SOME PRINCIPLES OF SOIL SURVEYING AND SOIL MAPPING FOR ROAD PURPOSES

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SYNOPSIS

This paper sets forth some conclusions on soil surveying and soil mapping as connected with physical and engineering properties of soil, which have been drawn by the writer from his research work during the academic year 1930-1931

Knowledge of soil conditions required for the efficient design of roads, necessitates the making of soil surveys Existing soil maps and profiles which are designed for agricultural use are not sufficient for the road engineer It is recommended that in addition to the soil grouping defined by the Bureau of Public Roads the soils be further characterized with respect to permeability and stability For the former the author suggests a method for determining the moisture equivalent of the soil by centrifuging, and for the latter a new test for shearing resistance The shearing resistance is measured by pulling out a rigid stake that has been driven into the soil for twelve inches, by means of a wire connected to the axle of an automobile through a dynomometer

The paper is divided into four divisions Under (A) general considerations referring to soil mapping and the preparation of soil profiles are advanced and subgrade problems are discussed in considerable detail Divisions (B) and (C) are devoted to discussions of the moisture equivalent and shearing resistance of soils and methods of determining these characteristics are proposed Under (D) some facts referring to the soil survey in the county of New Haven are presented and some general principles as to the preparation of soil maps for use in dirt road improvements are advanced

(A) SOIL MAP AND SOIL PROFILES IN HIGHWAY ENGINEERING

Knowledge of soil conditions is necessary for the efficient design of both improved pavements and dirt roads. For this purpose a special soil survey should be made, the results of which may be graphically represented in the form of soil maps and soil profiles

There are soil publications and soil maps prepared by the U S Bureau of Chemistry and Soils and by local agricultural organizations. Such information is designed for the use of agriculturists or of naturalists studying the soil as a natural body. These publications and maps may or may not be useful for the highway engineer who must have information relating to his own purposes (1), (2), (3) In the present report the subgrade survey will be discussed first; dirt roads will be examined under item " D " In the case of subgrade studies soil maps are not satisfactory They cannot give full information relative to all soils which make up the subgrade, and they often overlook small but important changes in soil condition Preparation of soil profiles is generally necessary for improved roads; this operation has recently been described in a publication of the U S Bureau of Public Roads (3). This publication is a complete scientific exposition of the subject and it would be ideal to be able to prepare such subgrade survey sheets as are suggested by the paper The writer believes, however, that such an ideal should be approached but gradually. There are two reasons for this, *first,* that it would be very difficult for states possessing a weak soil organization or none at all, to prepare such schedules in due time, *second,* construction engineers who should be advised by soil investigators, generally look sceptically on a situation overflooded with soil data Information to be successfully sold to them, should be concise and of indisputable practical value.

The Michigan State Highway Department recently published a full description of all soil profiles of the state (4) Obviously, with such data, any profile may be quickly prepared, but this is not the case generally Last summer the writer had an opportunity to become acquainted with the soil organization in New Hampshire There are ten divisions in the New Hampshire State Highway Department One man in each division belonging generally to a survey party, takes care of the study of soils, to which he devotes a part of his time A soil engineer attached to the central office is in charge of both the field soil investigations and the soil laboratory work. The soil men in the divisions are under the division engineer, but their soil work is directed by the soil engineer from the central office The principal purpose of these investigations is the study of subsoils under projected concrete pavements The preliminary soil classification of the Bureau of Public Roads (5) is used There are the following groups of soils in New Hampshire A-2, A-3, A-4 and occasionally, A-6 and A-8 Each of the groups which may give frost heaving, is divided into three subgroups (a) good, capable of two inch frost heaving, (b) fair, capable of four inch frost heaving, (c) poor, capable of six inch frost heaving. All the soil men are trained in what each group means A field party consists of two men provided with pick, shovel, and boring auger 1½ inch in diameter. First a large hole is made with pick and shovel, after which the boring starts. The depth of a boring is generally four feet below the surface either of the road or of the natural ground Borings are made at each station, or more often if changes in soil conditions occur between two stations Soil identification is made by visual inspection, the laboratory work has been reduced to a minimum

In the opinion of the writer the use of the preliminary soil grouping of the Bureau of Public Roads (5) is to be strongly recommended. This grouping is easily applied and understood For better evidence, the figures characteristic of a given group should be placed on the profile itself, and not on a schedule (3) The New Hampshire methods are desirable in the case of a soil organization that is not very strong In the opinion of the writer, however, the subgrade should be characterized from the point of view of its (a) permeability or capacity of easy drainage, and (b) stability or capacity for resisting shearing stresses Both properties should be expressed numerically The degree of permeability may be expressed by the moisture equivalent of the soil (item " B " of this report), and the stability may be characterized by the shearing resistance of the soil (item " C " of this report). Suggestions will be presented below relative to both of these values

(B) MOISTURE EQUIVALENT

INFLUENCE OF THE COLLOIDAL CONTENT

During the academic year 1930-1931 the writer collected over one hundred samples of soils in the County of New Haven, Connecticut, and tested them in the laboratories of Yale University Among other tests, colloidal contents of the soils and their moisture equivalents were determined The content of colloidal matter was determined by the Bouyoucos method (6), for all soils the fifteen minute test was made. The moisture equivalent was determined using the centrifuge. This equivalent represents the percentage of water retained by the soil under the action of a centrifugal acceleration equal to one thousand times the acceleration of gravity The method of the U S Bureau of Public Roads (7) was applied, samples of five grams each being tested The New Haven soils are rather light, with small amounts of colloidal matter The average throughout the county is 14 6 per cent of colloidal matter as referred to the dry weight of the sample The average of the centrifugal moisture equivalent, also referred to the dry weight, is 12 3 per cent The average ratio of both values is 0 84.

Moisture equivalent values below 12 were separated and plotted against the numbers of the samples (dotted line on Figure 1). Another curve on Figure 1 represents corresponding values of colloidal content determined by the fifteen minute test The respective average values in this case are 7.4 per cent and 10.0 per cent as referred to the dry weight of the sample. Their ratio is 0.74.

Professor Bouyoucos himself determined the moisture equivalent by the suction method He connects a Buchner funnel with a suction flask, places a sample of soil into the funnel with a filter paper on the bottom, soaks the soil with water, connects the flask to the suction pipe on the faucet, and allows the suction force to operate on the soil for a definite interval of time (generally ten minutes, sometimes more). For over twenty soils (sands, loams, and clays) the ratio between this moisture equivalent and the colloidal content as determined by the

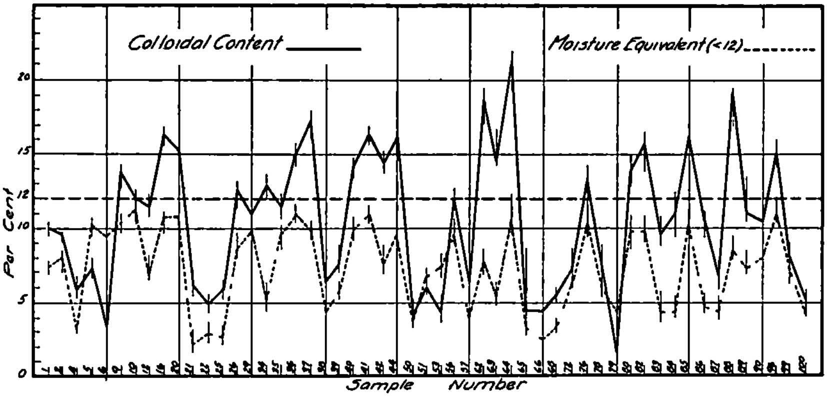

Figure 1 Relationship between the Colloidal Content and Moisture Equivalent of Subsoils, County of New Haven, Connecticut

fifteen minute test, was about 0.62, ranging from 0.52 to 0.71. The results obtained by Professor Bouyoucos are graphically represented on Figure 2. No data are available concerning the relationship of the

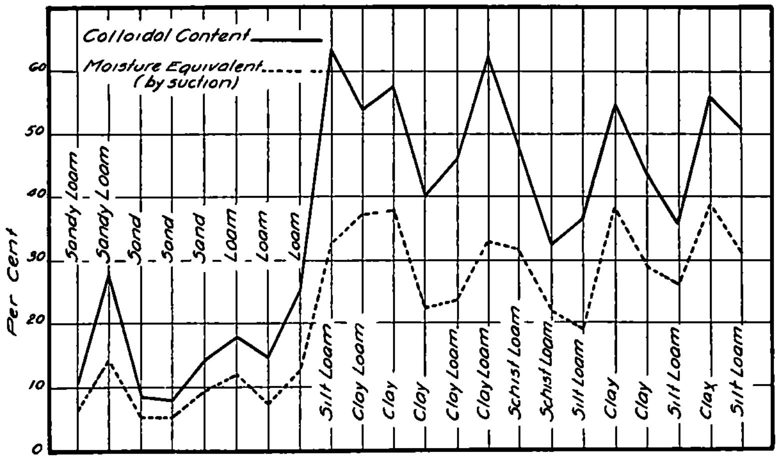

Figure 2. Relationship between the Colloidal Content and the Moisture Equivalent Determined by the Suction Method (After Bouyoucos)

centrifuge moisture equivalent and that determined by suction. The curves, Figures 1 and 2, suggest the possibility of eventually substituting for the relatively troublesome centrifuging the simple fifteen minute test proposed by Professor Bouyoucos. This possibility deserves further scientific study. At the present time the writer believes that the fifteen minute test should precede the centrifuging If the colloidal content does not exceed 18, the moisture equivalent is possibly less than 12 The subgrade in such a case is to be considered as porous, and no centrifuging is needed If the colloidal content is over 18, the centrifuge test should be made, and the figure of the moisture equivalent thus obtained may be checked by the value of the colloidal content

PHENOMENON OF WATERLOGGING

One of the difficulties in determining the moisture equivalent by centrifuging is the occasional squeezing of water not to the bottom of the crucible, but to the top of the sample, where it remains. This phenomenon, called "waterlogging," has been explained by Bouyoucos (8) by the compressive action of the centrifuging force, which compacts the layer of a heavy clay, especially of sticky type, to such an extent that the water is not thrown out but collects on the top of the layer The U S Bureau of Public Roads (9) explains waterlogging in the following way During the centrifuging intimacy of contact between soil particles is increased and the tendency is for water to be squeezed from the sample at both top and bottom The tendency of water to be forced to the top is resisted by the centrifugal force acting on the water This force is in turn resisted by the friction offered by the surface of the soil particles and the capillarity of soil If the resisting force is greater than the centrifugal force water remains on the top of the sample The writer presents here his own explanation of the phenomenon in question and proposes a method to avoid this inconvenience

ACTION OF FORCES DURING CENTRIFUGING

During the centrifuging the crucible is practically in horizontal position (Figure 3, *a*) The active forces acting on the soil particles in the crucible are

(*a*) *Force of gravity* (g) acting vertically and downward, as always

(*b*) *Hydrostatic uplift,* if any (hydr , up)

(*c*) *Centrifugal force* The centrifugal acceleration, a, depends on both the radius of rotation, r, and the number of revolutions, N, per unit of time If a minute be taken for such a unit, the acceleration, a, would be:

$$a = \frac{r\ N^2}{90}\ . \qquad (1)$$

By increasing or decreasing the number of revolutions, N, the value of the acceleration, a, may be made equal to any value. Generally a is made equal to 1,000 g, where g is the acceleration of gravity.

Three forces, that of gravity, hydrostatic uplift, and the centrifugal force act on the same mass As a force is the product of the mass by the acceleration, it is evident that the geometric addition of accelerations may be substituted for the geometric addition of forces themselves. It may be seen from Figure 3, *a*, that the acceleration of both the gravity and the hydrostatic uplift are very small in comparison with the acceleration of the centrifugal force, and may be neglected The centrifugal force, *C. F*, is practically the only active force which acts on the soil particles in the crucible

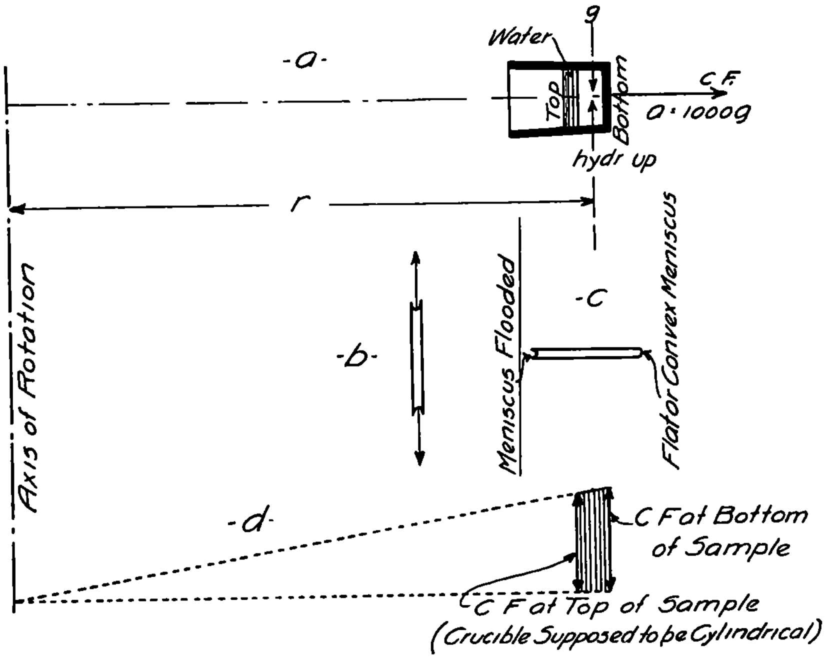

Figure 3 Action of Forces in the Crucible at Waterlogging

The diagram of the centrifugal force is represented in Figure 3 *d* This force is proportional to the distance of a certain point within the sample from the axis of rotation If the radius of rotation is great enough, the centrifugal force may be considered as uniformly distributed through the volume of the sample It may be easily demonstrated that the range of the centrifugal force acting under acceleration 1,000 times the gravity, is about $2 kg/cm^2$ as has often been stated.

The capillary force acting on the water should be neglected. Actually, although menisci exist on all the exterior surfaces of the sample, they do not possess any lifting force The vertical capillary forces (Figure 3, *b*) are counter-balanced, the meniscus on the bottom of the sample (on the right, Figure 3, *c*) is flat, or rather convex and has no lifting force, and if waterlogging takes place, the meniscus on the top of the sample (on the left, Figure 3, *c*) is flooded and therefore has no lifting force either (10) Thus besides the centrifugal force, the water is under action of both the gravity and the attractive molecular forces developed by the soil particles The former is negligible, and the latter furnish frictional resistance to the action of the centrifugal force If the water is squeezed out at the top, it means that the frictional resistance has been overcome Therefore the cause of the waterlogging should be sought elsewhere

In the opinion of the writer, the phenomenon of waterlogging corresponds to the case of compression of a clay layer on an impermeable base (Figure 4). Sticky gel is supposed to descend to the lower part of the sample, forming a crust on the top of the filter paper or close to it The overlapping molecular forces emanating from colloidal particles make this crust impermeable to water Suppose now that the clay is being underlain by a sand layer Water would be easily pulled

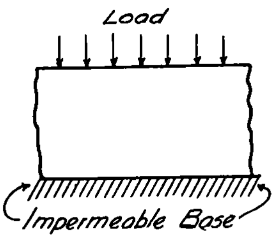

Figure 4

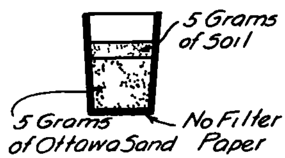

Figure 5 Preparing Sample for Centrifuging

off the surface of the sand particles, with the creation of a vacuum Owing to the cohesive forces of liquids, the continuous flow of water would be assured

PROPOSED METHOD OF DETERMINING THE MOISTURE EQUIVALENT BY CENTRIFUGING

The writer determined the moisture equivalent of washed and oven dried standard Ottawa sand and found it to be practically equal to zero, or more exactly, to about one tenth of one per cent by dry weight In the writer's experiments this value was neglected A study of the behavior of sand admixtures may be found in one of the recent publications of the Bureau of Public Roads (9) The writer repeated some of these experiments with Ottawa sand and found that the moisture equivalent of the mixture as a rule, decreases sometimes more rapidly than the sand content The law of this decrease is unknown Details of the study will be discussed elsewhere

On the other side mixtures of waterlogging soils with considerable percentages of sand *do not* waterlog at centrifuging Suppose the value of the moisture equivalent of such a mixture has been determined If the relation between the moisture equivalent and the sand content were known, the moisture equivalent of the waterlogging soil alone could be computed from this value Unfortunately, this cannot be done

It was therefore decided not to use mixtures of sand and clay, but to spread the clay over the top of a sand layer previously placed in the crucible. The order of the experiment is as follows:

(a) Place 20 gr of Ottawa sand in each of the crucibles used in the test. Do not use filter paper, for the Ottawa sand cannot pass through the holes in the bottom of the crucible Smaller quantities

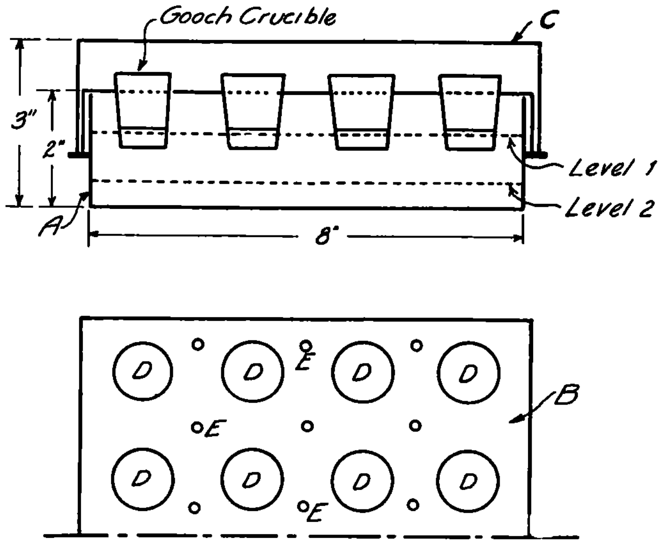

Figure 6. Device for Soaking and Draining

of sand may prove insufficient as they allow some colloidal particles to pass through the sand layer and leave the crucible together with the water

(b) Dry the crucibles with the sand in the oven until constant weight is reached It should be noted that the hygroscopicity of the Ottawa sand is quite negligible, and the constant weight may be quickly reached

(c) Spread the clay over the sand layer and allow it to soak water in the capillary way for six hours (Figure 6) Then the crucible is drained in the humidifier (Figure 6) for 12 hours and centrifuged for one hour under an acceleration of a thousand times the acceleration of gravity

The method was developed on local Connecticut clays and checked on the three samples of clay kindly forwarded by the Bureau of Public Roads. The characteristics of these soils are as follows.

MOISTURE EQUIVALENT

Soil	After Bureau of Public Roads Centrifuge	After Bureau of Public Roads Field	Writer's Experiments Centrifuge
S-5940	134 *	36	61
S-6265	95 *	60	51
S-6266	91 *	61	58

* Waterlogged

The soils S-6265 and S-6266 did not waterlog at all, but heavy cracks were produced during centrifuging. There was no water-logging in two of the four crucibles with soil S-5940, and a very slight waterlogging in the other two. It is to be added that a certain quantity of gel of the soil S-5940 escaped through the sand. Afterwards a variation of the method consisting of placing filter paper between the clay and the sand, has been studied. Samples of Iowa blue clay (S-5791, centrifuge moisture equivalent 37 with tendency to waterlog; field moisture equivalent 25), kindly forwarded by the Division of Engineering, Iowa State College, were used in addition to the three soils above mentioned. Ten grams (by dry weight) of Ottawa sand were placed on the bottom of the crucible and carefully covered with a wet filter paper. Five grams of soil under investigation which had passed through a No. 40 sieve were spread over the filter paper. In such condition, the soils S-6265, S-6266 and S-5791 did not waterlog at centrifuging. The soil S-5940 persisted in waterlogging. In all cases the values of the centrifuge moisture equivalent proved to be smaller than those determined by the Bureau of Public Roads. Strictly speaking, the experiments described do not represent a definitely elaborated method. They rather disclose an idea which, in the opinion of the writer, deserves further consideration.

The writer uses the following simple device for soaking and draining (Figure 6). A bearing plate, *B*, with holes, *D*, for Gooch crucibles, and a number of smaller holes, *E*, is placed on the top of a can, *A*. The capacity of the plate is 16 crucibles. When the can is filled with water to the level, 1, the soil in the crucibles absorbs water. When the soil is draining, only a little water is left on the bottom of the can (level 2). Some very wet cotton is placed on the bearing plate, *B*, in the space between the crucibles. In addition, when draining, the whole device is covered with a cover, *C*, in order to create a more or less saturated atmosphere inside the can, and over the bearing plate, *B*, thus preventing evaporation. The whole device is of galvanized iron; the surfaces in contact with water are thoroughly painted.

(C) STAKE METHOD FOR DETERMINING STABILITY OF THE SUBGRADE

OUTLINE OF THE METHOD

A rigid metallic stake $1\frac{1}{4}$ by $1\frac{1}{4}$ inches in cross-section and 41 inches long, is driven into the soil, to a depth of 12 inches. Through the

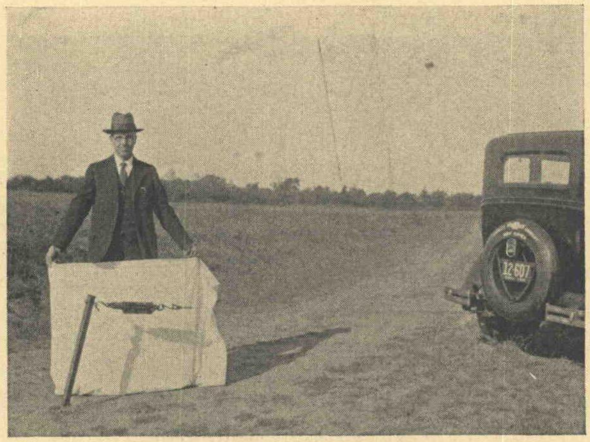

Figure 7

medium of a wire 12 feet long with a hook on the end, the device may be fixed to the rear axle of an automobile as shown in Figure 7. The height of the axle of the automobile is supposed to be one foot.

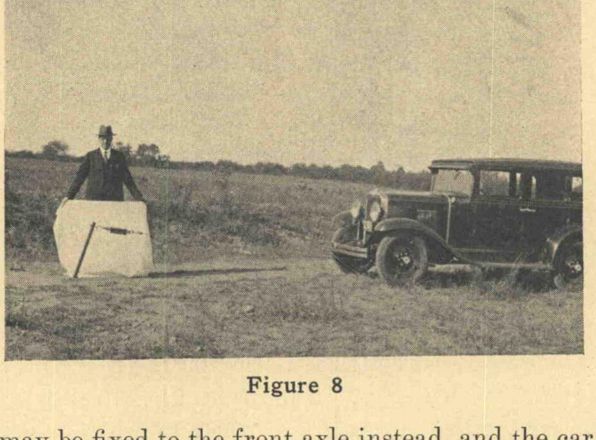

Figure 8

The hook may be fixed to the front axle instead, and the car moved in reverse (Figure 8, suggestion of Professor John C. Tracy, of Yale University). Upon being pulled, the stake is supposed to turn first about a " zero point " located on the stake itself. Experiments of the writer (11) with larger wooden piles have shown that this "zero-point" is located from 52h to 69h below the earth service, when h is the depth to which the pile has been driven (Figure 9, a), the average is not far from $2/3h$ When the stake reaches a certain angle to the vertical, the center of rotation moves to the surface of the earth

Cracks limited by a circle are formed on the surface of the earth, finally a conic body is pushed out Friction and cohesion of the soil, which are responsible for its total shearing resistance, are destroyed in this manner A scale may be introduced in the apparatus, and its maximum reading during the experiment should be taken A small

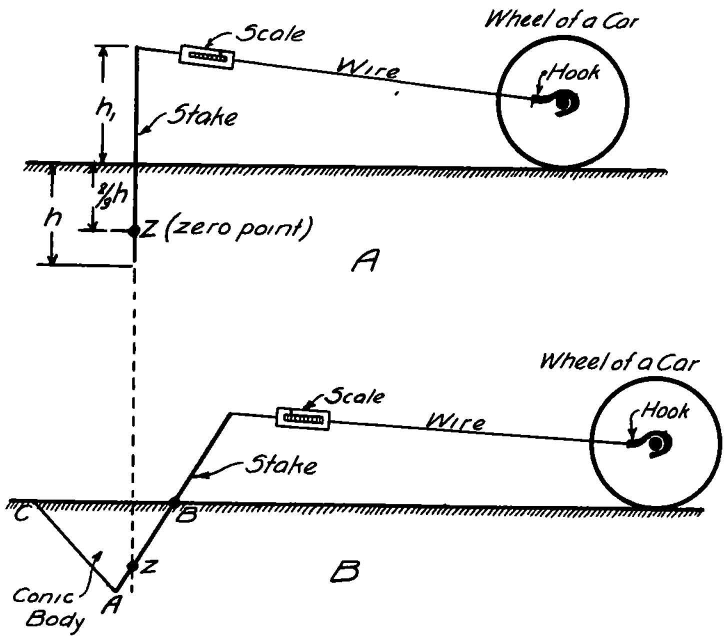

Figure 9. Field Stake Method

home-made metallic device may serve for this purpose It remains in its place when the back-contraction of the scale spring occurs Obviously, this device should be tight enough not to drop off No experiments have been made in very viscous soils where plastic flow prevails

THEORY

Three forces resist the pushing out of the cone ABC (Figure 9, b, and Figure 10), namely:

(1) Force of cohesion, c, acting along the surface of the cone The cohesion is supposed to be uniformly distributed over that surface and does not depend on the weight of the cone.

(2) Force of friction, f, forming the angle of friction, ϕ, with normals to the surface of the cone This force does depend on the weight of the cone

(3) Weight of the cone, W

The forces, c and f, when geometrically added in space, give a vertical resultant, R, their horizontal components vanish owing to the symmetry of the cone These horizontal components may cause deformations of the body of the cone, which, however, are not considered in the present case The force, R, is the shearing resistance developed

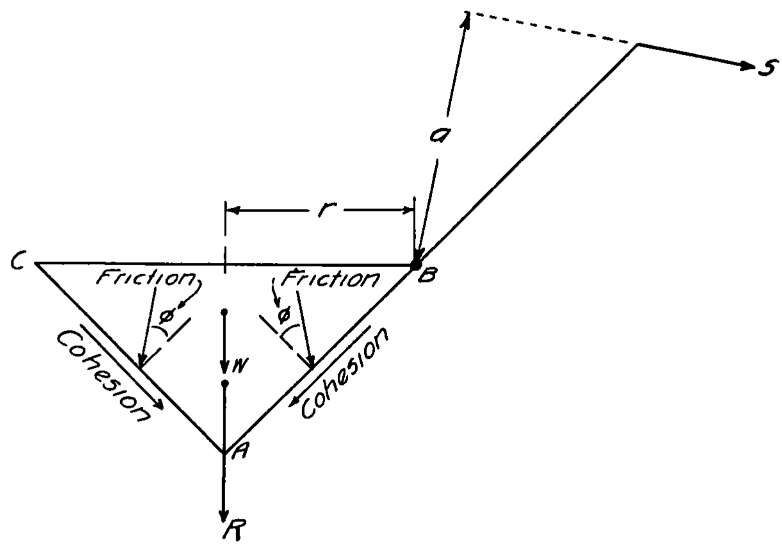

Figure 10 Action of Forces on the Earth Cone in the Stake Method

by the cone, and the sum $R + W$ is the force to be overcome in order to push out the cone

Let:

$S =$ reading on the scale;

$a =$ arm of the force S with respect to the point B, which is the center of rotation of the stake at pushing out of the cone,

$r =$ radius of the upper base of the cone

Then the condition of equilibrium immediately preceding the destruction of friction and cohesion, would be:

$$S\,a = (R + W)\ r \qquad (2)$$

There are two ways of solving this equation one approximate, and another more exact The approximate solution will be discussed first Neglect the proper weight of the cone and suppose a to be a constant Then from equation 2.

$$R = a\ \frac{S}{r} \qquad (3)$$

This means that the shearing resistance is proportional to the ratio $\frac{S}{r}$ or what is the same, to the ratio $\frac{S}{2r}$ Therefore, in order to obtain an approximation of the shearing resistance of a subgrade, it is necessary to drive the standard stake to the standard depth and to overturn the stake The ratio of both the reading on the scale and the average diameter of the hole produced on the ground may be called the *shearing characteristics* of the subgrade

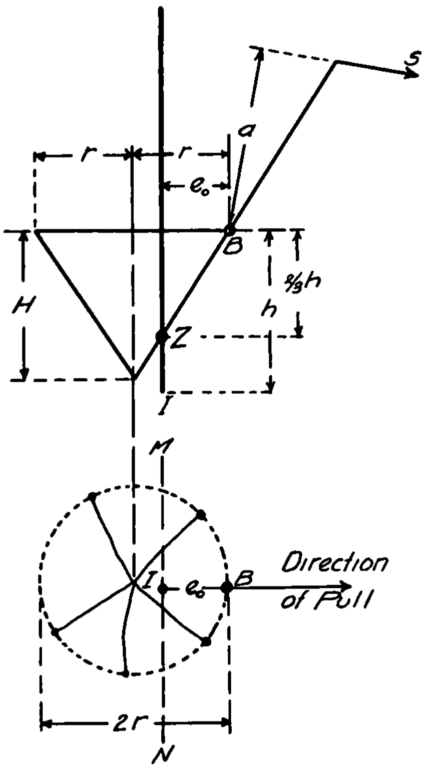

Figure 11 Recording the Data in the Stake Method

The more exact method requires the determination of the horizontal distance, e_o from the initial position of the stake to the final After driving the stake to its initial position, I (Figure 11), establish a line MN passing through I, approximately perpendicular to the eventual direction of the pull Then proceed to pull, doing it gently, by little jerks It is better to end the experiment as soon as well defined cracks on the earth's surface appear. in so doing, the diameter of the hole can be measured more accurately For this purpose, mark the ends of the cracks by small stakes whereupon the average diameter of the base may easily be established From field experiments S, $2r$, and e_o, may be determined and the following values may be computed, height of the cone, H, a, the arm of the force S, and upon assuming an average specific gravity—the weight of the cone, W Thereafter there will be no more difficulty in computing R in formula 2

The writer does not insist on the proposed size of the apparatus. It may be changed, and the depth of driving the stake increased, but if the idea of the test be approved, the size and the details should be standardized Comparable results may be obtained only when identical apparatuses are used At any rate the length of the stake above the ground should be considerable, otherwise the stake would be pulled out without destroying the cone Another thing to be noted is the necessity for introducing some safety device into the wire, which would break before the wire or before the axle of the automobile is damaged

SOME NUMERICAL DATA

The equipment at the disposal of the writer did not permit him to measure forces, S, over 260 lbs Therefore, many measurements refer to weak soils The soils (8), (9), (10), (11), shown in Table I

TABLE I

	Location of Experiment	Nature of Soil	Observed Values			Computed Values		
			s Lbs	$2r$ Ins	e_0 Ins	$\frac{s}{2r}$	C Cohesion Lb per Sq Ft	ϕ Assumed Angle of Friction Deg
1	North Haven, Conn	Clay, Weathered	85	15	6	5 7	133	0
2		Upper Horizon	75	16	6	4 7	92	0
3	Branford, Conn	Loam	220	14	4	15 7	466	0
4	New Haven, Conn	Fresh Gravel Fill	130	24	10	5 4	22	30
5	New Haven, Conn	from one	85	22	8	3 9	29	30
6	New Haven, Conn	month to	130	21	8	6 2	63	30
7	New Haven, Conn	one year	130	18	6	7 2	114	30
8	New Haven, Conn	old	210	18	7	11 7	208	30
9	Foxon Road, Conn	Fill of Stony Loam	220	22	x	10 0	y	
10	Foxon Road, Conn	Stony Loam, in Pit	260	16	x	16 2	y	
11	New Haven, Conn	Well Cemented Gravel	260	14	x	21 7	y	

x—not measured y—not determined
The moisture content by dry weight, determined without stony particles, was
Soils 1 and 2, 15 per cent on surface, 34 per cent at a depth of 14 inches
Soil 3, 18 per cent
Soils 4 to 11, inclusive, 5 to 6 per cent

may be considered as good material for subgrade The soil (3) is a firm loam, but possesses a centrifuge moisture equivalent close to 35 From these and other measurements the writer has drawn a preliminary conclusion that a soil may be considered as adequate material for subgrade if it possesses, shearing characteristics over 10, provided its centrifuge moisture equivalent is sufficiently low

(D) SOIL MAPPING FOR DIRT ROADS

The way of attacking the dirt road problem, in the opinion of the writer, should be purely practical Soil studies may be indicative, but final success can be based only on practical conclusions drawn from observations on experimental roads Soil mapping is useful for a preliminary subdivision of a given locality into zones, and in each zone a suitable type of road improvement should be sought and applied

It should again be emphasized that the existing soil maps have been prepared principally for agricultural purposes The immediate future of soil mapping is well characterized by one of the reports presented to the First Congress of Soil Science (12): "The agronomic tendencies in Soil Science are still strong and there is hardly any reason to minimize them For that reason, the tendency to have maps, which differentiate soils on the basis of agronomic characteristics deserves our attention and improvement" This is an indication that soil engineers should look for their own ends in soil mapping The same author, however, emphasizes an idea which may be utilized by engineers, namely, the proposal to map not only soil types and their variations, but also the specific soil characteristics A similar suggestion was made more than thirty years ago by a Russian soil scientist, Nefedov, but was accepted by no one

In engineering terms, the above idea may be formulated as follows: in preparing soil maps attention should be paid to plotting the physical properties of soils of importance for road building When mapping the subsoils of the county of New Haven Connecticut, the writer tried to prepare maps indicating different physical properties of soils, for example, size of grains, coefficient of uniformity, colloidal content; moisture equivalent, plasticity, etc, the maps showing the law controlling the centrifuge moisture equivalent proved to be the most adequate The county has been subdivided into five zones, (I), (II), (III), (IV), and (V), see Figure 13 All the observed values of the moisture equivalent have been divided into three classes

(a) Above 150 per cent of the average, i e, above 18 per cent

(b) Between 150 and 50 per cent of the average, i e, between 18 and 6 per cent

(c) Under 50 per cent of the average, i e under 6 per cent

Values of moisture equivalent between 150 and 50 per cent of the average can be found anywhere in the county; but the highest values (above 150 per cent of the average) are concentrated in zones I and II. The lowest values (under 50 per cent of the average) are to be found in zones III, IV and V only

It is known that the soil profile possesses several horizons The majority of Connecticut roads have existed perhaps 200 years, and more Therefore for such roads, the study of the horizon "A" in the adjacent field which is very important for the agriculturists, has but little practical value for the road builder An old road has a peculiar "A" horizon of its own produced by the combined action of the water, long continued traffic, and attempts of farmers to improve the road as they can New improvements of secondary dirt roads are located principally in the "B" horizon, therefore, as a rule, the writer extracted samples only from that horizon

Existing maps, both soil (13) and geological, were of help. It is obvious that, as a rule, the geological factor cannot be considered as

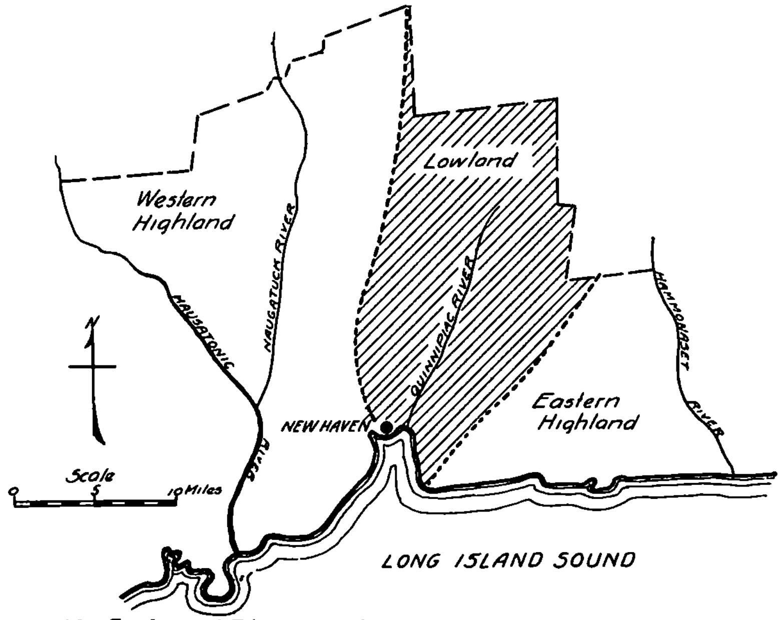

Figure 12 Geological Divisions of the County of New Haven, Connecticut

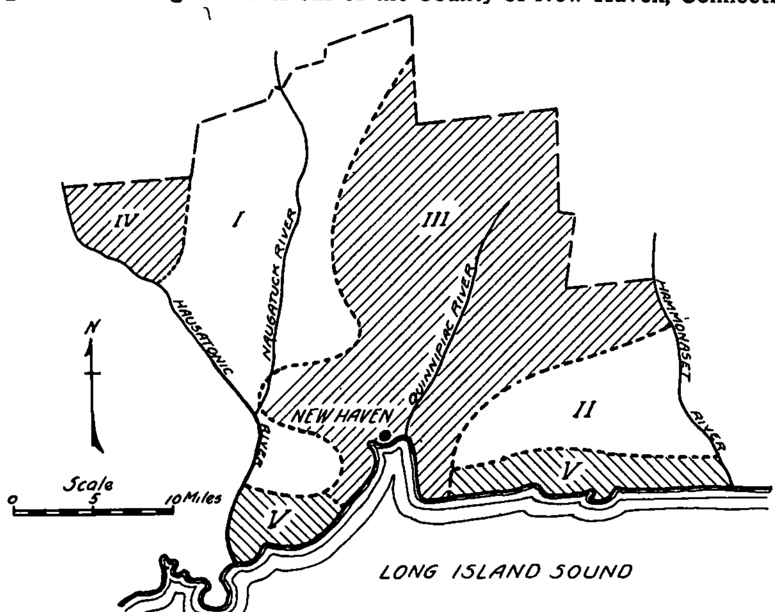

Figure 13 Zoning the County of New Haven According to the Moisture Equivalent of the Soil

basic for soil mapping However, sometimes the soil mapping in small areas may be controlled by geological considerations G W Robinson (14) recommends the recognition of two classes of soil maps, (a) for greater areas, and (b) for smaller areas In the first class, the large primary soil groups are to be shown, according to modern views of soil science The actual soil classification to be adopted for the maps of the second class will be governed mainly by local and practical considerations In some areas, classification according to the parent material will prove most satisfactory According to Robinson, this is the case of southeastern England, and of some areas in Wales This is possibly the case of the County of New Haven too, where zone III of the moisture equivalent practically coincides with the geological lowland formed by triassic sandstones and shale rocks with trap rock ridges (Figure 12) The composition of both highlands is different (schists, gneiss, limestone, etc), and different values of moisture equivalent in soils correspond to them

A map cannot tell how to improve the roads But it should disclose suggestions as to the use of analogous road types in the localities with analogous physical properties of soils and subsoil

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DISCUSSION ON SOIL SURVEYING AND MAPPING

ABSTRACTED

MR. C A HOGENTOGLER, *Senior Highway Engineer, U S Bureau of Public Roads* Comment is made that the significance of the tests proposed by Professor Krynine may be different in the cases of unchanging soils located below the line of seasonal change and those close to the surface which change with varying conditions of moisture, frost and temperature The first variety may be tested directly for bearing value, shear, etc, and in this connection the stake test may be highly significant. The results of tests performed on the second variety can do no more than disclose the characteristics furnished by the soil constituents, which can only be translated into terms of subgrade efficiency when the performance of subgrades having similar characteristics has been determined by pavement surveys With respect to the strength or weakness of a soils organization, or the most practical type of survey procedure there may be some difference of opinion Whether a soils organization is strong or weak depends, not on how many men are engaged or the extent of its activities, but rather upon the completeness with which the required information is obtained The information required in a given jurisdiction may be only that which can be secured from study of existing soil maps supplemented by visual examination of the material, application of such tests as the Rose moisture equivalent and lineal shrinkage test may suffice, or it may be necessary for the subgrade survey to approach that of the procedure published by the Bureau of Public Roads

The procedure published in the September 1931 issue of *Public Roads,* showing the extent to which some surveys may have to be carried, is merely a description of how surveys for highway engineering purposes have been made for the past several years by the Bureau in cooperation with the various state highway departments This procedure seems to have proven comprehensive enough in scope and simple enough in application to attract the attention of the construction engineers, and in consequence, at least ten state highway departments are now equipped by both adequate laboratory facilities and soils organization to carry on the soil survey work in all its completeness

PROFESSOR F H ENO, *Ohio State University* Professor Krynine has picked the two most important soil characteristics to give the designing engineer the best knowledge of the soil conditions for which he must design, namely, " Permeability or capacity for drainage " and " resistance to deformation under load " The point is raised, however, in connection with the proposed test for permeability that a more definite determination of colloidal content is needed than that furnished by the Bouyoucos 15 minute hydrometer method If we assume as correct the usual assumption that mineral colloids must be particles less than 0.001 or even .002 mm in diameter, then Bouyoucos' method gives no reliable measure of colloidal content

Investigators have usually accepted Stokes' law of freely falling bodies in quiescent water as applicable for determining soil grain size. According to this law, the diameter of the normal soil particle (specific gravity 2.65) which remains in suspension after 15 minutes approximates a diameter of 0.01 mm or less The suspension not only contains all clay particles but a large percentage of silt particles at the end of 15 minutes It takes 60 minutes to free the suspension from all the silt and 360 minutes to settle out clay particles down to 0.002 mm in diameter

From Professor Krynine's curves, it would seem that he is on the right track, but there are some rather wide divergences between his curves which may be due to his extremely approximate determination of colloids If a closer determination of colloids is made, these two curves of moisture equivalent and colloidal content might become parallel lines. When such results are obtained between any two factors, then a single test may be substituted for two tests

Professor Krynine has used a very simple and ingenuous method to secure his second factor—resistance to deformation under load. If this " shearing resistance " can be shown to have a definite relation to soil deformation under load, the design of road slabs over various soils would be simple.