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Use of Soil Survey Data in Design of Highways

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Abstract

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 pedagogical system of soil classification-ion was explained in detail and its use as a means of identifying soils in making soil surveys was described. These made of; in obtaining soil-survey data was also described. In areas where agri - cultural soil maps are not available, a method of identifying soils pedagogically by the use of a "key" was given.

While data obtained from agricultural soil maps or identifying soils pedagogically 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 con- statements, and, stilt, and clay is desired, as in mechanical stabilization of sub grade soils, the analysis of individual samples is absolutely necessary. Precise classi- fication 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 sub grade 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 surgical, the depth of the soil examined being about 3 ft., which is not, in many instances, of sufficient depth to give reliable data. Al- though placing a soil in its series classifi- cation indicates certain similarities as to arrangement and depth of horizons, parent material, etc., the to produce detrimental elasticity. Also, certain soil series occurring in the coastal plain may indicate a profile con- sisting 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. Ex- cellent sand, gravel, sand clay, and sand clay-gravel materials have been found be- neath soils of aeries classifications com- pletely 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 pedagogical 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 pedagogical system of soil classification is a very valuable tool to use in making soil surveys, but - ing data. A proper knowledge of the soil in a soil series will often indicate when it is necessary to obtain additional data.

1. **INTRODUCTION -** Soil surveys are made to obtain certain definite information concerning the soils to be encountered within an area. The amount and type of information depen

Upon the use to be made of the soil. For agricultural purposes information relating to tilling the soil and production of cropa ts 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 maybe divided into two classes, surveys to determine the characteristics of the soil as a foundation beneath such structures **as bridges,** build- ings, 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 necessitates both surgical and sub- surface 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 con- tent. 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 com- position, adsorbed ions, and degree of consolidation. The constituents of a soil and their amounts are determined by me- chemical analysis of a sample, while the effect of their shape, mineral and chemical composition, and absorbed ions is indicated by such testa as the liquid limit, plasticity Index, shrinkage factors, and hydrogen-ion concentration (per). The degree of consoli- dation ia 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 - 48.

Making a soil survey in accordance with the Standard Methods of Surveying and Sampling Soils for Highway Purpose, 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; how- ever; many of the problems indicated by the survey data may be found to be non- existent during construction, and quite serious problems may be encountered that were not indicated from the data. The need for elaborate and expensive under- ground drainage systems may be indicated, but when excavation is completed the condi- tion may be found to have been corrected to a great extent by removal of the sur- rounding 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 exca- vation. 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 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 repetitions in localities in which previous surveys had been made, or in areas whose **soils** are known by the **soils** engineer to belong to certain pedagogical soil series, the characteristics of which are familiar to him. Such is the case in North Carolina where pedagogical soil surveys have Been made and agricultural soil maps are Available tor about 90 percent of the coun- ties. Use has been made of these maps in making engineering aoil surveys since 1838 at considerable saving in survey cost as well as tn time. Where accuracy warrants, the use of these maps is supplemented by ad- additional data obtained from borings and samples taken at sufficient intervals to fulfill the accuracy requirements for the particular work.

2. LITERATURE REVIEW

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, com- monly 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 sub grade sup- port is measured by a modulus, designated as "k", derived from the bearing value of the soil. (It should be noted that the term
it is to serve, using a round steel plate, 30 in. in diameter. The pressure producing 0. 05-in. settle- ment is the bearing value of the soil, and the amount of this pressure in pounds per square inch divided by 0. 05 give 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 recom- mended by good authority is 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 en- countered. 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
Salt Soils	At - AS	50 - 150
Clay Soils	A6 - A7	50 - 100

The values given are based on the as- sumption that the type of soils exist to sufficient depth to realize the true strength of the material. For instance, a sub grade 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 Nortl. Carolina that had never been of much con- cern to anyone before. Water with sub- grade 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 pave- ment **slabs** was not unlike that of a pump. As the pumping action progressed, suf- ficient sub grade material was removed to cause the slabs to break several feet from the joint or crack. These short slabs be- gan 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 sub grade. The soils laboratory was called upon to investigate this new type of failure and develop some treatment of the sub grade, if possible, to prevent its occurrence on future work.
After considerable investigation and Study, it was found that pumping of con- crete pavement slabs was the result of heavy loads causing the slabs to deflect. When movement took place and free water was lying on the Sub grade, the water was ejected with some force, lace, but no harm are done as no sub- grade material was removed. It was also noticed that concrete pavements having sandy soil sub grades showed no signs of pumping to the extent that the sub grade 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 quan- tity to be ejected when the slab deflected, and (3) a sub grade composed of soil suf- ficiently 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 sub grade could not be effected to a satisfactory degree. The only remaining factor to be considered was the sub grade 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 sub grade 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 satis- factory for use in this type of work are given in Table 2.

TABLE2

Grading Limita For Blotter Course Materi- als For Use Beneath Concrete Pavements

Total Percent Passing			
Sieve No.	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
200	5-15	5-25	12-35

The amount passing the No. 200 sieve shall not be more than two third 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 are AASXO 'I' 88-49.

Blotter courses constructed of ma- terials 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 indi- cated at a later date, drain tiles are in- stalled 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 drain- age 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 cohesion less 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 fur- nished by the contractor in order to avoid certain difficulties that maybe 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

3. EXPERIMENTAL PROGRAM

Soil Survey Data Used In the Design of Flexible pavements

The usual conceptof a flexible pavement has been a pavement consisting of agree- gates 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 sub bases or bases composed of selected soil materials or soil-aggregate mixtures, which are covered with bitumen-oust 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 com- parable 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 under- lying sub grade in such a manner that their intensity is reduced to less than the bearing capacity of the sub grade soil. Both the rigid and the flexible types of pavement depend upon the strength of the sub grade; however, the nature of a flexible pavement permits utilization of the full strength of the sub grade, in most cases, instead of only a portion of it. Therefore, the bear- ing capacity of the sub grade 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 sub grade and of each layer in the pavement structure. This require- ment involves the determination of the bearing capacity of the sub grade soils to be encountered and the selection and deter- mination of the bearing capacity of the ma- trials used in each layer of the pavement structure. These bearing-capacity de- terminations 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 never- theless 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 teats as shear tests, penetration tests, and load tests, both miniature and full scale. In North Carolina full-scale load tests are con- ducted in the laboratory on prepared sub- grades composed of various soil materials. The soil is placed in a bin 14 ft. long, 3g ft. wide, and 2g 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, 6$s, 8, 10, and 13/s in. in diameter. The mois- ture 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 pro- ceedings for that year (2). The load test technique follows that developed by Housel and reported by him in 193B (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 sub grades whether they are used in sub grades or base courses. The bearing capacity of a material at certain moisture content, if tested as a sub grade, is the maximum for the material when used in a base course. The thickness of base course, placed on a given sub grade, that will produce this value of bearing capacity is the optimum thickness of base course for this material on this sub grade. For instance, if a base course material has a bearing capacity of 100 psi. When tested as on a 20 psi. Sub grade will still have a bearing capacity of 100 psi. , the optimum thickness for this base course material placed on a 20 psi. Sub- grade is 12 in. Greater thicknesses placed on a sub grade 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 tor elastic sub grades is the safest design.
Sub grades on embankments that are subject to subsidence due to settlement of the foundation soil beneath them, or sub grades on embankments that could not be compacted by rolling due to high water content in the soil, witl cause a rigid pavement to crack and fault excessively due to nonuniform settlement. A flexible pave- ment 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 tf the sub grade 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 con- struction of a base course, the use of their materials often permits the construction of a flexible pavement more economically than a rigid type. The type pavements and wilt-clay sub grades 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 coat to the point where the two types are comparable when the pavements must be designed for heavy vehicles.

4. RESULTS AND DISCUSSIONS

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 sub grades 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 sub grade soil to cause it to harden into a compact mass and not a often 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 re- sulting mixture, if the soil responds fav- orably 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 sub grade 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 sub grade are taken at intervals of 500 ft., after grading is complete, and sent to the laboratory for analysis and de- termination of a job mix. This type forces, due to the fact that the sub grade **soils** generally vary consider- ably in a short distance and often it is necessary to use only a small portion of the sub grade soil when it is 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 addi- tional amount of one of the components is reduced to a minimum. In North Carolina most of the Portland-

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Cement stabilization has been confined to the silt-clay type of soils; however, a few projects have been constructed using sandy soil sub grades. There are two reasons for this. In areas where sandy soils pre- dominate, base course or sand-asphalt materials are available, providing a cheap- er type of pavement. Also, sandy soils usually contain organic matter which pre- vents proper hardening of the soil. Al- though treating these kind of soils with calcium chloride prior to incorporating the Portland cement has been reported as an effective operation to prevent the detri- mental effects of organic matter, this treatment has not been used in North Carolina.

As early as 1938 It was recognized tkat some relationship existed between the re- quired amount of cement necessary for stabilisation and the **soils** found in the vari- ous 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 1S6 -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 ot 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. Con- tract 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 per- cent passing this sieve are considered as sandy aoils. Some attempts have been made to stabilize silt-clay soils with bi- tuminous 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. Prom the results of these test the amount of bituminous material necessary for stabilization is determined. The initial planning of a project of this type is often done by re- ferring to agricultural soil maps of the area, but the amount of the bituminous mater if 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 sta- bilization 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.

5. CONCLUSION AND FUTURE SCOPE

In this paper, as in others, the author has stated that the use of the pedagogical system of soil classification for identifying soils is a valuable tool in making engi- neering soil surveys for airports and high- ways 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 flexi- ble, 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 lo- cality 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 Bul- letin 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 engi- neer who should be capable of understanding thoroughly the purpose of every particular survey, in order to assure the information necessary and not waste time and effort securing useless data. He should have a knowledge of soil meets and its ap- placations to pavement design, subsurface drainage, sub grades, embankments, and all other phase of highway and airport design that can be benefitted by this science.

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