REPORT OF DEPARTMENT OF SOILS INVESTIGATIONS

C A Hogentogler, *Chairman*

ADSORPTION PHENOMENA IN RELATION TO SOIL STABILIZATION

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SYNOPSIS

After a short theoretical analysis of the different kinds of adsorption, the sorptive or surface behavior of soil materials is explained on the basis of the main soil forming processes Data are given on the surface character of soil material formed under varied conditions of weathering, and also on the possible change of this character by exchange adsorption (base exchange), and other surface reactions (soaps) The importance of these reactions for soil stabilization are demonstrated

Adsorption is defined as a change in concentration on surfaces An increase in concentration is called positive, a decrease negative adsorption It is generally agreed that the forces responsible for adsorption on surfaces are of the same kind as those responsible for chemical linkage in molecules There are two extreme types of chemical linkage the ionic or polar type which is due to the electrostatic forces acting between oppositely charged ions, and the homopolar type which is found in hydrogen and similar molecules While the theoretical treatment of the polar type of linkage resolves itself into the application of Coulombs law, the theoretical treatment of the homopolar type is much more involved and requires the tools of wave mechanics There are certain transition types between these two extreme kinds of chemical linkage, the electrostatic treatment of which, though incomplete, gives valuable semi-quantitative information

In the case of adsorption the electrostatic or polar type is represented by the adsorption of positive sodium and negative chlorine ions on the surface of a rock salt crystal growing in a sodium chloride solution The nonpolar type is represented by the adsorption of argon on charcoal Fortunately for the soil scientist, the adsorption phenomena on soil materials are mainly electrostatic in nature The sorptive character of soil materials is then a function of the amount of surface involved and of the number of positive and negative charges per unit surface Table 1 shows the specific surface of solid materials as a function of particle size

The factors influencing the surface character of soil materials are the chemical and mineral composition of the rock from which the soil is derived, and the climatic conditions under which the soil is developed The pedologists have found that the climatic factor is the more important in shaping the adsorptive character of the soil material. For a better understanding of this influence, the weathering of granite will be studied under different climatic conditions.

Granite is composed of three minerals: quartz, orthoclase and biotite with the chemical compositions SiO_2, $KAlSi_3O_8$, and $K_2HAl_3Si_3O_{12}—3Mg_2SiO_4$, respectively.

TABLE I
RELATIONSHIP BETWEEN PARTICLE SIZE AND SPECIFIC SURFACE OF SOLID MATERIALS

Radius	Specific Surface $\frac{(4\pi r^2)}{(4/3\pi r^3)}$
mm.	*1/mm.*
1.0	3
0.1	30
0.01	300
0.001	3000
0.0001	30000
0.00001	300000

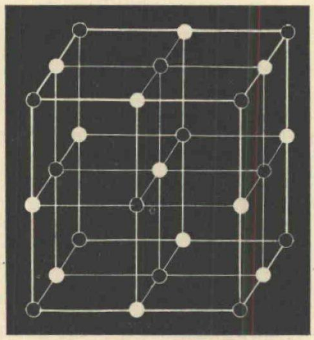

Figure 1. Structure of a Sodium Chloride Crystal

In the desert where a very small amount of precipitation and a rapid change of temperature between day and night occur, granite is subdivided mechanically into quartz, orthoclase and biotite because of the different magnitudes of the expansion coefficients of these minerals. These minerals are further subdivided as a result of the combined effect of temperature change and of the strains set up in the crystals under the conditions of their formation. After a geological time of weathering, the soil material produced will contain graded particles from larger to colloidal size, where the largest sized particles consist of those minerals that possess the lowest coefficient of expansion. The total chemical as well as the mineral composition of the soil material formed is not essentially different from that of the original granite.

If we contemplate the disintegration of granite in a humid northern climate, with higher precipitation than evaporation and with a normal temperature sufficiently high to assure growth of plants and trees, then in addition to the mechanical, there takes place a chemical type of weathering. The hydrogen ions, which are normally present in pure water in a very small amount, are increased in number because of the accumulation as acid humus of partly oxidized organic matter. These hydrogen ions will substitute for the alkali and alkaline earth ions on the surface of the mineral fragments. These cations are leached downwards together with colloidal inorganic particles, which are protected by organic coatings, until the electrolyte concentration is large enough for precipitation. The acid in this soil is strong enough to attack whole silicates and to dissolve them slowly. The ionic and colloidal products of this solution process are also washed downwards to the zone of precipitation. Since humic acids have a great protective effect on iron and aluminum oxides, these substances are carried farther away from the original material than is silica. Therefore, in the leached as well as in the accumulation zone there is a relative accumulation of silica. In this type of weathering a soil with three distinct horizons is developed: the leached surface soil, consisting mainly of silica sand, the zone of accumulation (clay and hard pans), and the zone of the unweathered parent material. The materials in these different zones exhibit distinct physical and chemical differences from each other. From the ash-gray color of the leached surface this type of soil has been called an ash-soil or, from the Russian, a Podsol. Soils which have been or are being formed under the influence of this kind of weathering are called podsolic.

The last type of weathering which we want to consider here is that which acts in a humid tropical country. There, the high temperature increases the speed of oxidation of organic material sufficiently to prevent its accumulation and the formation of humic acids. Under these conditions of high temperature and high humidity, the silica is dissolved and leached out of the soil material together with present mono and divalent ions. The tendency is towards an accumulation of hydrated alumina and iron oxides. This type of weathering is called lateritic and leads to the formation of the true laterites in the tropics and of the lateritic soils in the south.

It is logical that those minerals that are decomposed easily will first come into equilibrium with the weathering factors, and that the analysis of their weathering products will indicate the direction of the weathering process. Of course, the weathering products of the minerals most easily decomposed are those that possess the smallest particle sizes, namely the clay and the colloids. Since there is an accumulation of silica in the podsolic type of weathering and an accumulation of alumina and iron-hydroxides in the lateritic type, the ratio of silica over the sesquioxides in the colloid is of special importance in revealing the type of weathering which the soil has undergone as well as in indicating the surface character and therewith the adsorptive behavior of the fine sized material in the soil. Soils containing clay which possesses a silica-sesquioxide ratio larger than two are classified as podsolic, those that possess clays with a lower ratio, as lateritic. There are, of course, other soil formation processes of equal importance besides those just described.

This digression into the field of soil formation was not intended to be an exhaustive treatment, but was rather an attempt to give a general idea of the factors which shaped the character of the soil materials in the past, as an aid to a better understanding of their present behavior.

It has been demonstrated how climatic factors influence the chemical composition of the soil fines, it will be equally or possibly more interesting to see how this chemical composition influences the surface or colloidal behavior of the soil colloidal material.

Observations of the behavior of colloidal particles in an electric field have shown that those consisting of silicic acid possess negative, and those consisting of iron and alumina sesquioxides possess positive surface charges. By interpolation it can be expected that soil colloids composed of both silicic acids and sesquioxides of iron and alumina will have both positive and negative surface charges. The negative charges will increase in number with increasing silica-sesquioxide ratio, while the positive charges will decrease, et vice versa. Since, in general, free charges cannot exist uncompensated for any considerable length of time, these surface charges are neutralized by adsorbed ions which are found in varying distances from the colloidal surface These ions are not very strongly held and can be exchanged, therefore, for other ions of the same electrical character Thus, we find that soil colloids possess a certain exchange capacity for positive as well as for negative ions This exchange capacity is measured by the amount of ions of same electrical character that can be exchanged per hundred grams of soil defined partial pressure of water (hygroscopicity) and by the amount of water taken in when the soil is in contact with a free water surface (swelling), it can be determined from viscosity data of soil suspensions and also from data on the heat of wetting of dry soil materials Table 2 correlates the SiO_2/R_2O_3 ratio of soil colloids with their base exchange capacity and their affinity for water

This table shows some interesting relationships, swelling, hygroscopicity and heat of wetting increase with increasing

TABLE II

AFFINITY OF SOIL COLLOIDAL MATERIAL FOR WATER

Colloidal Property	Type of H-Colloid					
	Bentonite	Lutkin Clay	Wabash Clay	Putnam Clay	Susquehanna Clay	Cecil Clay
SiO_2/R_2O_3	5 0	3 8	3 2	3 2	2 3	1 3
Exchange capacity, ml /gm	0 95	0 82	0 78	0 65	0 47	0 13
Swelling, cc /gm	2 2	1 16	0 94	0 81	0 57	0 05
Hygroscopicity, %	21	20 1		18 1	15 5	6 1
Heat of wetting, cal /gm		15	14	14	12	6

These colloids were prepared according to the method of Bradfield During the course of their preparation the materials were dried at 105°C Experiments in our laboratory have shown that with the materials used drying at this temperature does not appreciably change the properties which are reported here There is, of course, a difference of the physical properties of a soil in situ and a dried and powdered soil The value of the presented data lies not in their absolute magnitudes, but in their functional relation

material With podsolic soils, the influence of the anion exchange capacity on their physical and chemical character is generally small and, therefore, will not be given detailed consideration at this time. On the other hand, this anionic exchange is of great importance with lateritic soils

In soil stabilization it is of greatest importance to know the affinity of the soil particles for water This affinity can and should be determined in several different ways It can be measured by the amount of moisture adsorbed by the soil material from an atmosphere with a well SiO_2/R_2O_3 ratio and, therefore, with increasing base exchange capacity, the amount of swelling per unit of base exchange capacity and per calorie of heat of wetting increases with increasing SiO_2/R_2O_3 ratio This means that with increasing SiO_2/R_2O_3 ratio the amount of swelling water increases faster than the energy of adsorption, or, that the bulk of the water adsorbed by soil colloids with high ratio is less strongly held than that adsorbed by colloids with a low ratio

It has been shown that the SiO_2/R_2O_3 ratio is a function of the weathering factors and therefore cannot readily be changed by the highway engineer What can be changed is the kind of ions that are adsorbed at the colloidal surfaces Table 3 shows the effect of exchangeable ions on the water affinity of clays Apparently the amount of water that soil colloids take up while swelling under optimum conditions varies considerably with the kind of adsorbed ions A comparison of the data on swelling with those on heat of wetting shows, among other things, the interesting fact that although a sodium-saturated clay takes in much more water than, e g , calcium-and hydrogen-clays, the energy involved in its swelling is smaller than that for these other clays Besides, the swelling of Na-clay takes place much more slowly, a phenomenon which minimizes the danger for the stability of a road in the potentially large swelling of a sodium clay

Potassium clays show the least affinity for water from the standpoint of amount of swelling as well as from the consideration of the energy involved This is a very desirable property in many cases, but for certain purposes a sodium clay is superior This is indicated by the data on slaking of soils with different ions on the exchange complex These data, obtained by the method of the Russian pedologists, demonstrate the practical importance of the fact that sodium clays swell considerably with a relatively small amount of energy involved Because of this property and also of the tendency for deflocculation of sodium clays, the surface pores of a dry clod put into water will close themselves and will permit only a very slow diffusion of the water into the interior of the clod Because of these properties, sodium clay takes an important place in the stabilization of gravel roads and bases

TABLE III

INFLUENCE OF ADSORBED IONS ON THE WATER AFFINITY OF SOIL COLLOIDS

Type of Clay	$\frac{SiO_2}{R_2O_3}$	Swelling in cc /gm *					
		Kind of ions					
		H	Li	Na	K	Ca	Ba
Bentonite	5	2 22	10 8	11 1	8 6	2 5	2 5
Putnam Clay	3 2	0 81	5 0	4 0	0 5	0 9	0 9
Wabash Clay	3 2	0 9	3 1	3 7	0 6	0 8	0 7
Iredell Clay	1 8	0 2	0 4	0 6	0 02	0 3	0 4
Heat of wetting† of Putnam clay, cal /gm		14	12	12	10	15	14

* The swelling was measured with the Winterkorn-Baver apparatus, reported elsewhere (3)
† The heat of wetting data were obtained with the Bunsen Ice calorimeter (2)

After the free NaCl has been washed out the sodium chloride treated surface soil tends towards dispersion and easy erodibility This disadvantage may be overcome by surface treatment with coagulative agents

Sodium chloride treatment of gravel roads and bases has proved very helpful in cases where the soil contained organic matter and lime in an amount sufficient to coagulate the clay to particles of the size and character of silt

Since highway engineers are showing

considerable interest in the plastic index of soil materials it may be in order to relate the effect of different adsorbed ions on this soil constant Calcium, magnesium and sodium ions have a tendency sium ions have a tendency to deflocculate the soil (1) [1]

On the basis of extensive investigations on the properties of soil colloidal materials, it has been possible to obtain

(1)

$$\begin{array}{l}\text{Soil}\\ \text{Colloid}\end{array}\left|\begin{array}{l}-H\\-H\\-H\\-H\end{array}\right. + X^{++} = \begin{array}{l}\text{Soil}\\ \text{Colloid}\end{array}\left|\begin{array}{l}-H\\-\\-\\-H\end{array}\right. X + 2H^{+}$$

(2)

$$\begin{array}{l}\text{Soil}\\ \text{Colloid}\end{array}\left|\begin{array}{l}-H\\-H\\-H\\-H\end{array}\right. + X^{+++} \left.\begin{array}{r}H-\\H-\\H-\\H-\end{array}\right| \begin{array}{l}\text{Soil}\\ \text{Colloid}\end{array} = \begin{array}{l}\text{Soil}\\ \text{Colloid}\end{array}\left|\begin{array}{ccc}-H & & H-\\-H & & H-\\ - & -X- & -\\-H & & H-\end{array}\right| \begin{array}{l}\text{Soil}\\ \text{Colloid}\end{array} + 2H^{+}$$

(3a)

$$\begin{array}{l}\text{Soil}\\ \text{Colloid}\end{array}\left|\begin{array}{l}-H\\-H\\-H\\-H\end{array}\right. + \begin{array}{c}\begin{array}{c}\quad\ \ H\ \ H\\ KOC—C—C—R\\ \ \ O\ \ H\ \ H\end{array}\\ \text{soluble in } H_2O\\ \text{insoluble in oil}\end{array} = \begin{array}{l}\text{Soil}\\ \text{Colloid}\end{array}\left|\begin{array}{l}-H\\-H\\-K\\-H\end{array}\right. \begin{array}{c}\begin{array}{c}\quad\ \ H\ \ H\\ HOC—C—C—R\\ \ \ O\ \ H\ \ H\end{array}\\ \text{Soluble in oil}\\ \text{Insoluble in } H_2O\end{array}$$

(3b)

$$\begin{array}{l}\text{Soil}\\ \text{Colloid}\end{array}\left|\begin{array}{l}-H\\-\\-\\-H\end{array}\right. X + \begin{array}{c}\quad\ \ H\ \ H\\ KOC—C—C—R\\ \quad\ \ H\ \ H\end{array} = \begin{array}{l}\text{Soil}\\ \text{Colloid}\end{array}\left|\begin{array}{l}-H\\-X—OC—\overset{H}{\underset{H}{C}}—\overset{H}{\underset{H}{C}}—R\\-K\\-H\end{array}\right.$$

to increase the P I The potassium ion in general lowers the P I, while the hydrogen ion may either increase or decrease it It is also important that potassium, sodium and in some cases magnesium ions have a tendency to deflocculate the soil (1) [1]

a certain insight into the geometry of the electrical surface structure of soil colloids This is treated elsewhere in more detail

[1] Numbers in parentheses refer to list of references at end

(2, 3, 5). Here a few reactions on soil surfaces will be schematically given which are of importance in low cost road construction. Treatment of unsaturated or

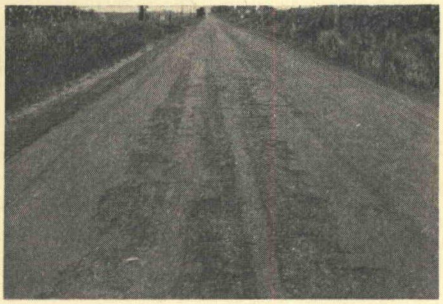

Figure 2. Section Oiled Without Pretreatment

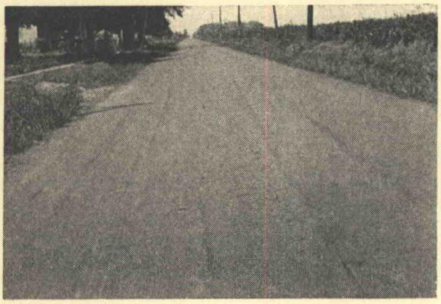

Figure 3. Emulsion-Like Treated Section

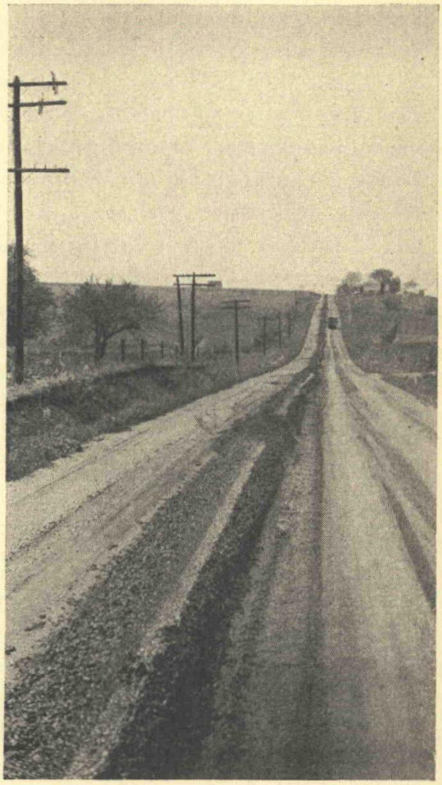

Figure 4. Oil-Treated Earth-Gravel Windrow After Heavy Rain. Mixture in Background Containing Soap.

TABLE IV

INFLUENCE OF ADSORBED IONS ON SLAKING TIME*

Type of Soil	Time in min. needed for slaking								
	Adsorbed Ions								
	H	Na	K	Ca	Mg	Nat	Ba	Al	Fe
Cecil	122	24	121	24	209	147	61	65	93
Hagerstown	26	341	35	23	49	15	32	20	15
Putnam	35	420	24	26	31	38	36	28	26

* The slaking time was determined with the method of the Russian pedologists.

hydrogen-soils with neutral salts liberates hydrogen ions. The effect of these ions in a salt-soil system on metal parts coming in contact with this system deserve thorough study. Bi- and polyvalent ions can link the soil colloids together, especially in the presence of organic material to form eventually strong structures like hardpans. This property may be utilized in base construction. Soaps, fatty-and naphthenic acids and like substances may react physically or chemically with the surfaces of soil materials and thus produce a change of their surface character. These reactions are of special importance in the case of bituminous mixtures where changing the water attracting character of mineral surfaces into water repellant properties is desired This effect has been treated in more detail elsewhere (4). Its importance for road construction is illustrated by Figures 2, 3, and 4 which show the effect of soap on oil-dirt and oil-gravel roads.

This paper has attempted to familiarize the highway engineer with the fundamental factors that govern the properties of this important road construction material—the soil. It has also been indicated how one can change the soil character within certain limits and thus improve the quality of this raw material for his purpose

The facts and suggestions given are presented with the hope that they will be of value toward the progress of highway engineering

ACKNOWLEDGMENTS

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DISCUSSION ON ADSORPTION PHENOMENA

MR. C. A HOGENTOGLER, JR, *George Washington University*· Studies under a fellowship in soil mechanics under the Department of Civil Engineering, Prof. F. A Hitchcock, Head, at George Washington University, have been concerned with the practical application of the theories of base exchange and colloid chemistry. These theories have long been recognized in the fields of both agriculture and ceramics but their application in the problems of engineering is of more recent development

In Table II of his report, Dr. Winterkorn illustrates how the chemical composition, indicated by the SiO_2/R_2O_3 ratio influences the swelling as well as other properties of clays In Tables 3 and 4 it is shown that in addition to the chemical composition the character of the colloid is affected also by adsorbed ions This means that soils of exactly the same chemical composition can undergo radical changes in character due to leaching with rain water, soil solutions or in the case of stabilized soils, with solutions of chemical admixtures Therefore, intelligent selection of soil binder requires knowledge, not only of the properties of the soil provided by its chemical composition but also possible variations of properties which might be produced by base exchange

This is especially important in the construction of base courses Although the character of the soil binder is just as important to the performance of road surfaces as base courses, trouble in road surfaces may be corrected as a maintenance measure Similar trouble in base courses cannot be so corrected and consequently may lead to expensive failure of the entire road structure

Especially to be guarded against are the water adsorptive soils which under the almost continuously moist conditions prevalent in bases are likely to expand and become lubricants and thus facilitate the sliding of the granular particles and cause failure instead of becoming binder to cement the aggregate into a stable mass The more the moisture content of the binder increases above the plastic limit, the more the soil fines become lubricants instead of binder

Because of this a threefold inquiry should be made when the use of chemical treatments is considered First, what will be the effect on the soil while the chemical is retained as an admixture, secondly, what will be the possibility of loss of chemical by base exchange, and third, how will the properties of the binder clay be affected if such base exchange occurs

The reports of the subcommittees on the use of calcium chloride and sodium chloride establish without a doubt that the effect of both of these chemicals may be highly beneficial in a number of ways They assist in maintaining dampness of the soil mixture and thus facilitate the compaction of the stabilized soils under traffic, by an electrolytic effect they enable the compacted mixture to attain density greater than that likely to occur in the untreated soils; and they minimize the volume change of the binder, which is productive of disintegration of the untreated surfaces with changing moisture conditions

The first prerequisite of detrimental base exchange as far as liberation of hydrogen ions is concerned is that the soil be acid or hydrogen ionized That is the pH should be less than 7 0 Even then, for complete base exchange to occur with any metallic salt a solution of the salt must be leached through the soil mixture in amounts far exceeding the exchange capacity The by-products of such exchange would be found principally in the bottom of the road surfaces where, they could not, even if they were objectionable by-products, come into contact with traffic nor cause corrosion of vehicles There would, however, be a loss of the stabilizing chemical and the benefits for which it was applied Even without leaching action limited base exchange will occur in any soils so that part of the benefits of the treatment as they concern the action of free salt in the soil solution might be lost, even under these conditions To preserve the full benefits of the chemical treatments, therefore every effort should be made to neutralize or "sweeten" acid soils by means of admixtures prior to or coincident with the application of the stabilizing chemicals

If base exchange is not repressed in

this way sodium ionized soils in varying amounts depending upon the character of the soil, permeability of the surface, etc, will result in the case of sodium salt treatments and calcium ionized soils in the case of calcium salt treatments

If such base exchange occurs after the stabilized roads have been covered with bituminous wearing courses, and furthermore, if because of this change the plasticity or swelling properties of the soil are increased, then the possibility of failure is materially increased

Even though the possibility of such detrimental change may be remote, the results, if it does occur, might be serious Therefore information on the properties of the metallic ionized clays, such as furnished by Dr Winterkorn's investigations,[1] as well as those of other authorities such as Russell, Joseph, Oakley and Marshall[2] is just as important as that having to do with the properties of the binders while retaining the stabilizing chemicals

The foregoing comments are sufficient to illustrate some of the applications of surface chemistry in soil stabilization The use of water retentive chemicals to maintain the stability of graded mixtures, the use of primes to increase the adhesion between aggregate and binder and the use of admixtures to prevent detrimental base exchange opens up a field with unlimited opportunities for profitable research

[1] Also, "Oiling Earth Roads" by Hans F Winterkorn, *Industrial and Engineering Chemistry*, Vol 26, page 815, Aug 1934, and "Sorption of Liquids by Soil Colliods II Surface Behavior in the Hydration of Clays" by L D. Baver and Hans F Winterkorn, *Soil Science*, Vol 40, No 5, Nov 1935

[2] "Soil Conditions and Plant Growth" by E John Russell, pages 191-193, Longmans, Green & Co 1932

PROF D P KRYNINE, *Yale University* Dr Winterkorn has brought to the attention of highway engineers the following facts (a) that climatic factors influence the chemical composition of the soil fines so that their silica sesquioxide ratio is a function of the weathering factors, and (b) that in turn the affinity of the soil particles for water depends on the value of that ratio The smaller the ratio, SiO_2/R_2O_3, the less is the affinity of soil colloidal matter for water (swelling, hygroscopicity), and so is the exchange capacity It follows therefrom that instead of modifying an unfavorable value of SiO_2/R_2O_3 it is easier to treat the soil with certain solutions and thus replace unfavorable ions oriented at the colloidal surface by others, more favorable Interesting examples from the geometry of the electrical surface structure are given

Highway engineers are of course very much interested in the geological and climatological data of the particular locality where they have to work These data, however, are only indicative in character since no engineer would base his conclusions exclusively on them He prefers, of course, to test actual soil samples and to examine direct numerical results of the corresponding physical tests Particularly the affinity for water is characterized in the current engineering practice (a) by the capillary motion of water in the given soil, (b) by consistency limits of the latter (plastic limit, liquid limit), (c) by its centrifuge and field moisture equivalent The results of these tests are characteristic for the soil in its natural state, and the tests themselves are easy to perform The tests in question, however, do not give any idea of what would become of the corresponding soils upon a possible replacing of unfavorable ions located at the colloidal surface by more favorable ones Inspired by the interesting paper by Professor Winterkorn the writer proposes to make the above mentioned tests not only using natural soils, but also those treated with different solutions In such a way interesting data on necessary treatment may be obtained in the laboratory and checked in the field

An approach to such a procedure has been made by Professor Winterkorn himself when he determined the influence of different adsorbed ions on the value of the plasticity index He found in this connection that calcium, magnesium and sodium ions have a tendency to increase the P I while potassium ions in general lower it The writer noticed from reference (2) that the clay samples of Professor Winterkorn were dried at 110°C The writer does not agree with such a procedure since water properties of soils, the liquid limit especially, are substantially different for air dry and oven dry soils The writer suggests that air dry soil samples only be used in highway soil investigations

The following simple field test has been introduced by Mr Routkovsky of Russia for characterizing the soil swelling

Five cubic centimeters of thoroughly packed soil are placed in a graduate (volume 100 cm^3, height 25 cm), then 50–60 cm^3 of water are added and the whole is mixed with a glass rod Thereupon water is added in order to complete the volume of the suspension to 100 cm^3 The soil volume is recorded when constant Mr Routkovsky gives a table permitting the determination of the clay content as a function of the final volume The writer's belief is that the Routkovsky's procedure adequately modified should be applied for determining the amount of swelling of both untreated and treated soils

Furthermore, the writer perfectly understands how important for a soil investigator is the knowledge of the value of the silica sesquioxide ratio He is skeptical, however, as to the possibility of introduction of this conception into the current engineering practice, at least in the near future It seems that the water property tests referred to, adequately modified and completed, are sufficient for immediate highway needs

This does not mean that the writer is opposed to the application of chemistry in highway soil engineering On the contrary, this important branch of highway technique should be adequately developed and properly applied As an additional example of such application fine sands might be cited since they show affinity for water like clays and are able to flow plastically Unstable saturated fine sands may be stabilized by the use of chemicals In this connection a recent movement in Europe, especially in Germany, under the slogan "Chemistry against the sand" is to be noted The process invented by Dr Joosten of Germany consists in forcing a solution of hydrofluosilicic acid or that of sodium silicate (chemical I) into the loose ground and later of a salt liquid (chemical II) The salt solution forms a gel with chemical I and binds loose material together Tests on fine sand solidification have also been recently made by the Connecticut State Highway Department

DR C D LOOKER, *International Salt Company* In his paper Dr Winterkorn discussed the properties of clay which had been made to undergo electrostatic or polar adsorption of certain ions under optimum conditions

Two general methods may be mentioned of effecting base exchange on clay colloids so as to cause the adsorption of the ions desired One is to treat the prepared hydrogen clay with the hydroxide of the metal to be adsorbed This leaves the accompanying hydroxyl ions which in some cases tend toward deflocculation of clay particles, the degree depending upon the character of the adsorbed positive ion The other is to treat natural clays with solutions of electrolytes consisting of salts of strong bases and strong acids Such salts are sodium chloride, potassium chloride, lithium chloride, calcium chloride and barium chloride Electrolytes of this nature tend toward flocculation of clay particles rather than deflocculation This is the method involved in treating clays used in road stabilization

The results obtained by the two methods may or may not be the same It is certain that different results may be expected in the presence of the admixed or dissolved salts that differ from those obtained when the salts have been largely or entirely removed by leaching or when they were not present in the preparation of the clay For these and other reasons it seems that more work must be done both in the laboratory and in the field before we can properly interpret the results

A small amount of sodium chloride has a noticeable effect on preventing volume changes in clay This has been used to advantage in the ceramic industry

While there may be slightly more swelling of a clay with adsorbed sodium ions than with adsorbed hydrogen, potassium, calcium and barium ions, as reported in Dr Winterkorn's paper, there is also less change of volume in sodium chloride clay, when alternately moistened and dried The potential effects of swelling are largely overcome by the slower rate of swelling and energy or force of swelling, as well as the imperviousness developed by the character of grain formation and the deflocculation of sodium clays when the salt concentration is reduced below a certain point This adds greatly to the retention of sodium chloride and resits free movement of water within the road mat tending to maintain compaction

Dr Winterkorn, *Author's closure.* Professor Krynine's discussion is oriented around three points

(a) his suggestion that the soil tests which are used in common engineering practice should be run with ion-treated soils,
(b) his criticism concerning the drying of the clay samples, and
(c) his skepticism concerning the introduction of the silica sesquioxide ratio into common engineering practice

The common engineering tests referred to have been run in our laboratory on treated soils for the last five years and only lack of space prevented extensive discussion of the results

Concerning his criticism, in our tests no difference was found in the reported properties of the colloidal material in question if that material was dried in the oven at 105–110°C or at room temperature over Phosphorpentoxide (Please refer also to the explanation on the tables)

Professor Krynine's skepticism about

the possibility of introducing the silica sesquioxide conception into common engineering practice does not negate the value of this conception as a chemical characterization of soils and as a help in the stabilization of soils by chemical means Soils of different regions have already been classified according to the silica sesquioxide conception and this information made available through the agricultural experiment stations This knowledge so necessary for any effective chemical stabilization of soils can never be obtained from any or all mechanical tests of soil-water relationships

The author is gratified for the interest shown in the discussion by Dr C D Looker, who emphasized the effect of free ions in the soil solution, and in the discussion by Mr C A Hogentogler, Jr. on ionic exchange and base stabilization It is hoped that this interest may spread sufficiently to make highway engineers realize and employ the means of chemistry, and also to foster more research projects in the important field of chemical soil stabilization

DISCUSSION ON ROAD STABILIZATION

Mr B E Gray, *The Asphalt Institute* Just a brief comment in regard to the use of asphaltic materials in the field of stabilization The development of satisfactory and universally applicable means of stabilizing soils is undoubtedly the most important thing we have now to consider However, we must keep in mind the fact that having developed a method which is applicable to one class of soil, we cannot always take it three or four hundred miles away and apply it without understanding the new conditions, and still expect to have the same satisfactory results. One of the obstacles to be overcome, in addition to that of finding out more about the soils themselves, is the resistance by engineers and designers to acceptance of the fact that they must think in quite different terms than they have previously done It is easy to think of massive surfaces of coarse particles bonded together and built up in heavy layers It is harder to conceive of accomplishing the same results with minute clay particles

The matter of soil stabilization divides itself roughly into two parts, one where the character of the soil is changed by some of the methods that have been previously outlined and with which I will not attempt to differ,—and the other, that of substituting in the particular soil some material which will preserve the characteristics of that soil when at its optimum moisture content It is well known, although not widely appreciated, that almost any soil, when at such optimum moisture content, can support very heavy loads with but little deformation If this condition could be maintained the year around, or putting it another way, if the soil could be so treated that it would have no volume change throughout the year, there would be little need for a pavement other than a thin wearing course to take care of abrasion

Asphaltic products are used in this connection either with a view to *surrounding a layer of earth* when at the optimum moisture content, so that water can neither get in nor out, employing a heavy asphalt coating, or to *replacing the moisture throughout* by a suitable low viscosity asphaltic product The first method has not yet progressed much beyond the laboratory stage, but the second method has been widely employed With sandy soils a good technique has already been developed, but with finely divided soils the results are still variable However so much success has been achieved, that it is only a question of time and research before even the most stubborn soils may be treated satisfactorily

Mr E O Rhodes, *Koppers Products Company* As a result of the investigations which we have made up to this time and our contacts with engineers who are interested in this subject of soil stabilization, it seems to us that engineers may be divided into two classes. First, those that have the ability and the willingness to select different types of aggregates and soils and combine them in proper proportion to obtain a certain amount of mechanical stabilization, Second, a group which may be willing but may not be able to proportion the material so that they can obtain such mechanical stabilization However, that does not deter them in the least They are just as anxious as the other group to go along with this new field of soil stabilization and deal with the materials which they have at hand In fact I think they are even more anxious to go ahead because they have worse conditions with which to contend That group is confronted with enormous problems The scientist has brought up difficulties that must be overcome and I am convinced that they will be overcome However, in order to do so it will be necessary to have fundamental researches of the kind we have had reported to us this morning There must be new methods of laboratory technique worked out Some excellent researches of that kind are going on abroad, more must go on in this country In addition, there must be new types of equipment developed in order to secure the results that are needed and these things must be correlated because we find a rather vague or inadequate dissemination of information in spite of the excellent efforts that have been put forth by Mr Hogentogler and his associates The situation seems to us to be this—that at the present time the engineers in the one group are provided with excellent information that enables them to carry along with their types of stabilization quite satisfactorily The engineers in the second group are more or less groping in the dark and they are coming to us asking how they can solve their problems We hope to give them all the assistance possible but I personally feel the assistance that they need most of all is the cooperative assistance that can be contributed by Mr Hogentogler and his assistants

Mr Lion Gardiner, *Jaeger Machine Company* The manufacturer must play a part in developing the proper equipment to construct these low cost roads and a recent discussion with several firms interested in the problem indicates there is confusion as to just what is needed Later contacts with eight or nine different state departments to determine their requirements still left confusion with respect to any one definite type of standard equipment which should be offered

Without question the available materials and the existing road surfaces in the several states do require quite a variation in the manner of treatment and type of equipment necessary for the most economical operation so essential in low cost road construction.

With respect to the type of stabilized road requiring the addition of pulverized clay, several new pieces of equipment are now available and it is definitely sensed that an economical method of preparing the clay off the subgrade and so freeing the operation from weather interference, will do much toward reducing the cost and time of construction This problem is being attacked

To carry on the program and adhere to the "low cost" road idea, we must obtain low construction costs It appears at present that the most efficient equipment will not be inexpensive but yet this equipment on worthwhile projects will materially reduce unit costs and improve quality Therefore, it is urged for the sake of the contractors that jobs of sufficient length be let so it may be possible to invest in equipment which will not only allow for low construction costs, but for completeness in the shortest possible time

I am sure you will find the manufacturers ready to cooperate to their fullest ability in an effort to keep down these costs and it is essential to both manufacturers and the contractors to develop as much uniformity as possible in the specifications and methods used

MR F T SHEETS, *Portland Cement Association* It is only natural that as a consulting engineer and Director of the development department of the Portland Cement Association I am interested in the possibilities of road soil stabilization by the utilization of portland cement The South Carolina Highway Department pioneered in this matter and some of the work that they have done in the last year or two is reported in the current issue of the Engineering News-Record Their work has since been extended to some further field experimentation this year We of the Portland Cement Association are naturally vitally interested in these possibilities and are making a thorough-going research in our own development laboratories in Chicago We have secured soil samples representative of the entire range of soils occurring in the various parts of the United States and, utilizing as best we can the fundamental principles of soil physics and chemistry, we are making a thorough exploration of the possibilities In this work we are getting at the question of durability of the resulting soils by means of cycles of alternate wetting and drying, and alternate freezing and thawing While our results so far have been rather gratifying, we are not making any rash statements or predictions of the ultimate outcome of our laboratory research When we have reached the stage that we feel we have some sound, well authenticated data or information, we shall be very happy to make it available to the Highway Research Board

SOIL STABILIZATION WITH EMULSIFIED ASPHALT

BY C L MCKESSON

Director of Engineering and Research, American Bitumals Company

The purpose of this discussion is to present to the engineering profession the results of studies in soil stabilization over a period of years in a private laboratory, and of construction practices growing out of these studies, not heretofore published except briefly and partially in a paper presented by the writer at the Annual