Another larger structure which is somewhat unusual is a 54-foot oolitic limestone arch bridge, carrying a stabilized gravel road 22 feet wide with a five-foot sidewalk on one side. This bridge spans McCormick's Creek a few hundred feet above the falls and carries the picnic ground road from the hotel to the Beech Grove area. This structure was built by the CCC camp which was located there for a two-year period.

PROGRESS IN SURFACE AND SUBGRADE STABILIZATION

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A thorough discussion of the subject of my talk would far overrun the allotted time, and I shall confine myself, therefore, to a hasty glance at past history, a review of our present practices, and perhaps a few suggestions as to the tendencies of the near future.

Accomplishments in the past have been retarded by a lack of a measure or yardstick for determining the relative values of respective soils. More recently, however, the U. S. Bureau of Public Roads has classified soils into groups easily identified by laboratory test, and various state highway commissions, the Highway Research Board, and other units have co-operated in the utilization of this classification in their investigation of subgrade and deep foundation conditions. The last five years have shown definite progress, and added information will become available at an international conference on soils and foundations to be held in Boston this summer.

According to the U. S. Bureau of Public Roads, as reported at the 37th annual meeting of the American Society for Testing Materials, the general status of soil investigation to date is as follows:

1. Disturbed soils and those close enough to the surface of the ground to be influenced by change of moisture, temperature, frost, etc., are tested in a dried and powdered state for shrinkage, plasticity, and similar properties, which disclose the characteristics of the soil constituents exclusive of soil structure.

2. Soils to be stabilized with admixtures or manipulation in practice are tested in samples prepared according to the construction procedure for properties required in stable fills, subgrades, and road surfaces.

3. Soils located below the line of seasonal change are tested by means of undisturbed samples in the laboratory, or by loading the soil in the profile for such engineering

properties as compressibility, elasticity, and stability which are furnished by both soil structure and soil materials.

4. Soils located below the line of seasonal change, whose structure is disturbed by the penetration of piles or other construction operations, are investigated by loading test piles in place, or by remolding samples from natural structure and at natural moisture content in the laboratory.

INDIANA STUDIES

In Indiana, our work has been confined to the first two of these groups, i.e., subsurface soil classification and the treatment of soils to acquire their maximum density in fills, subgrades, and secondary surfaces.

Recognizing the very apparent need of improvement in our own construction practices, the State Highway Commission of Indiana, through its Bureau of Materials and Tests, established a soils laboratory in the spring of 1934. During the first few months the efforts of this section were devoted to the study of clay-aggregate stabilization primarily for low-type surfaces. This work was soon extended, however, to include a definite program of investigation and improvement of subgrade conditions under both high- and low-type surfaces.

The value of moisture control in both subgrades and surfaces was indicated at an early date. Water, which is such a necessary part of most construction, becomes a definite agent of destruction if disregarded at a later date. Therefore, subsurface drainage studies were added to the program.

For the prosecution of this work it was necessary to develop both laboratory and field forces. These two groups work in conjunction with each other under a more or less definite schedule of operations. Field survey parties working under the direction of the Bureau of Materials and Tests make substrata investigations with soil augers at questionable points. Any unusual conditions of soil stratification and water seepage are noted. When borings disclose that trouble would be encountered during construction, the strata are carefully mapped for the purpose of studying the soil conditions. It is then possible either to devise an adequate drainage system or, if drainage would be impracticable, to strengthen the base.

Because soils shrink, swell, become unstable, and even flow under changing moisture contents, we have placed most emphasis on the determination of high-water tables. If a cut is made through a hill and the grade intersects water-bearing strata, it is absolutely necessary that the moisture be prevented from *reaching* the subgrade. This condition is corrected by the interception method. Drains are placed down the side ditches or across the subgrade at points determined by the soil survey party. In many cases it is possible to protect the subgrade by placing but a single line of drains down one side ditch. Systems as simple as this, of course, are somewhat unusual but can be satisfactorily used when a porous stratum intersects the center line of the road at an angle and the flow of water is across the road. In all cases it is necessary to determine the direction in which the water is flowing. If there is any doubt, the unstable area must be completely boxed with drains. For best results the water table should always be three or more feet below the subgrade. It is customary to backfill these drains with some porous material such as gravel or stone.

Another function of the field survey party is to sample carefully the various soils found on the project. These are then taken to the central soils laboratory and analyzed according to the tests devised by the U. S .Bureau of Public Roads. In general, this amounts to checking the soil at various moisture contents and determining the action at these points. It is possible, after making a complete test on the soil, to determine its shrinkage, plasticity, capillarity, and elastic properties. The laboratory tests must be carefully correlated to the field conditions. A silty soil in a rolling country having a low water table will make a fairly satisfactory subgrade. The same soil in a flat country with a high water table would be very unstable in this climate.

We are fortunate in Indiana in having soils which if kept fairly free from water make satisfactory subgrade materials. Fortunately, soils high in mica content, or elastic, as found in the eastern part of the United States, are absent in Indiana. Most of Indiana was covered by the glaciers at an early geologic period. The glacial till is non-uniform in composition, with the result that ground water is liable to flow in almost any direction. These areas must be very carefully investigated in order to prevent unstable conditions formed by excessive water content. It has long been known that, under certain moisture contents, ordinary soil containing a low amount of organic material can support almost any highway load. If unprotected, rainfall will enter the soils because of gravity and capillary attraction. Since most soils change volume with an increase in moisture content, it is very necessary to seal the surface of both high- and low-type roads. In many cases a road may be satisfactory during the summer and early winter months but fail when the moisture of spring thaws causes the soil to become unstable.

DEFINITION OF PROPERTIES

Before going further it might be desirable to define the common properties of soils as related to engineering design. We have acquired the habit of referring to stabilization as a method of combining soils, aggregates, and binders so as to provide a dense, partially impervious material which may be laid and compacted for use as a subgrade or surface. Actually, "stability" is only one of five major characteristics which a soil possesses in varying degrees, and our conception of stabilization is that of a mixture so designed as to include each of these characteristics to the best advantage for a permanent, uniform, material structure.

These qualities may be named as follows:

1. *Stability.* Stability is the property of a road or subgrade which enables it to resist lateral flow when subjected to a load. This property is due to the single or combined action of internal friction and cohesion. Internal friction is the property of granular particles which causes them to resist sliding over each other. Cohesion, or the tendency of particles to adhere to each other, is due either to the natural stickiness of clay or to small moisture films. In a given unit of soil containing moisture and voids, if the moisture films and voids are small enough, the soil will be stable. As the thickness of the moisture film increases, the particles will become lubricated and give, therefore, a loss in stability. Wet soil, on drying out, will pass through the liquid, the plastic, the semi-solid, and into the solid state as the moisture content decreases. It behooves the engineer, then, to retain the soils in the solid state.

2. *Compressibility.* That quality which permits a permanent decrease in soil volume when subjected to a load. This is due to changes in the void content.

3. *Elasticity.* Elastic soil will deform under load, but will later rebound to nearly its original position upon removal of the load. This type of soil is very unsuited for macadam or flexible type road construction inasmuch as it destroys internal friction and cohesion. Our Indiana soils, when elastic, are so because of excess moisture content. Many soils containing mica are elastic because of the character of the soil particles. As far as we know, we do not have this type of soil in Indiana.

4. *Permeability.* The permeability of the soil is a function of the void content and natural conditions of beddings. Permeability determines the rate at which free moisture rises and falls in a given soil. This property in most cases can be changed by manipulation with construction equipment.

5. *Capillarity.* The capillary properties of a soil are a function of the grain or pore sizes, the height of the water table, and the resistance to flow offered by the soil particles. It has been found that the capillary rise in sand is exceedingly rapid. However, because of the large pore sizes, the rise is very small, in some cases having a maximum of 18 or 19 inches. The capillary rise in finer materials is much

slower, with the result that high capillary properties are not always harmful. This is so because the slow rate of movement permits the dissipation of excess water before damage is done. It has been found that the material most endangered by capillary water is silt, because the rise is both rapid and high. Clays, of course, have the highest capillary properties, but in them the rise is so slow that it is not as a rule dangerous. Moisture in silty soils will freeze and cause a change in volume resulting in frost heaves and unstable areas. It has been found that in finer materials, such as clay and colloids, water does not freeze in a normal manner. In fact, there are some indications that water contained in the soil pores of the smaller capillary dimensions will resist freezing at temperatures as low as 70 degrees Centigrade.

The investigation of soil mixtures and admixtures for highway construction consists of combining natural materials, with or without the addition of the chemical, bituminous material, or other binder. It has been found that natural materials, generally available in Indiana, can be combined to form a stable base under a bituminous surface, or can be used as a secondary road surface. A mixture (Figs. 1-5) of crusher-run stone or bank-run gravels, with a predetermined amount of soil binder will, in effect, water-bind these materials. The application of a roller (Fig. 6) or the action of traffic will compact this mixture very quickly into a stable condition. We all know from experience that many of our old county roads are smooth and firm, providing satisfactory farm-to-market highways. However, they have not reached this condition over night or even in one or two seasons. It has required years of traffic and maintenance to get them compacted. The soil engineer has investigated this type of

Fig. 1. A stabilization project in Lenawee County, Michigan, illustrating mixed-in-place operations using a tractor and a spring-tooth drag.

Fig. 2. A stabilization project in Washtenaw County, Michigan, illustrating mixed-in-place operations using a tractor and a road grader.

Fig. 3. A stabilization project on the Spencer-Ashboro Road in Indiana, illustrating method of placing plant-mixed materials by means of trucks and spreader boxes.

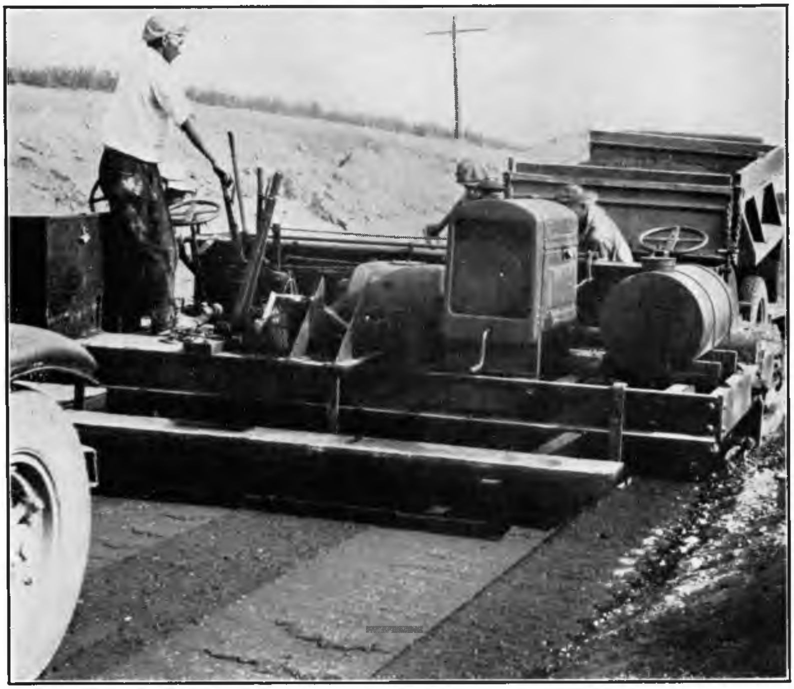

Fig. 4. A stabilization project near Hagerstown, Indiana, illustrating use of an Adnun paver in placing plant-mixed material transported in trucks.

Fig. 5. Wapella project in Illinois illustrating use of Barber Greene road mixing machine in stabilization work.

Fig. 6. Multiple pneumatic-tired roller used in Illinois. This type of roller provides both a kneading and a compacting action.

road and attempted to produce it artificially by construction methods. All materials used in the stabilized road should be investigated in order that the characteristics of the finished mix can be decided upon before the road is actually constructed.

A recent series of tests on samples taken from a well-compacted, traffic-bound stone road in excellent condition, produced some very interesting information. The gradation of particles from coarse to extreme fines, as found in the samples selected, was compared to the gradation of particles as laid on the road. To omit detail, the grinding action of traffic, combined with the incorporation of shoulder and subgrade material, had so changed the particle size that the amount of material larger than ¼ inch had decreased 33⅓%. Also, there is now more material passing the 270-mesh sieve than originally passed the 30-mesh sieve. The present gradation of materials is very close to the middle of the combined gradation which we now specify for artificial stabilization. This gradation is, of course, available to those interested.

SALT AND CALCIUM CHLORIDE

The naturally stabilized road surface is pleasing to the traveling public when slightly damp, since at that time there is no dust nor any pickup on a fast-moving vehicle. When this surface is exceedingly wet, the road will be stable and as non-skid as can be expected; but there will be a pickup on cars traveling at a high rate of speed since rain will soften or make plastic the upper ⅛- or ¼-inch. When dry, the road will be dusty because traffic will whip some of the soil fines from the surface. By adding a chemical such as calcium chloride or sodium chloride (salt) it is possible to do away with the objectionable dust feature to a very great extent. However, during extremely wet periods there will be some slight pickup on cars, especially during the early curing periods. The cycle that has been followed in Indiana consists of stabilizing a road by salt or calcium chloride and then applying a bituminous surface treatment when the road has been weathered and thoroughly compacted by traffic. It has been our experience in surface-treating these roads that large amounts of soil binder are not only unnecessary but can be very detrimental at times. This is due to the fact that under a surface treatment, capillary water will tend to accumulate and cause the clay to react as a lubricant rather than as a binder. By keeping the amount low and investigating the soil constants of the mix, it is possible to get a base which will not soften during the spring thaws.

Calcium chloride and common salt are the cheapest and most available materials for keeping a stabilized surface in the slightly damp condition most desirable. Salt tends to liquify during rain or periods of high humidity and thereby saturates the surface. Upon drying out, however, the salt crystallizes, filling the most minute voids and preventing further evaporation. Calcium chloride also liquifies during wet periods and penetrates through the lower part of the surface course to the subgrade. Unlike salt, however, calcium chloride does not crystallize as the surface dries. At that time it tends to reverse its action and by capillary action rises to the surface, thus drawing water from the subgrade. By this means the entire surface course is kept in a uniformly dampened condition.

Natural mixtures of stabilized materials have also been used in several recent projects in place of the water-bound macadam courses. Such courses should be laid on a firm, well-drained subgrade, and all compaction settlement should be completed at the time of construction. About 60,000 gallons of water will be required per mile of road six inches thick and twenty feet wide.

During the next construction season quite a few miles of traffic-bound gravel roads will be constructed in Indiana. If the gravel does not bind properly, specifications call for binder clay to be added. While water is not used in this type of construction, we will attempt to control the combinations of the soil binder and aggregate in order to get as nearly as possible the grading mentioned above. There seems to be a tendency among engineers to put too much soil binder with aggregate rather than too little. During the coming year, this type of construction will be carefully investigated in order that a more definite knowledge may be had as to just how wide the limits can be in order to afford a good factor of safety.

BITUMINOUS STABILIZATION

Bituminous stabilization is becoming quite generally used although we have tried very little of it in Indiana. Bituminous stabilization is divided roughly into two groups. The first group consists of mixing, either by road or plant mix, bank-run gravels and sand or crusher-run stone with liquid asphalt or tars. The asphalts used vary from the thin road oils to the heavier cut-back asphalts and emulsions. California, Wyoming, Utah, Minnesota and many other states have successfully used such mixtures with heavy road oils. The grading of the finished mix has in many cases been very similar to that suggested for clay-aggregate stabilization. Some of the recent work in Minnesota suggests that the use of aggregates containing a rather small amount of fines (0 to 10% passing the 200-mesh) mixed with an MC-4 liquid asphalt would give very good results. This work is described in the *Better Roads* magazine, December, 1935, issue. Our conditions in Indiana are similar enough to those in Minnesota to warrant some work along this line.

The second method of treatment consists of the injection or the mixing of slow-curing asphalts or emulsions into ordinary earth subgrades. The bituminous material enters the voids in the soil and prevents further absorption of moisture, thereby providing a stable subgrade, and, if the traffic is not too dense, a satisfactory surface. Some work along this line has been carried out in Missouri, and it is being carefully investigated by those concerned.

The incorporation of Portland cement in soils effects a reduction in shrinkage. Experimental sections using sodium silicate, lime, and various types of organic binders offer little information at the present time.

It is difficult to foresee the construction methods and designs which will be used by the highway engineer in the next five or ten years for secondary surfaces and bases, but the rapid advance of both the knowledge and technique of soil engineering indicates a real value in this type of design.

It is my prediction that the next few years will see quite extensive changes in earth-work construction. R. R. Proctor has quite definitely established the fact that for each soil and each type of equipment there is a specified moisture content at which the soil compacts to its most dense mass. Simple tests have been devised in which the engineer can determine whether he is getting the best out of his soil and construction methods. On roads where it is necessary to compact the fill in a short time in order that a high-type surface can be constructed, the use of controlled moisture contents in grading operations would be economically possible. This optimum moisture content method will continue to be used on mixtures of soils and aggregates for base purposes. The next step will be the combination of natural materials and cheap binders in order to provide a stable, splatterless surface throughout the year for intermediate-type roads. It will be an easy procedure then to construct the relatively thin wearing courses which are common today and secure a high-type highway. The engineer has progressed more rapidly in designing and constructing surfaces than he has in designing and constructing subgrades and bases. However, the two are now rapidly coming to the point of equilibrium.

THE CONSTRUCTION OF SMALL TREATED-TIMBER BRIDGES IN DUBOIS COUNTY, INDIANA

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The Indiana State Legislature at a special session in 1932 transferred all the township-maintained roads from the jurisdiction of the township trustees to the county highway systems. In the southern part of the state this resulted in a considerably larger undertaking than was originally anticipated, because in many counties the unimproved township-road mileage was larger than the improved county highway system.

In Dubois County, which is a typical example of many of the southern counties, there were three miles of unimproved roads for each mile of improved roads after the change. In the 755 miles which made up the new highway system were approximately 3,500 drainage structures. The maintenance of these structures and the construction of new structures to replace ones that had failed proved to be one of the problems in proportioning the revenue available for highway use, which amounted to approximately $85,000 annually.

After the making out of a tentative budget, since it was apparent that it would be impossible to build permanent structures, it was decided to build timber structures wherever the drainage area required something larger than could be taken care of with corrugated pipe.

The advantages of timber constructions were that they could be constructed rapidly, that they could be taken down and moved or have their roadway increased if they did not fit in with the future surfacing of the unimproved roads, that the entire expenditures could be kept in the county to help the farmers and the local unemployment situation if native oak timber was used, and, most important of all, that their