density of 125 pounds per cubic foot and 5 per cent moisture content, a conductivity of 17 was obtained at 70°.

CONCLUSIONS.

Thermal conductivity tests on 14 soils warrant the following conclusions:

1) The coefficient of thermal conductivity of soils above the freezing point increases with an increase in mean temperature. Values at 70° average about 5 per cent more than those at 40°;
2) In most cases the coefficient of thermal conductivity does not vary appreciably in a mean temperature range from -20 to + 25°;
3) The difference in thermal conductivity above and below the freezing point is dependent chiefly upon the moisture content of the soil. For air-dry soils there is practically no difference in the two values. At slightly higher moisture contents (2 per cent in sands, 5 to 10 per cent in fine grained soils) the conductivity is lower below freezing than above. With further increases in moisture content the conductivity of frozen soil becomes progressively greater than unfrozen. At the modified optimum moisture content the conductivity below freezing is on the average about 20 per cent greater than that above freezing;
4) At a constant density an increase in moisture content causes an increase in conductivity. On the average, the conductivity of a soil at 10 per cent moisture is more than twice that at 1 per cent;
5) At a constant moisture content an increase in density results in an increase in conductivity; the average increase is about 2½ per cent per pound per cubic foot increase in density;
6) The thermal conductivity of a given material is dependent upon its grading and particle shape as well as its density and moisture content. Tests on three materials, all pure quarts but with different gradings and particle shape, showed that at common moisture content and density an angular well-graded material had a conductivity of from 20 to 50 per cent greater than rounded, poorly-graded materials;
7) The thermal conductivity of crushed rock minerals of approximately similar gradings differ appreciably. The order of conductivities of four materials tested, from the least to the greatest, is: trap rock, granite, feldspar, and quartz; the relative magnitudes are: 1.0, 1.3, 1.4, and 2.5.

ACKNOWLEDGEMENT.

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For the Corps of Engineers, St. Paul District, Mr. E.J. Evans was in charge of laboratory tests for density and moisture control, and Mr. Harry Carlson was coordinator of activities under the direction of Mr. H.J. Manger, Engineer in charge of the Permafrost Investigation, and Colonel W.K. Wilson, Jr., District Engineer.

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FOR A SYSTEMATIC STUDY OF THE PROPERTIES OF SOILS AS RELATED TO THEIR PERMANENT CHARACTERS AND TO THEIR NON-PERMANENT CHARACTERS (STRUCTURE AND MOISTURE CONTENT)

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1. INTRODUCTION.

Among the numerous factors which affect the physical and mechanical properties of soils, are be considered:

1. the permanent characters : physico-chemical composition, shapes of particles, kind of their surface, particle size distribution, etc.
2. the structure and the moisture content, supposed uniform, which are capable of free variation within certain limits.

The moisture content is easy to determine by the measure of the difference between the wet weight P_h and the dry weight P_s of a sample of soil having the apparent volume V, from which are deduced:
the specific gravity of the wet soil: $\delta_h = P_h/V$ and the specific gravity of the dry soil: $\delta_s = P_s/V$.

Hence: $$e = \frac{P_h - P_s}{P_s} = \frac{\delta_h - \delta_s}{\delta_s}$$

The structure is much more difficult to define and even to conceive. It is relative to the arrangement of the particles and of the intersticial liquid in the soil. It is not sufficiently characterized by the measure of the real specific gravity of the soil δ_r which permits to cipher the 3 fractions c, ℓ and a of an unitarian volume occupied by the solid, the liquid and the air. This measure permits to define the value of the compacity:

$$e = \frac{\delta_s}{\delta_r}$$

(or of the porosity: $p = \ell + a = 1 - c$)
If the specific gravity δ_ℓ of the liquid is known (it is practically equal to 1 kg/dm3), can also be deduced the degree of moisture

$$g = \frac{\ell}{\ell + a} = \frac{\frac{\delta_h - \delta_s}{\delta_\ell}}{1 - \frac{\delta_s}{\delta_r}} = \frac{(\delta_h - \delta_s)\,\delta_r}{(\delta_r - \delta_s)\,\delta_\ell}$$

but these values give only a global aspect of the structure of the soil. Various structures are possible for the same compacity and the same degree of moisture. Practically, the undetermination is solved if the processus of compaction and the amount of the energy of this compaction are stated precisely.
A practical mean to define the compaction consists in the method first applied by R.R.PROCTOR.

The mean structure obtained in compacting soil layers of 5 cm of initial thickness under 10, 20, 30, 40 or 50 blows of a standard stamper at a determined moisture content is defined without ambiguity and can be reproduced at will. It may be admitted that the various arrangements of particles obtained in this way embrace all the possible cases. By uniform imbibition or dessication, it can of course be obtained for each arrangement of particles a whole series of moisture contents from the lack of moisture to the complete saturation.

Two soils, brought in such a same way in a defined state of compaction and then at the same moisture content, differ only by their intrinsic and permanent characters.
It is proposed hereafter to define a state of compaction and a moisture content which should be chosen for the comparison and the classification of soils based on these characters. This method is able to favour a synthesis of the relations between the properties of soils and their permanent characters.
On the other hand, in order to promote a systematic study of the inter-actions of the structure and of the moisture content of a soil, and of their action on its properties, is preconized the tracing of the curves of variation of each property as related to these two factors.

For all the steps of this study it is particularly important to have in hand a recording system, clear, practical and complete of the various states of the soil. For this purpose is described hereafter a basic recording system already presented in 1943 by the author in a report to the Association for Engineers A.I. Lg. and to the Belgian Association for testing materials (A.B.E.M.)

The primitive proceeding has however been improved since, in order to increase the field of its application and the clearness of the record.

2. RECORDING DIAGRAM OF THE STRUCTURES AND MOISTURE CONTENTS OF A SOIL, OBTAINED BY COMPACTION ACCORDING TO THE METHOD OF R.R. PROCTOR.

a) For a soil of determined specific gravity δ_r, if one plots as abscissus the value of ℓ and as ordinate the value of c, the corresponding points can cover the area of a right-angled triangle, of base 1 and of height 1 and whose hypotenuse corresponds to $\ell + c = 1$ or $a = 0$ (saturated soil). The states of the dry soil are represented on the c axis, the summits of the triangle correspond to $c = 1$ (solid plain), $\ell = 1$ (liquid only) and $a = 1$ (air only).
For any point inside of the triangle : $c + \ell + a = 1$, and the values of c, ℓ and a are shown on the vertical of each representative point.

On this diagram, the cross-lines of

$$e = \frac{\delta_h - \delta_s}{\delta_s} = \frac{\ell\,\delta_\ell}{c\,\delta_r} = k$$

correspond to $\frac{\ell}{c}$ = constant.

They are straight lines issued from the point of origin, and quoted according to the values of $\frac{\ell}{c}$

The cross-lines of $\delta_h = \delta_r + \ell\,\delta_\ell = K$ are parallel straight lines which cut the c axis in K/δ_r and the ℓ axis in K/δ_ℓ

The geometrical lines of $g = \frac{\ell}{\ell + a}$ = constant or $\frac{\ell}{1-c}$ = constant are straight lines issued from the summit (corner point) corresponding to c = 1 and quoted according to the values of $\frac{\ell}{1-c}$

b) For any value of δ_r, if one plots as abcissus the value of ℓ/δ_r and as ordinate the value of c, the corresponding points can cover a right-angled triangle of base $1/\delta_r$ and height 1.

For any point inside of the triangle : $c + \ell + a = 1$, and the values of c, ℓ and a are shown on the vertical of each representative point.

The straight lines issued from the point of origin correspond to $\ell/c\,\delta_r$ = k, or to e/δ_ℓ = k, thus practically to e = k

A straight line cutting the c axis in c = K and the ℓ/δ_r axis in $\ell/\delta_r = K/\delta_\ell$ or practically in ℓ/δ_r = K, corresponds to $c + \frac{\ell\,\delta_\ell}{\delta_r} = K$ or to $\delta_h = K\,\delta_r$

The straight lines issued from the point c = 1 correspond to $\frac{\ell}{\delta_r(1-c)}$ = constant, or to $\frac{\ell}{(\ell + a)\,\delta_r}$ = constant, or to g/δ_r = constant.

The fig. 1 corresponding to a large extent of values of δ_r , shows the various sets of lines, quoted as mentioned abovel A state of structure obtained by compaction at a determined amount of moisture according to the method of Proctor will correspond to the point plotted at the intersection of the lines quoted according to the values of e and δ_h

The curves of same compaction (under 10, 20, 30, 40 and 50 blows of standart stamper may be traced on the same diagram. The fig. 2, corresponding to a fine sand, of δ_r = 2,65

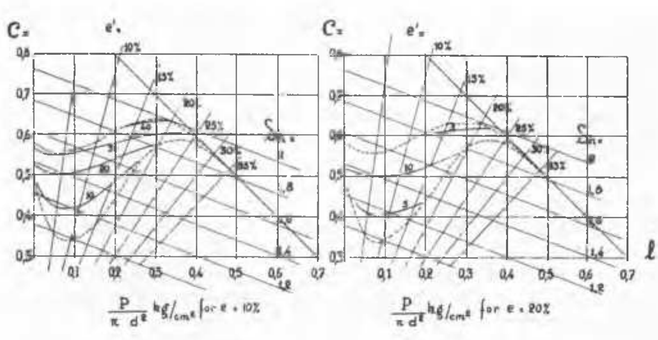


FIG.1

kg/dm³ shows the corresponding curves.

The area covered by the curves of same compaction comprises practically all the states of structure of the considered soil.

For each structure the amount of moisture can vary from zero to the saturation, but the corresponding states are not represented on the diagram. It bears only the representative points of the structures obtained by the compaction, with the corresponding moisture contents.

For the considered case, the critical structures will easily be found on the diagram. These structures, which correspond to a little variable compacity, are necessarily represented on the dotted line, which on the fig. 2 is nearly horizontal and is traced from the maximum of compacity which can be obtained at low moisture content, to the minimum of compacity, which can be obtained at high moisture content.

The points of this line correspond very closely to the critical compacities measured for this sand.

3. USE OF THE DIAGRAM FOR SYSTEMATIC STUDY OF THE PROPERTIES OF SOILS.

The question arises logically to define the structure and the moisture content at which should be studied first the relations between the permanent characters of the soils and their physical and mechanical properties.

Looking at the fig. 2, it is seen that a convenient choice can for instance be made of the point corresponding to the critical compacity and the moisture content leading to the absolute maximum of compacity.

Such a definition looks preferable to the one which would consist to choose for instance the point corresponding to the maximum of compacity under 25 blows of standard stamper, this later definition seeming too conventional.

The choice of the best definition of such a reference state must finally be based on the results given by several definitions of this kind. The values of c. and e at the chosen point for the soils brought into comparison must have the largest possible extent of variation.

The values of c. and e corresponding to the state of reference are themselves properties of the studied soils and can be used as a base of a first classification of these soils.

More generally, the proposed diagram can be used also in the systematic study of the variations of any property of a soil when the structure and the moisture content are varying. This point will be considered further.

4. CLASSIFICATION OF SOILS.

The principle of the use of the compaction under a fixed number of blows of standard stamper for the establishment of a classification of soils has been applied as soon as 1938, for instance in the prescriptions for earthworks included in the lastbooks of the state of Ohio.

This principle leads to choose as the base of the classification not the granulometric characters but the aptitude to compaction.

For the sands, this principle can be improved as shown hereafter:

For sands of the same mineralogic nature, and of particles whose shapes are similar enough to let the sands be sufficiently characterized by a nominal diameter and a coefficient of uniformity or of "spreading", the classification is only related to two factors.

Instead of the latters can be used the values of c and e as defined above. The sands will be classified into categories corresponding to well defined zones of location of the representative point chosen above. To each zone will be related defined values of the properties of the sands.

Each anomaly in this way will permit to detect the influence a variation in the nature of the sand or in the shape of its particles. Two other properties of the sands could be chosen for such a classification.

An investigation of the sands used in Belgium, conducted in this way was in preparation at the date of presentation of this paper.

5. STUDY OF THE VARIATION OF A PROPERTY OF A SOIL FOR ALL THE POSSIBLE STATES.

On the same diagram can be traced the "level-curves" representing the variation of a property of a soil if this property is not de-

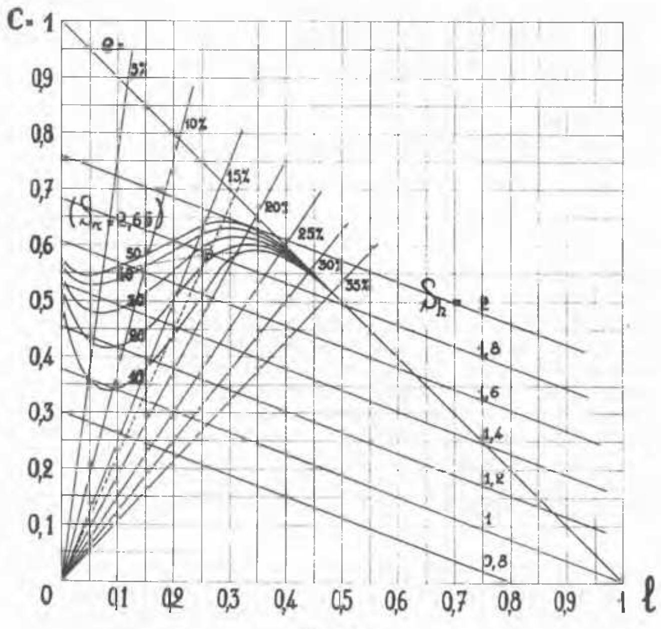


FIG.2

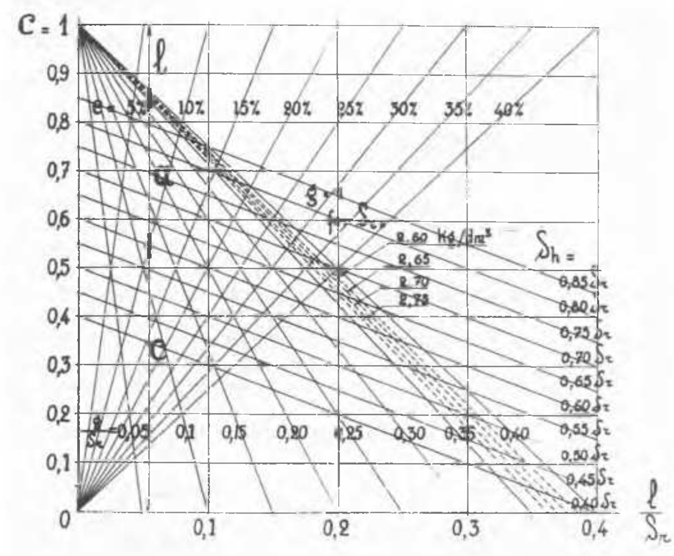


FIG.3

pendant of the moisture content, but only of the structure. This would be the case for the permeability coefficient, according to the law of Darcy. If this is not the case, the curves can still be traced but for a determined moisture content. For instance, in the case of the cone-test, the curves will be traced as shown on fig. 3.

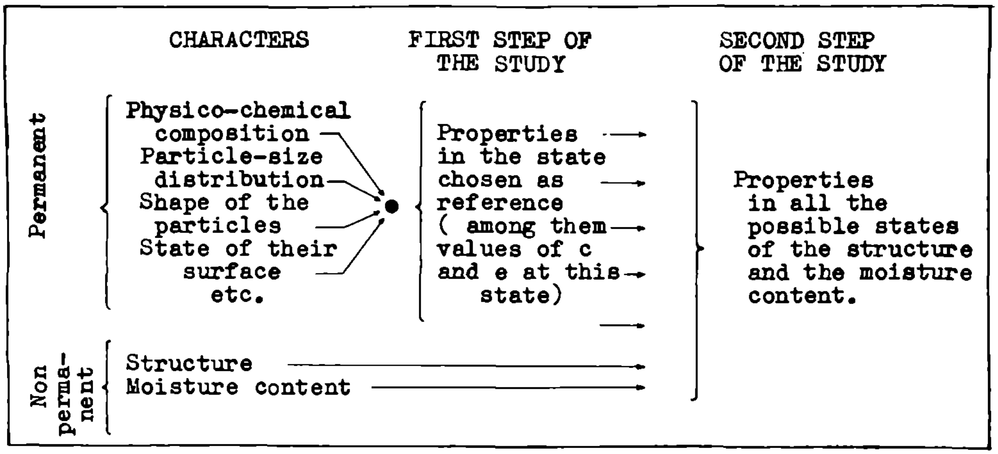
The case is particularly complicated in the study of the internal friction, for which are to be considered the modifications of structure in the sheared zone.

SUMMARY.

The study of the relations between the physical and mechanical properties of the soils and their permanent and non-permanent characters must rationally be conducted according to the scheme below:

The use of the proposed recording system permits to treat clearly and precisely the various questions which arise in this field, in the first step of the study as well as in the second.

As far as the first step of study is concerned, it facilitates the classification of soils based on the values of the compacity and of the moisture content in the state chosen as reference.



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Id5 A METHOD FOR ESTIMATING THE LOAD-SETTLEMENT CHARACTERISTICS AND BEARING VALUE OF CLAYS AND CLAY-SOILS FROM UNCONFINED COMPRESSION AND TRI-AXIAL COMPRESSION TESTS.

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SYNOPSIS

A method is proposed for obtaining estimates of bearing value of soil for footings of bridges and buildings and for airport pavements from laboratory compression tests, which is based upon the concept of a Natural Restraint Coefficient. This involves theoretical interpretations and correlations of laboratory compression tests with load test data. The method is applicable to clays and clay-soils for which the initial stress conditions and strength are approximately constant with depth. Consideration is given to the Test Conditions to be followed in the laboratory compression tests. On the basis of this concept an estimated load-strain curve can be drawn from laboratory compression test data, that can be used directly for estimating the probable load-settlement characteristics, probable bearing value and ultimate failure conditions of full-scale footings.

Load tests have been considered to be the most direct and useful method for determining the load-settlement characteristics and bearing value of foundation soils, and have been used quite extensively for the design of foundations of buildings and bridges and for airport pavements where heavy plane loadings are anticipated. For airport pavements the load tests are full-scale tests, because the size of the bearing plates generally used are equal