Use of Soil Survey Data in Design of Highways

L. D. HICKS, Chief Soils Engineer,
North Carolina State Highway and Public Works Commission

SOIL SURVEY METHODS

● AT the annual meeting of the Highway Research Board in December, 1948, this writer presented a paper entitled "The Use of Agricultural Soil Maps in Making Soil Surveys," which has been published in Bulletin 22. This paper is a sequel to that paper in that it deals with the use made of soil-survey data in the design of highways. Other methods of securing soil-survey data are discussed and the advantages of one method over another given. The use made of soil-survey data will be given in some detail in (1) the design of rigid pavements, (2) the design of flexible pavements for primary and secondary roads, (3) the selection of pavement type, and (4) soil stabilization for base courses.

In the original paper presented in 1948 the pedological system of soil classification was explained in detail and its use as a means of identifying soils in making soil surveys was described. The use made of available agricultural soil maps, which were made using the pedological system of classification, in obtaining soil-survey data was also described. In areas where agricultural soil maps are not available, a method of identifying soils pedologically by the use of a "key" was given.

While data obtained from agricultural soil maps or identifying soils pedologically are valuable, the data are of a general nature at best. Where the data are to be more precise, it is necessary to resort to systematic sampling. In many instances where the exact amount of the soil constituents, sand, silt, and clay is desired, as in mechanical stabilization of subgrade soils, the analysis of individual samples is absolutely necessary. Precise classification of soils demands that samples be taken and tested. In general, soils from the same horizon of the same soil series may, but not always, fall into the same subgrade group; but the value of the group index cannot be determined, except from the results of tests on individual samples. Also, agricultural soil mapping is surficial, the depth of the soil examined being about 3 ft., which is not, in many instances, of sufficient depth to give reliable data. Although placing a soil in its series classification indicates certain similarities as to arrangement and depth of horizons, parent material, etc., the similarities may be too general for the use to be made of the data. For instance, soils derived from granite and granite-gneiss may or may not have sufficient amount of mica in their C horizons to produce detrimental elasticity. Also, certain soil series occurring in the coastal plain may indicate a profile consisting of sand in the A horizon and sand clay in the B horizon, but the C horizon sometimes contains stratifications of pure clay or practically pure sand, or even Piedmont material, if the area is near the Coastal-Plain-Piedmont dividing line. Excellent sand, gravel, sand clay, and sand clay-gravel materials have been found beneath soils of series classifications completely alien to the soils of those series due to the fact that the surface soils had been transported and covered these materials which are of a different geological age.

The above is not given in condemnation of the use of the pedological system of classifying soils in making soil surveys, but, as stated before by the writer in another article (1), the method has its short comings. The pedological system of soil classification is a very valuable tool to use in making soil surveys, but where accuracy demands, the method should be supplemented with additional or supporting data. A proper knowledge of the soil in a soil series will often indicate when it is necessary to obtain additional data.

Soil surveys are made to obtain certain definite information concerning the soils to be encountered within an area. The amount and type of information depend upon the use to be made of the soil. For agricultural purposes information relating to tilling the soil and production of crops is sought, but when the soil is to serve as a structure or part of a structure, the strength and durability of the material is of prime importance. A soil survey made to secure information relating to the behavior of soil as a structural material may be called an engineering soil survey.

Engineering soil surveys may be divided into two classes, surveys to determine the characteristics of the soil as a foundation beneath such structures as bridges, buildings, dams, and those to determine its characteristics for use in the construction of highways and airports. Surveys of the former class require subsurface borings to depths below appreciable influence caused by the weight of the proposed structure in order to locate and sample the various strata of material. Soil surveys of this class will not be discussed in this paper. Soil surveys for the construction of highways and airports, if complete, require much data to give adequate information, and necessitates both surficial and subsurface exploration and sampling. The writer has covered one phase of this class of survey in his paper presented in 1948 and printed in HRB Bulletin 22 and will discuss other phases in this paper as well as the use made of soil-survey data in designing highways.

The greatest one factor affecting the stability and strength of soil is water content. For a given climate the degree of this influence is affected by the constituents of the soil mass (sand, silt, and clay), the amount of the various constituents, their shape and mineral and chemical composition, adsorbed ions, and degree of consolidation. The constituents of a soil and their amounts are determined by mechanical analysis of a sample, while the effect of their shape, mineral and chemical composition, and adsorbed ions is indicated by such tests as the liquid limit, plasticity index, shrinkage factors, and hydrogen-ion concentration (pH). The degree of consolidation is determined by comparing the density of the soil mass as it exists with the density of the soil when compacted in accordance with a standard test procedure such as AASHO Designation T 99-49.

Making a soil survey in accordance with the Standard Methods of Surveying and Sampling Soils for Highway Purposes, AASHO Designation T 86-49 will furnish data that is quite complete as far as type of soil, its location in the profile, existing water content, location of water bearing strata, etc., is concerned, and when placed in the hands of a competent and experienced soils engineer, will pay dividends; however; many of the problems indicated by the survey data may be found to be nonexistent during construction, and quite serious problems may be encountered that were not indicated from the data. The need for elaborate and expensive underground drainage systems may be indicated, but when excavation is completed the condition may be found to have been corrected to a great extent by removal of the surrounding material. The season of the year when construction is done will also have considerable influence on the seriousness and method of solving such problems. The author has found it to be a safer plan to face such problems during construction, when possible, and decide upon their solution at that time when all of the factors causing the condition can be more correctly analyzed.

In North Carolina the location of rock is found from soundings made by a location party organized for that purpose. This data is plotted on the profile sheet as a guide to the contractor in bidding on excavation. Muck beds are also located by a special party, and the data used in the disposal of this material. The use of vertical sand drains to accelerate the settlement of wet soils beneath fills have not been used in this state as yet, but the advantage of their use is recognized, and should the occasion arise, they will probably be used on important work. Their design will require a special soil survey.

It is seldom necessary to make as complete a soil survey as required in method AASHO T 86-49. Much of the data would be repetitious in localities in which previous surveys had been made, or in areas whose soils are known by the soils engineer to belong to certain pedological soil series, the characteristics of which are familiar to him. Such is the case in North Carolina where pedological soil surveys have been made and agricultural soil maps are available for about 90 percent of the counties. Use has been made of these maps in making engineering soil surveys since 1938 at considerable saving in survey cost as well as in time. Where accuracy warrants, the use of these maps is supplemented by additional data obtained from borings and samples taken at sufficient intervals to fulfill the accuracy requirements for the particular work.

SOIL SURVEY DATA USED IN THE DESIGN OF RIGID PAVEMENTS

A rigid pavement, as the name implies, is a slab of material rigid in nature, commonly supported by a foundation composed of soil, which is more or less flexible in nature. The strength of the rigid slab is measured in terms of its resistance to fiber stress, one half of which is used as the design stress, while the subgrade support is measured by a modulus, designated as "k", derived from the bearing value of the soil. (It should be noted that the term, bearing value, is used here instead of bearing capacity. The bearing capacity of a soil is that pressure, greater than which, will produce plastic flow, while its bearing value is that pressure, greater than which, will produce more than a stipulated settlement. The bearing value should, of course, never exceed the bearing capacity.)

The value of k is determined from test data obtained by loading the soil, in the condition of moisture and degree of consolidation under which it is to serve, using a round steel plate, 30 in. in diameter. The pressure producing 0.05-in. settlement is the bearing value of the soil, and the amount of this pressure in pounds per square inch divided by 0.05 gives the value of k.

The value of k, although determinable, is more often selected than determined. It is safe to select the value rather than determine it, provided a reasonable amount of discretion is used. The values recommended by good authority are based on average test data, and a reasonable error one way or the other has little affect upon the calculated thickness of the slab. Table 1 gives values of k used in North Carolina for the various types of soil commonly encountered. The Soils Laboratory of the North Carolina State Highway and Public Works Commission has had occasion to check some of these values for the most common soils occurring in that state by means of load tests.

TABLE 1

Type of Soil	BPR Subgrade Group	Range in Value of "k"
Sandy Soils	A2 - A3	150 - 300
Silt Soils	A4 - A5	50 - 150
Clay Soils	A6 - A7	50 - 100

The values given are based on the assumption that the type of soils exist to sufficient depth to realize the true strength of the material. For instance, a subgrade composed of a layer of sandy soil less than about 4 ft. thick underlain with a clay soil should not be given a k value between 150 and 300 but a value between 50 and 100, the range for clay soils.

About 15 yr. ago a type of failure of rigid pavements began to develop in North Carolina that had never been of much concern to anyone before. Water with subgrade material in suspension was being extruded at the edges and between the joints and cracks of the slabs of concrete pavements by the action of heavy vehicles. This extrusive action was called "pumping" because the action of traffic on the pavement slabs was not unlike that of a pump. As the pumping action progressed, sufficient subgrade material was removed to cause the slabs to break several feet from the joint or crack. These short slabs began to rock and pumping developed at the new crack. It was noticed that this new type of failure was taking place on new pavements as well as those that had been in service for years, so it was realized that the trouble was not in the slab itself but in the subgrade. The soils laboratory was called upon to investigate this new type of failure and develop some treatment of the subgrade, if possible, to prevent its occurrence on future work.

After considerable investigation and study, it was found that pumping of concrete pavement slabs was the result of heavy loads causing the slabs to deflect. When movement took place and free water was lying on the subgrade, the water was ejected with some force, carrying with it some of the fine-grained subgrade material. If free water was not present on the subgrade, movement of the slab took place, but no harm was done as no subgrade material was removed. It was also noticed that concrete pavements having sandy soil subgrades showed no signs of pumping to the extent that the subgrade soil was ejected.

These facts led to the conclusion that pumping of concrete pavements was caused by three factors which had to exist at the same time: (1) axle loads sufficiently large to cause movement or deflection of the concrete slab, (2) water in sufficient quantity to be ejected when the slab deflected, and (3) a subgrade composed of soil sufficiently impervious to permit free water to lie on it. Since these three factors had to exist at the same time, the problem could be solved by the elimination of one of them. Reducing the weight of the axle loads was out of the question, and it was found that preventing the entrance of water or its drainage from the subgrade could not be effected to a satisfactory degree. The only remaining factor to be considered was the subgrade material. It was reasoned that a rather pervious layer of material would act as a blotter and readily absorb the water entering the pavement cracks, joints, and sides and, as a result, the water would not be in a free state to be pumped out carrying fine-grained subgrade soil with it.

Material meeting the above requirements for a blotter course should be granular in texture and fairly well graded. The grading limits of four classes of materials satisfactory for use in this type of work are given in Table 2.

TABLE 2

Grading Limits For Blotter Course Materials For Use Beneath Concrete Pavements

Sieve No.	Total Percent Passing			
	Class A	Class B	Class C	
2"	100	100		
1"	75-90	70-100		
½"	60-75	55-100		
4	40-60	40-80		
10		30-65	100	100
40	15-30	15-45	40-75	40-100
200	5-15	5-25	12-35	12-35

The amount passing the No. 200 sieve shall not be more than two thirds of the amount passing the No. 40 sieve. The Liquid Limit and Plasticity Index of the material passing a No. 40 sieve shall not exceed 25 and 6, respectively, when tested in accordance with the method designated as AASHO T 88-49.

Blotter courses constructed of materials meeting the requirements given in Table 2 are constructed in trench sections, extending a foot wider than the pavement on each side. No provision is made for drainage at the time of construction; however, if saturation of the layer is indicated at a later date, drain tiles are installed at intervals through the shoulders. This is seldom necessary. A compacted layer of 4 in. has been found adequate to prevent the detrimental effects of pumping action.

Should the materials selected for this work be more open graded than the materials given in Table 2, the base is not considered as a blotter course but a drainage medium and the layer is extended through the shoulders. This, of course, requires more material and may or may not be more expensive, depending upon the relative cost of the materials. Also, these more-open-graded materials are generally quite cohesionless and may be quite difficult to haul over by the hauling equipment transporting the concrete materials to the mixer.

Materials for the work discussed above often occur locally; however, it is the general policy to require that they be furnished by the contractor in order to avoid certain difficulties that may be encountered when the state purchases and furnishes such materials. After the award of the contract, the laboratory samples and tests the materials proposed for use before they are purchased by the contractor and placed on the subgrade. Samples are again taken and tested after the materials are placed.

Subgrade soils that do not meet the requirements of the materials given in Table 2 are considered as subgrades conducive to pumping of concrete pavements and are required to be covered with a 4-in. compacted blotter course before placing the concrete pavement. This design for concrete pavements has been followed in North Carolina for the past 10 yr. and, to the best of the writer's knowledge, no "pumping" has developed.

SOIL SURVEY DATA USED IN THE DESIGN OF FLEXIBLE PAVEMENTS

The usual concept of a flexible pavement has been a pavement consisting of aggregates cemented together with bitumen. While such a pavement is still considered a flexible pavement today, the definition has been broadened to include pavements consisting of subbases or bases composed of selected soil materials or soil-aggregate mixtures, which are covered with bituminous wearing surfaces. By making use of the science of soil mechanics, it has been possible to construct flexible pavements at a cost and load-carrying capacity comparable to that of the rigid type.

The mechanics of the design of a flexible pavement is different from that of the rigid type in that the flexible type is assumed to possess no slab strength. The strength of a flexible pavement lies in its ability to withstand the pressures imposed upon its surface and to distribute them to the underlying subgrade in such a manner that their intensity is reduced to less than the bearing capacity of the subgrade soil. Both the rigid and the flexible types of pavement depend upon the strength of the subgrade; however, the nature of a flexible pavement permits utilization of the full strength of the subgrade, in most cases, instead of only a portion of it. Therefore, the bearing capacity of the subgrade may be used in the design of a flexible pavement instead of its bearing value. The bearing capacity of each layer of material in the pavement structure, including that of the wearing surface, can be utilized only if the layer has adequate support.

In order to design a flexible pavement that will support vehicles of a definite type with axle loads of a stated maximum, the design engineer must know the bearing capacity of the subgrade and of each layer in the pavement structure. This requirement involves the determination of the bearing capacity of the subgrade soils to be encountered and the selection and determination of the bearing capacity of the materials used in each layer of the pavement structure. These bearing-capacity determinations of the materials must be made at the condition of moisture and degree of compaction under which they will serve. This information must be furnished by the soil engineer, who must make all of the necessary investigations and perform all of the necessary tests for its procurement. Obtaining this information, although not strictly a soil survey procedure, is nevertheless soil data, and will be discussed in this paper.

Determination of the bearing capacity of a soil requires that some form of a strength test be made and, from the data obtained, arrive at its value. There are several methods of approach to this determination using test data from such tests as shear tests, penetration tests, and load tests, both miniature and full scale. In North Carolina full-scale load tests are conducted in the laboratory on prepared subgrades composed of various soil materials. The soil is placed in a bin 14 ft. long, 3½ ft. wide, and 2½ ft. deep at a moisture content and degree of consolidation found to exist in this type of soil in service, and tested by loading round steel plates, 6⅔, 8, 10, and 13⅓ in. in diameter. The moisture content of the soil and its degree of compaction is obtained from the results of moisture-density surveys, one of which was reported at the Twenty-Eighth Meeting of the Highway Research Board held in December 1948 and published in the proceedings for that year (2). The load test technique follows that developed by Housel and reported by him in 1936 (3). The writer has reported the use of this test in some detail in two other papers (4, 5) and will not discuss it here.

All soils are tested as subgrades whether they are used in subgrades or base courses. The bearing capacity of a material at a certain moisture content, if tested as a subgrade, is the maximum for the material when used in a base course. The thickness of base course, placed on a given subgrade, that will produce this value of bearing capacity is the optimum thickness of base course for this material on this subgrade. For instance, if a base course material has a bearing capacity of 100 psi. when tested as a subgrade, and it is found that 12 in. of it placed on a 20 psi. subgrade will still have a bearing capacity of 100 psi., the optimum thickness for this base course material placed on a 20 psi. subgrade is 12 in. Greater thicknesses placed on a subgrade of this same strength will show no increase in bearing capacity.

SOIL SURVEY DATA USED IN SELECTION OF PAVEMENT TYPE

Usually economics govern in the selection of pavement type and sometimes it is personal preference; however, certain facts revealed by soil-survey data can be used to justify the choice of one type over another. Highly micaceous soils possess detrimental elasticity, which is the worst enemy a flexible pavement can have. Expensive treatments may be necessary to overcome the elasticity of this type of subgrade and, even with such treatments, the results are not always 100-percent satisfactory. A rigid type of pavement for elastic subgrades is the safest design.

Subgrades on embankments that are subject to subsidence due to settlement of the foundation soil beneath them, or subgrades on embankments that could not be compacted by rolling due to high water content in the soil, will cause a rigid pavement to crack and fault excessively due to nonuniform settlement. A flexible pavement will serve much more satisfactorily over subgrades of this type than one of the rigid type.

It is now possible to design a flexible pavement for the heaviest traffic, and if the subgrade is suitable for either the rigid or the flexible type, the cheaper of the two is generally chosen. The availability of local soil materials suitable for the construction of a base course often makes the flexible pavement much the cheaper; also the proximity of stone that may be crushed locally, although more costly than local soil, is cheaper than a rigid pavement. In areas not too far from commercial material plants, the use of their materials often permits the construction of a flexible pavement more economically than a rigid type. The necessity for the use of blotter courses between rigid type pavements and silt-clay subgrades oftentimes places the rigid pavement at a disadvantage from the standpoint of cost; however, improvement in paving machinery and methods for concrete has reduced the cost to the point where the two types are comparable when the pavements must be designed for heavy vehicles.

SOIL SURVEY DATA USED IN STABILIZATION OF SOIL

Soil stabilization, as used in this paper, refers to the method of processing soil to render it suitable as a base course beneath a bituminous pavement. All methods of soil stabilization used in North Carolina have been applied to the construction of flexible pavements on secondary roads or roads carrying relatively light vehicles, those having maximum axle loads of 13,000 lb. The four following methods have been used:

1. Mechanical stabilization, a process in which granular materials have been combined with suitable clay soil subgrades to produce a base course material meeting the requirements.
2. Portland-cement stabilization, a process in which a sufficient amount of portland cement is mixed with the subgrade soil to cause it to harden into a compact mass and not soften in the presence of water or disintegrate from freezing or thawing or wetting and drying.
3. Bituminous stabilization, a process in which bituminous materials are mixed with the soil to waterproof the particles and furnish the necessary cohesion for stability.
4. Vinsol-resin stabilization, a process in which a treated resin, obtained in the extraction of other substances from pine stumps, is mixed with the soil. The resulting mixture, if the soil responds favorably to the treatment, resists wetting by water.

Mechanical stabilization, as has been defined above, has been restricted to clay soils derived from granitic rock. Clays from this type of rock are largely kaolinite and are more or less friable. They are not so difficult to mix with sand and serve as good binders. Before planning to construct a base course on a road using this form of stabilization, it is first necessary to ascertain if the subgrade soils are suitable. This is done by referring to the agricultural soil map for the area, if available, or making a soil survey of the road and identifying the soils pedologically. This determines whether or not this type of work will be satisfactory. If this type of stabilization is decided upon, samples of the subgrade are taken at intervals of 500 ft., after grading is complete, and sent to the laboratory for analysis and determination of a job mix. This type of work requires extreme care on the part of the construction forces, due to the fact that the subgrade soils generally vary considerably in a short distance and often it is necessary to use only a small portion of the subgrade soil when it is a heavy clay. However, an experienced soils inspector can control this type of work to where the number of sections that are necessary to correct by the incorporation of an additional amount of one of the components is reduced to a minimum.

In North Carolina most of the portland-cement stabilization has been confined to the silt-clay type of soils; however, a few projects have been constructed using sandy soil subgrades. There are two reasons for this. In areas where sandy soils predominate, base course or sand-asphalt materials are available, providing a cheaper type of pavement. Also, sandy soils usually contain organic matter which prevents proper hardening of the soil. Although treating these kind of soils with calcium chloride prior to incorporating the portland cement has been reported as an effective operation to prevent the detrimental effects of organic matter, this treatment has not been used in North Carolina.

As early as 1938 it was recognized that some relationship existed between the required amount of cement necessary for stabilization and the soils found in the various horizons of a definite soil series (6, 7). A testing program was inaugurated in which durability tests were made in accordance with AASHO Designations T 135-45 and T 136-45 on samples taken from the different horizons of the most common soil series found in the state. From the results of these tests the amounts of cement required to stabilize the various soils were determined. As a result of this work, the problem of designating the amounts of cement necessary to stabilize the soils on a project is solved by simply identifying the soils as to horizon and soil series and referring to the test data and cement requirement previously made for these soils. Contract estimates are often made, prior to grading, by referring to the agricultural soil map for the area in which a proposed road occurs. If the map is not available the soils are identified by a soils investigator. This procedure has been used quite successfully in the stabilization of over 700 mi. of secondary roads in North Carolina.

Bituminous stabilization in North Carolina may be divided into two classes, the stabilization of sands and the stabilization of sandy soils. Soils having 10 percent and less material passing a No. 200 sieve are considered sands, and those containing more than 10 percent but less than 35 percent passing this sieve are considered as sandy soils. Some attempts have been made to stabilize silt-clay soils with bituminous materials, but the results were not so successful and often uneconomical. Most of this type of stabilization now in this state is confined to sands as they offer less construction difficulties, and it has been found that this type of stabilization is quite successful and economical in certain localities. Samples are taken of the material to be stabilized and brought into the laboratory for tests. From the results of these tests the amount of bituminous material necessary for stabilization is determined. The initial planning of a project of this type is often done by referring to agricultural soil maps of the area, but the amount of the bituminous mater il required for stabilization is determined from the results of tests made on samples of the materials to be stabilized.

Only one project has been constructed in North Carolina using vinsol resin as the stabilizing agent. This material is quite selective and the results of tests made on the few soils chosen for this type of stabilization did not indicate much promise. It is probable that some of the soils in this state can be satisfactorily stabilized with this agent, but the satisfactory use of other agents, as portland cement and bituminous materials, and the availability of base-course materials in localities where there is any likelihood that vinsol resin can be used, has lessened the necessity for an extensive investigation of this stabilizing agent.

CONCLUSION

In this paper, as in others, the author has stated that the use of the pedological system of soil classification for identifying soils is a valuable tool in making engineering soil surveys for airports and highways but has also emphasized that the method may not give all of the information desired and has pointed out that where precise data are needed, the information must be obtained by other methods. The type of soil data needed for the rational design of pavements, both rigid and flexible, has been described by stating the problems confronting the design engineer. Also, the soil data needed in the selection of the pavement type most suited to the locality as well as that required by four forms of soil stabilization has been discussed. The selection and sampling of base-course materials has been discussed at some length in the first paper, published in Bulletin 22 and referred to at the beginning of this paper, and has not been mentioned.

Engineering soil surveys should be supervised by an experienced soils engineer who should be capable of understanding thoroughly the purpose of every particular survey, in order to secure the information necessary and not waste time and effort securing useless data. He should have a knowledge of soil mechanics and its applications to pavement design, subsurface drainage, subgrades, embankments, and all other phases of highway and airport design that can be benefitted by this science.

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