SOIL SURVEY PRACTICE IN THE UNITED STATES

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SYNOPSIS

This paper is a summary of replies to a recent questionnaire submitted by all the States on their soil survey practices. At present, all but 4 States are making such surveys, although 12 of these do so on a very small scale only. Of the other States, most follow, in general, the methods and procedure outlined by the A.A.S.H.O. and the Public Roads Administration. Two States make their surveys by methods outlined by the U. S. Bureau of Chemistry and Soils, classifying soil by the pedological method, rather than by the triaxial chart or the Public Roads classification. Other States also make use of the soil maps prepared by the Bureau of Chemistry and Soils in addition to following A.A.S.H.O. procedure.

Subgrade explorations are being made by means of test pits, 1½ in. standard soil augers, 4 to 10 in. post hole auger, and mechanized drills up to 36 in. diameter. The definite trend is to use of the larger post hole augers. Some States also use power samplers for taking 2 and 4 in. diameter undisturbed samples. Some subsurface exploration is also being done with electric restivity apparatus.

The extent of sampling is variable, as in some States samples are taken only where the suitability of material is questionable. Other States take samples at regular intervals along the line. Some States take samples only for visual inspection and general comparisons, while others make detailed field or laboratory tests on the samples.

It is recommended that sufficient borings be made to provide the accurate mapping of all soil horizons.

The location and direction of underground water flow is of great importance in subgrade soil behavior. It is suggested that all borings be extended to at least 3 ft. below subgrade elevation.

Before making a soil survey, consideration should be given to the purpose for which the results are to be used; a survey for the foundation of a structure must be conducted differently than the survey for a highway location. This paper deals with the problem and general practice of making a subgrade soil survey.

The purpose of the highway subgrade soil survey is to furnish the highway engineer information from which he can more accurately design a section of road. Formerly a material which looked good was considered good, and with the very meagre information available it was practically impossible to identify those materials which would perform badly or which would perform well. Likewise, it was equally impossible to predict those areas which would fail either in subgrade, embankment, or foundation; and it was equally difficult to account for many landslides and slips, which constantly occurred during construction or shortly after the completion of a project.

We have all had experience with pavement failures, which by all the known laws should not have occurred. We have tried extensive drainage but still we have had innumerable failures. These failures have finally brought forth the conclusion that they are probably developing through subgrade soil action. This conclusion has called for a thorough investigation of subgrade soils. Since the science of soil investigation is so very new, and the technique has been developed so rapidly, it was deemed advisable to make a survey of the methods being used by the various states.

A questionnaire was sent to all states requesting information concerning methods of making the preliminary soil survey, including underground explorations and sampling, and of the use made of the data obtained from the survey. As evidence of the interest being taken in this subject, it can be reported that all states replied to the questionnaire. This paper is a resume of the replies.

Since this paper is essentially a review of the methods now being used by the various agencies conducting soil surveys, we will quote at some length from the replies.

Alabama reports that the preliminary soil survey is run between the completion of the location survey and the drafting of the plans. Complete soil surveys are run only where unusual conditions are encountered, and the survey is then made according to A. A. S. H. O. methods. Alabama stresses the point that in the great majority of cases, a survey of the scope outlined by the Association is not necessary, so in these cases samples are taken at 500-ft. intervals only for study and for record. "Where the alignment on a new project follows an existing road, sampling is done at 500-ft. intervals to a depth of 12 in. below the proposed subgrade elevation, and from the test results on these samples, it is decided whether the existing roadway is a suitable subgrade; and if not, what will have to be done to make it so. Samples are also taken from the banks of existing cuts and from other sources of material for widening to determine its proper distribution and place in the completed work."

Alabama has a contract item, known as "Roadbed Topping," which consists of a compacted blanket of selected soils used to reinforce weak subgrades and ranges in thickness from 6 to 15 in., depending upon comparative experience in the same locality with soils of like characteristics. The preliminary soil survey here helps to determine where such topping is necessary and the required thickness.

The most common type of equipment used in making soil borings is the post hole auger of 8-in. diameter. This auger has been used successfully to a depth of 27 ft. and is found to be generally superior to augers of smaller diameter.

Alabama places a great deal of dependence in soil studies, and believes they have contributed greatly toward the success of the low cost road program in the state. Data, obtained from these surveys, are used fully in the preparation of plans and for the guidance of the resident engineer during construction.

Arizona has not as yet adopted a method of making underground explorations. In making their preliminary soil surveys in open country, test pits are dug approximately 1½ ft. deep each quarter of a mile. When cuts are encountered, test pits are dug to grade, providing the material can be readily excavated with hand methods. Wherever rock is encountered, no attempt is made to determine the extent. Sampling is done by making a cut down one face of the test pit, thus taking a composite sample of the stratum under investigation. Care is exercised to see that other strata are not included.

Arkansas makes borings with a soil auger along the centerline of the proposed location to the depth of the grade line in cut sections, during which a visual inspection is made to determine the depth of each soil layer. Sufficient borings are made to define accurately the lateral extent of each of the soil types encountered. These intervals are determined by the soils engineer making the survey. Representative samples are taken of each layer and sent to the laboratory for classification.

In California a study is made of the subgrade conditions on each project and is started while the preliminary location surveys are underway. This is done in order that the information may be available early in the design period; so that maximum economy may be obtained through the use of local materials insofar as possible. The routine soil surveys are made by the District Materials Engineer, and a soil profile is furnished as a portion of his completed report.

Mr. O. J. Porter, Senior Physical Testing Engineer of the California Division of Highways, in his paper, entitled, "The Preparation of Subgrades,"[1] gives the method used in California in making the soil survey. He says in part:

"Although the scope of investigation is usually dictated by the nature of the terrain and other project conditions, we usually first study the geology of the region; second, make borings to expose and sample the typical materials; and, third, perform tests to determine the essential properties of the soil. A proper balance between these three methods of attacking a subgrade problem will usually produce adequate data at minimum cost.

"The most common type of exploration used in this state consists of hand borings made with a soil sampler, similar in design to the larger power-operated sampler described by T. E. Stanton in the Proceedings of the International Conference on Soil Mechanics, Volume I, June, 1936. This outfit, driven either by hand or with a light, portable gasoline hammer, is suitable for obtaining 1 in. cores from penetrable ground to depths ranging up to 50 ft. Such borings, supplemented by tests on larger samples from relatively shallow hand auger holes, generally furnished sufficient information for preparing a soil profile through light grading work on valley projects.

"Explorations of a larger size, however, are often required adequately to disclose the materials available in heavy cuts on larger grading projects, and also to investigate any other local sources of material proposed for subgrade reinforcement. In such cases, larger borings are made with a special combination drilling rig, designed and built by the department for (a) heavy duty churn drilling, (b) making rotary borings up to 36 in. in size through earth and soft sandstone and shale formations, and (c) operating the larger size of sampler outfit.

"The churn drill is used to actuate a hammer for driving the sampler outfit, and also for breaking through rock and boulders not readily penetrated with the sampler and rotary tools. The larger diameter rotary borings are made to depths of 50 to 80 ft. to investigate ground water conditions and to examine the formations in place. Large undisturbed samples may also be obtained from the portion of the ground explored with the rotary tools."

[1] *Proceedings,* Highway Research Board, Vol. 18, Part II, p. 324, 1938.

The data, obtained from the soil survey, are used for the following purposes:

1. To determine the type of surface.
2. To determine the thickness of rigid pavements.
3. To determine the thickness of base for non-rigid pavements.
4. To determine the type and quantities of stabilizer for soil stabilization projects.

Colorado makes soil surveys using the method designated by the A. A. S. H. O. with the exception that the number of samples taken on any job is fewer than that recommended by the Association. By using glass bottles to carry small samples of materials duplications are easily avoided. Some little work has been done with undisturbed sampling.

Hand augers, similar to those recommended by the A. A. S. H. O., are used. When making surveys for borrow-pits, a Buda earth drill, mounted on a 1½ ton truck and making a 14-ft. hole, 20-in. in diameter, is used. This machine enables the engineer to make a thorough investigation of any proposed borrow or gravel pit.

Connecticut reports that they have never made any attempt to analyze the sub-soils encountered, depending entirely on a general knowledge of conditions in the various parts of the state for the determination of the thickness and type of base or surface to be used. However, prior to any preparation of plans for a new project, a very thorough survey of the service record is made of the road to be improved. From this survey, location of springs, rock, and general soil conditions are observed and used in designing the new roadbed.

Delaware follows closely the procedure outlined by the A. A. S. H. O.; however, as many test holes are drilled as may be necessary to determine the character and extent of all soils through the project. At least one hole is drilled wherever the grade changes from cut to fill, or level section, and wherever the presence of rock or underground water is thought likely. Considerable care is taken to locate sub-surface water, and a careful study of the source and best method of drainage is made.

Samples are taken of each material encountered and the routine tests are made for identification, according to the Public Roads Administration standard group classification. The suitability for various purposes of the materials encountered is determined by means of their group classification, and by knowledge of special local soil types or conditions.

The equipment used in making the soil survey consists of three sizes of the ordinary open type post hole auger of 4, 6, and 10 in. diameters with extensions for drilling to depths of 30 ft. An adjustable closed type post hole auger having one hinged side, which drills holes from 10 to 12 in. in diameter, is also included as standard equipment. It has been found that the smaller size augers are not satisfactory, since they do not remove a sufficiently large sample for testing purposes.

The methods used by Florida are practically the same as those set forth by the A. A. S. H. O., with the exception that a soil profile is not drawn. In making the underground exploration, post hole and soil augers are used. Care is taken in the exploration work to determine and locate all strata and points of change. Samples are taken of each soil type encountered. The soils engineer in charge of the investigation makes the field classification and determines what samples should be submitted to the laboratory for classification. The data collected on the soil survey are used in preparing plans and specifications for the project. The test results are shown on the plans as also are the methods of treatment of the unsatisfactory materials encountered.

In Georgia the general procedure followed is that after the centerline and approximate grade line of the new project have been established, the soil survey crew goes over the project making borings to about 4 ft. below the preliminary grades, taking samples of each stratum encountered. The borings are made with a 4-in. hand prospector's auger; the frequency of such borings depends upon the uniformity of the soil. Borings are taken often enough to establish the length and depth of all strata encountered. Only about two samples of each soil stratum are taken for each ten miles of roadway. In addition to the borings, all existing roadway cuts and open wells in the vicinity of the project are noted and studied. The information thus noted is used to establish the finished grade, to determine subgrade construction methods and thickness.

In Idaho the procedure is briefly as follows: (1) A brief reconnaissance is made over the proposed route taking note particularly of geographical features, drainage, nature of soil, outcroppings and extent of such, and in case of a realignment, particular attention is devoted to sections of failure on the old road and if possible cause of failure is noted. (2) Borings and test holes are then made in order to determine the extent, both horizontal and vertical, of all soil strata. Samples of each stratum encountered are taken to the laboratory for testing. In order to avoid excess sampling small samples of each soil type encountered are carried in small air-tight bottles. These samples are first classified as to texture, color, structure, and cementation. This enables a rapid comparison with samples already taken as each new stratum is encountered. This general procedure is followed until all soil types are logged. This underground exploration is made wherever possible with 1½-in., A. S. T. M. type soil augers. However, in gravelly soils test pits are dug when the auger cannot be made to penetrate. An attempt is always made to secure information to a depth of at least 2 ft. below the grade line. (3) The data thus obtained are used in designing for drainage, and for total depth of base and surfacing materials.

Iowa makes soil surveys only on those projects on which, after a preliminary field survey, such investigations are deemed warranted. Borings are made with 4 and 6-in. augers, and are carried to a mean depth of at least 2 ft. below grade line. Auger holes are spaced 100 ft. apart where there is uniformity in the soil layers and 25 to 50 ft. apart where the soil layers are more variable. A sample is taken from each soil layer for laboratory investigation. Core samples are also taken. These core samples are carefully sealed with parafine and shipped to the laboratory for determination of undisturbed densities and moisture content.

Field notes include information concerning location and direction of flow of underground water, extent of road failures, and a field sketch of the soil layers in profile and cross-section. This information is used to supplement the laboratory data. The information from these two sources is then used in working up the completed soil profile and for making recommendations for the treatment of the materials encountered on the project. These recommendations, estimates of quantities, and location of available treatment materials are included in the final plans of the project.

Indiana reports that soil surveys are conducted on all proposed projects as soon as plan layouts and proposed grade lines are available. Although a complete soil survey is conducted throughout a project, a soil profile is drawn only in those areas where definite and detailed soil stratification is encountered. In other areas a detailed log of the borings is tabulated. Borings are made with a standard 1½-in. soil auger to a point at least 4 ft. below the finished grade and often enough to record completely the depth and extent of all soil strata encountered. A representative soil sample of each stratum is taken for laboratory analysis. In making the field investigation, whenever any unusual moisture conditions are encountered the porosity, permeability and drainage characteristics of the soils are studied and reported. Heavy fill foundations are examined for stability.

Illinois conducts soil surveys after the methods of the A. A. S. H. O. and A. S. T. M., making a soil profile for use in design and construction. In the realignment of old roads, care and study are given to locations of points of failure, to the topography, surface drainage areas, surface geology, source and direction of flow of underground water and other pertinent data. Borings are made with soil augers at 50-ft. intervals unless changes in soil types require closer borings. All investigations are carried to at least 3 ft. below grade line. Borrow areas are also fully investigated. Illinois stresses the point that the soils engineer in charge of a survey party should have a basic knowledge of soil mechanics, drainage, and highway construction.

Kentucky has done little work on complete soil profiles. Most of the work to date has been confined to that necessary to the construction of stabilized base courses. Underground exploration has been confined to test pits and some work with soil augers.

Kansas conducts soil surveys for ordinary earthwork construction, for the determination of the surface type, for subgrade treatment or base course construction, for foundations, for large fills or ordinary fills on side hill locations, for unstable soils, and for underground water problems. Those surveys are generally conducted according to the A. A. S. H. O. methods; however, where the soil is of a sufficient depth and extends over a relatively large area, the soil survey methods of the U. S. Bureau of Chemistry and Soils are used.

All work on the soil survey is done by hand methods using hand equipment. Materials too hard to be penetrated by pits or by augering are in most instances classified as rock and are investigated either where they are exposed or by means of a core drill. The ordinary 4-in. orchard type auger has been found to be most desirable for making borings. Test pits are used through gravel and in rocky locations where the depth of rock is not excessive. Borings and test pits are made sufficiently close to determine the extent of the various soil types and are generally carried to a depth of two or three feet below grade line.

Rock and shale are located, and the strike, dip, and extent are determined by a geologist working independently of the regular soil survey party. Although the regular soil survey party handles all drainage problems met in the soil formations, the geologist makes a special study of all drainage features connected with rock formations.

Density tests are made on representative soils in cut sections and moisture tests are made on the deeper soils in proposed cuts, channel changes, and borrow pits where the soil moisture is not subjected to change.

A general reconnaissance study is made of roads in the vicinity, which are located on similar soils, to determine their servicability as subgrade soils and to determine the needs for the particular type of construction planned for the project.

The soils encountered in the survey are identified by visual inspection and by approximate field tests, such as feel, bite, etc., and all distinct soil types are sampled and sent to the laboratory for the routine tests. Compaction tests are made on all subgrade soil types which are encountered on a project.

During the soil survey a few preliminary borings are made to determine by visual inspection the nature of the underlying foundation soils for the larger fills. When saturated soils are encountered, a special survey is conducted. On this special survey, undisturbed samples are taken and are sent to the laboratory for testing.

Louisiana makes the subgrade soil survey as soon as possible after the location survey and preliminary plans are completed. Borings are made with either a 2¼-in. worm type or 4-in. post hole auger and in cut sections sufficient borings are made to map completely all soil layers to a depth of three to five feet below the proposed grade line. For fill sections borings are made to a depth necessary to establish a good foundation. Where poor foundation material is found, sufficient borings are made to determine its limits. Undisturbed samples are taken with a motorized drill rig of a type known as a mobile seismograph drill which is mounted on a 1½-ton truck chassis. Samples of each soil are sent to the laboratory for tests. These test results, together with field data, are used to plot a soil profile which is used for guidance in completing the design and during construction. Recommendations are made for the proper method method of handling of the materials encountered during construction.

Maine reports that soil surveys of subgrade conditions have become a general practice in their highway department during the past five years. Borings are made with soil augers of the spiral and post hole type and are made at 50-ft. intervals. If during the plotting of the soil survey in the field, a soil layer appears or disappears, intermediate borings are made to determine the extent of the layer. Ground water is carefully located and the direction of flow ascertained. Samples are taken from each bore hole and at least in 2-ft. intervals of depth and oftener if there is any visible change in soil type. All samples taken are sent to the laboratory for routine testing. In the laboratory any duplicate samples, of which there are generally many, can be discarded if found unnecessary. Some undisturbed samples are taken with a sampler; however, 95 percent of all samples are taken in the disturbed condition. The field men identify the soil through its visual characteristics into the various types as the survey progresses, and plot a field soil profile. When the laboratory tests results are obtained, a completed soil profile is made and is submitted with a written report of the survey for analysis and design.

In Maryland in the early stages of the soil work, an attempt was made to profile accurately all projects, taking into account every slight change in soil characteristics. Now such elaborate procedure has been eliminated by the introduction of "horse sense and practical methods." Work is now confined to locating strata of undesirable soils in cuts and taking care to see that such soils are mixed with other soils, so that the characteristics will be improved. This soil survey is conducted by the methods outlined by the Public Roads Administration and the A. A. S. H. O. In making investigations in deep cuts a 4 by 4-ft. hole is dug to a depth of 4 ft.; after which a 12-in. auger is used to a depth usually of about 15 ft. Investigations are continued below that point, using smaller augers to a depth of about 3 ft. below the proposed grade. Intensive study is made of swampy areas and for the location of ground water level and direction of flow.

Massachusetts to date has not attempted a complete soil profile, but rather has limited its investigation to the extent of peat, clay, and rock formations as a part of the preliminary study of a highway project. The investigation is limited to shallow borings with soil augers, and to shallow test pits to define the limits of shallow lying bed rock. Some work has been done with a Gish-Rooney resistivity apparatus and also with the seismograph.

Michigan has probably made the most radical departure from the accepted methods of making soil surveys. In 1925 soil surveys were started for research purposes using the system as outlined by the U. S. Bureau of Chemistry and Soils. In 1927 the first survey was made for design purposes by Dr. C. E. Kellogg, now Principal Soil Scientist, Bureau of Chemistry and Soils. Not until after 1929, however, did mapping for design purposes become a routine matter.

Mr. O. L. Stokstad, Soils Engineer of the Michigan Highway Department, in his article appearing in the 1938 *Proceedings* of the Montana Bituminous Conference, points out that the main purpose of soil classification is to provide soil information without necessitating continuous sampling and testing:

> "The important need for classification no longer exists insofar as a particular problem is concerned if its solution is provided by laboratory test results. For this reason the usefulness of the eight groups (A-1 to A-8), as developed by the Board of Public Roads, is definitely limited. This grouping emphasizes the laboratory approach to the field of soil engineering.
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> "It does seem necessary, however, to point out the need for a more comprehensive method of classifying soil in the field approach to the soil engineering problems.
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> "The previous mentioned eight groups do not lend themselves to the recording of detailed field information without a large amount of field work and voluminous special notes."

In making a soil survey in Michigan the great soil groups are divided into soil series having similar profiles, drainage, topography, and parent material; and these series are further classified into loam, silts, and clays. It has been found that the soil type may be used as a basis for the classification of physical and chemical data. "When used in this manner it provides a very useful tool in the study of soils for highway purposes. The Michigan State Highway Department in adopting this method of studying soils was immediately able to take advantage of the soil survey information available in the form of published county soil survey reports. In addition, it was also possible to profit by contact with the personnel of the Soils Department of Michigan State College."

Michigan has prepared a chart in which a few of the important design questions are answered in tabulated form. This makes soil information much more available to the average designer and has materially increased the utility of the soil survey. Michigan feels that the soil survey is the basis of all design, and as such, the information should be readily assembled in making the survey and the final results should be in as simple a form as possible for use in design and construction.

Mississippi makes subgrade soil surveys similar to the methods recommended by the A. A. S. H. O. Borings are made and samples taken with a 3-in. pod auger. When dense clay or hardpan is encountered, a chisel bit auger is used, and in gravel a spiral auger has proved satisfactory. These are all 3-in. augers and use ¾-in. pipe for the extensions. Borings are made at every station, unless a different type of material is encountered. Then intermediate borings are made until all layers are fully and completely mapped. A soil profile is plotted from the information collected in the subgrade soil survey. Information, concerning drainage problems and borrow pit areas, are also made available as a part of the information received from the survey. This information is all used during the design period and acts as a guide for the engineer during construction.

Minnesota uses, in general, the procedure outlined by the A. A. S. H. O. although the plotting of the data into a soil profile is not always carried out. The data obtained are summarized by the field men on special sheets thus presenting the data in tabular form. Sampling is very limited. Samples are taken only for check on the field identification, or where unusual border-line materials are found. Generally no samples are taken if the soils are of kinds whose characteristics have become well known from observation and experience. Undisturbed samples have not been taken. By means of the soil survey Minnesota establishes the relative merits of the different horizons of the soil profile; locates the positions of layers or pockets of undesirable soil materials, and areas and direction of flow of water-bearing strata.

Missouri uses the pedological system, as used by the U. S. Bureau of Chemistry and Soils, in making soil surveys for highway purposes. Missouri takes an attitude similar to that of Michigan, in that, of the three best known methods of classifying soils, the pedological system seems best to suit their needs. The other two methods seem to be limited in their scope because the classification by texture, as in the triaxial chart takes into account no other soil properties and the classification as developed by the Public Roads Administration is more an index of the behavior of disturbed soils and so does not take into account field conditions. The pedological system is essentially a reflection of drainage, topography, parent material, weathering agencies, as well as textural class. Missouri, however, does require that samples of each horizon of each soil type be taken and submitted to the testing laboratory for analysis. Field density tests are also made of each horizon in order that the theoretical soil shrinkage can be calculated for each horizon. Also in the light of past experience and test results, it is sometimes possible to recommend a treatment or placement of some particular soil materials in order that they may render better service in embankment or subgrade. Normal drainage is studied and any combination of soil or stone and soil materials, which would seem to create a critical situation as related to either normal or diverted drainage, is given special and careful consideration.

Montana follows closely the procedure recommended by the A. A. S. H. O. An auger similar to that recommended by the A. A. S. H. O. is used and borings are taken often enough completely to record the various soil layers. Borings are made under low fills to a depth of 3 ft. and under high fills to a depth of 6 ft. In cuts, borings are taken to a depth of 6 ft. and nearby exposed cuts are examined and deductions made from these. Samples are taken for laboratory analysis of each soil layer encountered.

Nebraska makes preliminary soil surveys in a manner similar to the method outlined by the A. A. S. H. O. Underground explorations are made with the hand auger or by digging test pits. Sampling is done with the augers and the frequency of taking samples is determined from visual classification made by the engineer during the survey. Nebraska at the present time is attempting to correlate data obtained from their soil surveys with the pedological data that have been assembled for the state by the U. S. Bureau of Chemistry and Soils and the University of Nebraska. This work has been carried on by the Bureau in Nebraska for 25 years and as a result, soil maps exist for practically every county in the state. Nebraska hopes to work out a procedure similar to that used by Michigan and Missouri.

Nevada uses a system of making soil surveys similar to that of the A. A. S. H. O.; however, they report a little different method of testing and sampling deep cuts. In deep cuts a series of holes are sunk from below grade line over the top of the ridge to be cut, attempting to sink each hole down to the stratum encountered at the top of the preceding hole. These holes are dug at intervals the entire length of the proposed cut. Thus they are enabled to map fairly accurately the profile of any cut. Samples are taken of each material and submitted to the laboratory for analysis.

In New Hampshire the preliminary soil survey is started in the winter and spring when it is possible to make a survey of all frost heaves and uneven sections. This enables special attention to be given to those areas which otherwise might be missed. Borings are made at 100-ft. intervals to a maximum depth of frost penetration. Wherever ledge is suspected, sufficient borings are made to show the profile of the ledge to help in estimating quantities and to eliminate, during design and construction, any pockets which might be formed by the ledge so that underground water will not be impounded. All swamp and muck areas are explored with a regular soil auger and a Michigan muck and marl sampler.

After the soil survey is made the information gathered, together with the laboratory analysis, is transferred to the road profile and colored according to type, so that it may be easily seen what materials will be found in any cut. The information thus gathered is used both in the design and in the construction.

New Jersey reports that they do not make subgrade soil surveys. They do, however, dig test pits to examine the ground for general soil types and location of rock. In areas of soft ground rod soundings are taken to determine the depth and consistency of such material.

New Mexico has only just started making soil surveys and has not as yet established a standard of procedure. Samples are taken for the most part only when visual and manual inspection of the material gives rise to any reasonable doubt as to the suitability of the material. Data gathered are used as a guide to judgment in making recommendation for use in construction on for remedial measures.

New York reports that to date only a few soil surveys have been made. The methods used are similar to those outlined by the Public Roads Administration and the A. A. S. H. O. Samples are taken either from test holes or from auger borings and are tested in the laboratory for classification according to the A. A. S. H. O. methods. Several types of diggers and augers are used in obtaining samples. They have used successfully a Pincer type post hole digger, a 4-in. and a 6-in. diameter post hole auger, and a hinged spoon. The information obtained from the survey is used to determine methods of stabilization of materials placed in embankments and found in unstable cut sections.

North Carolina, except in special cases, does not make detailed subgrade surveys. They do, however, make visual examination of subgrade soils prior to letting a contract and then make a thorough examination during construction. Sometimes when seepage is encountered a soil profile is made from data obtained from borings and the condition is adjusted either by grade change or by sub-drainage. Underground explorations are made with soil augers and samples of the different strata are sent to the laboratory for classification according to the A. A. S. H. O. requirements.

In North Dakota preliminary inspection is made of the project to determine the main characteristics of the soil profile. From cuts and borings the different soil layers are determined and, depending upon the type of soil encountered, about three samples per mile are taken and sent to the laboratory for analysis and classification. A continuous soil profile is plotted showing all soil strata and laboratory test results. Field densities are obtained for use in predicting shrinkage factors. The soil profile and all other information is used both during the design and during construction of the project.

Ohio began routine soil testing in 1934. The soil profile includes the mapping and presentation of data from a complete investigation of all soil and geological stratifications which may be encountered throughout a project and which may influence the design, construction, and maintenance of the section. The information for the subgrade soil profile is obtained by borings, test pits, and the examination of exposed cuts. Borings are made with 4 and 6-in. post hole augers and with $1\frac{1}{2}$-in. soil augers and are made at such intervals as are necessary for complete mapping of all subgrade strata. These intervals may be as close as 25 ft. or as far apart as 500 ft. depending upon soil conditions. A small sample of each new layer as it is encountered is taken for comparative purposes. This reduces sampling to a minimum and still insures a complete and accurate profile. Field density measurements are made for the purpose of determining a shrinkage factor.

Ohio has experienced considerable difficulty with landslides. Investigation indicates that causes of slides can be classified under five general headings, namely, unconsolidated soil, unsuitable material, settlement, side hill fills, and slipping plane.

In order fully to investigate the causes of a slide it is necessary to go carefully into records which might have a bearing. Ohio has found that the following information is important:

(1) Time of year when slide was first noted.
(2) Weather conditions.
(3) Past efforts for stabilizing the slide.

(4) Records of all slides in immediate vicinity.
(5) The presence of coal mines.
(6) Maintenance records on slide area.
(7) A careful geological log of the area.

The first step used in sampling a landslide is visual inspection. Samples should be taken from areas near the top, part way down on the slope, and near the toe. Samples are taken with a 6-in. post hole auger or by core borings. Undisturbed samples are taken near the toe. Density measurements are taken in all three areas. Samples are tested in the laboratory to determine the moisture content, mechanical analysis and other physical tests to classify the soils. On the undisturbed soil samples consolidation and shear tests are run. From all the information gathered from both the field investigation and the laboratory tests, it is generally possible to determine cause of slippage.

In Oklahoma the general practice has been to investigate the subgrades on those proposed grading jobs on which it is expected to place rigid-type surfaces, or on completed grades on which such pavements are to be placed. Only in very special cases are subgrades sampled where flexible type construction is to be used. In proposed new construction samples are taken in excavation of each stratum or change in soil type to 2 ft. below grade line. Such additional soundings in the same excavation are taken as seems necessary depending on the length of cut and the general conditions in the areas as to uniformity of the soil horizon. The field notes and the tests are studied in connection with the plans for the project and recommendations for correction of the soil as seen necessary are included on the finished soil survey report.

Soil surveys in Oregon are made by the location party during the location survey. Underground exploration is made by means of a soil auger or from open pits or shafts. Sampling is ordinarily done by the location crew using the auger or from the test pits. Samples are taken from each layer and are sent to the laboratory for analysis. Data obtained from the survey are used to determine the construction procedure and are used by the locating engineer in arranging the distribution of material. Particular care is taken in locating springs and underground flows as an aid in providing proper drainage. Soil surveys have only been under way in Oregon for about one year and the A. A. S. H. O. and Public Roads Administration classifications and methods are now generally used. Prior work was limited to the practical knowledge which the various engineers had obtained from the use of soils.

Texas conducts a complete soil survey much after the pattern set forth by the A. A. S. H. O. The organization of each of the 25 districts of the state includes two or more engineers who have had the advantage of an intensive training course in both the fundamentals of soil mechanics and the application of soil mechanics to design of roadway facilities. At the present time subgrade surveys are conducted under the direct supervision of these soil engineers and generally follow in convenient sequence the work of the location party. Methods of making soil surveys vary according to conditions. Exploration is done using soil augers, bars, picks, shovels, and post hole augers, and is carried to a depth of at least 3 ft. below the proposed grade. Excavations are carried 3 ft. below ground line where embankments are to be placed. The frequency of borings is determined by the extent of various soil strata and sufficient borings are made to define all strata both horizontally and vertically.

Samples are taken for each stratum encountered during the boring operations. As samples are obtained they are first grouped in accordance with the apparent visual characteristics, such as, color, texture, grading, and structure. This grouping is only for information and does not establish any similarity of quality of the soils. When this preliminary grouping has been completed, a sample of each of the materials is prepared for the linear shrinkage test which is made in the field. This is an unusual procedure and enables Texas to further classify soils in the field into more definite groups. Those samples within the preliminary grouping having equal linear shrinkage may be considered as soils having uniform characteristics and to have come from the same or similar formations. Using this basis of grouping, it is possible to take a few samples for submission to the laboratory for determination of the soil constants.

Information from both the field survey and from the laboratory test results is used for the development of a continuous soil profile for the project in question. Soils are grouped for indication on the soil profile by a process of selection and combination. First, the soils are visually inspected and linear shrinkage tests made. Those samples having similar visual characteristics and linear shrinkage are of the same character and are grouped together and a sample taken from each group for making routine laboratory tests. Second, the soils are finally grouped for indication on the soil profile by range of plasticity index ranging from 0 to 4, from 4 to 15, from 15 to 25, and above 25. From this soil profile the distribution of excavated material is determined. It further permits analysis of other features, such as the requirement for underdrains, the amount and type of consolidation required, and the moisture content necessary for desired density.

Utah conducts a complete soil survey similar to those outlined by the A. A. S. H. O. and the Public Roads Administration. Borings are made using post hole augers and standard 1½-in. soil augers, and if further exploration is necessary, pits are dug. The frequency of the borings depends on the strata encountered. Enough borings are taken to insure that all strata are fully mapped. Such explorations are carried to 5 ft. below the proposed grade line.

Samples are taken of each strata and submitted to the laboratory for complete analysis. A good deal of dependence is placed on the results obtained in testing both disturbed and undisturbed samples in the stabilometer, from a field bearing determination and from a study of general geological characteristics of the area. Care is taken to locate ledges of rock, water bearing strata, and any swampy or boggy areas. Field density determinations are also run using the standard Proctor method in order that shrinkage factors may be calculated for the materials met. Field moisture tests are also made to assist the design department in the determination of the amount of water necessary to obtain maximum density during the construction period. A complete soil profile is made by the soil engineer from the results obtained during the field investigation and laboratory tests. This information is used to assist during the design period and during the construction of the project.

Soil surveys in Vermont are conducted paying particular attention to land contours, drainage, vegetation, stoniness of soil, presence of boulders or ledge, exposed cuts, etc.

Special attention is given to swamp areas, filled in or made land, and water table levels. Underground exploration is made by the use of the post hole diggers and augers. The augers being from 1½ to 2-in. diameter. Bars for soundings are also used. Ordinarily field observations of soil removed from the borings or test pits are deemed sufficient analysis, but occasionally samples are taken for grading analysis and determination of stability in the laboratory. The subsoil data, when plotted on cross-sections and profiles gives the design engineer information concerning swampy and boggy conditions, underdrain requirements, rock quantities, and other similar information.

While Vermont does not conduct a complete soil survey according to the A. A. S. H. O. requirements, they do place a good deal of dependence upon their method, as outlined.

In Wisconsin soil surveys are conducted only in sections of the state where trouble with subgrade disturbances have been met. Equipment used consists of soil augers, post hole diggers, shovels, peat samplers, etc. On the preliminary soil survey the auger is used to a depth of 6 ft., save where marshes or peat swamps are encountered, in which case, the exploration is carried to a point deep enough to obtain solid footing. When and where the proposed grade line involves cuts greater than 6 ft., the procedure is to discontinue the preliminary soil survey at that point and subsequently continue at the time the rough grading work through such area is approximately complete. Any remedial measures necessary are decided upon at that time and executed while grading equipment is in the vicinity. Generally the soil survey starts with spacing auger holes at 25 ft. intervals using a serpentine design within the roadway limits. When any trouble potentialities are encountered the spacing of the borings is varied to locate the limits of the troublesome areas. Wisconsin has also used quite extensively an electrical resistance apparatus in making underground explorations. Marshes and swamps are explored with the use of sounding rods and peat samplers, and water table levels are carefully located.

The number of samples taken is very limited since much dependence is placed upon the present knowledge which the field personnel has developed about the major types of Wisconsin soils. The average number of samples taken does not exceed one to a mile. Samples are obtained with the soil auger or post hole digger and are transmitted to the laboratory for complete analysis using the standard P. R. A. classification. To date no undisturbed samples have been taken.

A complete soil profile is made using the data obtained from the field survey and laboratory tests. The results obtained from the soil survey data are used both in design and construction.

Wyoming has not yet entered fully into the field of underground exploration. They have recently purchased an apparatus similar to that used in California for the drilling and sampling of subgrade soils and with this equipment they expect to make complete soil surveys. Until the present time, such exploration work has been confined to shallow depths and there has been no attempt to follow the procedure outlined by the A. A. S. H. O. Some sampling was done with the methods of sample taking and the number, being left entirely to the discretion of the field or project engineers.

Tennessee, Virginia, West Virginia, and Washington have only conducted small scale surveys, such work having been done under the methods prescribed by the A. A. S. H. O. The explorations have generally been limited to areas where it was apparent from visual observation that difficulties might arise in construction from unsatisfactory conditions. Data obtained from such surveys have been used to determine where settlement is apt to occur, supporting power of soils under fills, and frost heave danger.

Pennsylvania, South Carolina, South Dakota, Puerto Rico, and Rhode Island have not yet conducted subgrade soil surveys; however, such operations are planned for the future. Rhode Island feels that because of the large, state-wide deposits of gravels of all gradations which are available at a cheap rate widespread soil investigations are unnecessary. An annual survey is made in late winter and early spring to note and remedy any failures.

Hawaii has only recently started subgrade soil studies. Each project is studied and tested in accordance with the terrain. The frequency of sampling and the methods used in taking samples are left to the discretion of the resident engineer. A special test machine for determining the bearing power of soils has been developed, which has proved very useful in the designing of subgrades and surfaces.

As a result of this study it is evident that today the generally accepted procedure in making subgrade soil surveys is similar to that outlined by the A. A. S. H. O. and the Public Roads Administration. The reports indicate that while all States using this method do not now make complete soil surveys and complete soil profiles it has generally been expressed that such work will shortly be done.

Subgrade explorations are being made by means of 1½-in. standard soil augers, 4, 6, 8, and 10-in. post hole augers; this equipment being supplemented with bars, pincer type diggers, spoons, picks, and shovels. A great many of the states continue to rely upon test pits as the only satisfactory means of subsurface exploration. However, the trend is quite definitely in the direction of using the larger type post hole augers.

The use of these augers means a considerable saving in time and effort over that required for test hole digging. These larger augers also have the advantage over the smaller size auger inasmuch as a large enough sample can be removed for comparison and testing purposes.

A number of the states report the use of portable, mechanized earth drills, boring test holes up to 36-in. diameter. While these rigs are costly they do make possible an accurate record of the underlying soil strata. However, such large equipment is generally considered unnecessary as adequate and accurate work can be done with much smaller equipment. California has for years sucessfully operated a power sampler taking 2 and 4-in. diameter undisturbed samples. Many other states report equal success. Borings have been made to depths ranging between 60 and 300 ft. at an average cost of approximately $1.00 per foot including rental of equipment and all operating costs. Similar sampling with other methods usually costs two to four times this amount.

Some subsurface exploration work has also been done using resistivity and earth resistant apparatus. These methods are still quite definitely in the experimental stage and hence have not as yet been adopted or used very extensively.

Wisconsin reports, "In the last two years we have been using not infrequently the electrical resistance apparatus. Our efforts with this equipment have been rewarded in most cases with a satisfactory degree of accuracy and in some instances we have been 'let down' with some information not too good." Massachusetts reports in the same general trend, however, emphasizing that the work was done only experimentally.

States generally agree that sufficient borings or test pits should be made adequately to map all strata encountered and should be deep enough to be 3 to 5 ft. below the grade line. This generally supplies enough information for the proper design of the roadway facilities. Many states report that the exploration is carried down below the grade line until a water bearing stratum is encountered or until a relatively impervious layer is met. This provides adequate information for the complete design of all underdrains.

Determination of the number of samples to be taken varies considerably in the various States. Several take samples from all test holes for submission to the laboratory while others go to the other extreme and take only samples of material of which there might be a question as to its suitability. Most States follow the center path, that of allowing the man in charge of the soil survey to determine what samples should be tested, but requiring that a sample from each stratum be submitted to the laboratory for complete analysis.

In order that sampling might be reduced to a minimum, the various States have devised methods of making field comparisons of the strata. The general procedure is to take a small sample in a bottle of stratum for comparison. Thus samples which have similar visual characteristics, such as, texture, color, grading, and structure can be classified in the field. Texas uses the linear shrinkage test as a further means of field classification. It is well, however, to note that no one can definitely ascertain the quality of soils except by making physical tests. Soils widely dissimilar in character may appear to be identical and similarily, soils widely dissimilar in appearance may actually have the same characteristics. It is necessary, therefore, that visual inspection be augmented by physical tests for grouping determination.

To make the field survey as comprehensive as possible, field bearing tests and field density determination tests have been devised and used very successfully. California, Utah, and Hawaii have all developed bearing value tests which throw considerable light on the field behavior of soils. These tests have been devised to answer two of the most important subgrade questions affecting pavement service, namely, the amount of resistance to displacement under moist to wet conditions and the volume increase and uplift resulting from absorption of moisture, subsequent to construction. The California method of making the test as reported by O. J. Porter is as follows:

"Tests are made by wetting the material to optimum moisture content and then consolidating the sample in a 6 in. cylindrical mold under a load of 2000 lbs. per sq. in. The sample contained in the mold is then tested for bearing value by penetrating the center of the compacted specimen at the rate of 0.05 in. per minute with a piston, 3 square inches in area. A dial fastened to the apparatus accurately measures the penetration of the piston. The loads for each increment of 0.1 in. penetration to a total of 0.5 in. are recorded. Following this operation the specimen is loosened, reconsolidated, and then placed in a tank of water, after first noting the height. During the soaking period the sample is confined within the mold by a porous disc and a 10 lb. weight which represents the surcharge effect upon the subgrade of a 4- to 5-in. thickness of pavement. After the specimen has soaked for four days the swell is recorded and the bearing value again determined for the compacted and soaked condition.

"The bearing value results, for both conditions of the specimen, are reported in pounds per square inch and also in the percentage of the loads required to obtain like penetrations of a standard sample of crushed rock surfacing material similarly tested. The expansion of the specimen during the test is recorded in percentage of the volume of the compacted sample before soaking."

Hawaii uses a slightly different method. The soil sample free of rocks and stones and soil particles larger than ⅜ in. is introduced alternately with water into the test pan at a rate which will insure saturation. The saturated sample is compacted under a static load, drained, released from the compaction load, surcharged with a load equal to the pavement weight and tested. The load is applied by a handwheel against a calibrated coil spring. Penetration of the piston is measured by a scale on the penetration rod. The load penetration curve is taken to indicate the comparative stability of the soil sample.

Utah has developed a bearing apparatus for making field determinations. The apparatus also can be readily adapted to use in the laboratory on either undisturbed or disturbed samples. With this machine accurate field determinations can be readily made and its use has solved some difficult bearing problems.

Many states report using field density measurements for the determination of shrinkage factors. These measurements are made following the methods as outlined by R. R. Proctor for the determination of the density of compacted soils. In performing the test, the loose surface soil is removed and a hole of about 8-in. diameter and 1 ft. in depth is dug, and the removed soil is carefully weighed. The volume of the hole is determined by filling it with a fine dry sand of known density. The weight of sand used determines the volume of the hole. The moisture content of the removed soil is determined by oven drying a small sample. From these data the dry density of the soil can be calculated. The shrinkage factor can be determined by comparing the dry density of the material in place with the compacted dry density as obtained by the standard laboratory method of compaction of soil.

After the field survey has been run and the laboratory test results obtained a complete soil profile should be made. Probably the best procedure in making a soil profile is to make a rough profile in the field during the time the boring and field testing are in operation. By this method all strata can be completely and accurately mapped.

The construction of the soil profile is essentially a drawing process, requiring only superficial knowledge of soils in its preparation. It should, however, be carefully checked against the field and laboratory data by the soils engineer before it is inked or utilized in design. The ground line should be indicated by a heavy solid line and the limits of each stratum by dashed lines. The characteristics of the several strata should be indicated on the drawing so that all information can be readily available. The various strata can be shown by some conventional system of symbols, by cross-hatching, by coloring, or by any other method.

There is one very interesting trend in the method of making soil surveys for highway purposes and that is the method used by Michigan and Missouri. They are using the methods of survey as outlined by the U. S. Bureau of Chemistry and Soils. Kansas and Nebraska have also experimented using this method wherever the information is available. These states take the position that inasmuch as many years of work has been done by the Bureau in making soil surveys, why should not this information be utilized by the highway departments.

"The Michigan State Highway Department has found that the pedological scheme of soil classification provides an excellent means of studying soils for general highway purposes and that it serves as a foundation for all other soil studies in the department. The soil type, in addition to serving as a unit in mapping, also serves as a unit to which laboratory test results, road behavior observations, construction problems, and maintenance experiences are related. In other words, the soil type serves as a means for classifying and coordinating the accumulated soil experience of the entire highway department personnel.

"Until quite recently the common impression has been that the highway engineer is interested only in those soil properties upon which the serviceability of the pavement depends. It is now quite generally agreed that the highway engineer is interested in the entire highway right of way. This wider interest requires consideration of such subjects as landscaping, erosion control, shoulder stabilization, and to some extent, land use. The intelligent and efficient handling of these subjects, especially by the design division, requires a method for classifying the soil which reflects a large amount of detailed information about each individual soil."

Michigan and Missouri feel that the pedological system of making soil surveys fulfills this requirement.

SUMMARY

To summarize this subject certain definite conclusions may be drawn from the replies received from the various States.

(1) Most states find that at the present time a soil survey conducted by the method outlined by the A. A. S. H. O. adequately fills their needs.

(2) Adjustments in the methods as outlined by the A. A. S. H. O. must be made for local conditions. No set rule can be successfully followed in all cases.

(3) Sufficient borings should be made to map completely all soil horizons. The interval between borings may be as little as 25 ft. in areas of great stratification, or as far apart as 1000 ft. over areas of very uniform soil conditions.

(4) The explorations should be carried to a depth of at least 3 ft. below subgrade elevation.

(5) Areas of ledge or rock should be explored fully to determine their extent. This can best be done using a power drill of a small diameter.

(6) Samples should be taken of each soil type encountered on the project under survey.

(7) Disturbed samples can best be taken, under normal conditions, using post hole augers of 4 or 6-in. diameter.

(8) Undisturbed samples should be taken of all questionable soils. This can best be done using one of the sampling devices now being used by the various states, for instance, the Porter sampler of California.

(9) All cuts and wells in the vicinity of a project should be thoroughly studied.

(10) Care should be taken to map completely all underground water areas which might influence the subgrade soil behavior. Direction of flow should also be ascertained.

(11) Complete soil profiles should be drawn, first in the field, and finally in the drafting room.

(12) The final soil profile should contain complete field and laboratory data.

(13) The final report of the soils engineer should include, in addition to the soil profile, recommendation for the proper use of all materials, so that these materials may render more efficient service in the subgrade.

(14) The methods of conducting soil surveys as outlined by the U. S. Bureau of Chemistry and Soils certainly should be studied by states where such surveys have been made with the thought of correlating this information for use in highway design.

(15) The purpose for making the highway subgrade soil survey is in order that recommendations may be made concerning the following points:

a. Necessary revisions in the proposed grade to secure a stable and satisfactory subgrade

b. Any necessary shifting of the horizontal alignment to prevent slides or secure an improved subgrade material

c. The design and location of special ditches and subsurface drains

d. Any necessary revisions of the standard fill slopes or cut slopes

e. Any necessary subgrade treatment and the type required

f. Selection of fill material

g. Determination of peat removal and rock quantities

h. Suitability of foundations for heavy fills

i. To determine the type and quantities of stabilizer material to be used on soil stabilization projects.