Local Sentiment

The cost of right-of-way easements has steadily decreased. In the beginning the individual land owner felt that he was being imposed upon and he set his price accordingly. Now, however, the land owner when approached on this subject will rarely even name a price. "Go ahead with the work and do what you think is the right thing" expresses the usual attitude of land owners involved. Public sentiment is so entirely in favor of this work that the land owner hesitates to place any obstacles in its way.

We now include in the specifications for all new roads the following paragraph, "Whenever the said proposed road improvement crosses or intersects another public highway the right-of-way shall be widened at the corners so formed so that the curves will have an external secant of 20 feet, using the straight sides of the roads as tangents. The gravel wearing surface shall also be widened to correspond. This work shall be done provided the Board of Commissioners of Whitley County secure easements." And as soon as the contract for the construction of the road is let the commissoners authorize the county engineer to secure the necessary easements.

In our specifications we make twenty feet the minimum distance from the point of intersection for starting our curves, and then we get as much additional land as the location of the work justifies and the land owner will permit.

The cost of this work when done at the time the road is improved adds so little to the cost of the entire project that it is negligible. It adds so much to the completed road improvement that it will be well worth the expense, even though it did add materially to the cost of the contract.

We feel that our efforts in this respect have been well worth while. The fact that we have not had a report of a single accident at one of the intersections so improved fully convinces us that we are on the right track and encourages us to go ahead with this work as rapidly as possible.

HIGHWAY SUBSOIL STUDIES

By V. R. Burton,
Deputy State Highway Commissioner, Lansing, Michigan

Subsoil studies of various kinds have recently engaged the attention of very many highway engineers. Much of the work done, while fundamental in its line and interesting in its ramifications, is yet of little practical value to the engineer.

We must have conclusions drawn in a definite way showing the effect of the soil properties on the design of works of engineering before they can ever become usable. A mathematical analysis of some few, a very few, problems giving a rational design may be possible. Others are incapable of any such solution, and must, from a practical standpoint, forever remain an empirical problem offering only statistical solution.

Problems with which engineering research workers in soils should concern themselves nearly always involve soil movement. I say **nearly** always, because there is the problem of the effect of alkaline soils on concrete, for instance, which is purely a chemical one not connected with any physical cause. In general, however, most problems for whose solution laboratory subsoil studies are made primarily involve soil physics and physical chemistry to the exclusion of the purely chemical.

The most important physicochemical factor which determines in a basic way the character of any sort of soil material is its colloidal content. The answer to the question of what a colloid is, is not so easy, as a good many different theories are in vogue; but the generally accepted idea is that it is a group or clot of molecules of certain non-crystalline substances too large to pass through a parchment filter. Its effect on the soil material may be easily understood when it is known that in sands it varies in amounts from nothing up to 8 or 10%; in clays the amounts may run up from 50 to 75% commonly, and in some peats is practically 100%. As the colloidal content of the soil increases, its suitability as a subgrade decreases. This colloidal material is the soil cement holding the finer particles of silt and sand together, and we must recognize its presence in any thoroughgoing laboratory soil study. Critics of this statement have completely misunderstood the colloidal function and its importance. It has been said that the study of the colloidal content is comparable to a study of the chemical composition of cement used in concrete. Nothing is farther from the truth. The colloidal content **is** the cement, and while we are not particularly interested in whether or not it is an aluminum or ferric compound, we do want to know how much of it there is in the soil material and the strength of its affinity for water.

A great deal of work has been done by soil scientists in the study of colloids with reference to its effect on the agricultural problem. Until very recently little attention was paid by engineers to the enormous mass of literature available on the subject, accumulated by soil scientists primarily interested in agriculture. It is felt that so far as soil materials are concerned, a thoroughgoing study of the colloid fractions is imperative if we are to obtain any fundamental understanding of their peculiar behavior under various conditions. Some

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idea of its importance may be obtained when it is realized that the following soil phenomena are directly dependent on the amount and character of the colloidal material: attraction for water, adhesion, amount of water which will freeze in the soil, vapor pressure, evaporation, water-holding capacity, capillary movement, percolation, plasticity, soil structure, and shrinkage.

Turning from the realms of physical chemistry to the purely physical, we are primarily and fundamentally interested in those phenomena of soil movement with which we must deal. We have first and most important of all, plastic flow, concerning which, unfortunately, very little is known. A plastic material is defined as a solid which holds its shape permanently under the action of small shearing stresses, but is readily deformed under a somewhat larger stress. On the application of shear a certain part of the force applied is used up in overcoming the internal friction of the material, and when the stress overcomes this friction, plastic flow is produced.

Plastic flow when produced by pressure of a small area on a very much larger body of plastic material has received scant attention from investigators. This condition produces both a shear at the edges of the area and a compression beneath it. Some studies have been made of the flow of plastic materials in a confined space from the standpoint of the imperfectly elastic effects of compression and from the standpoint of the flow under pure shear. But, so far as is known, very little has been done on a study of the manner in which a pressure is dissipated in a plastic material beneath a small bearing area, with the plastic material free to move from beneath this area.

Bearing Values of Soils

It is this phenomenon which interests us in the study of safe bearing values for foundations for structures. How much settlement of the foundation may we expect and to what distance will the earth pressure caused by the load be communicated before being dissipated in the surrounding earth? When may we be assured that further settlement will not be of a material amount?

Some work has been done along this line by various investigators. One of the most interesting of these tests was carried on jointly by the Wayne County Road Commission and the Civil Engineering Department of the University of Michigan. This test was inaugurated for the purpose of determining safe bearing values for foundation for the Fort Street viaduct in Detroit, and is reported by W. J. Housel in the September, 1928, issue of *The Michigan Engineer*. Loads on both square and round bearing plates, in sizes of one, two, four, and nine square feet, were applied, and the rate of settlement and extent of the communication of lateral pressure and shape of the displaced soil next to the plate studied.

It was found that the larger part of the settlement of the plates under load was due to the plastic flow of the material nearest the plate and that a smaller amount was due to compression. It is the concept of Mr. Housel that a pressure bulb is formed beneath and beyond the bearing area, temporary in character, which lasts only until the compression of the material within it has increased the internal friction to such an extent that equilibrium is established and flow ceases. The soil has been readjusted to its new condition by further consolidation and any active pressure disappears.

According to this article, where the cohesive strength was low and the fluidity high the shearing strength on the perimeter of the shearing plate was very small and the pressure bulb appeared at once. "The fluid characteristics of this soil make it relatively incompressible. If this material could be effectively confined, its bearing capacity would be greatly increased, but the very low cohesive strength does not furnish enough confining influence to make it suitable for carrying foundation loads. Consolidation of the material within the regions of inequality of pressure takes place very slowly, if at all. Foundations in this type of soil may never get beyond the temporary stage of the pressure bulb, but will be slowly settling over a long period of years. Bearing capacity in this type of soil is limited by the allowable rate of settlement, and the possibility of establishing equilibrium through the low cohesive power of the soil aided by the static head of the surrounding body of earth."

I have quoted at length from this article, as the discussion of these phenomena of plastic flow is distinctly applicable to the problem of fill settlement in peat marshes. This problem is of particular interest to those of us whose work lies in glaciated territory. Most of us in laying out roads have always avoided locations across open water in lakes, and yet we have many times run a line across a peat marsh with an innocent looking surface which proved to be almost as bad as open water would have been. In some instances, the results have been even worse, because of the fact that settlement occurred later on, necessitating frequent and expensive repairs.

This situation is caused by the flow of the peat from beneath the fill material in much the same way as has been described in the foundation tests. There is a definite load which the peat will carry and when this load is exceeded flow starts. As was noted in the bearing area tests both by Goldbeck in work done for the Bureau of Public Roads, and by Housel in the Wayne County work, total load plays a very big part. In many instances, where a narrow fill has satisfactorily carried the traffic for years without appreciable settlement, widening will cause flow to start and very serious settlement occurs. This is the case even where the grade was not raised to any extent and where comparatively large amounts of earth were placed in the original roadbed.

There is a difference, however, which alters the conclusion that materials lacking any very great cohesive force and of high fluidity, will not consolidate. Time is a large element in this consolidation, and if the material subjected to pressure remains for a considerable time under this pressure before relief may be obtained by a vertical expansion, there will be considerable consolidation. This means that the thickness of the peat layer beneath the fill largely determines the amount of settlement which will take place before equilibrium is established, both by the consolidation of the peat and by the static head of peat heaved up at the side. Therefore in filling peat marshes there is no particular cause for alarm when heaving begins. In fact, in deep deposits there should be much more concern shown if, after considerable fill material is placed, no heaving appears.

Fills across Peat Marshes

A great deal of work has been done in the investigation of fills on peat marshes in Michigan. This problem causes us considerable trouble, as the peat deposits are very widespread in our state and many times we must cross them in spite of the knowledge that we might almost nearly as well cross open water of the same depth. About 3% of our paved mileage is on this material.

In 1925 we made a fairly complete examination of a large number of fills over these deposits, with depths ranging from 1 to 66 feet. It became evident almost at once that the depth of the peat was by far the most important factor in determining the depth to which the fill would penetrate the peat. The character of the peat material did not seem to have such a marked effect, although there was a considerable difference observed between the effects of fill over peat and over lake clays. The slope of the mineral subsoil beneath the marsh deposit was also found to affect quite markedly the amount of fill material necessary in these places, since there was always a tendency for the fill material to flow down-hill. A diagram was prepared from the data given by the large number of cross sections examined, and an average curve gives the penetration to be expected for each depth of peat. A separate curve was necessary in order to determine the effect of lake clay. This purely empirical analysis indicated that the fill settlement increased uniformly in rather small amounts up to a depth of about 20 feet. As the depth exceeded 20 feet, the penetration increased very rapidly, until at 26.5 feet the peat was practically all displaced and the fill material reached the bottom instead of practically floating on it as in the shallower depths.

The shape of the cross section of the fill in this earlier investigation was nearly uniformly within vertical lines drawn from the toe of the slope at the marsh surface down to the bottom of the deposit. In most cases the bottom of the earth mass was less than the top in width by approximately the amount of the horizontal projection of the side slopes from the shoulder to the marsh surface. In 1927 and the early part of 1928 it was discovered that we were in some cases underestimating very greatly the amount of fill material necessary for certain deep peat deposits. It was quite evident from the amounts of overrun reported that there must be some swelling out beyond the vertical below the marsh surface.

A special study was then made of the deeper deposits and 60 more cross-sections were taken in eleven different marshes. It was quite a blow to our preconceived notions of how these fills should act to discover that in a number of instances there had been a considerable amount of lateral displacement taking place far beyond the vertical line below the toe of slope. The older locations which were the basis of the former study were again examined, and in two instances it was found that the cross-sections taken had just missed the points at which some swelling had occurred.

Two cross-sections showing this phenomenon are given in Figures 1 and 2. Figure 1 shows the fill made by dumping from a trestle, with the material hauled with industrial railway equipment. The fill material is a fairly heavy clay becoming plastic with higher moisture content. As will be seen, displacement took place laterally for a distance of about 130 feet on one side, following the slope of the hard clay

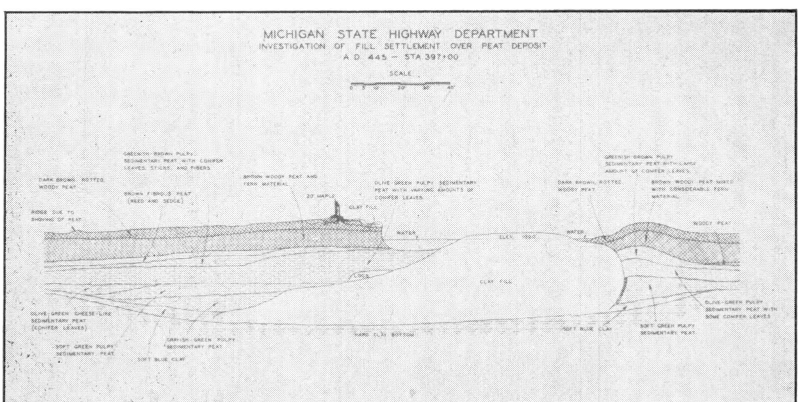

Fig. 1. Fill made of heavy clay by dumping from a trestle.

bottom. This was the fill which showed the most displacement of any one of those examined, and it will be noted in the cross-section that the depth of sedimentary peat both of a pulpy and cheeselike character is very great. This sort of material flows very readily, on account of its highly colloidal content. Compaction of this material is very difficult, and little resistance to the plastic flow of the fill material, much of which was dumped directly into water, is afforded.

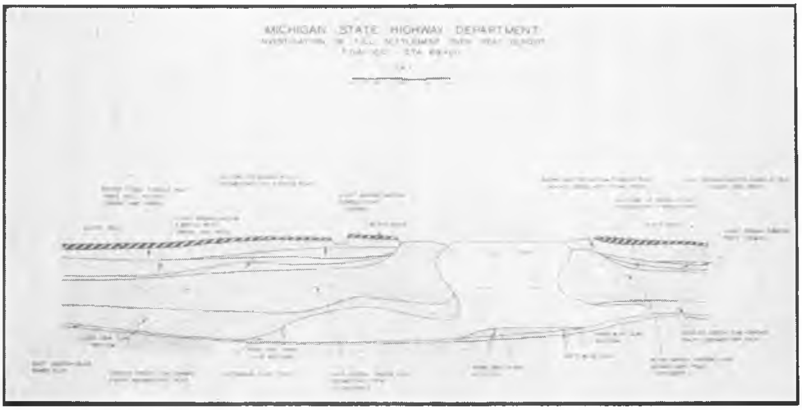

Fig. 2. Plastic flow of the fill material spreads out along the bottom.

Figure 2 shows quite a different phenomenon of the plastic flow of the fill material in that the material spreads out along the bottom for a long distance without any serious flow at the higher levels. Here again, we see very great depths of the highly colloidal types of peat; and, as in the former case, the fill was made from a trestle with industrial railway equipment.

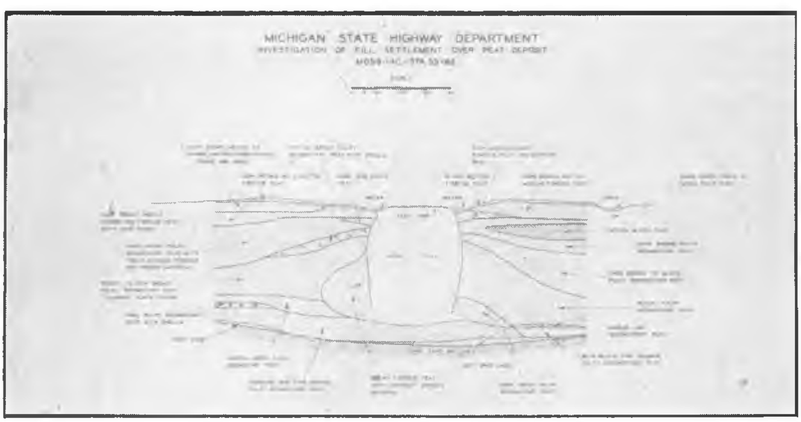

Fig. 3. Fill made of coarse sandy material.

Figure 3 shows a fill made with sandy material where the depth is very much greater than either of the other two cross-sections shown. The fill material here, however, was a very coarse sand; and in spite of the fact that the depth of sedimentary peat is very great, only a small amount of lateral displacement has taken place. This fill was made with trucks from a runway established on the old corduroy road in existence when the fill was started. It appears probable that the use of non-plastic material in this fill has very greatly reduced the tendency to lateral flow; and, in addition to this, the use of trucks over the material in the later stages of construction tended to compact the material going in. If the material had been of a plastic nature, it is probable that the compaction afforded by this method of placing would have materially reduced plastic flow. In ten out of twelve cases where lateral flow occurred, the fills had been constructed with industrial railway equipment, with no means of compacting the fill as it was placed. The use of teams or trucks insures a considerable amount of compaction while the fill is being deposited, and from present indications it appears that wherever possible this method should be used during construction.

It has been our policy in filling over peat marshes to insure as complete settlement as is possible during the construction so as to minimize the amount which is liable to occur later. In the case of the deeper deposits no special methods are necessary in obtaining complete penetration, except that of destroying the top crust by ditching or blasting before the fill is placed. The most difficult depths to handle are those from about seven or eight to twenty feet. These deposits are not deep enough to insure complete penetration by loading alone and too deep for us to follow our common practice of excavating and removing from the roadbed peat up to seven or eight feet in depth. When the depth becomes deeper than this the plastic peat flows into the trench to such an amount that this method is impractical. It has been found, however, that the use of dynamite along the edge of the fill after it has been heavily loaded, will, in many cases, insure considerable further settlement and aid in compacting the material which may be left beneath the fill.

Using Dynamite to Settle Fill

At the present time we are putting down holes ten feet apart along the shoulder line by means of the driving of scrap water pipe fitted with a wooden plug at the lower end. This pipe is driven to a point about half way between the bottom of the fill material and the bottom of the marsh. The wooden plug is then driven from the pipe and a half stick of dynamite exploded in order to create a pocket in which the rest of the dynamite may be placed. From twenty to thirty sticks of

50% straight nitroglycerin dynamite are placed in this pocket and from one hundred to one hundred and fifty feet of road shot at the same time. This is very effective in forcing the fill down and compacts the peat to a remarkable degree.

The method of filling is different in the intermediate depths as well, as two separate fills are used at first and every effort is made to drive these wedges of earth down as far as possible, both by an excess of loading and by the method of blasting just described. After these fills are driven as deep as possible, the center is loaded with the excess dirt and left to settle. This excess is later spread out to form the finished roadbed. There is some question as to the advisability of this method without some revision. In one or two instances some settlement has occurred in the center, and in another case the pressure of the center loading was sufficient to force the two wedges apart. It is therefore difficult to decide on just how far this loading may go in order to compact the peat sufficiently and still not increase the yardage by driving the two wedges apart. Further investigation along this line is necessary in order to determine whether or not this method should be abandoned.

Landslides

A further manifestation of the effect of plastic flow on highways is shown in the landslide so common in southeastern Ohio, southwestern Pennsylvania, and northwestern West Virginia. A thoroughgoing study of this subject has been made by George E. Ladd, Associate Economic Geologist, of the U. S. B. P. R., and is reported in the April, 1927, and October, 1928, issues of *Public Roads.*

According to Mr. Ladd, landslides exhibiting the phenomenon of plastic flow are the predominant type in the area studied. The material composing the slide is usually a mixture of shale and sandstone detritus which varies in clay content from small to rather large amounts. Even in cases where the clay lubricant was nearly absent and the fine particles were largely composed of sand and silt, their form was highly rounded. This shape of the particles accompanied by a high water content creates a quicksand condition which permits a movement quite as free as that in material in which there is a higher percentage of clay.

Masses of this material on the hillsides become unstable when the moisture content exceeds a certain critical point which varies with the character of the mass. The increased water content not only increases the lubricating properties of the materials, but adds weight to the mass; and when the internal friction is overcome by the shear forces arising from gravity, the whole mass slides down hill. Not only does this movement affect material outside of the construction lines of the highway, but cut banks and side fills composed of this material are also subject to it. The remedy is, of course, the maintenance of a water content below the critical amount wherever drainage can be effected.

Effects similar to these landslides have been observed in the use of materials for heavy fills which become plastic in the situation in which they are placed. This is especially true of very fine sands and extremely fine-grained or, one could well say, highly colloidal clays. Some of these materials when placed on a 1½ to 1 slope begin to flow, the slope bulges, and when a sufficient bulge has occurred a slough of the material follows. Since this action steepens the slope above the slough, more flow and sloughing follows. The only remedy for this situation is to place the material on a slope flat enough to stand, or, if large quantities of it must be used with some small amounts of better material available, place it in the interior of the fill and cover the sideslopes with a heavy blanket of the material which will take a steeper slope.

Some plastic flow also takes place beneath road metals, especially where the moisture content has been greatly increased during freezing and subsequent thawing. The material flows out from beneath the edge of the slab under heavy loads, leaving it unsupported, and breakage then occurs. The thickened edge undoubtedly helps some to confine this plastic material, but much better results are secured in using a width adequate to keep heavy loads away from the edge, thus eliminating or reducing the flow. This explains one of the reasons why we are successful in decreasing our thickness of pavement below that which good rural design calls for, in cities where we use wider pavements with curb and gutter.

The flow of soil material beneath traffic loading is by far the most important subject connected with pavement failure, and yet it has been scarcely recognized. We say that a clay soil when the "frost is coming out of the ground" has practically no bearing value. Water contents are observed which are far above anything which may be produced by saturating the unfrozen material. This clay and water mixture becomes practically a clay suspension, and as such is, when confined, almost incompressible. What, then, may we learn from studies of the compressibility of a soil in this state? The cohesive power is practically zero and the fluidity enormously high, and for this and moisture contents much below it we need fundamental knowledge of the laws of plastic flow in cases in which the material beneath the load is free to move.

Expansion of Frozen Soil

Besides plastic flow, there are other soil movements of great importance affecting highway work. The direct forces resulting from the expansion of frozen material are productive of much damage to both rigid and non-rigid surfaces. Pavement is heaved and broken, macadam is pushed up in a mound in which all bond is broken, gravel is humped up and the traffic bound crust destroyed. When thawing occurs, the broken surfaces go back into place over a material which is about the consistency of a good, thick pea soup. Flow of the material at once takes place and serious damage results.

It was pointed out in an article on the "Causes and Cure of Frost Boils," by G. C. Dillman, in the 1927 Proceedings of the National Research Council, that direct expansion from the freezing of soil was not sufficient to account for frost heaves. There must be an addition of water to the affected place while the soil is still frozen in order to produce vertical movements in the amounts observed. This addition, it was said, may occur in a number of ways: first, from the water contained in the soil itself, with additions from the unfrozen material below, by the freezing of ice in the capillaries; second, from an actual water flow under hydrostatic head through porous soil near the frost heave; third, from the thawing of ice underneath the pavement and the flow to the affected place by gravity. It is possible that a fourth might be added in the transfer of water vapor from the warm region of high pressure below the frost line to the colder low-pressure surface.

While the foregoing reasons serve to explain the existence of frost heaves, only those which are predicated on a transfer of moisture directly through the frozen soil can serve to explain the supersaturation following these heaves in a heavy soil. This is quite evident when it is considered that in many clay soils percolation of the water downward is practically an impossibility, especially in a clay already filled with water to normal saturation. There would then be no chance for the water formed on the thawing layers of ice between pavement and soil to add anything to the water content below, unless the soil were already practically a liquid suspension.

Further evidence along this line is had from an unpublished study "Investigation of Slab and Subgrade Movements under Low Temperature" made in Illinois during the winter of 1923-1924. Mr. Clemmer observed that "the moisture content (of the soil) will also follow the temperature cycle very closely, being much greater during freezing periods than during the warmer months, regardless of the amount of rainfall and coming back to normal after the frost leaves the ground in the spring of the year."

This phenomenon of moisture transfer through a frozen soil is to be investigated at Ann Arbor by the Michigan State Highway Department, in cooperation with the University of Michigan. A cold room capable of carrying a sustained temperature of more than 20°F. has been built in which to do the work. Soil cylinders 36″ long extracted from actual frost heaves will be placed in this room and a definite frost line maintained within the soil. These cylinders will be kept frozen for long periods and the moisture contents near the surface determined from time to time. In one cylinder capillarity will be free to act; in another it will be broken so that it will be possible to determine whether or not the action is largely a transfer by capillarity by water vapor rising through the soil. This question is highly practical, as the results secured from it will, to a large extent, determine the proper subbase material to be used to correct the situation arising from frost heaves.

Other soil movements are of importance to highway engineers, although they are by no means so productive of difficulty as those which have already been discussed. These other effects are largely erosive. The first is the effect of frost on masses of rock overhanging the highway, or on slopes so steep that when the forces of frost break loose the rock, particles are precipitated on the highway. This causes considerable trouble in mountainous territory, but is not a phenomenon which is of a great deal of interest to us in the Mississippi Valley.

Another erosive effect, however, which is of a great deal of importance is the movement of sand under the action of wind in the dune area. These sand dunes when denuded of vegetation begin to move under the influence of the wind with a movement which is practically irresistible; trees and buildings are buried beneath the advancing mound of sand, and there seems to be little which we can do to stop it. In some cases snow fence has been used to pile up the sand near the crest of the dune. This sort of process cannot be continued indefinitely on account of the fact that when the height of the drift formed is sufficient to bury the fence another fence must be placed on top of it, and that finally the slope of the sand material becomes so great that any further raising of the crest height by means of the fence simply means that the sand will slide down hill, rather than blow over the crest. The only real remedy for stopping the advance of sand dunes lies in the restoration of some sort of vegetation which will hold the sand in place.

The erosive effect of running water is also a soil movement which is productive of some trouble to highway engineers. Since certain classes of soil, light in texture, are very easily affected by running water, serious washouts may occur after heavy rains. There is one routine soil test which gives a very good indication of the behavior to be expected of the soil from the results of the test. This test is known as the slaking test, and simply consists of measuring the time taken by a compressed disk of the soil to slake away in a water bath.

It is the only one of our so-called routine tests which, to my knowledge, has any direct bearing on the highway engineer's problems.

All of the phenomena spoken of so far in connection with soil movements are capable of a common sense solution without any highly technical laboratory soil studies. Fundamental knowledge of the laws of plastic flow is desirable but by no means indispensable in attacking the problem. When it comes to the question of the effect on pavement condition of soils which are more or less intermediate in character, it is thought by some that the laboratory study affords a practical means of attack. I am extremely doubtful as to whether or not anything but a statistical solution of this problem is possible.

Variations in Soil

Many engineers have the idea that a soil is a simple material, when, as a matter of fact, it is a vertical profile of different classes of material, which, for purposes of classification and identification, are known by the manner in which the varying layers are arranged. These layers differ from each other in color, texture, structure, and composition, both physical and chemical. Variation in the characteristics of the various soils is noted by type names. The nomenclature used is universal throughout the United States and is kept uniform through the agency of the U. S. Bureau of Soils, to which all new types are referred for correlation. Profiles of mature soils in our climate consist of an upper layer of extraction called the "A" horizon, from which clay and silt has been removed by mechanical transfer, leaving it lighter in texture; and second, of a layer of concentration called the "B" horizon, which is heavier in texture, because of the silt and clay concentration caused by the removal of this material from the "A" layer. The parent soil beneath the "B" horizon is called the "C" horizon and is the original geological material which, in most of the northern United States, consists of glacial drifts and settlements. For engineering purposes it has been found necessary to add a "D" layer in cases in which the parent soil is directly underlain by a different type of geological material.

A brief description of the Wausau silt loam found in Michigan will give an idea as to the variations in texture to be found in a single soil profile. The top eight to twelve inches consist of a dark brown soil containing a high percentage of humus; below this is from four to six inches of a brown silt loam whose coloring is derived from the humus; below this horizon is a compact, tight clay from yellowish brown to reddish in color, varying in depth from seven to eighteen inches; and underneath this is a gravelly open substratum extending for considerable depths below.

The practical impossibility of determining the effect of this soil on pavement from a laboratory study of the physical properties of samples of this soil is perfectly apparent. In order to have an adequate idea of the physical properties of these soils, at least four samples would have to be investigated. If we wish to know the relative effects of the physical properties of these soil horizons on each other and on pavement which may be laid on any part of this variable profile in going from cut to fill or in cuts of varying depth, it can easily be seen that the mathematics of soil mechanics might become somewhat complicated.

The only way in which we may hope for a knowledge of effect of the different types of soil on pavement structures is by careful correlation in a statistical way of the soil type with the design of pavement. In this statistical study it will be necessary to take into account all of the factors which may to any considerable degree influence the condition as it exists at the time of the investigation. Obviously the design of the pavement cross-section, the underdrainage of the subgrade, the depth at which the pavement is laid in the soil profile, the edge of the pavement, the grade on which it is laid, the height of the water table—in the case of some sands, the strength of the pavement as shown by the mix used, the presence or absence of steel reinforcement, and many other factors must be taken into account in a study of this kind. In order to be able to study the effect of a single variable, all of the other factors must be the same when the effect of this variable is studied. Soil types vary within comparatively short distances, as do, of course, grade, underdrainage, etc. Work of this kind involves a slab by slab comparison, rather than the study of a considerable stretch of pavement, as is so often done to the exclusion of the other factors which have an important bearing on the problem.

In consideration of the number of factors involved, it is easily seen that a very large mileage of pavement must be gone over in order to get a sufficient number of examples in which the factors concerned are the same. This is a tremendous job; and without the aid of modern mechanical means of sorting and assembling, this sort of data could be classed as nearly impossible. It is being attempted in Michigan with these mechanical aids, and within a year's time we will know to a definite certainty just how much can be done with this sort of study. It is a question of the use of a great many examples in order to show a definite trend of the average. For a long time to come it is doubtful as to whether or not any other solution of this particular problem is possible.