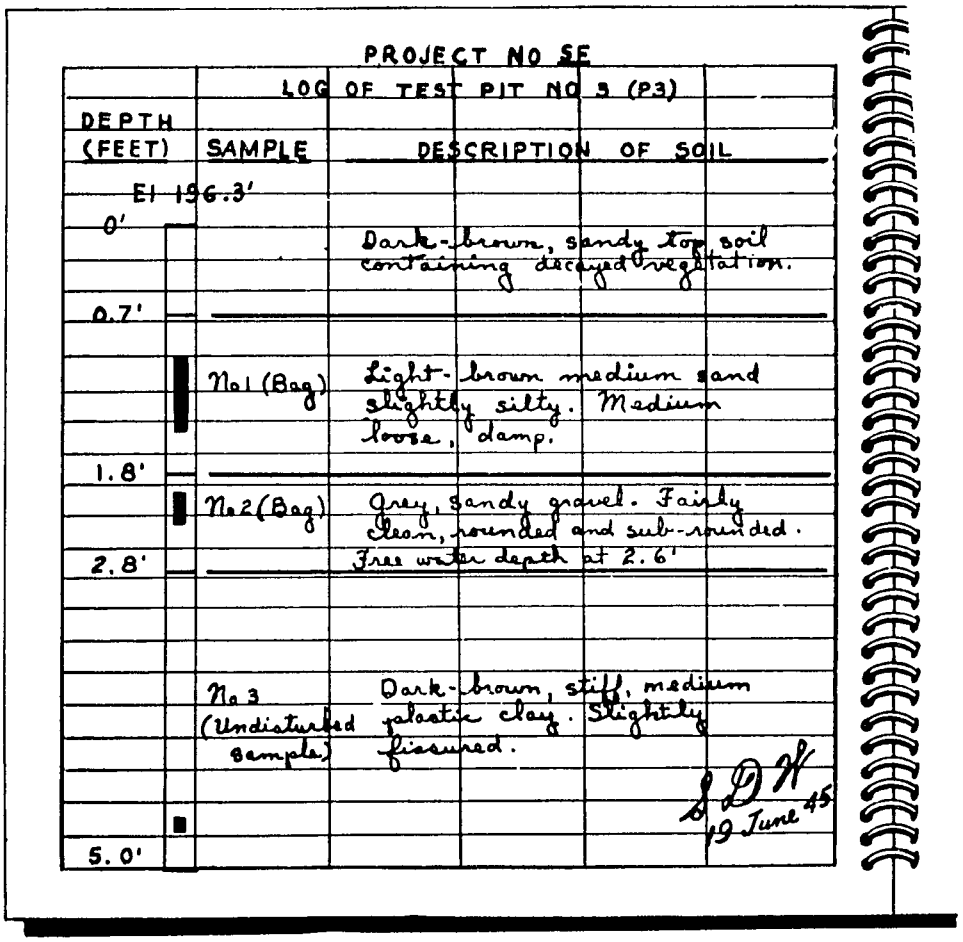
An example of a complete designation number is:

SF — P3 — 2

(BAG 1 of 2)

This designation means that the sample was taken on project SF, pit No. 3, that it is the second sample taken in this pit, and that the bag is No. 1 of a total of two bags.

The sample number is printed with indelible pencil on a tag which is then tied on the outside of the bag. A duplicate tag is placed inside the bag.



PROJECT NO SF

LOG OF TEST PIT NO 3 (P3)

DEPTH (FEET)	SAMPLE	DESCRIPTION OF SOIL
El 196.3'		
0'		Dark-brown, sandy top soil containing decayed vegetation.
0.7'		
	No 1 (Bag)	Light-brown medium sand slightly silty. Medium loose, damp.
1.8'		
	No 2 (Bag)	Grey, sandy gravel. Fairly clean, rounded and sub-rounded. Free water depth at 2.6'
2.8'		
	No 3 (Undisturbed Sample)	Dark-brown, stiff, medium plastic clay. Slightly fissured.
5.0'		

S D H
19 June 45

BAG SAMPLING PROCEDURES

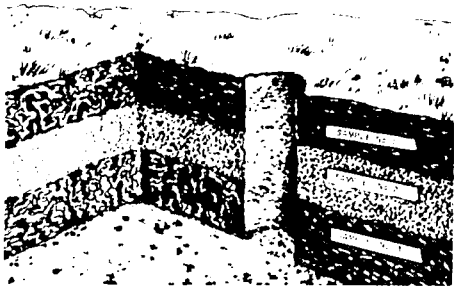
Size

Two small bags or half a large bag furnish enough material when all routine tests are required.

Individual Samples

When exploring foundation conditions, bag samples are taken of each individual type of soil encountered.

To take individual samples from a pit, trench, or exposed face:



1. Shave off loose and dried soil to obtain a fresh surface and to expose clearly any variations in the soil.
2. Take a typical sample of each type of soil or of those types requiring further investigation.

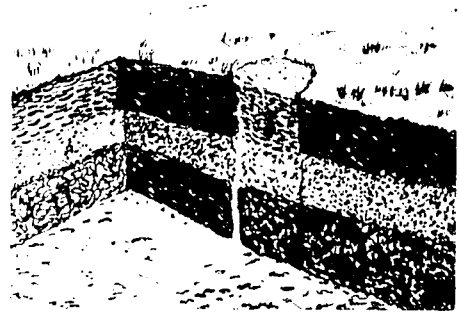
When sampling auger holes:

1. Place excavated soil along a row in correct order.
2. Take a typical sample of each type of soil.

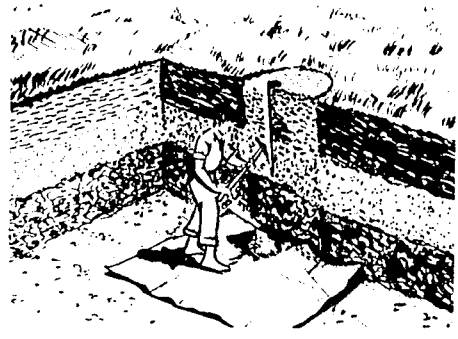
Composite Samples

The purpose of a composite sample is to obtain a representative mixture of all soil within a profile to be investigated or of the material contained in a stock pile or windrow. A test sample is obtained from composite samples by quartering (page 20) in the laboratory.

To take composite samples from test pits, trenches, or power-shovel cuts:



1. Remove any overburden or surface soil that is to be wasted.
2. Shave off loose and dried soil to obtain a fresh surface for taking sample.
3. Spread a quartering canvas or tarpaulin at toe of bank.
4. Excavate a channel of uniform cross section from top to bottom. Deposit material on canvas.
5. Collect and bag all material removed to assure that the sample contains the correct proportions.



For composite samples from auger holes, collect all material excavated from the hole after first removing overburden.

For composite samples from stock piles or large windrows, take particular care to obtain a representative sample. In dumping material on large piles, the coarse material tends to roll to the bottom, leaving the finer material in the upper portion.

To sample a small windrow, excavate and bag material from a short section.

MOISTURE-CONTENT SAMPLES

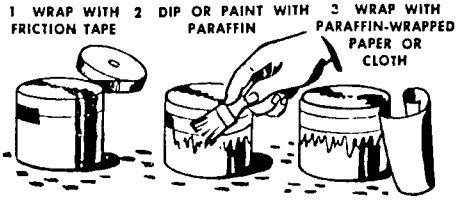
Size

Ten grams of soil is enough to determine natural moisture content of fine-grained soils. Much larger samples must be used for gravelly soils.

Containers

Metal boxes furnished with the set have tight fitting covers and do not require sealing if the test is made within 1 day after the sample is taken. Three suggested methods of sealing are shown below:

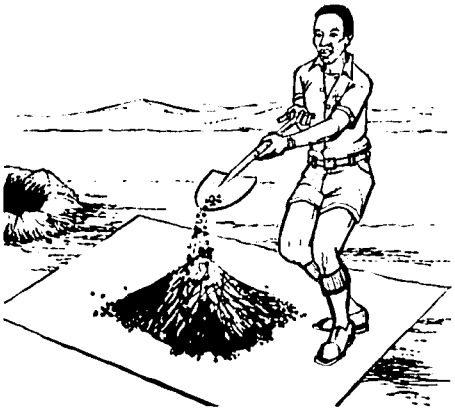
Any other clean containers having covers which can be sealed with friction tape or paraffin can be used for moisture content samples.



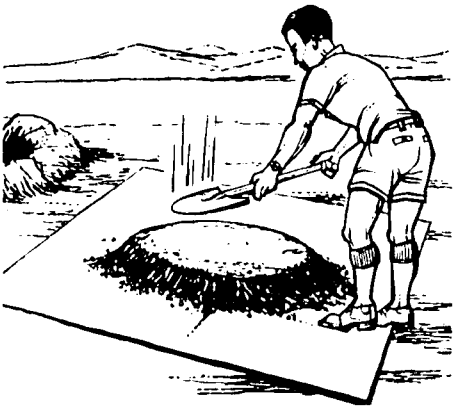
QUARTERING SAMPLES

The process of reducing a representative sample to a convenient size, or of dividing a sample into two or more smaller samples for testing, is called quartering.

Quartering Samples Weighing Over 100 Pounds

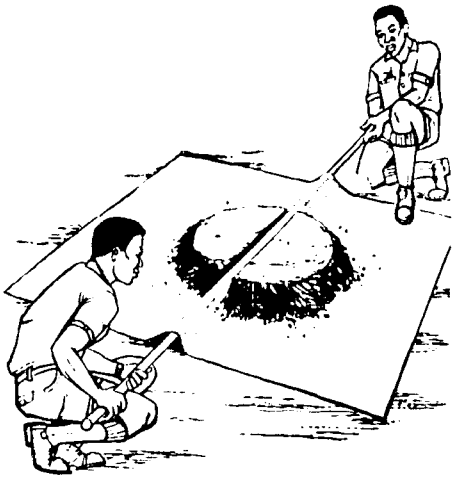


1. Mix and pile sample on canvas. Place each shovelful in center of cone so soil runs down equally in all directions to mix the sample.



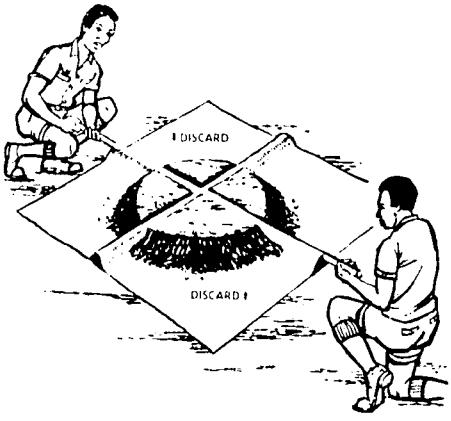
2. Flatten cone with a shovel, spreading material to a circular layer of uniform thickness.

3. Insert stick or pipe under center of pile (under canvas) and lift both ends, dividing sample into two parts. Remove stick, leaving canvas in folded position.



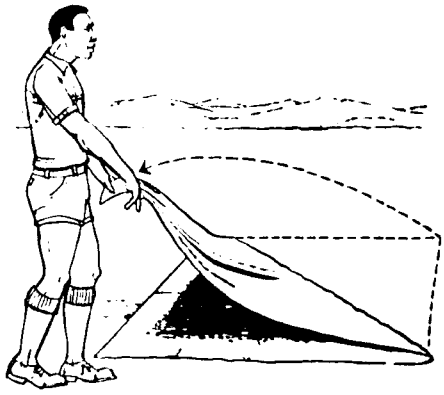
4. Insert stick under center of pile at right angles to first division and again lift both ends, dividing sample into four parts.

5. Discard two diagonally opposite quarters, being careful to clean fines from canvas.



6. Remix remaining material by taking alternate shovelfuls from each quarter. Repeat quartering process until sample is reduced to desired size.

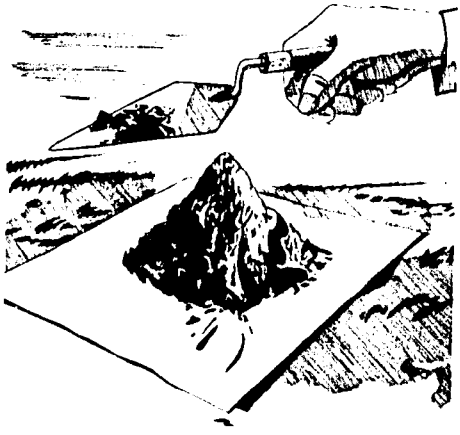
Quartering Samples Weighing 25 to 100 Pounds



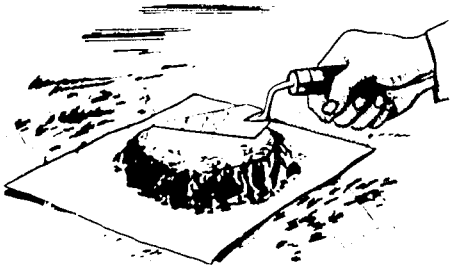
1. Pile sample on canvas and mix by alternately lifting corners of canvas and pulling over sample as if preparing to fold canvas diagonally.

2. Flatten and quarter as above.

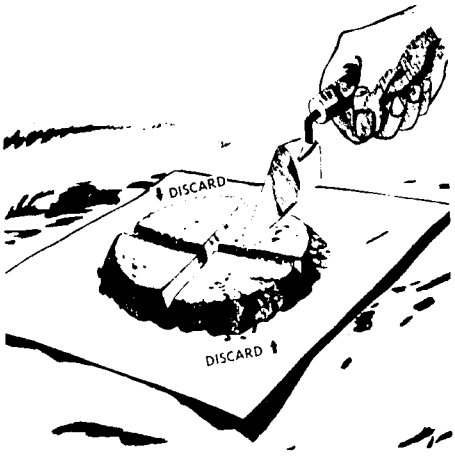
Quartering Samples Weighing Less Than 25 Pounds



1. Place sample on canvas or clean sheet of paper. Mix thoroughly with trowel and form into a conical pile.



2. Flatten cone by pressing downward with trowel.

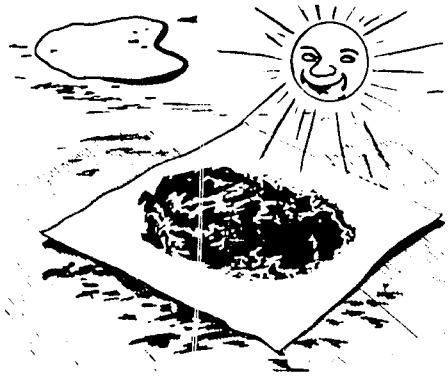


3. Separate into quarters with trowel and discard diagonally opposite quarters.

DRYING SAMPLES

Some lateritic soils exhibit changes in physical characteristics when tested under different conditions. The pretreatment given to lateritic materials should depend upon the actual conditions that will be encountered under field conditions. In areas of high rainfall it may be difficult to dry soils during construction. In that case the tests should be run from the natural moisture content, and not allowed to dry in the laboratory. If the construction is during the dry season or in an area of low rainfall, then the soils should be air dried in the laboratory. IN ALL CASES, THE LABORATORY PRETREATMENT SHOULD REFLECT ACTUAL FIELD CONDITIONS. For this reason, samples should not be oven dried prior to testing since the soils will not experience such high temperatures in the field.

Air Drying



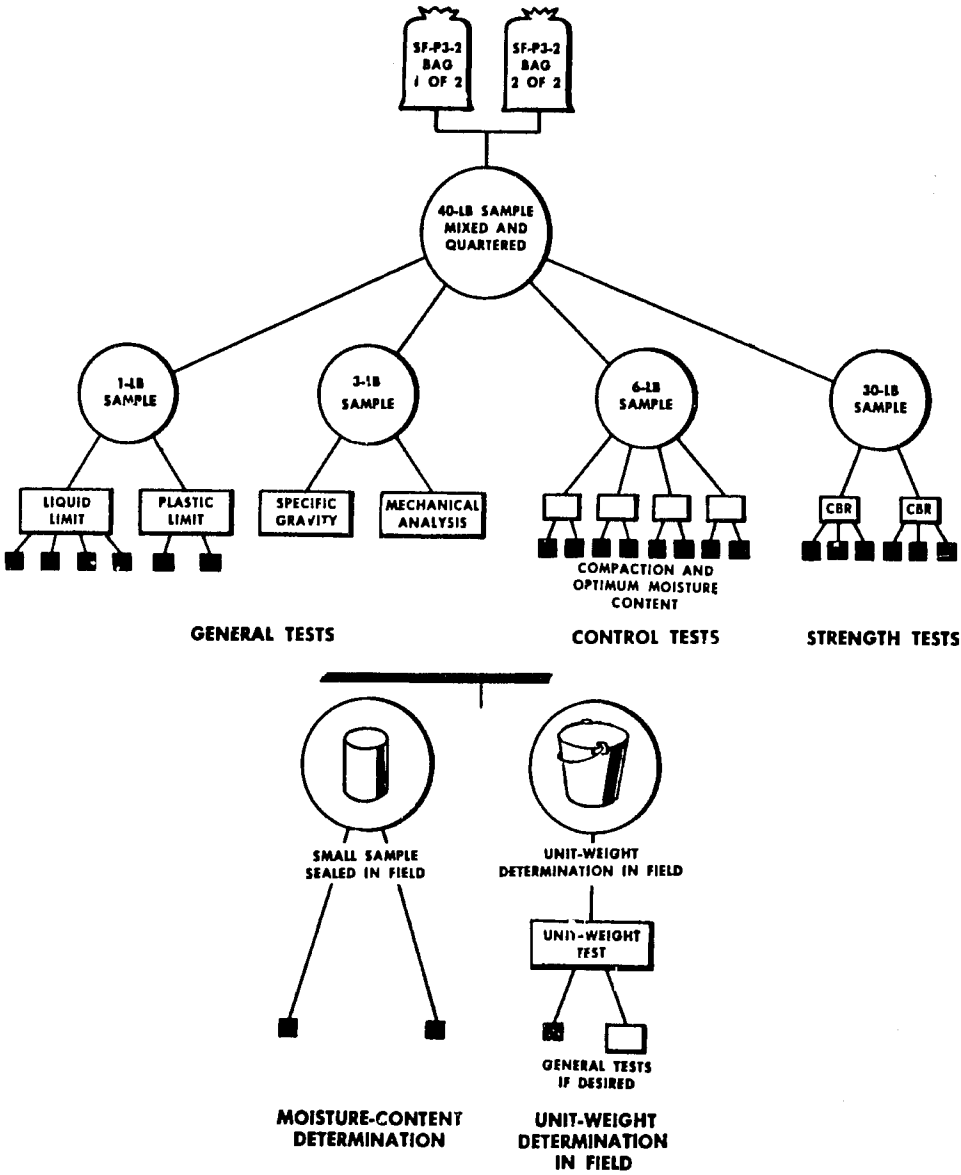
To air-dry material, place it in pans or spread it on a canvas and expose it to direct rays of sun or to a draft. Frequent agitation or stirring speeds up the drying.

In dry atmosphere, the material also dries readily inside the laboratory or in the shade. A fan blowing air over the sample greatly increases the rate of evaporation.

The sample as received from the field shall be thoroughly mixed and aggregations shall be thoroughly broken up in such a way to avoid reducing the natural size of individual particles. Do not dry the sample if it is to be used for tests at the natural moisture content.

TEST PROCEDURES

Soil tests are made (1) for general classification of soils, (2) for construction control, and (3) for determining soil strength.



General Tests

General tests are used to identify soils so they can be properly described and classified. General tests described in this bulletin are:

Specific-gravity test
Mechanical analysis
Plasticity tests

Control Tests

Control tests are used to assure that soils are properly compacted during construction so design standards are met in the field. The control tests described are:

Moisture-content test
Unit-weight determination
Compaction test for optimum moisture content

NOTE: The moisture-content test is listed as a control test, although it is also an essential part of most classification and strength tests.

Strength Tests

Strength tests are used to determine the load-carrying capacity of soils and their suitability for use in construction. Strength tests described are:

California bearing ratio test (CBR)
Unconfined compression test
Plate bearing test
Traffic test

Quantity of Soil Required for Tests

The quantity of material required for the various tests is illustrated on page 23. All tests are not required on each sample.

WEIGHING MATERIALS

Four scales or balances are included with the set. Use the one best suited for the purpose, depending on the weight of the object and the accuracy required.

ITEM	CAPACITY	ACCURACY
40-lb spring balance	40 lb	0.1 lb
60-lb spring balance	60 lb	0.1 lb
Torsion balance	4,500 gm	5 gm
Triple-beam balance	200 gm	0.01 gm

NOTE: If accuracy to 0.1 gram is desired with the torsion balance, cut small weights from nails or small metal strips and calibrate them on the triple-beam balance.

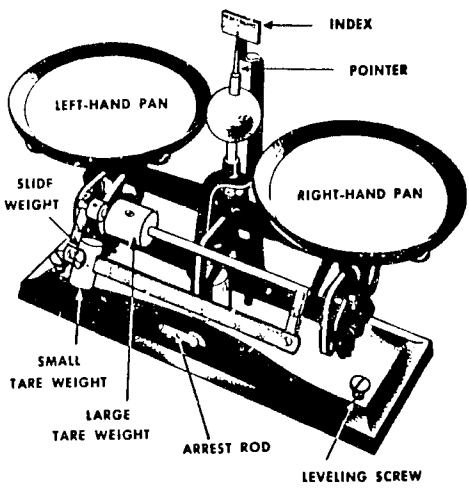
Use of Spring-balance Scales

Attach object to hook and suspend scales by holding top ring.

For objects weighing less than 20 pounds, read the weight directly on circular dial.

For objects weighing more than 20 pounds, add 20 or 40, as indicated by slide scale, to dial reading to obtain total weight. If object is to be weighed in a container, first suspend container, then set red hand on dial to indicate zero when black hand indicates tare weight. Red hand then indicates net weight of object and black hand the gross weight of container and object.

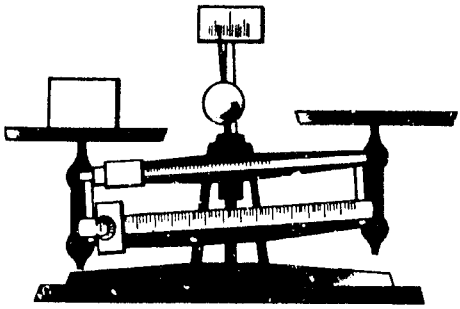
Use of Torsion Balance



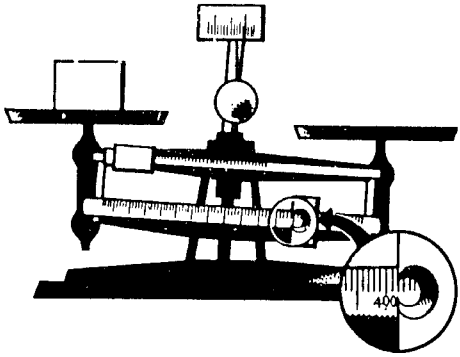
To set up the balance, lift from box and unlock scale by removing small plate from underneath base. Take out two screws projecting through base into lower beam. Place balance on a firm

level table or shelf where there is no vibration. With slide weight at zero, move tare weights to left until pointer swings equidistant on each side of index midpoint. Final adjustment is made easier by slight adjustment of the leveling screws. Always place and remove weights carefully to avoid damaging scales.

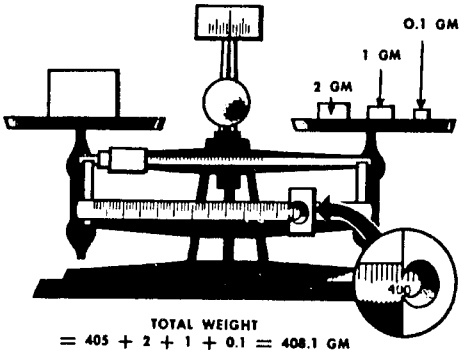
To weigh objects less than 500 grams:



1. Place object to be weighed on the left-hand pan. Pointer will swing to the left.



2. Move slide weight to right until pointer swings to the right. Then move slide weight one notch (5 gm) to left.

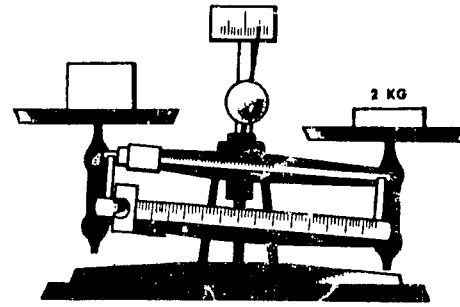


TOTAL WEIGHT
= 405 + 2 + 1 + 0.1 = 408.1 GM

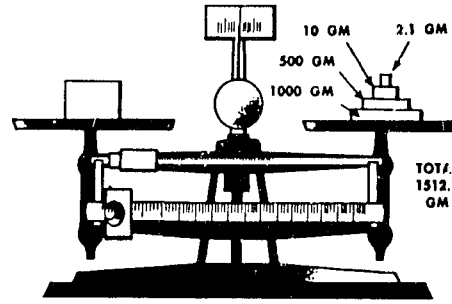
3. Add small weights to right-hand pan until pointer swings equidistant on each side of index midpoint. Total weight is sum of small weights plus weight indicated on scale.

To weigh objects more than 500 grams:

1. Place object to be weighed on the left-hand pan and the largest weight, or one known to be heavier than the object on the right-hand pan. The pointer will swing to the right.



2. Remove the weight and replace with next smaller one. If pointer swings to left, proceed with step 3. If pointer again swings to right, replace weight with next smaller weight until the heaviest weight which does not swing pointer to right is found.

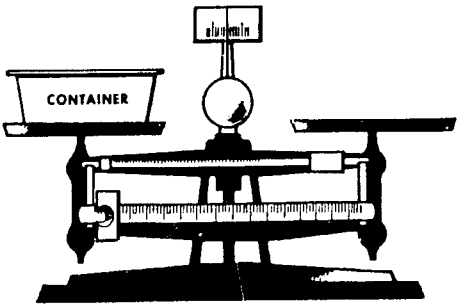


3. Add the next smaller weight to the right-hand pan and continue as before. Repeat until pointer swings equidistant on each side of index midpoint. Add up total weights on right-hand pan.

To weigh object in containers:

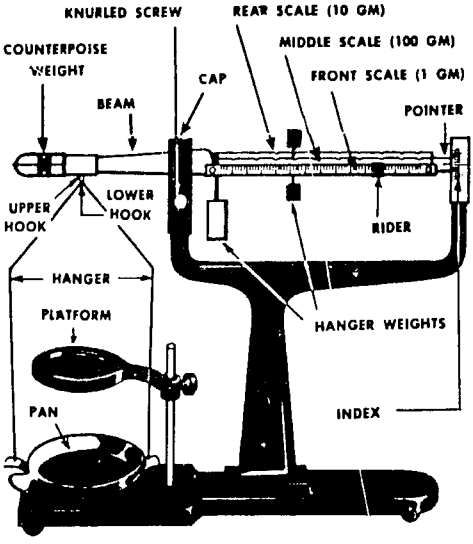
1. Place container on left-hand pan.

2. Slide large tare weight to right until scales are balanced.



3. Place object in cantainer and proceed as above.

Use of Triple-beam Balance



To set up the balance:

1. Carefully take all parts of balance out of box.

2. Remove cap, place beam on pillar, and replace cap.

3. Suspend hanger from upper hook and place pan in position.

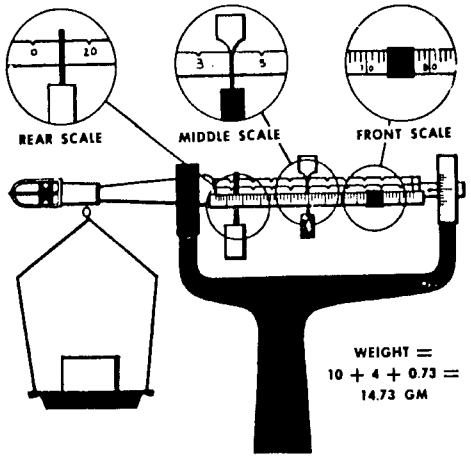
4. Place balance on a firm, level table or shelf where there is no vibration.

5. Turn knurled screw until knife edge of beam rests on its bearing and beam swings freely.

6. Set hanger weights at zero marks and adjust counterpaise weight until pointer swings equidistant on each side of index midpaint.

To weigh objects less than 100 grams:

1. Place object to be weighed in pan and shift middle hanger weight to right until placing it in the next notch causes pointer to drop below index midpoint. Each division on scale equals 10 grams.

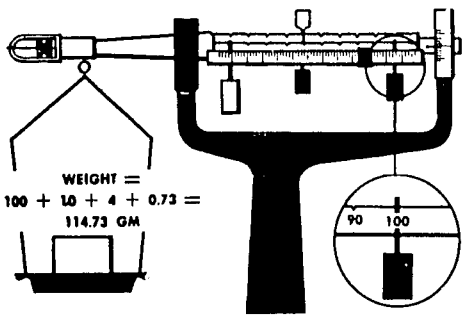


2. Lift rear hanger weight and adjust in same manner as for middle hanger weight. Each division on scale equals 1 gram.

3. Slide front rider to right with pencil until pointer swings equidistant on each side of index midpoint. Each small division on scale equals 0.01 gram.

4. Total weight equals sum of weights indicated by three scales.

To weigh objects between 100 and 200 grams:



1. Hang special weight furnished with balance on 100-gram notch on middle beam.

2. Proceed as before. Weight of object equals sum of weights indicated by the three weights and the rider.

MOISTURE-CONTENT TEST

The moisture or water content of a soil sample is the ratio of the weight of water contained in the sample to the oven-dry weight of the sample, expressed in percent.

Apparatus Required

Triple-beam balance

Oven	Spatula
Stove	Metal boxes

For average moisture-content determinations, the 4-ounce metal boxes are satisfactory, but much larger or much smaller samples and any suitable container can be used.

Procedure

1. Weigh container with wet sample to nearest 0.01 gram and record on data sheet.
2. Uncover container and place in oven to dry.
3. Remove from oven, replace cover tightly, and set aside to cool to room temperature.
4. Weigh container with dried sample to nearest 0.01 gram and record on data sheet.
5. If tare weight is not already available, clean, dry, and weigh container with cover to nearest 0.01 gram and record on data sheet.
6. Compute moisture content as shown on data sheet and in sample calculation.

NOTE: It is recommended that all containers used for moisture-content tests be numbered and their weights obtained in advance and recorded for reference.

DATA SHEET MOISTURE-CONTENT TEST	
Sample No	SF-D5-3
Date	19 JUNE 45
Can No	19
Wt wet sample + can (gm)	85.55
Wt dry sample + can (gm)	76.90
Wt water (gm)	8.65
Wt can (gm)	41.28
Wt dry sample (gm)	35.62
Moisture content (%)	24.3

Sample Calculation

To calculate the weight of water in sample:

Wt water = (wt wet sample + can) − (wt dry sample + can) = 85.55 − 76.90 = 8.65 gm

To calculate the weight of dry sample:

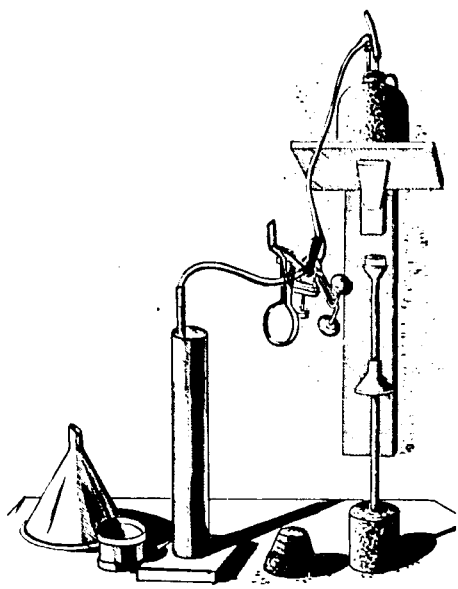
Wt dry sample = (wt dry sample + can) − (wt can) = 76.90 − 41.28 = 35.62 gm

To calculate moisture content:

$$\text{Moisture content} = 100 \times \frac{\text{wt water}}{\text{wt dry sample}}$$

$$= 100 \times \frac{8.65}{35.62} = 100 \times 0.243 = 24.3\%$$

Some loteritic soils are susceptible to irreversible changes of properties with drying. Ferrallitic soils are the most likely to change. The "aggregation index" can be used to measure such changes in physical properties due to dehydration. This index is the sand equivalent value of the oven dried sample divided by the same equivalent value of the soil in its natural state. An aggregation index of 1 would indicate a soil which displays no difference or no change in properties. The sand equivalent test measures the relative proportions of fines in soils. (AASHO Designation T-176-65.) This test should be performed in a central materials laboratory which should be equipped with the test apparatus.



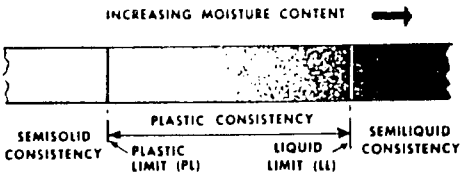
The change in properties can also be determined by performing the liquid limit test on air dried soil and comparing this with the liquid limit performed on the soil at the natural moisture content.

PLASTICITY TESTS

GENERAL

Clays and related fine-grained soils can be brought to a semiliquid consistency by mixing with water.

When this moisture content is reduced by evaporation and the sample is remixed, the material is plastic or putty-like. If the moisture content is further reduced, the material becomes semi-solid and cracks or crumbles when deformed. The range within which the material has a plastic consistency is called the plastic range.



The liquid limit (LL) is the moisture content of the material at the upper limit of the plastic range.

The plastic limit (PL) is the moisture content of the material at the lower limit of the plastic range.

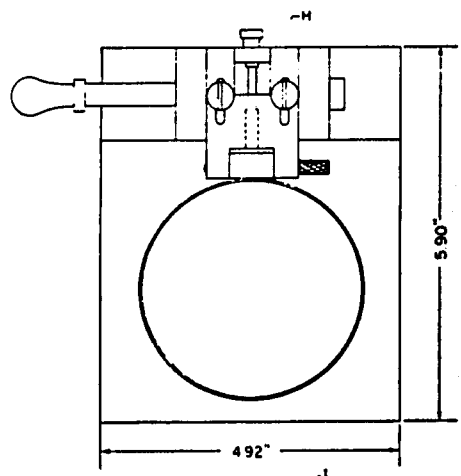
Since there is no sharp distinction between the semiliquid, the plastic, and the semi-solid states of consistency, arbitrary procedures for determining these limits have been standardized.

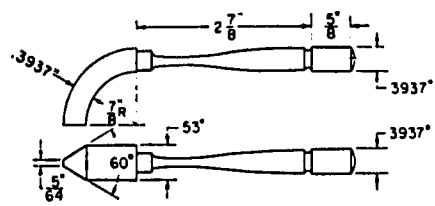
Apparatus Required

Liquid-limit device	Gas stove
Grooving tool	No. 40 sieve
Spatula	Oven
Battery filler	Saucepans
Triple-beam balance	4-oz metal boxes
Mixing dishes	Rubber-covered pestle

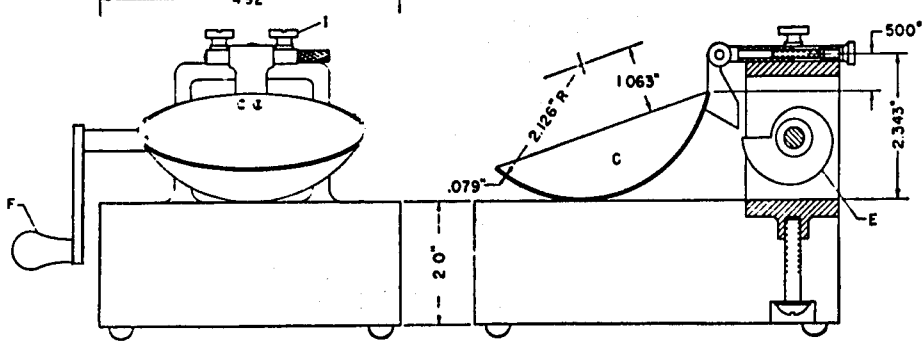
Adjustment of Liquid-limit Device

Before using the liquid-limit device, it must be adjusted so the cup in which the soil is placed falls exactly 1 centimeter. The handle of the grooving tool has a 1-centimeter gage which is used to measure this distance.





GROOVING TOOL



1. Remove cup from device and make a pencil cross at center of shiny spot caused by cup striking base.

2. Replace cup in device and turn crank until cup is raised to its highest elevation.

3. Insert gage and check distance from pencil marks to base in manner shown. Loosen lock screw and turn adjusting screw until distance is exactly 1 centimeter.

NOTE: The 1.0-cm gage must be placed to measure the distance from the shiny spot to the base and not the distance from the lowest point of the cup. Cylindrical gages with beveled edges cannot be used. Use a flashlight or other strong light behind gage when checking distance.

Preparation of Sample

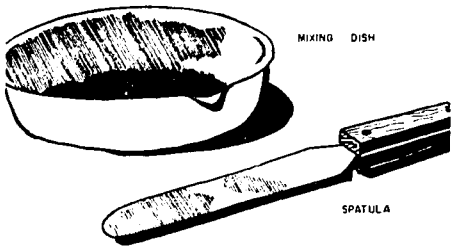
Plasticity tests are made only on the soil fraction which passes the No. 40 sieve. The separation on the No. 40 sieve is made either by dry sieving or by a slower wet process.

The field conditions should determine the preparation method. The results of the plasticity tests run both wet and dry will indicate the change due to dehydration.

Dry Method

1. Powder about 150 grams of dry material with rubber-covered pestle on clean, smooth surface.

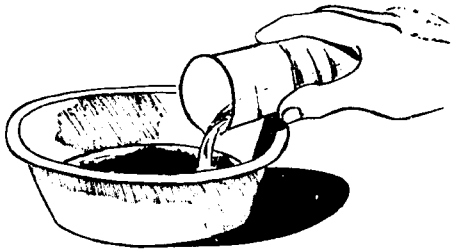
2. Screen powdered sample through the No. 40 sieve and discard the material retained on sieve.



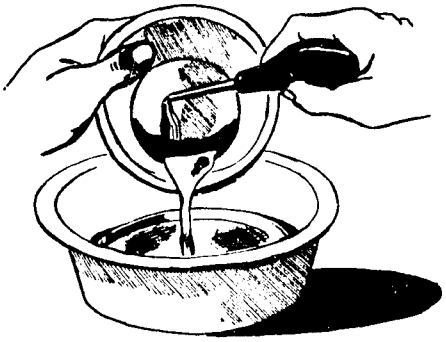
3. Mix soil passing No. 40 sieve with water until it has the consistency of a very thick, smooth paste. Cover with damp paper or cloth and let stand for not less than 1 hour.

Wet Method

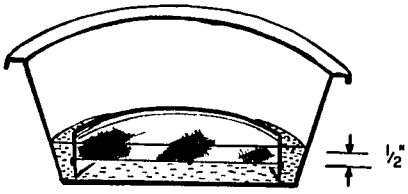
1. Break up the required amount of material with rubber-covered pestle or rolling pin.



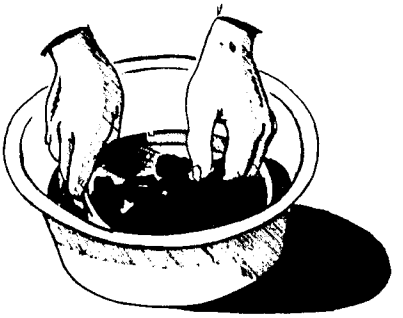
2. Transfer sample to saucepan and cover with water. Let soak until all material is disintegrated. This may require 2 to 12 hours.



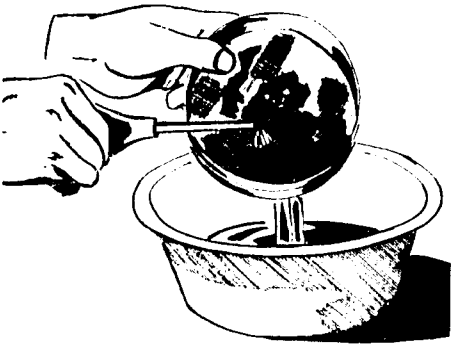
3. Place a No. 40 sieve in a saucepan and transfer entire soaked sample into the sieve. Wash any material still adhering to the soaking pan into the sieve by squirting water from the battery filler.



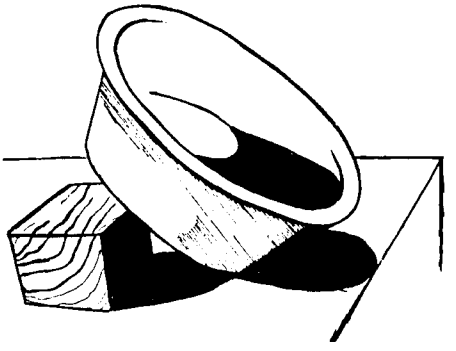
4. Pour clean water into pan containing sieve until level of water is about ½-inch above mesh in sieve.



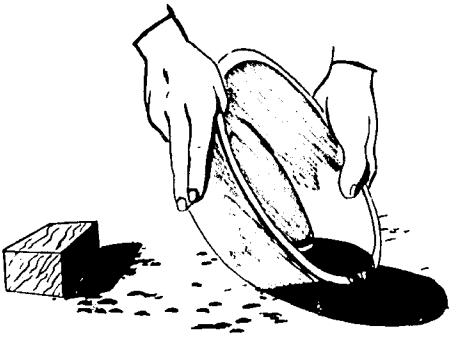
5. Without lifting sieve, agitate it with one hand. At the same time, stir material with the other hand until all fine material appears to have passed through sieve.



6. Hold sieve slightly above water surface in pan and squirt water from battery filler onto sieve until retained particles and the sieve are clean. Discard material retained in sieve.



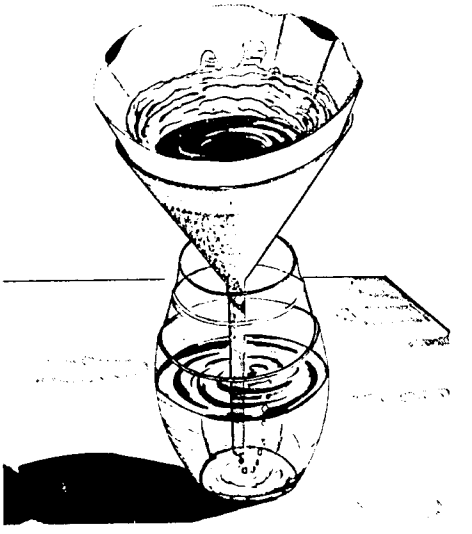
7. Place pan where it will not be disturbed and block it up on one side so water on the other side barely reaches rim of pan. Allow soil to settle for several hours.



8. Pour off liquid slowly by gradually increasing tilt of pan until cloudy layer overlaying the sediment reaches rim of pan.

9. Air-dry material to the consistency of a thick, smooth paste and put in small mixing dish.

For most lateritic soils, material in suspension will settle out. If there is no indication of this after several hours, the following method may be used.



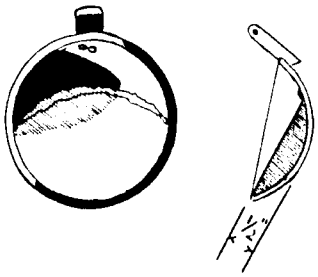
Place filter paper in a funnel and place wet soil inside the funnel as shown on the above figure. Place the funnel in a jar or other container and allow to stand until all the excess water is filtered off.

LIQUID-LIMIT TEST

Just before making liquid-limit test, thoroughly mix sample once more with spatula and set aside about 1 heaped teaspoonful of material for the plastic-limit test.

Test Procedure

1. Transfer enough material from mixing dish into brass cup of liquid-limit device to fill the cup about one-third full.



2. Hold cup and use spatula to mix and spread material, forming a smooth cake about ½ inch deep in lower half of cup.

3. Hold grooving tool with rounded edges downward, index finger against flat face.

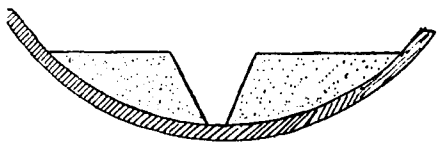
4. Place point of tool on upper edge of soil cake with tool perpendicular to surface of cup.

5. Draw tool down through the center of cake along a line extending from the center of the cup handle. At the same time, tilt the tool so it remains perpendicular to the bottom surface.

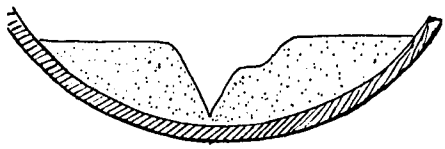
For clays containing little or no sand, cut groove with one smooth continuous stroke.

For very sandy clays, silts having little plasticity, and some organic soils, the tool cannot be drawn through sample without tearing sides of groove. For these soils, cut groove with a spatula and check dimensions with tool.

6. Clean grooving tool by wiping thumb over cutting edge before laying it aside. If soil dries on tool, time is lost in cleaning it later.



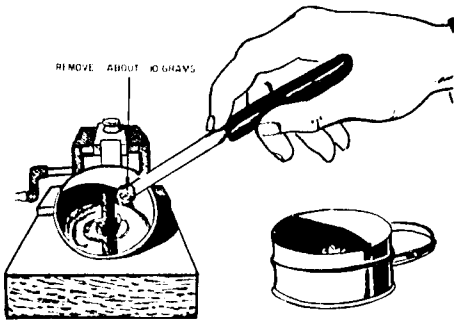
BEFORE TEST



AFTER TEST

7. With striking parts of the liquid-limit device clean and dry and height of drop properly adjusted, place cup in device, turn crank at rate of about two blows per second, and count number of blows required to close bottom of groove for a distance of about ½ inch.

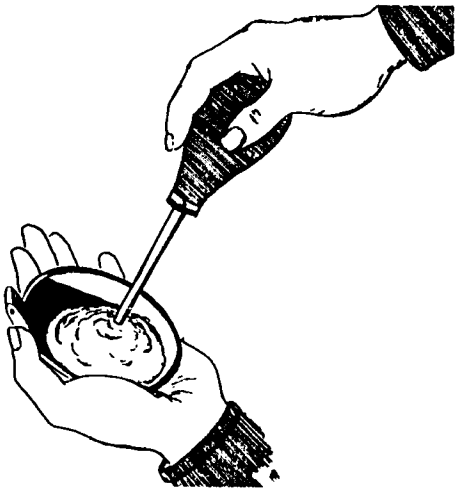
NOTE: If groove is not closed ½ inch in 25 to 35 blows, add water and remix or dry sample to a consistency within this range.



8. Remove cup from device, remix and regroove sample, and repeat step 7. If second test gives same number of blows as first or does not differ more than one blow, record both numbers on data sheet.

If difference is more than one blow, repeat test until three consecutive tests give a reasonable consistent sequence of numbers, such as 30-32-30, or 30-28-30 (typical of a humid atmosphere) or 30-32-34 (typical of a dry atmosphere).

9. Remove approximately 10 grams of material from closed portion of groove. Place material in small metal box and cover tightly.



10. Remove cup from device, remix and regroove sample, and repeat steps 7, 8, and 9.

11. Place about 20 grams of material from mixing dish into liquid limit cup. Add a slight amount of water and mix to a uniform paste having a consistency within the 10- to 20-blow range.

12. Groove sample and repeat steps 7, 8, 9, and 10.

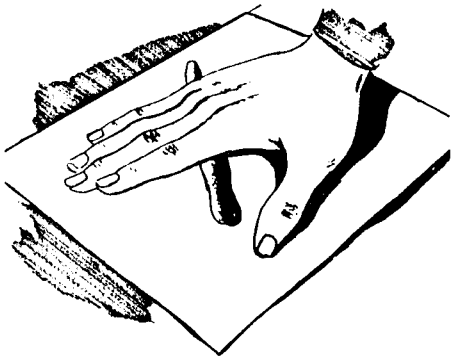
13. Determine moisture content of all samples obtained during test. (Cans must be properly numbered and recorded.)

14. To determine the liquid limit of the wet sample, air dry the sample and perform the blow count determination at different moisture contents as the soil slowly dries out.

PLASTIC-LIMIT TEST

The small sample which was set aside at the start of the liquid-limit test is allowed to dry to a consistency such that the material will not stick to the hands, yet can still be rolled into a thread without crumbling.

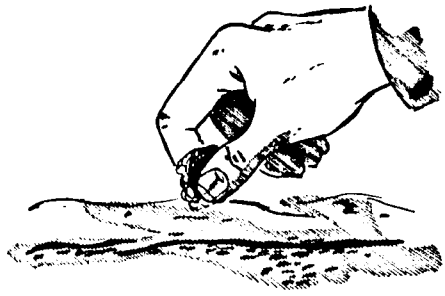
Procedure



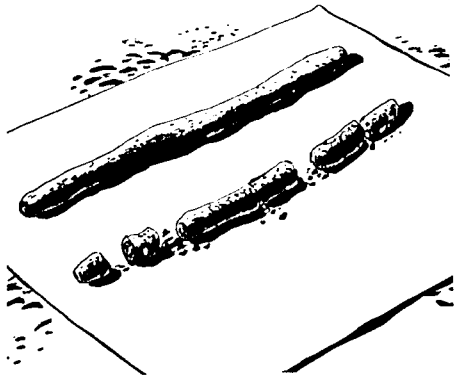
1. Take not more than one-half of this sample and roll with palm of hand on any clean, smooth surface such as a sheet of paper, to form a ⅛-inch thread about 3 inches long.

2. Fold thread and press together into a lump, and then roll it out again.

3. Repeat step 2, gradually reducing moisture content by evaporation as the sample is handled, causing threads to become stiffer.



4. The plastic limit (PL) is reached when the thread crumbles into a number of pieces while being rolled.



NOTE: If any doubt exists as to whether the PL has been reached, lump the pieces together and roll out again.

5. Immediately place the crumbled thread into a small metal box and determine moisture content.

6. Make another PL determination for a check, using material from remaining portion of original sample.

Data Sheet

The same data sheet is used for both the plastic-limit and liquid-limit tests.

PLASTICITY INDEX

The numerical difference between the liquid limit (LL) and the plastic limit (PL) is the plasticity index (PI).

$$PI = LL - PL$$

For example:

$$LL = 38$$
$$PL = 22$$
$$PI = 38 - 22 = 16$$

DATA SHEET
PLASTICITY TEST

Initials SDW

Date 19 June 45

Sample No	SF-B3-2					
Type of test	LL	LL	LL	LL	PL	PL
Can No	3	7	1	4	5	8
No of blows	31-29-29	30-31	16-15	16-17	–	–
Wt wet sample + can (gm)	48.65	43.88	40.97	44.96	34.64	37.11
Wt dry sample + can (gm)	43.97	40.60	38.23	41.36	34.15	36.13
Wt water (gm)	4.68	3.28	2.74	3.60	0.49	0.98
Wt can (gm)	31.28	31.76	31.40	31.92	31.88	31.71
Wt dry sample (gm)	12.69	8.84	6.83	9.44	2.27	4.42
Moisture content (%)	36.9	37.1	40.1	38.1	21.6	22.2

DATA SHEET

SIEVE ANALYSIS

Wt of original sample 431 GM

Wt after prewashing 411 GM

Washing loss 20 GM

Sample No SF-P3-2

Initials SDW

Date 19 June 1945

SIEVE OR SCREEN	SIEVE OPENING (MM)	WT RETAINED ON SIEVE (GM)	WEIGHT PASSING SIEVE (GM)	WEIGHT PASSING SIEVE (%)
2"	50.8			
1½"	38.1			
1"	25.4	0	431	100.0
¾"	19.1	20	411	95.4
¼"	6.35			
No 4	4.75	122+4=126	285	66.1
No 10	2.00	121	164	38.1
No 40	0.42	86	78	18.1
No 60	0.25			
No 100	0.149	37	41	9.5
No 200	0.074	15	26	6.0
Retained in pan		6		
Washing loss		20		
Pan total		26		
TOTAL		427		

Remarks: Error: 451-427 = 4 gm (added to wt of material retained in No 4 sieve). Largest size particle = 1"

MECHANICAL ANALYSIS

The determination of grain-size distribution in a soil, called mechanical analysis, is made by a screening process (sieve analysis) for coarse-grained soils, and by a settling process in water (wet mechanical analysis) for fine-grained soils. When both processes are used on the same sample, the test is called combined mechanical analysis.

Wet Sieve Analysis

Because of the tendency of some lateritic soils to form aggregations, a sieve analysis should be made on the sample after the fines are removed by washing.

Apparatus Required

Torsion balance	Saucepans
Set of sieves	Oven
Set of portable screens	Triple-beam balance
Paint brush	

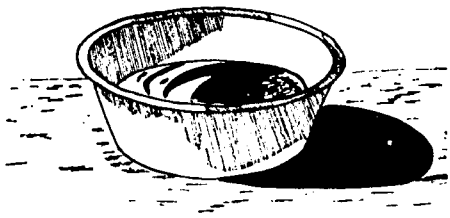
Preparation for Gradation Test

1. Two samples shall be selected by the method of quartering or by use of a sample splitter—one for the gradation test and the other for moisture content.

2. The gradation sample shall weigh, in its natural condition, not less than the amount indicated in the following table:

Nominal Maximum Sieve Size	Approximate Minimum Weight of Sample, kg
No. 4	1.0
½"	2.0
¾"	3.0
1"	4.0
1½" or over	5.0

3. The moisture sample shall weigh at least 30 per cent of the gradation sample.



4. Weigh the gradation sample in its wet condition and place in a container. Add sufficient water to the sample in the container to cover it.

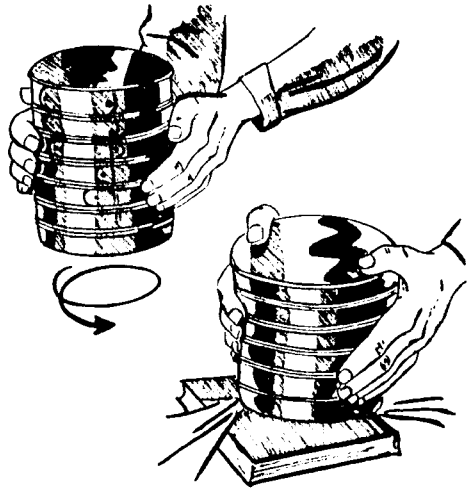
5. Prepare a nest of two sieves with a No. 200 sieve on the bottom and a No. 10 sieve on the top.

6. Transfer the sample to the nested sieves and wash with running water. When the sample is larger than can be handled at one time on the nested sieves, wash a portion of the sample and transfer it to a container in which it is to be dried.

NOTE: Tapping of the sieves expedites the washing procedure.

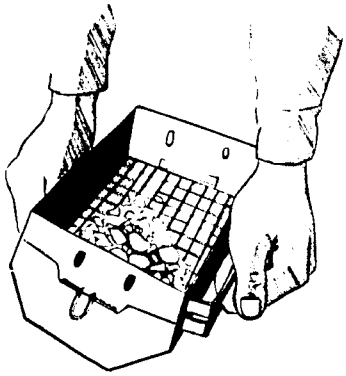
7. Dry and combine the washed material retained on the nested No. 10 and No. 200 sieves to a constant weight at a temperature not to exceed 230°F (110°C).

NOTE: The dry weight to be used in the computation for the gradation shall be computed using the initial wet weight and the moisture content of the sample.

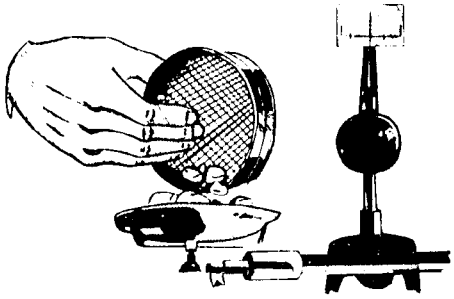


8. Transfer dry sample to set of sieves (coarse sieves at top, fine sieves at bottom) with the sieve pan on bottom. Place cover on top and shake the stack vigorously with a horizontal rotating motion. The sieves may be jarred occasionally by dropping lightly on several thicknesses of magazines. Do not drop directly on work bench or table; this will damage sieves. The shaking period depends on the amount of fine

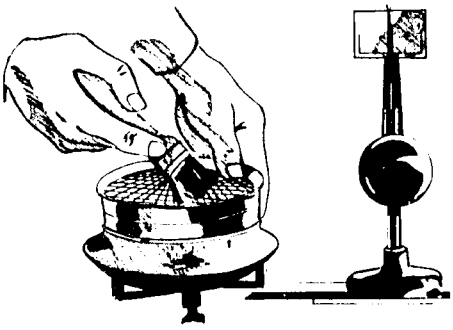
material in the sample, but should not be less than 15 minutes for most fine-grained soils.



NOTE: Large samples containing many coarse stones should first be screened through the portable screen set. The number and size of screens and sieves to be used depends on the type of soil tested and the purpose of the test. It is often permissible to omit a few of the intermediate sizes, as illustrated by the sample data sheet.



9. Transfer material from largest screen to pan of torsion balance and weigh to nearest 5 grams. Record size of largest particle. Place material in separate container and save until test is completed.



NOTE: For samples weighing less than 50 grams, weigh each fraction on triple-beam balance to nearest gram.

10. Repeat procedure for each successively smaller screen size. Individual stone particles caught in the wire screens should not be forced through screens but should be removed by hand and included with fraction before weighing. The finer sieves should be inverted over the scale pan and brushed clean.

Sample Calculation

1. Obtain sum of weights retained on each sieve and check this total against the weight of original dry sample. If error exceeds about 3%, reweigh each fraction or repeat test.

2. If error is less than 3%, apply numerical value of error to weight of largest fraction.

3. Compute the weight of material passing each sieve. For example:

Wt passing No. 4 sieve =

(wt of original sample) — (wt of material retained on No. 4 and all larger sieves)

$$431 - (20 + 126) = 431 - 146 = 285$$

4. Compute the percentage by weight of material passing each sieve. For example:

$$100 \times \frac{\text{wt passing No. 4 sieve}}{\text{wt original dry sample}}$$

$$= 100 \times \frac{285}{431} = 66.1\%$$

Grain-size Distribution Curve

Plot a grain-size distribution curve on semi-logarithmic paper as shown. Since at least four cycles are often required to plot the curve, two sheets of three-cycle paper furnished with the set may be pasted together.

WET MECHANICAL ANALYSIS

The physical characteristics of a fine-grained soil are generally identified with greater accuracy by the plasticity tests than by the grain-size distribution. However, a wet mechanical analysis is required to determine the percentage of material smaller than 0.02 mm in diameter. Laboratory equipment required for the analysis of grain sizes less than 0.07 mm in diameter (passing No. 200 sieve) is not included in the set. The test described below uses improvised equipment.

Apparatus Required

Set Equipment

Triple-beam balance	Gasoline stove
Spatula	Metal boxes
Oven	Stop watch

100-cc graduated cylinder

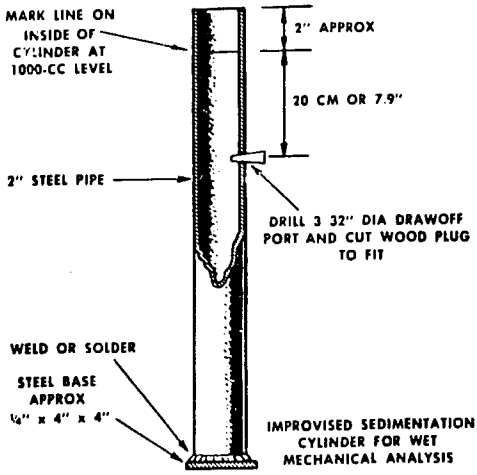
Improvised Equipment

Rubber-covered pestle
Sedimentation cylinder (see below)

Deflocculating Solution. Prepare a solution in the proportions of 1 gram of deflocculating agent to 20 cc of water. Suitable agents generally available are:

Gum arabic
Sodium bicarbonate (baking soda)
Sodium silicate (commercial waterglass)
Sodium Hexa Meta Phosphate (recommended for lateritic soils).

Improvised Sedimentation Cylinder



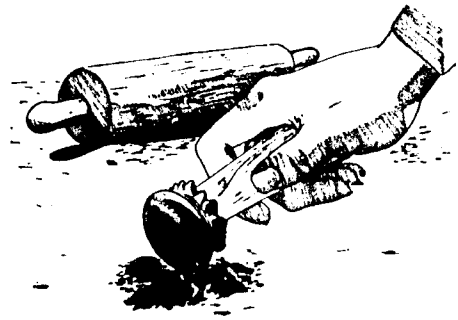
A sedimentation cylinder can be improvised from a piece of 2-inch steel pipe about 24 inches long or from any other cylinder having about the same diameter, such as the guide for compaction tamper. Seal or cap one end and add 1000 cc of water. Mark water level on inside of cylinder. Measure down 20 cm (7.9 inches) from this mark and drill a 3/32-inch hole. Cut a wood or cork plug to fit hole. Clean cylinder with hot soapy water before use.

Size of Sample

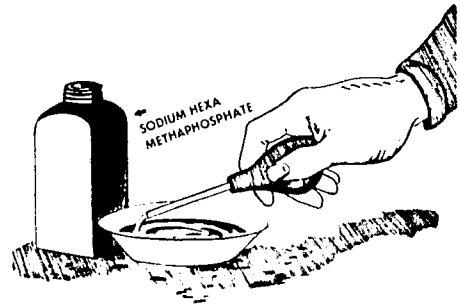
Wet mechanical analysis is made on samples in which most of the material passes a No. 40 sieve. (For coarse-grained soils, see combined mechanical analysis.) The size of the sample should be proportional to the sand content of the soil. Select 30 to 50 grams (dry weight) for clays and silts, and 50 to 150 grams (dry weight) for sandy soils.

Procedure for Determining 0.02-mm Fraction

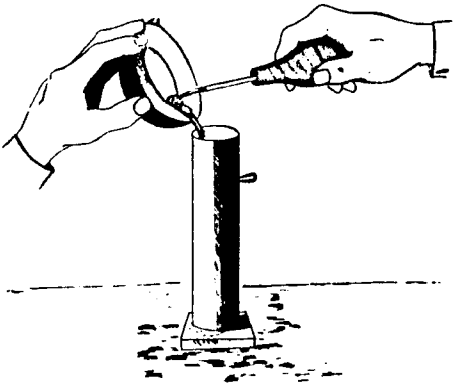
1. The sample used should be either air dried or at the field moisture content on the portion passing the No. 10 sieve (in the same manner as preparing wet soil for the liquid limit test). The dry weight to be used in the computation for the wet mechanical analysis shall be computed using the initial wet weight and the moisture content of either the air dried or field moisture content sample.



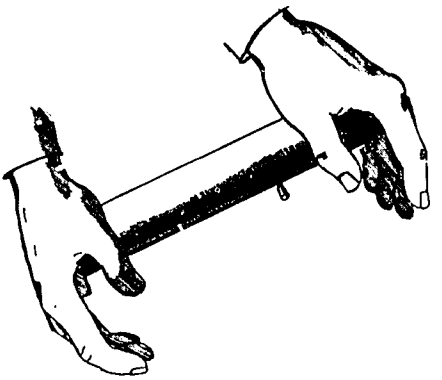
2. Pulverize air dried sample with rubber covered pestle and transfer to suitable mixing dish. Take care not to break down individual particles.



3. Place pulverized air dried soil or the wet soil in mixing dish and mix sample with enough water to form a thin slurry, add 20 cu cm of deflocculating solution, and let soak until thoroughly disintegrated. Soaking time should increase with plasticity and dry strength of sample. Allow 2 hours for nonplastic soils and up to 12 hours for very plastic clays having high dry strength.



4. Transfer slurry to sedimentation cylinder, washing all fines from mixing dish with jet from battery filler. Add water up to 1000-cc mark.



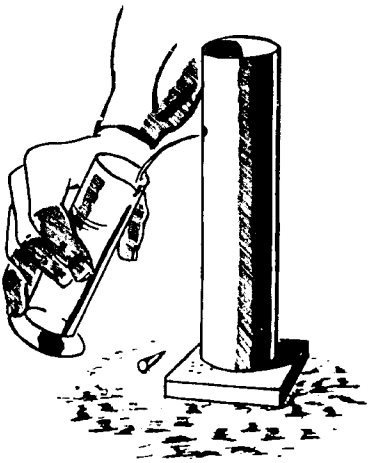
5. Shake cylinder vigorously for 1 minute. Use palm of left hand as a stopper and completely reverse cylinder end for end.

6. Set cylinder on firm base in a protected corner of the laboratory where it is not exposed to direct sunlight or other one-sided heat.

7. After 9 minutes elapse (see table, page 37), remove plug in drawoff port and collect 100 cc of suspension in graduate.

8. Pour the 100 cc of suspension into a metal box or evaporating dish and place in oven to evaporate.

9. Weigh the oven-dried residue to nearest 0.01 gram.



10. Compute percentage of grain sizes smaller than 0.02 mm as shown below:

% Passing No. 10 Sieve = 85% = 0.85

Wt original sample = 36.82 gm

Wt residue (from 100 cc) = 1.73 gm

Percentage smaller than 0.02 mm =

$$1000 \times \frac{\text{wt residue}}{\text{wt original sample}} =$$

$$1000 \times \frac{1.73}{36.82} = 47.0\ (0.85) = 40.0\%$$

Correction Factors

The above procedure is correct for average conditions (specific gravity of 2.68, water temperature of 68° F.). Minor variations from average conditions do not greatly affect accuracy of test results and may be neglected. Large variations in either water temperature or specific gravity should be corrected by varying the elapsed time in minutes before drawoff (step 7) as indicated below.

WATER TEMPERATURE (°F)	ELAPSED TIME (MINUTES) SPECIFIC GRAVITY				
	2.00 to 2.19	2.20 to 2.39	2.40 to 2.69	2.70 to 2.99	3.00 to 3.19
40-49	19	16	13	11	10
50-59	16	14	11	9	8
60-69	14	12	9	8	7
70-79	12	10	8	7	6
80-89	10	9	8	6	5
90-99	9	8	7	6	5

Procedure for Determining other Grain-Size Fractions

To obtain the entire grain-size curve of a fine-grained soil, several points of the curve must be determined by wet mechanical analysis. Generally three points are sufficient, approximately at 0.05, 0.02 and 0.005 mm, to plot the portion of the grain-size curve in this range. The improvised equipment can be used by preparing a separate suspension for each point desired as described above and withdrawing 100 cc of the suspension after an elapsed period determined from the wet mechanical analysis chart. The percentage of material smaller than each of the sizes selected is then calculated as shown above.

Using Wet Mechanical-analysis Chart

Elapsed time of drawoff for various specific gravities and suspension temperatures to determine the percentage of any desired grain size can be obtained from the chart for wet mechanical analysis shown on opposite page.

Example No. 1

To obtain elapsed time for determining percentage of grain sizes smaller than .010 mm under average conditions.

The average-condition line intersects the 0.010-mm line midway between the 30- and 40-minute lines, indicating an elapsed time of 35 minutes.

Example No. 2

To obtain elapsed time for determining percentage of grain sizes smaller than 0.02 mm if specific gravity of soil is 2.95 and temperature of suspension chamber is 100° F.

1. Extend line from 2.95 on specific-gravity scale through 100° F on temperature scale to edge of chart.

2. Draw diagonal line from intersection at edge of chart parallel to average-condition line.

3. Intersection of 0.02-mm line with this diagonal line is midway between 5- and 6-minute lines, indicating an elapsed time of 5½ minutes.

COMBINED MECHANICAL ANALYSIS

Size of Sample

For soils containing little material larger than ¼ inch, use about 200 grams of dry material. For gravelly soils, use a sample containing about 200 grams of dry material passing a ¼-inch screen.

Test Procedure

1. Determine dry weight as on page 27.

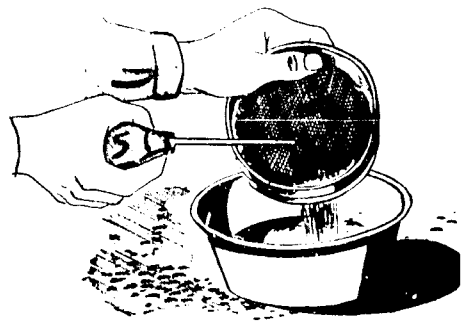
2. Remove by hand particles larger than ¼-inch diameter, and place them in dish containing about 500 cc of water and 20 cu cm of deflocculating solution.

3. Wash particles thoroughly to remove all fines adhering to their surfaces, and set them aside in a pan.

4. Pulverize fine portion of sample. Place it in the water containing deflocculating solution in which stones were washed, and mix thoroughly.

5. Proceed with wet mechanical analysis as described before, (step 4, page 37) except that the material in sedimentation cylinder is not wasted after withdrawing the 100-cc sample.

6. After completing the wet mechanical analysis, shake cylinder thoroughly and wash all soil into a No. 200 sieve. Rinse cylinder to transfer any remaining soil grains into sieve.



7. Thoroughly wash material in sieve under a jet of water, allowing all fines to be wasted.

Place sieve with retained material in oven to dry. Also place dish with stones removed at start of test in oven.

8. Turn sieve upside down over a clean piece of paper and clean sieve by brushing and tapping. Add the stones and make sieve analysis on this combined material (page 26).

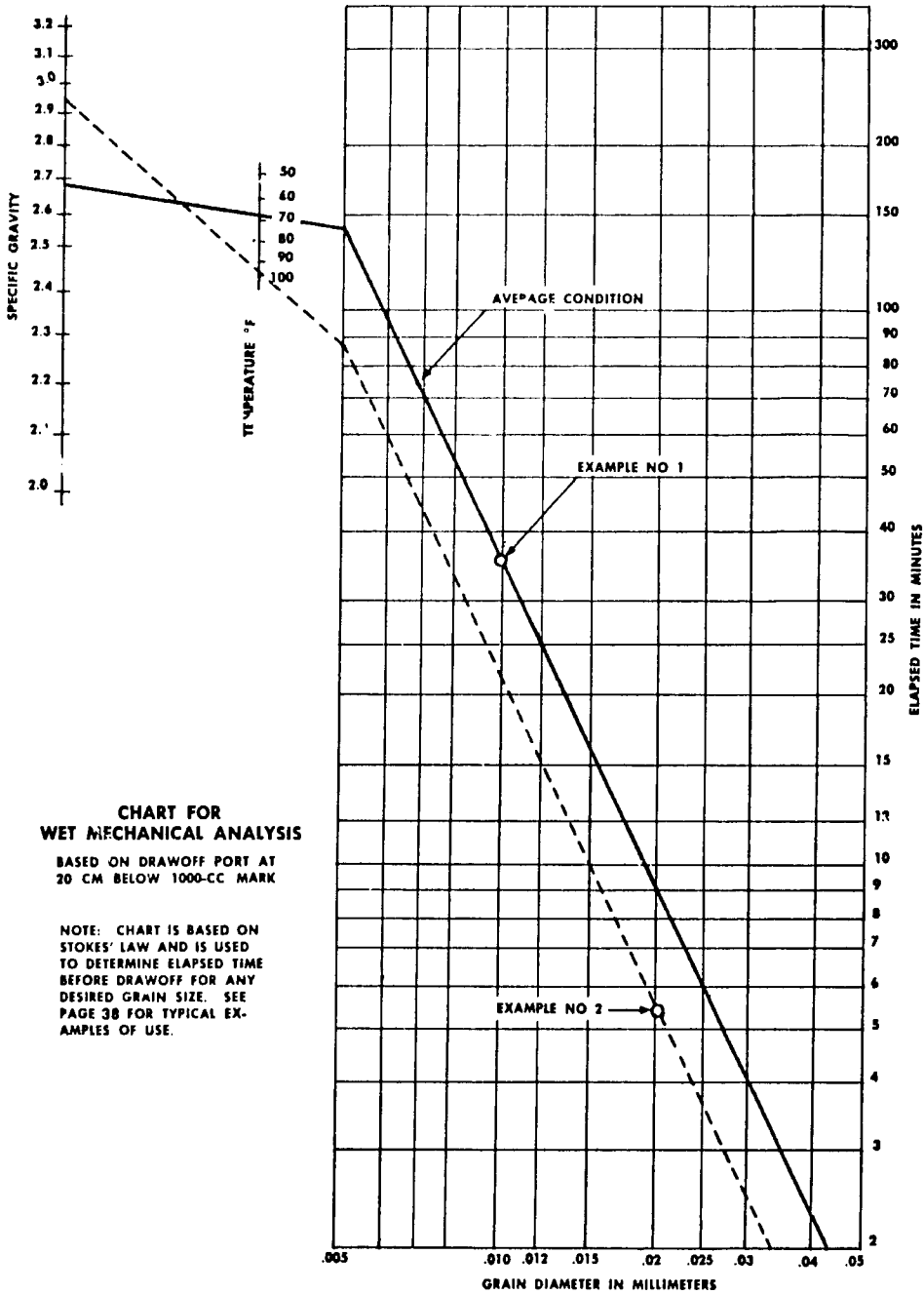


CHART FOR WET MECHANICAL ANALYSIS

BASED ON DRAWOFF PORT AT 20 CM BELOW 1000-CC MARK

NOTE: CHART IS BASED ON STOKES' LAW AND IS USED TO DETERMINE ELAPSED TIME BEFORE DRAWOFF FOR ANY DESIRED GRAIN SIZE. SEE PAGE 38 FOR TYPICAL EXAMPLES OF USE.

Sample Calculation

Calculated dry wt original sample = 431 gm

Wt residue (from 100 cc after 9 minutes) = 1.26 gm

Percentage smaller than 0.02 mm =

$$1000 \times \frac{\text{wt residue}}{\text{wt original sample}} =$$

$$1000 \times \frac{1.26}{431} = 2.9\%$$

Sieve analysis calculations are based on original weight of dry sample (431 grams) and are made in the same way as shown on page 26.

UNIT-WEIGHT DETERMINATION

GENERAL

Use

Unit-weight determination (also called density test) is used to control compaction of embankments and base courses.

Definitions

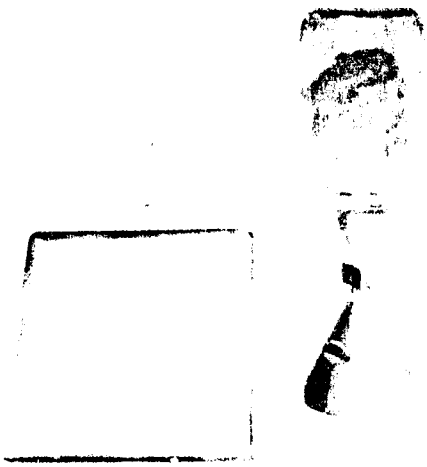
Wet unit weight or wet density is the wet weight per cubic foot of material in place. Dry unit weight or dry density is the weight of solid material per cubic foot of soil in place.

DENSITY OF SOIL IN PLACE BY THE SAND-CONE METHOD

Apparatus

1. The apparatus consists of a 1-gal. jar and a unit consisting of a cylinder valve with an orifice and having a small funnel on one end and a large funnel on the other end.

2. Sand. A clean, dry, free flowing sand having few, if any, particles passing the No. 200 or retained on the No. 10 sieves.



3. A scale accurate to 1.0 gram and a balance accurate to 0.1 gram.

4. Stove or oven for drying moisture content samples.

5. Small pick, chisels, or spoons for digging test hole; cans for drying moisture samples; and cans with lids.

Procedure

1. Determine the volume of the jar attachment up to and including the volume of the valve orifice:

   a. Weigh the assembled apparatus.
   b. Place the apparatus upright and open the valve.
   c. Fill the apparatus with water until it appears over the valve.
   d. Close valve and remove excess water.
   e. Weigh the apparatus and water and determine the temperature of the water.
   f. Repeat the procedure at least twice. Convert the weight of water, in grams, to milliliters by correcting for the temperature.

2. Determine the bulk density of the sand to be used in the field test as follows:

   a. Place the empty apparatus upright on a firm level surface, close the valve and fill the funnel with sand.
   b. Open valve and, keeping funnel at least half full of sand, fill the apparatus. Close valve sharply and empty excess sand.
   c. Weigh apparatus with sand and determine the net weight of sand by subtracting the weight of apparatus.

3. Determine the weight of sand required to fill the funnel:

   a. Put sand in the apparatus and weigh apparatus and sand.
   b. Seat the inverted apparatus on a clean, level surface.
   c. Open the valve and keep open until after the sand stops running.
   d. Close the valve rapidly, weigh the apparatus with remaining sand and determine the loss of sand. This loss represents the weight of sand required to fill the funnel.

4. Determine the density of the soil in place as follows:

   a. Prepare the surface of the soil to be tested so that it is level.
   b. Seat the inverted sand cone on the soil surface and mark the outline of the funnel.
   c. Dig the test hole inside the funnel mark. Place all loosened soil in a container being careful to avoid losing any material.
   d. Seat the apparatus in the previously marked position, open the valve and after the sand has stopped flowing, close the valve.
   e. Weigh the apparatus with remaining sand and determine the weight of sand used in the test.
   f. Weigh the material that was removed from the test hole.
   g. Mix the material thoroughly and secure

and weigh a representative sample for moisture determination.

h. Dry and weigh the moisture sample.

Calculations

1. Calculate the volume of the density apparatus as follows:

$$V_1 = GT$$

where:

V_1 = volume of the density apparatus, in milliliters,

G = grams of water required to fill the apparatus, and

T = water temperature-volume correction shown in column 3 of Table I.

Table I—Volume of Water per Gram Based on Temperature

Temperature		Volume of water, ml per g
deg. Cent.	deg. Fahr.	
12	53.6	1.00048
14	57.2	1.00073
16	60.8	1.00103
18	64.4	1.00138
20	68.0	1.00177
22	71.6	1.00221
24	75.2	1.00268
26	78.8	1.00320
28	82.4	1.00375
30	86.0	1.00435
32	89.6	1.00497

2. Calculate the bulk density of the sand as follows:

$$W_1 = \frac{62.427\ W_2}{V_1}$$

where:

W_1 = bulk density of sand, in pounds per cubic foot,

W_2 = grams of sand required to fill the apparatus and

V_1 = Volume of apparatus, in milliliters (Paragraph (a)).

3. Calculate the moisture content and the dry weight of material removed from the test hole as follows:

$$w = \frac{W_3 - W_4}{W_4} \times 100$$

$$W_6 = \frac{0.2205\ W_5}{w + 100}$$

where:

w = percentage of moisture, in material from test hole,

W_3 = moist weight of moisture sample, in grams,

W_4 = dry weight of moisture sample, in grams,

W_5 = moist weight of the material from test hole, in grams, and

W_6 = dry weight of material from test hole, in pounds.

4. Calculate the in-place dry density of the material tested as follows:

$$V = \frac{W_7 - W_8}{453.6\ W_1}$$

$$W = \frac{W_6}{V}$$

where:

V = volume of test hole, in cubic feet,

W_7 = grams of sand used,

W_8 = grams of sand in funnel and

W = dry density of the tested material, in pounds per cubic foot.

SPECIFIC-GRAVITY DETERMINATION

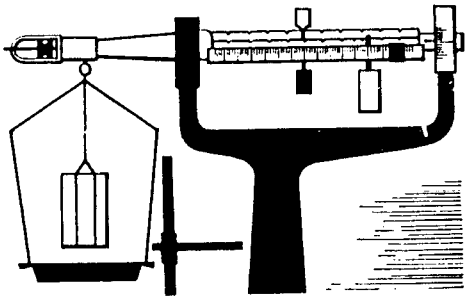
Equipment for determining specific gravity is not included in the set. However, it can be easily improvised from available equipment. The procedure to be used depends on the size and type of sample.

INDIVIDUAL STONES

The specific gravity of individual stones weighing less than 200 grams can be determined by weighing on the triple-beam balance. Usually the specific gravity of stones with their natural moisture content is required.

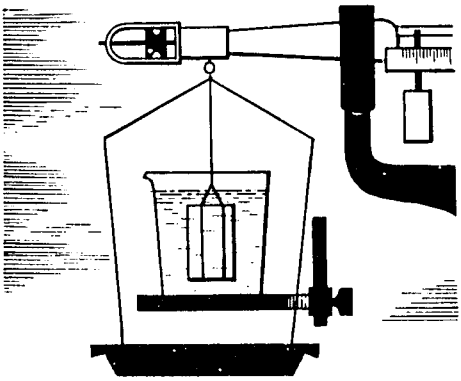
Apparatus Required

Triple-beam balance
Light cord or thread
Small can to hold water



Procedure

1. Loop a small thread around stone and hang from lower hook on triple-beam balance. Weigh to nearest 0.1 gram.



2. Place small can of water on platform, immerse object in water, and reweigh to nearest 0.1 gram.

3. Calculate specific gravity of stone as shown in sample calculation. If cord or thread is very light, its weight can be neglected.

Sample Calculation

Wt of stone in air ..... **163.4 gm**

Wt of stone in water ..... **100.7 gm**

Specific gravity

$$= \frac{\text{wt stone in air}}{(\text{wt stone in air}) - (\text{wt stone in water})}$$

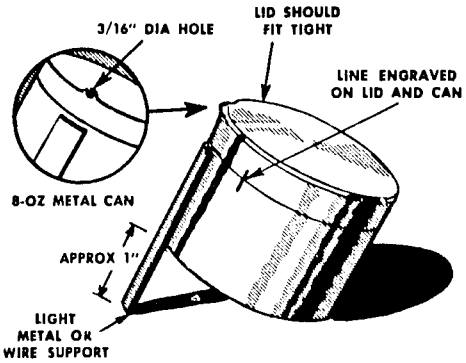
$$= \frac{163.4}{163.4 - 100.7} = \frac{163.4}{62.7} = 2.61$$

SOIL SAMPLES

The average specific gravity of soil samples can be determined by the following method.

Apparatus Required

Torsion balance
Gasoline stove
Constant-volume can
Pan
Battery filler

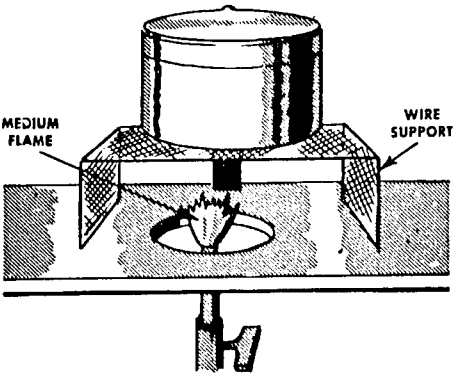


Procedure

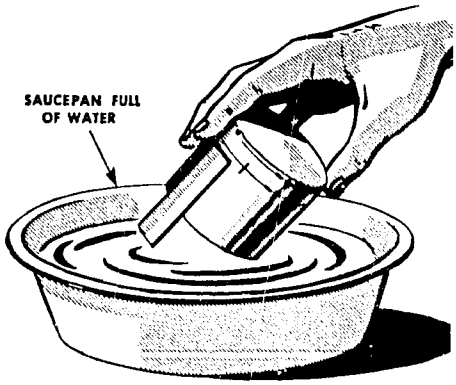
1. Weigh constant-volume can with lid to nearest 0.1 gram.

2. Place air-dry sample (50 to 150 grams) in can and weigh to nearest 0.1 gram.

3. Add water to fill can about one-half full, close cover, and boil gently over stove far at least 30 minutes.



NOTE: Boil gently so soil does not splash out small opening in cover. Can may be suspended several inches above flame, placed on hot metal plate, or placed in hot oven. For clean sands, boiling can be omitted and a thorough stirring with a rod substituted.



4. Remove can from stove and immerse in a pan of water at room temperature. Allow to cool.

5. Remove can from bath, holding it with hole on top, dry outside with towel, and carefully fill with water to level of rim around hole. Weigh to nearest 0.1 gram.

NOTE: If the lid does not fit tight enough to prevent water from leaking out, either use a stiff waterproof grease or seal by wrapping with tape. The weight of grease or tape used is included in oil weight determinations.

6. Empty contents of can, rinse clean, and refill with water from pan used to cool sample. Dry outside of can and reweigh to nearest 0.1 gram.

7. Compute specific gravity of sample as shown in sample calculation.

Wt of can ..... **76.1 gm**
Wt can + dry soil ..... **222.6 gm**
Wt can + soil + water ..... **406.4 gm**
Wt can + water ..... **351.1 gm**
Wt dry soil = (wt can + dry soil) − (wt of can) = 222.6 - 7.61 = 146.5 gm

Specific gravity =

$$\frac{\text{wt dry soil}}{(\text{wt dry soil}) + (\text{wt can} + \text{water}) - (\text{wt can} + \text{soil} + \text{water})}$$

$$= \frac{146.5}{146.5 + 315.1 - 406.4} = \frac{146.5}{55.2} = 2.65$$

Use of Pycnometer Top

If the pycnometer top illustrated on page 15 is available, the procedure for specific-gravity determination is essentially the same as above, except that a much larger sample is used.

COMPACTION TEST FOR OPTIMUM MOISTURE CONTENT AND MAXIMUM DRY DENSITY

General

The density to which a soil is compacted with a given compaction method varies with its moisture content. The moisture content which gives the highest dry unit weight is called the optimum moisture content for that method of compaction. Generally the optimum moisture content is less than the plastic limit. Optimum moisture content decreases with increased compaction.

The laboratory compaction method described below has been adopted by the Corps of Engineers, since it generally produces about the same density as is obtained on the job with heavy construction equipment. This method is known as the Modified American Associatian of State Highway Officials (Modified AASHO) method.

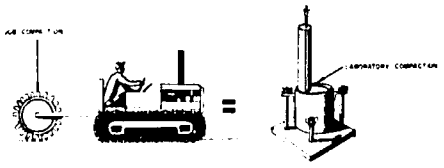
If the soil cannot be dried in the field before compaction, the laboratory compaction curve should be run from the field moisture content, allowing the sample to dry out approximately 2-3% for each point.

If the field moisture content is below optimum moisture, then additional moisture should also be added to some samples to bring the moisture content above the optimum moisture.

Apparatus Required

Torsion balance	Stove
Triple-beam balance	Screen, ¾-inch
Metal boxes	Spatula
Compaction mold	Rolling pin
Compaction tamper	Steel straightedge
Oven	

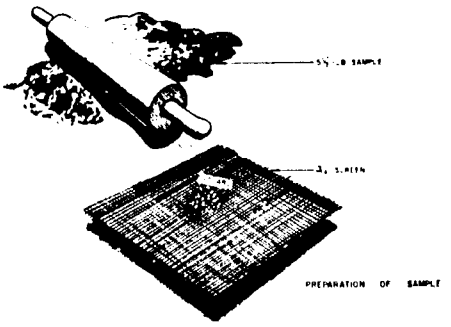
Preparation of Sample



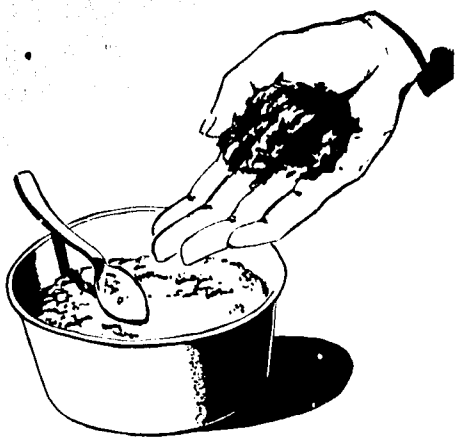
1. Prepare 5 representative samples each containing 2½ kg (5½ lb) of dry material smaller thon ¾ inch.

2. Break up lumps of fine material by rolling on flat surface.

3. Screen through ¾-inch sieve and discard retained portion.



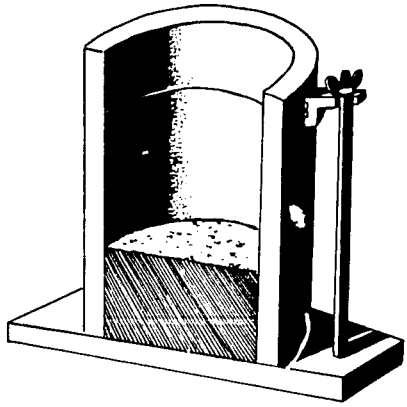
Test Procedure



1. Mix one sample thoroughly with enough water to form a damp mix that crumbles when released after being squeezed in the hand. Do not get this initial mix too wet.

2. Add more water in 50 cc increments to the remaining 4 portions.

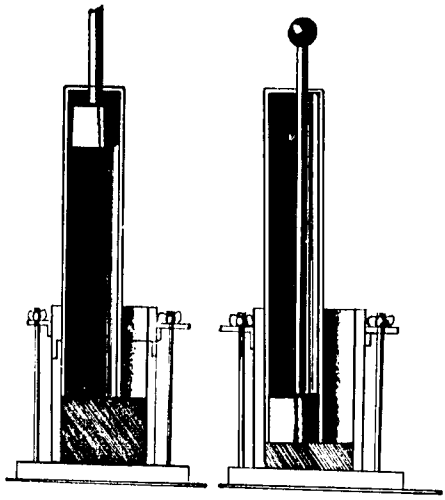
3. Place each of the 5 portions in a waterproof container and allow to cure for a minimum of 4 hours.



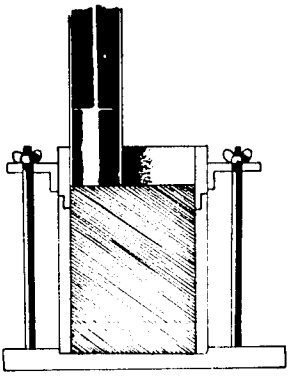
5. Take one cured portion and divide into 5 equal parts. Place one part in compaction mold and level surface by hand.

6. Place compaction tamper with guide on material in mold. Lift tamper handle until tamper reaches top of guide, then release handle, allowing tamper to drop on sample.

4. Weigh compaction mold on tarsion balance to nearest 5 grams; then attach base plate and collar and place on firm foundation.

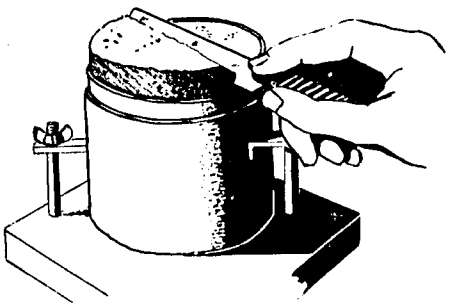


7. Change position of guide and again drop tamper. Repeat process, systematically covering entire surface of sample until tamper is dropped 25 times.



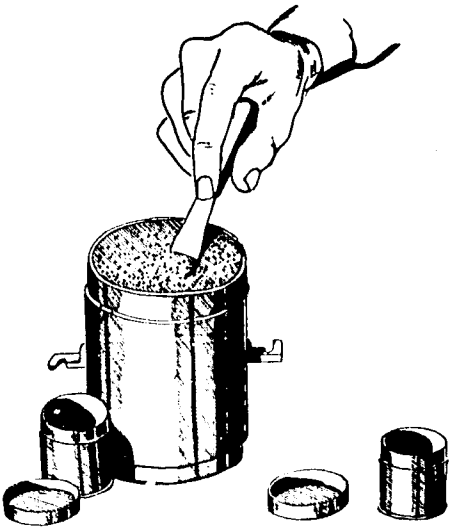
8. Remove tomper from mold, put another portion of sample in mold, and tamp as above. Repeat for remaining portions.

NOTE: Each compacted layer should be about 1 inch deep, and the entire compacted sample should extend at least ½ inch up into the extension collar. The weight of sample required for this purpose is determined by trial and will vary with different soils.



9. Remove collar and with knife trim sample down to rim of compaction mold. Check final leveling with straightedge.

10. Remove base plate and weigh mold containing compacted sample to nearest 5 grams.



11. Take moisture-content samples (10 to 25 grams each) from top and bottom of mold. (The average value is used in final calculations.)

12. Remove compacted soil from mold, repulverize with rolling pin, and place in pan.

NOTE: Frame and jack of the CBR testing equipment can be used to push compacted soil out of the mold, although the sample can be dug out by hand.

13. Repeat steps 5 through 12.

14. Make several additional determinations, each time adding more water, until the weight of compacted sample shows a decrease.

Sample Calculation

Wet unit weight = 0.066 × wt wet sample (gm)

= 0.066 × 1825 = 125.5 lb per cu ft

$$\textbf{Dry unit weight} = \frac{100 \times \textbf{wet unit weight}}{100 + \textbf{moisture content (\%)}}$$

$$= \frac{100 \times 120.5}{100 + 7.4} = 112.2 \text{ lb per cu ft}$$

DATA SHEET

Sample No SF-P4-1

COMPACTION TEST FOR OPTIMUM MOISTURE CONTENT

Initials SDW

Date 19 JUNE 1945

No of layers 5

No of blows per layer 25

Weight of tamper 10 LB

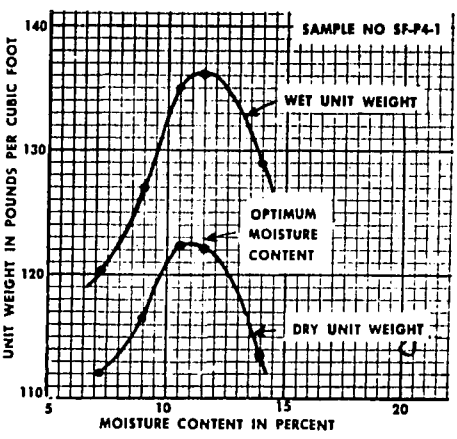
Height of drop 18"

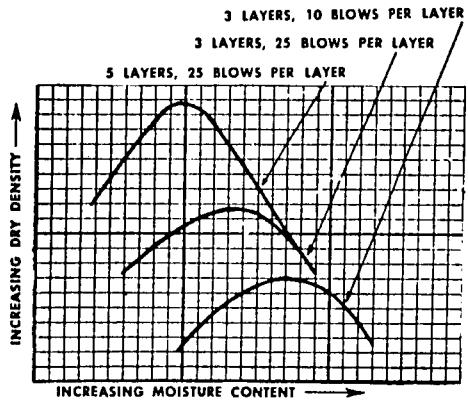
Test No	1		2		3		4		5	
Wt wet sample + mold (gm)	3,860		3,955		4,080		4,095		3,990	
Wt mold (gm)	2,035		2,035		2,035		2,035		2,035	
Wt wet sample (gm)	1,825		1,920		2,045		2,060		1,955	
Wet unit wt (lb per cu ft)	120.5		126.7		135.0		136.0		129.0	
Can No	3	7	1	4	5	8	2	10	6	9
Wt wet sample + can (gm)	42.24	45.34	40.36	42.92	38.96	41.11	50.85	47.61	53.88	49.50
Wt dry sample + can (gm)	41.52	44.36	39.63	41.98	38.32	40.19	48.90	45.96	51.10	47.31
Wt water (gm)	0.72	0.98	0.73	0.94	0.64	0.92	1.95	1.65	2.78	2.19
Wt can (gm)	31.28	31.76	31.40	31.42	31.88	31.71	32.08	31.64	30.96	31.66
Wt dry sample (gm)	10.24	12.60	8.23	10.06	6.44	8.48	16.82	14.32	20.14	15.65
Moisture content (%)	7.0	7.8	8.9	9.3	9.9	10.9	11.5	11.5	13.8	14.0
Average moisture content (%)	7.4		9.1		10.4		11.5		13.9	
Dry unit wt (lb per cu ft)	112.0		116.1		122.3		122.0		113.3	

Optimum-Moisture-Content Curve

Plot unit weights against moisture content on graph paper.

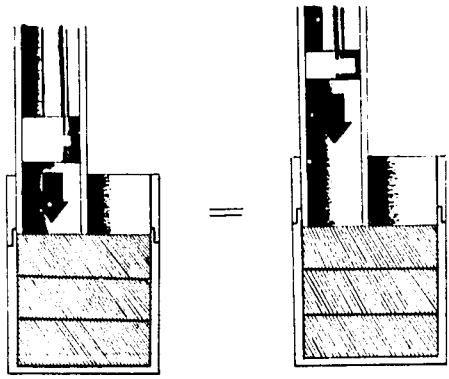
The optimum moisture content is the moisture content at the peak of the dry unit-weight curve.





Modification of Test Procedure for Special Conditions

The above test procedure may not produce the same densities as those produced on the job by construction equipment. For example, airborne equipment may produce lower densities and heavy construction equipment, higher densities. In this case, modify the laboratory procedure by varying the number of layers, the height of drop, and numbers of blows per layer to produce an equivalent density.



The standard Proctor test is generally used for laboratory compaction of cement-stabilized bases. The mold is filled in 3 layers with 25 blows per layer, using a 5½-pound tamper with a 12-inch drop. To use the set equipment, a 6½-inch drop with the 10-pound tamper gives equivalent compaction. If the soil being tested is a uniform fine sand, the tamper may cause upheaval when dropped instead of compaction. If this occurs, first tamp with several light blows to establish initial stability before proceeding with test.

Optimum Moisture Content for Gravelly Soils

The optimum moisture content of gravelly soils should be corrected as shown below, if the percentage of gravel larger than ¾ inch exceeds about 25%.

Sample Calculation

Material larger than ¾ inch = 40%

Material finer than ¾ inch = 60%

Optimum moisture content, fine portion = 15%

Optimum moisture content of total soil =

$$\frac{\text{\% fine portion} \times \text{optimum moisture content (\%)}}{100}$$

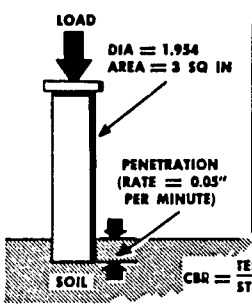
$$= \frac{60 \times 15}{100} = 9\%$$

CALIFORNIA BEARING RATIO TEST

GENERAL

Definition

The California bearing ratio (CBR) is a measure of the shearing resistance of a soil under carefully controlled density and moisture conditions and is used with empirical curves for designing flexible pavements. It is expressed as a percentage of the unit load required to force a piston into the soil divided by the unit load required to force the same piston the same depth into a standard sample of crushed stone.



STANDARD VALUES

PENETRATION (IN)	UNIT LOAD (PSI)
0.1	1000
0.2	1500
0.3	1900
0.4	2300
0.5	2600

$$CBR = \frac{\text{TEST UNIT LOAD}}{\text{STANDARD UNIT LOAD}} \times 100$$

Unit-load values for various depths of penetration into the standard sample are standardized. The CBR used in design is the 0.1- or 0.2-inch penetration value, whichever is greater. For most soils, the 0.1-inch penetration value is the greater.

Test Conditions

The CBR of a soil varies with its compaction, moisture content when compacted, and moisture content when tested. Therefore, to duplicate job condition, these factors must be carefully controlled when preparing samples.

Unless it is certain that the soil will not accumulate moisture after construction, CBR tests are performed on soaked samples.

Types of Tests

CBR tests can be made in place on the job, using improvised equipment, or in the laboratory on either undisturbed or laboratory-compacted samples. In-place tests are made only on the soil at its existing moisture content but laboratory tests can be made on either soaked or unsoaked samples. Whenever possible, the

test is made on undisturbed soil. For design purposes it is necessary to test laboratory-compacted samples which may not duplicate the density and moisture conditions obtained by job compaction. Therefore, in-place tests or tests on undisturbed job-compacted samples must be made during construction. If results do not agree with preliminary data used for design, either the design must be modified or the job-compaction procedure changed to produce the required CBR.

Preparation of Samples

Procedures to prepare laboratory-compacted samples for testing have been established for different soils to duplicate conditions likely to develop during and after construction. These procedures apply when moisture content during construction will be controlled to optimum for maximum modified AASHO unit weight, and the soil will be compacted to at least 95% of this maximum unit weight. If other compaction controls are used, the procedures must be modified accordingly.

The CBR of low-plasticity, nonswelling soils (such as silty sands, inorganic silts, and clayey silts) is greatly affected in both the soaked and unsoaked state by compaction moisture and density to which compacted. For these soils, three samples are compacted to various densities at the optimum moisture content predetermined by the modified AASHO method of compaction (page 44). Each sample is tested after soaking, and the results plotted to determine CBR at 95% of the maximum unit weight (see page 55).

The CBR of noncohesive soils (such as clean sands and sandy gravels) is not greatly affected by compaction moisture. Since these soils readily compact under traffic, the test is run on a sample compacted to maximum unit weight.

The CBR of swelling soils (such as clays and organic silts) varies greatly with soil condition. Special studies are required to determine the most satisfactory moisture content and compaction method. Once these factors are determined, the test is run on a sample which is similarly compacted.

TEST ON LABORATORY-COMPACTED SAMPLES

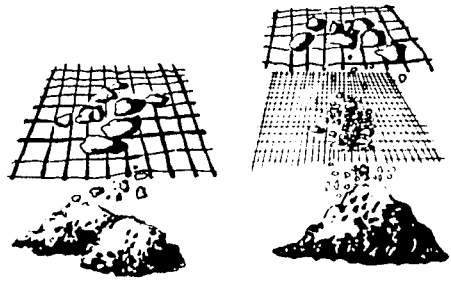
Apparatus Required

CBR equipment
Dial extensometer
Bucket
Compaction tamper
Stove
Oven
Pans
Spring balance
Triple-beam balance
Steel straightedge
Metal boxes
Mixing tools
Rolling pin
Butcher knife
Stop watch

Preparation of Sample

As previously described, the method of preparing the sample depends on the type of material being tested.

To prepare low-plasticity, nonswelling soils:



1. Pulverize about 100 pounds of material with rolling pin, shake through a ¾-inch screen, and throw away material which is retained. Replace wasted material with an equal weight of similar material which passes a ¾-inch screen, but is retained on a ¼-inch screen.

2. Determine optimum moisture content of this material using the modified AASHO method with the following exceptions:

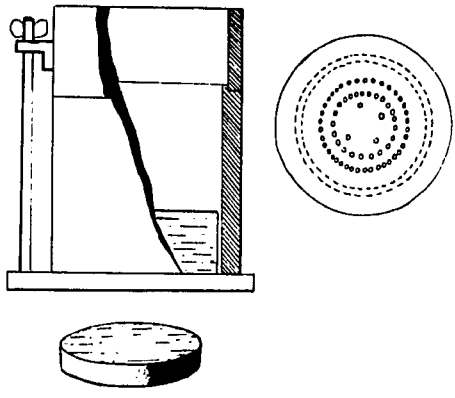
a. Use ¾-inch maximum-size material.

b. Use the CBR compaction mold instead of the 1/30-cubic foot mold.

c. Compact material with 55 blows per layer instead of 25. The compacted layers should be 1 inch thick.

d. Use fresh material for each compaction sample.

e. To determine optimum moisture content accurately, compact four samples within 2% of optimum (plus or minus).



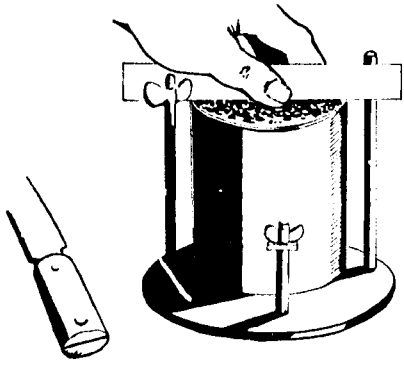
3. Mix remaining material (about 25 pounds) with enough water to bring moisture content to the optimum as determined in step 2. The moisture content of material must be within 0.5% of the optimum. Cover material with a damp cloth to prevent loss of moisture before compaction.

4. Weigh three CBR molds and clamp molds and extension collars to base plates. Insert spacer disc over base plate in each mold.

NOTE: If spacer disc is not provided wtih equipment, make a disc 2 inches thick and 5.93 inches in diameter of metal or hardwood. (Wood should be soaked in hot paraffin to make waterproof.) Also, if base plate is not perforated, drill 28⅛-inch holes through plate.

5. Compact three samples in molds taking moisture-content samples (20 to 50 grams each) from top and bottom layers of each mold before compaction. Compact one sample with 55 blows per layer, the second with 25 blows per layer, and the third with 10 blows per layer. Top layer of material should extend at least 1 inch into extension collar, and each compacted layer should be about 1 inch deep.

NOTE: If moisture content of the three compacted samples varies from the optimum by more than 0.5%, the test must be rerun.



6. Remove collar of each mold and with knife trim sample down to rim of mold. Check with straightedge.

7. Remove base plate and spacer disc and weigh mold containing sample.

8. Place filter paper on base plate, then turn mold upside down and attach to base plate. The sample is now ready for soaking (page 50), or testing (page 51), if soaking is not required.

To prepare noncohesive soils:

1. Determine optimum moisture content of material (step 2, page 49).

NOTE: Rigid control of optimum moisture content for noncohesive soils is unnecessary. Three tests are generally sufficient.

2. Compact one sample at optimum moisture content (step 5, above) using 55 blows per layer. Then weigh sample and proceed with steps 6, 7, and 8 above.

To prepare swelling soils:

1. Determine the most satisfactory moisture content and compacted unit weight. The values used are those which result in the least swell when sample is soaked.

2. Mix sample with enough water to produce desired moisture content (step 1).

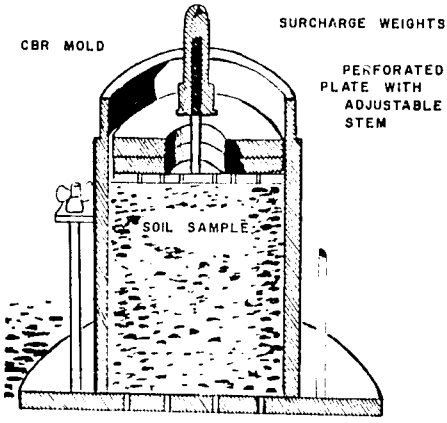
3. Compact sample in mold as described in step 5 above, except the number of blows used is the number required to produce the desired unit weight (step 1 above).

4. Weigh sample and proceed with steps 6, 7, and 8 above.

The above procedures are generally necessary for preparing all samples. However, after an engineer becomes familiar with the soils and probable variations in CBR test results for a given area, it may be possible to reduce the number of samples and to simplify the procedures.

Soaking Sample and Measuring Swell

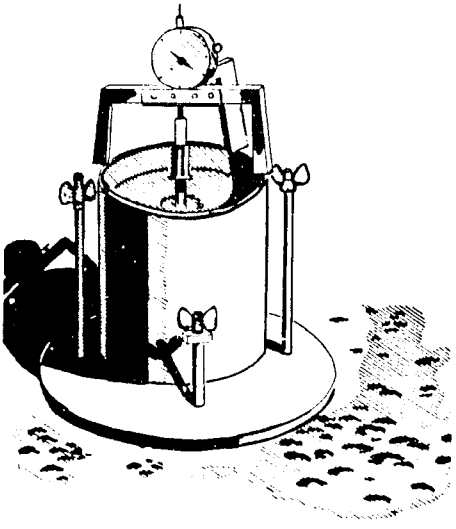
To duplicate field conditions, the sample is soaked under a **surcharge weight** which is equivalent to the weight produced by the soil, base, or pavement which will overlie that material in the completed structure. One 5-pound lead weight used in the laboratory as a surcharge weight represents 3 inches of overlying material. To determine required number of surcharge weights, estimate total thickness of overlying material and divide by 3. However, the total sur-



charge weight must not be less than 10 pounds (two lead weights). If the estimated surcharge weight varies by more than 10 pounds from the surcharge weight which would be used in final design, the test should be repeated using the corrected surcharge weight.

To soak the sample:

1. Place wire screen or filter paper on top of sample. Then place perforated plate with adjustable stem on filter paper. Next put required number of surcharge weights on plate.



2. Place tripod clamp with dial extensometer on rim of mold and adjust stem of perforated plate. Record reading on dial. Take off tripod.

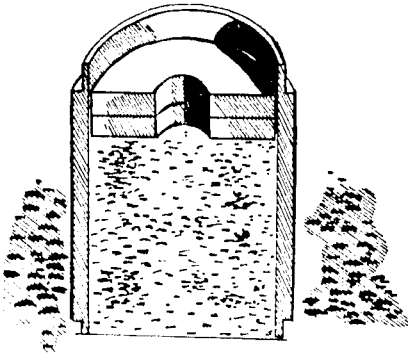
NOTE: Mark location of tripod legs on mold so additional readings can be taken from same position.

3. Immerse sample in bucket of water and let it soak for 4 days, or until it is thoroughly saturated and does not expand further. Place tripod clamp on sample each day and record dial reading and time of reading.

4. After 4 days, remove mold from water, pour excess water from surface, and let it drain in vertical position for about 15 minutes.

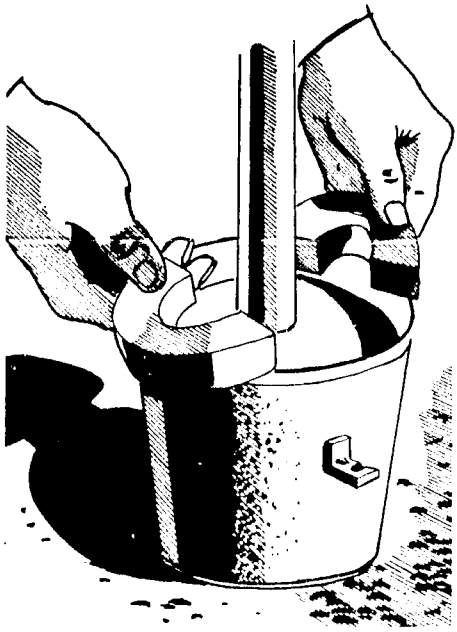
5. Remove lead weights, perforated plate, and filter paper. Sample is ready for testing.

CBR Test Procedure (Penetration Test)



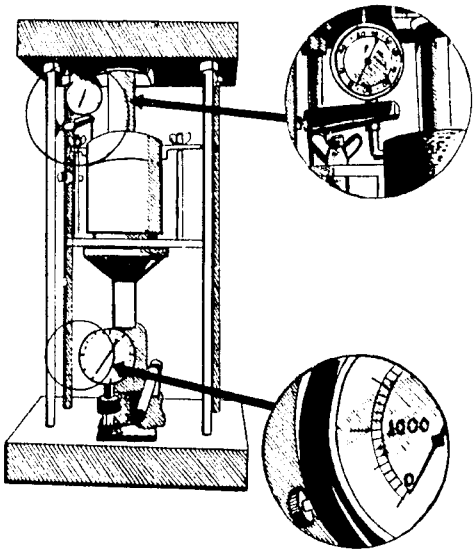
1. Place surcharge weights on samples equal to weight of surface which will overlie the material. (See Soaking Sample and Measuring Swell, page 50.)

NOTE: For very soft samples having a CBR of 3% or less, only one 5-pound weight should be added before seating the piston (step 2). Additional weights can then be added as re-



quired by cutting the weights in half and inserting each half from opposite sides.

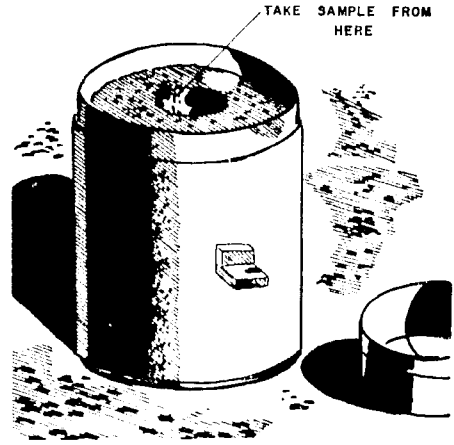
2. Place mold on thrust bearing in loading frame and adjust so piston is centered on sample. Raise jack until piston is seated with a 10-pound load. Since this load is too small to be recorded on pressure gage, it can be estimated by slightly rotating the piston by hand as jack is raised. Set dial gage on hydraulic jack to read zero.



3. Adjust extensometer so stem bears on rim of mold. Set dial face to zero reading.

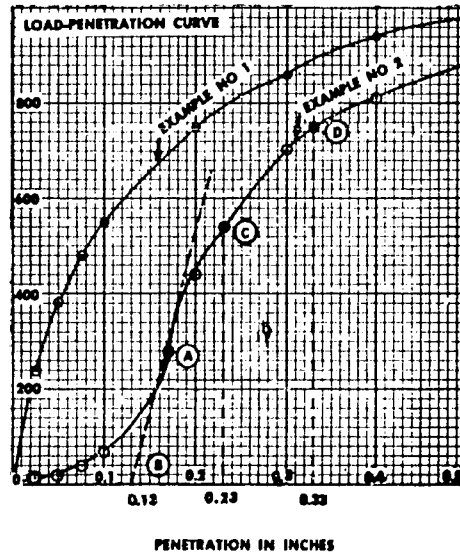
4. Apply load smoothly by hydraulic jack so rate of penetration of piston is approximately 0.05 inch per minute. Rate of load application can be controlled by timing with a stop watch. Record load readings at 0.025-, 0.050-, 0.075-, 0.1-, 0.2-, 0.3-, 0.4-, and 0.5-inch penetrations.

5. Release jack, take mold from loading frame, and remove surcharge weights and base plate.



6. Take a small sample (20 to 50 grams) from top inch of mold for moisture content.

7. Plot a load-penetration curve on cross-section paper. If curve is uniform as in example No. 1, the CBR is calculated for 0.1- and 0.2-inch pene-



trations from recorded loads. If curve has reverse bend, as in example No. 2, draw a line tangent to the steepest point of the curve (point A) and extend line to base to form a corrected zero (point B). Then read corrected load values for 0.1-inch penetration (point C) and 0.2-inch penetration (point D).

Sample Calculation

Compaction data

Calculations are same as for compaction test

Moisture-content and unit-weight data

Wt wet sample + mold .....17.1 lb
Wt of mold ..... 7.9 lb
Wt of wet sample (difference) ..... 9.2 lb

Vol of sample =

$$\frac{\text{area} \times (\text{ht of mold} - \text{ht of spacer disc})}{1728} =$$

$$\frac{(3.14)\,(3)^2 \times (6.00 - 2.00)}{1728} =$$

$$\frac{28.26 \times 4}{1728} = 0.0654 \text{ cu ft}$$

$$\text{Wet unit weight} = \frac{\text{wt of wet sample}}{\text{vol of sample}} =$$

$$\frac{9.2}{.0654} = 140.6 \text{ lb per cu ft}$$

Moisture content top layer =

$$\frac{3.05}{40.10} \times 100 = 7.6\%$$

Moisture content bottom layer =

$$\frac{2.66}{32.40} \times 100 = 8.2\%$$

Average moisture content =

$$\frac{\text{moisture content top} + \text{moisture content bottom}}{2} =$$

$$\frac{7.6 + 8.2}{2} = 7.9\%$$

Dry unit weight =

$$\frac{\text{wet unit weight}}{100 + \text{average moisture content}} \times 100 =$$

$$\frac{140.6}{100 + 7.9} \times 100 = 130.3 \text{ lb per cu ft}$$

Swell data

Reading after 4 days .....0.121 in
Original reading .....0.105 in
Swell (difference) .....0.016 in

Percentage swell =

$$100 \times \frac{\text{swell}}{\text{ht of sample}} =$$

$$100 \times \frac{0.016}{4} = 0.4\%$$

CBR data

Load at 0.1-inch penetration = 3150 lb

$$\text{Unit load} = \frac{\text{test load}}{3} =$$

$$\frac{3150}{3} = 1050 \text{ lb per sq in}$$

CBR at 0.1-inch penetration =

$$100 \times \frac{\text{unit load at 0.1-inch penetration}}{\text{standard unit load}} =$$

$$100 \times \frac{1050}{1000} = 105\%$$

DATA SHEET

SAMPLE NO SF-P1-2

CALIFORNIA BEARING RATIO TEST

TYPE OF SAMPLE:
- LABORATORY COMPACTED ✓
- UNDISTURBED
- FIELD (IN PLACE)

DATE 19 JUNE 1945
INITIALS SDW
SURCHARGE Two 5-LB weights
TYPE OF SOIL Clayey sand

COMPACTION-TEST DATA FOR OPTIMUM MOISTURE CONTENT

MOLD NO	1	1	1	1	1
NO OF LAYERS	5	5	5	5	5
NO OF BLOWS PER LAYER	55	55	55	55	55
WT WET SAMPLE + MOLD (LB)	21.0	21.3	21.7	21.6	21.4
WT OF MOLD (LB)	7.9	7.9	7.9	7.9	7.9
WT OF WET SAMPLE (LB)	13.1	13.4	13.8	13.7	13.5
VOL OF SAMPLE (CU FT)	.0982	.0982	.0982	.0982	.0982
WET UNIT WEIGHT (LB PER CU FT)	133.4	136.5	140.5	139.5	137.5
CAN NO	5	7			
WT WET SAMPLE + CAN (GM)	63.69	66.07			
WT DRY SAMPLE + CAN (GM)	61.88	63.98	(To be filled in from test data)		
WT WATER (GM)	1.81	2.09			
WT CAN (GM)	31.28	31.76			
WT DRY SAMPLE (GM)	30.60	32.22			
MOISTURE CONTENT (%)	5.9	6.5			
AVERAGE MOISTURE CONTENT (%)	6.2	6.9	8.0	9.0	10.0
DRY UNIT WEIGHT (LB PER CU FT)	125.6	127.7	130.1	128.0	125.0

MOISTURE CONTENT AND UNIT WEIGHT OF TEST SAMPLES

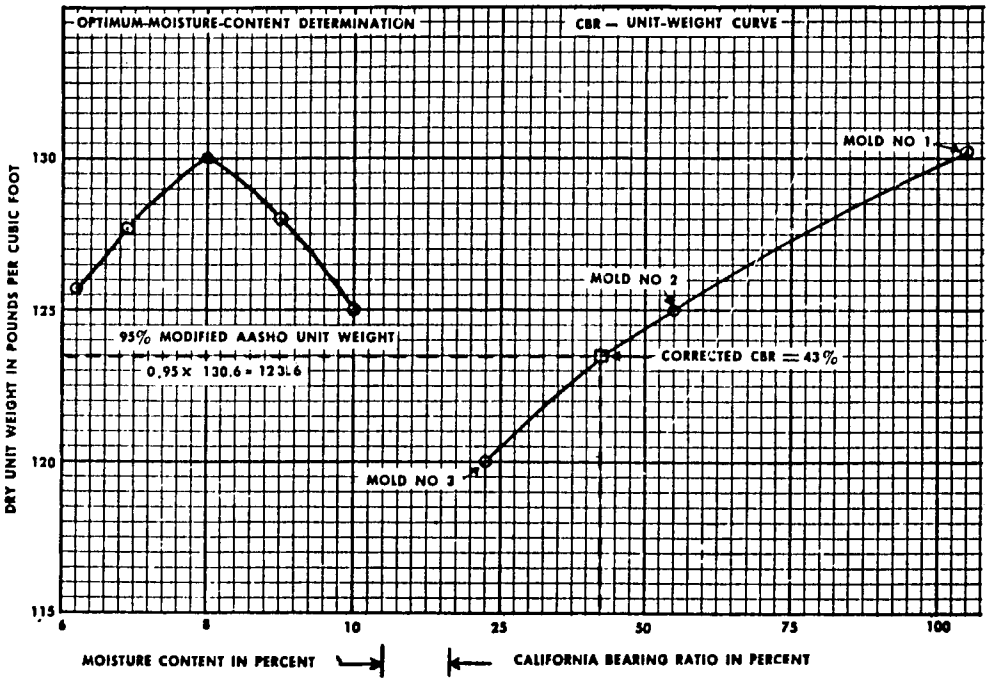
MOLD NO	1			2			3		
NO OF LAYERS	5			5			5		
NO OF BLOWS PER LAYER	55			25			10		
CONDITION OF SAMPLE	BEFORE SOAKING		AFTER SOAKING	BEFORE SOAKING		AFTER SOAKING	BEFORE SOAKING		AFTER SOAKING
WT WET SAMPLE + MOLD (LB)	17.1			16.7			16.4		
WT OF MOLD (LB)	7.9			7.9			7.9		
WT OF WET SAMPLE (LB)	9.2			8.8			8.5		
VOL OF SAMPLE (CU FT)	0.0654			0.0654			0.0654		
WET UNIT WEIGHT (LB PER CU FT)	140.6			134.6			130.0		
MOISTURE CONTENT SAMPLE FROM	BOTTOM	TOP	TOP INCH	BOTTOM	TOP	TOP INCH	BOTTOM	TOP	TOP INCH
CAN NO	1	4	5						
WT WET SAMPLE + CAN (GM)	74.55	66.98	71.15						
WT DRY SAMPLE + CAN (GM)	71.50	64.32	67.48	(To be filled in from test data)					
WT WATER (GM)	3.05	2.66	3.67						
WT CAN (GM)	31.40	31.92	31.68						
WT DRY SAMPLE (GM)	40.10	32.40	35.60						
MOISTURE CONTENT (%)	7.6	8.2	10.3						
AVERAGE MOISTURE CONTENT (%)	7.9			7.7			8.3		
DRY UNIT WEIGHT (LB PER CU FT)	130.3			125.0			120.0		

SWELL DATA

DAY OF MONTH	TIME OF DAY	ELAPSED TIME (DAY)	MOLD NO 1 GAGE READING	MOLD NO 1 SWELL (IN)	MOLD NO 1 SWELL (%)	MOLD NO 2 GAGE READING	MOLD NO 2 SWELL (IN)	MOLD NO 2 SWELL (%)	MOLD NO 3 GAGE READING	MOLD NO 3 SWELL (IN)	MOLD NO 3 SWELL (%)
19	1000	0	0.105								
20	1030	1	0.113	0.008	0.2						
21	0930	2	0.117	0.012	0.3	(To be filled in from test data)					
22	1100	3	0.121	0.016	0.4						
23	1000	4	0.121	0.016	0.4						

CBR DATA

PENETRATION (IN)	STANDARD LOAD (PSI)	MOLD NO 1 TEST LOAD (LB)	MOLD NO 1 TEST LOAD (PSI)	MOLD NO 1 CORRECTED CBR (PSI)	MOLD NO 1 CORRECTED CBR (%)	MOLD NO 2 TEST LOAD (LB)	MOLD NO 2 TEST LOAD (PSI)	MOLD NO 2 CORRECTED CBR (PSI)	MOLD NO 2 CORRECTED CBR (%)	MOLD NO 3 TEST LOAD (LB)	MOLD NO 3 TEST LOAD (PSI)	MOLD NO 3 CORRECTED CBR (PSI)	MOLD NO 3 CORRECTED CBR (%)
0.025		1,350	430	40		30	10			240	80	60	
0.050		2,010	670	Corrected Curve		60	20			450	150	Corrected Curve	
0.075		2,610	870			120	40			600	200		
0.100	1,000	3,150	1050			210	70	540	54	690	230		23
0.200	1,500	4,560	1520			1320	440	740	49	910	340		21
0.300	1,900	5,610	1870			2100	700			1020	340		
0.400	2,300	6000+				2430	810			1050	350		
0.500	2,600	6000+				2640	880			1050	350		



Corrected CBR at 95% Modified AASHO Density

To determine the corrected CBR of low-plasticity nonswelling soils (page 49), it is first necessary to obtain the CBR of three samples compacted to different unit weights (page 50). The relationship between unit weight and CBR for each of the three samples is plotted on cross-section paper. Then draw a horizontal line at a unit weight obtained for the sample compacted with 55 blows per layer. The intersection of this line with the CBR-unit weight curve determines the corrected CBR at 95% modified AASHO density.

STABILIZATION

Lateritic soils are sometimes stabilized to alter their physical properties, increase their strengths and durability, provide water proofing and thus produce a more satisfactory foundation material than the same unstabilized soil. Lime, cement, asphalt and sand are common stabilizers used. Laboratory testing must be performed if these stabilizers are used to insure that the design criteria can be achieved and to determine if stabilization is worth the time and money. The stabilization test program should be performed in a well equipped laboratory, such as central material laboratories where curing facilities for the samples are available. Care must be taken not to add too little or too much stabilizer to a soil. Generally a minimum of 2% for lime, 3% for cement and 5% for asphalt must be added to a soil before desired results can be realized. Most lime treated lateritic soils can be stabilized with 4 to 6% cement. Most lateritic soils do not exhibit significant swelling and shrinking characteristics, but a check should be made prior to and during the laboratory stabilization program.

Under field conditions it is very hard and expensive to dry and break down a plastic soil mechanically. In a high rainfall area it may be impossible. Cement may be used to stabilize those soils having a plasticity index of 15 or less and not more than 15% minus No. 200 sieve. Soils with these physical characteristics can be mixed with the crudest type of mixing equipment. With better equipment the plasticity index and percent minus No. 200 sieve may be increased to 20. Lime is usually more practical where the plasticity index and the minus No. 200 sieve exceed these values. Soils having plasticity indexes greater than 10 and more than 30% passing the No. 200 sieve are generally not adaptable to bituminous stabilization. Micaceous soils and those containing high organic contents also do not respond favorably to bituminous treatment. If the material to be stabilized has a plasticity index greater than 15 and laboratory strength tests show that the lime treated soil will not give strengths to meet design standards, lime and cement should be used in combination.

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