# SOIL INVESTIGATIONS IN RUSSIA

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Only 15 or 20 years ago the profession of Civil Engineering had but vague ideas on the behavior of soils in foundation sites and in fills and cuts of highways and railways Particularly among highway engineers many failures were attributed to " poor subgrade " without entering into details as to what was the real cause of the failure

Modern engineering soil science which may be called " Applied Soil Physics and Soil Mechanics " began to develop principally in the United States about 1914, and is equally interesting to both highway and foundation engineers, the former however seem to have been pioneers in this study In Russia too, highway engineers led in engineering soil research The paper of Koch[1] and the consequent studies of the American soil investigators attracted the attention of Russian highway engineers about 1922, when the first years of the revolution were over, and scientists resumed their work The author of this paper was the first in the Russian technical press to show the necessity for making use of the work of agricultural soil scientists These men had for a long time studied soils and their properties, principally from the agricultural point of view, naturally they neglected one of the factors more important to the engineer, namely the load factor This deficiency was to be made good

In 1923 the present Russian Government created a special Highway Research Bureau (B P Gervais, chief), provided it with a laboratory and put several field parties at its disposal Agricultural soil scientists were then called in for cooperation The point of view from which the investigators started was as follows: Laboratory investigations alone are insufficient for obtaining satisfactory information about soil properties. A special field service must be organized for investigating and recording peculiar local conditions, such as—geomorphological data, topographic relief, and climatic conditions.

Russia has about 2 million miles of roads, the exact number being unknown Of this enormous mileage only one per cent have a hard stone surface, and 99 per cent are common earth roads From the very beginning Russian soil research took a different direction than that of

America, American investigations concentrating mostly on subgrade problems, while the Russians have been almost exclusively interested in earth roads, *i e*, in roads without hard surface The problem of improving earth roads is one of the most important for Russia from the point of view of national economics, as is also true of all other undeveloped countries Thus, upon the demand of the Russian delegates, the Association of Road Congresses in France included the discussion of earth road construction and maintenance in the program of the Sixth International Congress to be held in the United States in 1930.

In what follows, only four items of the activity of the Russian Highway Research Bureau will be considered: (a) preparation of soil profiles; (b) design of standard soil mixtures; (c) study of the frozen soils; (d) study of the rolling process

## SOIL PROFILES

In a soil profile soil horizons (A, B C) are indicated, the origin of soils and their classification is specified, and levels of the ground water established; also all possible unfavorable conditions due to the presence of water must be indicated in the profile.

Since the preparation of soil profiles was entrusted to agricultural soil scientists, these profiles and maps, while made very carefully, often carry many details which do not always seem relevant to the practicing highway engineer Yet in many cases very interesting conclusions have been drawn from such, at first glance, impractical soil profiles and maps They, for instances, often indicate the absolute and inevitable necessity of a relocation of a road; or the impossibility of making a deep cut or ditch in a locality where the underlying soil is of a nature making it susceptible to erosion, etc.

It is hoped that a new generation of highway engineers possessing the requisite knowledge of soil science and having a broad view of Highway Engineering, will definitely standardize highway profiles and maps

## DESIGN OF SOIL MIXTURES

Further, the Research Bureau made efforts to work out standard proportions of sand and clay mixtures for earth roads' building It was at least necessary to establish the principles on which the design of such mixtures was to be based Of course, the Russians were aware of American attempts in the same province.[3] The basic principle of the Russian school of soil scientists is that soil is a product of both the original geological formation and the effects of local climatic, topographic and other conditions. This being so, one soon had to conclude that it was impossible to design a general standard for the whole country and that an individual one was to be sought for in each zone However, the first attempt of the Research Bureau gave the following proportions for standard mixtures

| | |
|---|---|
| Grain size 0.00–0.01 mm | 20 per cent |
| Grain size 0.01–0.05 mm | 15 per cent |
| Grain size 0.05–0.25 mm | 30 per cent |
| Grain size 0.25–1.00 mm | 35 per cent |

An attempt was made by Prof G. A Zaslavsky to solve the problem of standard mixture in a mathematical way based on an idea somewhat similar to that of Fuller on concrete mixes The denser and the less porous a mixture is, the better it meets highway requirements The voids of the coarse fractions are to be filled with finer ones, and the voids of these with clay, which is also to act as the cementing material. Samples prepared on the basis of this theoretical formula must be tested in the laboratory and possibly somewhat modified in the light of these tests.

FROZEN SOIL

Russia is known as a classical country of frost. This however, is true only for some of its regions Near Moscow the penetration of the frost into the soil and subsoil is not more than 4 or 4½ feet Measurements of the depth of frozen soil were made near Pskov simultaneously on the roads themselves and on the adjacent snow covered fields. The difference between the two was astonishing In the spring after the snow melts, the frozen soil in the fields is only a few inches deep, while that under roads is three or four feet deep. This difference persists for one month or more This means that during a certain time an enormous frozen body, something like a frozen earth dyke, is to be found under the road, disturbing drainage conditions The study of this phenomenon is being continued

Still more serious for Russia is the problem of permanently frozen soils which occupy an enormous area in Siberia and extend also south of the Chinese frontier. The upper layer of the permanently frozen soil thaws in summer, yet from a certain depth on, its temperature is always below freezing point In Yakoutsk the frozen depth exceeds 350 feet, being however less in other localities (for instance, in Poustozersk 58 feet, in Taldan about 220 feet and so on).

Permanently frozen soil is as hard as rock; but under masonry structures, masonry being a fair conductor of heat, it thaws, originally hard surfaces become soft, and the structure may fail. Of course,

**Figure 1. "Naled" or "Taryn," Successive Ice Layers Formed by Water Rising from the Ground**

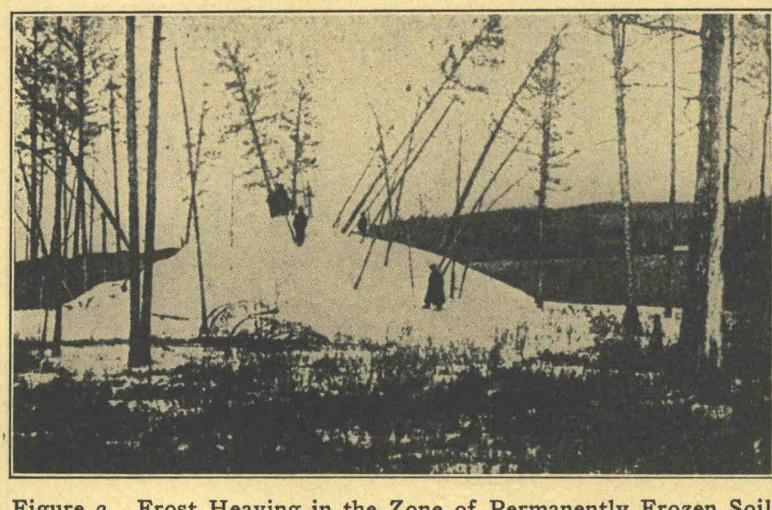

**Figure 2. Frost Heaving in the Zone of Permanently Frozen Soil, 22 Feet High**

roads constructed in such country never can be considered as stable. Even wooden bridges suffer. (Figures 1, 2, 3, 4.)

A thorough study of the permanently frozen soils is necessary for Russia. Inquiries were made on similar conditions in the United

States and in Canada, but little data have been obtained. There are in Russia notable geological works referring to this state of soil,[3] but data necessary for a practicing highway engineer are not yet available.

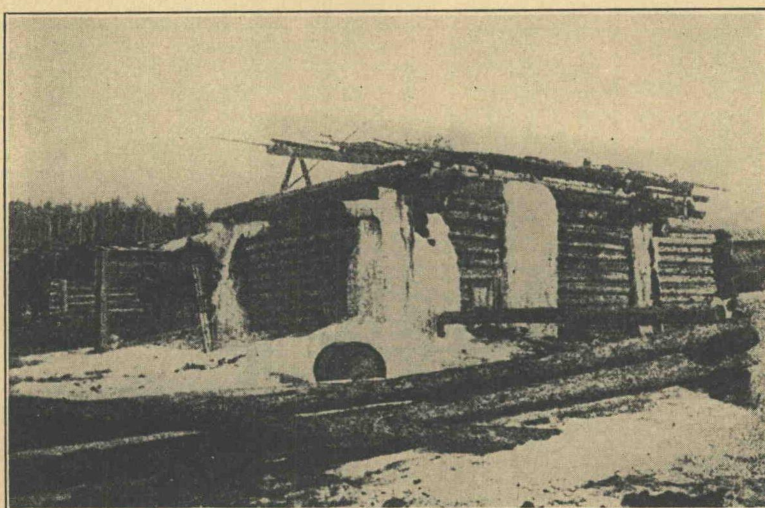

Figure 3. A Little Wooden Building Filled with Ice Formed with Water Risen from the Ground

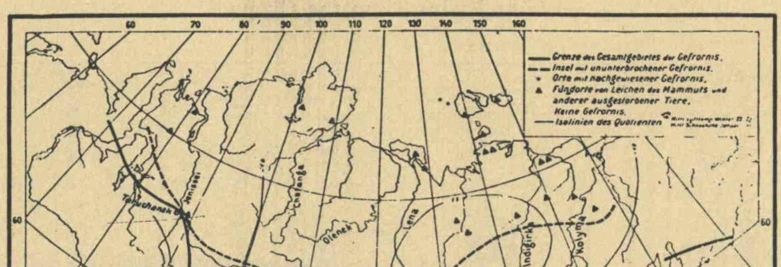


Figure 4. Distribution of Permanently Frozen Soil (Occupies Approximately Half the Area of Europe)

At the present time when many American engineers go to Russia as consultants, I think that it is worth while to tell you of the peculiarities of that country. It must be also recalled here that the prevailing traffic in Russia is not automotive but horse-drawn which of course has its specific effects on the road

ROLLING OF EARTH ROADS

Finally let us look at results of Russian experimental studies on rolling of earth roads It has been demonstrated that during the rolling process not only soil compression takes place, but also a horizontal displacement of the soil particles both on the top and within the interior mass of rolled fill The amount of this displacement which is often considerable, depends on the value of the coefficient of internal friction of the soil The denest layer of rolled soil is to be found not on the top but somewhat below. Also, a certain water content is necessary to make the rolling effective.

RESEARCH

I wish now to tell you briefly of some research problems studied in the laboratory under my direction—the Highway Engineering Laboratory of the Moscow Institute of Technology, which when literally translated is called "Moscow Superior Technical School." Our laboratory in Moscow occupies approximately the same modest area that is occupied by the soil laboratory of the Massachusetts Institute of Technology, and has about the same equipment, with the exception, naturally, of the outdoor large scale experimental retaining wall test.[4]

Many efforts have been made by the author's laboratory staff to bring the mechanical analysis of soil to a certain degree of perfection. A special device called "Opaloscope"[5] has been designed and constructed by the brilliant young physicist Mr. G. I Pokrowski (of the atom of time fame and author of a great number of papers on optics) in order to study optically the size and shape of soil particles in suspension. In these experiments it was also demonstrated that the well known Stokes' law is not applicable to particles below 0 3 $\mu$ (0 3 micron).

A synthetical study is now being made to determine what degree of accuracy in mechanical analysis is really needed in highway engineering. Mechanical analysis is a troublesome operation, and time and work saved on it are of great importance.

We use Atterberg's tests and also other routine tests, as water content determination, saturation capacity etc —practically in the same way as it is done in this country. "Standard Compression Test" recommended by Dr. Terzaghi also will be soon adopted in our Moscow laboratory. We may seem late in this, but I recall that also in the Arlington laboratory of the U. S. Bureau of Public Roads this test is not very extensively used for highway purposes.

We work on some problems in soil physics and soil laboratory practice. Amongst them are: (a) scale like nature of clay particles; (b) entrapped or pinched air in soils; (c) optical methods of determining water content of soils without disturbing the regular march of the experiment as one is obliged to do when the usual procedure is followed; (d) water movement in soils. I will say a few words on each of these problems.

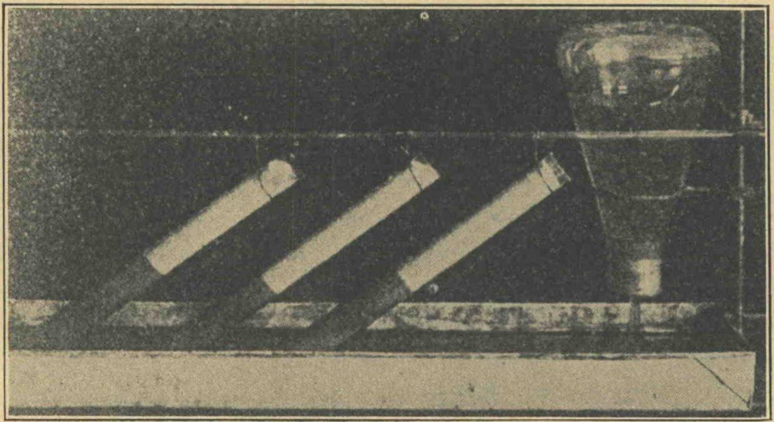

**Figure 5. Capillary Movement of Water in Inclined Tubes Filled with Clay Powder**

On the scale-like nature of clay particles, I have already published an article in "Public Roads."[6] The method merely consists in filling a glass tube with dry clay as it is done for studying the capillary movement and observing the tube immersed in the water not vertically, but in an inclined position. Observations show that the movement of the capillary water is not vertical, but parallel to the inclined axis of the tube which, of course, suggests a laminary structure of the clay. (Figure 5.)

In the actual state of our knowledge of soil mechanics, no one doubts that wet clay represents a system of soil and water intimately bound together. Besides this, bubbles of entrapped air, often microscopic in size, may be dispersed in the water and pressed against the soil particles with a pressure intensity which is determined by the state of stress in the water.

A glass tube about 1 inch in diameter was filled with dry or rather hygroscopically moist clay powder to the height of 4 inches. On the bottom of the tube a cheesecloth screen was tied to prevent the soil from falling out; instead of the cheesecloth a perforated metallic bottom may be used The tube was immersed in 4 inches of water; then for 35 days from time to time the tube was taken out of the water, carefully dried with a rag and weighed The barometric pressure and temperature were recorded at each weighing. It was also found that the weight fluctuated owing either to contraction or expansion of the bubbles of entrapped air in accordance with the laws of Boyle-Mariotte and Gay-Lussac As the air contracts, the water enters into the soil in the tube, and its weight increases On the contrary, when the air expands, the water is driven out of the tube, and the total weight decreases.

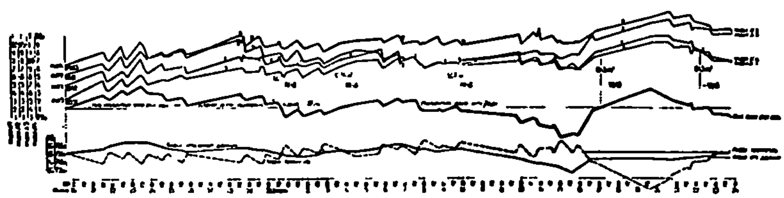

**Figure 6. Fluctuations of Weight of Tubes Filled with Saturated Clay Due to the Presence of Entrapped Air**

There is an exception to this rule which corresponds to a violent decrease in atmospheric pressure In this case the air seems not only to drive the water back, but forces its way through the water and escapes. Therefore an increase of weight instead of a decrease is to be noted in this case (Figure 6 )

The author of this paper cannot say whether considerable quantities of air may be entrapped in the deep layers of ancient natural clays. But as to relatively modern deposits, especially artificial fills, there is no doubt of the presence of entrapped air therein.

Thus water seems to penetrate into the interior of artificial fills during a decrease in barometric pressure or a considerable rise of temperature The combination of these two factors may be dangerous to newly constructed railroad or highway fills during floods or heavy rain storms It is also true for poorly constructed earth dams as well. Any fresh fill will probably show considerable settlement during a continued decrease of barometric pressure following a rain The practice of dragging graded earth roads in damp weather seems to be justified because it tends to drive the entrapped air out and thus consolidate the central portion of the fill.

In laboratory work one must carefully drive out all the air from soil samples to be tested, in order to obtain accurate results.

Now I pass to the determination of water content of a soil. Under actual conditions of laboratory practice this operation is exceedingly simple in itself. But it involves the extraction of samples from the soil tested, which practically must be considered as causing serious interference or even destruction of the experiment, especially if water movement in soils is studied. In order to avoid troubles of this kind optical methods have been devised. The previously mentioned Mr. Pokrowski designed and constructed an apparatus called "Reflectometer"[7] which permits the determination of the water content by observation of the sample through the walls of a glass tube or glass box, without touching The water content modifies the color of the soil and its reflecting capacity If the investigator is in a position to measure the reflecting capacity and if he knows the relation between this capacity and the water content of a given soil, he can determine the water content very easily. For handling the reflectometer, no special knowledge of physics is required.

The reflectometer together with other apparatus was applied to the study of the laws of water movement in soils, especially those of capillary movement and of percolation of rain water into the ground Some conclusions have already been drawn and published in part,[8] but the bulk of the work is yet to be done.

Such was the state of soil investigations when the author left Russia at the end of July, 1929.

BIBLIOGRAPHY

1. Proceedings Am Soc. C E , 1914, vol XL, page 269.
2. Conference of American Highway Engineers and Chemists, 1917; American Society for Testing Materials, 1920; Works of Prof F. H Eno, of Prof. C. M. Strahan and others
3. Writings of Schestakovitch, Soumgine, Nikiforoff and others.
4. Eng. News-Record, October 17, 1929
5. Soil Investigations of 1927 (in Russian) Moscow, 1928
6. Public Roads, January, 1928.
7. The first attempt of Mr Pokrowski to design the reflectometer has been published in "Kolloidehemie"; the present device is modified
8 Public Roads, August, 1929 Soil Investigations, II, 1929 (in Russian)—in print.

# DISCUSSION

ON

# SOIL INVESTIGATIONS IN RUSSIA

MR. I B MULLIS, *U. S. Bureau of Public Roads.* The speaker has read this splendid paper by Prof Krynine with great interest. Russian scientists have already contributed much to the science of agricultural soils and it is confidently believed that they will perform their latest mission equally as well in furthering the science of road construction.

The major activity of the Russian Highway Research Bureau seems to be directed to the solution of the problems of earth road construction and maintenance. This is a problem which confronts not only Russia but the entire world In the United States of America we have about 3 million miles of roads, of which about 626,000 miles are surfaced, leaving more than 2¼ million miles of earth roads in a more or less unimproved condition.

Regardless of the extent of transportation developments, we must continue to provide earth roads where the limitations of traffic and finance make the higher types impracticable. But to make a system of roads most efficient, each type must be developed to its highest degree of economic efficiency. This can be accomplished only through research.

In the days when macadam surfaces constituted the major type, it was universally recognized by highway engineers that hardness, toughness and density of the surface mass were highly essential characteristics. In the development of gravel, sand-clay and topsoil surfaces, similar characteristics have been generally sought.

In Dr. Strahan's classical work[1] on semi-gravel, topsoil, sand clay and other road materials in Georgia, he stresses the desirability of the hardness of sand and gravel for furnishing the essential resistance to wear, a graded mixture of coarse and fine inert particles for producing the essential mechanical bond and increasing the density; a suitble quantity of good strong cementing clay for binding the mass and resisting the penetration of water; the manipulation of the mixture in a wetted state for the purpose of puddling and spreading the clay over the particles of sand and silt; and lastly maximum compaction by various means equivalent to tamping by blunt pointed implements such as horses hoofs, narrow tired wagons, multiple ring rollers, etc.

Strahan also specified certain minerals and materials which on account of their softness or other undesirable characteristics are not suitable for use in road surfaces. Those listed by him are: feldspars (presumably the weathered ones), micas, schists, hard pan or other soft friable material.

Recently Hogentogler and Terzaghi[2] have, in a very comprehensive paper grouped uniform subgrades, arranged according to the characteristics conspicuous in their performance. They have divided these subgrades into 8 groups ranging from highly stable topsoils, and less stable clays to the least stable materials such as mucks, micaceous and other soft or elastic soils in various states of moisture. In this grouping essential characteristics, such as cohesion, friction, etc, have received careful attention.

In the time allotted only a brief summary of some of the more important features of certain common rocks, minerals and soils and their suitability for fill or surface materials seems possible.

According to Dr Lord[3] the resistance to wear of igneous and metamorphic rocks containing an abundance of hard minerals such as quartz is greater than that of similar rocks rich in softer minerals such as mica, serpentine, calcite, etc. Foliated metamorphic rocks are as a rule deficient in toughness and are therefore not well adapted to road construction. Sedimentary rocks are usually deficient in wearing properties, except in the case of highly indurated sandstones, containing a moderate amount of siliceous clay cement and limestones or dolomites rich in quartz and having very little clay

Tests made by Kellerman[4] show that the percentages of wear and absorption in crushed stone, slag and gravel increase in a general way with decreasing densities

Pure quartz sand is extremely hard, usually consisting of irregular rounded particles without cleavage and forms one of the most durable and useful materials used in road construction. As a material for fills and road surfaces it is most useful when associated with very limited quantities of clay which act as a water resistant and also as a binder. This added clay also reduces the permeability and increases the density of the mass—two additional characteristics which seem important.

Sands formed from frothy or vesicular lava may be quite hard due to the presence of glassy or other hard substances but possess little toughness, are light in weight and usually possess a high capacity for water. Only the denser varieties of these sands have much, if any, value as a material for roads

Pure quartz silt may probably be found in very limited areas, but it is most commonly found mixed with sands and clays As a rule it exists as particles of rock minerals or rock flour in varying states of weathering ranging from that of fresh rock particles of more or less hardness to that of material which may be as soft as talc The particles may be of almost any shape and the pore space may vary from that possessed by sand to enormous percentages such as that of Celite or other microscopic aggregates all of which are extremely light in weight and are not adapted to earth road building purposes

For convenience clays will be grouped into three classes, viz , ball or highly plastic clays, kaolins and intermediate types. Ball clays are characterized by their great density strength and toughness when puddled and thoroughly dried, their great plasticity when wetted and their high shrinkage upon drying In the thoroughly compacted and cemented state Bleininger and Howat[5] found that certain ball clays possess a tensile strength ranging from 135 to 210 pounds per square inch Kaolins on the other hand while generally plastic require less water for producing workability, are less dense upon drying from the puddled state and possess less strength than the highly plastic clays. The tensile strength according to the tests by Bleininger and Howat ranged from 104-147 pounds per square inch. According to Segar[6] the cementing substance contained in kaolin, dries to a soft powder-like mass of low strength while that contained in ball or highly plastic clay dries to a horn-like mass of considerable strength. The intermediate clays of course possess characteristics between the types just described

Chalk and other light-weight and soft minerals absorb large quantities of water, erode easily and are not desirable road materials.

Sands, silts or clays containing vegetable matter either in the form of humic solutions or in states of more or less decomposition absorb water in greater abundance and tend toward higher porosities than similar materials free from humus

From information obtained chiefly from ceramists it seems that ball or highly plastic clays should furnish a denser and tougher bond for sand-clay and gravel mixtures than that furnished by kaolins possessing low cohesive properties. The major difficulty, however, in making this suggestion practical seems to be that of uniform mixing such clays with sands. It seems that fine grinding or the reduction of the clay to a slurry of buttermilk-like consistency before mixing with the sand are possible methods.

Regardless of the type of material, maximum compaction seems always essential To accomplish this most effectively, the moisture content of the material to be compacted and the method of compacting are of paramount importance Sand-clay mixtures for road surfaces should first be puddled[1, 7] and then be compacted as rapidly as drying permits by well distributed traffic or by a tamping roller[1]

In compacting highly plastic clays a suitable moisture content is essential, otherwise the rolling will be less effective. When too dry, the soil will be incoherent but if too wet it will be "spongy" and therefore cannot be compacted The most suitable moisture content for rolling is when the soil coheres upon being squeezed in the hand but not wet enough to "ball" or show plasticity; this is the moisture content equal to that termed by farmers as the "optimum moisture condition" for cultivating crops

For compacting earthwork the tamping or multiple ring rollers seem to be more effective than the usual type. On one earth dam in California[8] where sprinkling to the moisture state just suggested was practiced, followed by the use of sheep's foot tampers, the 85-foot dam settled not more than 0 1 foot in 2 years A similar method of sprinkling followed by the use of a 10 to 12 ton 3-wheel roller has also been found to be an essential factor in reducing soil shrinkage in adobe subgrades in Stanislaus County, California[9]

BIBLIOGRAPHY

1 Bul of the University of Ga , Vol 22, No 5a, June, 1922.
2 Public Roads, May, 1929
3 U. S. Dept Agric Bul., 348
4 Public Roads, June, 1929.
5 Trans Amer. Ceramic Soc , Vol. 14, p 274 (1914).
6 Collected writings of Herman A Segar, Vol 1, p 417.
7 Univ. Calif. Agric Expt Sta , Bul. 472, p. 25, September, 1929
8 Eng. News-Record, Vol 102, No 10, p. 388, March 7, 1929.
9. Lippincott, J. B Engineering Rept on Conditions of Southern Calif State Highways, 1921, Los Angeles.

MR. C. A HOGENTOGLER, *U. S. Bureau of Public Roads.* Professor Krynine's very interesting and valuable discussion of Russia's investigations discloses the fact that in common with other investigators, Russia is seeking an answer to the all important questions:

1 How can soils be best identified in the laboratory, and
2 What is the significance of the laboratory identification of soils with respect to their performance in service?

These questions are equally important to the highway engineer, the foundation engineer and the agricultural engineer, and they must be answered before permanent progress can be made in the sciences based upon soil performance

Of special importance to the highway engineer is the third question: What is the practical significance of the performance of soils in service with respect to road construction?

Progress in appreciable amount has been made by the U. S. Bureau of Public Roads in its efforts to answer these three questions.

The investigational procedure which furnished this progress consisted of the following:

1. Surveys of roads in service by both engineer and soil scientist to determine both the soils or soil profiles on which failures occur and the character of the failure.
2 Laboratory investigations to determine the soil constituents responsible for particular subgrade performance
3 Laboratory investigations to determine the soil tests best suited to disclose the presence of those soil constituents which exert a dominating influence upon the serviceability rendered by road surfaces.

For assistance rendered in this connection, special credit is due Dr Charles Terzaghi, who furnished the principles of soil physics which explain the significance of the laboratory tests and W. I. Watkins, the soil scientist, whose keen appreciation of the importance of relatively small details in the mapping of soil profiles facilitated the correlation of the results obtained in the laboratory with those furnished by the field investigations

The results furnished by these investigations disclose that the degree of such physical characteristics as internal friction, cohesion, capillarity, shrinkage, expansion, elasticity and ability to heave during frost action possessed by soils is dependent to a large extent upon the presence of such soil constituents as sand, silt, clay, colloids, diatoms, mica flakes and organic matter. Furthermore, the presence of these important constituents is disclosed with a fair degree of precision by relatively simple test constants as follows:

1. The lower liquid limit or the minimum moisture content possessed by the soil when in the liquid state
2 The plasticity index or the moisture content of the soil when at the yield point subtracted from the minimum moisture content when in the liquid state.

3 The shrinkage limit or the moisture content of the soil when compressed to minimum volume due to capillary pressure.
4 Centrifuge moisture equivalent or the moisture content of a soil when compressed by a centrifugal force equal to 1000 × gravity.
5. Field moisture equivalent or the moisture content possessed by a soil when refusing to absorb additional water dropped upon the surface of the soil cake

For obvious reasons, the mechanical analysis has but minor significance with respect to the identification of fine grained soils.

Soil identification by means of the test constants depends upon two facts:

(a) The results furnished by tests performed upon a material possessing particular physical characteristics bear a definite relation to each other and
(b) The interrelationship existing between test results changes as physical characteristics possessed by the tested materials change. In order to construct a practical soil identification chart, therefore, it was only necessary to determine by means of laboratory tests, the individual interrelationships existing between the test results possessed by the soil constituents found by the field surveys to exert an important influence upon the serviceability of road surfaces.

I wish to emphasize that the little success which we claim to have obtained in the development of a rational method of identifying soils is due mainly to the fact that we studied the properties possessed by the individual soil constituents separately, in combination with each other, and in combination with natural soils Only by this method of attack were we enabled to understand the properties possessed by natural soils. After the characteristics of the important soil constituents were determined, the presence of the various constituents in natural soils was easily recognized.

Along with this method of soil identification there was developed also a tentative grouping of subgrades.

In this grouping, sand instead of being a material which possesses merely a given grain size becames group A-3 material which possesses internal friction, but neither cohesion nor detrimental capillarity. Members of the sand group are identified with respect to the ability possessed by their grains to resist sliding over each other

Silt, instead of being a material which possesses only a given grain size is divided into two groups: A-4 subgrade which possesses internal friction, capillarity in appreciable amount and neither cohesion nor elasticity in appreciable amount; and A-5 subgrade which possesses internal friction, both capillarity and elasticity in appreciable amount and no cohesion.

Likewise, the clays are divided into two groups A-6 subgrade which possesses both cohesion and capillarity in appreciable amount, but neither internal friction nor elasticity; and A-7 subgrade which possesses cohesion, capillarity and elasticity in appreciable amount but no internal friction.

Thus, for two soils possessing equal grain size, one possessing a liquid limit equal to 40, a plasticity index equal to 14, and a shrinkage limit equal to 20, would be a group A-4 subgrade and the other possessing a lower liquid limit equal also to 40, a plasticity index equal to 10, a shrinkage limit equal to 34, would be an A-5 subgrade.

The soil designated as the A-4 subgrade should be thoroughly consolidated by means of a heavy roller and may be covered with a macadam if desired. This soil will function well in fills and will be improved for use in hydraulic fills by additions of sand. Important frost heave is not to be expected in this soil when occurring in the dense state and when the ground water elevation is moderately low.

The soil designated as A-5 subgrade in contrast, is not apt to be permanently consolidated by rolling. Without treatment it is not apt to function satisfactorily as subgrade for macadam. It is not suitable for use in hydraulic fills, is difficult to drain, and is apt to suffer important frost heave unless the ground water elevation is exceptionally low.

This method of soil identification under discussion is disclosing more and more that the performance of soils under service conditions is to a large extent dependent upon the presence of important soil constituents.

Consider for instance dense clay. In the field its capillary rise may be unimportant, it would form hard clods, would not drain well and consequently may not be productive of good crops. It may serve well in a core wall in a dam As subgrade it is apt to be impermeable, may be consolidated, and is not apt to suffer important frost heave. And according to laboratory test it would be an A-6 subgrade.

Merely adding lime to this soil changes its character very appreciably In the field its porosity is increased, its capillary is increased, it drains better and consequently is apt to be productive of better crops Its increase in permeability decreases its efficiency as core wall material. As subgrade it is apt to suffer detrimental volume change and its possibilities for suffering detrimental frost heave are increased. According to laboratory test it becomes a group A-7 subgrade.

By the further addition of soda ash, both the soils field and laboratory performance is apt to change back to that indicated for group A-6.

The mechanical analysis is not apt to disclose the difference existing between these two soils. Therefore, according to mechanical analysis we have but one soil performing in two different ways in service. According to the results furnished by the physical tests we have two different soils each performing in its particular characteristic manner in service.

Consequently in the final mapping of our soil profiles, the different soils comprising the profiles are designated with respect to their efficiency as subgrades as A-3, A-5, etc., and not with respect to their identification as used for agricultural purposes

In conclusion it is to be emphasized that the results of our subgrade investigations in their present status furnish a rational basis which might well be used in soil research performed for any purpose. In reaching this stage of progress we feel that we have really reached the beginning instead of the ending of an investigation of road design with respect to subgrade support.

Prof. F H. Eno, *Ohio State University*. I feel that it is a happy event that we may have Professor Krynine with us at this ninth annual session of the Highway Research Board to bring us a brief paper on Russian soil study.

It is a satisfaction to know that Professor Krynine and his co-workers have arrived at many conclusions paralleling the conclusions reached in the United States; namely, the *use* of the work done by Agricultural soil scientists, the need of carrying the research into practical field experiments, the need of soil-minded Highway engineers, the need of standardized highway profile and topographic maps showing soil areas and profiles as well as surface topography, and the arriving at an approximate soil mixture that would make a fairly stable earth road.

The United States like Russia has more than 2,000,000 miles of earth roads, many thousands of miles of which should be cheaply treated in some way so that the farmer may be able to reach the state and county systems. Probably the cost should be kept below $2000 per mile, outside of the cost of grading and drainage structures.

The experience in Ohio seems to show that wherever it is necessary to cut through the A horizon into the B or C horizon there is a distinct danger from trouble in the sub-grade of the road. The greater porosity of the top soil and the increasing tightness of the soil horizons below slows up percolation, causes saturation along the plane of the reduced porosity and this saturation forms seepage lines, springs, and mud pockets.

The Russian attempts at soil mixtures for stabilized surfaces are checked fairly well by the conclusions reached by Professor Strahan of Georgia. His results are approximately as follows:

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|---|---|---|---|
| Clay-silt | 0 to 02 mm | in diameter | 12 to 18 per cent |
| Silt-sand | 02 to 074 mm | in diameter | 5 to 15 per cent |
| Sand | 074 to .221 mm | in diameter | 20 per cent |
| Sand | .221 to 1 40 mm | in diameter | 45 to 60 per cent |

Professor Krynine's statements regarding the problem of handling bridge foundations upon permanently frozen soils brings up the thought whether it would not be possible to core drill the frozen soil, set in piles to such depth that the heat would not thaw the supporting soil around the bottom of the pile and by this means get a permanent undisplaceable foundation for both wooden and masonry bridges in that region.

I agree with Professor Krynine upon the desirability of determining to what degree of fineness it is necessary to go in making a mechanical analysis of the soil. It has seemed to me that if the analysis has been carried to the point where the volume of soil below 003 or 002 m m in diameter has been determined with the sub-divisions of soil above that point, sufficient information will be given regarding the granular composition of the soil.

Professor Krynine's conclusions regarding the character or shape of soil grains as he interprets the capillary action shown in the illustrations of his article in the Public Roads for January, 1928 may be questioned.

In the case of sand, the capillary water surface in the tube of sand rises parallel to the surface of the water in the pan due to the large pore spaces in the sand and the absence of friction to flow in such spaces, as Professor Krynine says.

In the case of the fine grained soil, however, it is my opinion that the fact that the surface of the capillary water remains nearly normal to the axis of the tube *is not due* to the form of the soil particle so much as it is due to the slowly moving capillary action held in restraint by the friction to flow caused by the exceedingly small capillaries This slow movement permits capillary water to advance as far on one edge of the tube as upon the other edge for, both edges are placed in the water at the same instant and the action is similar all the way across the tube.

If the illustrations are examined closely it will be noted that there is a slight tilt to this capillary surface which may be accounted for by the slight difference in head of free water on the end of the tube

In order to check Professor Krynine's statement similar tests were made with Ottawa quartz sand which is quite generally known by American engineers. It is a pure quartz natural sand as nearly spherical grained as any sand could be. This was sifted into the usual size by a set of sieves and each size tried in tubes as Professor Krynine illustrated in his January, 1928, article.

The sizes acted as follows:

That passing a 35 and retained on a 48 sieve rose parallel to the source of supply

That passing a 48 and retained on a 65 sieve rose nearly at 90° to axis of tube

That passing a 65 and retained on a 100 sieve rose practically at 90° to axis of tube

That passing a 100 and retained on a 150 sieve rose practically at 90° to axis of tube

That passing a 150 sieve rose practically at 90° to axis of tube

The same action occurs with these spherical grains of sand as that observed by Professor Krynine

In the illustrations in Professor Krynine's article published in Public Roads of August, 1929, are two illustrations of an ellipsoid of soil formed by capillary action, which seem to prove his conclusions, but one of these balls is almost spherical and appears elongated on the bottom, caused undoubtedly by the added force of gravity upon the capillary moving water. In figure 3 of this article, however, the ball *is* elongated horizontally in a small amount, but if Professor Krynine's argument is good the ball should be more markedly flattened.

Minerals in breaking down into fractions follow the lines of least resistance which are marked out by the form of the crystallization. It stands to reason, therefore, that the general form of the particle will be the same for the fine fractions that it is for the coarser fractions. This statement seems to be true of sizes observed down to those requiring 200 magnification.

I believe, therefore, that the angle which the surface of capillary water makes with the axis of the soil tube is dependent largely upon the size of the capillary modified by the smoothness or roughness of the particle surface

One practical application of Professor Krynine's discussion of entrapped air occurs to me. It is connected with the compression of the soil due to rolling. This compression reduces the pore space in soils, therefore, it increases the percentage of that pore space which is filled with water at the time of rolling This in turn reduces the extent to which capillary water from below can rise into the soil beneath the pavement because free air is entrapped and cannot give way to the capillary water beneath.

Such action is beneficial to better roads *because* the soil left in this condition beneath a paved surface will remain longer, if not permanently, in more stable condition preserved from saturation by this inability to displace the air with capillary water from beneath.

Dean Anson Marston, *Iowa State College* I will say a few words about Professor Krynine's paper which I was asked to discuss. It was a very interesting paper and the subject is important. It is important not only to highway engineers but also to engineers in general. The science of foundations is just really beginning and we will never be satisfied in our engineering work until we are able to give some rational explanation of the various foundation phenomena which we observe. I wish to emphasize the idea which Dr. Krynine has advanced, that this study is not one that can be carried out adequately in one or merely two or three localities. It requires investigations widely distributed geographically Localities require individual study in determining their particular characteristics. I am glad that in the United States fine work is being done in this line by the Bureau of Public Roads. I was much interested in October to listen to a paper at the meeting of the American Society of Civil Engineers by Dr. Terzaghi's successor, a member of the staff of the Massachusetts Institute of Technology. He told about the fine work being done there and which is being carried on, although Dr. Terzaghi unfortunately has gone back to Europe.

At Iowa State College we have done considerable research in these lines. I was assured just before I left the state that a bulletin giving the results will be ready very shortly. It is a cooperative bulletin of the Bureau of Public Roads and the college It will contain a very interesting confirmation by our Professor Griffith of the correctness of using Boussinesq's formulæ in determining the pressures downward through soils from concentrated loads at the surface. Professor Griffith has verified the formulæ by measuring the displacements in the soil at different depths. He finds that they correspond closely to those calculated by the Boussinesq formulæ. Regarding frozen soils we too have had much experience with them in Iowa, although they do not remain frozen. They wreck our roads for about a month every spring