We are indeed fortunate that nature has provided certain determinable factors to influence the formation and disposition of soils. Since we know that a fairly systematic arrangement of this material does exist in the field, we have but to convert this knowledge into engineering terms in order to apply it to our soil problems. Of course, the conversion is not as simple as the preceding statement implies; nor will this procedure supply data for the solution to all our problems arising from the use of soils. Nevertheless, it is a logical means for enlarging our store of highway-engineering knowledge and making it more useful to ourselves and to others who have similar interests in soils.

What is it we wish to know about the soil that will tell us more than does a pedological name such as Brookston, Miami, or Crosby? First, the soil should be identified and classified on the basis of accepted engineering tests. For instance, the B horizon of Brookston must have a meaning in terms of natural density and moisture content, liquid limit and plasticity index, or perhaps grain-size distribution. When the properties of the material are expressed in that manner, we can recognize it in the light of engineering usage. But further than that, we need information concerning the physical characteristics that determine the behavior of the material in the field. The strength of the soil as measured in compression or shear tests, the relative resistance to flow of water measured in permeability tests, the rate and height of capillary rise of moisture in the soil, the compaction characteristics of the soil, etc., are all desirable and sometimes necessary parts of the tie between pedology and engineering.

One needs but to observe soils in place to tell that there are some differences between any two horizons, just as there are differences between any two types. Added to these variables are the changes in the properties of a soil caused usually by the altering of its natural structure, its density, or its moisture content. In highway construction these factors are constantly involved. Thus, before we can really know the engineering properties of natural soil formations, we must determine how the soils are influenced by these factors. This, of course, requires tests under numerous conditions, for the combinations of soils and variables make possible an almost unlimited number of situations. The work involved may be reduced, however, if the tests and test data are planned and interpreted in accordance with the probable use of each soil
type. And this probable use can be determined to a great extent by the location, the topography, and the amount of area covered by the soil.

The natural structure of most of the soil types is exceedingly complex. Thousands of years were required for these structures to be formed, and they cannot be duplicated by man. A change in the structure of a soil, especially one that is plastic and fine-grained, causes extensive changes in its characteristics. Once disturbed, this soil will not—at least during our lifetime—resume its original structure or characteristics. Sometimes it may be necessary yet not desirable to change the structure of a soil by disturbing it; likewise, it is possible that with some materials the disturbance or recompaction may not be necessary, but may prove to be desirable. Variations in moisture conditions are common to soils in the field, and this factor has been given considerable attention in recent years, especially from the standpoint of compaction. Yet, little is known concerning the effect on other properties than compaction caused by high-moisture contents. This is true especially for the saturated state, when the soil is as wet as it can possibly become. Undoubtedly, saturation is the critical moisture condition, as nature shows us in the spring when the soil sometimes contains maximum moisture and apparently has minimum resistance to destructive forces.

The results of strength tests on a few common soils well illustrate the fact that characteristics of soil do vary with types, with horizons, or with changes in structure, moisture content, and degree of compaction. The influence of differences between types and horizons is of varying magnitude, as may be shown in a comparison among two horizons of Delmar and one similar horizon of both Clermont and Abbington. In location and origin these soils are quite dissimilar, though the topography is about the same in each case. The Delmar occupies nearly level, upland till plains in early Wisconsin-drift areas, while the Clermont is of Illinoian-drift origin, lies in flat, upland regions, and has much poorer internal drainage than does the Delmar. Typical location for both of these soils is southeastern Indiana. The Abbington is different from either of the others in that it is found in old glacial lake or river beds and has a much greater content of granular material. This particular material was sampled in northwestern Indiana, although deposits of Abbington are not confined to that area.

The stress-strain curves in Fig. 1 are graphical representations of some of the data obtained from laboratory compression tests on these soils in their undisturbed states. In the tests the soil samples were supported laterally by a hydrostatic pressure while they were loaded longitudinally with a force that was increased until the material failed either by a decrease in the load that could be supported or because of
extreme deformations. Since the specimens were all of equal dimensions, the stresses could be expressed in terms of total loads, and the strains could be noted as inches of deformation in the material caused by these loads. One similarity between the laboratory test loading and a typical field condition—both having the element of lateral support—is indicated by sketches accompanying the stress-strain diagrams.

The curves show that the maximum strength of the Delmar B horizon was almost four times as great as that of the A horizon of the same soil. The deeper B horizon material was unusual in that it was sampled from a dense clay pan, while the soil from the A horizon had a loose structure common to materials near the ground surface. Thus, this comparison is not one for average conditions, because in most soils the difference between materials in separate horizons is not so pronounced; however, these extreme conditions do exist. The compressive strength of the Clermont B soil was about equal to that of the Delmar A material, although the fact that the Clermont deflected more under moderate loads than did the Delmar A, shows that they were unlike in strength characteristics. The maximum stress in the Abbington sample was intermediate, but when this soil is compared with the Clermont, it must be considered relatively strong. Naturally, these soils were not all equal in density or moisture content; but again, if we are to deal with natural soil structures in the

Fig. 1. Stress-strain curves and loading analogy obtained from triaxial compression tests on natural samples of different soil types.
field, it is important that we know the characteristics of the soils in their existing states.

For a comparison of the effect of breaking down the original soil structure and remolding the material or of increasing its moisture content, consider the case of the Miami soil. This material, common in the Wisconsin-glaciated section of central and northern Indiana, occupies the higher and better-drained areas in regions of rolling topography. In Fig. 2 are shown stress-strain curves through compression tests on samples from the B horizon of this soil. The samples were confined laterally and then loaded to failure in the manner previously described. Results of tests on six specimens are included. Of the six samples, two represented the material in its natural state, two were prepared by merely destroying the natural structure and remolding the soil to its original volume, and the last two consisted of soil recompacted to the maximum unit weight and corresponding moisture content determined by the Proctor compaction test. Each of the specimens had an original moisture content approximately 80 per cent of that required for saturation of the soil. However, the moisture content of three samples—one of each type—was increased to about 90 per cent of saturation or more before they were tested in compression.

The curves on the left represent the three specimens having

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**Fig. 2.** Stress-strain curves obtained from triaxial compression test on samples of Miami B horizon having varied conditions of structure, density, and moisture content.
the lower moisture contents. It is seen that by simply remolding the soil the strength of the material was slightly reduced. The remolded soil had less stiffness also, since it deformed more under a given load than did the natural-structure sample. On the other hand, when the soil was recompacted to the increased unit weight, both the strength and the stiffness were increased considerably.

The stress-strain relationships for the three samples having the higher moisture contents (the curves on the right) indicate that there were considerable decreases in the strength of the samples caused by increasing their moisture contents by a relatively small amount. Again, the natural-structure specimen had a strength slightly greater than that of the remolded material and, as before, the recompacted sample of greater density was the strongest of the three, although it was practically saturated while the other two were not. Another effect of increased moisture was the loss of stiffness in the soil. All the samples that had higher moisture contents were deformed more under relatively light loads than were the samples having lower moisture contents. This matter of deformation cannot be disregarded, for excessive deformations in many cases may constitute failure even though the soil may not be stressed to its capacity. The recompacted soil, as the curve on the left shows, will, when 78 per cent saturated, almost reach its maximum strength at 7 per cent strain. This strain in a seven-inch depth represents a deformation of about one-half inch. If the soil is for some reason limited to this amount of deformation, then on the right the curve for recompacted soil 97 per cent saturated shows that the soil has failed to reach its maximum strength at 7 per cent strain. It appears then that, when the soil is almost saturated, its maximum strength cannot be utilized. This limitation would be even more severe on the natural and remolded samples, and the effect of complete saturation on the strength and stiffness of the soil in these two conditions can easily be pictured.

The results that have just been presented show some of the strength and deformation characteristics of this soil. The results of all the engineering tests combined give, to the best of our knowledge, at least part of the engineering characteristics of soils. If the results of other tests on the Miami soil were shown, it would be seen that variable conditions affect other characteristics to greater or lesser degrees. The important thing to be considered, however, is the application of these results to field conditions. For example, the tests must have significance in terms of cuts and fill, borrow and waste, embankment and subgrade, etc. Visualize a common cut-and-fill section with a profile including both high and depressed places on an upland area and slopes leading to lowlands in a stream valley. In this situation it is probable that the fill in the lowlands will be made at least partly with
material taken from the cut. In other words, some of the soils will be loaded in their undisturbed states, and some of the soils will be disturbed and recompacted before being loaded.

The compaction characteristics of the soil or soils in the fill determine the density to which the material will be placed. Capillarity, permeability, and consolidation tests should indicate the probable moisture contents and rate of settlement, if any, that will occur after the fill has been made. The results of the tests, if they are to be practicable, must, of course, be modified by information concerning underlying materials, ground-water table, floods, and similar conditions. Strength tests, and possibly tests for expansion and shrinkage, on the recompacted soil at the condition it will likely attain in the field will indicate in advance whether the material is desirable fill for the location. Eventually, the strength-test data should be an important factor in the design of the pavement for this condition.

The tests may show also that it is desirable that the materials in the cuts or near ground elevations be recompacted in order to improve their strengths and drainage properties. In sections where poor soil must be replaced with better material, it may be that suitable borrow can be found nearby if the soil map is available and the characteristics of the mapped soils are known. These, of course, are but a few of the many factors that may be involved in such a field situation.

Knowing that topography is a major influence on the formation of soils, we can predict the condition in which the soil will probably be used for highway construction. A thorough record of the engineering characteristics of many soils combined with pedology and maps that locate the soil types in the field provides a good basis for analysis of our soil problem. In fact, it appears that these factors form a natural combination. To make this combination more complete and more workable is one goal for future highway research.

CHERT AS A DELETERIOUS CONSTITUENT OF INDIANA AGGREGATES

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The term “chert” has been applied to many types of rock. However, it is now usually restricted to rocks composed predominantly of micro-crystalline silica that are opaque except in thin sections. The distinction between chert, flint, opal, and chalcedony is not clear-cut; but the term “flint” is usually applied to black varieties of micro-crystalline silica; opal is a hydrous, amorphous form of silica; and chalcedony is a translucent, microscopically-fibrous variety of quartz.