PAPER ON "THE METHODS AND POSSIBILITIES OF ROAD-SOIL INVESTIGATIONS

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According to statements issued by the U S Bureau of Public Roads, the admixture of gravel to the top layer of soil was found to improve the quality of certain poor subgrades in the State of Washington In California similar results have been obtained by mixing the top layer with sand or with decomposed granite The value of experiences of this kind could be compared with the value of the experience, that a certain ointment relieves the pain, if applied on a sore skin Their usefulness cannot be contested However, if medical science had not proceeded beyond the point of accumulating facts of this type, it would be practically on the same level as it was two centuries ago The medical progress realized during the last centuries essentially consisted in a study of the physiology of the skin, in a careful investigation of the physicochemical processes involved in the functions of the healthy skin and of the pathological modifications produced by infection I purposely refer to this medical fact, because the problems of the dermatologist and of the highway engineer have far more in common than one might expect after a superficial examination Both the skin and the top layer of soil are the seat of reversible physicochemical processes which are by far too complicated to be expressed by mathematical formulæ Both the skin and the top layer react by structural changes as soon as the external conditions of their existence change, and neither the dermatologist nor the highway engineer can possibly plan an appropriate treatment of a pathological degeneration unless he is thoroughly familiar with the physiology of the structure he has to deal with Our knowledge of the physiology of the skin is elaborate enough to fill a two-semester university course In contrast to this the physiology of the subsoil, which is by no means less complicated than that of the skin, is completely ignored by the overwhelming majority of highway engineers, and the deficiency of subgrades is explained by vague terms as insufficient drainage or excessive volume change, terms whose meaning practically dissolves as soon as we attempt to correlate them with physical facts and with the physical conditions existing within the soil

Hence one of the most outstanding problems of road-soil investigations consists in developing a theory of topsoil behavior, not more mathematical, but at the same time not less scientific, than the physiology of the living skin Without such a theory as a basis, it is useless to attempt anything like a systematic subgrade improvement Before presenting this problem in its totality, I am obliged to split it up into its essential components and to explain the physical nature of each one of them individually, frankly pointing out the gaps in our knowledge.

THE SUBGRADE AS AN ELASTIC FOUNDATION

From a purely mechanical point of view and disregarding all the possible complications, our problem consists of determining the maximum stresses in an elastic, continuous mat, the road surface, supporting concentrated loads and supported by a homogeneous, elastic medium In applied mechanics this problem is dealt with on the assumption that in every point covered by the mat, the soil reaction is equal to the deflection, the ratio

$$s = \frac{\text{pressure}}{\text{deflection}}$$

being a constant of the subgrade Hence if we plot on a cross section of the road the values of s as ordinates, we should obtain a horizontal line (Figure 1) This assumption is far from correct The s-line

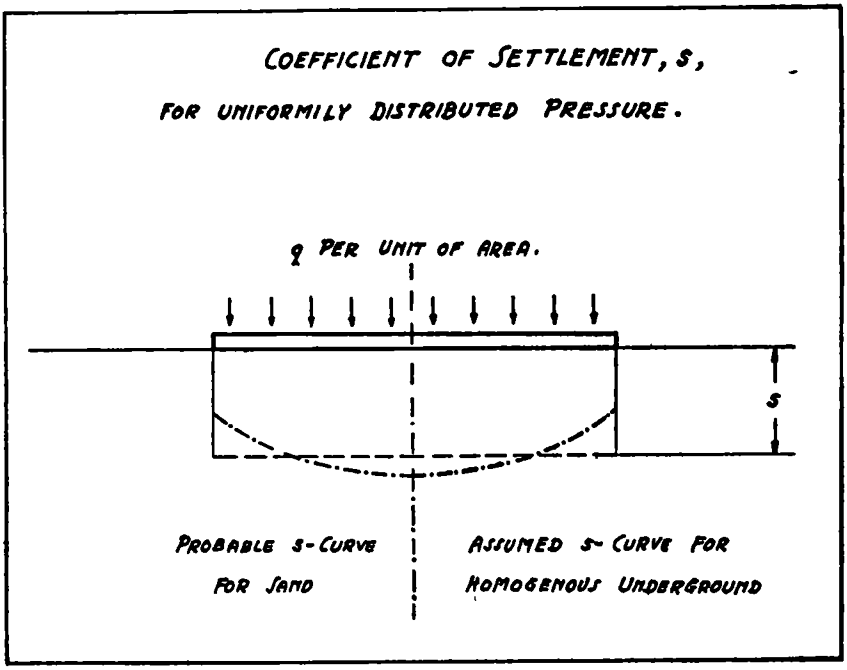

Figure 1

is a curve, whose shape very probably depends on the character of the soil It may even be possible that the s-curve for cohesionless soils may be correct in a sense opposite to that of the curve for plastic soils It would be very advisable to clear up this point before we invest any amount of time in elaborate stress computations

The most common complication we are apt to encounter in practice arises from the fact that the subgrade consists of two superimposed layers with different elastic properties, known as subsoil and raw soil In case we provide the road surface with a sand or gravel base, we have then to deal with three different layers Since the width of the road is very considerable compared to the thickness of the layers, we ought to have at least a vague conception of the effect of the thickness of the individual layers on the elastic behavior of the whole system For the time being we have no conception whatever Preliminary tests seem to indicate that the compressibility of the individual layers decreases rapidly with the ratio between the thickness of the layer and the width of the mat

LAG OF DEFLECTION

However, assuming that the behavior of a system of superimposed strata of elastic material be known, we would not yet be in a position to compute stresses which develop in the road surface, for the following reasons The theory of elasticity on which any such computation is based presupposes that the external pressure instantaneously produces the corresponding deflection In contrast to this fundamental assumption, the deflection in fact develops gradually, for two essentially different reasons (a) The time required while the structure of the material (i e, the mutual arrangement of the grains) is adapting itself to the modified stress conditions and (b) the time required to force the excess water out of the voids of the soil Both factors have been covered by a series of experimental investigations, so that the laws which govern the effect of these factors are known with sufficient accuracy The effect of factor (a) is practically independent of the volume occupied by the material subject to change, while the effect of factor (b) increases rapidly with this volume For very permeable soils (effective size greater than 0 1 mm) factor (a) dominates For soils with very low permeability (effective size smaller than 0 002 mm) the time effects are dominated by factor (b). For intermediate types of soils both factors may be of equal importance In the field of foundation engineering the effect of factors (a) and (b) is shown by the fact that buildings continue to settle, sometimes for many years, although the bulk of the load remains constant The effect of these factors is still more important in connection with the behavior of the subgrade of roads, since the loads acting on the road surface are without exception temporary in character. No proper interpretation of observed phenomena can possibly be attempted unless the nature of the two retarding factors (a) and (b) is clearly understood

SEASONAL CHANGES IN THE UNDISTURBED SUBGRADE

The foregoing remarks would cover the mechanical aspect of the subgrade problem if the properties of the subgrade were permanent In practice, however, these properties change from season to season in a most complex manner There is no more resemblance between the soil we deal with in the laboratory and the top stratum of the soil in the fields than between leather and the skin of the living animal, and attempts to reproduce actual soil conditions in the laboratory are no more promising than attempts to reproduce the properties of the living skin by boiling dry leather in soup It is hardly an exaggeration to say that the processes which are going on within the soil are as complicated as the physicochemical processes called life There is, in addition, the following remarkable relationship between the life of the soil and the life of the skin In both cases continuous regeneration takes place, as far as substance is concerned, while the structure itself is permanent In a study of the origin of certain land forms in limestone country we were obliged to conclude that the development of these forms was associated with the gradual removal of a layer of rock with a thickness from a few feet to more than 1,000 feet All the nonsoluble rock constituents passed temporarily through the state called soil Nevertheless the layer of soil covering the landscape remained practically unchanged in spite of continuous exchange of substance Thus the structure called the natural soil represents a highly complex state of equilibrium with the characteristic property that every process produced by the manifold external physical and chemical agencies is practically reversible. No such state could possibly be artificially produced in a soils laboratory. At the same time it should be remembered that this complex state is strictly confined to a layer not more than four or five feet thick Whatever is below that depth can be compared to a storage room, the material not yet being drawn into the cycle which we may call the life of the soil

The agents acting within the living soil are both of a chemical and of a physical nature, the structure being the result of chemical changes, dissolving processes, circulation of water and of solutions, simple precipitation, flocculation, surface tension and the mechanical activities of living organisms The physical aspects of these processes consist essentially of shrinkage due to evaporation, expansion due to water invading the voids and additional expansion due to freezing As a result of experimental studies, combined with a physical interpretation of the test results, we know that the volume changes associated with the drying and wetting of soils are nothing but phenomena of elastic contraction and expansion, the corresponding pressures being produced by the surface tension of the capillary water Suppose we have a layer of fine-grained, homogeneous soil, surrounded by a rigid ring, the upper surface of the layer being horizontal and in contact with the air Due to the difference between the vapor pressure of the liquid and of the water vapor contained in the air, the water gradually evaporates and the water content of the soil decreases The laws which govern this process are now well known The drying process proceeds from the surface of evaporation towards the interior and has precisely the same effect on the distribution of the water through the soil as though the water were forced out of the soil by means of an external pressure The pressure which develops in the soil as a result of the evaporation process has been called the capillary pressure Starting at the surface of evaporation, the capillary pressure advances towards the interior of the sample, the intensity of the pressure being a maximum at the surface of evaporation In very fine-grained soils the maximum value of the capillary pressure can be as high as several hundred atmospheres In such soils the capillary pressure causes the formation of a stiff and almost impermeable crust, whose thickness increases with time according to the following laws

At equal speed of evaporation and equal maximum value of the capillary pressure the rate of increase of thickness of the crust is proportional to the permeability of the material. For the same material the thickness of the crust increases the more rapidly the slower the water evaporates Rapid evaporation causes the formation of a thin, but very hard, crust, while slow evaporation results in the formation of a thicker, but softer, crust

Consider now a layer of subsoil which contains the roots of trees (Figure 2) In this case each one of the roots represents a cylindrical surface of evaporation located within the soil Starting at the skin of the roots, the capillary pressure invades cylindrical spaces surrounding the roots, the diameter of these spaces increasing with time The volume changes associated with the pressure cause the formation of shrinkage cracks within the soil The character of the system of cracks there formed depends essentially on the distribution of the roots throughout the soil and the system itself produces drainage conditions within the top soil which are completely different from the drainage conditions within the raw soil, even in case the raw materials of both soils are exactly alike

During a period of twelve months the soil undergoes the following changes In spring, after the snow melts away, topsoil and subsoil become almost completely saturated with water At the same time the evaporation process starts in on account of the trees starting to bud The growth of vegetation is associated with the development of capillary pressure in the soil around the roots The cracks

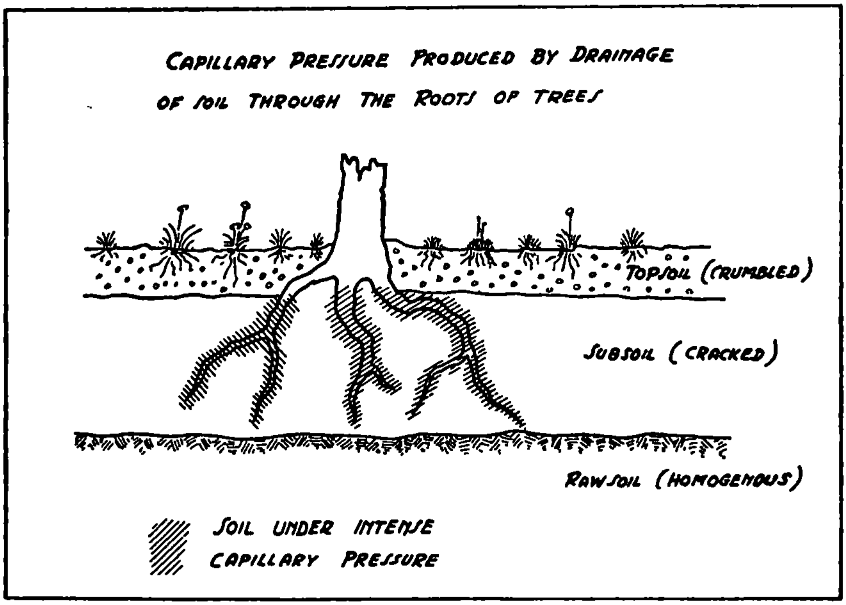

Figure 2

which form in the soil as the result of the capillary pressure serve both as storages for water and as conduits for draining off the excess According to the ratio between the precipitation and the consumption of the water by the trees, the general trend of flow will either be from the cracks towards the roots or through the cracks following the direction of topographical drainage Late in fall, when evaporation through the roots practically ceases, the average capillary pressure acting in the soil decreases, the soil expands, and, as a consequence, its permeability increases

Finally, during the wintertime the soil, previously saturated with water, will freeze While freezing, the volume occupied by the water increases by about 10 8 per cent The structural changes produced in the soil by the freezing of the capillary water are not yet clearly understood It seems that the change in structure of the soil is not due merely to the increase in volume of the water, but, in addition, to the action of certain forces of crystallization acting while the water is freezing Due to the action of these forces, freezing causes partial drainage of the strata located underneath the zone of freezing Scanter still is our knowledge concerning the effect of the presence of air on the change in volume of the freezing soil The only fact we know thus far is, that the freezing process loosens the structure and in the spring, when the ice melts, the permeability of the soil and the drainage conditions will be very different from what they were in the fall Nevertheless, the whole change produced by freezing is strictly reversible, because the soil has passed through the same cycle of freezing and thawing for ages, year after year

Suppose now, we destroy the forest, thus stopping the current of water which flowed year by year through the roots, a, b, c, etc (Figure 2) into the trees Hence the principal surface of evaporation will shift from the surfaces of the roots scattered throughout the soil towards the boundary between subsoil and top soil. Considering the fact that the capillary pressure acting within the spaces adjoining the surface of evaporation amounts to many atmospheres, the structural importance of the change becomes at once evident The conditions of the formation of cracks and of cavities have completely changed It will take many annual cycles before a new structure develops which again reacts to a variation in atmospheric conditions by a reversible change, and the drainage conditions in this new subsoil will, probably be quite different from what they have been before

STRUCTURE OF RESIDUAL SUBSOILS DERIVED FROM THE DISINTEGRATION OF ROCKS IN SITU

The transformation of rock into soil is associated with a change in its chemical composition, from the fissures and cracks towards the interior of the material The change in chemical composition is associated with a volume change. As a result of this volume change the individual rock fragments, partially or wholly decomposed are forced apart and represent, in a state intermediate between rock and soil, an accumulation of individual fragments, whose structure cannot possibly be reproduced except by repeating the process through which it originated. In certain rocks as are, for instance, the granites, or the andesites, the structure seems to be almost homogeneous, the voids being filled with the products of rock decomposition In others, as are certain shales, the structure is sponge like, including big voids, whose sides are lined with clay. Experience seems to show that the arrangement and the character of the individual rock fragments contained in the layer intermediate between rock and soil has a very important bearing on the stability of the layer Thus the rapid creep and the spontaneous landslides which are so characteristic for certain parts of Pennsylvania and of West Virginia seem to be essentially due not to a certain property of the soil derived from the rock decomposition, but due to the structure resulting from the process of decomposition, combined with the presence of an abundant water supply.

SOIL CONDITIONS BENEATH HARD ROAD SURFACES

I have dealt at some length with the natural soil in order to show how numerous are the factors which govern the behavior of a soil located near the surface A change in the type of vegetation which covers the ground produces a change in the physical properties of the top layers, although the raw material of the soil remains essentially unaltered. We must expect still more radical changes if we strip the top soil completely off and replace it by an impermeable concrete mat. By doing so, we locally reduce the surface water supply to zero. We change the conditions of surface evaporation to an unknown extent and finally we provide on both side of the road an open ditch or strip, where the subsoil is in direct contact with the air

As a result of this artificial change, the circulation of water which, prior to the construction of the road, chiefly proceeded vertically upward or downward, will be replaced by a circulation chiefly in a horizontal sense, toward the axis of the road or from this axis outward The distribution and the intensity of the capillary pressure produced by evaporation will be utterly different from what it was before, which in turn will cause a thorough modification of the drainage properties of the soil Last, but not least, a thorough change will occur in the temporary and permanent air content of the soil The air content of the soil affects both the permeability of the soil and the volume change produced by freezing to a very important extent From certain observations we suspect that an air content of 10 or 15 per cent may reduce the volume expansion of the freezing soil to a small fraction of what it would be for a saturated soil, although the mechanics of this modification are not yet clearly understood The life process of the vegetation plays an important part in providing the soil with its gas content Hence, if we strip the top soil and replace it by a hard surface, the effect of freezing on the soil may change considerably. In brief, the construction of the road causes the subsoil to degenerate into something less complicated and less highly organic than the original subsoil and it will take several years before the functioning of the degenerate subsoil develops into a set of seasonal, reversible changes, representing a state of dynamic equilibrium between the structure of the soil and the periodical changes in the conditions of its existence

The equilibrium structure will obviously depend on the material of which the soil consists But it also will depend on the structure of the soil before the road was constructed Thus the outcome of the process may be very different according to whether the road surface was established on a subsoil with the delicate and rather spongy structure characteristic of soils moulded by the action of roots, on a raw soil which for the first time since its formation comes into contact with atmospheric agencies, or on a fill composed of individual chunks. It finally will depend on the ratio between precipitation, evaporation and run-off, which in turn depends on the character of the locality and on the permeability of the raw soil Evaporation means capillary pressure, secondary stresses and cracking, while saturation means release of pressure and elastic expansion

METHODS OF ROAD SOIL INVESTIGATION

From the preceding discussion, it is obvious that we cannot possibly approach the problem of subgrade investigation with the crude tools used in applied mechanics No fairly reliable computation of stresses, bearing capacity and volume change will ever be possible. At the same time it will be impossible to take any advantage of our experiences made in the line of subgrade improvement, unless we get a very clear conception of every one of the physical factors which determine the behavior of the subsoil This is precisely the situation in which the physiologist finds himself when dealing with the functions of the living organism and as a consequence our methods will be of necessity similar to his We have to split up our problem into its components, then reduce each one of the components to its simplest physical terms, and finally try to explain the working of the whole complex phenomenon as the result of the cooperation of a number of individual physical factors

The first one of the partial problems consists of working out a method for describing and identifying the material of which the soil consists The physical effect of seasonal changes depend essentially on volume changes produced by wetting and drying Since the intensity of swelling and shrinking and the lag in expansion are determined by the elastic constants of the material, it seems logical to base the classification of these materials on their elastic constants, and on their permeability, especially since these constants can be determined by a comparatively simple procedure For the raw soil below the limit of possible frost action and of the action of organic life, the elastic constants and the coefficient of permeability obtained in the laboratory are practically identical with those of the soil in the ground For the subsoil, however, these constants merely serve for identifying purposes. They have very little in common with the corresponding constants of the soil itself, since these constants for the subsoil may vary during the year within very wide limits The technique of the tests is on the point of being brought into standard shape

The next step would consist in a physical investigation of the individual processes which enter into the life of the subgrade Considering the rudimentary state of our knowledge and experience the principal danger resides in underestimating the number of unknown quantities which enter into our equations Due to an erroneous conception concerning the number of factors involved in the phenomena relating to soils, most of the investigations which have been made thus far are practically worthless In order to get anywhere we must exclude every possible disturbing factor and isolate the one phenomenon we wish to investigate The questions we should answer first are about as follows:

(a) What is the distribution of pressures acting on a rigid, uniformly loaded mat supported by a homogeneous, perfectly cohesionless or perfectly plastic medium?

(b) What is the effect of the air content on the volume change produced by the freezing of a wet accumulation of grains?

(c) What is the rate of evaporation through a concrete mat compared to the rate of evaporation on a free-water surface, exposed to the air under precisely the same conditions as the concrete?

(d) What are the changes in volume and in permeability produced by a continuous flow of seepage water through a layer of crumbled soil?

The traditional practice in dealing with similar problems was to take a soil and to start experimenting However, the material called soil already involves so many variables as the shape of the grains, the structure, the intensity of the capillary pressure acting at the time of the test, etc, that no two experimenters could arrive at similar results Hence, in order to answer our fundamental questions we should at first not even attempt to experiment with soils We must select very much simpler materials which have nothing in common with the soils, but the one property we wish to study Thus, in handling the first problem we would select lead, or plasticine From cube tests we know that the plasticity of these materials corresponds exactly to the plasticity of clay without being associated with those properties which cause in tests with clays the lag of compression and the gradual increase of the internal friction Then, after we have learned about the behavior of the plastic material pure and simple, we should proceed to study the complications produced by the hydrodynamic stresses, finally equipped with the knowledge thus acquired, we would venture to approach a crumbled soil Or when dealing with the second problem, we would start out with a study of the freezing of uniform wet sands with a known air content

The result of these and similar investigations would represent a series of well defined fundamental facts, serving as a rational basis for the interpretation of the complex phenomena which we face in practice In a similar manner the physiololgist has split up the functions of the living tissue into the phenomena of expansion and contraction, of percolation and diffusion, surface tension and capillary movement, and he has studied every one of these aspects of the life of the tissue individually, under the simplest possible physical conditions Without knowing about the results of these investigations he would be utterly incapable to explain any of the complex manifestations of the life of his material

The last step would consist in a study of the properties of the subgrade in the field It would be useless to attempt any elaborate studies of that type before we have mastered the elementary principles of our subject, that means before we have a clear conception of the fundamental facts For the time being we cannot do any more than to sample the subgrades and to correlate the properties of the raw material with the results of the observations made in the field, as has been suggested by Mr C A Hogentogler in his outlines for a condition survey In making the survey, it will be essential to extend the investigations down to the raw soil, and to show on the survey sheets a cross-section of the road and of the ditches, a soil profile, the approximate grade of the ditches, and to state the type of vegetation which covers the surface on both sides of the road (cultivated, meadow, or forest) In addition to this, it would seem to be very promising to make observations concerning the volume change of the soil as a whole Due to shrinkage and swelling, and due to volume change produced by freezing, the surface of the soil moves periodically up and down There is hardly anything that brings the combined effect of the property of the soil, the influence of the locality and of the climate more clearly into evidence than the amplitude of these periodical oscillations Hence the writer suggests the installation in convenient localities of simple devices, by means of which these movements could be measured Such devices should consist of two bench marks, one of which should be located at the boundary between top soil and subsoil, and the other below the bottom of a three or four foot casing, driven to a depth of four or five feet into the ground The difference in elevation between these bench marks should be measured after periods of excessive drought, of continuous rainfalls, after periods of frost and after the melting of the snow, the error of observation not exceeding one-half of a millimeter There could in addition hardly be any simpler and more reliable method for securing general information concerning the effect of the construction of the road on the character of the subgrade than by comparing the relative movement of such bench marks established near the center line of a hard-surfaced road with the relative movement of a pair of bench marks located on the original ground beyond the range of influence of the artificial changes produced by constructing the highway

One of the most interesting, but from a physical point of view most difficult, investigations concerns the soil movements of the type encountered in West Virginia Since the conditions leading to these movements cannot be reproduced in the laboratory except on a very limited scale, the interpretation of the observed facts will require first of all to clearly separate all the individual factors involved in the phenomenon, with a view to estimating afterwards their relative importance

ARTIFICIAL IMPROVEMENT OF THE SUBGRADE

The last group of problems we have to deal with consists in a study of the artificial improvements of the subgrade by means of providing a permeable sub-base, by the admixure to the subsoil of foreign material and by chemical ingredients It is obvious that no such study can be made before we have a very clear conception of all the factors on which the behavior of the untreated subgrade depends Our present conceptions of the effect of artificial improvements are utterly crude and probably altogether erroneous This is particularly true of our conception of their effect on drainage and on frost action, as we may learn from the following considerations

By mixing a cohesive soil with gravel its permeability may either decrease or increase, depending on the ratio between the two components The presence of a layer of sand or gravel between the subgrade and the road surface is not likely to increase the speed of evaporation, because the air contained in the voids of the porous layer becomes saturated with water vapor which in turn stops evaporation Side drains such as used in Massachusetts for improving poor subgrades could not possibly have any effect, unless the height of the capillary rise of the water in the subgrade be smaller than the difference in elevation between the side drains and the top of the subgrade, that means smaller than a few feet In soils even with a very small percentage of clay (particles smaller than 0 002 mm) the capillary rise is very much greater unless the soil is cracked through and through In a similar manner our conceptions of the effect of the admixture of coarse materials or of clay on the bearing capacity and on the compressibility of the subgrade are far from satisfactory Thus, considering the size of the area over which the pressure of a wheel is spread by the stiff road surface, it is very difficult to conceive wherein the advantage of strengthening a top layer of subgrade not more than six or eight inches thick would lie The stabilization of sand by an admixture of clay cannot possibly be effective, unless the clay never has a chance to get soaked to the limit of its water-holding capacity There seems to exist one method only for investigating the effect of our artificial subgrade improvements We must first of all study the effect of the remedial measure by observation in the field, then work out a hypothesis concerning the physical effect of the improvement, and finally to plan laboratory tests for checking whether or not our conception is correct If it were found to be erroneous, we should have to work out and to check another theory. Thus it would be very advisable to study in the laboratory the process of evaporation and of condensation within the voids of a layer of sand enclosed between wet soil and an impermeable cover, or to study the effect of a similar layer on the depth to which the frost is apt to penetrate the soil Only with the results of such systematic tests at our disposal would we ultimately be in a position to make intelligent use of the experiences gathered by actual practice Until this is the case, we have to continue our experimentation in the field and to record our observations as completely as possible, with a view to utilize the information thus obtained at a later date.

No large scale experiments have yet been made in the line of improving the subgrade by chemical methods, except by nature itself. The stabilizing processes used by nature consist essentially of transforming reversible colloids into irreversible ones (certain types of hardpan) and in lining the sides of the voids with incrustations (certain types of loess, and clays precipitated from a suspension in water saturated with lime) It would certainly be worth while to try to imitate some of these processes in the laboratory, but on the other hand it would be premature to predict the practical applicability of the results thus obtained

CONCLUSIONS

The relations between the character of the subgrade and the traffic resistance of the road are almost as complex as are the physiological processes involved in the life of an organism There is no hope for successfully reducing the problem to a simple problem of resistance of materials Future progress will depend on our success in analyzing individually every one of the many factors which determine the behavior of the road, for the purpose of providing a basis for the correct interpretation of the results of actual experience in the field Without such an analysis we will never be in a position to apply the experience acquired in one section of a country to the improvement of our construction methods in another

The analysis requires the solution of four different types of problems

(a) Selecting such characteristic properties of the soil which can be easily and reliably determined and which, at the same time would be sufficient for identifying the raw material of which the soil consists In principle, this problem is solved What remains to be done merely concerns the technique of the procedure

(b) A study of the physical processes involved in the seasonal changes of the subgrade The most difficult part of this investigation has been successfully accomplished by the discovery of the relation which exists between shrinkage, swelling, lag of expansion, coefficient of permeability, surface tension and the elastic properties of the soil material The future investigations will consist essentially of a series of experimental studies, guided by the knowledge of the underlying physical principles which is already available

(c) Systematic collection of empirical facts concerning the behavior of natural and of artificially treated subgrades (Condition survey) The essential requirement for the success of a condition survey consists of recording all the facts which determine the condition of the road Since our knowledge of the processes involved in the breaking up of a road is still incomplete, there is always the danger that essential facts may be overlooked Hence the program for the survey should even include observations concerning such factors, which for the time being seem to be of minor importance, as the soil profile, the type of vegetation covering the adjoining ground, and the like The survey should be associated with observations concerning the periodical (seasonal) movements of the road surface and of the adjoining ground

(d) The last step will consist in an attempt to estimate the relative importance of the factors which cause the deterioration of the roads, such as volume changes due to drying and to freezing, unequal compression of the subgrade, lateral flow of the subgrade, undercutting of the shoulder by slacking of the soil, etc , to construct a picture of the life of the subgrade, i e , of the periodical changes the subgrade undergoes year by year, and finally, to determine the modifications these changes undergo as a result of different kinds of artificial subgrade improvement In brief, what we drive at is not a mechanical theory of road-resistance, such theory being inconceivable—but something that we may call a physiology of the normal and of the artificially modified subgrade

The prerequisite for successful work along such lines already exists as a result of recent investigations concerning the mechanics of soils The chief difficulties which have to be overcome are of a psychological rather than of a technical nature They reside in the incapacity of most of the professional men to grasp the true nature of the problems involved Engineers are trained to deal with materials with exceedingly simple properties and as a consequence they invariably underestimate the complexity of the processes involved in soil behavior They speak of a coefficient of internal friction, of permeability, of drainage properties, of cohesion and bearing capacity, as if these data represented simple and well defined properties of the soil They fail to grasp the fact that the soil is not a material but an organism, whose properties cannot be understood unless we trace them back to their basic physical origin On the other hand, agricultural soil experts are apt to overemphasize the importance of the chemical aspects of the phenomena Else they would have realized long ago the essentially mechanical character of shrinkage and swelling, and they could not have overlooked the periodical appearance and disappearance in the soil of such tremendous, purely mechanical forces as are the capillary pressures associated with the processes of evaporation.

Hence one of the most urgent tasks consists of initiating observers into what little we know thus far about the physics of soils. Equipped with this knowledge they will automatically refrain from approaching soil problems with conceptions derived from structural engineering With observers thus prepared for their work, the solution of our problem will be merely a question of time.