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THE OHIO STATE UNIVERSITY AND THE OHIO DEPARTMENT OF HIGHWAYS

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CORRELATION OF GEOLOGICAL STUDIES BY VARIOUS GOVERNMENTAL AGENCIES IN OHIO

by

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Many groups, State, Federal, Educational and Industrial, accumulate various kinds of basic geologic data as a by-product of their regular activities.

In Ohio, the State Geological Survey has made a persistent effort to establish voluntary, friendly, unofficial relationships with these various groups. It has been found by long experience that the Survey has many services which are of value to such organizations, and that they many times have geologic information which can supplement and enlarge its reservoir of scientific facts. Such a mutual understanding of each other's activities eliminates duplication and increases the efficiency of all concerned. By such friendly cooperation, a high degree of correlation of geological studies is attained.

In most states, the geological survey or its equivalent organization acts as such a clearing house for basic geologic information. It has, therefore, been found mutually beneficial for the Highway Geologist to become personally acquainted with the activities and services of the Geological Survey in the state in which he operates. An acceleration of such cooperation is highly to be desired, and, for this reason, a complete directory of the State Geological Surveys is supplied herewith.

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Madison, 6
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Horace D. Thomas, State Geologist

AIDS OF THE OHIO GEOLOGICAL SURVEY FOR HIGHWAY ENGINEERS

by

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Ohio Geological Survey

The Geological Survey of Ohio was first organized in 1837 for the purpose of collecting, studying and interpreting all available data pertaining to the origin, extent, use and valuations of geological and mineralogical resources of the state, and making this data available for use by commerce, industry and the public in general. Over the years, a great deal of information has been collected and published.

It is the purpose of this paper to point out some of the material available, both published, and unpublished, and to show where it might aid the highway engineer in his work.

I will begin with the small scale publications and progress to the larger scale, pointing out along the way some of the possible utilization of these in the planning, construction and maintenance phases of highway work.

Of course, we have the state maps at a scale of one inch to eight miles. The geological map (Figure 1) shows the general picture of bedrock in the state. From this, the broad areas of limestone, shale, coal and so on may be delineated. The areas of Permian and Pennsylvanian in the southeast represent the coal-bearing measures; the Mississippian through the central portion and in the northwest, shales and sandstones; the Devonian of the central part, limestones and shale; the Silurian and Ordovician limestones, dolomites and shales. The regional structure is also shown here. The Highway Testing Laboratory has used this as a part of the base for their generalized engineering soils maps.

The part which shows the general soil types in the unglaciated southeastern part of the state is based on the state geological map. Here the soils are residual and a knowledge of the parent rock underneath is necessary for determining soil type.

Another state map shows the glacial deposits (Figure 2). In western, central, and northeastern Ohio, the soils are generally Wisconsin till. This map shows the areas of moraine in a general way. Along the lake and in northeastern Ohio are the lake plains, the lacustrine clay soils. This general knowledge is important in the planning and design stage as one of the criteria for pavement design. The generalized soils map of the state, in part, is based on the glacial divisions.

The state mineral industries map, along with the directory of mines and quarries, is useful in telling the engineer the type and number of aggregate producers, which may influence the estimated cost for the roadway, in a given region.

A publication, Peat Deposits of Ohio, will be of assistance in helping to avoid troublesome peat areas, or where unavoidable, can help the engineer more fully understand their nature. It discusses the distribution of deposits by counties. Here is shown the general distribution of peat deposits in Ohio (Figure 3), giving areas of peat and location of deposits.

A geologic map index of Ohio is published by the U. S. G. S. It shows published geologic maps in a graphic manner. The material listed here includes not only that published by the Ohio Geological Survey, but also other agencies as well as individuals, who have contributed to the geologic mapping of the state. Examples of some of the material shown by this index are: Geology and Mineral Resources of the Cleveland District; Coal Fields of Ohio; Glaciation of Northwestern Holmes County; and Water Resources of Montgomery County.

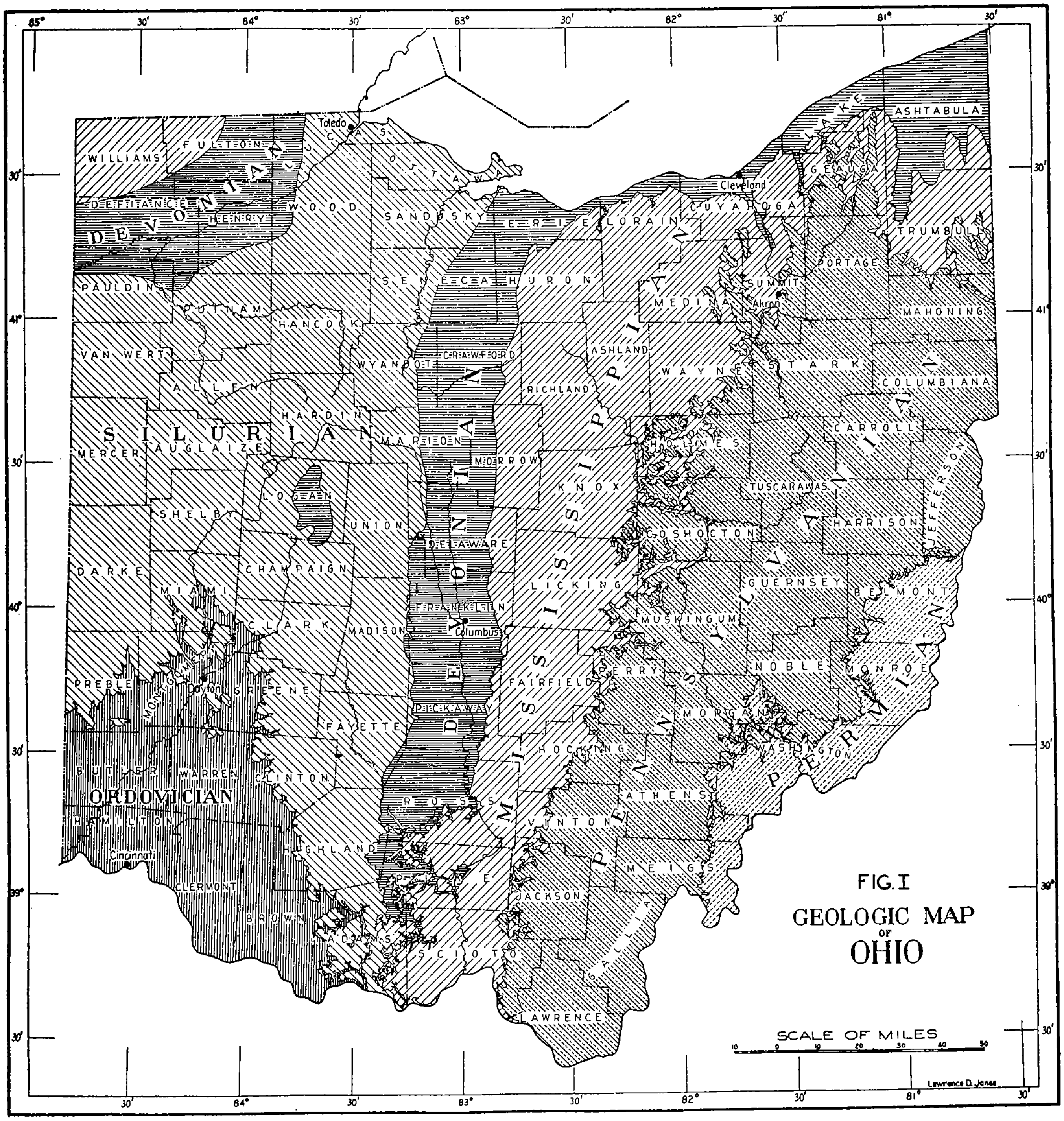
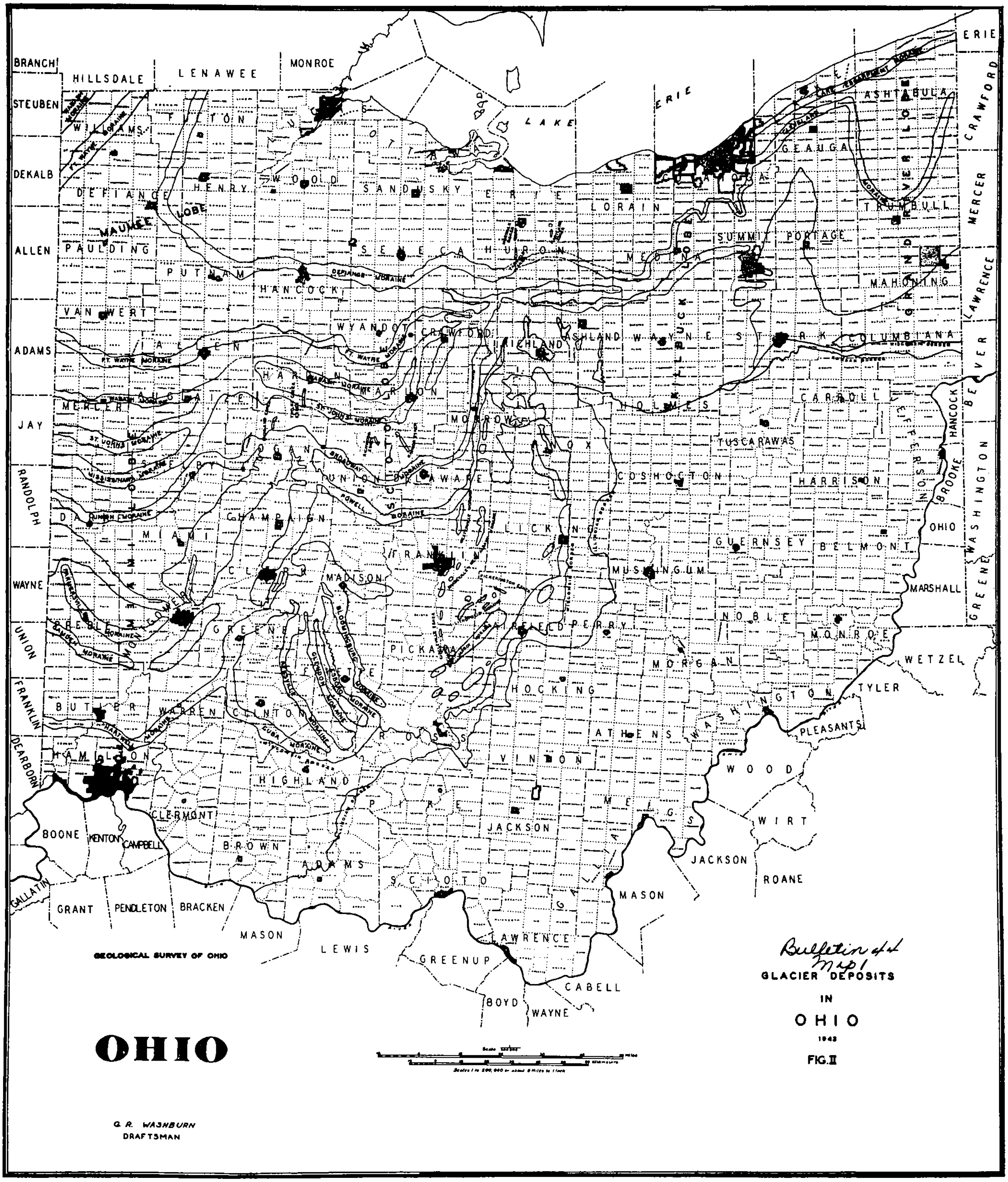


FIG. I
GEOLOGIC MAP OF OHIO



Bulletin 44 Map 1

GLACIER DEPOSITS IN OHIO 1943

FIG. II

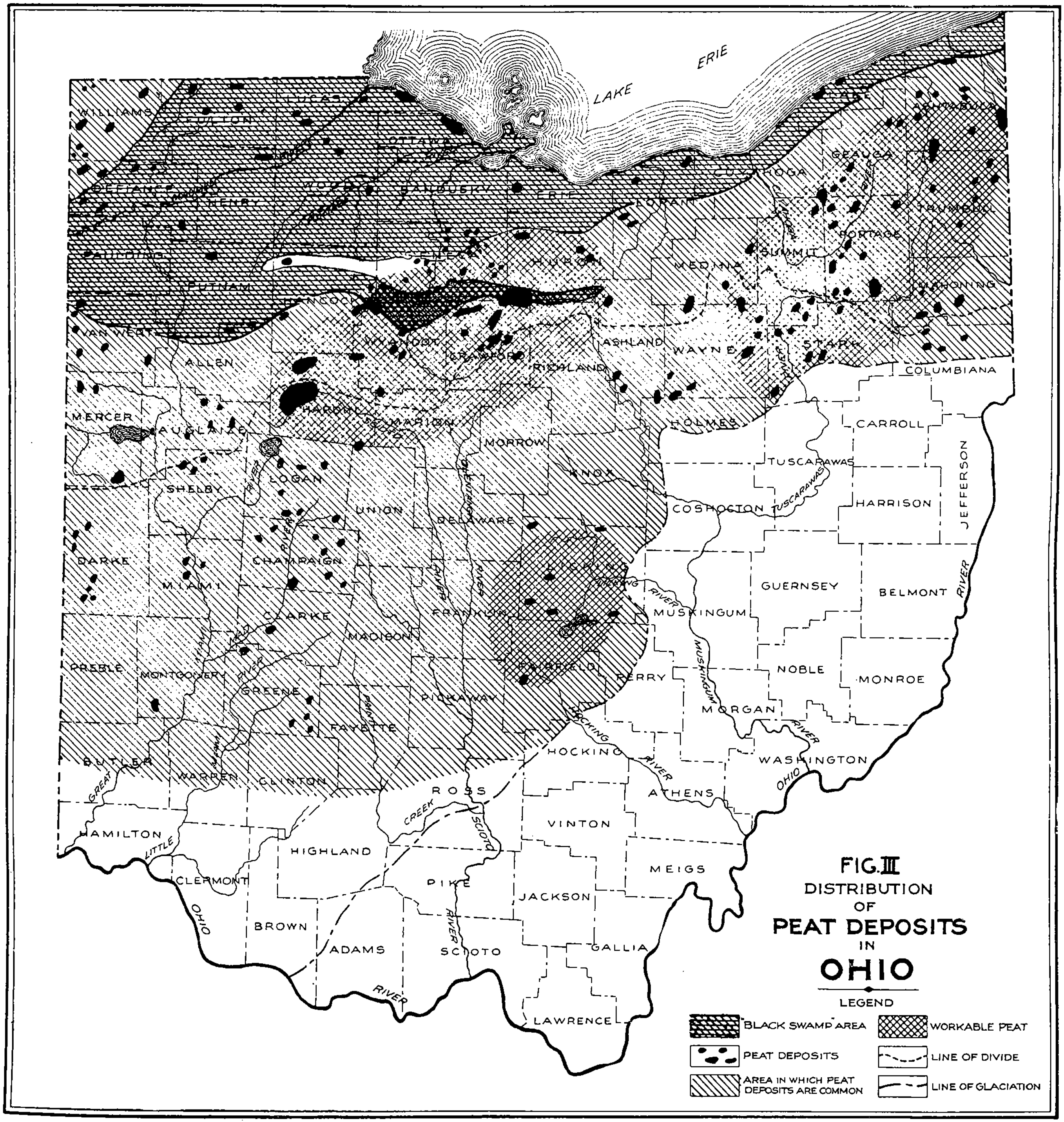


FIG. III
DISTRIBUTION OF PEAT DEPOSITS IN OHIO

In a more detailed way, county bulletins, which give physiography, stratigraphy, glacial and economic geology, are available. County reports completed are: Columbiana, Coshocton, Delaware, Franklin, Hamilton, Highland, Holmes, Jackson, Jefferson, Lawrence, Muskingum, Perry, Vinton and Wayne. The older reports are at a scale of one inch to three miles, while the later maps are at a scale of one inch to one mile.

An example of the later publications is Coshocton County. Here geologic map units are superimposed on a base map. They represent different time as well as rock units. Descriptions of those units are usually given in the accompanying text. These can add considerable to the planning engineers knowledge along the right-of-way. Use of them can help in the planning for an intelligent exploration program by pointing the way to areas where drilling should be more intensive and by indicating where sampling can be held to a minimum. These maps, while two-dimensional in character, can be three-dimensional in scope.

In deep cuts, these reports can throw some light on weathering and physical characteristics of the rock involved and thus be of assistance in slope design.

One special publication, of a type which engineers would probably like to see more of, is Hyde's Geology of the Camp Sherman Quadrangle, published by the Survey in 1921. In this publication, the rocks are described in engineering terms and related to engineering usages. As an example, on this map, the Logan sandstone is described/5/ as, "fine-grained gray or yellow sandstone, 275 feet thick in eastern portion of quadrangle, much less in western portion. These sandstones always form steep slopes with little or no soil; the sandstones are tough and can be excavated with pick and shovel, only with great labor. Free of water. Excavation will require little or no revetment. Slopes are usually wooded".

On the inch to the mile scale, the Survey has a number of aids to the highway engineer. The areal geology map, again as in the county bulletins, of use for all phases of work in southeastern Ohio, where overburden is thin and the soil residual; in the glaciated portion for use in deep cuts and bridge foundation work.

Another, of more use in the glacial and outwash plains area, is the surficial geology map. Here is shown the areas of ground moraine, composed mainly of till, terminal moraine, which may have poorly sorted sand and gravel with stony moraine or may be simply clayey moraine. Associated with terminal moraines are kames, eskers, and outwash sands, all containing varying amounts of sand and gravel and in varying degrees of sorting. Also shown are the alluvium and terraces associated with recent drainage. Here is a definite aid in many phases of highway work.

Pleistocene maps of a number of the quadrangles are in open file at the survey office. Another source of the type information is to be found in the county ground water bulletins. These again delineate the glacial deposits as associated with the ice sheets rather than on the basis of differences in character. However, certain properties can be "read" into these glacial features, which make them of value to the highway engineer in the preliminary planning, including drilling and sampling, and design stages. The potential for availability of construction materials, thus effecting the economny of the plans, is also present.

From the various subsurface records of the survey, top-of-rock maps are constructed on the inch to the mile quadrangle base. These are of varying degree of accuracy, depending upon the control and amount of data available. As time goes on and more data for a certain area is available, these top-of-rock maps become more accurate in their detail. Here contours at various intervals are given as drawn from well and section data. These combined with

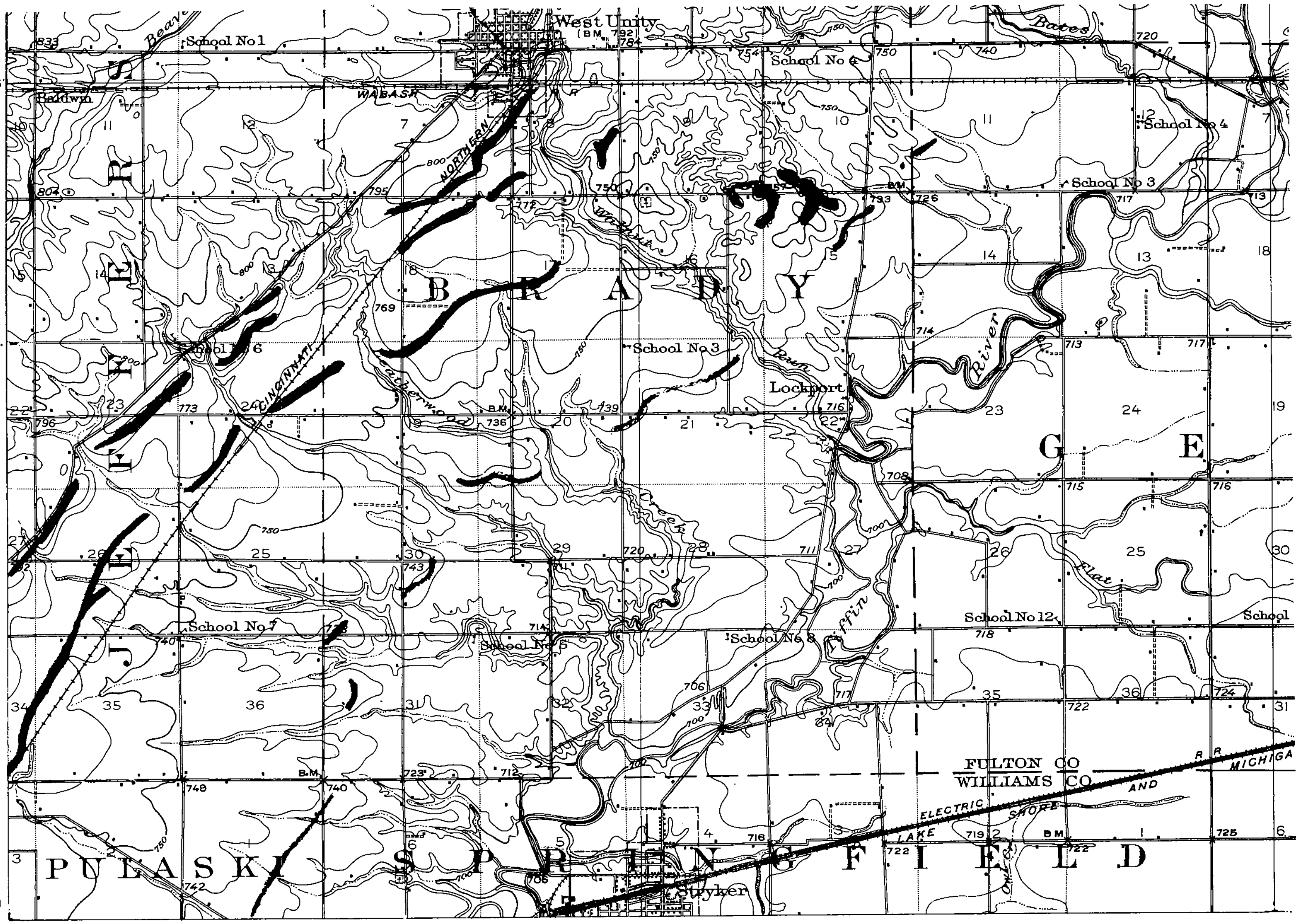


FIG. 4 BEACH RIDGES OF A PORTION OF ALVORDTON, O. - MICH. QUADRANGLE
AFTER F. CARNEY

geologic maps make available to the engineer knowledge as to the amount of rock to expect in cut, depth to rock in foundation work and again provide background for exploration along line, as well as being of use in the location of construction material sources.

Structure contour maps are of use in the interpretation of the locations of outcrop with respect to the road profile and are of most value in the unglaciated portion of the state. For construction materials location, however, their use is more widespread.

Of a more restricted nature, geologically, are reports such as Carney's beach ridges, as yet unpublished. Maps on open file, however, show the position of the abandoned glacial lake beaches in the lake plains of northern Ohio. Many of the earliest roads in this region were constructed on these sand and gravel beach ridges. A pattern of these ridges is shown here. (Figure 4). Some of these areas contain as much as 10,000 yards of material in one-quarter mile. In the lake plains proper clays and silts predominate, making for a difficult foundation situation, since drainage is poor.

Two very basic aids to highway engineers are handled through the Ohio Survey. The first, topographic quadrangles, showing culture, water and relief features are published by the U. S. G. S. in several scales. The majority of Ohio quadrangles are on the inch to the mile scale ($\frac{1}{62,500}$, 15 minutes). However, recently, more areas are being covered by the inch to one-half mile scale ($\frac{1}{24,000}$, $7\frac{1}{2}$ minutes). The constant demand for larger scale maps, especially in areas of considerable economic importance, has led to the publishing of the $7\frac{1}{2}$ minute quadrangle. The detail is considerably improved in these larger scale maps. These maps are revised, brought up-to-date and reprinted from time to time. The other, aerial photographs, are published by the Production and Marketing Administration of the U. S. Department of Agriculture in several scales. The largest scale available is the 1" = 400 ft.

scale; contact size scale is 1" = 1667 feet. In the preliminary and planning stages of both new construction and realignment, these are invaluable basic tools.

All of these geologic tools can be of aid to the highway engineer in the various phases of highway work .... in preliminary planning - for terrain, foundation, soil and geologic studies; in specific planning and design - as an aid to more detailed exploration for more efficient utilization of field exploration tools, both drilling and geophysical, for pavement design, for foundation studies, slopes in cuts, road alignment, possible slide areas, troublesome areas as peat bogs and sink holes and ground-water conditions plus the many other problems to which a knowledge of the character of the "ground" is fundamental in construction - for the location of borrow pits and construction materials as well as problems which come to light in the process of construction; and in maintenance - for slide correction, water supply, drainage improvement, subsidence, and pavement failure.

For the foundation condition of each site, whether complex or simple, is the direct result of the geologic processes, environment, and history of the area, therefore, a complete determination and understanding of the general geology of the area is necessary.

Much remains to be done in making geology a more definite aid, particularly so in a quantitative way. In its proper place, along with the many other tools at the disposal of highway engineers, geology can be of material assistance.

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APPLICATION OF GEOLOGY TO HIGHWAY ENGINEERING AS SEEN BY A HIGHWAY ENGINEER

by

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It has been my privilege and pleasure to attend all the meetings of this group since the conception of a symposium on geology, as applied to highway engineering, was initiated by the Virginia Department of Highways in 1950, under the leadership of Mr. W. T. Parrott.

I have enjoyed and benefited immensely from the papers and interesting discussions fostered by the excellent presentation of the subjects. However, I must confess I have been somewhat disappointed in that so few of the papers dealt with the application of the knowledge of geology to the solution of highway engineering problems.

Although my knowledge of geology is limited and was acquired primarily through the study of the various folios, bulletins and publications of the Pennsylvania and United States Government Geological Surveys, and supplemented by observations made in connection with more than thirty years of highway engineering experience, I believe I am well aware of the possible benefits that can accrue in the solution of highway engineering problems if proper utilization is made of the training of qualified geologists, especially those who have some working knowledge of highway location, design or construction.

During the past several years, the numerous and intricate problems involved in the design and construction of durable and adequate highways to modern standards have become very technical indeed. Construction and right of way problems, especially those involving the building of the limited access type in urban areas and the rugged mountain sections of Pennsylvania, require not only the services of the civil engineer, but also the assistance of chemical engineers in the control of materials, sanitary engineers in the handling of problems dealing with sanitation, mechanical engineers in the operation of complicated equipment, electrical engineers in connection with the design and operation of tunnels, and also mining engineers and architects.

Since the science of geology is primarily concerned with the earth's structure and the elements or materials that affect the structure, it stands to reason that the knowledge of the geologist should be utilized in the field of highway engineering. In Pennsylvania, we have made use of the services of geologists, but I believe not to the fullest extent possible.

To a minor degree, the highway engineer is continually changing the earth's topography by cutting away mountains and filling in valleys. He also places heavy fills and structures in various locations on the earth's surface. These changes sometimes upset the forces that tend to hold the earth's surface in equilibrium.

Those who have had the privilege and pleasure of traveling through the great Commonwealth of Pennsylvania know that it is not only noted for manufacturing, but also, that it possesses vast valuable mineral resources such as bituminous and anthracite coal, oil, gas, iron ore, immense quantities of limestone and other materials. Although Pennsylvania ranks third in population, its population is concentrated in a relatively few areas, and vast areas are sparsely populated.

The central part of Pennsylvania is mountainous and very rugged. The northwestern and southeastern parts are rolling and produce high quality and abundant agricultural and dairy products of the highest quality. The climate varies from mild in the southeast to very cold in the northern and mountainous sections. Rainfall averages about forty inches.

The glaciers moved over the northeast and northwest corners of the State. In the northwest corner those glaciers filled in ancient stream beds and thereby materially changed the former natural drainage.

The beautiful streams, the heavily wooded mountains and the rich agricultural areas, watered by adequate rainfall, make Pennsylvania the tourists' delight. When one travels through or flies over Pennsylvania, he is always looking on a land teeming with abundant life. Under the rich soils and the beautiful forests outcrop about fifty thousand feet of geological formations, making Pennsylvania the geologists' paradise.

Geologically, Pennsylvania is made up of rocks of Pre-Cambrian to Cretaceous in age. A narrow band of red rocks of the Triassic period crosses southeastern Pennsylvania from the Maryland to the New Jersey State lines. Most of the rocks are of sedimentary origin, except in the southeast where crystallines of various types predominate.

West of the Allegheny front, the strata are gently folded and are seldom more than ten degrees out of horizontal. East of the front, the strata are more intensely folded and faulted. The intensity increases to the east and southeast, except where the older rocks are overlain by the Triassic. For the most part, the Triassic beds have gentle dips. In the west, where the strata are nearly horizontal, subsurface drainage is difficult to handle. In the east, where the strata are folded and faulted, the problem is not of too much concern.

In the 70's and 80's, the Second Geological Survey of Pennsylvania made a complete geological survey of the State by counties. More than one hundred and fifty volumes were published, but unfortunately, and inasmuch as there were no accurate base maps available at the time, the information was recorded on inaccurate maps. Since then, the United States Geological Survey has completed and published topographic maps of all the quadrangles in the State.

Numerous folios, bulletins, ground water reports and other publications with geologic information recorded on these topographic maps have been completed by the

United States Geological Survey and the Pennsylvania Geological Survey. However, these publications are primarily in the bituminous coal fields, and only a few of the quadrangles outside of those areas where mineral resources are important, have been completed. Many of the publications are out of print, but all can be found in public libraries and second-hand bookstores.

In spite of all the information available for the use of those who know how to use it, very little profitable use is made of the information by the highway engineer. This is where the assistance of a geologist can be most helpful to the highway engineer. The geologist should know not only where to find the information, but with some experience in highway construction, he should know how to apply his knowledge to the solution of highway problems.

This question has often been asked by engineers in our Department, "What can a geologist do to assist us in the solution of our problems?". Some of the answers I have given are as follows:

1. A geologist can be very helpful in locating sand, gravel and stone deposits, as well as other suitable road building materials from the vast amount of geological information available to a geologist who knows where it can be found and how to interpret it.

In Pennsylvania, I have in mind the information contained in the Second and subsequent State geological surveys, agricultural soil maps, aerial photographs and various other publications of the United States and State Geological Surveys. When such publications are not available and when information of a more detailed character is required, the geologist's training makes it possible for him to furnish the needed information.

2. In the location, design and construction of highways, the geologist should be very helpful in pointing out potential unstable and slide areas. In glaciated areas, the location of ancient stream beds and bog areas, which sometimes are troublesome, can be detected and investigated. If these unstable

areas can be recognized in advance of the establishing of the location, it is often possible, by a modification in the alignment, to avoid possible trouble and expense.

In the heavy cuts, the relation between the strike and dip of the strata and the direction of the center line of the highway is very important in the design of slopes. In fill areas, especially side hill fills, this relationship must be given very careful study. When the highway can be designed at right angles to the strike, steep slopes can be provided in rock cuts. Where the center line parallels the strike in sharply inclined strata, extreme care must be used in locating the highway and in designing the slopes.

Joints in the rock formations and planes of fracture must be considered in the design. Although it is very seldom possible to design a highway so as to maintain the most desirable relationship between the direction of the highway and the strike of the rock, the complications involved in the various deviations should be anticipated, recognized, and planned for accordingly.

3. The geologist's knowledge of the structure should also be of great assistance to the engineer in the location of subsurface drainage facilities. Here again, the relationship between the direction of the highway and the strike and dip of the strata is very important. Because of lack of knowledge or through an oversight of this relationship, costly subsurface drainage is often ineffective, whereas less costly drainage, properly located, would be much more effective.

4. In Pennsylvania, we are frequently troubled with landslides, some of which are serious and often difficult to overcome or correct. Most of these slides are encountered in the bituminous coal region which is generally west of the Allegheny front where the strata are almost horizontal. In this area, there are alternate layers of coal, soft and hard shales and soft and hard sandstone, interspersed with numerous layers of impervious clay. However, we

are also troubled, but to a lesser degree, in the glaciated areas and in the ridge and valley sections where the strata are strongly folded and faulted.

5. In estimating the cost of excavation and arriving at a suitable shrinkage factor, it is essential that the character of the excavation be determined. In areas where the topography is rolling and the strata are practically horizontal, the determination can sometimes be made by a plane table survey.

In the more tightly folded rocks, the results are more difficult to obtain. In heavy cuts, seismic and resistivity tests, as well as core borings, are often required. The geologist is equipped to determine the most advantageous locations and extent of the tests required. Furthermore, he is better qualified to analyze and interpret the results of those tests.

Core boring tests are the most costly. This test is also the one most commonly used by the highway engineer. I firmly believe that by using the seismic and resistivity methods, supplemented by a few core borings, more extensive and better information concerning subsurface material and conditions is obtainable at much less cost, particularly when the data are interpreted by a qualified geologist.

6. On the basis of a scientific determination, satisfactory foundations for heavy fills and structures, especially bridges, must be accurately determined and provided. The geologist by his knowledge of stratigraphy can best determine where tests are necessary, and the type of test most satisfactory and most economical for the purpose. His knowledge of the structure of the rocks often makes it possible to accurately determine, by a very few well placed core borings, better information than is now generally obtained by the many more borings not scientifically located.

The logs of water and gas and oil wells are available in geological publications and some of these are of considerable value in foundation designs.

Mining maps may also be very helpful.

The State of Kansas, I understand, plots a geological section for every major bridge project. Such information must be of great assistance to the bridge engineer.

7. On many highways already built, troublesome slides, rock falls and unstable conditions are prevalent, or impending. The geologist should be able to assist the highway engineer in devising plans to stabilize these areas.

These are some of the problems in which, I believe, the knowledge of the geologist should be of great value to the highway engineer. However, to the geologist who is not versed in highway engineering problems, I would like to suggest a cautious approach. Remember the highway engineer may not be versed in geology, but he has gained, by experience, considerable knowledge of the effect of disturbing the natural balances in his construction of highways. Also remember the highway engineer, in choosing a location and a design, is thinking largely in terms of the life of the improvement.

Because the geologist so often thinks in terms of ages, rather than the life of the improvement, it is difficult at times for the engineer and geologist to meet on common ground. Today, the design of most highways is usually based on an anticipated traffic twenty years hence. Any additional widening or additional traffic lanes which may necessitate further disturbance of the topography, must be handled and financed by a future generation, coping with conditions economic or otherwise existing at that time.

Furthermore, it must be remembered that people sometimes choose to live and commute from rather isolated places. Wherever they live, or choose to go, roads must be built. Sometimes these roads, because of limited funds, must be built in narrow valleys adjacent to wild streams where they will be washed out, or they may be located in mountainous sections on steep slopes where occasional slides will block the highway. At times, they will be built over areas where slides have, and will continue to occur, and often funds will not permit the expensive corrective measures necessary to give complete stability and satisfaction.

In the soft coal areas of Pennsylvania, we have many places on our roads where the surface is moving downward and outward due to slides below roadway elevation. We know how to correct these slides, but in most cases, the cost of correction would far exceed the cost of maintaining the highway by merely adding to the pavement as it settles.

The administration of a highway department is much more complicated than meets the eye. One burdened with the responsibility is in about the same position as an administrator of a large corporation which may be engaged in the production of automobiles.

In the case of the automobile industry, the assembly line is geared to produce automobiles in such quantities as the public will absorb at the price. The administrator, or foreman, may sometimes see a way to reduce the cost, or improve the product, but if he can take advantage of the reduction in cost or improvement in the quality only by stopping the assembly line, the change is not made except at an opportune time. When the management ceases to produce automobiles or profits turn into losses, the management begins to hear from the stockholders, and very often a change in the administrator is made. The administrator knows, therefore, that these changes must be made without disrupting production.

The highway administrator is in the same position. He is primarily interested in the production of plans, and from these plans roads are built. The number of plans for which bids can be received is dependent on the funds available for highway construction. It is possible that the geologist may see some things that may result in obtaining a slightly better bid, or some change that may improve the quality of the road, but the highway administrator will hesitate to incorporate the change in the plans if the change stops the assembly line. Highway administrators also have boards of directors, by that I mean elected officials, and also stockholders, and by that I mean taxpayers and voters. Some of the latter are very vociferous in their demands and think they have the controlling interest in the corporation, and it sometimes appears that the board of directors pays considerable more attention and acts much quicker than is the case in private industry.

The highway administrator, must, therefore, due to the very limited and inadequate funds available to maintain, replace and add additional facilities to take care of the changing and substantial traffic increases, be very careful about adding to the already high cost of building adequate highways.

Although no administrator, or highway engineer, wants to see any failures in his work, and especially those failures that might endanger life and property, at the same time, no highway engineer can afford to design for every eventuality.

He must also be very careful that the engineers do not devise plans that will result in expensive preliminary investigations to prevent failures in construction which investigations may be even more costly than the correction of such failures, should they occur. He must be even more careful that as a result of these preliminary investigations, work is not required in the contract to assure 100% factor of safety, which sometimes may cost many times what it would cost to correct the failures that possibly can, but seldom do occur.

In this paper, I have tried to give my views as I think a highway engineer sees the application of the knowledge of geology to the solution of highway engineering problems. In doing this, I have had three objectives in mind:

First, because this group is primarily made up of geologists and soils engineers, and also because the application of geology to highway engineering is not too well established in the highway industry, and therefore, the geologist with few exceptions, is not too familiar with the problems involved, I have touched on many of the things I believe a geologist can do to assist highway engineers in providing better highways.

Second, I have prepared this paper with the idea of distributing it among the engineers in our Highway Department, so they may have some idea of what the geologist can do to assist them in solving their problems; and

Third, I intend to distribute this paper among the various schools in Pennsylvania giving courses in geology, so that the professors and students will have some idea of the opportunities of a geologist in the field of highway engineering.

OHIO'S EXPERIENCE IN THE USE OF GEOPHYSICAL METHODS IN SUBSURFACE EXPLORATION

by

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This paper is intended to present some of the factors to be considered and the experience of the Ohio Department of Highways in the utilization of geophysical methods in the investigation of subsurface conditions related to highway construction. First, it is believed desirable to mention briefly the general policy of the Department in relation to subsurface investigations in that this has bearing on the extent to which both drilling and geophysical exploratory methods are used.

General Exploration Policy

Quite an extensive investigation is made of subsurface conditions in connection with all major highway improvements. This information is obtained for the purpose of designing pavements, subdrainage, embankments, cut slopes, and structure foundations. Roadway subgrade and embankment foundation conditions are investigated every 200 to 300 feet along the proposed centerline. Soil and rock conditions in cut sections are determined in similar detail. Where poor subgrade and embankment foundation areas are encountered, both longitudinal and lateral extent of such areas are determined. Likewise, where side hill cuts and fills occur, subsurface conditions are determined laterally as well as along centerline. For structures, subsurface conditions are determined at each abutment and pier location. Experience has resulted in standardized designs with respect to certain subsurface conditions. Other conditions require more detailed analysis for individualized design treatment.

In conducting any exploratory program, there are two general factors that must be considered. First, the purpose for making the investigation dictates the type of information required. Second, the element of time is critical from the standpoint of usefulness of the information to the designer and cost of the exploratory program. No one exploratory method has been found satisfactory for obtaining the subsurface information desired with respect to all problems encountered. Therefore, in an attempt to cope with any problem encountered, the exploratory equipment of the Department includes rock core drills, mechanical earth augers, drive-rod sounding units and geophysical methods. Because of the degree of detail generally desired, drilling methods are more extensively used by the Department. However, owing to both surface and subsurface conditions, certain sites do not lend themselves to rapid and extensive exploration by drilling methods. Geophysical methods are capable of supplying certain general details concerning subsurface conditions and offer the advantage of portability and speed of application. These methods are, therefore, used by the Department to supply information otherwise extremely difficult and time consuming to obtain. Before relating some of the factors to be considered and the Department's experience, it is believed of general interest to very briefly present the history of the development and the fundamental principles of these methods.

History

There have been a number of geophysical methods developed for the purpose of studying the physical characteristics of the earth and for measuring disturbances occuring within the earth. Of these several methods, only the electrical resistivity method and the seismic refraction method have been adapted to the investigation of subsurface conditions related to civil engineering problems.

The electrical resistivity method stems from scientific interest in measuring self potentials within the earth and the electrical resistance of large earth masses, this work occuring as early as 1830. In 1883, an unsuccessful attempt was made to find mineral deposits by measuring the earth's resistance. The principle of the method as it is used today was developed in 1912 in connection with the study of two and three dimensional electrical problems. The method was first successfully used to measure the resistivity of earth masses in 1925. Its first commercial application was in the exploration of metallic mineral deposits in 1927.

The seismic refraction method stems from scientific interest in earthquakes and the elastic properties of the earth's crust. The principle of the seismic refraction method was set forth about 1851 and during that year ground motion of the type resulting from earthquakes was first produced artificially by use of explosives and registered by use of crude seismometers. The first mechanical seismograph was developed during World War I and the first successful commercial application of the method was made in 1923 in the location of salt domes. The first discovery of oil resulting from the use of the mechanical refraction seismograph was in Texas in 1924.

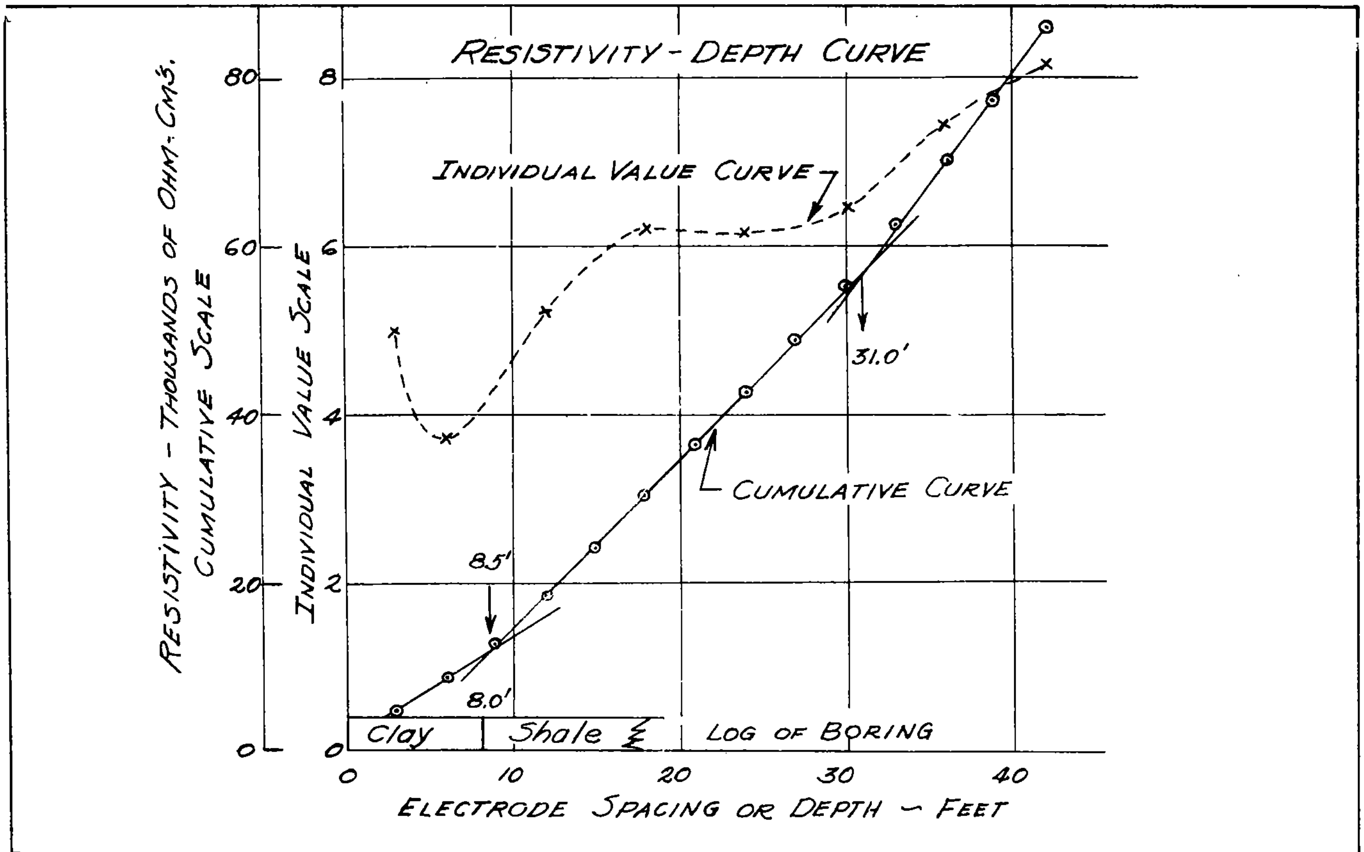
Although these methods were initally used for mineral and petroleum exploration, they were soon applied to civil engineering subsurface investigations, first, in the search of granular materials, and later, in the investigation of foundation conditions. They have been applied by the Bureau of Public Roads in connection with highway work since 1933. They have been used by the Corps of Engineers and Bureau of Reclamation for subsurface reconnaissance of proposed dam sites. They have been applied by the U. S. Geological Survey in ground water reconnaissance work. They are now utilized by the majority of the state highway departments.

Principles of the Electrical Resistivity Method.

The electrical resistivity method measures the resistance of the earth materials to the flow of a direct electric current through them. The usefulness of the method in subsurface investigations stems from the fact that different earth materials exhibit different resistances to the flow of current. This characteristic is a result of mineralogical composition, dissolved salts and organic acids in the pore water, and the general structural characteristics of the material.

In a very general way, the principle of the electrical resistivity method may be likened to that of measuring the resistance of a wire to the flow of an electric current, whereby the current flowing through the wire and the voltage drop between two points are measured and the specific resistance of the wire is computed. However, unlike the case of the wire, where specific resistance is measured, the value measured in earth materials is an "apparent resistance" influenced by the specific resistance of the various materials through which the electric current flows. The principle is further complicated by the shape of the electrical field.

A number of methods of instrumentation and field techniques of making measurements have been developed, however, they all apply the same general principle. Figure No. 1 illustrates the general principle involved by the electrical resistivity method. In its most general form, the method employs two outer current electrodes and two inner potential electrodes forming four distinct contact points with the ground. These electrodes are placed on or just beneath the ground surface in line with each other and equidistant apart. This arrangement is of significance in that any other arrangement results in complicating the resistivity equation. A direct current of known magnitude is caused to enter the ground through one of the current electrodes and leaves the ground through the other. With the current flowing through the ground, the drop in potential is measured between the two intermediate potential electrodes. The "apparent resistivity" is computed by the formula:



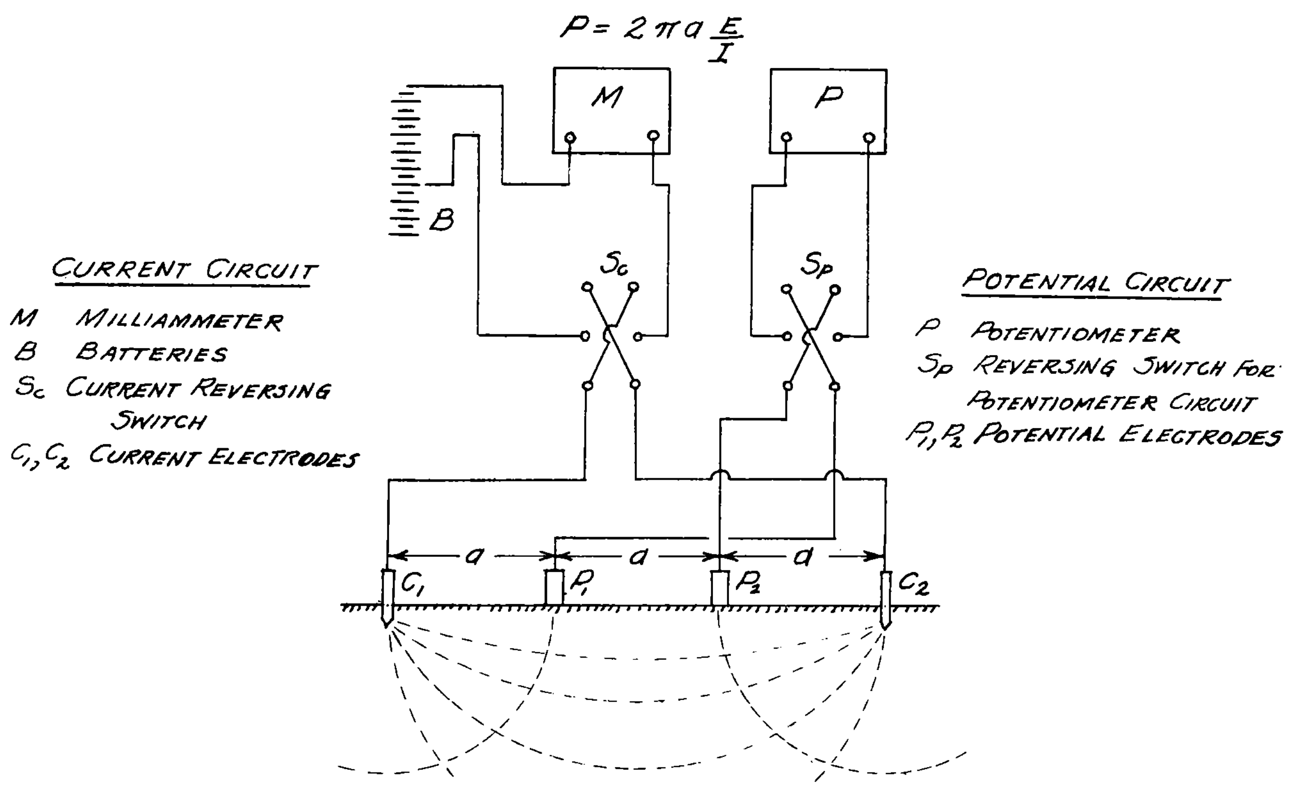


DIAGRAM
ELECTRICAL RESISTIVITY METHOD

FIGURE No. 1

$$p = 2\pi a \, (V/I)$$

in which

p = "apparent resistivity" in ohm-centimeters
2π = a constant
a = distance between adjacent electrodes in centimeters
V = measured potential drop in volts
I = current imparted to the ground

The effective depth of the test is considered equal to one-third the distance between the current electrodes. Thus, by increasing the electrode spacing, the "apparent resistivity" can be determined for materials at increasing depths. This manner of testing is commonly used in subsurface investigations by holding the test station as a fixed point, taken as the middle of the electrode spread and increasing the distance between electrodes in a constant incremental manner. Thus, a series of "apparent resistivity" values are obtained which are plotted versus respective depth increments or electrode spacings on an arithmetic plot. These points define a curve showing the trend of "apparent resistivity" of the subsurface materials with increasing depth and is referred to as the resistivity-depth profile. Changes in trend of the curve are then analyzed as possibly reflecting physical changes in subsurface materials. Both theoretical methods and empirical methods have been developed for interpretation of the resistivity curves. Less laborious empirical methods have been found reasonably satisfactory for use in civil engineering work.

Mr. R. Woodward Moore of the Bureau of Public Roads proposed a plot of accumulative resistivity values derived from the arithmetic sum of the individual values. These values result in a plot composed of straight-line tangents and the tangent intersections are analyzed as possibly representing physical changes in subsurface materials.

Principles of the Seismic Refraction Method.

The seismic refraction method measures the rate at which mechanical energy is transmitted through subsurface materials. Owing to their elastic properties, different materials exhibit different velocities of transmission of mechanical energy. The manner in which the energy travels through the ground and the technique employed by the refraction method in recording its rate is illustrated by Figure No. 2.

If an impact force is created at the ground surface at a point source, such as that by an explosion or by a blow from a sledge hammer, an elastic wave train is generated in the subsurface materials. A wave front emanates from the point source radially in all directions and downward until it reaches the rock surface. The wave front upon striking the rock surface in turn creates an elastic wave train in the rock. This wave train also travels laterally and downward but at a much higher velocity. As the wave front within the rock travels outward from its source, it creates a series of wavelets in the overburden material along the overburden-bedrock contact. These wavelets travel through the overburden back to the ground surface. The envelope of the series of wavelets in the overburden is the refracted wave. There is a distance on the ground surface from the point source of energy at which the direct wave and the refracted wave arrive at the same instant. This distance is dependent upon the relative velocities of the materials. At points closer to the source point, the direct wave front arrives first, and at points further distant, the refracted wave front arrives first.

In the seismic refraction test, the time of arrival of the wave front is registered at the ground surface at a series of distances from the "shot point". This is illustrated by the schematic diagram of the measuring equipment. The arrival of the wave front is registered by means of a seismometer or geophone planted firmly on the ground surface. The geophone consists of a coil of wire

DIAGRAM OF SEISMIC REFRACTION METHOD

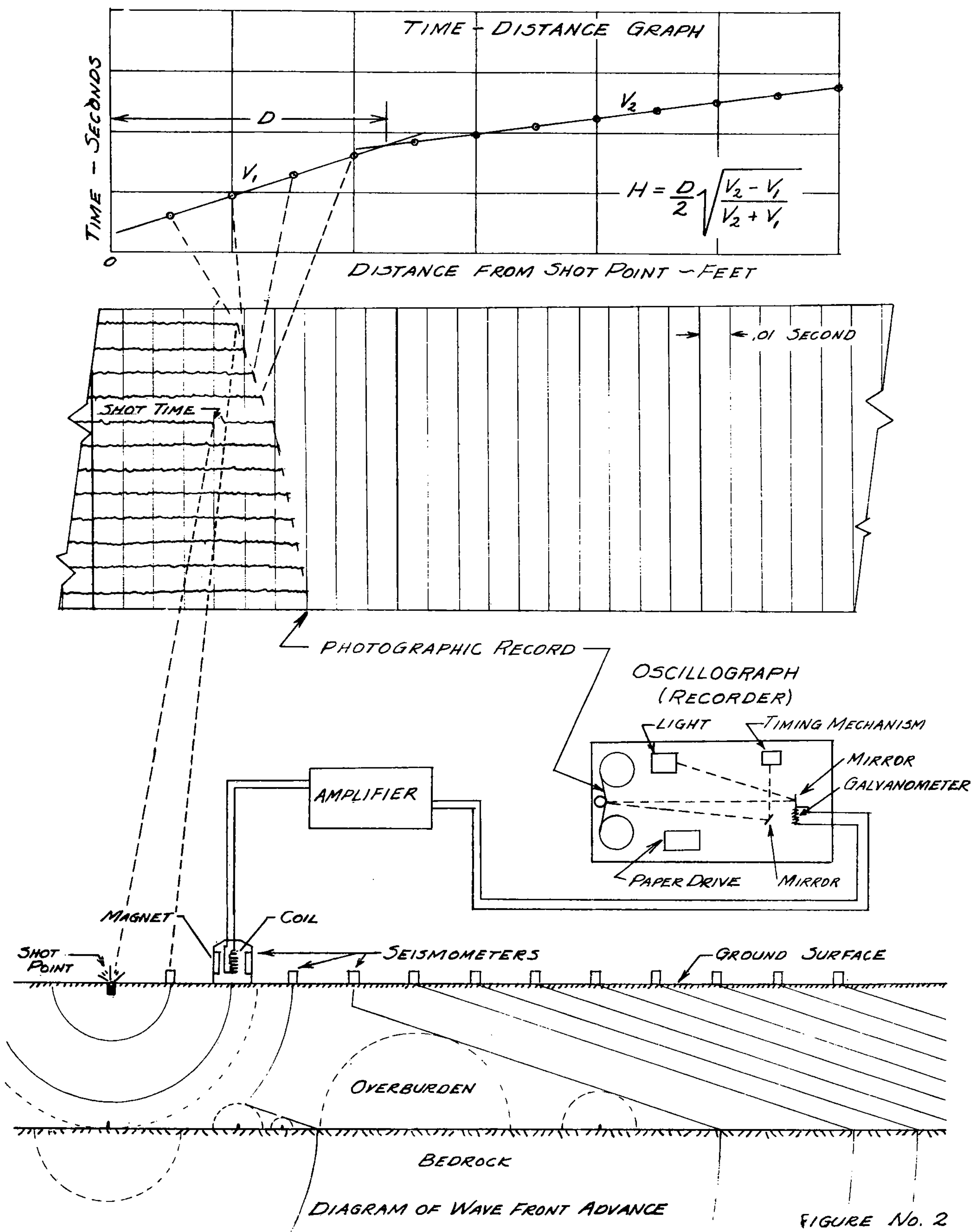


DIAGRAM OF WAVE FRONT ADVANCE

FIGURE No. 2

suspended in the annular space between the poles of a permanent magnet. The coil is suspended with its axis vertical and is free to vibrate in the magnetic field. The wave front is transmitted to the geophone case and the inertia of the suspended coil causes it to move relative to the magnet thereby inducing an electrical impulse in the coil circuit.

The electric impulse from the seismometer is transmitted by means of a cable to an amplifier circuit where the impulse is strengthened and transmitted to a galvanometer. The galvanometer consists of a coil suspended in a permanent magnetic field. Attached to the galvanometer coil is a mirror which serves to reflect a beam of light focused on it. Activation of the galvanometer coil by the amplified electric impulse from the seismometer produces deflection of the mirror on which the light beam is focused. The deflected light beam is registered on photographic paper. Timing lines are also recorded on the photographic paper. The timing lines are created by a beam of light which is interrupted at 0.01 second intervals by an electrically driven timing mechanism. The timing light beam is focused on a mirror which reflects it onto the photographic paper.

The recording instrument has an integral part, a light-proof photographic paper magazine. During a test, the paper is fed through the recorder by means of a variable speed paper drive which is electrically driven and governor controlled. The exposed photographic record feeds directly into a daylight developing tank for development and fixation of the seismic record for field inspection.

Each seismometer has its own amplified and galvanometer circuit in the recording instrument resulting in a separate trace on the photographic record. The seismometers are connected to the instrument by a unitized cable with each seismometer having a double conductor wire insulated against cross feed. The siesmometers are normally set in line with each other equidistant apart with the shot point in line with the spread. A circuit from the instrument to the shot point is also provided for detonating the explosive and for recording the instant of detonation.

Knowing the distance of each seismometer from the shot point and the time required for the wave front to reach each seismometer as determined from the seismic record, a time-distance plot is prepared of the travel of the wave front. From this plot, the velocity of the wave front through each layer is computed. This plot also discloses the distance from the shot point at which the refracted wave overtakes the direct wave.

In the two layer case illustrated, with velocity of the layers and the point of intersection known, the depth to bedrock may be computed by the formula

$$H = \frac{D}{2}\sqrt{\frac{V_2 - V_1}{V_2 + V_1}}$$

where:

H = depth to bedrock
D = distance from shot point to point of intersection
V_1 = velocity in the overburden
V_2 = velocity in the bedrock

As is evidenced from the explanation of basic principles, the electrical resistivity equipment is less complicated in instrumentation than is seismic refraction equipment. Electrical resistivity equipment may be purchased at a cost ranging from approximately five hundred to twenty-five hundred dollars depending on the degree of refinement of the instrumentation. Seismic refraction equipment costs approximately six thousand dollars. Either type of equipment requires a crew of at least two men for reasonably efficient operation. Either type may be transported in the trunk of an automobile. The equipment may be carried by the crew to sites inaccessible by automobile, however, where the site is a considerable distance from the highway, at least three men are needed.

Factors to be Considered and Experience in Utilization.

The Department has employed geophysical methods since the spring of 1951. Initially, these methods were employed by contract, however, since the spring of 1952, the Department has owned and operated both electrical resistivity and seismic refraction equipment. To date, more varied use has been made of the electrical resistivity method, however, this has no bearing on the relative merits of the two methods. Owing to the difference in the basic principles employed by the two methods, under certain conditions, one may offer definite advantages over the other.

The electrical resistivity method has been used in the investigation of subsurface conditions associated with landslides, peat bogs, deep cut sites, and structure foundations. The seismic refraction method has been used to a limited extent in the investigation of depth to bedrock at structure sites. In a number of cases, success has been realized in their application, however, in other cases application has been less successful. A number of factors have bearing on the extent to which these methods are employed by the Department and on the success or failure of their application.

Both the electrical resistivity and seismic refraction equipment must be maintained at a high order of efficiency in performance. Instrument maintenance in the field by necessity is the responsibility of the instrument observer and this necessitates that personnel used for this purpose have certain special qualifications. The operator of either electrical resistivity or seismic refraction equipment should have a knowledge of electrical circuits used in scientific instrumentation as well as a basic knowledge of geology. In addition, the operator of seismic refraction equipment should have knowledge of electronic circuits, optics, and photographic processes as applied in scientific instrumentation and some knowledge of explosives. Finally, for the realization of good field technique in the use of these methods, the observer must possess patience and a genuine interest in his work. It has been the experience of the Department that personnel with these qualifications are not abundant. It has been our general experience that men having the required scientific background with interest in geology, soil mechanics, and foundation engineering are only interested in learning the fundamental principles of geophysical methods. In consideration of this fact, it is pointed out that geophysics is a scientific field in itself and most men entering this field find employment with petroleum, mining, or geophysical exploration firms. Because of lack of personnel, the Department has not utilized geophysical methods as extensively as it is believed they could be used to advantage.

Assuming both good instrumentation and field technique in application have been realized, interpretation is of utmost importance to the success of the geophysical investigation. Skill in interpretation can be developed only through experience, however, a knowledge of local geology, an understanding of the principles involved by the procedure, and an awareness of the effect of disturbing factors on test data are aids to interpretation. The greatest aid to the development of skill in interpretation is considerable time spent as an instrument observer.

Information concerning subsurface conditions is determined indirectly in that contrasts in the property measured by the geophysical method are interpreted as being associated with other physical changes in subsurface materials. Therefore, calibration tests are essential to the interpretation of the significance of changes occuring in the physical characteristic measured by the test procedure. For this reason, geophysical methods are rarely employed without drilling methods being used to at least give reliable information for calibration purposes. Erroneous calibration information will result in incorrect interpretation of exploratory data. The lateral extent to which calibration information is applicable has also been found to be limited in

Ohio owing to major subsurface changes in stratigraphy occuring in comparatively short lateral distances.

In the case of either the electrical resistivity method or the seismic refraction method, contracts in the physical property observed by the method must be significantly great to be reflected clearly in the measurements. This limits the application of the methods to definition of major subsurface changes. Generally speaking, success has been realized with the electrical resistivity method in defining boundary conditions between fine-grained soils as a group, granular materials, and various types of bedrocks such as shales, sandstones, and limestones. Materials occuring in Ohio that have been found extremely difficult to differentiate when bounding each other are, peat and clay, residual clay and indurated clay or soft clay shale, sand and coarse grained sandstone, and firm siliceous shales and fine-grained sandstones. In the case of a lower velocity stratum underlying a higher velocity stratum, the seismic refraction method is unsuccessful in defining the presence of the lower velocity stratum or the thickness of the higher velocity stratum. In Ohio, higher velocity limestones sometimes are encountered overlying lower velocity shales, thus limiting the use of the seismic method when this condition is encountered. Bedrock types in Ohio are also encountered comparatively thinly interbedded. Owing to the resolving power of the test methods and the physical characteristics measured, geophysical methods are not satisfactory for defining detail of interbedding.

Both geophysical methods are subject to outside interference which may introduce considerable difficulty in obtaining reliable observations. In using the electrical resistivity method, it has been found extremely difficult to obtain reliable test data on railroad right of ways and near pipelines owing to the effects of stray currents. In using the seismic refraction method, interference from electrical transmission lines and excessive noise or ground vibration may result in difficulty in obtaining test data.

The usefulness of geophysical methods in the exploration of soil conditions is limited to establishing boundary conditions between fine grained soils as a group, granular materials and bedrock. Generally, more detail is desired than information concerning these major subsurface changes. Therefore, where conditions permit, highly efficient mechanical earth augers are used by the Department to define the limits of types of subsurface materials and to supply samples for laboratory analysis and classification. However, two conditions limit the utiliaation of mechanical earth augers; first, the ground surface may be too soft or the surface relief too pronounced for the movement of motorized equipment; second, bouldery soils cannot be penetrated by earth augers. Under such conditions, geophysical methods may furnish information not otherwise obtainable. Such conditions occur in Ohio and when encountered, the Department has realized benefits from the use of geophysical methods.

One of the more difficult and time consuming subsurface exploration problems is that of a deep cut into rock. Considerable detail is generally desired concerning materials to be encountered by the excavation for the purpose of slope design. The physical properties of the bedrock can be disclosed only by core drilling. However, terrain conditions are frequently not favorable to the easy movement of drilling equipment and the availability of drilling water may be a major consideration. In addition, coring of rock is much slower than augering of soil. For such investigations, geophysical methods offer two distinct advantages; one, portability, and two, speed of application. Core drills can be used to supply the desired detail concerning the physical characteristics of the bedrock at point locations. Geophysical methods are useful in filling in detail concerning the depth of bedrock and disclosing major changes occuring in lateral extent. The Department has used these methods repeatedly in this manner for the purpose of reducing the amount of core drilling required otherwise and thereby expediting such investigations.

Summary.

The experience of the Department in the use of geophysical methods is in general agreement with that reported by other organizations. Owing to the basic principles employed, they are not applicable to the investigation of all subsurface conditions encountered. The subsurface detail these methods are capable of disclosing is limited. However, in the investigation of subsurface conditions for civil engineering purposes, no one exploratory method has been found complete satisfactory for obtaining the desired detail under all circumstances. Geophysical methods correctly used afford the engineer additional tools for obtaining more complete information with greater economy in time and cost. In this respect, the Department has found these methods to be a definite asset. In closing it is re-emphasized that it has been the intent of this paper to create an awareness of the factors to be considered and not to discourage the utilization of geophysical methods.

IMPORTANCE OF GROUND WATER STUDIES TO HIGHWAY ENGINEERING[1/]

by

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Reports on underground water resources are destined to be of increasing value to the highway engineer as more is learned about the occurence and movement of ground water and the importance of its control in highway construction and maintenance. Reports describing ground-water conditions and the related geology in various parts of the country have been published in increasing numbers in the past decade, largely resulting from the program of cooperation between the Geological Survey and local or State agencies. These ground-water reports and the records on which they are based contain much of value to the highway engineer, the chief contributions to his work being geologic data, information relative to ground-water conditions, and descriptions of methods used to determine the hydraulic properties of earth materials.

In Ohio, as a result of the cooperative program between the Geological Survey and the Ohio Division of Water, water-resources reports covering all or parts of six counties have been published and reports on eight other counties are in preparation or in process of publication. Geologic data in the more recent of these reports include maps showing the character and distribution of the consolidated and the unconsolidated deposits and descriptions of their physical and water-bearing properties. These maps also show the locations of consolidated rock outcrops and contours on the surface of the consolidated rocks. From these maps, the approximate depth to

1/ - Publication authorized by the Director, U. S. Geological Survey.

bedrock can be computed and the general type of overburden determined for any place within the area covered. As a direct result of water-resources studies in Ohio, the highway engineers who planned the new turnpike had available for their use much valuable geologic information on Mahoning, Summit and Cuyahoga counties.

Another source of geologic data available to the highway engineer, resulting from the growing interest in water-resources studies, are logs of wells which drillers in some states are required to file with appropriate State agencies. In Ohio, a regulation has been in effect, since September 1947, requiring drillers to submit the log of every well drilled, and now more than 65,000 well records containing valuable data on the geology and ground-water conditions in every part of the State are on file with the Ohio Division of Water.

The highway engineer is interested in ground-water conditions, themselves, chiefly in connection with drainage problems, but not infrequently he has direct need of water-resources information as an aid in the development of ground-water supplies. An example of the latter need is the problem of providing small water supplies at 30 interchanges and service areas along the new Ohio turnpike. In response to this need, the Ohio Division of Water, largely from information already on file, has in preparation a brief report describing ground-water conditions along the turnpike at each of the locations. This report is expected to be of value also to commercial interests such as motel or restaurant owners who may want to build at those places.

Other ground-water-supply problems result if highway cutting or grading operations locally change the shape of the water table and cause wells adjacent to the right-of-way to do dry. Restoration of the water supply may involve a new well or deepening of the old well. A similar need for water-resources information usually confronts a highway department whenever new supplies are needed for farm buildings or dwellings that have been moved because of the relocation of highways.

Ground-water conditions are of interest to the highway engineer chiefly in connection with drainage problems, the importance of which may be judged by the fact that about 20 cents of every dollar spent on highway programs is for drainage structures. Factors that largely determine ground-water conditions in an area and that bear most directly on highway drainage problems are the character of the saturated materials and the range of fluctuation of the water table. In connection with the former, water-resources studies may often reveal subtle differences between deposits of similar type, some of which have an important bearing on drainage problems. For example, when the glacial deposits in Portage County, Ohio, were being mapped, as part of an investigation of the water resources, a slight, through diagnostic, difference was discovered between two till deposits of Wisconsin Age. Though almost identical in their appearance, till of early Cary age is more sandy, contains less clay, and is better drained than till of late Cary age. The difference between these tills has had important results economically in terms of land value. Farms underlain by till of early Cary age, being better drained, generally are more prosperous than farms developed on the poorly drained till of late Cary age. No doubt this correlation could be extended also to maintenance costs and the conditions of the roads in the area.

Water-level records also are important with respect to highway-drainage problems. Test holes may furnish data on the position of the water table at any particular time but it is of even greater importance in the design of drainage structures to know its annual range of fluctuation. The records of observation wells, a number of which are maintained in each area chosen for water-resources investigations, may provide this information. In Ohio, the U. S. Geological Survey and its cooperating agencies, principally the Ohio Division of Water, maintain water-stage recorders on 127 wells scattered over the State and periodic tape measurements are made in 66 additional wells. The records of most of these observation wells are published annually in water-supply papers of the Geological Survey and biennially in bulletins of the Ohio Division of Water.

Another phase of ground-water study of pertinence to highway engineering concerns methods, developed largely within the past 20 years, for determining the hydraulic properties of earth materials. Just as the electrician has his tools and methods for measuring the voltages, currents, and resistances in an electrical system to enable him to predict the functioning of its components, so too have the hydraulic engineer and the geologist developed methods and devised field techniques for determining the hydraulic properties of an aquifer system that permit them to make sound estimates of yields of wells, drawdowns in wells, interference between wells, injection rates and pressures, and many other things of importance to the sound planning of a water system. Some of these methods are simple in application, involve no great expenditure of time, require little equipment, and are directly applicable to problems of highway drainage.

Methods of determining the hydraulic properties of a water-bearing bed are based on the relationship between its permeability and storage capacity and the shape or rate of growth of the cone of influence developed around a source of hydraulic disturbance in the bed being tested. In practice, the natural hydraulic system of the aquifer is disturbed, either by pumping water from a well or by injecting water into the aquifer, and noting in the test well and in observation wells, the resulting effects on water levels or pressures in the aquifer. Most commonly, the field data are analyzed by means of the Theis non-equilibrium formula, which was developed about 1935 under the direction of C. V. Theis of the U. S. Geological Survey, who based its derivation on the analogy between the movement of ground water under ordinary hydraulic gradients and the flow of heat by conduction. Once the hydraulic properties of the aquifer, -- its coefficients of storage, permeability and transmissibility -- have been determined, the drawdown produced by a pumped well, or the magnitude of the rise in water levels caused by recharging operations, can be computed for any time and for any point in the aquifer. Stated in practical terms, from the results of a preliminary pumping or recharge test (which, in most cases, need not be complicated or elaborate) calculations may often be made that would tell the highway engineer in advance such things as the rate of pumping required to dewater a particular water-bearing bed or the rate at which surface runoff could be discharged into an underground sump without causing the water to back up and flood a highway during a flash flood.

An example of a highway-drainage problem to which the principles of ground-water hydraulics were profitably applied is a situation that confronted highway engineers a few years ago in Ohio. Plans for a new highway in the Miami River valley at Dayton called for an underpass beneath an existing road. The underpass was to be excavated in highly permeable glacial gravels to a depth approximately 4 feet lower than the highest position of the water table, as disclosed by a 5-year period of record in a local observation well. There would be times, therefore, when the new highway would, in all probability, be flooded at the underpass unless the glacial gravels in the vicinity could be dewatered below grade level. To accomplish this, highway engineers decided to construct a drain and install a sump pump that would operate automatically whenever the water table reached a certain height. It was anticipated that pumping at a high-enough rate would create a cone of depression in the water table of sufficient size to keep the highway dry. The principal question that arose involved the rate of pumping that would be required to accomplish the desired result. The Geological Survey, in cooperation with the Ohio Division of Water, was making a study of the water resources of the Dayton area.

Tests by the State Highway Department held promise of affording valuable data about the hydraulic properties of the glacial gravels in an important industrial area along the Miami River. In conjunction with these tests, the Geological Survey made a controlled pumping test at the site, using the facilities already installed by the Highway Department to determine the hydraulic properties of the aquifer, as an aid in planning the drainage facilities.

As highway-building programs of the future become larger, there undoubtedly will be increasing need for ground-water data and for the application of the principles of ground-water hydraulics to problems of highway engineering. As his needs increase, the highway engineer will become ever more aware of the contributions that are being made in the course of water-resources studies and will seek to apply to his own work the results of these studies or the methods of analysis that are an outgrowth of them.

EFFECT OF COARSE AGGREGATE ON CONCRETE DURABILITY

by

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The many miles of old concrete pavement and thousands of concrete structures in use in the United States illustrate the value of portland cement concrete as a construction material. Many of these structures and pavements have been in service for decades, and show little or no effect from weathering. They demonstrate that good materials, properly used, produce durable concrete.

Throughout the country, however, one may observe some concrete that has failed because of lack of durability, that is, lack of ability to adequately resist the effects of weathering. These structures constitute only a small percentage of the total concrete used, but are, nevertheless, important from an economic standpoint. Many factors affect the durability of the concrete. Among these are the quality of the materials used, design factors that determine exposure conditions, and workmanship in construction.

In recent years, several problems of concrete durability that involve the aggregate have been recognized. An important one of these is the alkali-aggregate reaction problem, of greatest concern in the West and South (1)*. In the midwest, the most important problem is freezing and thawing durability involving the coarse aggregate.

Since 1943, extensive investigations of concrete durability have been carried out in Indiana. Conducted by the Joint Highway Research Project at Purdue University, these studies were initiated to determine the cause of concrete deterioration in pavements on the state highway system.

* - Figures in parentheses indicate references listed in the bibliography.

FIELD PERFORMANCE SURVEYS.

Extensive field performance surveys were made and reported by Woods, Sweet and Shelburne (2). More than 2600 miles of concrete pavement were inspected and the prevalence of defects noted. The significant defects were found to be the so-called "D-line" cracking and blowups. These are illustrated in Figures 1 and 2. The D-lines are small, closely spaced cracks, roughly parallel and usually filled with a dark colored deposit. They form first along joints and major cracks or the edges of the pavement, and gradually progress further and further into the slab. Blowups are buckling failures of the slab, caused by internal compressive stresses that exceed the strength of the concrete.

D-lines and blowups were almost invariably associated in deteriorated pavements. Since the blowups could be readily identified and counted, even after patching, they were used as the measure of performance in statistical analyses of the survey data. It was found that no significant correlation existed between performance and the variables of subgrade soils, traffic, fine aggregate and cement source. However, a highly significant realtionship was found between source of the coarse aggregate and the pavement performance as measured by the number of blowups per mile.

Table 1 shows a summary of the results of the performance survey. Five aggregate sources, used in a little more than 10 percent of the total mileage, were responsible for nearly half of all blowups in the state. Actually, one source alone was used in 97 miles of pavement that developed more than 25 percent of the total blowups counted.

Figure 1. Severe D-Line Deterioration on a Highway Pavement.

Figure 2. Blowup on Airfield Taxiway.

TABLE 1. SUMMARY OF COARSE AGGREGATE PERFORMANCE

Performance Classification	No. of Aggregate Sources	No. of Paving Projects	Total No. of Miles	No. of Miles Without Blowups	Average No. of Blowups Per Mile	Total No. of Blowups
Significantly Bad	5	54	284.4	2.4	4.11	1168
Poor	14	23	86.7	8.4	3.28	285
Indeterminate	119	236	1935.0	541.2	0.49	949
Significantly Good	17	62	316.8	299.0	0.007	2
Total	155	375	2622.9	851.0	0.92	2404

LABORATORY INVESTIGATIONS.

Since the materials that caused bad field performance passed all standard acceptance tests, an obvious need for laboratory research on the problem existed. Accordingly, extensive research programs were started to investigate the chemical and physical characteristics of the aggregates.

Although a very minor amount of deleterious chemical reaction between some aggregates and cements is believed to exist in Indiana, no correlation between chemical characteristics of the aggregates and their field service records has been found. The results of the physical testing program have, however, been very significant.

The initial testing program was concerned chiefly with crushed stone aggregates, for which homogeneous samples could be obtained. Significant correlations were obtained of field performance with the aggregate pore size (volume of pores $<$ 0.005 mm. in diameter), the degree of saturation (portion of total pore space filled with water by vacuum saturation), and the freezing and thawing durability of concrete in which the aggregates were used. The results of these early tests were reported by Sweet (3) and summarized, along with the results of subsequent studies, by Lewis and Woods (4) and Lewis (5).

Table 2 shows the results of some of these studies that led to the correlations stated above. It will be noted that, in all cases, the aggregates with good field performance have smaller losses in modulus of elasticity per cycle of freezing and thawing, lower degrees of saturation, and smaller volumes of voids $<$ 0.005 mm. in diameter than do the aggregates with bad field performance.

TABLE 2. SUMMARY OF AGGREGATE TEST RESULTS

Coarse Aggregate Designation	Quarry-Wet Degree of Saturation	Concrete Tests: Degree of Saturation	Concrete Tests: Durability Index (b)	Volume of Voids (a): Total	Volume of Voids (a): < 5μ
Good Field Performance					
90-1S	66	45	0.01	0.10	0.01
1-1S	66	55	0.03	0.07	0.05
67-2S	33	51	0.08	0.04	0.02
Bad Field Performance					
9-1S	94	97	3.17	0.23	0.12
47-2S	--	95	0.91	0.11	0.11
3-1S "H"	96	90	2.64	0.20	0.20
3-1S "D"	97	96	2.97	0.16	0.14

(a) Expressed as the ratio of void volume to solid volume.

(b) Percentage decrease in dynamic modulus of elasticity per cycle of freezing and thawing.

Gravel coarse aggregates are heterogenous mixtures of many types of rock and therefore, the degree of saturation and pore size tests are not readily applicable to them. Recent studies of gravels (6, 7) have shown that heavy media separation processes may be used to separate the deleterious from the durable particles. The deleterious fractions are found to be characterized by low specific gravity, high absorption and high degree of saturation, and poor durability in concrete subjected to freezing and thawing. The low specific gravity materials considered to be deleterious consisted chiefly of chert and sandstone with badly weathered fragments of other rock types.

All of the studies conducted show that the nondurable aggregates in Indiana are characterized by high porosity, especially in the voids 0.005 mm. in diameter. These materials readily reach a high degree of saturation. Field deterioriation of concrete containing these materials is caused by the action of alternate freezing and thawing on these aggregates in a highly saturated condition.

CORRECTIVE MEASURES WHEN INFERIOR AGGREGATES ARE USED.

In connection with the studies to determine the causes of concrete deterioriation, several projects included tests to find means of improving the durability of inferior aggregates. The results of these studies (6, 8, 9) have indicated that a number of measures may be used to improve the durability when inferior materials must be used for economic reasons. Air entrainment is quite effective in improving the durability of concrete made with some aggregates; with others, it is relatively ineffective. The use of dry aggregate in the mix, and any drainage that can be provided to prevent subsequent saturation of the concrete are indicated as being beneficial in extending the life of the structures in which inferior aggregates are used.

In addition to the measures listed above, production methods can often improve the quality of the aggregate. Thus, selective quarrying procedures may be used to avoid the poorer ledges of stone in a quarry. Commercial heavy median separation processes offer a means for removing the deleterious fractions of gravel aggregates.

GEOLOGIC NATURE OF THE INFERIOR AGGREGATES.

The aggregates used in Indiana consist principally of crushed limestones and dolomites and glacial gravels. Both good and bad performing materials are found in each type of aggregate. As noted previously, the deleterious constituents of the gravels are chiefly cherts and sandstones, with badly weathered and porous fragments of other rock types.

With respect to the deleterious crushed stones, they seem to resemble each other chiefly in their porosity and absorption characteristics. Wide variations in color, texture, and purity are found. It has not been possible to make dependable correlations of performance with geologic formation. The quality of the material is not only different in different locations or horizons within a formation, but also varies laterally in given strata within some formations.

The conditions of geologic origin of a rock, and the subsequent history of weathering and alteration, determine its composition, internal texture, and internal structure. These factors, in turn, control all of th chemical and physical properties that determine the value of the material as an aggregate (10). It seems probable that the greatest contribution that can be made by geologic studies, at least at the present time, to the investigation of aggregate durability is in the field of detailed petrographic analyses. Such study of the internal composition, texture and structure of materials having known service records and physical characteristics has not been extensively utilized. It does, however, offer at least a possibility of correlation of such factors with performance, and might furnish basic information helpful in understanding the manner in which the materials react to absorption of water and freezing conditions. Certainly petrographic study of the aggregates should be given greater attention to determine the value of the information obtained.

SUMMARY

The major problem of concrete durability in the midwest is one of resistance to alternate freezing and thawing. Deterioration is chiefly caused by certain unsound coarse aggregates that are highly saturated at the time freezing takes place. Research work on Indiana aggregates has shown that the inferior aggregates are characterized by:

(a) High degree of saturation under vacuum,

(b) Large volume of voids smaller than 5μ in diameter, and

(c) Poor durability in concrete subjected to laboratory freezing and thawing tests.

Corrective measures that may be used to obtain better durability of concrete made with inferior aggregates include selective quarrying or heavy median separation, the use of air entrainment, drying and drainage.

No dependable correlation of performance with geologic factors has yet been made. However, the use of petrographic analysis to determine the basic geologic characteristics of materials with known field service records should be given greater attention.

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GEOLOGY IN THE ENGINEERING CURRICULUM

THE HIGHWAY ENGINEER'S VIEWPOINT

by

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SYNOPSIS

Geology as it applies to highway engineering is considered in the light of the economical highway and the training of the junior engineer as a designer of highways in the atomic era. Some college curriculums of the present are reviewed and a criterion is established for determining the adequacy of present geology courses. A geology course which is believed to be adequate and meets the criterion is outlined for consideration.

INTRODUCTION

The goal of the highway engineer is to design and build good highways economically in order that the user may transport himself and his goods economically. In this atom-powered age, with its futuramic vehicles and construction machines, it is the goal of the educator to help the junior engineer to attain a substantial background through a well-planned curriculum. Often the need arises for reviewing the courses in our civil engineering curriculum to determine their adequacy. The question is; what courses may we consider? Inasmuch as a knowledge of geology enables the engineer to design the economical highway, and the engineer considers geology as essential as mathematics, physics, and chemistry; then we may well consider the geology courses offered to the engineer.

In view of the requirements set forth above and in view of the fact that little has been said about what kind of geological training our future highway engineers should receive, it is the aim of this paper to consider the geological training available to the junior engineer.

Need for Geology Training in Highway Engineering.

Geology has occupied an important place in higher education in the United States since its introduction into the college curriculum by Benjamin Silliman at Yale University in 1802. Although the subject was not immediately popular, it gained steadily in recognition among the country's academic institutions. Significantly, the pioneer of technical education in the United States, Rensselaer Polytechnic Institute, included geology among the basic scientific subjects of the technical curriculum initiated there. Although the date is not definitely known, it is believed that a course in geology was first offered at Rensselaer in 1829. Since that time, geology has, of course, become established as an essential element in technical education, and the engineer of today could no more do without geology than he could without mathematics, physics, or chemistry.

In civil engineering, geology is of fundamental importance, inasmuch as every branch of civil engineering has some contact with the earth's surface and subsurface. Quite evidently the civil engineer must know the materials under foot in order that he may design and construct the structures he will place in contact with them. Furthermore, the answers to many engineering problems related to surface configuration of the earth must be drawn from geolog.

Geology and the geologist serve in important capacities; the service rendered is found in the application of the findings of the pure science to the special problems of the engineer. In the solution of most engineering construction problems, it is the task of the geologist to state the probable difficulties, and that of the engineer is to overcome them.

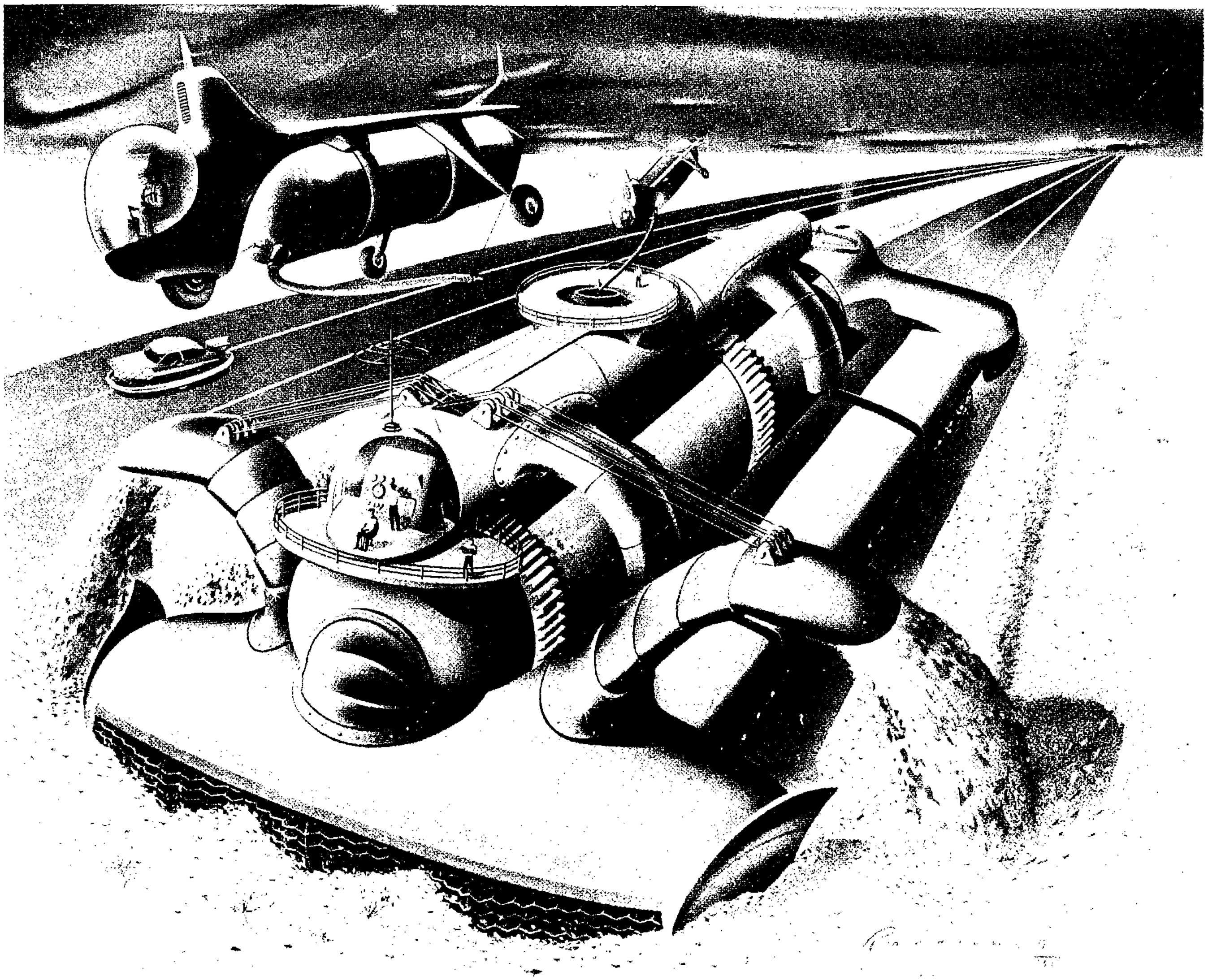

Figure 1. The geology training of the future engineer will receive far reaching importance when machines like this lay 30 miles of turnpike per day. Courtesy, L. D. Cole Company, Advertising-- San Francisco.

The materials of construction,as found in nature, are generally located by the engineer-geologist, whereas the engineer proves and uses them. It is the common understanding of the problems encountered in highway engineering and the exchange of ideas between civil engineers and geologists that will insure better highways tomorrow. The fundamentals of geology should become an essential part of the mental equipment of every civil engineer, particularly the highway engineer. Inasmuch as highway engineering is believed to be representative of the works performed by the civil engineer, the remarks recorded here will be associated more generally with that field.

The highway engineer's interest in geology will continue and even increase at a more rapid pace. In fact, with the advent of atomic power, futuramic vehicles, and futuramic construction machines for our roads, some of which may be powered by atomic energy, highway requirements may be drastically altered in the foreseeable future. Thus, the geology courses in our engineering curriculum may need revision to keep up with the pace. The revision needed is that which is necessary to enable the highway engineer to learn more geology and more about the applications of the science. Even though we are faced with the terrific destructiveness of the hydrogen bomb, we should provide for the future by devising a means of using this destructive force in our construction practice where some natural obstacle stands in our way. For example, consider the possible need for a larger passage across the Isthmus of Panama, in the event of World War III. Perhaps a path could be blasted across the Isthmus, using a few hydrogen bombs, thus enabling construction of a highway to replace or supplement the canal. The Highway Engineer will look to the geologist to determine the feasibility of future operations such as this.

Another facet that points up the need for reviewing the geology training of future engineers is the economics of a positive highway building program.

In a recent study by the Automobile Manufacturers Association, it was stated that we cannot afford to waste three billion dollars yearly, especially when at least two billion is due to the inadequacy and obsoleteness of our present interstate system. In effect, the need is emphasized that the highway engineer must provide a more economical highway. It has been said that given sufficient money, the engineer can build a highway that will meet all traffic requirements, design standards, and withstand all kinds of weather. However, with a given highway requirement and a given amount of money, it is up to the engineer to design an adequate highway for a given situation. It is emphasized here that the adequately trained engineer can be of considerable assistance in meeting the requirements of saving the highway user the waste incurred. When the more economical use of our highway system is provided for a sound knowledge of geology, the highway engineer will have been important in preventing the waste.

Attention is now placed upon the importance of geology as it is brought before the student engineer and the engineer-in-training. Will the geology courses as presently offered assist the future engineer to cope with the economical problems and the design requirements of the future? In order to determine the answer to this question, (1) a brief discussion is given of geology as applied in highway engineering; (2) some of the geology courses found in our present curriculums are discussed; and (3) a criterion is offered as a standard by which present courses in geology may be compared; and (4) finally, the geology course to meet the criterion is suggested.

Geology is Used In Highway Engineering.

Where geology plays an important part will only need brief mention here. Geology is a basic tool in many of the following phases of highway engineering; preliminary surveys; location surveys; design of subgrades, base courses, drainage structures, and pavements; and in control and testing of the materials of construction. The highway engineer relies on the staff geologist or his own knowledge of geology in the selection of the best route for the highway based upon a study of the following factors: topography, geological structures, local highway materials, sources of selected borrow and aggregates for granular base course, location of ground water and its effect on drainage, and the character of surface soils.

Increase in the use of geology in highway work is indicated by a recent survey compiled by S. E. Horner, Chief Geologist, State Highway Commission of Kansas and E. Dobrovolvy, Geologist, U.S.G.S. It was shown that there was an increase from 43 gologists in 1949 to 89 in 1951, who were employed as full time staff geologists by state highway departments.

In general, when a highway engineer is designing a road, he calls on his own background training and experience as well as the staff geologist. However, there are innumerable cases where the engineer uses his own judgment in the design. Mr. Everett Scroggie, Bridge Design Engineer of the Tennessee Valley Authority says that usually the bridge engineer has to make his own interpretations of available data, since the expert geologist is not always available for consultation at a moments notice. However, for very special cases, the bridge engineer will call on the expert geologist.

Before the footings for a major bridge are designed, geological exploration is essential. Both engineers and geologists study and interpret the results of the exploration. The geologist establishes the facts whereas the engineer interprets and designs on the basis of the facts presented. In general, limitations of funds do not permit a staff geologist to be available for all types of engineering work; hence, the engineer must use his knowledge of geology, obtain the facts, make his own interpretations and then design the structure. The need for geology training for highway engineers to meet these circumstances is readily apparent.

The engineer often calls upon his own resources to establish the distribution of suitable borrow material for foundations or embankments or suitable mineral aggregates for pavements. He uses his geology background and experience to locate and specify the suitability of the earth's crust for a specific problem and designs the project to make the best use of the available materials. Much of the research that has been done at Purdue University by the Joint Highway Research Project has demonstrated how a knowledge of geology is essential in highway engineering where suitability of aggregates is concerned.

In recent years, corrective action for highway landslides both in West Virginia and Ohio, as well as elsewhere, has been possible as a result of analysis of geological conditions. Highway engineers and geologists have been active in this respect. Mr. R. F. Baker, Engineer of Soil Mechanics, State Road Commission, West Virginia, has contributed a great deal of knowledge in this respect. Also, Mr. Harry Marshall, Geologist, Ohio Department of Highways, has contributed with applications of knowledge of geology to highway engineering and has established excellent methods of corrective action.

Some of the Present Courses in Geology are Good.

A survey was made of some of the geology courses that are offered in engineering curriculums. It was found that most colleges offer courses primarily for the purpose of demonstrating the basic principles of geology. A few typical examples were selected from school catalogues and are enumerated. At Purdue University, junior civil engineering students are required to take only a two-hour course. It includes application of geology to engineering practice with special attention to problems in foundations, excavation, water supply, and tunneling. Electives in Engineering Geology are offered to seniors and graduate students.

At Ohio State University, third year engineers take Engineering Geology 435 (five credit hours) with two-hour laboratory. This course imparts the principles of physical geology and the materials composing the earth, with special emphasis on relationship of geology to engineering work. The laboratory consists of studies of common rock-forming minerals and rocks, topographic and geologic maps. Many good electives also are available.

The geology course for civil engineers at Texas A & M is embodied in a three-hour course including a three-hour laboratory. This course demonstrates the principles of dynamic and structural geology as applied to common minerals and rocks with their relationships and applications to excavation and foundations. Advanced Engineering Geology may be taken for four hours credit. The latter is a survey of those phases of mineralogy, petrology, historical geology, structural geology and sedimentation that may be applied to engineering problems.

Case Institute of Technology has a required course in geology without laboratory work which is required of all junior civil engineering students. The course includes the fundamental principles of geology and their applications to engineering. Emphasis is placed upon the physical characteristics of earth materials, geologic processes and their bearing on tunneling, excavation, foundations, road building, reservoirs, dam sites, water supply, and soil mechanics. A brief review is made of earth history and major economic mineral deposits.

At Michigan State College, the junior civil engineering student takes Engineering Geology 306 which includes a two-hour laboratory. This course is a study of the fundamental principles of geology as applied to civil engineering practice. Minerals, rocks, aerial photographs, topographic and areal geology maps, and geology cross sections are studied in the laboratory.

The student becomes acquainted with the source of geologic literature and maps and prepares written reports based upon the laboratory problems and relevant literature.

Only a few typical examples have been listed; however, it is felt that these few are typical of the curriculums in general. This study indicates among other things, that, in general, a two- or three- credit hour course stressing the basic principles of geology is being offered to engineering students. However, it is felt that more than this is needed such as in the course at Michigan State where applications of fundamental principles to actual engineering practice is well worth the time and effort expended by the student.

The Geology Course for the Civil Engineering Curriculum.

In general, there is a continual struggle to offer courses which demand student time. Competition is keen across the college campus to introduce new ideas to the future engineer. The present feeling among college administrators is to obtain a balance within present courses, i.e., not offer courses which require more student time but to offer changes which will bring courses up to date and yet continue to meet present curriculum requirements. Therefore, it is believed that any new ideas in geology courses will have to be introduced into present courses or offered as elective courses.

The geology course for the civil engineer must show how in engineering practice use is made of the science and skills of geology in site investigations; surveys for the location of construction materials; correlations of exploration data with soil mechanics data obtained in the laboratory and application of correlations to the design of project; anticipating and controlling of landslides; planning underground structures with a knowledge of type and structure of materials to be encountered; and finally, applications of geologic literature, reports, and maps, and topographic maps and aerial photography.

As near as can be determined, the course offered at Michigan State College more nearly accomplishes the program outlined in the preceeding paragraph than any other course presently offered by the other colleges surveyed. For those engineering colleges not presently offering a complete and adequate program for civil engineering students, the following remarks are offered for consideration.

To meet the requirements outlined in this paper, an engineering geology curriculum of six to eight hours will be needed. One three-hour course in basic principles as applied to engineering practice including two hours of laboratory a week will suffice. In addition to stressing fundamentals, this course should demonstrate how minerals, rocks, and soils originated and are related to a composite pattern arrangement of the earth's surface. How aerial photography, topographic and geologic and pedologic maps are related to this composite arrangement of the earth's surface must be demonstrated also.

The second semester course should be practical and emphasize the applications of geologic literature, reports, maps and data to engineering practice. The student should be shown how geologic literature, and maps, aerial photographic data may be used in planning subsequent field sampling. In the laboratory assignments, the student should be assigned projects where science and skill may be conveniently combined to establish sufficient data for the planning preliminary surveys, design, final locations and construction of all classes of engineering projects. Thus, the student will gain a know-how for gathering design data that will save many man-hours and cost.

In the elective course, it should be possible to stress applications of the newest tool of the engineer and geologist, i.e., photo interpretation. Engineers as well as geologists have discovered the application of photo interpretation to engineering practices. The engineer-in-training should be introduced to the many applications of photo interpretation while in college. The present geology course usually covers the association of topography, climate, vegetation, structural forms and parent materials with the earth's crust. However, highway engineering of the future calls for the course to go two steps farther, i.e., first, it must show the relationship of airphoto patterns to topography, climate, vegetation, structural forms and parent material, and, secondly, the course must demonstrate how the airphoto is used in engineering practice. Thus, with a given airphoto pattern identified, the engineering problems are anticipated, field investigations are thoroughly planned for sampling the representative or typical areas, and then the correlated data is included as a basis for the final design and construction practice with a minimum of time and effort expended.

The geology courses can present challenging features for the future engineer. Many airphoto patterns of the earth's crust have been thoroughly identified and are now easily recognized. The challenge is seen in the thousands of yet unidentified patterns. The intrigue of a new pattern is even more challenging than the mysteries read in today's novels or that come across the police blotter. The engineer-in-training can be encouraged to make studies on his own to discover the engineering significance of the yet unsolved airphoto patterns.

SUMMARY.

It has been pointed out that training engineers to appreciate the applications of geology to the fullest extent is essential in order that more economical highways will be planned and constructed in the foreseeable future. Some typical geology courses have been reviewed to determine if the future engineer will have the perspective needed to apply a geological fundamental to the solution of an engineering problem, but some have been found wanting. A geology course or courses are suggested for the civil engineering curriculum to meet the requirements of this atomic era. Finally, emphasis upon application of airphoto interpretation and geological

fundamentals to engineering practice need to be emphasized and fully demonstrated in classroom and laboratory in order to give the future engineer adequate training.

GEOLOGICAL AND SOILS ENGINEERING

ON

OHIO TURNPIKE PROJECT NO. 1

by

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Ohio Turnpike Project No. 1

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<u>The Project.</u>

At this moment, the construction of one of the most ambitious projects in the history of highway engineering is proceeding at an increasing tempo. Ohio Turnpike Project No. 1, when opened to traffic on October 1, 1955, will make a reality the sorely needed and long awaited modern super highway which will traverse the full width of Ohio and connect the Pennsylvania Turnpike with the Indiana Toll Road now under design.

Statistics can be notoriously dull, yet the following few facts and figures, mainly taken from the 1953 Annual Report of the Ohio Turnpike Commission, in themselves convey some impression of the magnitude of Project No. 1;

(a) To finance the construction of the 241-mile highway, an original bond issue of some $326,000,000 was required.

(b) Value of construction contracts let through 1953 totalled $211,894,154 for 61 out of a total of 62 construction sections. It is of interest to note here that this construction cost to date exceeds the estimates of the Engineering Report[1] of 1951 by only 2.14% despite generally rising construction costs since preparation of the estimates.

(c) Earthwork Quantities

Excavation (total, including structures)	-39,632,787 Cu.Yds.
Borrow	-30,499,500 Cu.Yds.

(d) Paving Concrete . . . . 7,041,287 Sq.Yds.

(e) Selected Subbase material[1] . . . . . . 2,243,700 Cu.Yds.

The foregoing data tend to become even more impressive when recognition is made of the tremendously accelerated pace at which design and construction of the project must proceed (time for design and construction approximately 39 months) in order to most economically bring it to completion.

Soils and Geologic Problems.

The Civil Engineer, the Soils Engineer, and the Engineering Geologist, viewing the almost astronomical quantities of earth and rock required to be moved in a limited time, and with the knowledge that the entire length of the 241-mile road is located in the glaciated region of Northern Ohio, will probably suspect that a wide variety of soils and geologic problems are involved. It was the writer's rewarding (and sometimes rather trying) experience to be associated with the recognition, study, and solution of these problems from the inception of the project, when he had charge of the soils and geologic reconnaissance and development of data related to these aspects of the work in connection with preparation of the Engineering Report, on the basis of which the financing of the Turnpike was successfully consummated.

It became apparent, during the preliminary office studies, and to agreater degree during the field reconnaissance, that the problems would be numerous and various. Subsequent developments have furnished no basis for altering this appraisal. It was further recognized that many of the potential soils problems, as such, were created by or related to features of the glacial geology of the region. It was the original impression, which has also remained unchanged, that due to this intimate relationship, no clear line of demarcation could be drawn between the fields of soils engineering and geological engineering. Because space and time limitations necessitate something less than a full discussion of matters lying in both fields, it will be attempted to limit the scope of this paper so as to place primary emphasis on the geologic environment of the soils problems. In the following review, it is considered convenient to separate the development of the project into three phases, namely;

I. Reconnaissance and Engineering Report.

II. Design Phase.

III. Construction Phase.

It will be recognized, of course, that some degree of overlap naturally occurred between the latter two phases.

I. RECONNAISSANCE AND ENGINEERING REPORT.

The discussion of this phase in the following paragraphs is an extract of the text of the Engineering Report, and Slides Nos. 1, 2 and 3, used in the oral presentation were prepared from Report Plate No. 3 (in color), referred to in the text, and a black-and-white copy of which appears herewith as Figure 1.

ENGINEERING GEOLOGY AND SOILS

Geology and Soils of Northern Ohio - General

In the design and construction of a modern turnpike, a detailed study of the characteristics of the terrain to be traversed is of critical importance. Roadway and structures must be founded on the native soils and rocks, and as these materials vary in their nature and supporting capacity, design must be properly adjusted to achieve sound and economical results.

Figure 1, Soil and Geologic Data, has been prepared specifically to illustrate the major geologic and soil features of the proposed route and their influence on location and design. The underlying bedrocks of northern Ohio are sedimentary in origin and range from comparatively soft clay shales to massive limestones and hard sandstones. The predominant feature of the fundamental geologic structure is the Cincinnati Anticline, a regional arch of the rock strata that was produced by warping of the earth's crust in past geologic time. To either side of the axis of this structure, which trends approximately from Cincinnati to Toledo, the strata dip away on a very gentle slope of some 20 to 30 feet per mile. The central uplifted portion of the arch has long since been eroded away, with the result that the proposed line crosses roughly parallel outcrop areas of successively younger to older rocks from east to west (Figure 1).

During the glacial periods, northern Ohio was covered by at least three separate advances of continental glaciers. The most recent of these, the Late Wisconsin, exercised a profound effect on topography, drainage and soils. Pre-glacial valleys were largely filled with deep deposits of drift, existing drainage systems were greatly altered, and a mantle of till and glacial lakebed deposits of varying thickness was laid down over the bedrock of the entire area.

From the Pennsylvania line westward through Mahoning and Trumbull Counties, and the eastern portion of Portage County, the proposed route traverses rolling upland terrain covered for the most part with only a thin layer of glacial till. In western Portage County, and portions of Summit, Cuyahoga, and Lorain Counties, areas of deeper drift and till, as well as moraine areas, are encountered. The moraines are low, irregular hills and ridges of unsorted material deposited by the glacial ice as it halted its eventual retreat for a considerable period of time along an approximately stationary front. These areas require particular study because the soil types they contain are extremely variable and include not only sands and gravels of suitable quality for construction purposes, but sandy clays and silts of poor to good supporting capacity, and peat and muck deposits filling undrained depressions or kettles which are to be avoided by the alignment, if possible, because they create treacherous foundation conditions.

Near Elyria, in Lorain County, the proposed line enters an area of distinctly different topographic and soil characteristics. During glacial times, Lake Erie extended considerably beyond its present shores and reached its maximum extent as glacial Lake Maumee (Figure 1). Deposits of laminated lake bottom silts and clays were laid down over most of the area to help produce the present day topography of very flat to gently undulating plains. Stands of the lake at successively lower elevations are marked by abandoned shorelines and offshore deposits consisting of rather well-defined low ridges of sandy and gravelly material which contrast sharply with the otherwise predominating heavy silty and clayey soils of the region. The latter soils, combined with the flat terrain, are responsible for a variety of drainage, grade-line, and foundation problems requiring special attention in design.

In central Fulton County, the line passes over a lobe of the Defiance Moraine, and in Williams County, it leaves the abandoned lake bottom as it crosses the former western shoreline of Lake Maumee near West Unity. The remainder of the route to the Indiana line traverses a more elevated terrain of till plains and moraine areas similar in character to that encountered in some eastern portions of the State.

Preliminary Office Studies.

A complete set of consecutive aerial photographs at contact scale of 1:10,000 (1 inch equals 867 feet), covering the strip of territory roughly $1\frac{1}{2}$ miles wide, within which other considerations had indicated the final route would be located, was reserved exclusively for terrain, foundation, soil and geologic studies. A band 2,000 feet wide, centered on the preliminary alignment, was located on the photographs for particularly detailed study, but all features of possible interest covered by the photography were investigated.

All available agricultural soil maps and county soil reports were studied, and under the stereoscope, using relatively recently developed techniques of terrain interpretation, the boundaries of the various agricultural soil areas were identified and marked on the photographs. The county soil reports furnished a wealth of preliminary data on soil composition, typical profile development, origin, depth to and character of parent material, texture and drainage characteristics. These data, although prepared originally for agricultural purposes, were later correlated with engineering soil classifications, and served to eliminate much unnecessary and time consuming soil sampling and testing.

Geologic maps and publications of the Ohio Geological Survey and the U. S. Geological Survey were studied, and all data of engineering importance within the strip covered by photographs were compiled on the photographs. Through the cooperation of the Ohio Geological Survey, a series of unpublished map manuscripts showing the locations of abandoned glacial lake shorelines in the western half of the State was made available. These manuscripts, compiled some forty years ago by Frank Carney, geologist of the Survey, proved to be amazingly accurate. From them and stereoscopic study of the photographs, these features were precisely delineated for later field check as possible sources of granular construction material and areas of favorable drainage and subgrade conditions.

Coal maps prepared by the State Survey furnished the basis for interpreting on the photographs locations of outcrop lines and structure contours of commercially workable coal beds where they are crossed by the proposed line, mainly in Mahoning County.

Detailed soil profiles, and results of extensive laboratory soil tests compiled by the Ohio State Highway Testing and Research Laboratory for state highway projects in the general vicinity of the proposed line were studied in detail. The locations of the profiles were plotted on the photographs, thereby making possible a preliminary correlation between the engineering soil classifications and the agricultural soil areas and nomenclature which had previously been marked on them. Similarly, numerous data pertaining to locations and types of existing bridges, as well as boring records and foundation conditions, were procured from Department of Highways sources and noted on the photographs.

During stereoscopic study of the photographs, soil and drainage patterns, as they appeared on the photographs, were correlated with the other types of information that had been compiled, and a preliminary estimate of terrain conditions to be encountered was formulated. A detailed check list was prepared to include all conditions and features requiring later field examination. Unfavorable areas of muck and peat deposits were readily identified and marked so that even the preliminary alignment could be adjusted to avoid them. The preliminary office studies of the photographs and compilation on them of all available terrain information in concise form made possible a rapid, thorough, and systematic field examination of the proposed route.

The Field Reconnaissance.

In the field, a special study was made of the active and potential coal producing areas, almost entirely in Mahoning County, traversed by the proposed line. The mineable coals in this area are the Lower Kittanning and possibly the Middle Kittanning seams. Insufficient seam thickness precludes use of underground mining methods, but a combination of currently favorable market conditions and a short haul to the Youngstown area where these coals are in particular demand, has encouraged a number of rather unusually active large scale stripping operations.

Active and abandoned mines were examined to determine the depth and character of cover, the coal thickness, quality, approximate elevation and the probable economic limit of overburden removal. Several mine operators were interviewed, and local practices in the matter of royalty payments to owners of coal lands, plans for future operations and other local aspects of the industry were ascertained.

The coal outcrop lines and structure contours previously sketched on the photographs were checked and revised where necessary to fit field observations or reliable data furnished by mine operators. At one location where the line crosses a strip mine, the volume of mining waste requiring removal, replacement, and compaction was determined by field measurement.

A total of 68 hand auger borings was made along the length of the line. Guided by the agricultural soil boundaries previously delineated on the photographs, boring sites were selected so as to obtain samples and profile data for each major agricultural soil series encountered. Application of the pedologic concept of soil type distribution made possible a rapid and representative sampling program not otherwise feasible within the time limitations. The locations of all borings were precisely marked on the photographs and a log was prepared for each hole, whether samples were retained or not, on which were noted pertinent soil profile data, depth to water table and a preliminary engineering classification of the soil based on visual examination. The retained samples were later re-examined, and 57 of those considered to be most representative of reasonable large areas were forwarded to the State Highway Testing and Research Laboratory for testing and engineering classification.

The location and character of rock outcrops, and the nature of the soil profile in streambeds, railroad and road cuts, quarries and strip mines were recorded in detail. Much information pertinent to design of drainage structures, such as the type and extent of ditching and agricultural drain tiling in the flat lake plains areas, and the occurence of acid mine waters in the coal stripping areas of Mahoning County, was gathered. In the western half of the State, where rock is usually concealed under heavy cover, local well information such as depth to and type of bedrock and character of overburden, was procured.

Frost damage on existing roads was studied with reference to type and thickness of pavement probable volume of traffic and subsoil and drainage conditions. Existing highway structures, particularly those for which subsurface information was available, were inspected to appraise from their actual performance the suitability of the original substructure design to local foundation conditions.

A preliminary survey was made of possible sources of construction materials. In addition, the field studies included the examination and sampling of all promising deposits of natural materials in the proximity of the line.

Conventional type core borings for foundation studies were made at the crossings of the Sandusky and Cuyahoga Rivers, and Meander Reservoir. To supplement these borings, an extensive program of geophysical surveys was completed by the Lee Oil and Natural Gas Company of Baltimore, Md., under the direction of the Consulting Engineers.

The electrical resistivity method of substructure exploration is based on the use of equipment which passes a current into the ground through electode stakes and measures the electrical resistance of subsurface materials at definite increments of depth. The electrical measurements are plotted as resistivity against depth, and changes of material are indicated by changes of direction or shape of the resulting curves. From these curves, the general character and depth of underlying material can be interpreted. However, the method is not entirely complete in itself. A knowledge of influence of local geologic factors, as well as information on general underground conditions to be expected, are essential for reliable interpretation of the resistivity logs. In the surveys here described, the location of each resistivity station was plotted on the aerial photographs, on which had been noted the large volume of subsurface data previously compiled in the other phases of the reconnaissance. These data furnished the background information required for accurate interpretation.

Resistivity measurements were made at the proposed sites of virtually all stream crossing structures larger than culverts; at all other structures larger than culverts; at all other structure sites where foundation conditions were considered questionable; and at the sites of heavier cuts to determine depth of cover over rock for backslope design.

Use of the resistivity surveys resulted in a more thorough appraisal of foundation conditions of sufficient accuracy for estimating purposes than could have been obtained by any other means in the time available. A summary of the investigations completed is shown below:

COUNTY	NO. OF RESISTIVITY STATIONS		
	CUTS	STREAM CROSSINGS	ROAD & RAILROAD CROSSINGS
Mahoning.	5	3	10
Trumbull.	1	5	5
Portage	3	1	4
Summit	2	2	3
Cuyahoga	4	5	6
Lorain	8	1	4
Erie	1	1	13
Sandusky	0	4	15
Ottawa	0	2	7
Wood	1	1	9
Lucas	0	2	12
Fulton	0	4	14
Williams	0	3	12
Total	25*	34	114

* Also includes some structure locations.

<u>Correlation with Designs and Estimates.</u>

Pile or spread footings for structures were estimated after reviewing all available subsurface data in the form of borings, interpretations of resistivity measurements, field recommendations and foundation information for existing structures.

The profile for the entire length of the proposed line was restudied in order to prepare estimates of special excavation quantities. In areas where shallow fills rest on soils of doubtful supporting capacity, a depth of undercutting below normal grading to remove the undesirable material was estimated. Quantities of muck and mine waste excavation were similarly computed. In the deeper cuts where rock would be encountered, backslope design, including location of benches where considered necessary, was based on determination of top and character of rock made by the geophysical and geological studies. In particularly low-lying flat, poorly drained areas, the grade line was kept elevated in accordance with field recommendations.

A complete tabulation, based on the field study, was made of all existing and potential sources of construction materials, for use in pavement design and estimating unit costs. Results of soil tests on the samples taken in the field were correlated with available State Highway Testing Laboratory soil profiles and maps, and found to be in general agreement with such data.

Coal outcrop lines were located on the photogrammetric maps, and from them and a consideration of probable economic limits of stripping, areas of damage to existing and potential mining operations were delineated. In addition to areas suffering direct damage, areas of mineable coal to which access would be cut off were estimated, and a total acreage of coal damage was compiled. Using prevailing royalty prices and average local coal yield per acre, a total cost for coal damages was estimated and is included in the estimated cost of the project.

Possible damages to oil and natural gas installations, and to non-operating leases, were investigated. A nominal sum to cover such damages has been included with the estimate of coal damages.

* * * *

In reviewing the foregoing in retrospect, and in view of the extensive and detailed soils and geologic studies made during the design phase, it may not be amiss to comment that the preliminary studies were necessarily generalized. The prime purpose of the Engineering Report was to furnish a sound statement of feasibility and an estimate of cost of the project. The basic designs of all items of major expense, e.g., bridges, roadway, drainage structures, etc., were refined only to the extent necessary to fully achieve this purpose. Similarly, due to severe time limitations, the soils and geologic reconnaissance studies were accomplished in approximately the same degree of detail.

II. THE DESIGN PHASE

Engineering Organization - General.

Immediately following successful marketing of the revenue bond issue, preparation of plans and contract documents for the entire length of the Project had to proceed virtually simultaneously and with all possible speed. Completion of this monumental task required skilled engineering services on a scale far beyond the resources of any one or several of the larger qualified engineering firms in the country. For design and construction purposes, therefore, the Project was divided into 21 Design Sections which were, in turn, subdivided into a total of 62 Construction Sections. Sixteen outstanding engineering firms, designated as Contracting Engineers, entered into agreements with the Ohio Turnpike Commission for the preparation of detailed construction plans for one or more Design Sections, and for later supervision of construction in the same sections. A roster of Contracting Engineers is given in the Appendix.

Functions of the Commission.

The Ohio Turnpike Commission is composed of Messrs. James W. Shocknessy, Chairman; O. L. Teagarden, Vice-Chairman; A. J. Allen, Secretary-Treasurer and Member; J. Gordon McKay, Member; and Samuel O. Linzell, Member Ex-Officio.

Under the general direction of the Commission, Major General Robert S. Beightler (U.S.A. Ret.) Executive Director, Mr. Charles P. Smith, Executive Assistant, Frank C. Dunbar, Jr., General Counsel, and Mr. T. J. Kauer, Chief Engineer, assisted by a staff of engineers, have the task of making a final review of all Plans and Contract Documents before they can be certified as ready for advertising. Mr. G. K. Jewell, Soils and Foundation Engineer, advises the Chief Engineer on matters involving soils and foundations.

Functions of the Consulting Engineer.

The J. E. Greiner Company of Baltimore, Maryland, is the Consulting Engineer to the Ohio Turnpike Comission for Ohio Turnpike Project No. 1. The responsibilities and duties of the Consulting Engineer were, and are, numerous, diverse and complex; therefore, only those most pertinent to the topic of this paper are summarized as follows:

1. Establishment of Design Criteria for embankments, foundations, roadway, drainage, etc.
2. Assistance to the Commission with preparation of the General Specifications, including, for example, specifications for Earthwork, Borrow, Selected Subbase, and all other items, relating to soils, foundations, construction aggregates, etc.
3. Preparation of Specifications, and supervision of preparation of Contract Documents, for test boring contracts.
4. Review of completed Plans, including Soil Profiles, and recommendation to the Commission to accept same when considered ready for advertising for bids.
5. General supervision and coordination during the Design and Construction Phases, of all activities of the Contracting Engineers connected with soils and foundation studies; and furnishing advice and assistance, as required with problems encountered.

Functions of the Contracting Engineers.

The responsibilities and functions of the Contracting Engineers are broadly outlined in a document entitled, "Specifications for Contracting Engineer's Services" and which forms an integral part of the agreement for engineering services to be furnished to the Commission. Several pertinent extracts are as follows:

"General Summary:

The Contracting Engineer shall be required to execute, or supervise the execution of, such soil and geologic studies, tests, investigations, and subsurface explorations as may be required for the proper design of roadway pavements; special subgrade, subbase, and/or base courses; embankments; structure foundations; backslopes in cuts; for the determination of shrinkage or swell factors to be applied to grading quantities; for design of special subsurface drainage installations; and for the exploration of any special or unusual subsurface conditions (e.g., coal, peat, or muck deposits) which may be encountered and which may influence design. All pertinent data resulting from these tests, studies, and explorations, shall be plotted or recorded to produce a Master Soil Profile, which portrays as accurately and in the most detailed fashion practicable, the soil and subsurface conditions existing throughout the section. (Note: for appearance of Typical Master Soil Profile, refer to Figure 2). During the progress of construction work, the Contracting Engineer shall execute, or supervise the execution of, such soil tests, investigations, and explorations as may be required to determine the suitability of foundation, subgrade, construction aggregates and embankment materials, and to assure adequate compaction of embankment and subbase courses, all in accordance with the letter and intent of the plans and specifications. The foregoing will include the supervision of such soil load tests and test pile installations as may be required during the progress of construction work to check original substructure design or to modify design if previously undisclosed conditions are encountered.

This work will normally consist of such items as the making of auger borings and probings, the opening and sampling of test pits, in-place density determinations, field classifications of soils, as well as laboratory operations such as standard soil classification, sieve analysis, compaction, Atterberg Limit, permeability, time-consolidation, frost resistance, and California Bearing Ratio tests. All laboratory and field tests required for inspection and supervision of grading, earthwork, paving and foundation excavation operations will likewise be considered the normal responsibility of the Contracting Engineer.

Inspection (Test Borings).

All boring operations shall be under the supervision of the Contracting Engineer or his representatives. The inspectors shall check the drillers' written logs for accuracy; verify elevations and description of materials; transmit location sketches; assist the drillers or foreman in finding locations; maintain particular supervision to insure the proper taking of undisturbed samples; furnish or relay decisions regarding total depth of hole; keep a running log of all operations, and generally enforce the specifications. Personnel assigned to this work should be qualified by reason of an educational background or practical experience in geology and/or soil mechanics.

Preparation of Soil Profile.

General.

The Contracting Engineer shall prepare a Master Soil Profile (Note: refer to Figure 2), for each contract section, using a base standard profile sheet on which are plotted the existing ground lines and proposed grade line (or individual data for each lane in portions of the section where topography and separated alignment warrant) to convenient horizontal and vertical scale. The vertical sequence and lateral extent of the various soil layers, location of top-of-rock, if present and other subsurface data developed as outlined below, shall be plotted to scale or recorded on the profile. In some instances, detailed diagrams of the soil profile tied in to the master profile will be useful to overcome scale or space limitations. The master profile shall be reproducable and copies shall be made available to the Commission as requested.

Wherever applicable, standard methods of surveying and sampling soils (A.S.T.M. Designation D420-45; A.A.S.H.O. Designation T86-49) should be used."

Test Boring Contracts.

The contracts for test borings were the first construction contracts to be awarded, since the data furnished by the borings were essential for design of structure foundations and, to a lesser degree, influenced embankment and cut slope design. Satisfactory completion of the subsurface investigation program presented numerous difficulties because of the tight design schedule which necessitated almost simultaneous operations over most of the Project length; the fact that a number of drilling contractors were tied down to

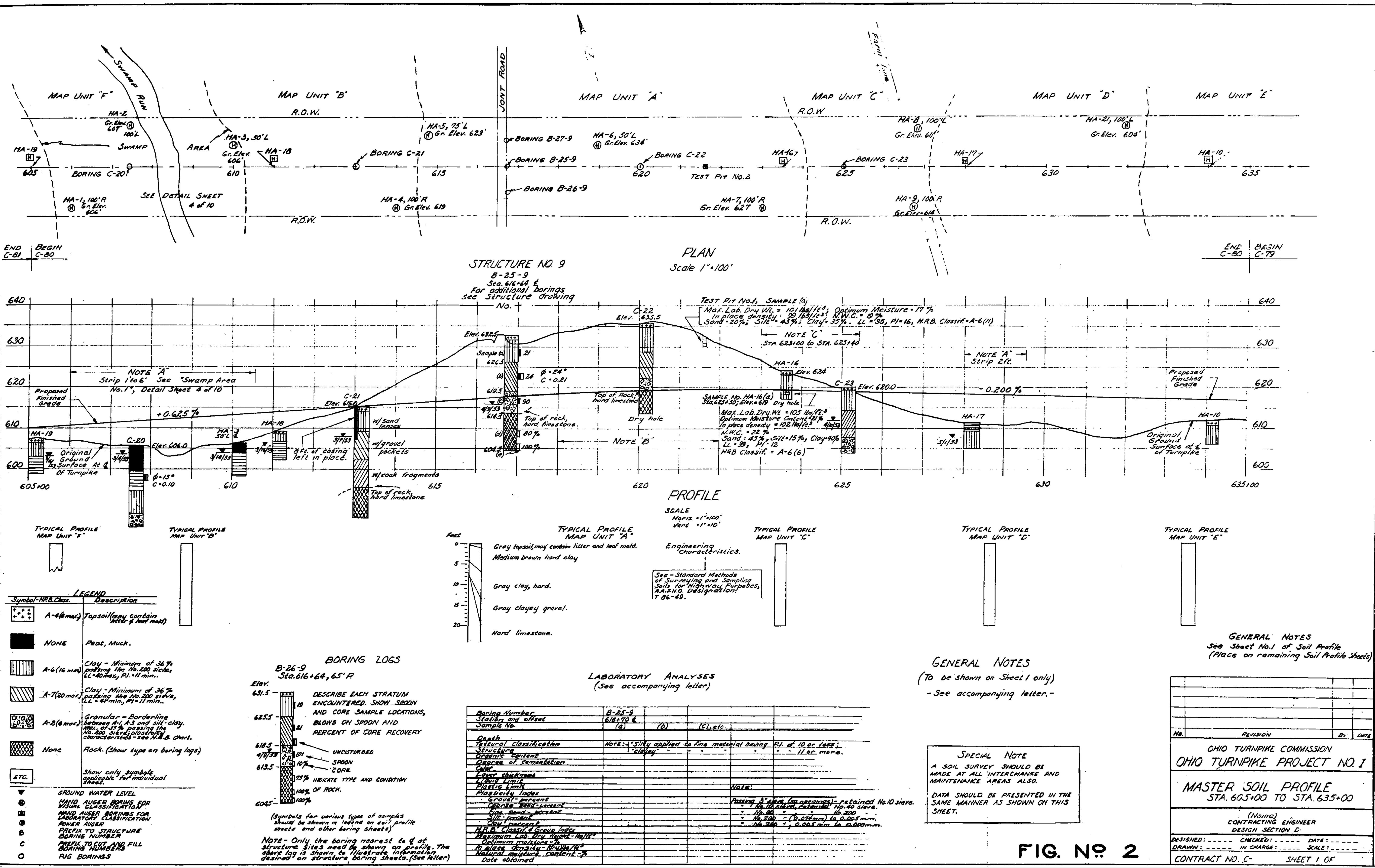

MAP UNIT "F"
MAP UNIT "B"
MAP UNIT "A"
MAP UNIT "C"
MAP UNIT "D"
MAP UNIT "E"
SWAMP RUN
SWAMP AREA
JONT ROAD
Farm line
R.O.W.
BORING C-20
BORING C-21
BORING B-27-9
BORING B-25-9
BORING B-26-9
BORING C-22
TEST PIT No.2
BORING C-23
SEE DETAIL SHEET 4 of 10
END C-81
BEGIN C-80
END C-80
BEGIN C-79
PLAN
Scale 1"=100'
STRUCTURE NO. 9
B-25-9
Sta. 616+64 ℄
For additional borings see Structure drawing No.
TEST PIT No.1, SAMPLE (a)
Max. Lab. Dry Wt. = 101 lbs/ft³; Optimum Moisture = 17%
In place density: 99 lbs/ft³; N.W.C. = 19%
Sand = 20%; Silt = 45%; Clay = 35%. LL = 35, PI = 16, H.R.B. Classif. = A-6(11)
NOTE "C"
STA. 623+00 to STA. 625+40
NOTE "A"
Strip 2ft.
NOTE "A"
Strip 1' to 6' See "Swamp Area No.1", Detail Sheet 4 of 10
Proposed Finished Grade
+0.625%
-0.200%
Original Ground Surface at ℄ of Turnpike
NOTE "B"
SAMPLE No. HA-16(a)
Max. Lab. Dry Wt. = 105 lbs/ft³
Optimum Moisture Content = 21%
In place density = 102 lbs/ft³
N.W.C. = 22%
Sand = 45%, Silt = 15%, Clay = 40%
LL = 39, PI = 12
HRB Classif. = A-6(6)
Top of rock, hard limestone.
Dry hole
8 ft. of casing left in place.
PROFILE
SCALE
Horiz. = 1"=100'
Vert. = 1"=10'
TYPICAL PROFILE MAP UNIT "F"
TYPICAL PROFILE MAP UNIT "B"
TYPICAL PROFILE MAP UNIT "A"
TYPICAL PROFILE MAP UNIT "C"
TYPICAL PROFILE MAP UNIT "D"
TYPICAL PROFILE MAP UNIT "E"
Grey topsoil, may contain litter and leaf mold.
Medium brown hard clay
Gray clay, hard.
Gray clayey gravel.
Hard limestone.
Engineering Characteristics.
See - Standard Methods of Surveying and Sampling Soils for Highway Purposes, A.A.S.H.O. Designation: T 86-49.
LEGEND
Symbol - HRB Class. - Description
A-4(8 max.) - Topsoil (may contain litter & leaf mold)
NONE - Peat, Muck.
A-6(16 max.) - Clay - Minimum of 36% passing the No.200 sieve, LL = 40 max., P.I. = 11 min.
A-7(20 max.) - Clay - Minimum of 36% passing the No.200 sieve, LL = 41 min., PI = 11 min.
A-2(4 max.) - Granular - Borderline between A-1, A-3 and silt-clay. Max. of 35% passing the No.200 sieve; plasticity characteristics - see H.R.B. Chart.
None - Rock. (Show type on boring logs)
ETC. - Show only symbols applicable for individual sheet.
GROUND WATER LEVEL
HAND AUGER BORING FOR VISUAL CLASSIFICATION
HAND AUGER BORINGS FOR LABORATORY CLASSIFICATION
POWER AUGER
PREFIX TO STRUCTURE BORING NUMBER
PREFIX TO CUT AND FILL BORING NUMBERS
RIG BORINGS
BORING LOGS
B-26-9
Sta. 616+64, 65' R
DESCRIBE EACH STRATUM ENCOUNTERED. SHOW SPOON AND CORE SAMPLE LOCATIONS, BLOWS ON SPOON AND PERCENT OF CORE RECOVERY
UNDISTURBED
SPOON
CORE
INDICATE TYPE AND CONDITION OF ROCK.
(Symbols for various types of samples should be shown in legend on soil profile sheets and other boring sheets)
NOTE - Only the boring nearest to ℄ at structure sites need be shown on profile. The above log is shown to illustrate information desired on structure boring sheets. (See letter)
LABORATORY ANALYSES
(See accompanying letter)
Boring Number
Station and offset
Sample No.
Depth
Textural classification
Structure
Organic content
Degree of cementation
Color
Layer thickness
Liquid Limit
Plastic Limit
Plasticity Index
Gravel - percent
Coarse sand - percent
Fine sand - percent
Silt - percent
Clay - percent
H.R.B. Classif. & Group Index
Maximum Lab. Dry Weight - lbs/ft³
Optimum moisture - %
In place density - lbs/ft³
Natural moisture content - %
Date obtained
NOTE: "Silty" applied to fine material having P.I. of 10 or less; "clayey" 11 or more.
GENERAL NOTES
(To be shown on Sheet 1 only)
- See accompanying letter. -
SPECIAL NOTE
A SOIL SURVEY SHOULD BE MADE AT ALL INTERCHANGE AND MAINTENANCE AREAS ALSO.
DATA SHOULD BE PRESENTED IN THE SAME MANNER AS SHOWN ON THIS SHEET.
GENERAL NOTES
See Sheet No.1 of Soil Profile
(Place on remaining Soil Profile Sheets)
No. - REVISION - BY - DATE
OHIO TURNPIKE COMMISSION
OHIO TURNPIKE PROJECT NO. 1
MASTER SOIL PROFILE
STA. 605+00 TO STA. 635+00
(Name)
CONTRACTING ENGINEER
DESIGN SECTION D-
DESIGNED: CHECKED: DATE:
DRAWN: IN CHARGE: SCALE:
CONTRACT NO. C- SHEET 1 OF

FIG. Nº 2

similar work on the New York State Throughway, the Garden State Parkway, the West Virginia Turnpike, and elsewhere; and the sheer volume of work to be accomplished.

A total of eleven contractors completed 22 contracts involving approximately 58,120 feet (11 miles) of earth borings and 8,812 feet (1.67 miles) of core borings in rock at a total cost of some $431,254. Borings required for supplemental studies after the main program was completed increased the total footage of earth borings to 60,405 (11.42 miles) and the overall cost to $441,785.

Average unit prices, which may be of interest, were as follows:

Earth Borings, $3\frac{1}{2}$" casing	$ 6.28 per foot
Earth Borings, $2\frac{1}{2}$" casing	5.94 per foot
Earth Borings, Mud Drilling Method	5.95 per foot
Core Borings, $2\frac{1}{4}$" Diam.	7.30 per foot
Undisturbed Samples, 3" nom. diam.	12.58 per each
"Shelby" Tube Samples, 3" nom. diam.	14.08 per each
Casing left in place	2.50 per foot

In order to satisfy the somewhat varying practices and requirements of the individual Contracting Engineers (e.g., sampling techniques, size of undisturbed sample, etc.), the basic specifications were, in some cases, modified by Special Provisions. In other cases, to attract additional bidders, alternate bids were taken based on use of the so-called mud drilling method as well as standard practices.

It may be of interest to note in passing that arrangements have been made to eventually make all rock cores and soil samples remaining after testing available to the State Geologist and educational institutions for record and research purposes.

Applications of Soils and Geologic Information.

As indicated previously, it was the responsibility of each Contracting Engineer to prepare a detailed soil profile for his Construction Sections. This work was completed as early in the design phase as practicable so as to be of maximum use in furnishing subsurface data essential for selecting the most advantageous final profile grade line; for modifying standard embankment and cut slopes where unusual subsurface conditions exist; for design of necessary underdrainage; for developing design and construction procedures where the line crosses peat swamps; for determining areas and limits of unsuitable material excavation both in cuts and at embankment sites; and for resolving numerous other design problems related to geologic and soil conditions.

To fulfill these purposes, it was intended that the soil profile present in a reasonably detailed manner a complete record of logs of test borings and hand and power auger borings, field and laboratory soil test results (H.R.B. Classification, direct shear, unconfined compression, consolidation, in-place density, moisture-density relationships, etc.), all referenced to original ground line and profile grade line.

The variety in the methods used, and the number of Soils Engineers involved representing several schools of thought in this field resulted quite naturally in the employment of differing basic approaches to field laboratory, and drafting problems and procedures. However, reasonable uniformity of type and quantity of information presented on the profiles was achieved.

The completed profiles and boring data sheets were classified as Informational Drawings and were appended to each set of plans sold by the Commission to prospective bidders. In this manner, the large volume of soil and geologic data which had been developed for each Construction

Section was made available to bidders for their review and study.

It is contemplated that the soil profiles will continue to serve a very useful purpose. They will provide the Contracting Engineers and the Contractors with a basis for predicting the locations and types of soils and subgrade problems to be encountered, so that necessary design modifications and/or changes in construction procedure can be planned in advance. Kept up to date during the construction phase by the addition of data resulting from a continuing program of routine and special soil tests, they will eventually provide a valuable "as built" record of the soils, ground water, and other subsurface conditions encountered, as well as a record of localized or special remedial measures that were applied to solve construction problems caused by soil or subsurface conditions.

One further application bears mention. Arrangements have been made with the Commission by the State Geologist to procure a complete set of prints of the profiles because of their permanent geologic interest. If placed end to end, the individual profiles would represent a 241-mile long detailed soil profile extending completely across the width of Ohio.

Figure 2, although prepared for another project, presents the typical makeup and appearance of many of the soil profiles prepared for Ohio Turnpike Project No. 1.

III. THE CONSTRUCTION PHASE

(Author's Note)

The original oral presentation of this paper included a discussion of various specific or typical problems, directly related to geologic conditions, which were and are being encountered during construction. The discussion was illustrated with a considerable number of Kodachrome slides which depicted many details which cannot be conveyed in comparable fashion by the necessarily brief summaries given below. It will no doubt be appreciated that several of the more complex problems would require individual papers of some length for complete coverage.

Problems Associated with Coal Seams.

Figure 1 illustrates the areal extent of the Allegheny (Lower Productive Coal Measures of the early geologists) and Pottsville formations of the Pennsylvania System in northern Ohio. It had been recognized from the time of the original reconnaissance studies that direct and indirect damages to coal lands under and immediately adjacent to the Turnpike right-of-way in Mahoning County would be a consideration in determining the eventual cost of property acquisition in that area. Essentially, it might be said that the local geological environment was responsible for posing a specialized problem of property appraisal.

Fortunately, the coals in the area are not generally of sufficient thickness to economically warrant the use of deep mining methods, and, therefore, no major problems of surface support for roadway and structures (in contrast to portions of the Western Extension of the Pennsylvania Turnpike where underground mining operations created formidable problems) are involved. Current operations are limited to strip mining, primarily in the Middle Kittanning (Ohio No. 6) and Lower Kittanning (No. 5) Coals, which locally attain maximum thicknesses of some 48 inches and 39 inches, respectively. Some Brookville (No. 4) Coal is also being taken out. It is expected that future strip mining operations will, in general, follow a similar patter.

As a matter of interest, it is mentioned that until recent years, strip mining of the coals now being actively worked was basicly a marginal business. However, the increased demand by the nearby Youngstown market for these coals has materially changed the economic picture.

The Ohio Turnpike Commission acquires all necessary right-of-way in fee simple, which includes all mineral, mining and other subsurface rights. For the most part, acquisition is by negotiation with the owner, based on an elaborate and equitable system of appraisal by disinterested experts. Resort to acquisition by condemnation is made only in the small minority of cases where normal negotiations fail. In either event, where parcels of property known or claimed to be coal land were under consideration, it was deemed highly advisable to make appraisals of coal damages, if any, apart from and in addition to the usual appraisals of damages to surface lands, buildings, and improvements.

The tremendous task of appraisaing and negotiating the acquisition of all Turnpike right-of-way in the eastern half of the project was assigned to the firm of Rudolph, Carpenter, Dunlap and Free[(2)] as duly appointed Land Agents representing the Commission. Their complex operations were supervised and coordinated by the Commission's Chief of Right-of-Way Acquisition, Mr. C. W. Hartford, and the Consulting Engineer, Mr. A. C. Galbraith, an experienced Mining Consultant, and Mr. R. A. Helwig, a coal operator with many years of practical mining experience, were retained to assist the Land Agents in performing that phase of the appraisal work related to coal damages.

A review was made by the Mining Consultant and the writer of all coal and geological data which had been developed during reconnaissance studies. (and for convenience recorded on aerial photographs), and by test borings

(2) Later Carpenter, Lehman, Dunlap and Free, following the death of M. J. Rudolph.

previously made in connection with the preparation of Master Soil Profiles. This information served to identify and delineate those areas where further detailed field studies were considered necessary. These studies consisted largely of examinations of outcrops and exposures in abandoned and active strip mine openings, review of boring records made available by mining companies, and interviews with property owners and coal operators to determine local lease and operating practices and the like. To augment these data, some 40 prospect borings totalling approximately 2600 linear feet, and specifically located so as to permit determination of the areal extent, thickness, quality, and depth of each coal seam, were completed under the direction of the Mining Consultant. These borings established conclusively that, in certain areas of interest, pre-glacial erosion and/or subsequent glacial action had reduced the top-of-rock surface below the coal horizon, a condition which is frequently concealed by a mantle of till and later alluvial deposits of variable thickness. In other words, the geologic history and character of the area dictated the need for a considered amount of prospecting with borings as the only positive means of verifying the continuity and uniformity of coal seams known from other studies to occur at certain horizons.

After sufficient factual data had been collected, it became possible to reasonably estimate the monetary damages done to the coal lands by the right-of-way taking. Each parcel of property was, of course, considered individually. Nevertheless, certain broad criteria or premises were formulated as the basis for appraisal, and they can be outlined as follows:

(1) Generally, under current local economic conditions and assuming a reasonably large operation with reserve acreage available, it is profitable to strip as much as 2 feet of

overburden for each inch of merchantable coal in a seam, e.g., to mine a 24 inch seam, up to 48 feet of cover can be handled. (This admittedly "rule-of-thumb" but practical assumption was useful in defining the area beyond which no damages incurred, because of excessive depth of overburden).

(2) Areas of coal land are considered damaged if rendered

(a) Unavailable or inaccessible by the R/W taking;

(b) Uneconomical to work because of small residual area available;

or (c) impossible to work because of practical consideration, e.g., support of Turnpike R/W, disposal of spoil, necessary drainage ways, etc.

(3) As an average for the coals in the area, the recoverable quantity of merchantable coal in a seam is 125 tons per acre per inch of seam thickness.

(4) A fair estimate of royalty is equal to that payable under an existing lease for a given property, or to that currently being paid for comparable coal lands, with the additional consideration that coal land

(a) which is under lease and being actively mined is valued at 100% of the full royalty value.

(b) which is under lease but not being actively mined is valued at 80% of the full royalty value.

(c) which is undeveloped and not under lease is valued at 50% of the full royalty value.

Appraisals of coal damages, derived in this general manner, were used by the Land Agents, acting for the Commission in negotiating final settlement for each parcel of property. In the several cases where condemnation proceedings proved necessary, the boring records, coal maps and cross sections, and other factual data which had been compiled, as well as the availability of the Mining Consultant to serve as an expert witness, were all invaluable in aiding to properly present the Commission's case.

It can be conservatively stated that the application of what might be termed the geological engineering approach to the coal land appraisal problem resulted in financial benefits to the Commission as well as to property owners having valid claims. The Commission paid coal damages only on the basis of factual evidence. Claims by owners who contended, through honest misunderstanding, ignorance, or simply the hope of financial gain at the Commission's expense, that their property was underlain by coal, when in fact coal was either totally absent or present to a lesser degree, were either denied or reduced. By the same token, equitable reimbursement was made to owners of coal lands which suffered actual damages. No firm estimate of the savings to the Commission resulting from denial of invalid claims can be made, but, in the opinion of the Land Agents and other Commission representatives, they exceeded many times over the cost of the special studies. Additionally, as in intangible consideration, the Commission benefited in the field of public relations when it became apparent to property owners and the press that a conscientious effort was being made to settle valid claims in an obviously fair manner.

Water Supply Problems.

The initial program of construction of service plazas (restaurants and gasoline station services) on Ohio Turnpike Project No. 1 contemplates completion of eight pairs of such facilities located more or less equidistantly over the length of the project. It will be appreciated that numerous factors, in addition to water supply considerations, enter into the final choice of locations of these facilities. Included among the attributes of an ideal location are: (a) adequate sight distance in both directions; (b) flat grades; (c) good drainage and foundation(for service buildings) conditions; (d) suitable topography requiring minimum grading quantities; (e) attractive scenery, including wooded areas on the site, adaptable for development as picnic grounds; and (f) absence, for some 2000 feet in both directions, of structures, culverts or other construction features or conditions which would interfere with, or unreasonably increase the cost of, construction of deceleration and acceleration lanes.

Obviously, selection of sites was a matter of effecting the most advantageous compromise. Before each tentative location was accepted as fixed, suitable studies were completed to give assurance that an adequate water supply could be developed by one means or another. A preliminary survey indicated that municipal or village supplies could be negotiated for at two locations (where independent supplies would be difficult or costly to develop), leaving the remaining six as subjects for further detailed subsurface studies.

Many localities in northern Ohio crossed by the Turnpike are generally known to be poor in available ground water resources, and this condition has progressively deteriorated in recent years to the point of being of widespread serious concern. In some areas, even a reasonably good house or farm well, producing 3 to 5 gallons per minute, is difficult to locate. In other districts, wells of this capacity range are numerous, but larger supplies are not common. These facts are of interest when considering the estimated requirements of the service plazas, which range from 165 to 270 g.p.m. (after 10 years of operation), and are based on the following general considerations:

1. Average usage per car, derived from records of the Pennsylvania Turnpike
2. Anticipated volume of traffic as estimated by the original traffic engineering studies
3. Peak requirement is taken as 3 times average daily requirement during peak month

The Ohio Division of Water cooperated fully in these studies by compiling from their files and making available numerous well records and geological data relating to the area (generally on a township basis) surrounding each proposed site. For the purpose of this paper, a summary of the procedures followed and results achieved for one typical site, SP-1 in Springfield Township, Mahoning County (Contract Section C-1, Design Section D-1) may be of interest.

Surface strata at the site, under thin cover of till, are the Freeport members (mainly shales and thin-bedded shaly sandstones, the latter sometimes water-bearing) of the Allegheny formation. They are underlain by the remaining members (shales, sandstones, limestones, coals, etc.) of the Allegheny, including the Clarion sandstone which is frequently an aquifer. Aquifers in the Pottsville formation below usually include the Homewood and Massillon (or Connoquenessing) sandstones.

Records of local wells in the Freeport, Clarion and Massillon sandstones show yields of from 10 to 30 g.p.m. and 50 g.p.m. is considered a possible maximum. Yields from the Massillon generally range from 5 to 30 g.p.m.

Test Well No. 1 (an 8-inch diameter rock well) was started within the then-available right of way at the proposed site (Surf. Elev. 1247.4), and taken down through the upper sandstone aquifers. Water was encountered but not in large quantity, and it was decided to continue the well down to the Massillon to determine its local water-bearing characteristics. This member was penetrated from Elev. 891 to 882, and the well was discontinued at a total depth of 373 feet (Elev. 874.4). Controlled constant-rate and stepped-rate pumping tests, under the immediate supervision of Mr. Edward J. Schaefer, Consulting Hydrologist, were performed on the well. Analysis of the resulting data indicated that (a) yield of the well under sustained pumping can conservatively be estimated at 17 g.p.m.; (b) most of the total yield is from the upper portion of the well (the Massillon at this location proves to be both thin and an indifferent aquifer); and (c) there is little prospect of developing the total desired capacity of 200 g.p.m. by any reasonably efficient system of wells located within the proposed site (an area approximately 1200 feet square).

To determine whether ground water conditions in the upper sandstones as indicated by Well No. 1 were typical, Test Well No. 2 was put down some 1200 feet to the west to a depth of 107 feet (which corresponded, at the new location, to an elevation somewhat below that of the main acquifer in Well No. 1). Rough bailing tests indicated a yield of not more than 6 g.p.m. Therefore, no pumping test was run, and the well was abandoned.

These developments indicated the necessity for a re-evaluation of the factors involving the final choice of location of the service plaza. Alternate locations were considered in detail, and were rejected as being undesirable or because of excessively costly grading requirements. It was finally decided that the most advantageous and economical procedure would be to accept the original site as final, develop an adequate water supply elsewhere, and bring it to the site by pipeline.

In the course of further investigations, the writer conferred with

Messrs. Edward J. Schaefer and J. W. Cummins, Geologist, Ohio Division of Water. The latter, a specialist on the geology and water resources of Mahoning County, suggested that exploratory drilling in the Yellow Creek and/or Mill Creek Valley areas, both known to at least partially overlie buried pre-glacial valleys, might locate water-bearing gravels. Available geological maps (3) particularly a bedrock contour map, suggest the extension of the Yellow Creek bedrock valley some unknown distance south of the point where it is crossed by the Turnpike. However, the contours shown in this vicinity are based on rather scattered data from wells located along the valley flanks, and are necessarily sketched approximately.

Additional indications of the presence, general cross-sectional shape, and location of the bedrock valley were gleaned from a study of test boring logs recorded on the Master Soil Profile. Several borings, previously made to determine foundation conditions for design of the stream crossing structure, showed strata of very silty and/or cemented sand, gravel and boulders overlying bedrock, the latter at a depth of some 75 feet and one boring recorded a near-surface static water level. These data, combined with those derived from the maps, were considered sufficiently promising to warrant a joint recommendation by Messrs. Schaefer and Cummins, and the writer, that one or more test wells be drilled in the area. Subsequently, a site some 500 feet east of the stream crossing was selected by the writer in the hope of more nearly locating the thread of the pre-glacial watercourse.

(3) Advance prints of maps showing bedrock strata, bedrock contours, and alluvial and glacial deposits of Mahoning County, to accompany report entitled "Water Resources of MahoningCounty, Ohio", by J. W. Cummins, in preparation for publication by State of Ohio Department of Natural Resources, Division of Water, in cooperation with U.S. Geological Survey.

An 8-inch diameter gravel well was drilled to a depth of 100 feet (14 feet into shale, limestone and coal blossom was later gravel-packed), and following an 8-day period of careful development with surge block, pumping tests were performed. Extracts of interest from E. J. Schaefer's report on the analysis of these tests are given as follows:

"Careful analysis of the drawdown curve . . . . has convinced the writer that the permeable gravels encountered in the test drilling are deposited in a channel cut in glacial materials (sand, gravel, silt and clay) of lesser permeability. The computations indicate that this channel is only a little more than 100 feet wide at the test site". * * * * "The analysis and computations in the report show that the 8 inch test well drilled in the valley of Yellow Creek is capable of yielding 175 g.p.m. under continuous pumping".

Provision has been made in the final design for drilling an additional well near Yellow Creek (primarily as stand-by), installation of a 14,000-foot pipeline to the service plaza, and utilization of the 17 g.p.m. capacity of Well No. 1. Thus, there is every possible assurance that the 200 g.p.m. estimated requirement will be amply met.

The Lake Maumee "Flatlands"

Fig. 1 illustrates the generalized location of the former shoreline associated with the maximum extent of glacial Lake Maumee, the ancestor from which present Lake Erie is descended through a series of subsequent lake stages of lower elevation and lesser area. Approximately half of the project length is located within the confines of the old lake bottom.

The soils are primarily derived from lacustrine silts and clays, reworked glacial tills, and comparatively minor areas of sandy and gravelly beach ridge, dune, and near-shore deposits. The topography, although moderately to gently rolling in some sections, is characteristically a rather monotonously level plain - the so-called "flatlands" of northern Ohio. Data presented on Fig. 1 also indicate that both the engineering soil classifications and the agricultural soil series designations quite distinctly reflect the influences of the parent materials and topography.

Influences on Design

The unusually flat terrain of the lakebed plain markedly influenced certain features of Turnpike Design. For example, "Turnpike under" grade separation structures usually prove to be the most economical design. A majority of the state, county and township road crossings, therefore, are characterized by approach embankments to structures over the Turnpike. Generally speaking, main line Turnpike grades are such that light to moderate fills predominate and the infrequent cuts are usually shallow. The obvious net result of these conditions is that earthwork construction is primarily predicated on borrow operations.

The poorly drained lakebed silt and clay soils, in their virgin condition, were "cold" and "heavy", and of little value for agricultural purposes. Originally, this was the region of the dreaded "Great Black Swamp", which was the locale of many events of importance in the early history and legend of Ohio. In more recent years, the practical benefits of surface and underdrainage have become widely recognized, and today most of the now-productive and valuable cultivated land is underlain by extensive farm tile systems which discharge to small streams and a network of drainage ditches constructed and maintained by the several counties. Consequently, farmers are particularly drainage conscious; and demonstration to their satisfaction that the Turnpike design criteria provide for adequate drainage was an essential factor in successfully negotiating for right of way. Construction Plans typically make meticulous provisions for properly collecting and carrying off drainage from intercepted tile lines; for adequate capacity of drainage ditches and culverts based on conservative assumptions and criteria; and for a minimum degree of disturbance to existing and future ditch and stream drainage.

Influences on Construction

One of the objectives of the earthwork specifications (E-1 Roadway Excavation) is to ensure that no excessively frost-heaving soils will be present in the top foot of subgrade. To this end, the specifications state (based on the experience of the Ohio Department of Highways) in part, "Soils having maximum dry weights of less than one hundred and three (103) pounds per cubic foot, and having plasticity index of ten (10) or less and containing fifty (50) percent or more silt (0.074-0.005 mm) shall not be used in the top twelve (12) inches of embankment." The requirement for cut sections is substantially the same.

Although this specification requirement has proven valuable and workable without undue hardship to the contractors, well-coordinated programs of sampling and testing of the available borrow materials and selective operation of the borrow pits have been essential in some sections.

Certain other aspects of borrow operations in the area are typical. The relatively high water table prevailing during the heavy rainfall months dictates that borrow pits be comparatively shallow and of large areal extent. As a result, much consideration was devoted to formulating practical but effective restrictions and requirements relating to the location, operation, and final dressing-up of borrow pits to prevent the creation of health and safety hazards, as well as ugly scars on the landscape. In many instances, the pits will be transformed into ponds and lakes which will be of value to farm owners, as water and wild life conservation measures, and as attractive additions to the scenery.

An important additional effect of the soil, topographic, and natural drainage conditions is that winter and wet-weather earth moving operations are usually either severely curtailed or completely impracticable. The Constractors' operations schedules are, therefore, of necessity somewhat flexible, and are geared to the urgency of "making embankment while the sun shines." By contrast, some of the construction sections in the eastern portion of the project contain substantial quantities of rock and granular material excavation which permit work, on a reduced scale, to continue during periods of unfavorable weather.

Substructure for Bridges

A considerable number of changes and modifications to bridge foundations have proven necessary during construction. In many instances, they fall into the routine or "to be expected" category common to any large construction project involving foundation work. In other cases, they are directly related to extremely variable subsurface conditions which are quite characteristic of glaciated country and frequently difficult or impossible to completely detect and appraise by the use of conventional test boring procedures.

One specific foundation problem is mentioned here briefly primarily because it is so typically representative of a general type of problem often associated with the end products of glaciation. The piers of the twin bridges carrying the Turnpike over the Sandusky River were originally designed to be supported by spread footings founded on compact alluvial sandy silts, and silty sands and gravels at elevations varying from some 5 to 20 feet above the limestone and dolomite bedrock. The design further contemplated that the river pier footings and shafts would be formed and poured "in the dry" following excavation and de-watering within steel sheet pile cofferdams.

At several river pier locations driving of sheet piling encountered severe difficulties. It was soon apparent that float boulders (glacial outwash) randomly distributed in the subsurface below the stream bed were the cause of uneven penetration and premature refusal. Hard driving, or overdriving beyond normal refusal, resulted in split sheets, curled tips, and damaged interlocks. Every effort was made to remove boulders as the excavation was carried down to closely follow advance of the sheeting. This effort was, at times, successful; in other cases, the sheeting had already been irreparably damaged, or the boulders (up to room size) were too large to be extracted or broken.

The Contractor resorted to every ingenious expedient "in the book" to cope with these problems. For example, at Pier 4-S, double rows of piling packed with clay grout, and additional pile "blisters" around large boulders or weak points, were placed. Some four months were devoted to repeated efforts to dewater the cofferdam long enough to permit footing construction. In every case, local imperfections in the seal achieved by the sheeting created "boils" which caused the originally firm bottom materials to degenerate into an unacceptably unstable condition. At the Pier 5-N cofferdam, a total of eight attempts to dewater proved unsuccessful.

In the face of these difficulties, the Contractor was finally obliged to request permission to use underwater tremie concrete seals at three of the six river piers, and they were successfully completed. It is of interest to note that the Contracting Engineer had made a detailed study of the test boring data (which showed occasional boulders) and had recognized the possibility that "in the dry" construction as shown on the plans might not be feasible for all piers. The Special Provisions, therefore, were prepared to allow the use of, and payment for, tremie seals if proven necessary.

The increased cost to the Commission resulting from unfavorable foundation conditions is some $35,000, not an unduly large amount. An evaluation of direct and indirect costs to the Contractor by reason of expensive cofferdam construction, delays, and disruptions of his construction schedule, is obviously not appropriate here.

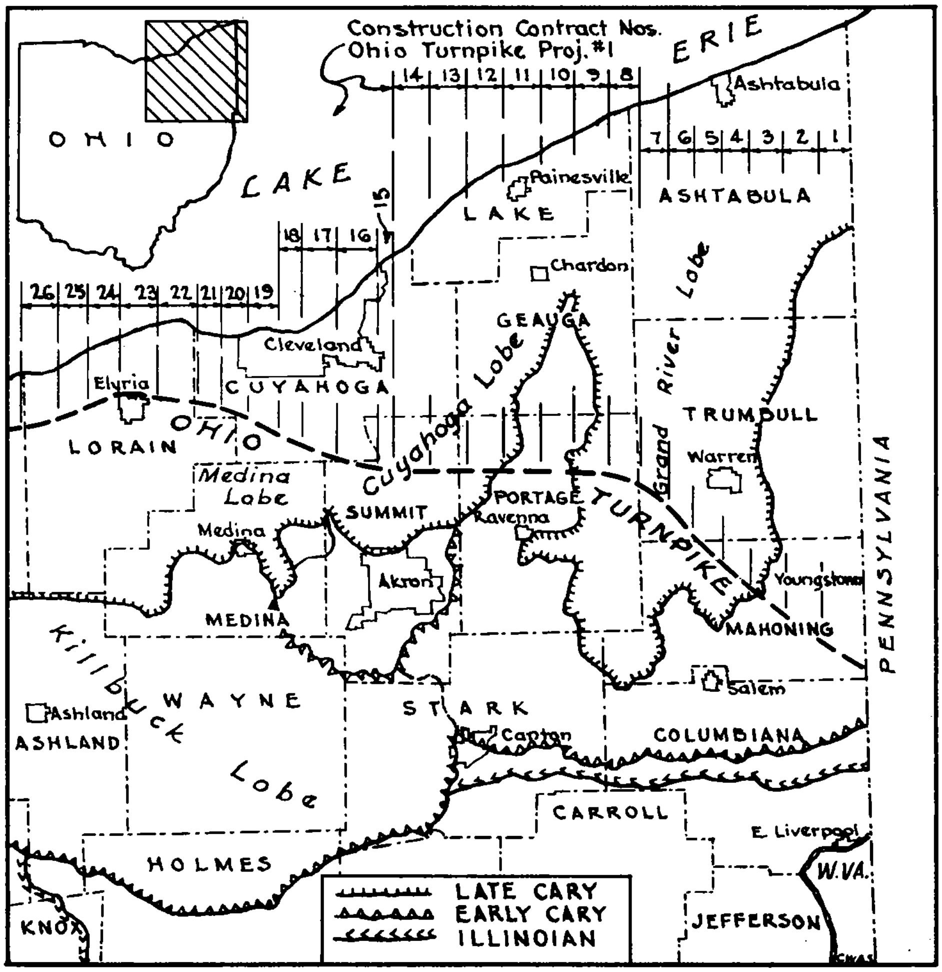
Glacial Till

A general class of materials encountered in quantity at various localities in the eastern sections of the project, (particularly in Design Sections D-1 and D-6) has come to be referred to by engineers and contractors alike, with something less than affection, as the "Blue Till". Fig. 3 shows the route of the Turnpike in relation to the till sheet boundaries in northeastern Ohio, and further illustrates that the materials in question are the tills of early Cary and (mainly) late Cary Ages.

For the most part, problems associated with these tills have been encountered in cuts of sufficient depth (usually over 8 to 10 feet) to penetrate into the relatively unweathered bluish-gray silty clay and clayey silt parent materials; and in embankment construction involving the use of these materials. Individual problems have ranged widely in scope and importance, and numerous variable factors (e.g. completion schedule of the construction contract involved) have required consideration in effecting satisfactory solutions. Therefore, only a generalized summary of the types of problems involved, and the remedial measures applied, can be attempted here.

Subgrade Problems in Cuts

Although average test data tabulated below indicate a silt content in the tills of less than 50%, a few local areas have been encountered where



Location of Ohio Turnpike in Relation to Tills of Northeastern Ohio

[Adapted from Fig. 1, "Correlation of the Tills of Northeastern Ohio by Size Analysis", by V. C. Shepps, Jour. Sed. Pet., Vol. 23, No. 1, p. 35, Mar. 1953. Till sheet boundaries by G. W. White]

FIG. No. 3

percent silt exceeds 50% (and P.I. is 10 or less), and removal and replacement has been necessary to satisfy all specification requirements for top foot of subgrade. Little, if any, difficulty has been experienced in achieving the minimum specified density of 103+ pounds per cubic foot (for top foot).

In most instances, the necessity for removal and replacement of these materials has been predicated on certain peculiar performance characteristics rather than on failure to meet the letter of specification requirements. As indicated by the grain size analyses, the silt-sized fraction generally exceeds the clay sizes. In a natural, undisturbed condition, the tills are typically firm and compact (and possibly pre-consolidated by past glacial action). However, in common with many silts, they are particularly prone to become unstable when subjected to vibration, shearing stresses, remolding and further compaction. Numerous cases have been experienced where the originally firm subgrade has shown a distinct tendency to become "rubbery" and "quaky" under a few passes of concentrated wheel loads, followed by rapid deterioration under additional construction traffic into a "quick" and virtually impassable condition. Unfortunately, this "bad" behavior, which is obviously related to structure, grain size, moisture content, and compaction characteristics, is encouraged by the heavy earth-moving equipment commonly used today. When loaded, these monsters impose wheel loads on the subgrade which very probably will never subsequently be equalled in magnitude by any normal usage of the finished pavement.

Treatment of the aforementioned conditions has varied in scope and degree according to individual circumstances. Time is an essential consideration - where it has been available, drainage measures such as early excavation of side ditches, installation of underdrains, proper shaping of the grade, etc., have proven beneficial. In at least one case, it was feasible to modify the grade line to raise it above the "blue till". At several other locations, discing and harrowing the top foot or so of subgrade to facilitate drying, followed by recompaction, has been effective. Where the completion schedule has required early paving operations, more direct and costly measures of removal (usually ranging from 1 to 3 feet in depth) of the offending unstable materials and replacement with stable granular materials (sand and gravel, granulated slag, random-sized sandstone, etc.) were employed, both with and without accompanying installation of underdrains.

Regarding underdrain installations, it should be mentioned that the locally variable texture of the tills in some areas has been considered to be a mixed blessing. Some areas of unstable subgrade were directly ascribed to the presence in the till body of irregular lenses, seams, and stringers of fine sands and silty gravels which act as reservoirs and feeders to maintain the adjacent material in a wet condition. Conversely, the random occurence of zones of some permeability has undoubtedly, in some cases, contributed largely to the effectiveness of underdrains in stabilizing otherwise rather impermeable till.

"Blue Till" in Embankment Construction

The problems which have been experienced in using till materials for embankment construction are closely allied to those previously discussed and the considerations involved in their solution have been much the same. It was noted early in construction operations that a large proportion of these materials could be compacted to specified densities at allowable moisture contents (up to optimum plus 2 percentage points, Standard T-99 Proctor) and still exhibit the afore-described unacceptable instability under wheeled construction equipment. It was also determined that if compaction is performed at moisture contents in the range of optimum plus zero or less, these undesirable characteristics are usually absent or negligible.

Time, weather, and available fill area permitting, it has proven feasible (in wet borrow sections) to spread the material on the grade; to blade, disc, and harrow it to achieve the desired moisture content; and to compact it without undue difficulty to a satisfactorily stable condition. Payment has been made to the Contractors for any extra work performed (e.g. additional drying effort) beyond the requirements of the specifications; nevertheless, these costs are considerably less than those imposed by the alternative of waste and borrow. In several instances, layered fill construction, consisting of lifts of broken shale, sandstone, or other available material placed between several lifts of till has proven helpful. Where time and limiting physical conditions have not been favorable for employment of these procedures, a program of controlled waste and borrow based on the use of as much till material as practicable, has perforce been followed.

Experience on this project has proven that under reasonably optimum conditions and with proper care, the till materials can be utilized to build perfectly satisfactory embankments; but also, that under other less favorable conditions, such use may be difficult or impracticable. It is considered important that engineers and contractors assocated with major earthmoving projects which involve these materials be fully aware of their presence and characteristics.

Test Data

Further compilation and evaluation of test data is necessary before any firm correlations between the physical composition of the tills and their characteristics as construction materials can be derived. Additional correlations, if feasible, between test data, performance, and age of the tills (see reference given on Fig. 3) may have interesting practical applications on future projects. A few preliminary data, developed and made available by the respective Contracting Engineers [(4)], are given below:

Design Section	Liquid Limit	Plastic Limit	Plast. Index	% Silt (0.074-0.005)	% Clay (-0.005 mm)	% F.M.C.*	** Opt. M.C.	** Max. Density p.c.f.
D-1: Avg.	19.3	13.5	5.8	37	17	11.9	10.9	125
Range	17-20	12-15		34-39	14-21	Max. 13	9.5-11.8	122-128
D-6 C-16: Avg.	25	17	8	45	32	15	12.5	122
Range	22-31		3.8-11.6	39-46	29-41	13.5-18.2	11.7-13.6	119-123
C-18: Avg.	26.9	17.8	9.1	40	27			
Range	22.6-31.1	16.5-20.2	6.0-11.6	35-48	16-38			

* - Field Moisture Content (Spring 1954)

** - Optimum Moisture Content and Maximum Laboratory Dry Density (Standard Proctor T-99)

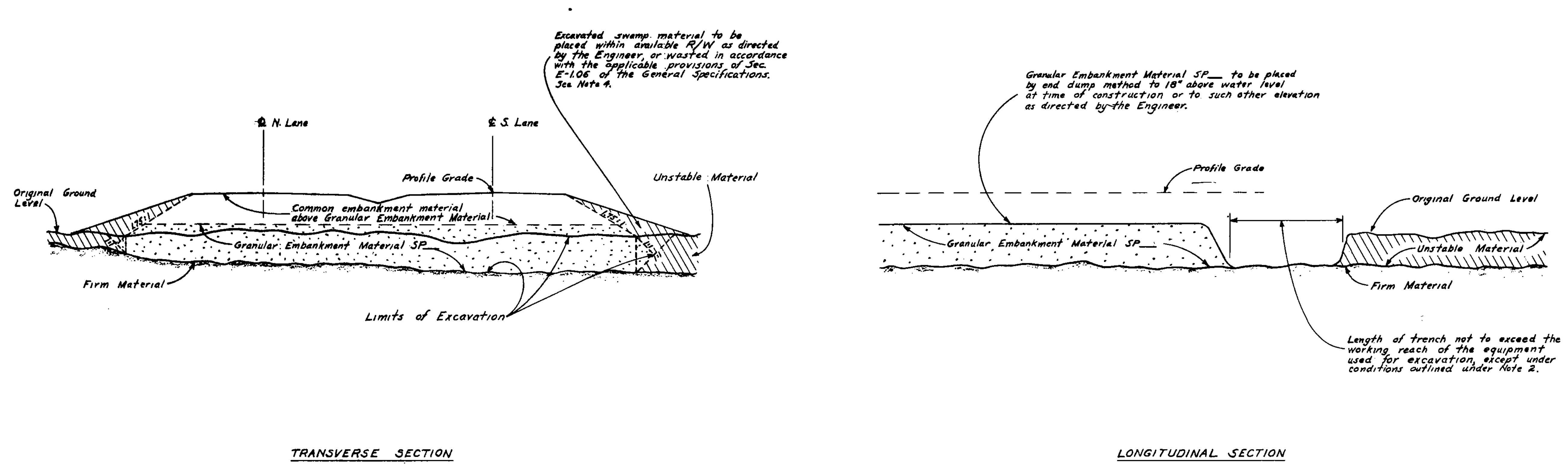
(4) - See Appendix.

Peat Swamps - General.

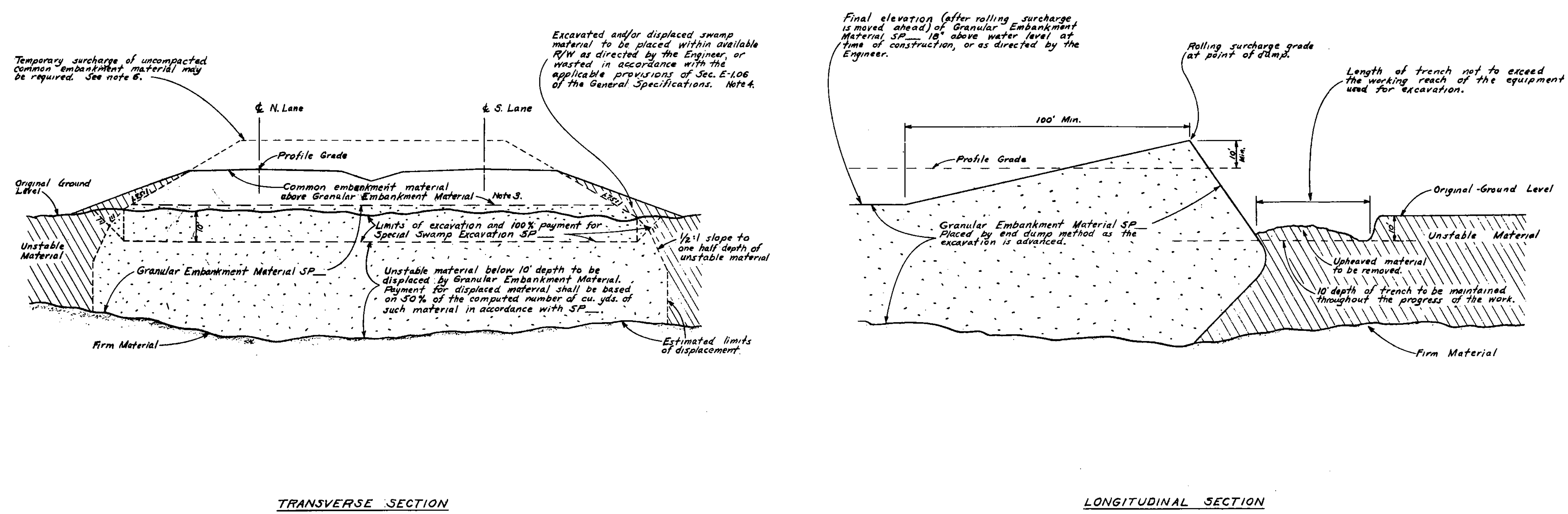
It was evident even during the earliest preliminary air photo and field studies of the tentative alignment that the prevalence of peat swamps in some portions of the route would create a certain class of design and construction problems. In some cases, initial alignment adjustments, based entirely on office studies of the air photos, were made. Additional changes to avoid swamps, where practicable, were effected as the reconnaissance studies progressed. Detailed investigations completed later, in connection with the preparation of Master Soil Profiles, delineated the areal extent and depth of previously identified swamp areas and also located several areas of "buried" swamps (i.e., concealed by later till or alluvial deposits) which had escaped prior detection.

Early consideration was given to the selection of the method or methods (including vertical sand drains and the several variations of the method involving displacement of unstable materials by use of explosives) deemed most applicable to the conditions at hand. The so-called "Michigan Method" was chosen because of its relative simplicity and economy. Additional strong consideration was given to the long history of successful application to comparable swamp conditions by the Michigan State Highway Department, largely due to the pioneering efforts of Mr. O. L. Stokstad and his associates.

The method(s) essentially involves either systematic complete excavation of unstable materials, and backfill (Method No. 1); or a combination of partial excavation and displacement, and backfill (Method No. 2). "Rolling" and uniform surcharges are used to advantage as required, and, for some deeper swamps, the treatment is culminated by jetting a granular fill and surcharge to saturation to complete the process of embankment consolidation and stabilization. Figure 4 pictorially presents the elements of the



METHOD NO. 1
(TOTAL EXCAVATION)



METHOD NO. 2
(PARTIAL EXCAVATION AND DISPLACEMENT)

FIG. Nº 4

NOTES

1. Excavation and backfilling shall be carr progressively across the swamp and so c ordinated as to leave an open trench no to exceed in length, at any one time, t working reach of the equipment used for excavation, unless written permission to an alternate procedure is granted by th Engineer.

2. Upon approval of the Engineer, the excav and backfilling may be carried on as separ operations where excavation of swamp materials results in a dry trench.

3. All embankment materials placed abov water (except surcharges) shall be compact in accordance with the applicable provision of Section E-1.08 of the General Specificatio

4. Surplus waste swamp material in excess that used to flatten slopes as directed the Engineer shall be disposed of in acc ance with Section E-1.06 of the General S ifications. Shaping of the slopes in th swamp area and disposal of waste swam materials shall be accomplished prior to paving operations.

5. The Contractor shall at all times mainta suitable drainage by ditches, temporary cu or other methods satisfactory to the E ineer during all operations of excavati and backfilling. This work will be conside incidental to the work of Special Swam Excavation.

6. A temporary surcharge of uncompacted common embankment material may be re quired after completion of the embankme to profile grade. The surcharge, where quired, shall be placed to limits and eleva as directed by the Engineer. The surcha shall be left in place for 90 days unless prior removal is authorized by the Engine Payment for placing and removal of this t of surcharge will be separate as provided SP__ Special Swamp Excavation.

GENERAL NOTES:

1. This is a preliminary typical drawing by the Consulting Engineer, J Greiner Co., for use by the Contract Engineers for reference in prepar Contract drawings.

2. Methods and sketches adapted Appendix B, "Field Manual of Soil E ineering", Third Edition, August 19 published by the Michigan State H way Department.

No.	Revision	By

OHIO TURNPIKE COMMISSION

OHIO TURNPIKE PROJECT

SPECIAL SWAMP EXCAVATIO

SP__

CONTRACTING ENGINEER
DESIGN SECTION D-__

DESIGNED ____ | CHECKED ____ | DATE 7-19-5
DRAWN EAL ____ | IN CHARGE EWAS | SCALE 1"=20'

CONTRACT No. C-__ SHEET __ OF

method(s) and further describes details of procedure. This drawing was originally prepared to assist the several Contracting Engineers confronted with peat swamp problems in satisfactorily making provisions for this type of construction in the Plans and Specifications. Such provisions have generally included (a) definition of limits of swamp areas on the Plans; (b) preparation of typical drawings similar to Fig. 4 for inclusion with the Plans, to indicate acceptable construction procedures (and for the information of bidders not familiar with the method(s); (c) preparation of estimates of pertinent quantities of excavation, granular backfill, etc.; and (d) preparation of appropriate Special Provisions (the notation SP -- of Fig. 4) for incorporation with the General Specifications. By these means, every Construction Contract involving appreciable quantities of embankment construction through peat swamps has anticipated this condition; contract unit prices and quantities are applicable, and the usually costly and time-consuming necessity for handling "unforeseen" (i.e., not covered by the contract) subsurface problems by Extra Work Order procedures has been avoided.

It should be mentioned that each peat swamp has been considered as an individual problem. Through the medium of Special Provisions, every effort has been made to "tailor" the basic method(s) to the specific condition. Typical variations involve factors such as type of backfill material; type and height of surcharge; and provisions for installation of settlement guages, for check borings, jetting procedures, disposal of peat and spoil materials, etc.

It has always been a matter of interest to the writer that the "Michigan Method" is basically empirical. Generally, no complex computational or laboratory testing procedures are involved. Successful application (particularly of Method No. 2) depends primarily on mature judgment and experience as well as a working knowledge of what might be termed the "anatomy" of peat swamps, i.e., the normal depositional sequence, distribution, and properties of the several types of materials typically present (fibrous peat, shell marls, marly clays, organic clays or "sedimentary peat", etc.). Careful regulation of depth and rate of excavation, and rate of embankment construction, so as to maintain optimum conditions, are essential for the achievement of complete displacement of unstable materials in deep swamps.

A question may arise regarding the necessity and advisability of deliberately fixing final alignment through known areas of peat bogs. The answer must be that exacting line and grade criteria, combined with other and frequently dominant considerations, may dictate that the Turnpike must be successfully constructed through areas of less than favorable subsurface conditions.

Example - Application of Method No. 1.

Peat Swamp, Sta. 212-217 Portage County
Construction Contract C-12
Design Section D-4

Contracting Engineer - Howard, Needles, Tammen & Bergendoff

Contractor - R. B. Potashnick Company

This location has been selected as a rather typical example of primary application of Method No. 1, with additional limited use of Method No. 2. The peat swamp is representative of a considerable number of such swamps, large and small, which are common features of a belt of "kame and kettle" topography associated with the interlobate moraine system which extends through the Portage - Summit County area (see Fig. 3).

At the time of construction (Nov. - Dec. 1953), the existing water table, due to an unusually dry preceding summer and fall, was considerably lower than anticipated. It was feasible, therefore, to perform direct excavation to a depth of some 15 feet (Method No. 1). Method No. 2 procedures were correspondingly curtailed and were limited to a relatively minor area where firm bottom shelves off to the south to a depth of some 20 feet. The usual 10 foot "rolling" surcharge and an additional 10 foot uniform surcharge (common embankment material), were employed throughout.

This swamp is also an interesting illustration of certain very useful aspects of the geologic environment. Here the source of granular material was a sand-and-gravel kame deposit present in a cut a mere several hundred yards to the east. The Contractor benefitted financially by receiving payment both for roadway excavation and granular embankment material for moving each yard of such material. Additional advantage was taken of the ideal haul situation by setting up what can best be described as a "text-book" earthmoving operation. A group of scrapers, moving uniformly in a circling traffic pattern, moved a steady supply of granular material from the cut to the backfill and rolling surcharge area. As each load was dumped, a battery of 6 to 8 bulldozers, moved forward in unison, bladed the material over the face of the surcharge, and retreated in barely sufficient time to permit the next load to be dumped in front of them. This efficient operation, conducted with almost split-second precision, permitted completion of the bulk of the swamp treatment work in about ten days.

Preliminary quantity and cost data pertaining to this swamp are given below.

Contract Item	Estimated Quantity	Contract Unit Price	Cost
Special Swamp Excav.	36,000 cu. yd.	$ 1.00	$ 36,000
Granular Embankment Material	48,700 cu. yd.	2.50	121,750
Check Borings	900 lin. ft.	4.00	3,600

Illustrations

Kod. 1 (Dec. 2, 1953) - General view of swamp, facing east, during progress of complete excavation and backfill.

Kod. 2 (Dec. 2, 1953) - Engineer standing on firm bottom (pebbly, "blue" silt-clay). Note sharp contact with overlying very soft and plastic marly "blue" clay (removed by excavation), which is in turn overlain by fibrous and disseminated peat.

Kod. 3 (Dec. 2, 1953) - Close-up of backfill operation. Battery of dozers in foreground, source of material from cut in background.

Example - Application of Method No. 2.

Peat Swamp, Sta. 833 - 838, Williams County, Construction Contract C-59 Design Section D-20

Contracting Engineer - Conseer-Townsend and Associates

Prime Contractor - V. N. Holderman & Sons, Inc.

Sub-Contractor - Ruby Construction Company, Inc. (Earthwork and Drainage)

This swamp may be considered somewhat non-typical and of particular interest for identical reasons. First, it is the deepest swamp that has been encountered on the project. Secondly, it is the only one to which application of the jetting procedure was deemed necessary.

In this case, the swamp is not closely associated with typical "kame and kettle" topography. It seems more likely that it originated from a relatively isolated deep kettle formed by gradual melting of a large mass of glacial ice stranded in the till sheet. Figures 5 and 6 portray the structure of the deposit in plan and profile as developed by the preliminary subsurface investigations.

It will be noted that the original swamp surface is overlain by a veneer of later alluvial deposits. Before construction started, the area presented the innocent surficial appearance of a slightly marshy pasture.

Even now, stereoscopic study of the air photo (with outline of swamp sketched) does not adequately suggest the nature of the subsurface condition. It was not until detailed field studies were made for preparation of the Master Soil Profile that the actual condition was discovered and explored. All of which well illustrates that whereas air-photo interpretation techniques are invaluable tools, they are neither universal nor infallible; and that they must be supplemented, for final design purposes, by adequate field investigations.

During the design stage, an analysis of the feasibility of modifying the alignment to avoid the swamp indicated that this alternative was not economically warranted because of offsetting damages such a change would cause elsewhere. Next, comparative cost estimates were prepared for trestle vs. embankment construction. This study was based on conservative estimated unit prices for swamp treatment, and firmer estimated costs for twin structures (unusually high because of length of piles required). It indicated that embankment construction (by Method No. 2 procedures, with additional provision for jetting operations), if deemed practicable, would result in a saving of not less than several hundred thousand dollars (later substantiated by contract unit prices). It was also concluded, with the valuable assistance of Mr. O. L. Stokstad, Consulting Soils Engineer for the Contracting Engineer, that this type of construction would be technically feasible despite the exceptional depth of the swamp. Practical considerations dictated, however, that investigations be made regarding the potential availability of two items of critical importance - suitable granular material in sufficient quantity for embankment and surcharge construction, and a plentiful and convenient water supply for jetting operations. Although these preliminary studies were not entirely definitive, the results were believed to be sufficiently promising to

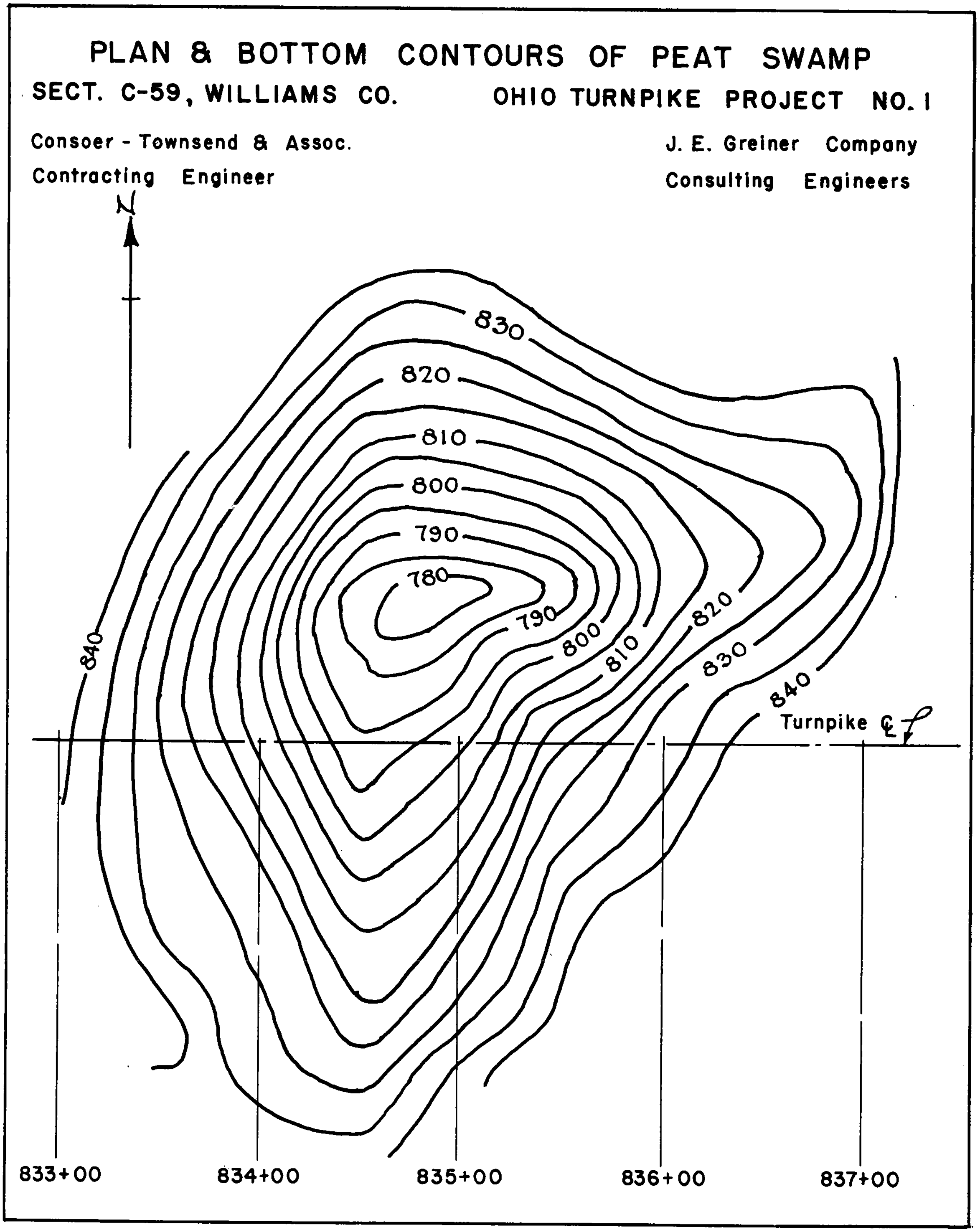

PLAN & BOTTOM CONTOURS OF PEAT SWAMP
SECT. C-59, WILLIAMS CO.
OHIO TURNPIKE PROJECT NO. 1
Consoer - Townsend & Assoc.
Contracting Engineer
J. E. Greiner Company
Consulting Engineers
N
830
820
810
800
790
780
790
800
810
820
830
840
840
Turnpike ℄
833+00
834+00
835+00
836+00
837+00

FIG. NO. 5

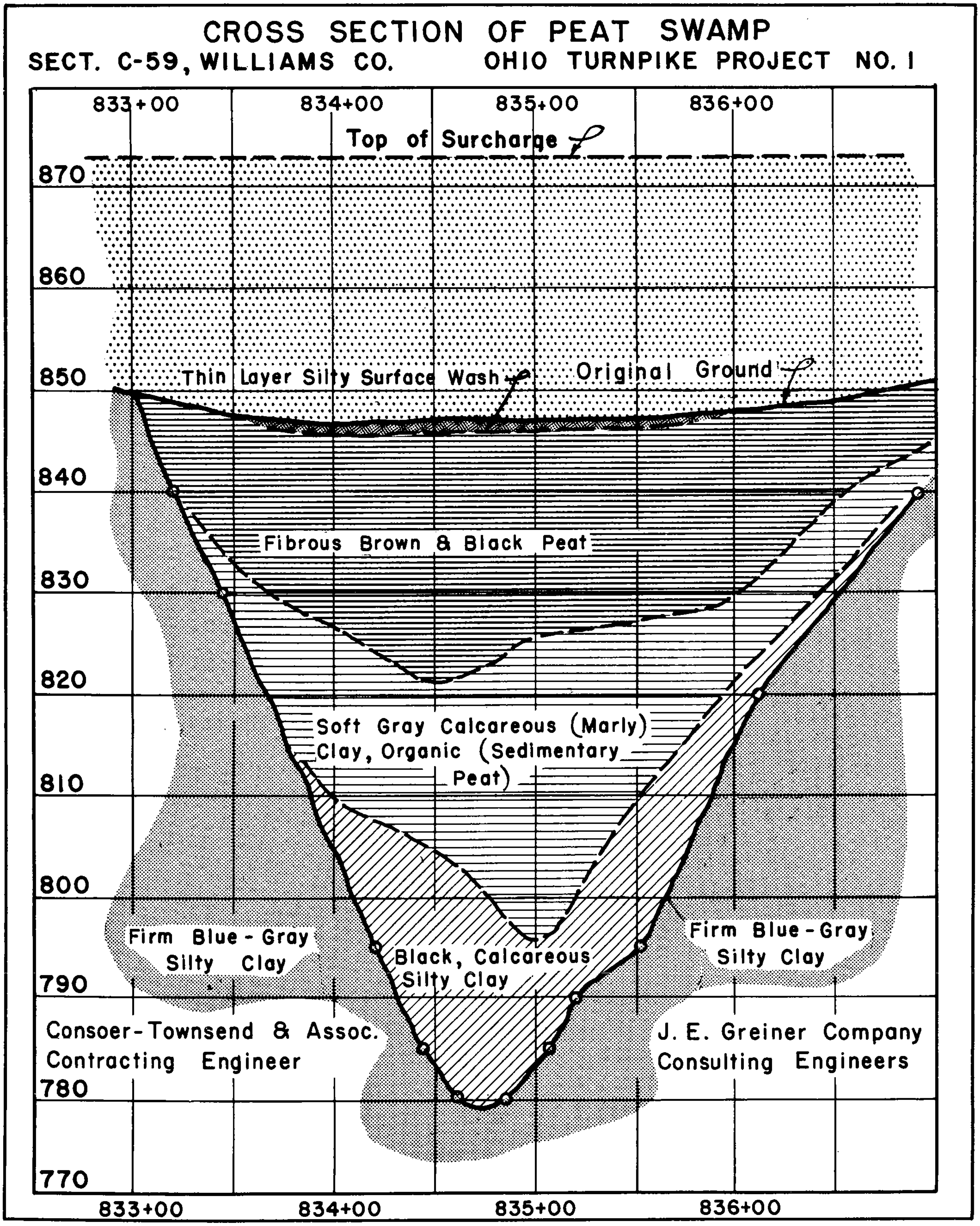

CROSS SECTION OF PEAT SWAMP
SECT. C-59, WILLIAMS CO.
OHIO TURNPIKE PROJECT NO. 1
833+00
834+00
835+00
836+00
Top of Surcharge
870
860
850
840
830
820
810
800
790
780
770
Thin Layer Silty Surface Wash
Original Ground
Fibrous Brown & Black Peat
Soft Gray Calcareous (Marly) Clay, Organic (Sedimentary Peat)
Firm Blue-Gray Silty Clay
Black, Calcareous Silty Clay
Firm Blue-Gray Silty Clay
Consoer-Townsend & Assoc.
Contracting Engineer
J. E. Greiner Company
Consulting Engineers

FIG. NO. 6

justify the assumption of a calculated risk that sources of these items could be developed. Accordingly, the final decision was made to employ embankment construction, and the Plans and Specifications were prepared on that basis.

Work on this swamp started in October, 1953, and progressed at a slow but steady rate to substantial completion in June, 1954. A source of excellent sand (apparently a river terrace or modified glacial outwash deposit) was successfully located near Beaver Creek, a tributary of the Tiffin River. The length of haul (6 to 7 miles), and restrictions imposed on trucking operations over county roads, were controlling factors in determining the rate of embankment construction. However, the leisurely pace of the operation was considered advantageous rather than otherwise, insofar as it decreased the possibility of trapping masses of unstable materials within or beneath the body of the fill.

Final profile grade at this location is a maximum of some 15 feet above the original swamp surface. The normal embankment, a 10-foot "rolling" surcharge, and an additional 10-foot uniform surcharge were all constructed of sand. Partial excavation and backfill (Method No. 2) proceeded in normal fashion, with minor modifications as required. For example, here also the water table was found to be abnormally low, and it proved desirable to increase the depth of direct trench excavation to some 15 feet to facilitate displacement and upheaval of the wetter, more plastic materials below.

A detailed description of the jetting procedures is not given here, since they generally followed the Michigan practices described elsewhere in the literature[5]. However, several features of this specific application are worthy of special mention.

This phase of the work was performed by the Dunbar Drilling and

(5) See reference on Fig. 4.

Supply Company of Delta, Ohio, as sub-sub-contractor. The source of water was a large capacity well drilled immediately adjacent to the embankment. Distribution to the top of the surcharge was effected by means of a highly efficient and portable arrangement of lightweight aluminum irrigation pipe fitted with locking slip couplings. Jet points were located on 10-foot centers parallel and normal to the centerline, and were hooked up in groups or "spreads" of 36 or more. When the jetting at one "spread" layout was completed, the system was readily moved to the adjacent location. The entire surcharge area was covered by stages in this manner.

One unique variation of the usual procedure was developed. Instead of working the jet pipes down to the bottom of the granular fill by jettings, prior to performing the required concentrated jetting operation during stage withdrawal, the Contractor elected to pre-drill a hole at each pipe location. The jet pipes were then placed in the holes and the operation proceeded in the usual manner. The pre-drilling was very efficiently performed by a custom-built mobile rig which employs 20-foot auger flights powered by a compressed air motor. Setting the jet pipes by this method saved the Contractor considerable time. As a valuable by-product, it also furnished a complete system of check borings on 10-foot centers, from which it was determined in detail that unusually complete displacement of unstable materials from beneath the fill had been achieved.

Final settlements of the surcharged embankment, resulting from the jetting process, were of the order of some 2 to 4 feet. It may be of interest to briefly explain that the purpose of the jetting operation is to densify and stabilise the embankment. The saturation of the granular material to a "quick" condition, in addition to encouraging more compact arrangement of individual particles, tends to promote an outward bulging of the granular mass at the contact with the adjacent body of soft swamp materials, thereby improving the stability of the whole system. An explanation given elsewhere (6) is as follows:

> "The embankment is consolidated by the increase in weight from the added water and by the action of the water in the granular fill material. Bedause of the "quick" condition of the embankment material and the increased weight, any weak plane which exists or develops in the underlying peat is quickly penetrated by the fill material and the peat is forced out by the pressure of the overlying fill."

Since the original presentation of this paper, embankment construction and paving operations at the locality have been completed. Recorded settlements have been negligible, and it is believed that the overall operation will prove to be entirely successful.

Preliminary quantity and cost data pertaining to this swamp are given below:

Contract Item	Estimated Quantity	Contract Unit price	Cost
Special Swamp Excavation	53,000 cu. yd.	$ 2.25	$119,250
Granular Embankment Material	138,000 cu. yd.	2.40	331,200
Hydraulic Fill Consolidation (Jetting)	20,000 lin. ft.	2.00	40,000
Check Borings*	1,050 lin. ft.	10.00	10,500
		Total	$500,950

* Not used. See Text.

Illustrations

A series of Kodachrome transparencies, covering all phases of the operations, is available.

(6) P. 106 of manual referenced by Fig. 4.

Slide Conditions

In the oral presentation of this paper, brief reference was made to a major design and construction problem caused by subsurface conditions in the area immediately east of the Turnpike crossing of the Cuyahoga River (Construction Contract C-14, Design Section D-4). At this locality, the Turnpike grade approaching the bridge (primarily a high-level viaduct across a relatively wide valley and narrow river) involves heavy side-hill and cut-fill embankment construction over an area of old slump topography which is undoubtedly the result of past failures of the natural slopes developed on alluvial-lacustrine silts and clays of glacial origin capped by later till deposits.

The local geologic setting, and the design studies and construction measures undertaken to date (and still in progress) to assure embankment stability, are all of considerable complexity. It is deemed preferable, therefore, that further discussion of this problem be deferred until it can be presented in some detail subsequent to completion of construction operations.

CONCLUSION

In the foregoing discussion, an attempt has been made to indicate the manner and degree in which the geologic and soils environment of glaciated northern Ohio has influenced Turnpike design and construction. The scope and various phases of the studies which were required and the mechanics of providing for performance of them in a large engineering organization have been sketched.

It can be said without qualification that Ohio Turnpike Project No. 1 represents a distinct step forward in the applications of Soils and Geological Engineering to modern highway construction. It is believed that the many soils and geological engineers who were associated with design and construction of the Project will, as the years pass, have ever increasing reason to derive satisfaction from their efforts in making it a successful and enduring reality.

* * * * * * *

APPENDIX

ROSTER OF CONTRACTING ENGINEERS

OHIO TURNPIKE PROJECT NO. 1

Design Section	Contract Section	Length in Miles	County	Contracting Engineers
1.	1,2, &3	15.2	Mahoning	Richardson, Morehouse, Ramsey & Fisher, Pittsburgh, Pa.
2.	4,5,6&7	15.9	Mahoning Trumbull	Ammann & Whitney New York, New York
3.	8,9 & 10	13.9	Trumbull Portage	Howard, Needles, Tammen & Bergendoff, Kansas City, Mo.
4.	11,12,13, & 14	18.8	Portage Summit	Howard, Needles, Tammen & Bergendoff, Kansas City, Mo.
5.	15	0.5	Summit	J. E. Greiner Co. Baltimore, Md.
6.	16,17,18, & 19	16.9	Summit Cuyahoga	Hazelet & Erdal Cincinnati, Ohio
7.	20,21,22, & 23	15.1	Cuyahoga Lorain	Knappen, Tippetts, Abbett & McCarthy, New York, N.Y.
8.	24,25,26 & 27	17.6	Lorain Erie	Charles E. DeLeuw Chicago, Illinois
9.	28 & 29	7.7	Erie	Hardesty, Hanover, Andrews, Clark & Buckley, New York, New York
10.	30	0.3	Erie	Hardesty, Hanover, Andrews Clark & Buckley, New York, New York
11.	31,32 & 33	10.7	Erie	Balke & Watkins Cincinnati, Ohio
12.	34,35,36, & 37	16.3	Erie Sandusky	Brown & Blauvelt New York, New York
13	38	0.1	Sandusky	Hardesty, Hanover, Andrews, Clark & Buckley, New York, New York

Design Section	Contract Section	Length in Miles	County	Contracting Engineers
14.	39,40,41 & 42	16.8	Sandusky Ottawa	Porter-Urquhart Associated Newark, New Jersey
15.	43,44 & 45	12.3	Ottawa Wood	Sanzenbacher, Morris, Taylor Brookhart & Tyo Toledo, Ohio
16.	46	0.3	Wood Lucas	J. E. Greiner Co. Baltimore, Md.
17.	47,48 & 49	12.2	Lucas	Alden E. Stilson & Assoc. Columbus, Ohio
18.	50,51 & 52	12.0	Lucas Fulton	Vogt, Ivers, Seaman & Assoc. Cincinnati, Ohio
19.	53,54 & 55	11.5	Fulton	General Industries Engr. Co. Philadelphia, Pa.
20.	56,57,58 & 59	14.7	Fulton Williams	Consoer-Townsend & Assoc. Chicago, Illinois
21.	60,61 & 62	12.9	Williams	Glancy, Carle, McFarland Youngstown, Ohio

In this type of engineering soil mapping the physical characteristics of the soil in its natural environment are considered. In each map unit, the topography, landform, parent material, soil profile and drainage characteristics are relatively uniform. These components are of importance to engineers engaged in location, design, construction, and maintenance of highways.

Engineering Soil Mapping Projects Sponsored by the Bureau of Public Roads

The Bureau of Public Roads has cooperated with the United States Geological Survey and the State highway departments of Illinois, Maine, New Jersey, Rhode Island and Virginia, for the purpose of producing engineering soil maps. Aerial photographs have been used in each project to obtain some of the soil and terrain information.

A cooperative agreement made in 1945 for mapping the 15-minute Fairfax Quadrangle in Virginia provided that the Geological Survey would do the necessary office correlation of published information and prepare the engineering-soil and supplementary maps, while the Bureau of Public Roads would make the soil survey. The 13 soil map units in the quadrangle were delineated on the basis of the following factors: (1) geologic material; (2) soil texture and consistency; (3) internal drainage; and (4) topography.

In cooperative agreements with States, the mapping projects are partially financed from Federal-aid funds, but the respective States are responsible for producing the soil maps and descriptive reports. The highway departments have made separate agreements for personnel of the State University to do the work. The University usually designates a member of its staff to be in charge of the project, but much of the detailed office and field work is done by students engaged in graduate study in the departments of engineering, geology, and agriculture. Inasmuch as the project involves a correlation of engineering, geologic, and agronomic information, it is advantageous for staff professors and library facilities to be readily avialable for consultation.

Some supervision and coordination is required on the part of the Bureau of Public Roads when the State cooperative soil-mapping project is being set up, to assure that the mapping personnel have the proper understanding of the procedures for mapping and that the resulting maps and reports will be technically adequate. Thereafter, the Bureau makes periodic inspections of the project and reviews the soil maps and bulletins prior to their publication.

The general procedure for soil mapping in these cooperative projects is as follows: (1) study of published information, including aerial photographs, and compilation of items to be investigated by field reconnaissance; (2) development of a general idea about delineation of maps units, and tentatively delineating some soil boundaries on the photographs; (3) field reconnaissance, in which soil profiles are examined in road cuts, stream banks and other exposures, or by means of auger borings, and sampling of soils for delineated map units; (4) soil testing; (5) delineation of all soil map unit boundaries on the aerial photographs, after making additional field investigations where necessary; (6) additional soil sampling and testing to establish the range in soil characteristics for each map unit; (7) transfer of the photographic soil boundaries to a base map; and (8) writing the description of the map units, including the application of the information to highway engineering.

Various authors have described the principles of aerial photographic interpretation of soils (1), (2)[1] and the detailed procedure for soil mapping (3), (4), (5), hence, these principles and procedures will not be discussed in this report.

System of Soil-Map Unit Symbols

The method of presenting the soil-unit descriptions on the maps has differed for each cooperative mapping project. However, the system of map-unit designations developed by Lueder (6) while working on the New Jersey project and used in mapping the counties of that State, has been used, with modifications, by the Bureau of Public Roads in mapping soils for part of the Natchez Trace Parkway (4), as well as on the current cooperative mapping project in Rhode Island. Since the modified system of letter and numeral symbols is adaptable to any area, irrespective of the ground condition, it will be described in some detail.

The map-unit symbols consist of a variety of letters and numerals to designate various geologic soil, and environmental factors, which are shown in figure 1. A dash (-) is used to separate the geologic-material symbols from those pertaining to soil profile and ground conditions.

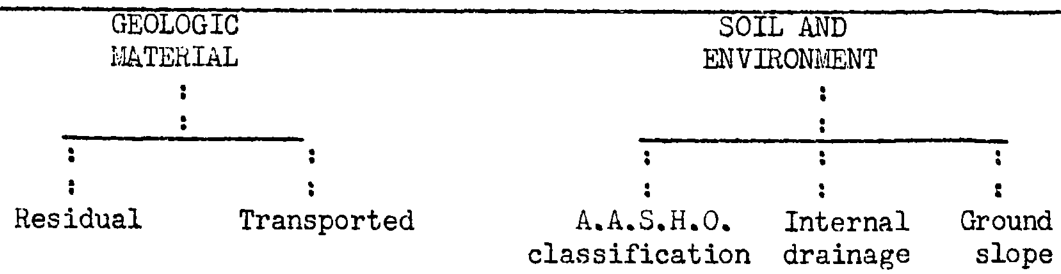


Figure 1. -- Geologic and soil factors in soil mapping.

The letter symbols used to designate geologic materials in New Jersey are given in table 1. The letters I, S and MM indicate igneous, sedimentary and metamorphic rocks, respectively. Specific rock types in each of the three major rock classes are indicated by lower-case letters, which are usually the first letter of the rock type. For example, limestone is given the symbol "Sl" and granite is "Ig." Alluvial, glacial, marine (or coastal plain) and windblown materials are indicated by the letters A, G, M and W, respectively, while the specific landform or formation is indicated by a capital letter. For example, "AF" signifies alluvial fan and "GL" is glacial lakebed.

Some of the geologic materials and landforms are not susceptible to symbolization in a bi-letter system. The geologic unit may be complex, and an area may not be properly identified by a landform name, consequently, special symbols are used. Some of the special symbols used in New Jersey are shown in table 2.

1/ Numbers in parentheses refer to the bibliography.

A numeral on the right side of the dash in the map-unit designation indicates the soil classification within the depth normally significant to the highway engineer. In flat topography, the significant depth is only a few feet, while the soil at depths of more than 10 feet may have significance when the topography is steeper. The soil classification system used in the mapping is that prepared by the Highway Research Board in 1945 and adopted by the American Association of State Highway Officials, which is designated M 145-49 in the specifications of the latter organization (7). As shown in table 3, only the predominant groups in the classification are used; differentiation of the subgroups is not attempted. For example, the A-7-5 and A-7-6 subgroups are both indicated by "7." Combined numerals, such as 24, indicate that the soils of the map unit vary, either laterally or vertically, but are predominantly in the A-2 and A-4 groups.

Table 3. --Symbols used to designate soil classification groups.

Map-unit symbol	A.A.S.H.O. group	General description of soil
1	A-1	Stone fragments, gravel, or sand; nonplastic to slightly plastic binder
2	A-2	Silty to clayey gravel and sand; nonplastic to moderately plastic
3	A-3	Fine sand; nonplastic
4	A-4	Silty; nonplastic to moderately plastic
5	A-5	Silty; slightly plastic; elastic
6	A-6	Silty clay; moderately plastic
7	A-7	Silty clay or clay; moderate to high plasticity; high volume change

The letter "C" on the right side of the dash signifies a significant B-horizon development in the soil profile (8). The recognition of this development is important in soil mapping, particularly when the B-horizon soil is considerably more plastic than that of the C horizon. In relatively flat topography, much of the earthwork may be in the B horizon, while in undulating or rolling topography special design or construction practices may be required at transitions from cut to fill sections to prevent the failure of pavements placed on the B-horizon soil.

It is believed that four symbols are sufficient to designate the internal drainage potential of the soil due to its textural and structural properties, as well as the relative depth to the ground water table. These symbols and their definitions are given in table 4. The four classes conform to the following soil-drainage classes used in pedologic mapping in the United States: excessive, well, imperfect and poor (8). The determination of whether the drainage symbol denotes a soil condition or the relative position of the water table can usually be determined by reference to the other symbols of the map unit.

Table 4. --Internal drainage symbols for soil map units.

Map unit symbol	Internal drainage potential	Limitations on usage
e	Excellent	Granular material. Ground water table is at such depth that is is not significant.
g	Good	Permits traffic or excavation soon after rains. Position of ground water table is usually not significant.
i	Imperfect	Trafficability usually poor and excavation impractical during significant periods. May have occasional high ground water table, particularly in low topography.
p	Poor	Ground water table usually near ground surface. Earthwork difficult during winter season and for considerable time after rain.

When topographic maps are not available, ground slope descriptions on soil maps are of importance in (1) making route determinations, route comparisons, and preliminary surveys of the chosen route; (2) preparing estimates of excavation quantities; and (3) aiding the drainage engineer in the determination of runoff. The soil mapper must have some idea of ground slope in order to determine the depth to which the soil profile should be described. The approximate ground slope can be readily determined by stereoscopic examination of aerial photographs, hence, should be incorporated in the map unit description. Symbols to indicate certain ranges in ground slope were introduced in the Natchez Trace Parkway mapping, and are being used in Rhode Island. The three slope classes shown in table 5 are recommended for mapping in most regions. However, in some regions it may be desirable to have more than three slope classes or change the slope ranges given in table 5.

Table 5. --Symbols used to designate ground slopes.

Symbol	Slope
f	Flat. Approximately 0 to 3 percent.
m	Moderate. Usually between 3 and 10 percent, but some flatter or steeper slopes may be included in the map unit. Steeper slopes are short.
s	Steep. Most of slopes are greater than 10 percent, but there may be small areas having flatter slopes.

Two examples will be given to show how the symbols are used in engineering soil mapping, and the application of the maps and map-unit descriptions to highway engineering.

Natchez Trace Parkway

The Natchez Trace Parkway, when completed, will extend from Nashville, Tennessee, to Natchez, Mississippi, a distance of about 450 miles. The Bureau of Public Roads is responsible for construction of a highway which will extend the length of the Parkway. Although some sections of the highway had been completed in 1948, only a preliminary line had been established from just north of the Tennessee River in Alabama to U. S. Route 41, near Tupelo, Mississippi, a distance of about 62 miles. The Bureau decided to prepare an engineering-soil strip map which would include the preliminary line from this Tennessee River - Tupelo sector, in order to give its personnel some experience in soil mapping and to further develop the system of symbols for designation of soil factors, as well as to have a map which would aid the soils engineer in making a detailed soil and materials survey of the route and assist the location engineer in designing a location of the surveyed route.

This illustration is for a portion of the Parkway at the "fall line," or where the sedimentary rocks outcrop from the coastal plain materials. Figure 2 is a geologic map of the area which includes the trapesoidal illustrative strip near its center. The topography is quite variable, with local relief of about 300 feet. Consequently, several geologic formations of Mississippian and one of Upper Cretaceous age outcrop in the area, although some of them were not identified in the soil-mapping project. Table 6 shows the map unit symbols for geologic materials and the corresponding formations, which, with the exception of recent alluvium, are identified in the geologic column of figure 2.

Table 6. --Engineering soil-map unit symbols for geologic formations, Section 2-D, Natchez Trace Parkway.

Map-unit symbol	Geologic formation
SsV1/	Bethel sandstone
ShV	Ste. Genevieve calcareous shale
MV	Tuscaloosa (marine or coastal plain)
AR	Recent alluvium
SlV	Warsaw limestone
Slhs	Various Mississippian, from Hartselle through Ste. Genevieve

1/ Symbol "V" indicates a vertical variation in the geologic material.

Figure 3 shows the engineering soil map at the left while the aerial photograph at the right has the soil units delineated. In this type of mapping, the soil-unit boundaries are delineated on the aerial photograph, by use of a stereoscope, then transferred to a base map. Figure 4 shows how two adjacent, similar map units are differentiated on the aerial photographs.

The Natchez Trace engineering-soil report, which contains the strip map, describes the engineering characteristics of each map unit (4). For example, the description of the SlV-pim 6 unit is as follows:

> "The topography is undulating, with some limestone depressions, and underlain by bouldery, plastic A-6 soil; bedrock normally occurs at a depth of less than 10 feet. Limestone boulders on or near the ground surface interfere with earthwork. Depressed areas have a high ground water table during substantial periods. Although limestone might be quarried from this unit and used for road surfacing, the quarry opening will normally be made in unit SlV-s."

Although no immediate plans have been made for construction of the highway in this sector of the Parkway, it is anticipated that the engineering soil strip map will aid in: (1) the design of the location on the preliminary surveyed route; (2) planning the detailed soil survey along the designed location; and (3) the search for borrow, base course, and surfacing materials.

New Jersey Map-Unit Descriptions

To show the application of engineering-soil descriptions of map units in New Jersey to highway location, a fictitious terrain area, shown in the block diagram of figure 5, will be used. This is a glacial landscape, in which the front of the glacier remained relatively stationary for a long period, with the result that part of the soil load of the stagnant ice was deposited as a knobby end or marginal moraine (GMM). Sediments were washed outward from the end moraine and glacier front to form a glacial outwash deposit (GO). The outwash sediments were predominantly gravel in some sectors, while in other sectors, practicularly the later deposits, the material is more silty. Blocks of ice were either washed into the GO sector or the front of the ice was once south of the present end moraine and the blocks of ice were broken off as the ice receded. Later, these blocks of ice melted, and the depressions are now partially filled with water and muck (Z). As the ice receded from the end moraine, it deposited till (GM) to a considerable depth on the higher ground. The end moraine served as a dam for the glacial meltwater, with the result that a temporary lake was formed, in which sediments were deposited (GL). The aerial photographic patterns of four of the major engineering-soil map units are shown in figures 6 through 9.

The descriptions of each of the map units shown in figure 5 are given in the New Jersey engineering-soil reports. All of the pertinent portions of the description of the GO unit in Union County (11) are shown in table 7 to indicate the detailed nature of these reports. However, only the "Engineering Aspects" are shown in tables 8 through 11 for the other major map units. Slight changes are made in some portions of the New Jersey descriptions, (11), (12), (13), in order to fit the units used in this illustration. The description of the Z unit is given in table 2.

To illustrate the application of the engineering soil information, assume that a highway is to be constructed between Ann and Bea, figure 5. A straight line connecting the two towns would cross the following soil units: GO-12gef, GMM-24igs, GL-67pf and GM-4 im. Reference to tables 7 through 11 shows that: (1) the GO-12 gef is a very desirable unit from all aspects of highway alignment, design, and construction; (2) undesirable horizontal or vertical alignment might be required in the GMM-24igs unit, considerable earthwork will be involved, and a subbase will be needed on the silty and clayey soils; (3) the GL-67pf unit should be avoided because of low bearing capacity and poor drainage conditions; and (4) the design problems in the GM-4im unit are caused by imperfect drainage conditions and high silt content of the soil.

The preferred location of the highway between Ann and Bea, from a soil engineer's viewpoint, is shown in figure 10. A considerable portion of the alignment is in the GO units. A field investigation should be made to determine whether there is a buried muck deposit between the two Z units about one mile east of Ann. If there is a muck bed, some change in the highway location might be made. A field investigation should also be made at Cap Creek to determine the best location for a drainage structure, from the viewpoint of foundation conditions and approaches. The grade and elevation of the bridge approach on the east side of Cap Creek may be affected by the topography of the GMM unit, but this unit will also afford reasonably good material for use in the approach embankments. The distance the road should be continued in the GMM unit will be governed by the topography, the quantity of excavation required in the unit to provide satisfactory horizontal and vertical alignment, and the quantity of earth from the GMM unit that can be used economically in the roadway of the two adjacent soil units. Field investigation of topographic conditions in the GMM unit might dictate that the road cross a corner of the GL unit on a raised grade line. Table 10 shows that a raised grade line may be advisable on the GM-4im unit because of the imperfect drainage condition and susceptibility of the silty soil to detrimental frost action. All of these soil conditions, in addition to geometric design standards, land use, and other criteria, should be considered by the location engineer while he is designing the highway location.

After the location of the highway has been established, the soils engineer should use the soil map and descriptive report to plan and make a detailed soil survey. The published information will indicate the areas in which the efforts of the soil survey crew should be concentrated. Not much time need be spent in the GO units, unless there are some small muck deposits which have not been delineated on the map. All muck deposits should be investigated to determine the nature and extent of the material because the muck should be removed from the roadway. The type and extent of the investigation to be made at Cap Creek will be governed by the size and type of the drainage structure. If it is a major structure, some undisturbed samples of the foundation soil may be obtained for laboratory analysis. If there are some recent alluvial deposits along the creek, some of the strata may contain plastic clays.

Considerable effort should be expended in investigating the soil condition in the GMM unit because a large volume of earthwork may be involved, some of the excavated material may be used in the embankments on adjacent soil units, as well as in subbase courses, and there may be seepage conditions due to the presence of lenses or thin strata of clay. Some help may be gained from the study of the aerial photographs when investigating susceptibility to seepage. If a depression (kettle) near the roadway contains water which is at a higher elevation than the grade line, seepage should be anticipated.

Sufficient time should be spent in investigating the GM unit to determine: (1) where drainage conditions dictate a raised grade line; (2) whether the material from probable cut sections can be used in the upper portions of embankments, and (3) if the subgrade soil in cut sections is frost susceptible.

For each of the soil units, sufficient samples should be obtained for laboratory testing to provide the test data required in roadway and pavement design.

The published map and report will also serve as a guide in the search for materials suitable for use as borrow and in the subbase, base, and surface courses of the pavement, as well as for aggregate in concrete structures. In general, the GO-12gef unit will be the best source of good construction materials, but portions of the GMM-24igs and GO-24gf units contain suitable subbase material and should be used wherever it is economical to do so.

The soil map and report are of value during the highway construction stage to (1) locate sources of borrow when planned cut and fill do not balance, and (2) determine the best location for access roads to borrow and sand-gravel pits. They are also of value to determine the possible sources of material for maintenance of the road.

Adequacy of the Engineering-Soil Maps and Reports

The two examples show that the engineering-soil maps and reports describe the soil units in sufficient detail so that the information may be extremely valuable in reconnaissance and preliminary surveys, planning detailed soil and materials surveys for the design of a location, and for construction of highways. They were used in the preliminary location of part of the Garden State Parkway in New Jersey, and are used by the State for planning routine soil surveys. They also have great potential value to county and township engineers who have limited facilities for making soil and materials surveys or for testing soil samples. Commercial organizations can use the information in searches for materials and for planning and designing structures.

The system of map-unit symbols described in this report indicate the most important soil profile and environmental characteristics of the map units. The code symbols can be readily mastered by the soil mapper as well as the user of the maps because most of the symbols suggest specific characteristics of the map units. This report and the cited references may not contain all of the symbols required in a specific mapping project. However, additional symbols for other geologic materials and soil conditions can be added to the symbol framework which has been presented.

The symbols are applicable to soil-mapping projects in which aerial photographs are the only source of office information, although some generalization may be necessary unless a field reconnaissance is made. The generalization can be accomplished by either combining two or more symbols for the same map-unit factor or omitting one or more of the factors from the map-unit designation.

The aerial photographs should be considered as only one of the tools used in collecting the soil information. If geologic, pedologic, and engineering maps and reports are available, they should also be used in the engineering-soil mapping project. Even when the allied reports and maps are the principal source of soil information, the aerial photographs are a valuable aid in serving as a base on which the soil units are delineated.

Even though the office sources of information are good, and consultations are held with geologists, pedologists and other specialists, the soil mapper should make sufficient field investigations to establish the accuracy and reliability of the engineering soil maps and reports.

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Table 1.--Code symbols used to designate geologic materials in New Jersey (3)

A	ALLUVIAL - Material deposited in present location by fresh water. Characterized by segregation and stratification. Coarser sizes deposited by faster-moving streams, etc., fine sizes by slower-moving streams or in stagnant waters.
AD	ALLUVIAL DELTA - Material carried by stream or river and spread mostly underwater, in a delta-shape where the stream or river is slowed upon entering a much larger body of water.
AF	ALLUVIAL FAN - Material brought down from adjacent higher hills or mountains by fast-moving streams and spread in fanshape where the stream is slowed by the flatter gradients of a valley floor.
AM	ALLUVIAL MANTLE - Material of alluvial origin, covering a considerable area but possessing neither the delta nor the fan land form. Also used to identify alluvial materials of complicated origin.
AO	OLD ALLUVIUM - Alluvial material which has been in present location long enough to have developed discernible soil horizons.
AR	RECENT ALLUVIUM - Alluvial material of relatively recent deposition. The term "recent" indicates that the area is occasionally subject to deposition and/or erosion.
G	GLACIAL - Material deposited in present location by glacial ice or waters running under, through, or from the glacial ice.
GD	DRUMLIN - A portion of the glacial ground moraine (GM) that is raised slightly above the surrounding area, is elliptical in plan and is extremely compact. Usually unstratified clay and boulders (till).
GE	ESKER - Material deposited by waters flowing as a stream under a glacier. Assorted by water-action and, hence, somewhat stratified. Usually occurs as a granular ridge, more or less continuous, and frequently extending many miles.
GK	KAME - Material deposited by water flowing as a stream from the end of the glacier. Texture of the deposit is similar to that of eskers (GE). Kames appear as a raised, mound-like land form.

Table 1.--Code symbols used to designate geologic materials in New Jersey (3) - (Continued)

GKG	KAME GROUP - A number of kames closely grouped and giving a hummocky, raised land form.
GKT	KAME TERRACE - A number of kames arranged together so as to give surface configuration or land form similar to that of a terrace. Usually more hummocky than a non-glacial terrace. (See T - Terrace).
GL	LAKEBED - Material of glacial origin deposited in waters which were ponded during the glacial period but have since drained. Silty or clayey.
GM	GROUND MORAINE - Material deposited by melting glacier. Usually an irregular sheet of unassorted sized. Includes scattered boulders in clay or fine sand, giving a texture identified as "till".
GMM	MARGINAL MORAINE - Material deposited when the edge of the glacier remained stationary for a length of time. Usually an unassorted, heterogeneous accumulation forming a more or less continuous ridge.
GO	OUTWASH PLAIN - Material deposited by waters issuing from the end of the glacier. Assorted, tending to be granular near the marginal moraine (GMM), becoming finer-grained at greater distance. Usually a broad area, sloping gently away from the marginal moraine (GMM).
GS	STRATIFIED DRIFT - Glacial material deposited by water and, hence, assorted and stratified. Applied to water-deposited materials of compled or uncertain origin, or those possessing no clearly defined land form.
I	IGNEOUS - Rocks formed by the solidification of molten earth materials. Those that solidified at the earth's surface are fine-grained (extrusive), and those that solidified underground are coarse-grained (intrusive).
Ia	GABBRO - Igneous rock composed primarily of ferromagnesian minerals, with some feldspar. Medium to coarse-grained and dark in color. Diabase is an important variety.
Ib	BASALT - Igneous rock composed primarily of ferromagnesian minerals, with some feldspar. Usually dark-colored and fine-grained. Commonly known as "trap" rock.
Ig	GRANITE - Igneous rock composed primarily of feldspar and quartz. Usually medium to coarse-grained and light in color.

Table 1.--Code symbols used to designate geologic materials in New Jersey (3) - (Continued)

Il	LAVA - Igneous rock of variable composition and characterized by glassy texture.
Is	DIABASE - See Ia, gabbro.
M	MARINE - Material deposited in present location by the action of ocean or sea current, tides and waves.
MB	BEACH - Marine material, usually of sand-sized grains. A product primarily of the sorting and abrasive action of waves.
MM	METAMORPHIC - Rocks formed by the action of pressure or heat, or both, on previously solidified igneous or sedimentary rocks.
MMg	GNEISS - Metamorphic rock, banded in appearance, derived from either sedimentary or igneous rock, with derivation from the latter more common.
MMl	SLATE - Metamorphic rock, fine in texture, with many closely spaced cleavage planes resulting from metamorphic action. Derived primarily from sedimentary shale.
MMs	SCHIST - Metamorphic rock ranging in character between gneiss and slate. Tend to split with smooth, even surfaces, but coarser-grained than slate.
MTM	TIDAL MARSHES - Marine shore-line development of plant-root growth mixed with silt and/or clay in shallow water areas protected from wave action. Level of marsh area is close to that of high tide.
S	SEDIMENTARY - Rocks formed by the cohesion or consolidation of previously transported materials. Texture, stratification, etc., depends primarily on history prior to consolidation.
Sa	ARGILLITE - Sedimentary rock composed of silt or clay-sized grains and exceedingly compact. Similar to shale, but harder and more resistant to weathering.
Sc	CONGLOMERATE - Sedimentary rock composed of gravel and boulder sizes usually embedded in a matrix of finer material. Larger sizes are well-rounded.
Sh	SHALE - Sedimentary rock composed of silt or clay-sized grains, and, hence, fine-textured.

Table 1.--Code Symbols used to designate geologic materials in New Jersey (3) - (Continued)

Sl	LIMESTONE - Sedimentary rock, composed primarily of calcium carbonate which precipitated to form the deposit. Also includes rock composed of shell fragments.
Ss	SANDSTONE - Sedimentary rock composed of sand-sized grains.
T	TERRACE - Alluvial material, originally a flood-plain adjacent to a flowing stream but abandoned when the stream eroded to lower levels, Also includes deposits of glacier melt-water origin having the characteristic terrace form.
W	WINDBLOWN - Material deposited or moved to present location by action of wind. Usually has a narrow range of grain sizes.
WD	DUNES - Windblown material, usually of sand-sized grains. Movement is along, or close to, the ground.
WL	LOESS - Windblown material, usually of silt-sized grains. Movement is usually through the air, and possibly, over great distances, During air-travel, might be described as "dust".

(Rutgers University plans to revise Report No. 1 in 1955. The revised edition will probably make some changes in the definitions given in the above table, as well as define additional geologic materials).

Table 2.--Special symbols used in soil mapping.

C - Contrast Between Horizons - Indicates soil areas in which the B and C horizons are sufficiently dissimilar to warrant individual treatment in design and construction. The B horizon usually contains a larger percentage of fine soil particles and is more plastic than the C horison. (3)

D - Depressions - Denotes small sections with poorer drainage (surface and/or subsurface) than is usually found in the surrounding area. Where the poorly-drained sections are of large extent, they are labeled with appropriate code symbols. (3)

F - Filled or Made Land - Used without additional designation. Denotes areas in which the original ground surface has been covered by varying depths of fill material. The fill may have been placed to cover unsatisfactory soil conditions or to raise the ground surface above the ground water-table. The fill material is frequently industrial or municipal waste. (9)

R - Denotes a range of conditions far beyond that which can be described with any degree of precision by the coded symbols. Usually the areas so labeled on the engineering soil maps are described and discussed in the corresponding county report. (3)

V - Variable geologic formation - Placed as a suffix to the geologic symbol. Used when the soil is stratified and the extreme variations in the soil profile are of major importance. The symbol may also be used to denote a vertical variation in consolidated geologic material.

X - Exceptional - Placed as a suffix to the geologic symbol. Used to identify conditions that cannot be described accurately by the coded symbols. (10)

Z - Swamp - Used without additional designation. Denotes swampy areas where the ground water-table is at the ground surface during most of the year, and the surface or near-surface soils are generally high in organic content. The characteristics of the materials underlying the organic surface layers usually resemble, in all important aspects, those of the surrounding map units. (10)

/ - Diagonal Bar - Used to separate two mapping symbols where both materials are present at the ground surface, but the individual occurrences of each are too small to permit separate mapping. (3)

Table 2.--Special symbols used in soil mapping. (Cont'd)

__ - Horizontal Bar - Used with code symbols above and below the bar. The material described by the upper symbol appears at the ground surface and is underlain at shallow depths by the material described by the lower symbol. The compound symbol, in the form of a fraction, is applied where the underlying material differs considerably from the surface soil and occurs close enough to the surface to warrant consideration in design and construction. (3)

INDEFINITE BOUNDARIES - Broken lines represent indefinite boundaries or broad transition zones on the engineering soil map. In some cases, the gradual soil change may be attributed to the variable degree of border intermixing between two essentially dissimilar soil areas which occurred during, or since, soil deposition and development. In other cases, there appear gradual transitions between similar soil areas described by one mapping notation to those described by another notation. (10)

Table 7.—Description of GO-24gf unit (11)

PARENT FORMATION

A. Geologic Identification - Glacial outwash, composed of nonresidual, stratified materials, deposited during the Wisconsin glaciation by melt waters flowing from the glacial terminus.

B. General Characteristics - Predominantly assorted deposits, largely composed of sand and silt sizes, with some gravels and cobbles. The various sand and gravel sizes usually occur in well-defined layers or beds. In most GO areas, silt is found in lenses or pockets and in the A horizon. The deposits are largely derived from quartz, sandstone and shale. Red-brown to yellow-brown colors predominate.

C. Underlying Formations - Usually occur at depths in excess of 10 feet and need not be considered in ordinary highway construction. May be identified generally as soft, red shale.

LAND FORM - Broad, noticeably flat plain which merges into the relief of the underlying shale on the west and passes, usually abruptly but sometimes gently, into the higher terminal moraine on the north.

SOILS

A. Type - In GO areas, silty sands, sands, and gravelly sands predominate throughout the profiles.

B. Depth to Bedrock - Usually greater than 10 feet.

C. Correlated Agronomic Series - Dunellen.

D. Profile Contrast - Slight in GO areas. In these areas, light textures, high quartz contents, and relative recency of deposition have held profile development to a minimum.

E. Engineering Classification - Sandy in GO areas, being largely classified as HRB A-2-4 and, occasionally, HRB A-4. Where silt has covered sand and gravel, the upper horizons are classified as HRB A-4, while the deeper soil usually meets the requirements of the HRB A-2-4, A-1-b or A-1-a. Engineering test values are as follows:

Table 7.--Description of GO-24gf unit (11), (Cont'd)

GO-24			
Horizon	A	B	C
Depth, In.	6-16	30-42	Deep
Pass #4, %	95-100	95-100	95-100
Pass #200, %	30-45	25-40	20-30
Silt, %	*	*	*
Clay, %	*	*	*
LL, %	NL-20	NL-20	NL
PI, %	NP-3	NP-3	NP
Max. D., pcf	*	118-121	109-112
Opt. Moist. %	*	9-11	11-13
HRB Class.	A-2-4 to A-4	A-2-4 to A-4	A-2-4
Group Index	0-2	0-2	0

* Values unnecessary or not significant.
NL Nonliquid. Sample not susceptible to liquid limit test procedure.
NP Nonplastic. Plasticity index zero or cannot be determined.

DRAINAGE CONDITIONS - Soils mapped as GO have excellent internal drainage and low capillarity. Because of their flat surface however, runoff characteristics are poor, and it is probable that the materials are saturated, following heavy precipitation, for longer periods than might be indicated by their textural classification. Because of uncertainty regarding the depth to, and conformation of, the underlying shales, the depths to water-table may show considerable variation. Nevertheless, due to the thickness of the deposits, the water-table can usually be expected to lie at moderate depths.

ENGINEERING ASPECTS

A. Alignment - Not affected by the topography of these areas.

B. Cuts and Fills - Negligible, except where shallow cuts may be desirable in order to penetrate the silty surface layers and take advantage of the underlying granular deposits.

C. Embankment and Borrow - Most of the GO materials are suitable for both embankment and borrow, although the silty surface layers may occasionally prove unsatisfactory.

D. Pavement Support - Fair to excellent for most GO materials. Poor for the silty surface layers, but usually fair to good for the underlying granular layers.

Table 8.--Engineering aspects of the GO-12 gef unit (12).

Alignment - Not affected by the topography of these areas. However, buried or depression accumulations of organic material should be avoided.

Cuts and Fills - Negligible, due to flat surface. Small, unmapped muck deposits must be excavated.

Embankment and Borrow - Material is suitable for both.

Pavement Support - Rated as generally good to excellent where drainage is average or better than average.

Table 9.--Engineering aspects of GMM-24igs unit (13)

Alignment - Upon approaching the terminal moraine, road alignment will definitely be influenced by this prominent land form. However, within the area mapped as GMM, road alignment will be less affected.

Cuts and Fills - Frequent cuts and fills will be necessary, ranging from 5 to 25 feet.

Embankment and Borrow - The majority of GMM materials may be considered good to excellent for use in embankment construction and as a source of borrow.

Pavement Support - Usually good to excellent, with occasional areas rated fair. In depressions, the presence of silt and clay suggests a need for subbase.

Table 10.—Engineering aspects of GM-4im unit (11)

Alignment - Not influenced to any significant degree either by land form or texture.

Cuts and Fills - Usually negligible.

Embankment and Borrow - Questionable for both embankment and borrow. Proposed materials should be sampled and tested.

Pavement Support - Fair to occasionally good. Because of the imperfect drainage conditions, raised gradelines are considered advisable in some areas.

Comments - High silt content of the soil and imperfect drainage conditions provide a combination that is particularly susceptible to detrimental frost action.

Table 11.--Engineering aspects of GL-67pf unit (11)

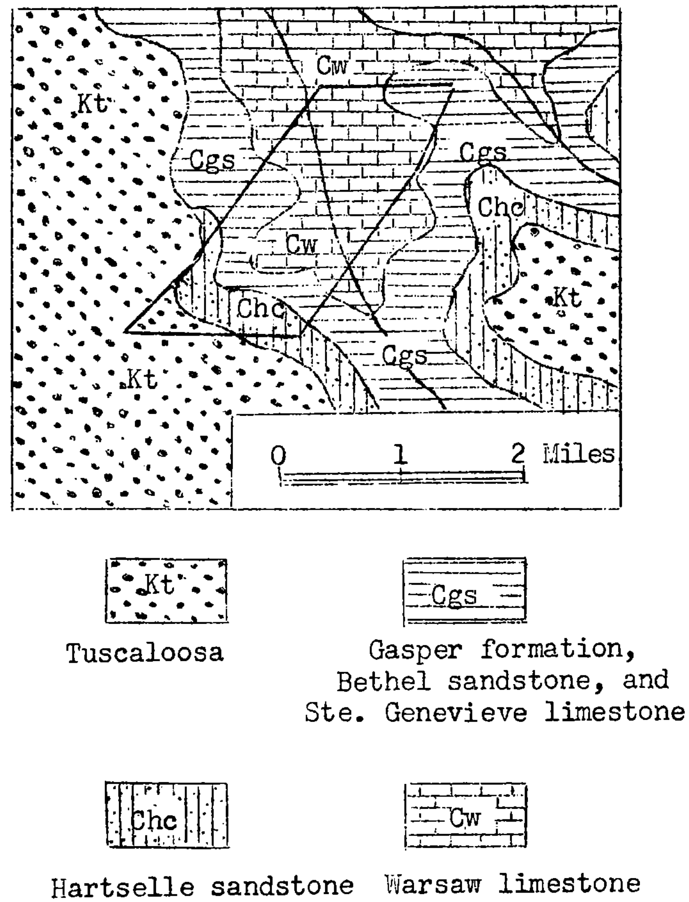
Alignment - Not materially influenced, in a physical manner, by the nature of the GL areas, although substantial depths of fill may be required to satisfy grade requirements. Poor pavement support and drainage conditions make it desirable to avoid these areas.

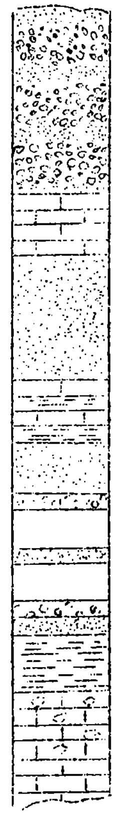
Cutsand Fills - Cuts are seldom required. Medium and high fills are often necessary.

Embankment and Borrow - Unsatisfactory, due to low maximum densities and heavy textures.

Pavement Support - Poor to very poor. Subbase and/or raised grade lines are usually required.

Comments - Poor drainage and heavy textures provide a combination that is usually susceptible to detrimental frost action.





Feet	
100-200	Tuscaloosa formation. Irregularly bedded gravels, sands and clays. Chert predominates in gravel. Some gravel is indurated.
50	Bangor limestone. Argillaceous, shaly limestone.
100	Hartselle sandstone. Thick bedded, medium grained.
50	Golconda formation. Interbedded limestone and marly shale.
40	Cypress sandstone.
100	Gasper formation. 20-foot bed of oolitic limestone at top; 10- to 25-foot bed of asphaltic oolite in base. Intermediate section is greenish blue marly shale containing a 20-foot bed of soft, fossiliferous sandstone.
10-20	Bethel sandstone.
40-50	Ste.Genevieve formation. Thin-bedded, soft, calcareous shale. 2-foot bed of limestone at base.
	Warsaw limestone. Light to dark gray, thick-bedded, sometimes cross-bedded, coarsely crystalline, highly fossiliferous. Weathered sections contain chert.

Geologic column for southwest portion of geologic map.

(Geologic map and column are based on "Geology of Alabama," by G. I. Adams, C. Butts L. W. Stephenson, and W. Cook. Special Report No. 14, Geological Survey of Alabama, 1926)

FIGURE 2. - GENERALIZED GEOLOGIC MAP OF PART OF SECTION 2-D AND ADJACENT AREA, NATCHEZ TRACE PARKWAY

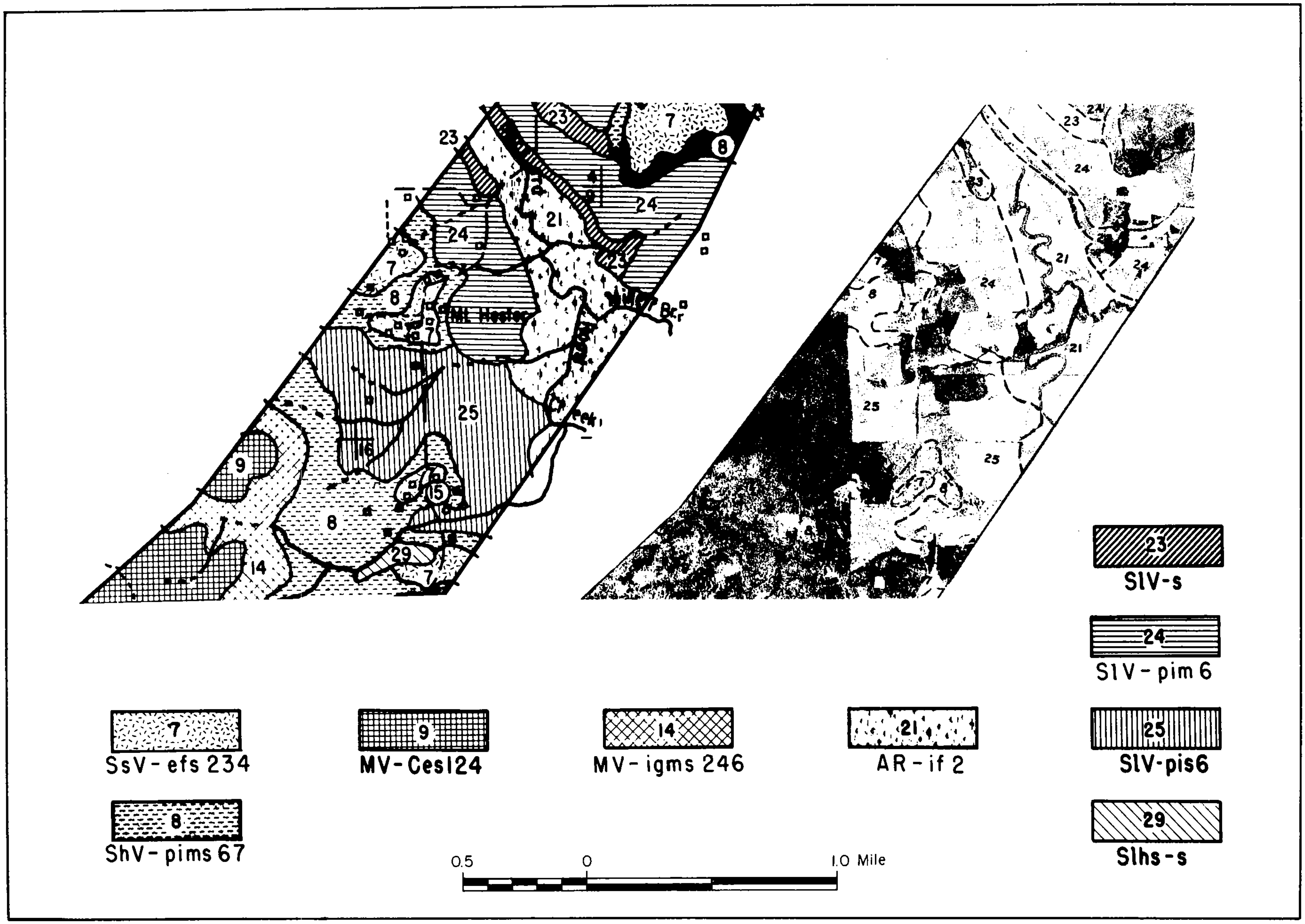


Figure 3.- Engineering soil map and aerial photograph of part of Section 2-D, Natchez Trace Parkway

Figure 4.--Stereophotograph of map units S1V-pim6 and S1V-pis6.

These two units are derived from limestone. There are some sink-hole depressions in both units. Boulders may be distinguished on the ground surface, as at B. The more bouldery portions of the units are used for pasture or woodland.

Unit S1V-pim6 has generally moderate slopes but includes some short steep slopes. Much of the surface water is collected in depressions and discharged through subterranean channels, hence, some faintly discernible gullies disappear at the edge of depressions. The photograph color tone is medium gray mottled with darker gray.

The ground slopes of unit S1V-pis6 are relatively steep. Extensive surface drainage channels have been formed in some areas.

The unmarked area in the lower left portion of the illustration is composed of units derived from sandstone and shale. The wooded angular knob near the base of the "V" in the S1V-pis6 designation may also be capped with sandstone, but the area is too small to be differentiated on the engineering-soil map.

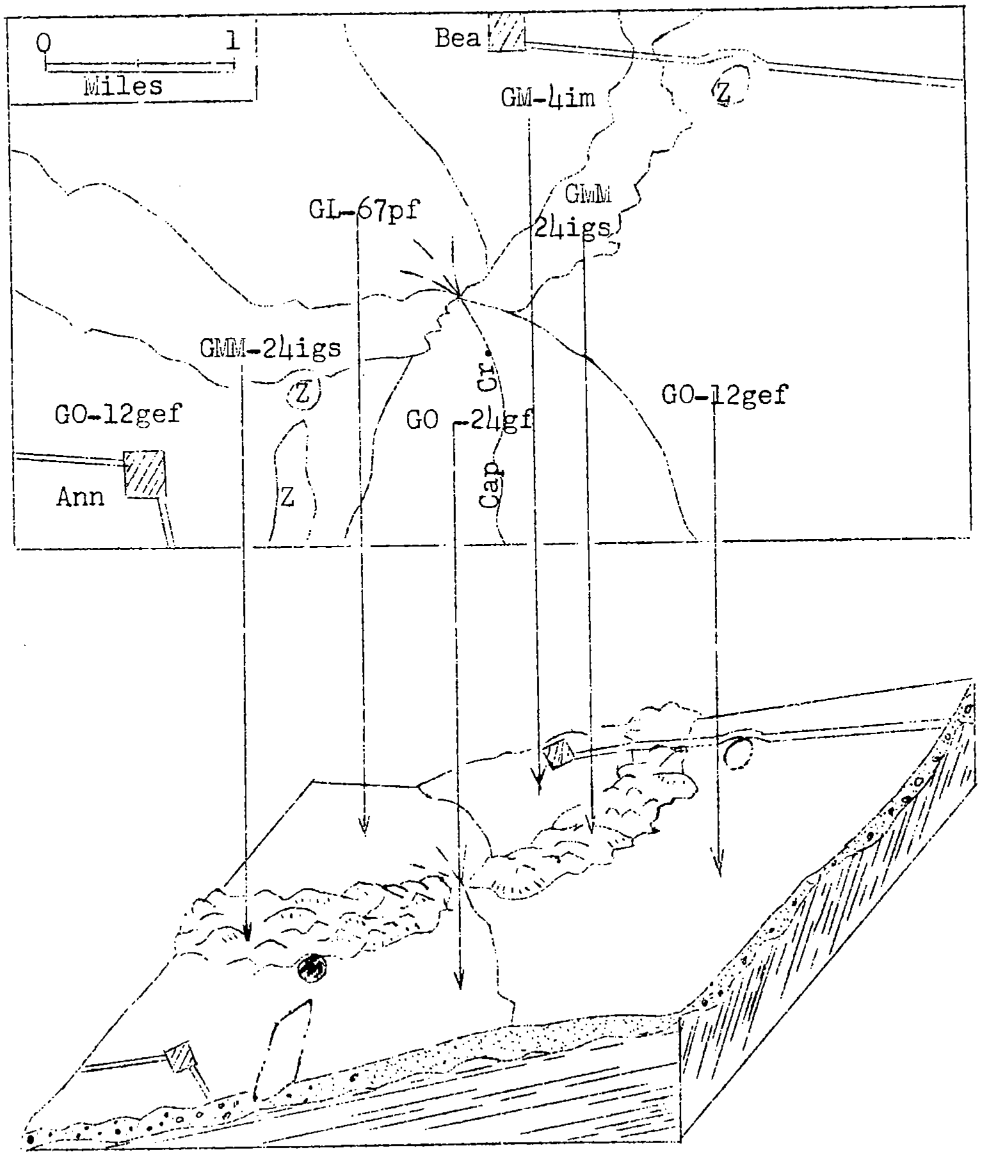


Figure 5. --Block diamgram of glacial landscape and engineering-soil map, showing delineation of landforms into soil units.

Figure 6.--Stereophotograph of map unit GMM-24 igs.

The road extending from top to bottom of the stereophotograph is located on the crest of the end moraine. Steep ground slopes, knobbiness or angularity of the topography, depressions having no surface outlet but containing no water, the pit near the left margin of the area, and the uniformly light gray color tones in recently cultivated fields, are all indicative of the granular nature of the soil. However, depressions (kettles) containing water and organic matter indicate that some of the soil is not very permeable.

Figure 7.--Stereophotograph of map unit GO-24 gf.

The scars caused by glacial melt-water are the dominant feature of the photograph. These channels are but a few feet in depth, but the fact that they still exist is a usual indicator that the dominant texture of the underlying strata is gravel. Another indication that the soils are porous is that the roads require no drainage structures. However, the moderate gray, uniform color tones in recently plowed fields indicate that the surface soil is silty. Although this gravelly silty soil may extend to a depth of only about 2 feet, the map unit is given the textural designation "24," because earthwork for highway projects will be slight and a considerable percentage of the excavation will be in the silty soil.

Figure 8.--Stereophotograph of map unit GM-4im.

In recently cultivated fields, the color tones are uniformly moderate gray, which is indicative of silt. However, slightly darker mottles in some areas indicate imperfect internal drainage. Although the underlying bedrock may be responsible for the higher elevation in the western portion of the area, the bedrock influence is not reflected in the soil pattern for the general appearance of the soil is the same at all elevations.

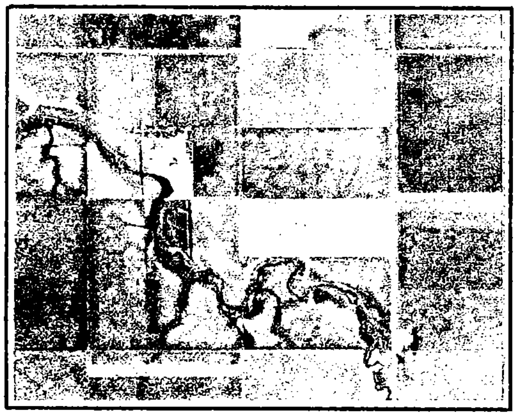


Figure 9 .--Aerial photograph of map unit GL-67 pf.

The glacial morainic dam which caused the deposition of the lacustrine soils in this area was located several miles southward. The meanders of the stream are indicative of flat topography. Except at the margin of the valley wall, the color tones are dark, and there are numerous dark phantom drainage lines, both of which indicate the poorly drained, plastic nature of the soil.

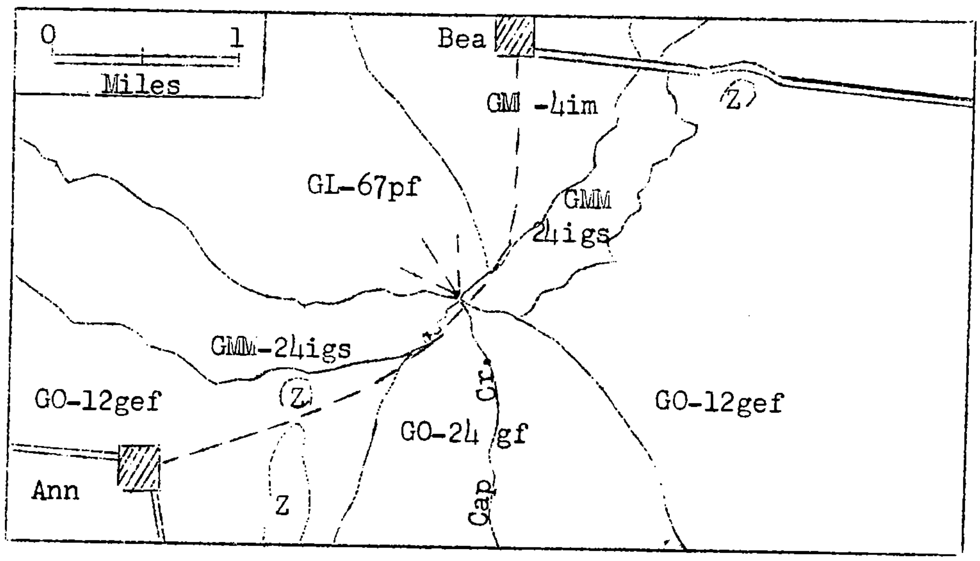


Figure 10. --Engineering soil map of glacial landscape. Dashed line shows best location for a highway between Ann and Bea,. based on soil conditions.

CONCRETE AGGREGATE REACTION IN VIRGINIA

By: Phillip L. Melville

ABSTRACT

Concrete aggregate reactions can be divided into two groups: chemical and physical. Each one is discussed and illustrated with examples of occurrences of concrete disintegration. The paucity of pathological data has been a handicap in studying the reactions and making a final diagnosis. As more information is gathered it becomes more obvious that calling the aggregate "inert" is not only erroneous but it is misleading.

INTRODUCTION

In hydraulic cement concrete, the aggregates are customarily designed as being "inert" while the cement is referred to as being "active". Obviously, in our non-perfect world the adjectives can be used only with relative meanings. Even so, to describe aggregates as being without active properties is both erroneous and misleading.

Aggregates have to a small or large degree an inherent power of action - or resistance - in relation to themselves and to their surroundings. The fact that very often that power of action has been small enough to be negligible has misled us and we claim that aggregates are "inert". Once in a while the obvious truth is called to our attention, sometimes in rather blunt fashion, and we become very concerned with aggregate reactions. The chemist knows that pure water will slowly dissolve glass. The engineer might select water in a glass container as a typical example of inertness. The latter's point of view is undoubtedly pragmatic - and rightly so, but there is no escape from the fact that our technical knowledge is as safe and sound as the theoretical truths upon which it rests.

CHEMICAL REACTIONS

Among concrete aggregate reactions, the engineer is certainly most aware of those of a chemical nature. As a matter of fact, it has often been an abused practice to blame any poor performance of concrete to unfavorable chemical reactions. It may be that the complexity of chemistry, combined with the lack of chemical knowledge among some civil engineers, has been used as a convenient screen to cover a multitude of sins!

From the historical point of view it is interesting to recall one of the earliest recognized chemical incompatibilities in concrete which was observed at Buck Dam on the New River in Virginia. It has been lengthily described in technical literature as an occurrence of so-called "alkali" reaction. The reaction must still be going on between the cement and the phyllite as the concrete has obvious "growing pains" and repairs seem to be needed continuously.

In addition to this more famous - or infamous - example of chemical reaction, a number of other occurrences have been logged although in most cases, a lack of detailed chemical and petrological analysis has prevented the confirmation of the diagnosis of the engineers in the field. The Virginia Council of Highway Investigation & Research, a cooperative agency sponsored jointly by the Department of Highways and the University, has initiated a state-wide survey of highway concrete structures to record occurrences of chemical reactions. To date only the field work for one of the eight highway districts has been completed.

There is no doubt that chemical reactions in concrete have been brought to light by the survey. The information is still meager but is being completed slowly, and some laboratory research projects have been initiated to be correlated with the field work. Unfortunately, as it is but too well known among geologists and civil engineers, such projects are usually time-consuming and always tedious not to mention that they often necessitate the use of expensive equipment. The need for a knowledge of the chemical reactions might be justified in two ways: the necessity for preventive action; the knowledge that no location is per se immune.

Because the "alkali" reaction is important, it might be à propos to discuss it briefly. Basically the alkalies in cement (sodium and potassium oxides) react on certain siliceous compounds including: tridymite, opaline, chert opal, chalcedory, obsidian, and cristobalite. In addition, some dolomites, limestone, phyllites, rhyolites, quartzites and sandstones which contain reactive minerals have been placed on the engineers' black list. Under average field conditions it takes about two years in a damp atmosphere at normal temperatures for expansion and cracking of the concrete to develop. Although there is no complete agreement as to the chemical requirements of a "high alkali" cement, empirical findings have placed the boundary at 0.6% total alkalies. It is known that some of the portland cement manufactured today in Virginia has about .65% total alkalies.

Has the above reaction been observed in Virginia? In addition to the classic example of Buck Dam there is evidence of this type of deleterious reaction recorded by the Department of Highways. The best known case - to the writer - is located in Botetourt County in the Valley of Virginia. A section of concrete pavement built in 1938 is divided into two projects. Both use the same materials with one exception. The cement is a portland type II and the coarse aggregate is a crushed stone, essentially Shady dolomite from the Lower Cambrian. The northern project contains some fine aggregate from the same source while the southern one has only a James River Tertiary sand.

Several years ago, some minute map cracking and the appearance of "D-lines" were called to the attention of the Research Council. A visual inspection revealed that they were concentrated in the northern project. It was also found that on the 9-inch vertical edges along the shoulders were some yellow-gray spots. The stain was found to be a kind of scab and although no pathological report is available on them, visual evidence was considered sufficient to result in a diagnosis of "alkali reaction". Obviously, the continuous abrasive action of traffic prevented the formation of deposits on the surface.

A very similar occurrence has been observed on the same route in a bridge over the James River. In addition to the deposits, extensive cracking of the guard rails was noted. The aggregate used came from the same local quarry used for the pavement, at about the same time.

It is not known as yet whether the deleterious reaction should be ascribed to the Shady dolomite or to the Erwin quartzite which outcrops in the same quarry. It would appear that the size of the material (i.e., its gradation) is an important factor. This is in agreement with reports from other research agencies and in the present case the finer the aggregate, the more reactive it would be.

A number of occurrences of expansive reactions of concrete has been reported in southwest Virginia, most of it involving Ordovician limestones. Because of the similarity to typical "alkali" reactions, the poor concrete performances have been under suspicion but no more definite information is available to the Council. It is understood that very cherty limestones were used in all the concrete mixes.

An entirely different kind of chemical reaction has been receiving more and more attention in recent years. It is concerned with the presence of small amounts of deleterious matters on the surface of aggregate particles. The coatings are usually of organic nature and affect appreciably the quality of the concrete and the entrained air in particular. In many an early concrete structure, a local river aggregate was used and localized poor performance resulted when foreign matters found their way to the mixer. Recent reports indicate a coating on Tertiary or Recent deposits, small enough not to cause rejection under A.S.T.M. specifications, but which may be large enough to result in drastic changes in the concrete.

PHYSICAL REACTIONS

In recent years, concrete technologists have discussed the effect of the physical properties of the aggregate on concrete. There is general agreement on one point: The physical properties of the aggregate have an important bearing on performance. But the accord usually ends there. This is rather to be expected because while the effect, whence the cause, of chemical reactions can be studied, measured and recorded, those of physical reactions are elusive. Physical reaction can only be observed if there is some awareness of the process and if there are measurable changes. For instance, measurable changes in length when temperature varies can be observed at the proper moment. The most common physical reactions involve temperature changes but unfortunately there is a lack of conclusive evidence on the effect of temperature on concrete.

However, it is known that the relative volumetric and linear coefficients of expansion of the various constituents affect concrete performance, but in what direction is not known. It was believed that small coefficients were desirable although the reverse may be true and it has even been questioned whether all the ingredients should have coefficients as nearly equal as possible. Temperature will also result in physical action as heat affects water, changing it from solids to liquids and to gases. This in turn is related to the pore structure of concrete which has been recognized more and more as a fundamental property. The structure has been conveniently studied by the way it affects specific gravity although further research on pores should be rewarding. It has been clearly established that for many aggregates, performance in concrete varies directly with the specific gravity of the materials. This explains the poor performance of some porous cherts and sandstones, friable shales and limestones either as crushed rock or as constituents in gravel. This would explain some of the inferior concrete pavement performance occasionally recorded in Virginia when the aggregate is changed from stone to gravel, such as Route 29 in Campbell County before reconstruction.

One last factor affecting physical reactions is the specific heat. Some basic research has been undertaken by the Council and others although results to date do not appear significantly related to field performance.

CONCLUSIONS

It is logical to conclude from the review of chemical and physical reactions that it is indeed erroneous and misleading to describe aggregates as being "inert". Even in relation to the "activity" of the cement, the aggregates are far from having a negligible power of action. The fact that it may be small at times does not invalidate its importance. Here as in many another place is a need for further data and further research. The Council accepts the problems caused by the activity of aggregates as part of its challenge to provide better concrete for better highways.

EARTH RESISTIVITY INDICATES SUBSURFACE GEOLOGY

By: Arthur B. Mobley

Many methods of subsurface exploration are employed today by the highway engineer to facilitate the construction of better highways more rapidly and more economically. One of the most successful geophysical methods being used by road builders in many parts of the world makes use of the electrical resistivity of the earth formation. More than two decades have elapsed since the Bureau of Public Roads began to develop methods and equipment adapted especially to shallow subsurface investigation and to explore their range of application. Until instruments, field techniques, and interpretative procedures could be developed and refined and until the value of the methods could be proven in the field, little was published regarding the work. However, in recent years a number of papers have been published calling attention to the usefulness of a profession's new tool. Since a part of the Bureau's activity has been demonstrations to various State highway departments and other agencies that have expressed interest, direct exploration data have not always been available for comparison at the time of test. In most cases, however, some information on the formation under test has been available or has been obtained by direct means during the course of the investigation.

There are available ample data from diversified projects surveyed by the Bureau to show the correlation of the actual subsurface structure with that predicted from the resistivity test data.

Brief Description of the Earth-Resistivity Test

The equipment developed by the Bureau of Public Roads is shown in figure 1. The three units, consisting of the instrument case containing the potentiometer and milliammeter, the battery box containing sufficient batteries to supply approximately 155 volts to the current circuit, and the reels containing a quantity of wire that will permit depth investigations to 150 feet, can be readily carried over any ordinary terrain. The battery box is equipped with additional compartments for carrying incidental equipment such as tools, tapes, electrodes, etc.

In making a depth test the four electrodes are placed in a line spaced the distance A apart, hereafter referred to as the electrode spacing. As shown in figure 2, it is assumed that an equipotential bowl or hemisphere of radius A is set up around each of the two outside current electrodes. Every point on the surface of a hemisphere is at the same potential due to the current flowing from C_1 to C_2. The potential drop or potential difference between the two hemispheres is measured by a separate potential measuring circuit using P_1 and P_2 placed on the ground where the equipotential hemispheres intersect the ground surface. The measured values of E, the potential drop, and I, the current flowing in the circuit, are inserted in a simple formula: $P = 2\pi A \; E/I$ and the resistivity per centimeter cube is obtained. The calculated resistivity applies to a zone of soil A centimeters in depth. There is an empirical relation such that the electrode spacing is equivalent to the depth involved. It is relatively simple to expand the electrode spacing A to greater and greater values and thus obtain values of resistivity corresponding to greater and greater depths. Resistivity is plotted against electrode spacing or depth as shown in figure 3. The computed values of resistivity are shown plotted as a dashed-line curve and replot is made of cumulative values of resistivity. Straight lines are drawn through as many points as possible on the cumulative curve resulting in an intersection at a point, shown by the arrow, which has been found to approximate closely the depth of the overburden to a second geologic layer such as a hard rock. This is an empirical procedure which was developed by the Bureau of Public Roads and reported on in a paper published in 1944 1/. The trend in the dashed-line curve at a depth of 10 feet is significant in establishing the validity of the intersection obtained at 13.0 feet as representing the thickness of the surface layer. No attempt will be made to present a thorough discussion of the theoretical aspects of the resistivity test in this paper. Instead, field data obtained from resistivity tests made at widely scattered locations throughout the United States will be presented in an effort to show how the geophysical data can be used in a study of a variety of highway construction problems requiring reasonably thorough investigation of the subsurface for their proper solution. For further information and a short selected bibliography on the subject of geophysical methods of exploring the subsurface, the reader is referred to other recently published material dealing with the subject 2/ 3/ 4/ 5/.

Distribution of States Using Geophysical Tests

Figure 4 graphically illustrates the extent to which geophysical exploration, primarily by earth-restivity procedures, has become established in the United States. The herringbone areas show the 19 States that already have geophysical equipment for use in highway construction work. The cross-hatched areas indicate five additional States likely to acquire resistivity equipment and make use of it in their subsurface exploration within the next few months. The dotted areas denote conservative States that have expressed interest in the possibilities of the earth-resistivity test while the vertical lined areas show three States that have had a limited experience in the use of the geophysical test procedures in the past. Sixteen States are shown as having no direct contact with the work of the Bureau of Public Roads to date.

1/ "An Empirical Method of Interpretation of Earth-Resistivity Measurements" by R. Woodward Moore. AIME Technical Publication No. 1743, 1944.

2/ "Geophysical Methods of Subsurface Exploration in Highway Construction" by R. Woodward Moore. PUBLIC ROADS, Vol. 26, No. 3, August 1950, pp. 49-64.

3/ "Symposium on Surface and Subsurface Reconnaissance". Special Technical Publication, No. 122, ASTM, 1951, pp. 89-228. (Papers by eight authors).

4/ "Geophysical Methods Adapted to Highway Engineering Problems" by R. Woodward Moore. Geophysics, Vol. 17, No. 3, July 1952, pp. 505-530.

5/ "Geophysical Methods of Subsurface Exploration Applied to Materials Surveys" by R. Woodward Moore. Highway Research Board Bulletin No. 62, 1952, pp. 85-107.

Useful Materials Located Within the Limits of the Project, by Earth-Resistivity Test, Offer Substantial Economic Saving

Earth-resistivity surveys conducted by the Bureau of Public Roads on 12 miles of the Baltimore-Washington Parkway in Maryland were responsible for locating enough sand and gravel within the right-of-way limits to furnish sufficient select borrow for topping material to provide a 12-inch layer over the subgrade of a 4-lane divided highway for the entire 12-mile section.

Figure 5 shows two 30-foot constant depth traverses obtained on the project. The traverse at the top of the figure is typical of a survey over clay soil in the area. The curve is rather flat and the resistivity values are low, approximately 20,000 ohm-cms. throughout. The curve at the bottom of the figure is typical for sand in the same area. The variations in resistivity values are reflections of the depth of overburden upon the sand. The lower traverse was made at the southern end of a 4-mile section under contract.

Earlier experience in that part of Maryland had established that resistivity zones higher than 250,000 ohm-cms. usually contained a high percentage of sand and gravel free from silt and clay within a 30-foot depth below the surface. The area in the vicinity of this traverse was further explored and a resistivity contour map of the area was drawn as shown in figure 6. The encircled crosses labeled "DT" denote resistivity depth test locations. The solid circles show five locations where borings were made to check the resistivity data and obtain samples for testing in the laboratory. The results of the 24 depth tests made in the test area were checked satisfactorily by this small number of borings. Excellent material was found precisely in the center of an 8-mile section which required a 12-inch granular topping layer over unsuitable subgrade material. The resistivity test provided reliable information concerning the subsurface materials that were encountered during the construction of the Parkway.

Earth-Resistivity Test Results Successfully Correlated With Direct Methods in a Variety of Construction Problems

<u>Landslide conditions</u>.--One of the more difficult subsurface exploration problems confronting the highway engineer today is that of evaluating the probability of landslides prior to design and construction. Surface geology surveys and large numbers of borings are usually resorted to for adequate design information. The limited amount of work done to date on this problem with the resistivity test method has been encouraging. It appears that this test may be helpful in eliminating many borings.

Figure 7 shows three depth test graphs obtained in April 1954 on a section of a proposed relocation of U. S. Route 60 just east of Charleston, West Virginia. The graph to the left is the result of a depth test 328 feet left of the railroad at Station 382+50. The boring data confirms rather well the resistivity curve. The drill, however, was stopped by the shale stratum at 23 feet whereas the resistivity curve indicates the bottom of the shale layer overlaying sandstone at 39 feet. The elevation of the indicated sandstone ledge checks well with an elevation found for outcropping sandstone elsewhere in the immediate area. The curve in the center of the figure was made at the same station only down the slope to within 157 feet of the railroad. Here shale is indicated at 19 feet below talus overburden. The graph to the right of the figure was made 60 feet left of the railroad and still on the same section.

Shale was located at 21.5 feet below ground elevation at this point. Using the information from these three tests plus others a cross section was drawn of Station 382+50 as shown in figure 8. The results of the resistivity test and drill holes are shown as marked and the probable slip plane of the shale surface is outlined. Knowledge of the sandstone ledge at elevation 710 should be useful for more economical terracing and benching design. The close agreement in elevation between the two tests locating the sandstone should confirm the engineer's interpretation that the sandstone found by the drill was actually ledge rock and not a large broken boulder that had moved down the hill. Information such as that shown in figure 8 can be obtained rapidly and in areas where truck or jeep mounted auger equipment could not reach.

Slope design.--Earth-resistivity surveys by Bureau of Public Roads personnel had been rather limited in the western States prior to the spring of 1954. Figure 9 shows calibration data (left-hand graph) obtained over hard dolomitic limestone, weathered material, soil-boulders and silty soil in southeast Idaho on the Fish Creek project just east of Lava Hot Springs. The right-hand graph shows curves in the lower part of the graph that are typical of the data obtained over several deep cut sections on the project. Obviously, soil conditions, perhaps very poor soil, existed to the full depth of the three tests shown. A sample of soil from a 10- to 12-foot auger hole when tested in the laboratory should indicate the conditions to be expected at grade some 30-40 feet below the surface. The material indicated by the fourth curve in the graph is a very dense dolomitic limestone, outcropping in a shallow cut bank near the test site, which should extend downward to a considerable depth. This material should be satisfactory quarry material for use elsewhere on the project.

Figure 10 shows three depth tests made on Route 6 near Netcong, New Jersey, during September 1950. The center graph shows a test that was made over a drill hole on centerline at Station 503+00. The tests to left and right of center (left graph and right graph) were useful to project to either ditch line the cross section of the underlying gneiss rock. If, for example, the centerline cut at Station 503+00 was 21 feet, the excavation to the left of centerline would involve earth slopes, whereas the excavation to the right of centerline may involve a rock bench for the first 5 feet above grade. The resistivity test on centerline, over subsurface conditions proven by the drill, was used as a calibration for the lateral tests. A detailed knowledge of the subsurface is extremely important in New Jersey as that State asks for bids for excavation on a classified basis. Therefore, in this survey the resistivity test was used to supplement the drill, thereby increasing the amount of information gathered in the limited time available for subsurface work and also to remain within the budget allowed for such work.

Bridge foundations.--The successful application of the earth-resistivity test to subsurface studies of bridge sites has been thoroughly demonstrated.

In June 1953, a resistivity test made on a gravel bar in the Mad River near Warren, Vermont, produced data for the curve shown in figure 11. The resistivity test showed changes at depths approximating the sand and gravel and bedrock as found by the drill at a nearby drill hole location. Tests for bridge piers should be possible while working from boats over water-covered areas, the electrodes being floated into position for successive electrode spacings.

On March 19, 1954, several grade separation structure sites were investigated along the Maryland National Pike, U. S. Route 240, in the vicinity of Rockville, Maryland. Here again the resistivity test confirmed the findings of the drill. In figure 12 the graph (upper left) indicates that the weathered rock the drill crew found to exist from the surface to 40 feet, continued for at least another 30 feet and would probably be good foundation for a bridge abutment. The graph (upper right) also indicates weathered rock from near the surface down to 50 feet where the rock becomes harder and more dense. If the drill record had not been available to identify the material, certainly the two lower curves obtained in the immediate area would suggest which materials were encountered. The graph (lower left) was made over a weathered schist bank in an exposed cut located in the immediate area. The similarity of this curve to the two upper curves is evident. The graph (lower right) shows the type of curve obtained when the weathered schist is underlain by hard material. The upward trend in the curve at 21 feet is significant as it indicates the harder layer. If there was no change in material the curve would trend toward a horizontal asymptote near 100,000 ohm-cms. At this particular site no drilling would have been necessary, unless samples were desired for laboratory test, to identify the subsurface materials encountered.

Location of materials of construction.--One of the more important applications of the resistivity test is in locating sand and gravel or quarry material suitable for use in construction work.

Figure 13 contains curves for data obtained near Grangeville, Idaho, in a survey to establish the presence of an adequate supply of lava rock which was being quarried from a relatively small working face for use in local road construction. The left-hand curves show data from two constant-depth resistivity traverses, one over an area underlain by good quarry material, the other indicating the presence of unsuitable material for the first 150 feet and outlining the lateral contact of this material with the lava rock being sought.

The small contour map shows this contact to better advantage. The 10,000 ohm-cm. contour should delineate the boundary conditions rather closely. Note that the early part of traverse No. 1 parallels an exposed face of the existing quarry area where suitable material exists to a depth of about 22.0 feet, or 2.0 feet deeper than the depth involved in the traverse.

The depth curves on the right show the way in which the resistivity data disclose good material (upper graph) or unsuitable material (lower graph). Two or three hours work was sufficient to get the information shown in the figure. A third resistivity traverse running at right angles to traverse No. 1 in the vicinity of Station 2+00 would have served to further prove the area, together with extensions of the two traverses shown.

Some years ago it was possible to make a resistivity survey of a tract of land immediately adjacent to an area where sand and gravel pit operations were in progress. Over the intervening years this area has been excavated making possible a direct check of the test results. A brief description of this survey follows.

After several preliminary tests had indicated that a resistivity survey should prove of value, a network of some 30 to 40 constant depth traverses were run throughout the area. Figure 14 shows data from two of the traverses which were run in a direction parallel to the existing working face, and at distance of 225 and 375 feet to the west. The zones of high resistivity indicate areas where practically no stripping would be required and where the gravel would be sandy, having little or no objectionable amounts of clay or silty materials. The low resistivity zones indicate either much greater depths of overburden or a large increase in the amount of clay or silt within the gravel down to a depth equal to the electrode spacing used in the tests (25 feet). A single boring or test pit would suffice to determine which of these two conditions exist. Both conditions are to be avoided in the interest of savings in cost of stripping or in the cost of washing out the clay or silt at the processing plant. Figure 15 shows similar traverses made over an area to the northwest of the existing pit and here the conditions are much different. Heavy overburden and large clay inclusions are indicated in this area.

Figure 16 is a view of the working face in the vicinity of the high resistivity zone appearing in figure 14 between Stations 5+50 and 7+00 of traverse No. 11. The absence of overburden and the excellent character of the gravel is clearly shown. Figure 17 shows a view of the working face as abandoned about 50 feet east of Station 7+30 of traverse No. 16, where excessive thickness of overburden and the presence of a white clay stratum below a 10- to 12-foot stratum of gravel halted excavation operations.

A resistivity contour map of the entire area is shown in figure 18. The heavy shaded line in the lower portion of the figure represents the outline of the working face of the pit at the time the tests were begun in September 1940. The irregular broken line several hundred feet back to the west represents the working face as it appeared in April 1944. It is of interest to note that excavation was terminated in the vicinity of the 200,000 ohm-cm. contour in the northwest area in line with a suggestion made in 1940 that this contour might be taken as outlining a limiting condition beyond which stripping and clay inclusions would prove prohibitive.

Figure 19 illustrates how it is possible to relate a resistivity traverse made immediately adjacent to an existing working face with other such traverses at greater distances away from the face of the pit. The relation in this figure serves to show that conditions existing at the working face will continue to hold for some distance back into the adjoining area. Data of this character should be of value in placing shovel equipment to obtain a needed amount of clean sand and gravel.

Resistivity Test Useful in Planning Boring Program and Confirming Sounding Rod Data

Arbitrarily spaced borings may fail to show localized subsurface anomalies. Many borings carried to an arbitrary depth have failed to show the presence of materials at slightly greater depths likely to affect the stability of a structure. Figure 20 shows three depth tests considered typical of those useful in verifying sounding rod data and supplementing and augmenting the data obtainable by borings. In the left-hand graph, the steady rising trend in the field curve (dashed-line curve) is conslusive evidence that the ledge rock located by the sounding rod is actually a continuous rock formation down to a depth of 42.0 feet. Rather inexpensive rod soundings may be confirmed by a 20-minute resistivity test.

In the middle graph of figure 20 the very startling change to a low resistivity layer at a depth of 35.0 feet occurs at a depth just 2 or 3 feet below the lowest elevation reached by borings made in the area when the bridge site was explored originally. Although the extremely low resistivity could be caused by a relatively stiff clay formation of marine origin in which salt particles are still imprisoned, it also could be a result of unstable silty materials of more recent river deposits. Whatever the source of the low resistivity readings, a resistivity survey prior to the boring program would have indicated that a 10-foot deeper boring was needed to obtain samples of the underlying stratum for laboratory analysis for stability of the material. Again, in the right-hand graph, a very firm layer of slag outcropping in a shallow cut bank near to the proposed pier location can be assumed with some certainty to exist to a depth of 47.0 feet beneath the surface, thus providing a dependable foundation condition for the pier.

Conclusion

The resistivity test has proven itself to be a valuable means for evaluating subsurface conditions met with in highway construction rapidly and economically.

If time permitted, many other examples of the successful application of the resistivity test to highway engineering problems could be provided from the field data now on file with the Bureau of Public Roads. In the rare situation where geologic conditions are found to be entirely unfavorable at a particular location, this fact can be established by a comparatively few tests and at nominal cost. If the geology of the area is favorable, a resistivity survey on a single project may provide savings sufficient to underwrite a geophysical explorations program for many years into the future.

Geophysics in shallow engineering studies has surely come of age.

FIGURE 1.—RESISTIVITY APPARATUS USED BY THE BUREAU OF PUBLIC ROADS

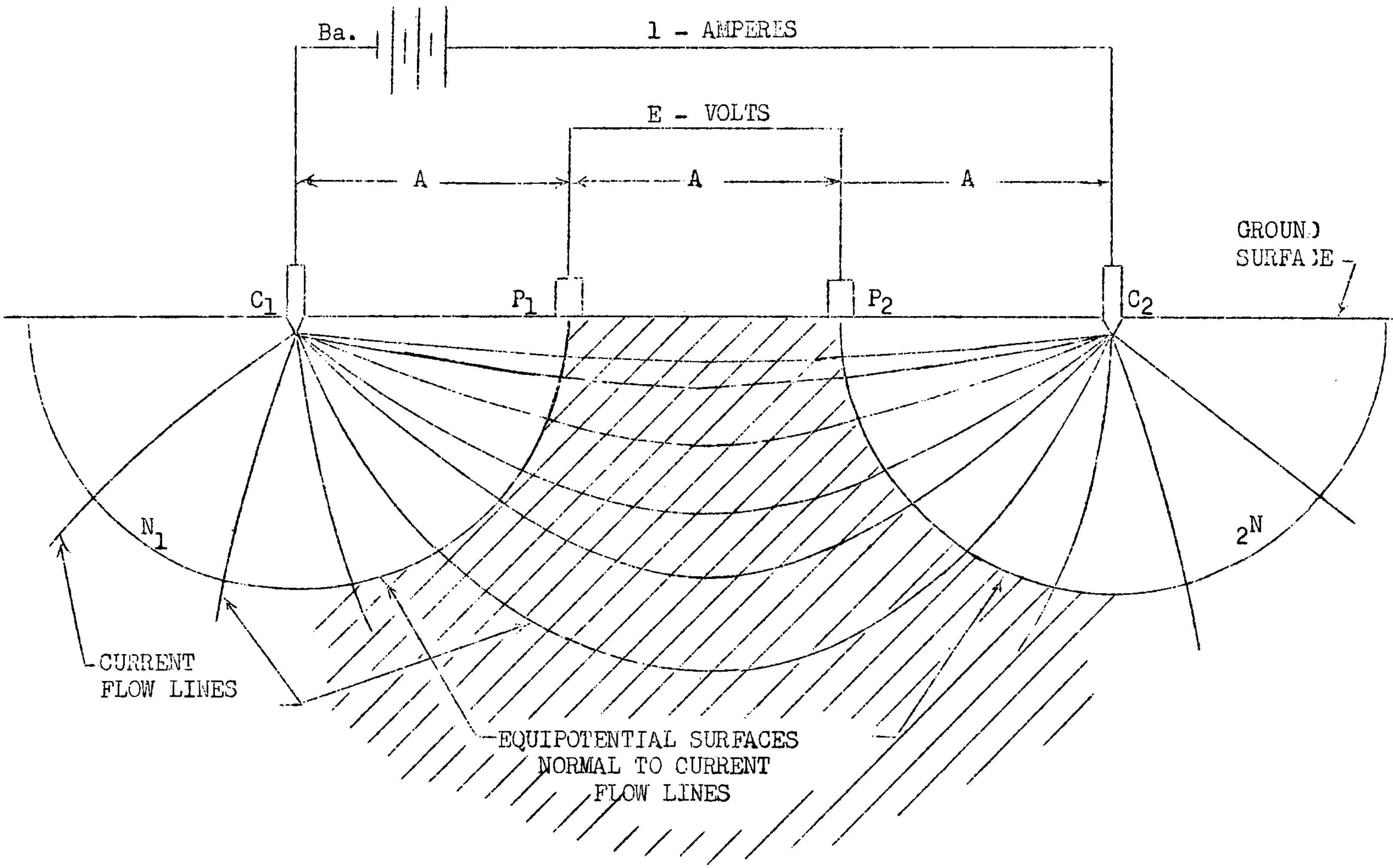


FIGURE 2 - EQUIPOTENTIAL BOWLS ASSUMED BENEATH CURRENT ELECTRODES WHEN MAKING EARTH-RESISTIVITY TESTS.

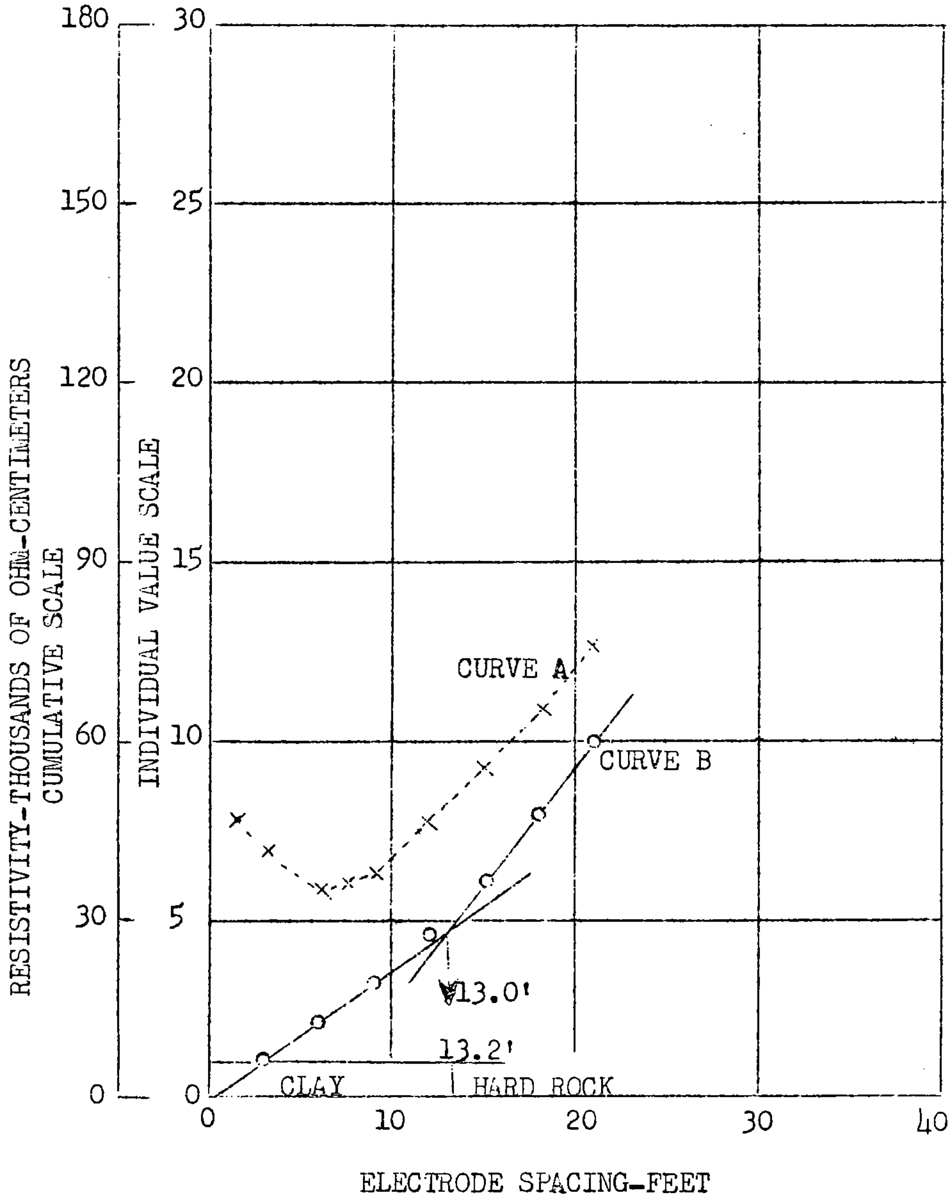


FIGURE 3 - EMPIRICAL METHOD OF ANALYSIS APPLIED TO RESISTIVITY CURVE FOR A CLAY STRATUM UNDER-LAIN BY ROCK IN THE VICINITY OF WASHINGTON, D. C.

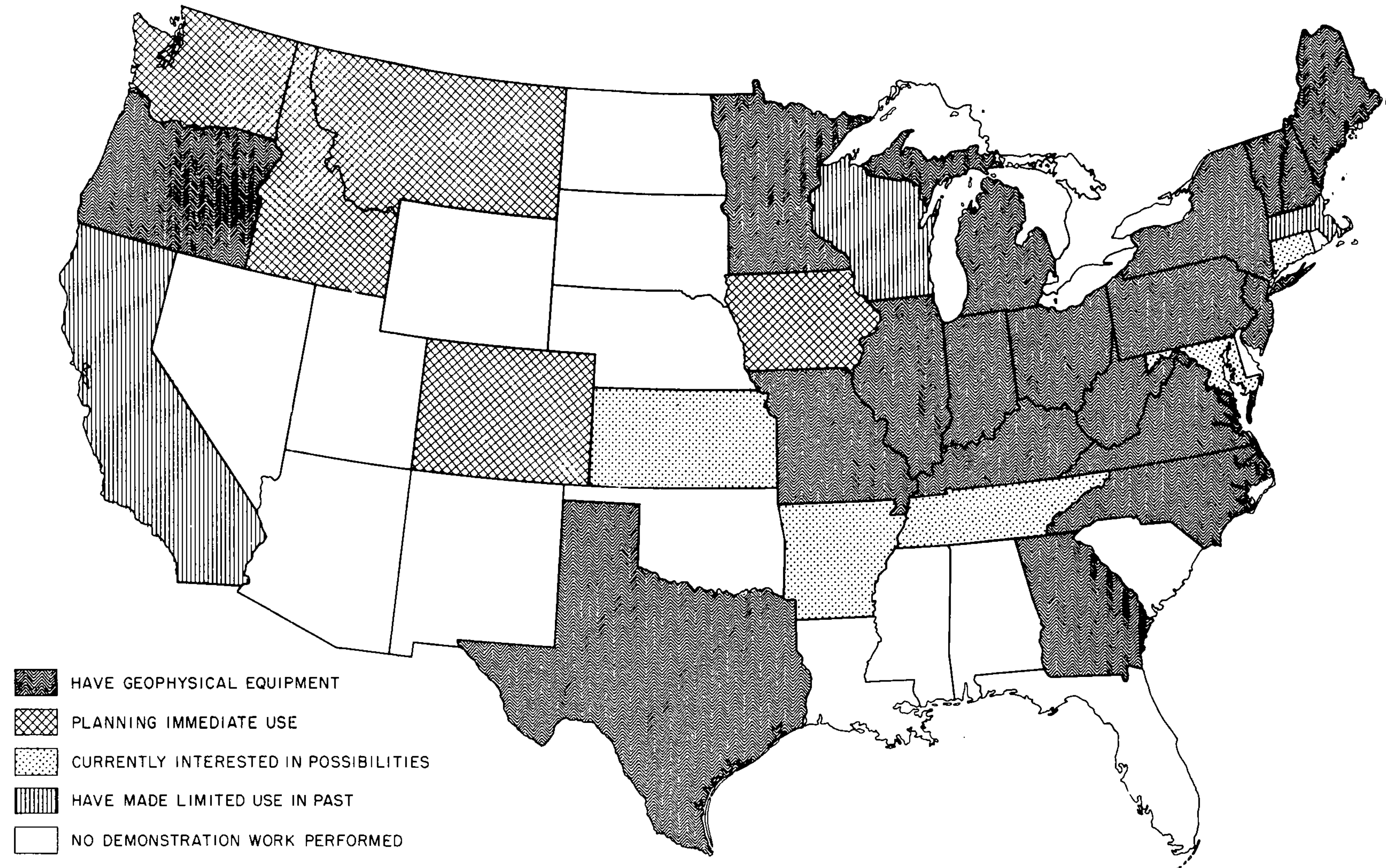
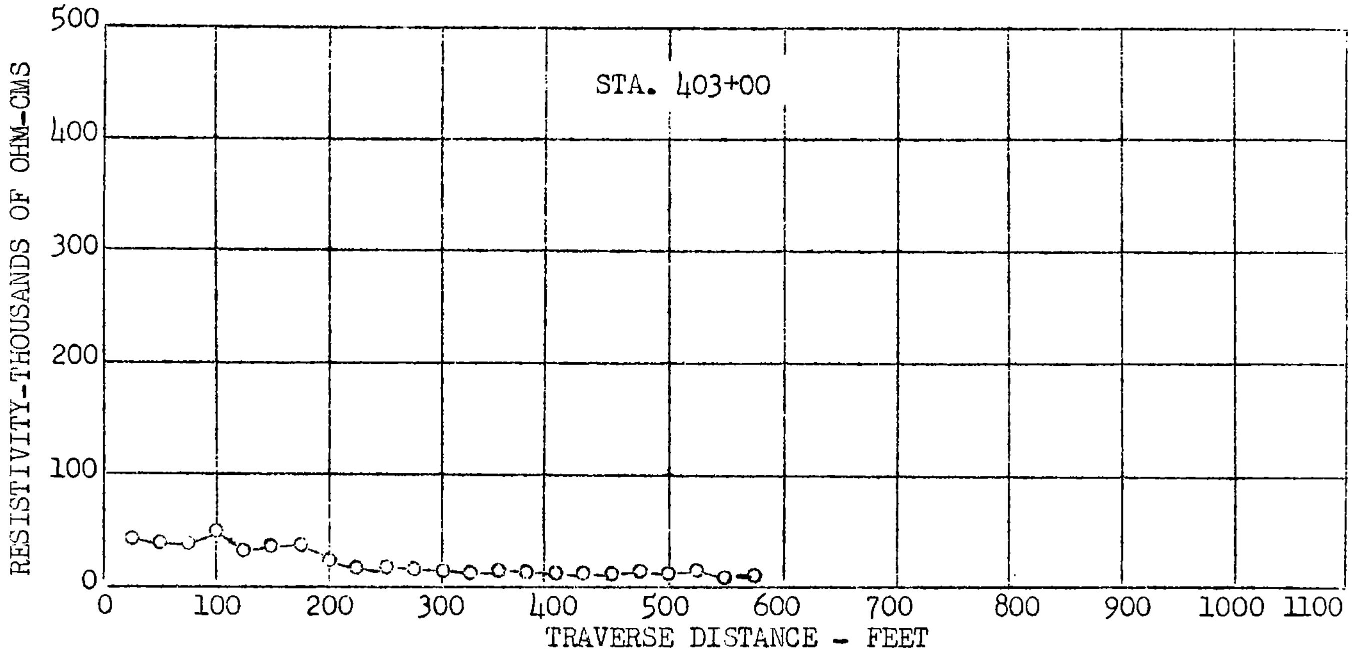


FIGURE 4 - MAP SHOWING CURRENT USE OF GEOPHYSICAL METHODS IN HIGHWAY CONSTRUCTION IN THE UNITED STATES. (SEPTEMBER, 1954)



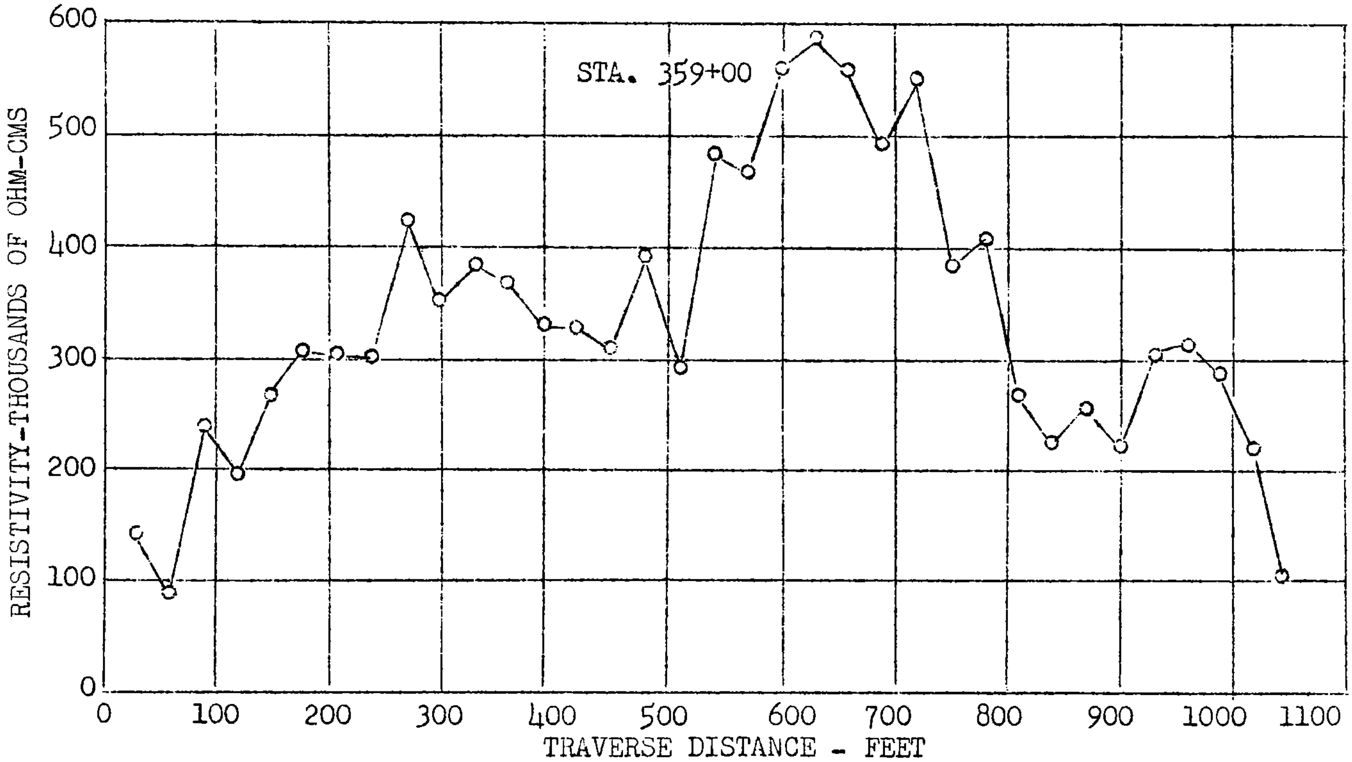


FIGURE 5 - THIRTY-FOOT CONSTANT DEPTH TRAVERSES OVER SAND (LOWER GRAPH) AND OVER CLAY PROVIDE CONTRASTING DATA ON THE BALTIMORE-WASHINGTON PARKWAY, PROJECT IDI-IE4.

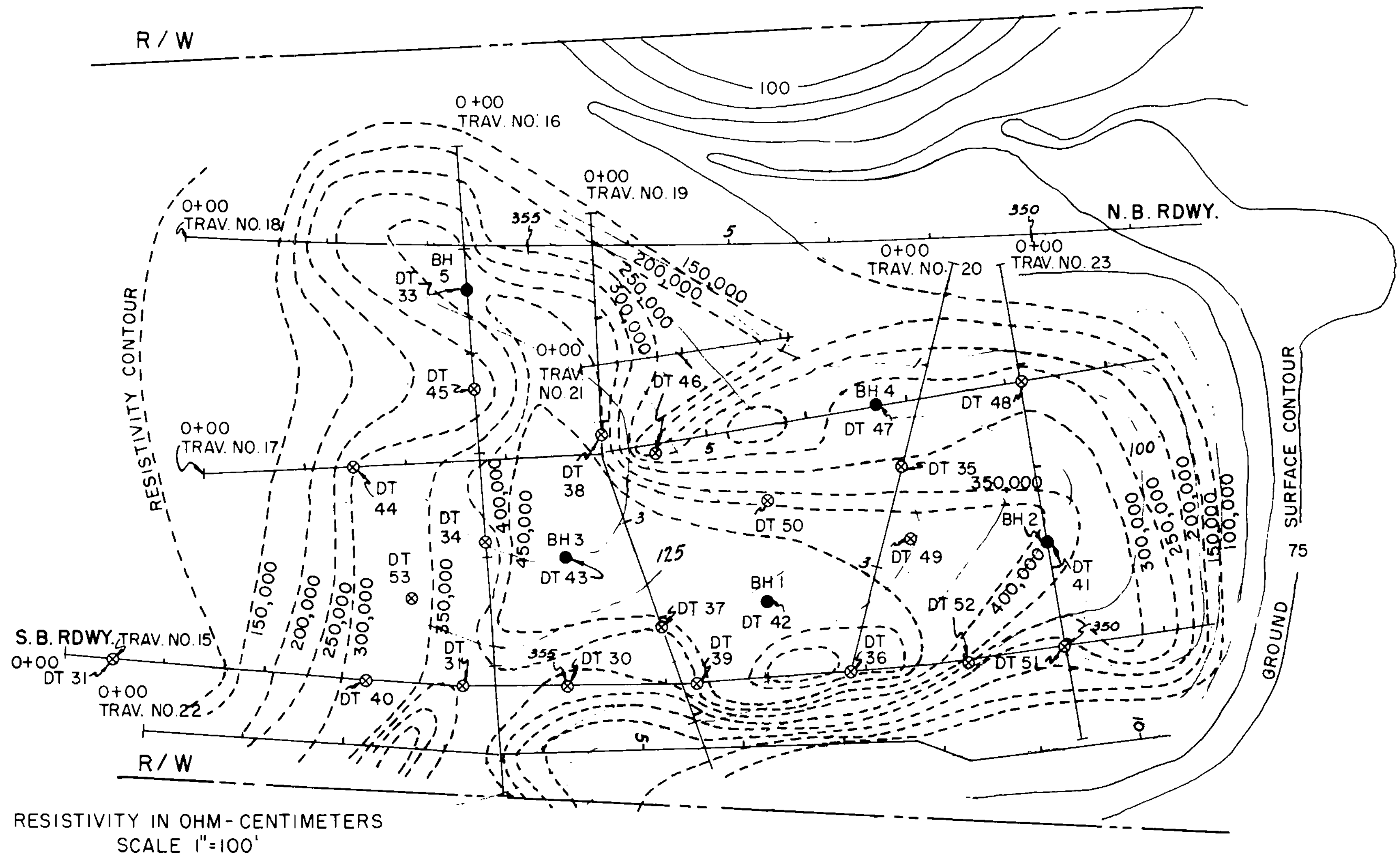
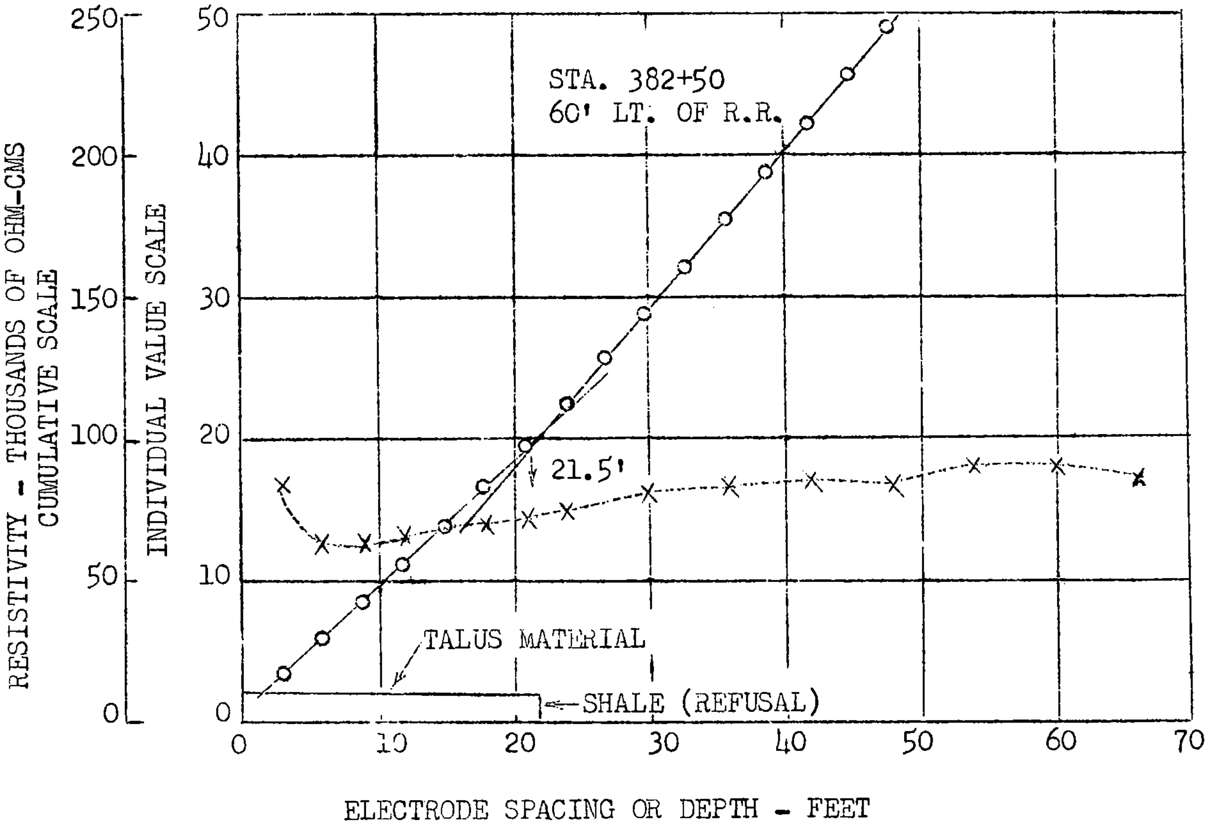


FIGURE 6 - RESISTIVITY CONTOUR MAP SHOWING SAND AND GRAVEL DEPOSIT LOCATED BETWEEN PROJECT STATIONS 348+00 AND 358+00 BALTIMORE-WASHINGTON PARKWAY.



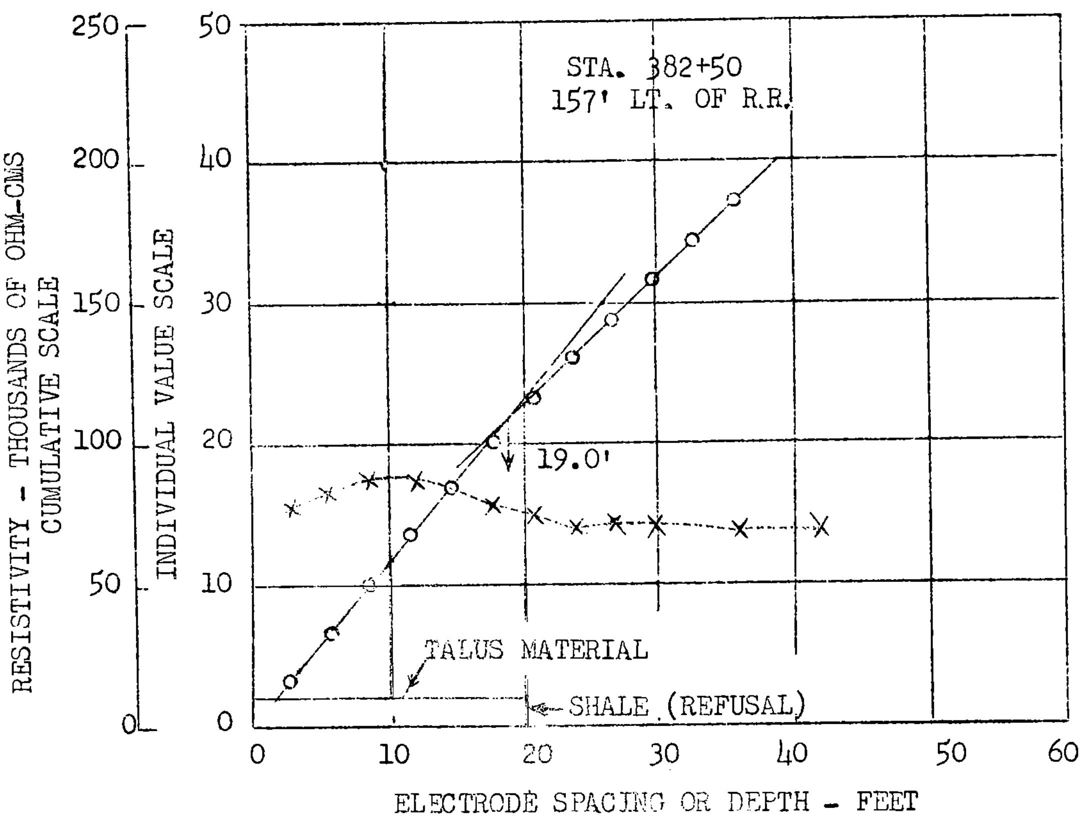


FIGURE 7 - DEPTH TESTS AT STATION 382+50, PROJECT FA221(12), ON U.S. ROUTE 60 EAST OF CHARLESTON, WEST VIRGINIA, EXPAND DATA OBTAINED BY DRILL IN EFFORT TO DETERMINE PROBABLE SLIP PLANE IN POTENTIAL LANDSLIDE AREA.

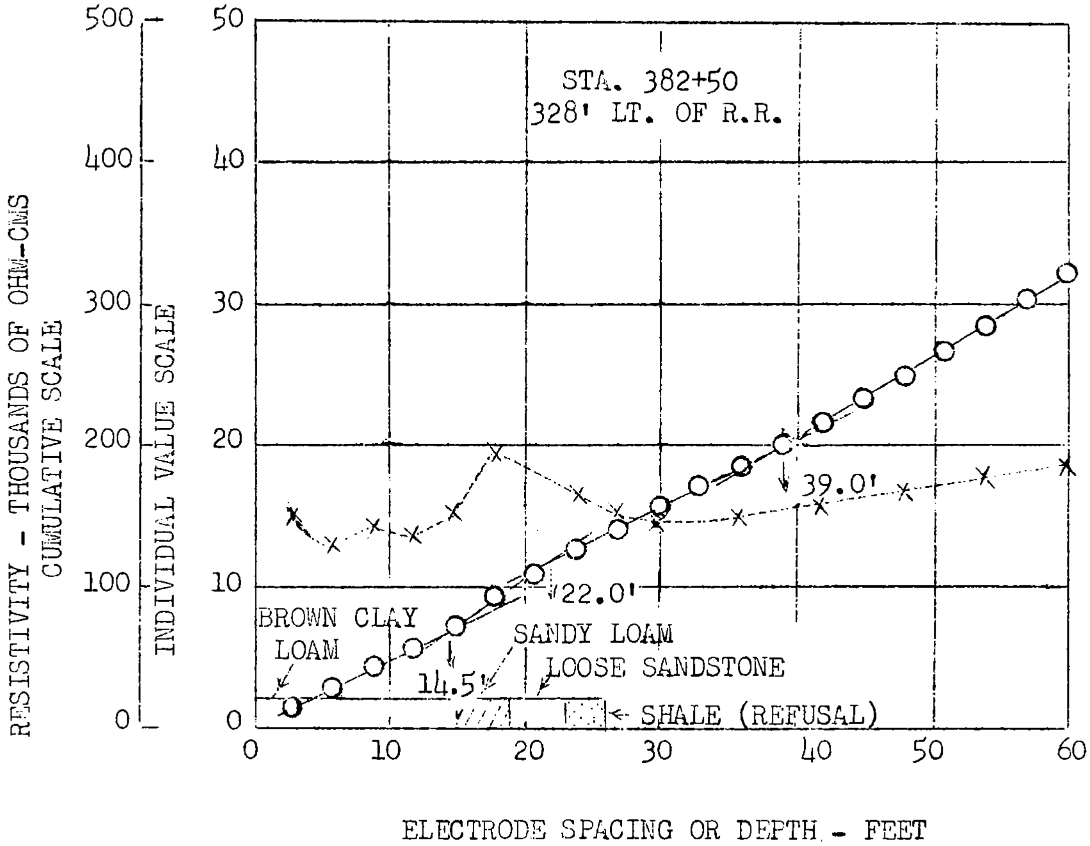


FIGURE 7 (CONTINUED) - DEPTH TESTS AT STATION 382+50, PROJECT FA221(12), ON U.S. ROUTE 60 EAST OF CHARLESTON, WEST VIRGINIA, EXPAND DATA OBTAINED BY DRILL IN EFFORT TO DETERMINE PROBABLE SLIP PLANE IN POTENTIAL LANDSLIDE AREA.

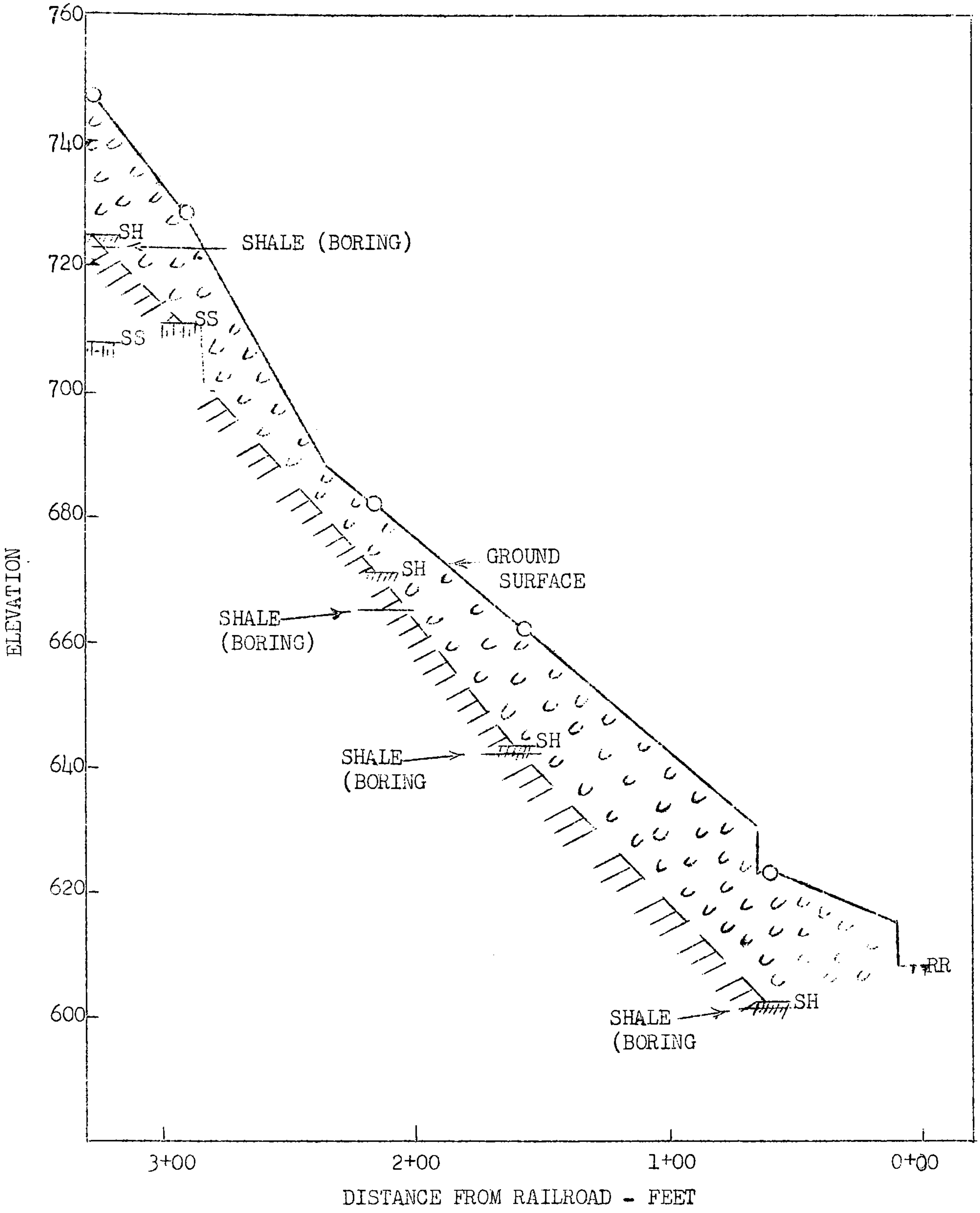


FIGURE 8 - CROSS-SECTION AT STATION 382+50, PROJECT FA221(12), ON U.S. ROUTE 60 EAST OF CHARLESTON, WEST VIRGINIA, SHOWING GROUND SURFACE AND THE BEDROCK CONTOUR FOUND BY EARTH-RESISTIVITY TESTS.

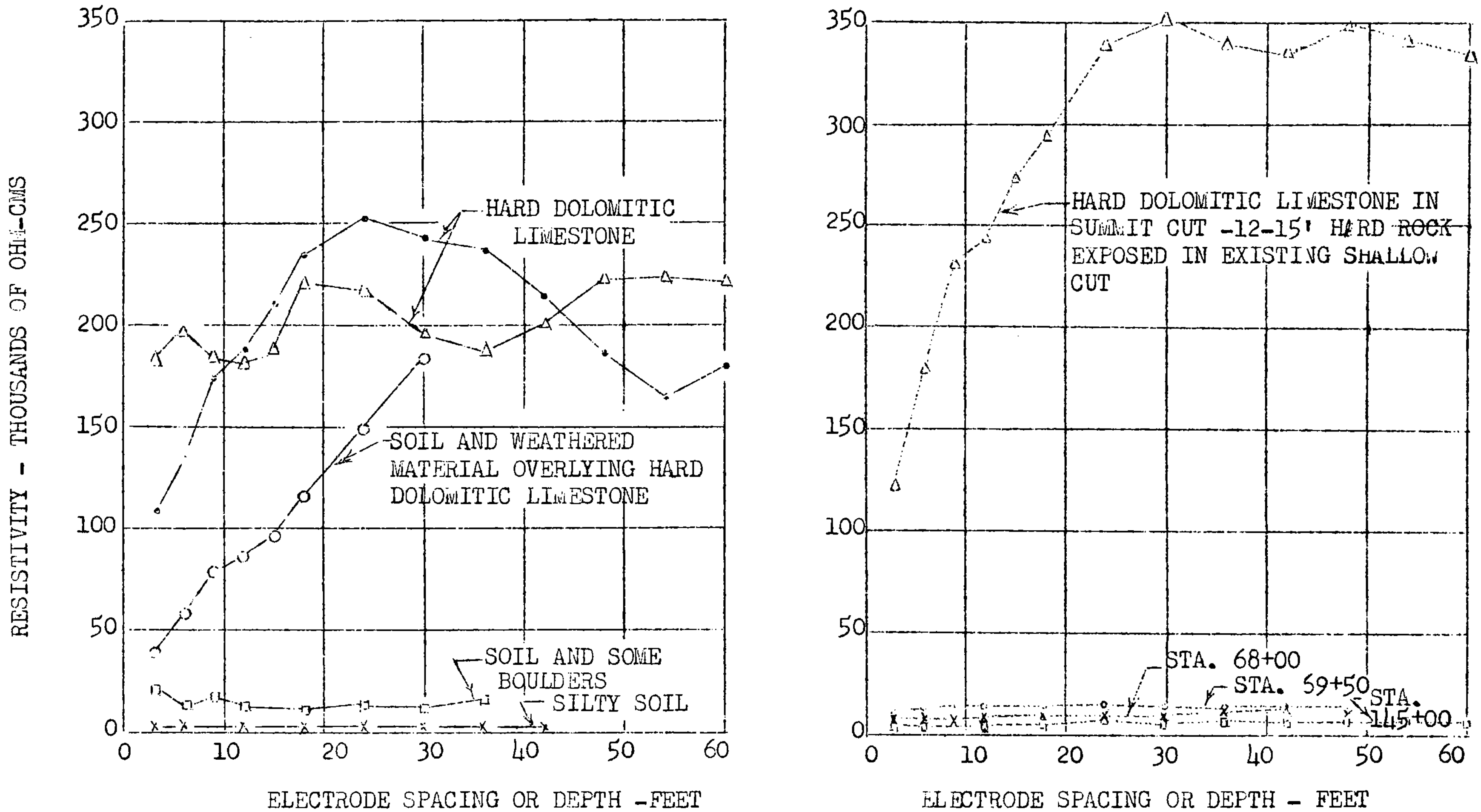


FIGURE 9 - RESISTIVITY CALIBRATION CURVES (LEFT) AND TYPICAL FIELD CURVES OBTAINED ON FISH CREEK PROJECT FA-148(1) IN SOUTHEASTERN IDAHO

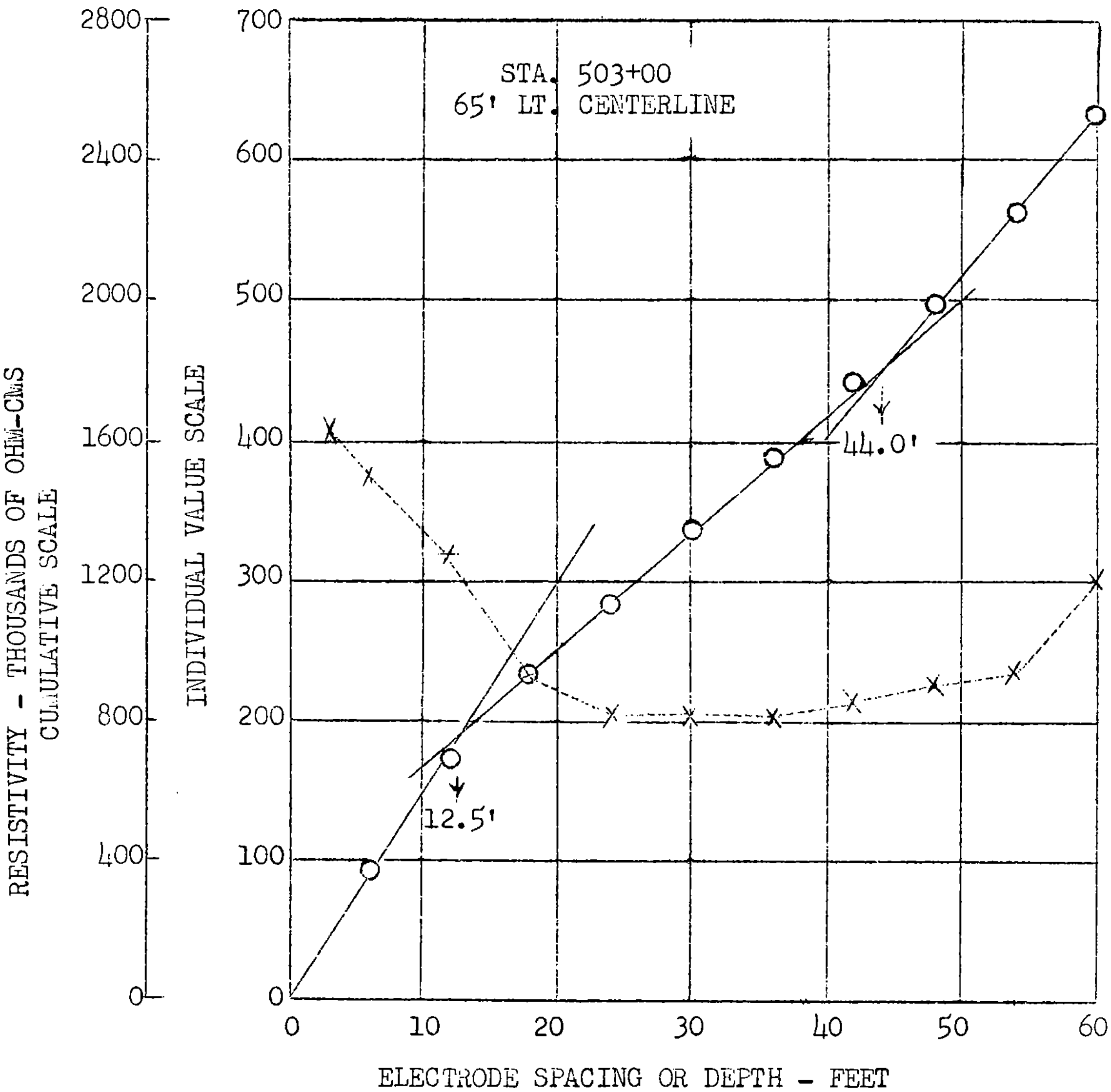


FIGURE 10 - DEPTH TESTS AT STATION 503+00 ON ROUTE 6 NEAR NETCONG, NEW JERSEY, PROVIDE CROSS-SECTION OF SUBSURFACE ROCK FOUND UNDER CENTERLINE BY THE DRILL.

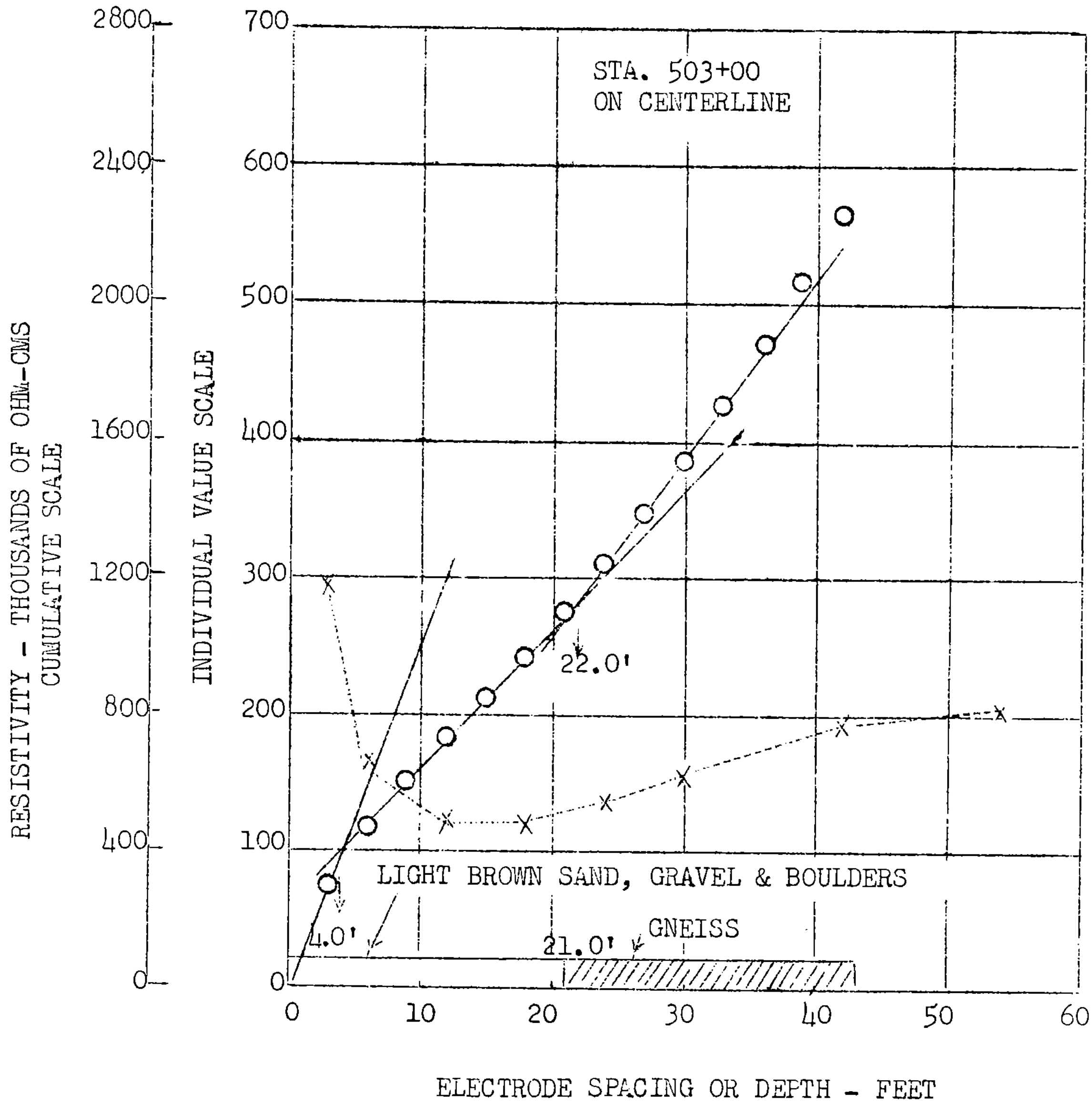


FIGURE 10 - DEPTH TESTS AT STATION 503+00 ON ROUTE 6 NEAR NETCONG,
(CONTINUED) NEW JERSEY, PROVIDE CROSS-SECTION OF SUBSURFACE ROCK FOUND UNDER CENTERLINE BY THE DRILL.

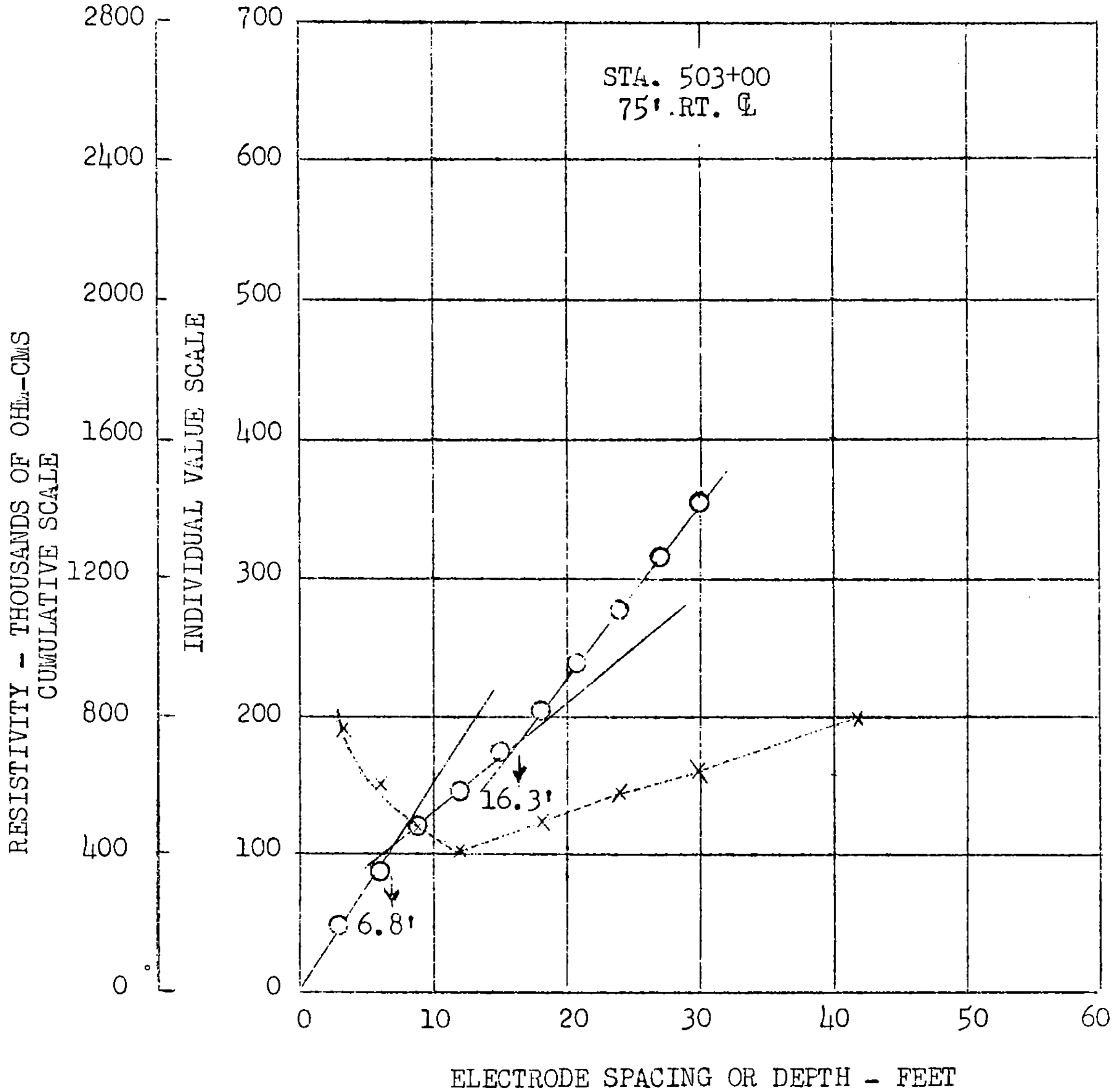


FIGURE 10 (CONTINUED) - DEPTH TESTS AT STATION 503+00 ON ROUTE 6 NEAR NETCONG, NEW JERSEY, PROVIDE CROSS-SECTION OF SUBSURFACE ROCK FOUND UNDER CENTERLINE BY THE DRILL.

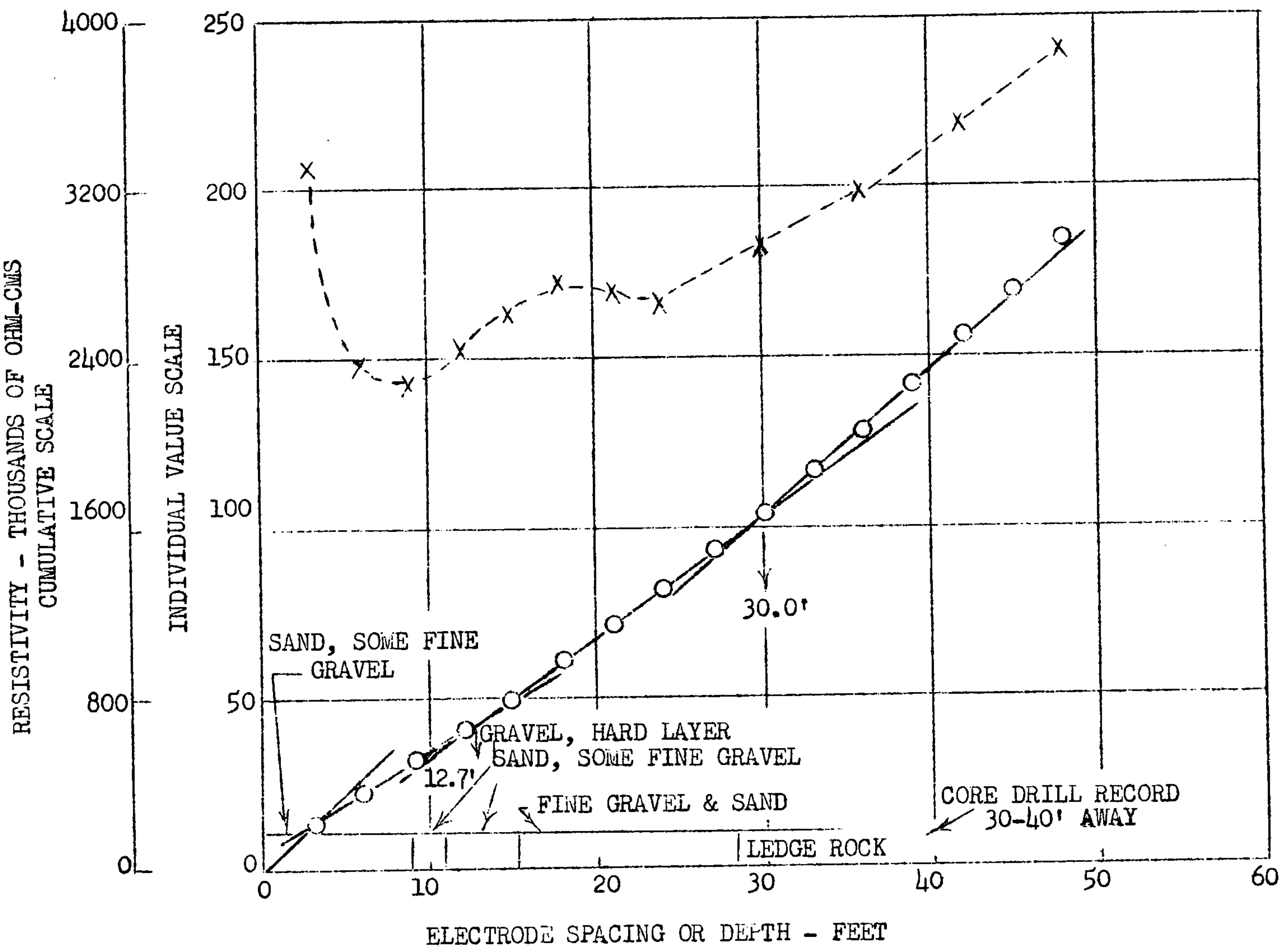


FIGURE 11 - EARTH-RESISTIVITY TEST AT BRIDGE SITE ON MAD RIVER NEAR WARREN, VERMONT

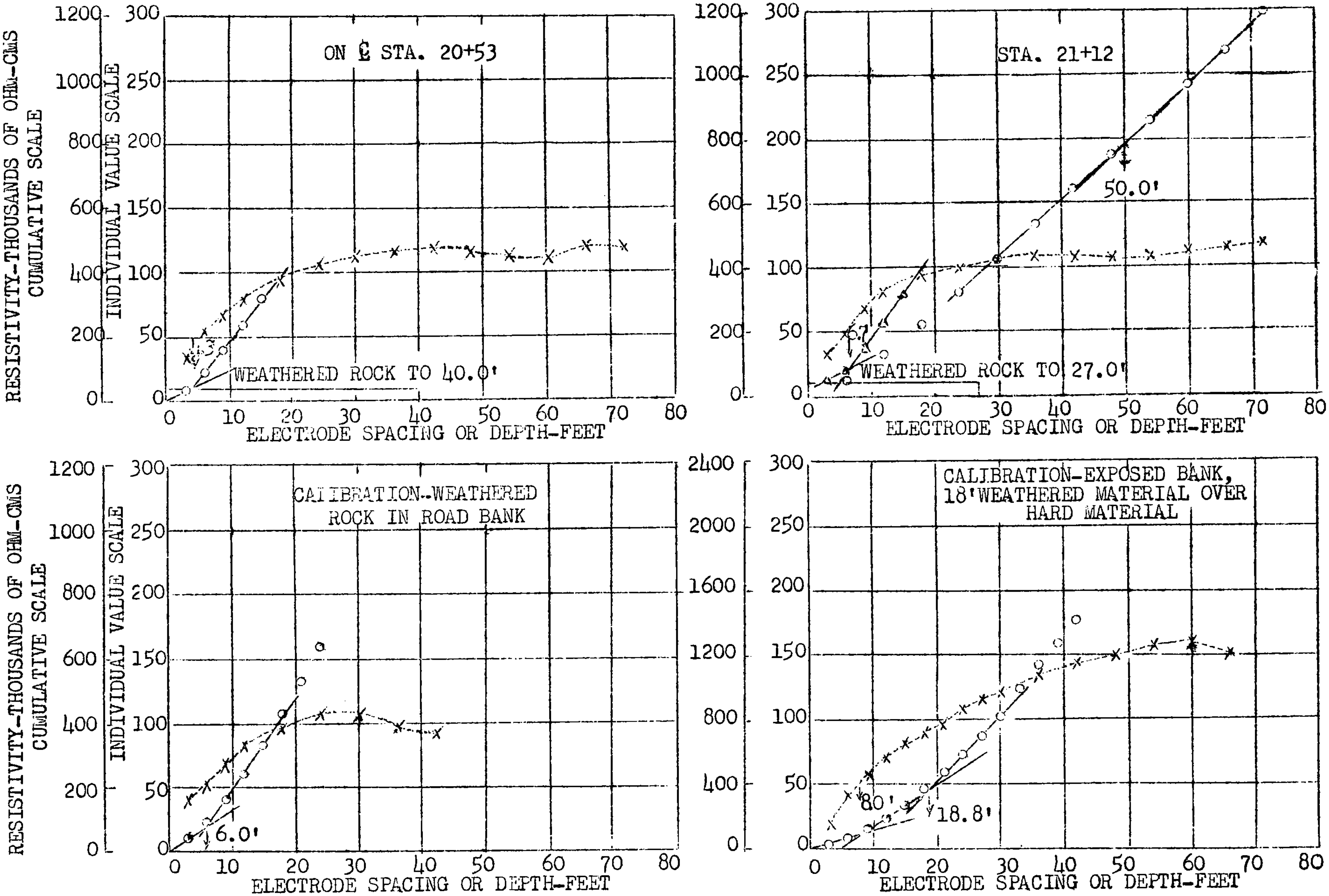


FIGURE 12 - RESISTIVITY TESTS ESTABLISH IDENTITY OF FOUNDATION MATERIALS FOR GRADE SEPARATION STRUCTURE ON MARYLAND NATIONAL PIKE, U.S. ROUTE 240, WEST OF ROCKVILLE, MARYLAND.

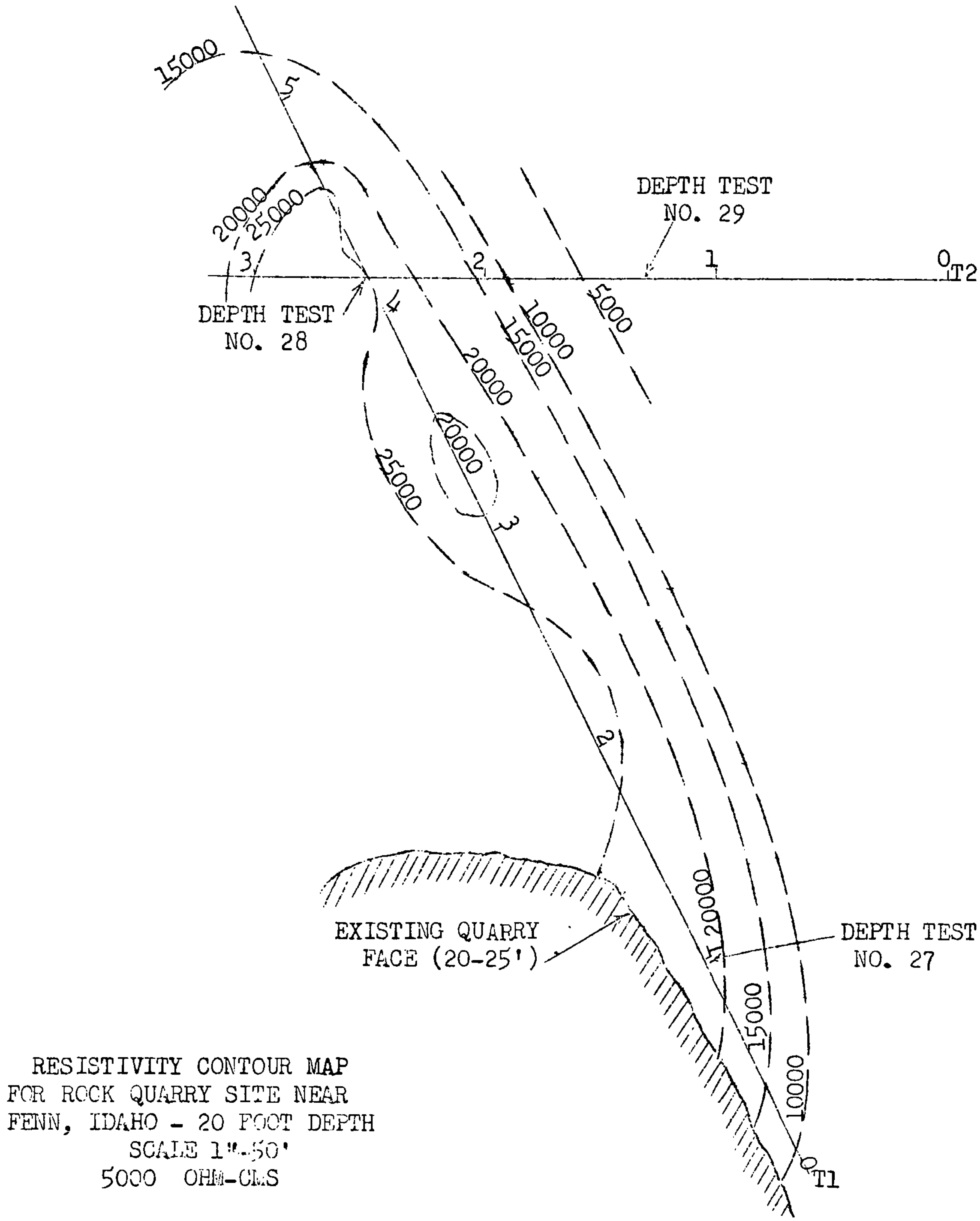


FIGURE 13 - EARTH-RESISTIVITY TESTS OUTLINE BOUNDARIES OF USEFUL LAVA ROCK IN EXTENDING QUARRY OPERATIONS NEAR FENN, IDAHO

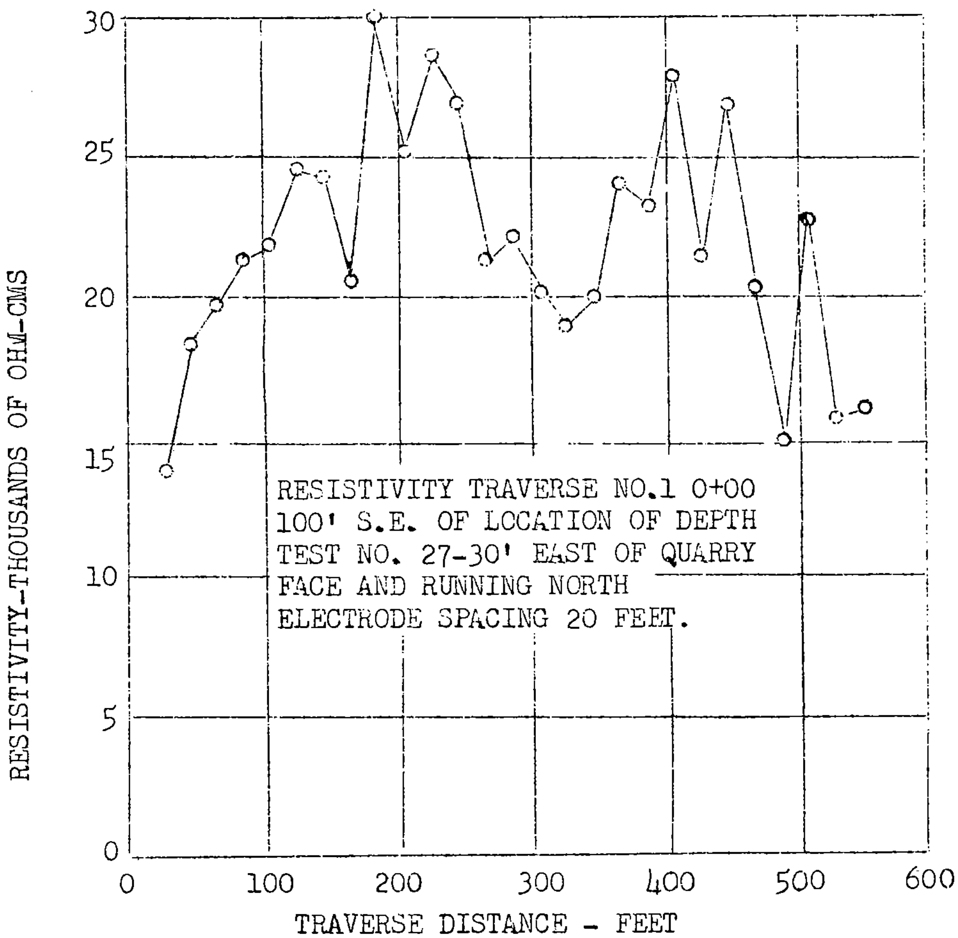


FIGURE 13 - EARTH-RESISTIVITY TESTS OUTLINE BOUNDARIES OF USEFUL LAVA ROCK IN EXTENDING QUARRY OPERATIONS NEAR FENN, IDAHO

(Continued)

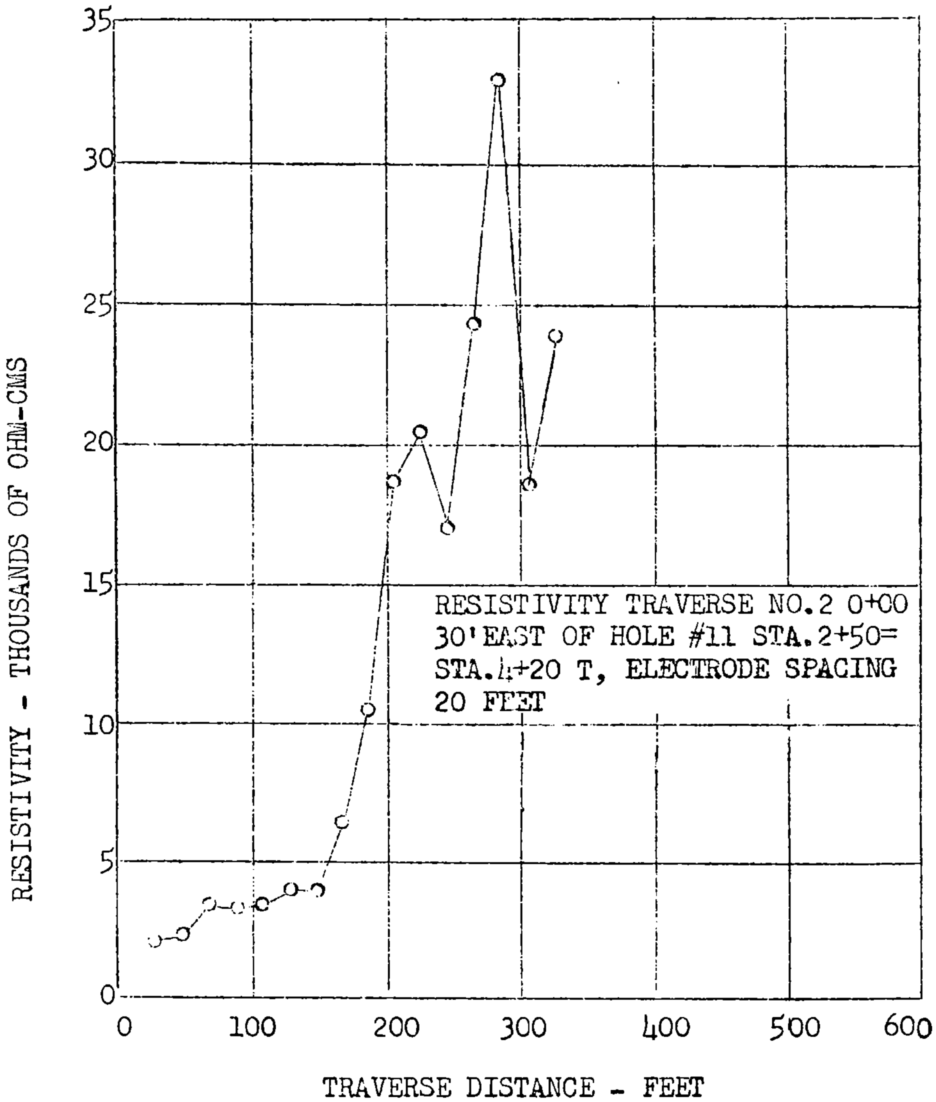


FIGURE 13 - EARTH-RESISTIVITY TESTS OUTLINE BOUNDARIES OF USEFUL LAVA ROCK IN EXTENDING QUARRY OPERATIONS NEAR FENN, IDAHO

(Continued)

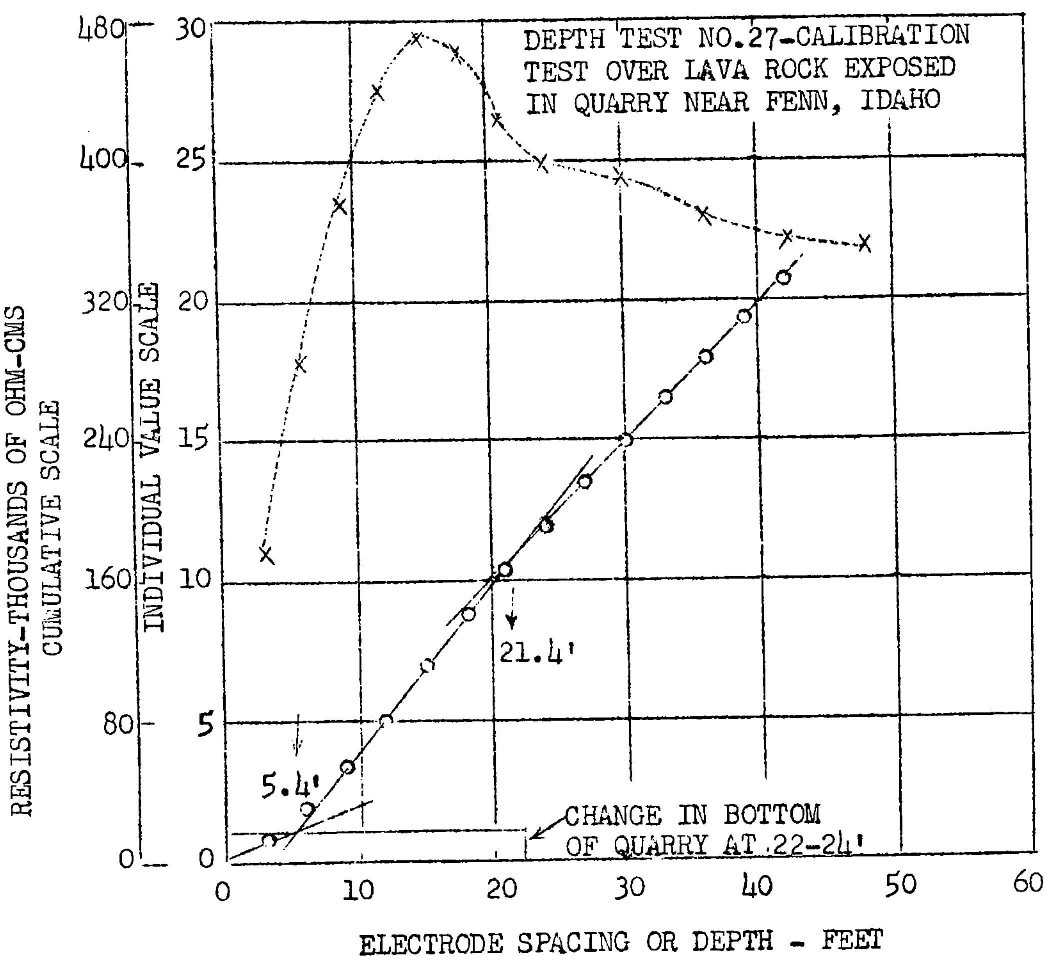


FIGURE 13 - EARTH-RESISTIVITY TESTS OUTLINE BOUNDARIES OF USEFUL LAVA ROCK IN EXTENDING QUARRY OPERATIONS NEAR FENN, IDAHO

(Continued)

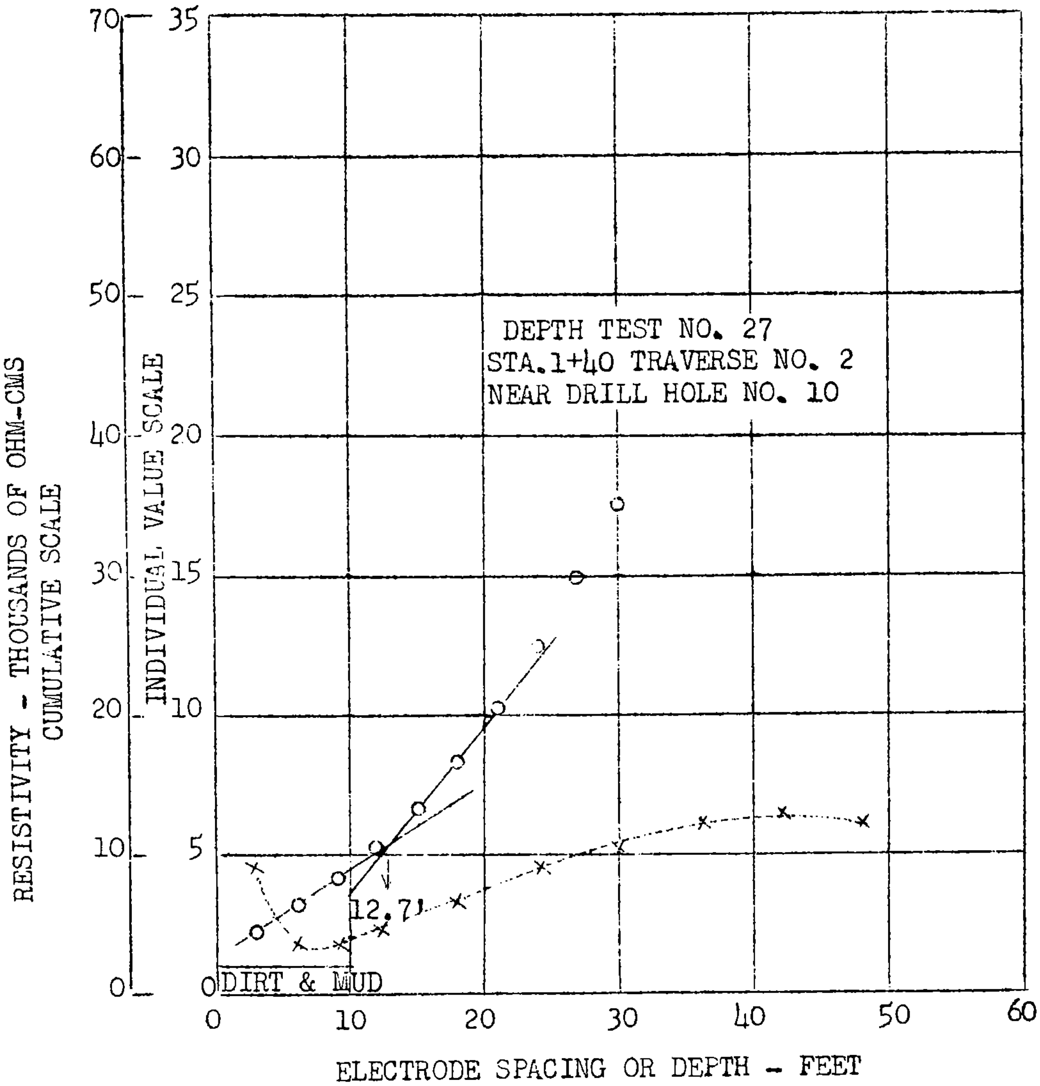


FIGURE 13 - EARTH-RESISTIVITY TESTS OUTLINE BOUNDARIES OF USEFUL LAVA ROCK IN EXTENDING QUARRY NEAR FENN, IDAHO

(Continued)

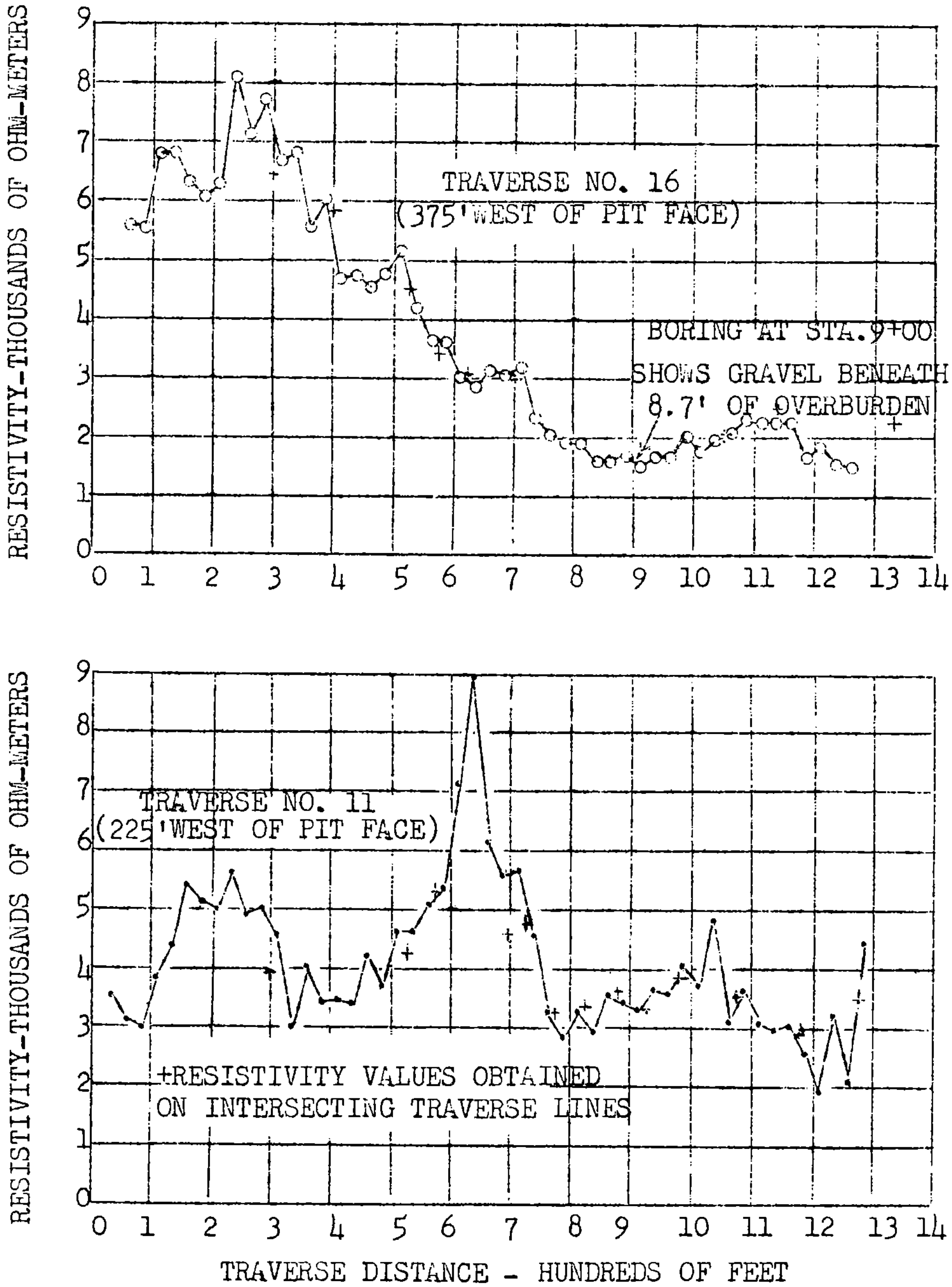


FIGURE 14 - RESISTIVITY TRAVERSE DATA SHOWING EFFECT OF VARIATION IN DEPTH OF OVERBURDEN AND INCREASING AMOUNTS OF CLAY WITHIN 25-FOOT DEPTH IN AREA ADJACENT TO PIT.

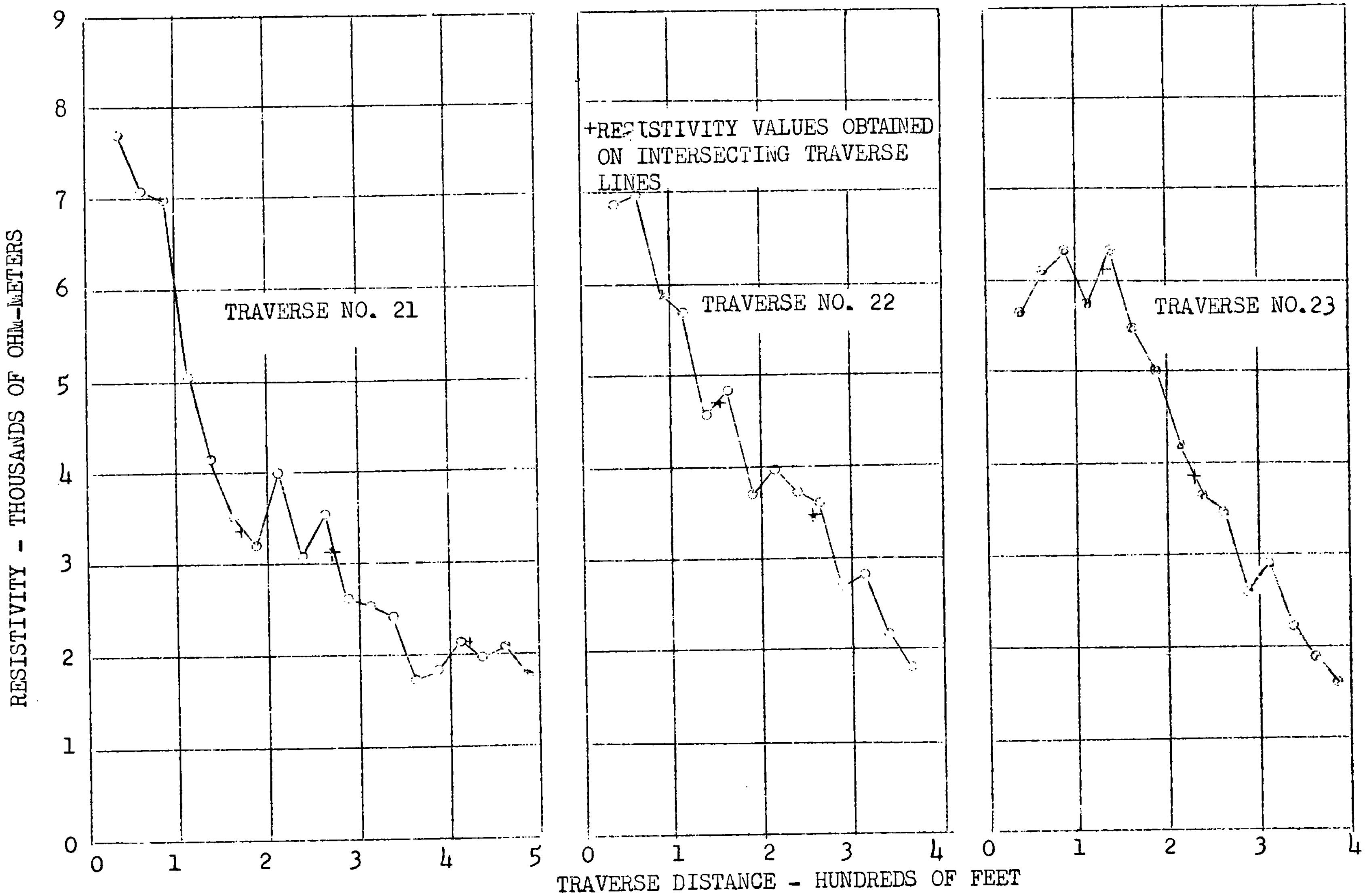


FIGURE 15 - RESISTIVITY DATA TYPICAL OF AREA NORTHWEST OF EXISTING GRAVEL PIT SHOWING EFFECT OF PASSING FROM THICK SANDY GRAVEL TO CLAYEY GRAVELS AND HEAVY OVERBURDEN. ELECTRODE SPACING 25 FEET.

Figure 16.—View showing working face in vicinity of high resistivity zone of Traverse No. 11, figure 14, between Stations 5+50 and 7+00.

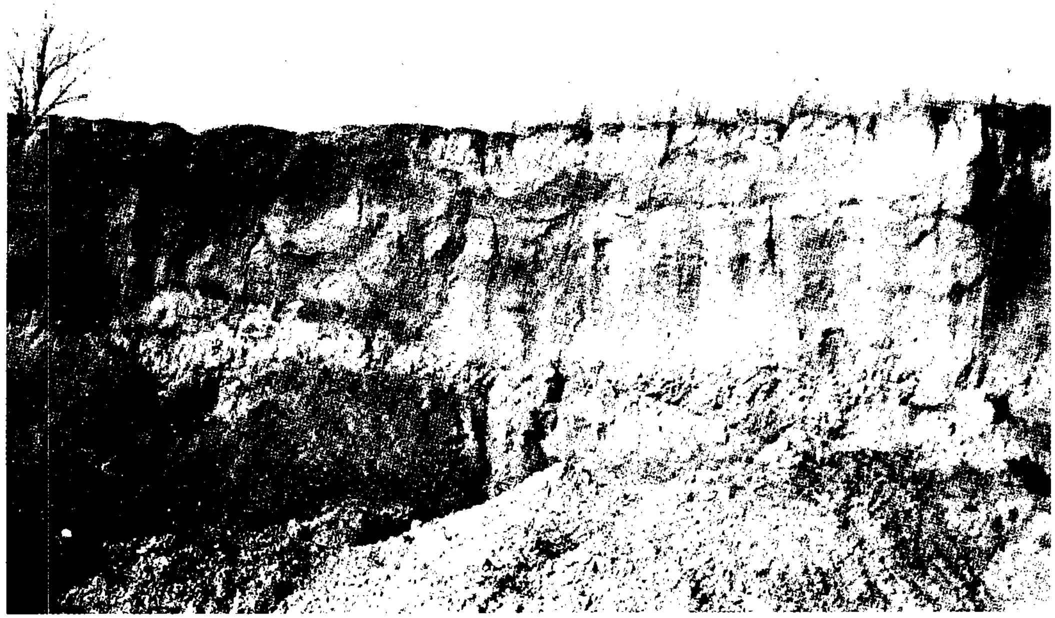


Figure 17.—View of Working Face 50 Feet East of Station 7+30, Traverse No. 16, in Vicinity of 2000-Ohm-Meter Contour Shown in Figure 18. Note Heavy Overburden Overlaying the Gravel.

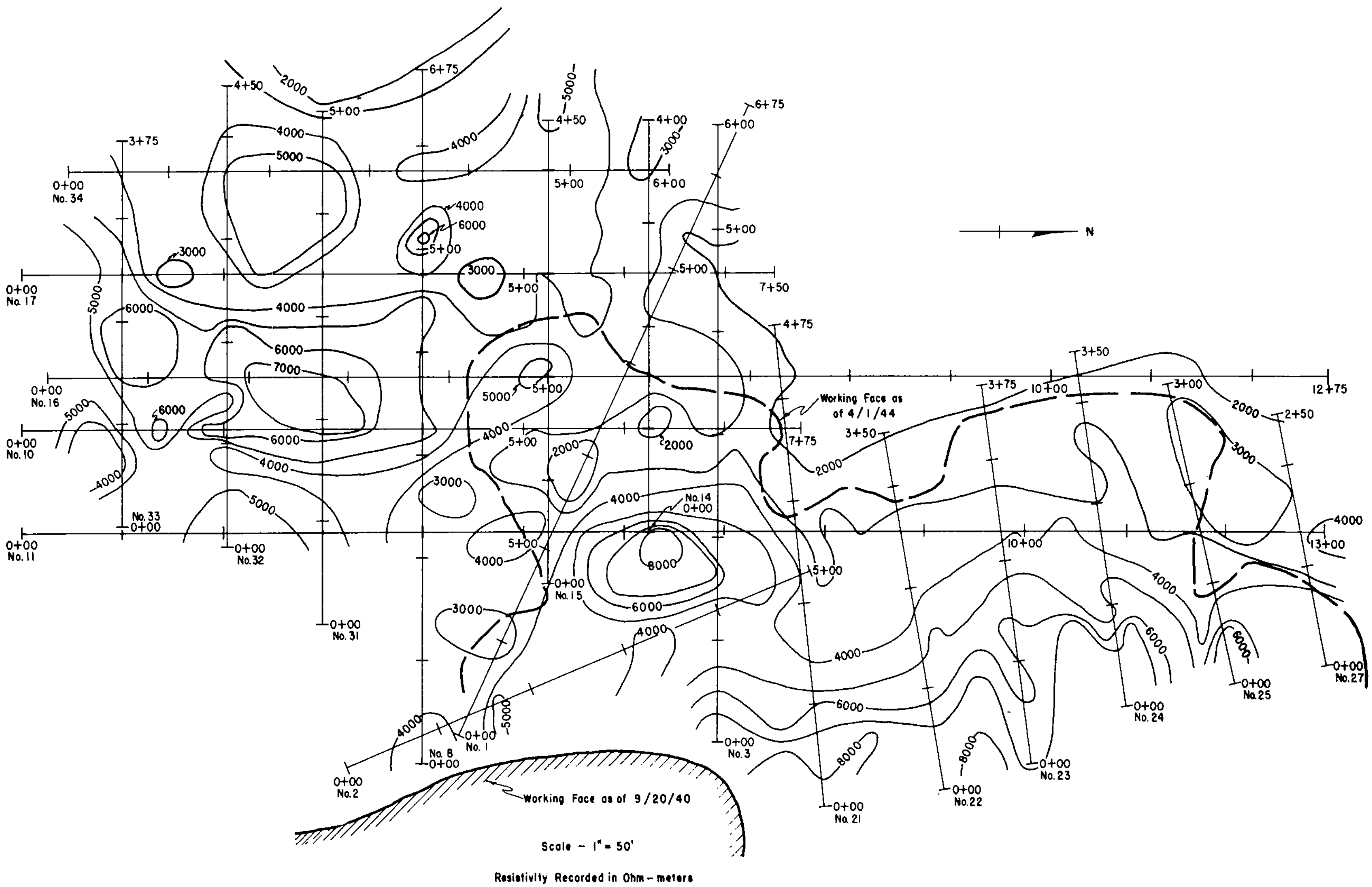


Figure 18.—Resistivity Contour Map of Area Adjacent to Gravel Pit Near Muirkirk, Maryland

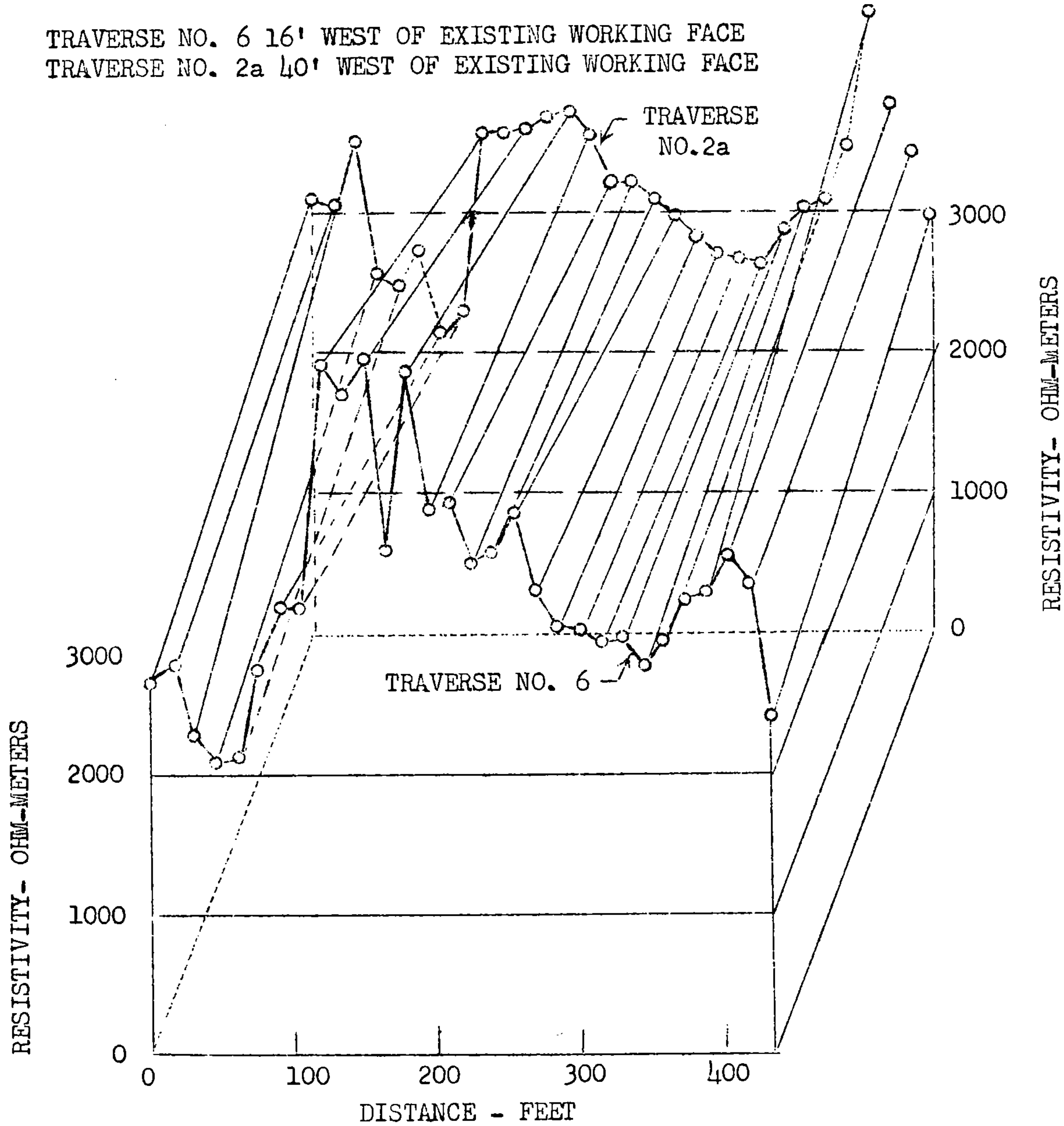


FIGURE 19 - ISOMETRIC DRAWING SHOWING CORRELATION BETWEEN TWO ADJACENT RESISTIVITY TRAVERSE LINES.

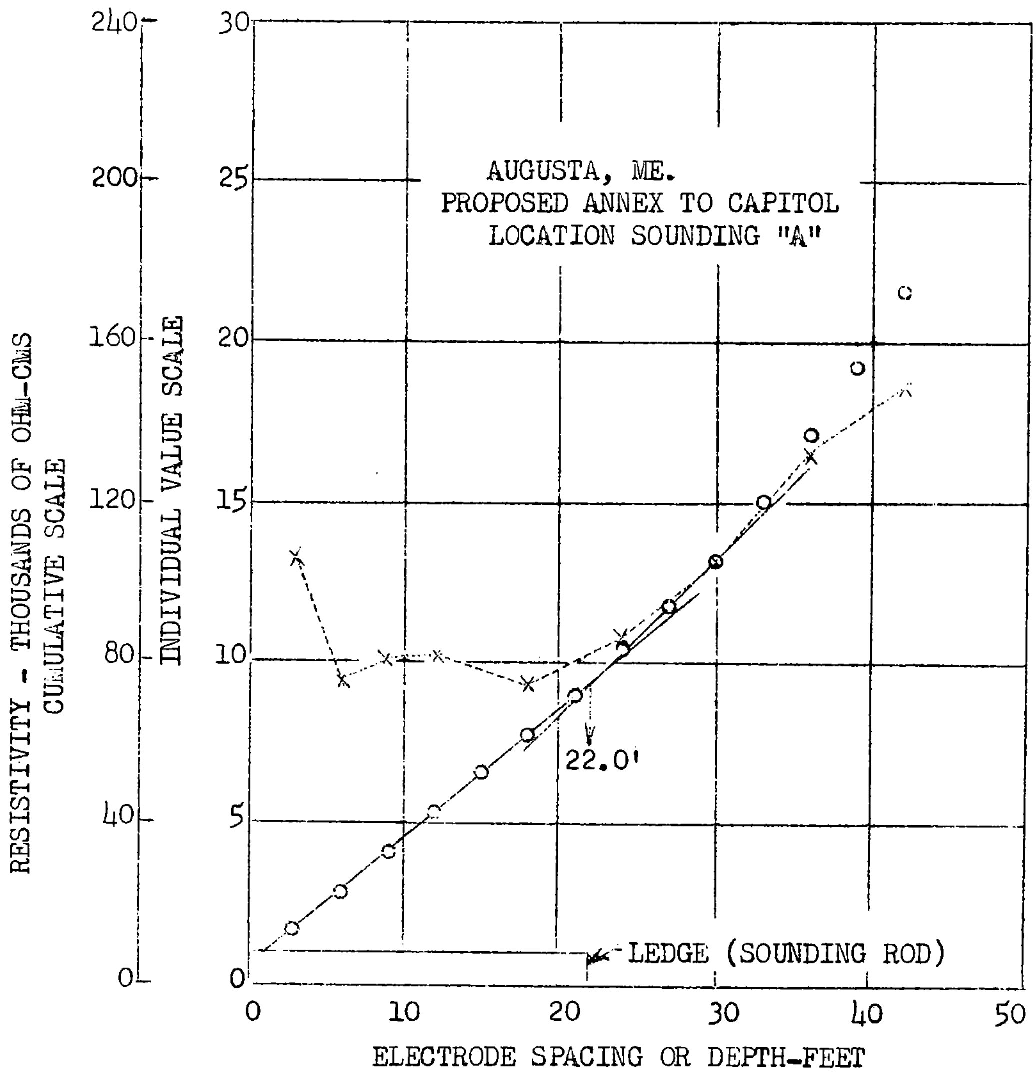


FIGURE 20 - EARTH-RESISTIVITY TESTS USEFUL IN CORROBORATING SOUNDING ROD DATA, DETERMINING PROPER DEPTH OF BORINGS AND GUARANTEEING SURFACE CONDITIONS TO CONSIDERABLE DEPTHS

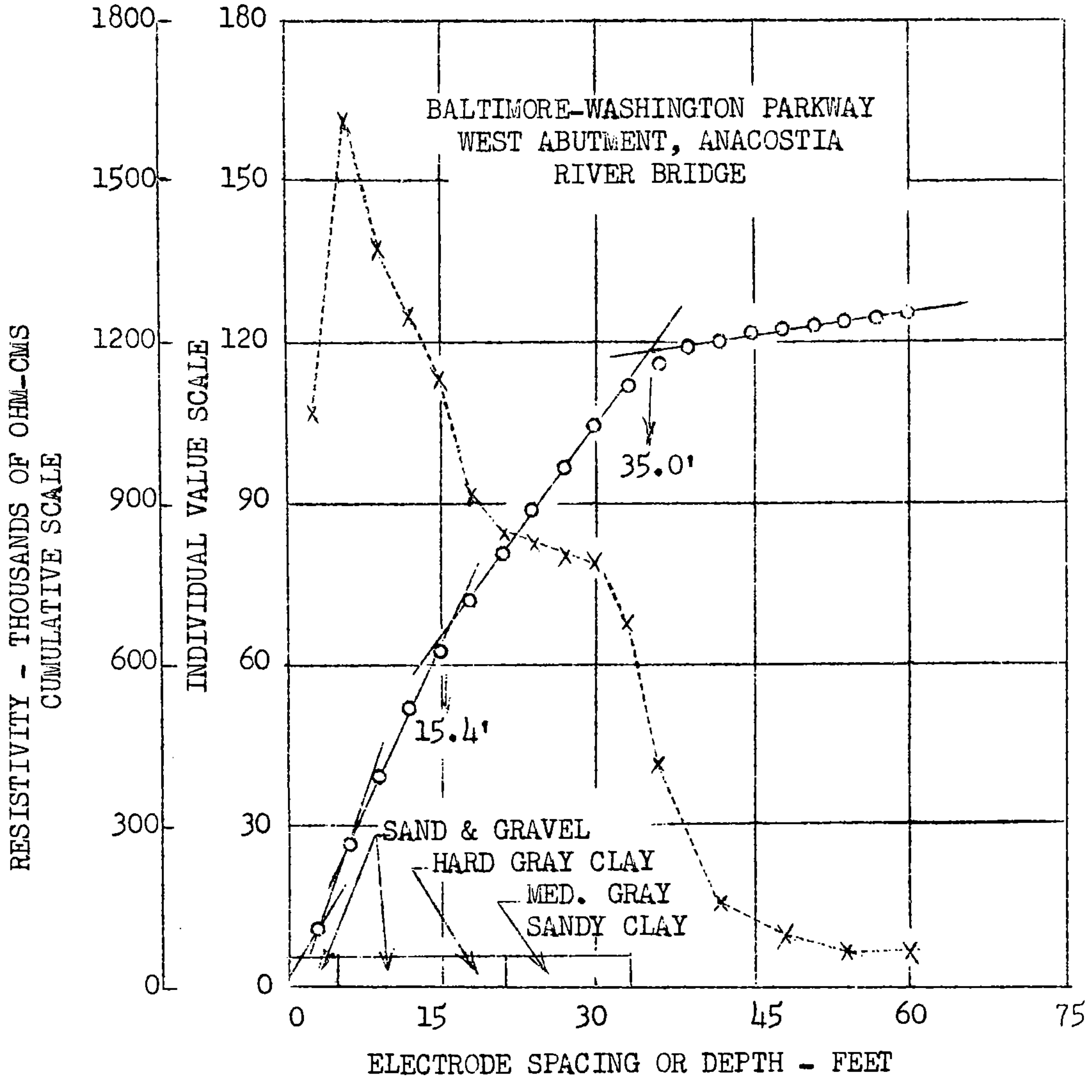


FIGURE 20 - EARTH-RESISTIVITY TESTS USEFUL IN CORROBORATING SOUNDING ROD
(CONTINUED) DATA, DETERMINING PROPER DEPTH OF BORINGS AND
GUARANTEEING SURFACE CONDITIONS TO CONSIDERABLE DEPTHS

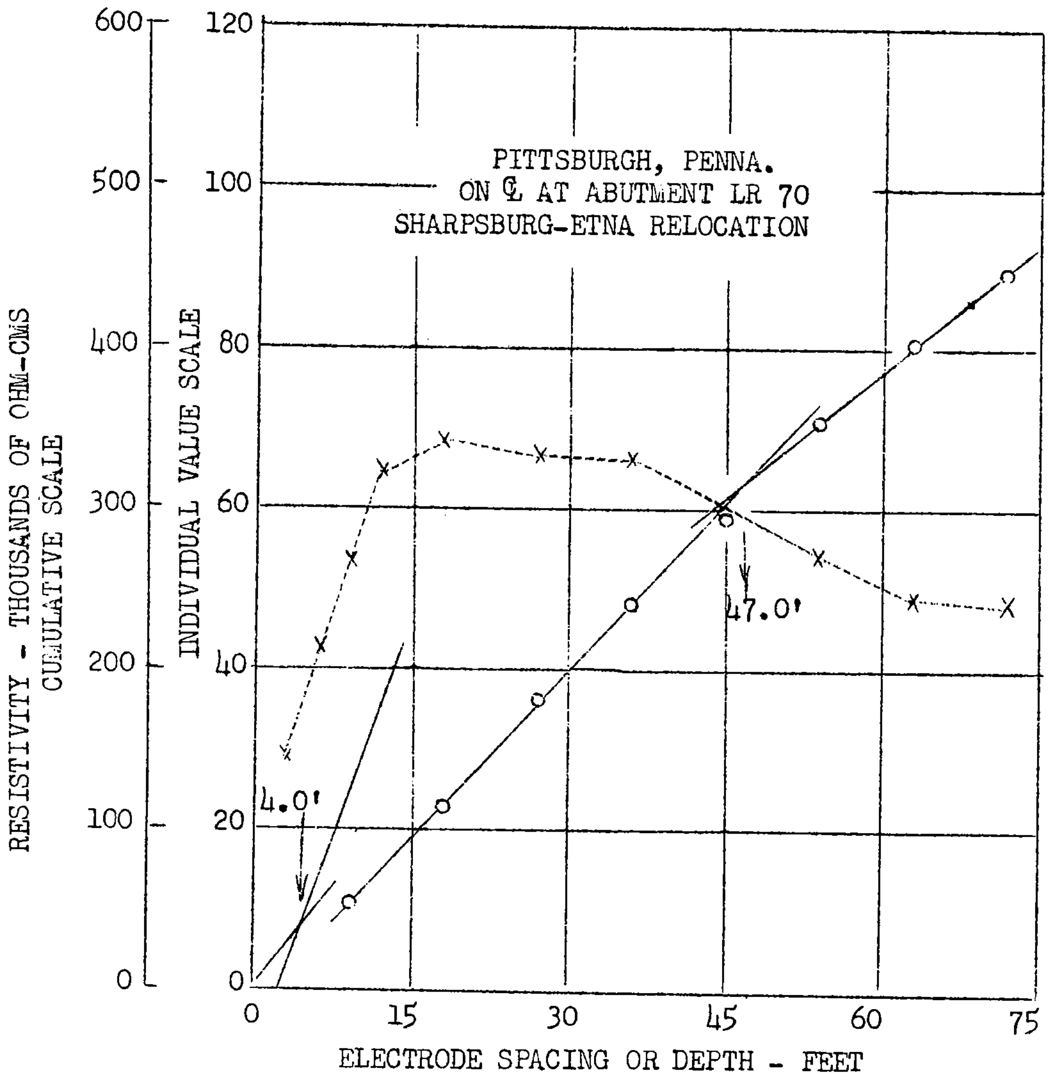


FIGURE 20 (CONTINUED) - EARTH-RESISTIVITY TESTS USEFUL IN CORROBORATING SOUNDING ROD DATA, DETERMINING PROPER DEPTH OF BORINGS AND GUARANTEEING SURFACE CONDITIONS TO CONSIDERABLE DEPTHS

ENGINEERING GEOLOGY OF THE CHESAPEAKE BAY BRIDGE

By: Carl W. A. Supp

ABSTRACT

The $45,000,000 structure, dedicated July 30, 1952, extends 4.3 miles across Chesapeake Bay, linking Maryland's Western Shore with Delmarva Peninsula. Superstructure consists of simple and cantilever deck spans, 2920' suspension main bridge, and 1720' through cantilever span. Substructure is entirely on steel piles up to 135' long and penetrating to lowest Elev. - 203' M.S.L.

Two alternate locations were investigated by 38 borings, totaling 7372 linear feet, the deepest reaching Elev. - 355'. Representative grain-size analysis, time-consolidation, Atterburg Limit, compression, and related laboratory tests on 501 ordinary and 93 undisturbed samples furnished quantitative data for substructure design. To enable 3-shift drilling, and eliminate shore-based survey crews and delays during periods of restricted low-level visibility, barges were positioned by use of special sextant charts which afforded virtually instantaneous graphical fixes based on observed angles between night-lighted, elevated shore signals.

Two shore-to-shore geologic sections were developed, depicting unconsolidated Coastal Plain formations penetrated, including recent and Pleistocene silts, sands and gravels; the Aquia (Eocene); and the Monmouth, Matawan and Magothy (Upper Cretaceous). Explorations of the drowned Pliocene (?) valley of the Susquehanna encountered 1.5 miles west of the Eastern Shore beneath 65-90' of water, were of critical engineering importance, and are of unique geologic interest. Former channel, approaching 5000' in width, bottom at Elev. -170, and filled with up to 100' of highly compressible organic silt, necessitated use of longest piles on project.

Integrated geologic and soils studies proved exceptionally valuable in all phases of the project.

INTRODUCTION

On July 30, 1952 the Chesapeake Bay Bridge, which extends some 4.3 miles over water to link Maryland's Western Shore with the Delaware - Maryland - Virginia Peninsula, was formally opened to traffic. It was the writer's rewarding experience to be associated with the earlier phases of this project, beginning with the preliminary reconnaissance and control surveys and continuing through the subsurface exploration program, geological and soil studies, and preparation of the engineering report. This association afforded an unique opportunity to observe and, possibly to a very minor degree, to contribute to the ever closer relationship between applied geology and certain branches of the broad field of civil engineering. It is with a brief review of this relationship that this paper is primarily concerned.

ACKNOWLEDGEMENTS

The writer gratefully acknowledges his indebtedness to Mr. Herschel H. Allen, Senior Partner, J. E. Greiner Company, Consulting Engineers, whose outstanding engineering talents were largely instrumental, over a period of many years, in guiding the Bay Bridge project from inception to successful completion; and whose farsighted appreciation of the benefits which can frequently be derived from close collaboration between the engineer and the geologist has been a continuing source of encouragement. Harry M. Brown, Chief Engineer; Raymond Archibald, Robert A. Gilmore and William H. Pall, Associate Engineers; and Bruce Herman, Resident Engineer, all of the staff of the J. E. Greiner Company, furnished guidance and advice. Colleague engineers included Charles E. Sumwalt, who conceived a special application of the use of sextant charts for accurately fixing test boring locations; William R. Cook, Charles L. Young and Addis E. Casey who were responsible for the completion of horizontal control, hydrographic and topographic surveys; and many others to whom credit is due.

Sincere appreciation is expressed to Dr. Joseph T. Singewald, Jr., Director of the Maryland State Department of Mines, Geology and Water Resources, for his cordial cooperation and assistance, as well as to Dr. Robert M. Overbeck, Ground Water Geologist of the same agency, who reviewed the geologic sections prepared by the writer and made many valued suggestions. All quantitative soil tests were performed in the Soil Mechanics Laboratory of the University of Maryland, under the expert supervision of Professor Edward S. Barber.

GEOGRAPHIC LOCATION AND ALIGNMENT

With the recent completion of the Annapolis Bypass Section, Route 50 is a modern dual-lane controlled access highway extending from Queenstown on the Eastern Shore to Route 301 three miles south of Priest Bridge on the western shore.

On the Eastern Shore it connects to U. S. Routes 213, 13, and 113, and many important state routes, making the bridge readily accessible to all cities and shore resorts on the Del-Mar-Va Peninsula as well as to the metropolitan areas of Wilmington, Philadelphia and New York.

On the western shore, modern interchanges connect Route 50 with the dual-lane Ritchie Highway, linking Baltimore and Annapolis, and with Route 301 which leads to the Potomac River Bridge. These connections provide an excellent through route for north-south traffic by avoiding the congested areas of Baltimore and Washington.

The curve in the bridge structure was dictated by a requirement of the United States War Department, that it cross the main navigation channel at right angles, so as to enable outbound vessels to complete a turn in the sailing course opposite Sandy Point Lighthouse and resume a straight course before passing under the bridge. (Slide No. 2 shows a general perspective of the structure and the geographic setting as depicted in the design stage).

The present location and structure resulted from exhaustive comparative cost and feasibility studies of alternate sites and types of crossing. In August, 1947, the State Roads Commission of Maryland decided to have independent studies made to determine the feasibility and cost of a tunnel crossing. In May, 1948, "Report on Chesapeake Bay Tunnel" by Ole Singstad, Consulting Engineer, of New York City, and Palmer and Baker, Inc., Consulting Engineers, of Mobile, Alabama, was presented to the Commission. Analysis of the comparative costs and merits of the bridge versus the tunnel crossing revealed that estimated construction cost of a bridge was approximately 10 million dollars less than the estimated cost of a tunnel; and that in addition to other advantages, a bridge would provide superior traffic serviceability by virtue of greater roadway width (28 feet vs. 23 feet), larger vertical clearance above roadway (16 feet vs. 14 feet), and elimination of the necessity for restrictions on transit of cargoes of gasoline and explosives. In June 1948, the Commission concluded that a bridge crossing would be most advantageous, and instructed the J. E. Greiner Company to proceed with preparation of an engineering report (1). This report presented a comprehensive summary of the history of the development of the project, detailed design and cost data, analysis of the results of subsurface explorations, and other pertinent engineering considerations.

In making the comparative studies of bridge versus tunnel crossing, two different locations were considered. The tunnel studies were based on a straight line, hereinafter called the "Tunnel Line", extending from the extreme tip of Sandy Point to Kent Island (Plate 5) at an average distance of about 4,000 feet north of the "Bridge Line" finally adopted (Slides Nos. 1 and 2 and Plate 6). The "Bridge Line", as previously indicated, was selected for the comparable bridge study after it was ascertained that a bridge at the location of the "Tunnel Line", would, in order to satisfy criteria for unimpeded water-borne traffic established by the War Department, be unduly costly. Detailed subsurface explorations, hereinafter described, were completed at each of the two locations.

PREVIOUS WORK

In connection with the Maryland Primary Bridge Program of 1938, commenced by the State Roads Commission and interrupted by World War II, preliminary studies were made of a Bay crossing at the approximate location of the "Tunnel Line". Some 29 test borings, extending from shore to shore, were completed in August and September by the Gow Division of Raymond Concrete Pile Company, under the supervision of The J. E. Greiner Company. Although samples were no longer available, the logs were found useful for planning the boring operations here described, and for supplementing the data obtained from the latter (See Plate 5). To the writer's knowledge, no geological investigations or detailed soil studies were included in the 1938 exploration program.

(1) Numerals in parentheses refer to items in the bibliography.

Numerous publications of the Maryland Geological Survey (2), (3), (4), (5), (6), (7), were of value in reviewing known geological relationships in the area. Two guidebooks prepared by Stephenson, Cooke and Mansfield for the Sixteenth International Geological Congress (8), (9), were particularly useful for their concise summary of more recent concepts of the geology of the Chesapeake Bay area.

DESCRIPTION OF THE STRUCTURE

A necessarily brief description of the bridge structure may be of interest at this point (Slides Nos. 3, 4, 5 and 6 show design plan and profile; No. 7 is aerial photograph of completed structure). A filled causeway forms the western approach to a series of beam spans, girder spans and deck truss spans which ascend on a 3 percent grade to meet the main channel span, a suspension bridge, which has a total length of 2920 feet and a 1600 foot main span. Horizontal clearance is 1500 feet and minimum vertical clearance above mean high water is 186.5 feet. A descending 2 percent grade crosses a long series of deck cantilever spans to a through cantilever bridge, over an eastern channel of the Bay, which allows lateral clearance of 690 feet and minimum vertical clearance of 58 feet at the low end; from which point a series of deck trusses, girder spans, and beam spans leads to a filled causeway which extends to the shore of Kent Island to form the eastern approach. Total length of bridge structure is 20,570.5 feet.

SURVEYS

Horizontal and Vertical Control

A detailed discussion of the surveys made in connection with the project is not within the scope of this paper. Very brief reference, however, to those phases of the surveys pertinent to the completion of the subsurface exploration program, is deemed appropriate.

All precise horizontal control surveys were based on existing U.S. Coast and Geodetic Survey triangulation stations, or positions derived from them. During the reconnaissance surveys, a number of suitably located stations in the area were searched for and recovered, namely Gate, 1932, Labrot 1933, Hack 1932 and Green 1932 on the Western Shore; and Norri 1932 and Kent Island North Base 1844 on the Eastern Shore. An interesting account of the recovery of the latter, which had been reported lost since 1859, has been published by Beavin (10). A description of control survey procedure both before and during construction has been given by Young (11). The use of U.S.C. & G.S. control, and corresponding coordinates referred to the Maryland State Coordinate System, enabled the locations of all test borings to be conveniently and permently defined.

Vertical control was based entirely on U.S.C. & G.S. bench marks recovered on both the Eastern and Western Shores, using the published elevations referred to Mean Sea Level datum.

Hydrographic Survey - Use of Sextant Charts

A detailed hydrographic survey was completed of the entire project area across the width of the Bay. A sonic sounding machine, operated from a power launch, furnished a continuous accurate record of water depths beyond the 2-fathom line along numerous ranges running across the width of the Bay as well as parallel to the shorelines. Hand soundings were used inshore. Procedures followed were more or less orthodox with one exception which is here mentioned because of its later application to the problem of locating test borings in areas distant from shore.

As a means of controlling the hydrographic survey, the so-called sextant chart method, frequently used by the U. S. Engineer Department for similar surveys, was adopted. Special charts, the computation and construction of which was based on the use of existing U.S.C. & G.S. hydrographic stations of known position (Sandy Point Lighthouse 1898; C.B.A. Exp. Tower No. 5; Matapeake; Mylander's Silo; and Radio Tower No. 9, 1945), were prepared for the project area. The sextant chart is, in effect, a graphical solution of the three-point problem, by means of which simultaneous measurements, with two sextants, of pairs ("left-hand" and "right-hand") of horizontal angles between three fixed shore signals afford a virtually instantaneous position "fix". Time and space limitations do not permit further discussion of the theory and construction of sextant charts here. Appendix A contains a brief analysis after Bostwick and Rosenzweig (12). (Slide No. 8 and Plate 1 illustrate the appearance of a typical chart).

GEOLOGY OF THE CHESAPEAKE BAY AREA

A considerable body of literature pertaining to the regional geology has been published (8), (9), for which reason a detailed description is not considered to be warranted here. The brief review following is adapted from text originally prepared by the author for inclusion in the Engineering Report (1).

Coastal Plain

The site of the Bay Bridge is situated on the Atlantic Coastal Plain which, in Maryland includes the Eastern Shore, Chesapeake Bay, and Southern Maryland (Plate 5). The formations underlying the Coastal Plain in the Chesapeake Bay region are sedimentary beds of sands, silts, clays, marls, gravels and diatomaceous earth, ranging in age from Cretaceous to Recent. Generally, they are unconsolidated or only partly consolidated, although indurated layers are occasionally encountered in several of the formations. These deposits have never experienced violent earth movements, and consequently very nearly retain their original substantially horizontal attitudes. The older formations have been slightly tilted or warped, resulting in a regional dip to the southeast on the order of approximately 12 to 40 feet per mile.

Piedmont Plateau - Fall Line

Adjoining the Coatal Plain to the west is the Piedmont Plateau, a rolling upland composed of hard, ancient, crystalline rocks. The boundary between the Piedmont and the Coastal Plain is frequently described as the Fall Line (or Fall Zone) and is considered to be the line connecting the lowermost points at which the streams from the Piedmont descent by falls or rapids from the comparatively hard crystalline rocks to the unconsolidated, more easily eroded sediments of the Coastal Plain. Therefore, the Fall Line coincides with the head of navigation on most of the larger rivers of the Chesapeake Bay region. This consideration, and the frequent availability of conveniently located water power, were in the early days the deciding factors in the selection of sites for cities such as Trenton, Philadelphia, Baltimore, Washington and Richmond.

The Fall Line has a particular significance from the Engineering standpoint, since it approximates the line along which the hard crystalline rocks disappear beneath the overlapping, younger sediments of the Coastal Plain. The surface of the rock basement is generally interpreted to be an ancient peneplain, sloping to the southeast, developed on schists, gneisses, granites and related rocks, predominantly of pre-Cambrian age. The mass of overlapping unconsolidated sedimentary formations, wedge-shaped in section, becomes progressively thicker, and records of wells and test borings penetrating to bedrock become correspondingly sparser, as the distance southeast from the Fall Line is increased. A recent boring at Annapolis penetrated some 1000 feet of sediments without encountering bedrock, and at Salisbury, on the Eastern Shore of Maryland, an exploratory boring for oil reached the crystalline basement at 5568 feet. At Fort Monroe, Virginia, bedrock was reached at 2240 feet below sea level. (Author's Note - The Engineering Report (1) contained the statement: "From all considerations, therefore, it is highly improbable that bedrock will be encountered in any phase of the construction of the Chesapeake Bay Crossing". This safe prediction was, of course, later substantiated).

Geologic History and Present Day Physiography

The comparatively recent geologic history of the region, as recorded in the sedimentary formations of the Coastal Plain, has been one of continuing cycles of depression of the area below sea level, deposition of sediments, uplift above sea level, erosion of the new land surface, followed by recurrence of the cycle.

It is generally considered that during Pliocene time a large portion of the Chesapeake Bay region was subjected to differential upwarping, and the presently drowned valleys of Chesapeake and Delaware Bays, and of the Potomac, York, James and Rappahannock Rivers were carved by the streams cutting down into the soft uplifted sediments of the Coastal Plain and Continental Shelf. At the close of Pliocent time the area experienced further tilting or warping, and the rivers were again drowned, converting them into estuaries. During Pleistocene time which followed, there occured a series of alternating rises and falls of sea level. Glacial epochs were times of low sea level because of the tremendous quantities of water frozen in the continental ice caps, and the rivers flowed in their old Pliocene valleys. Interglacial stages, when the ice retreated, were times of high sea level and drowning of the stream valleys. Each recurring glacial and interglacial stage caused a repetition of the cycle. There is strong evidence that each new interglacial stage was marked by a progressively lower sea level, for the still recognizable old shorelines and terraces appear to form a descending series of which the lowermost is considered to be the youngest. In Maryland, these Pleistocent terraces, in descending approximate elevation above sea level are given by Stephenson, et al (8) as the Brandywine (270 feet), Cohaire (215 feet), Sunderland (170 feet), Wicomico (100 feet), Penholoway (70 feet), Talbot (40 to 45 feet), Pamlico (25 feet) and the Princess Anne (12 feet). Available evidence seems to indicate that the present day sea level is somewhat higher than the lowest stage during the climax of Pleistocene glaciation, but much lower, to a degree still controversial, than the maximum during the same period.

The Pleistocene history of the region explains the origin of many of the present day physiographic features. Of these, the most impressive is the intricate and extensive system of navigable inland waterways. The present shoreline of submergence is typified by its irregularity and the comparatively short streams rapidly broadening toward their mouths, with tidewater penetrating their lower reaches. The trunk of the dendritic system of waterways is, of course, the Chesapeake Bay, which is more properly classified as an estuary, as are the Potomac, Patuxent and Patapsco Rivers. In reality, the Chesapeake Bay is the ancient drowned valley of the Susquehanna River.

THE TEST BORING PROGRAM

15 borings totalling 2380 linear feet were made on the "Tunnel Line" and 23 borings totalling 4992 linear feet were completed on the "Bridge Line", from which a total of 501 ordinary "dry" spoon samples and 93 undisturbed samples were recovered for examination and testing. (The locations of borings and the two geologic sections based on them are given by Slides Nos. 9 and 10 and Plates 5 and 6). The deepest boring, No. D-32 and 32-A on the "Bridge Line", penetrated to Elev. 354.5 below M.S.L.

Borings were made by the Gow Division of Raymond Concrete Pile Company, under a cost-plus type of contract with the Maryland State Roads Commission, following the generally accepted procedure for Gow type borings. Total cost of the drilling program was approximately $200,000, or roughly 0.44 percent of the total final project cost. Floating equipment used included two steel scows approximately 100 feet in length and 30 foot beam, a chartered tug boat, and sundry small craft.

A number of rather formidable problems presented themselves for solution. A rapid design and construction schedule required that the borings be completed as expeditiously as possible. As a result, work started at the end of December, 1947 and was completed in mid-June, 1948. During the winter months, the Bay, about 4 miles wide at both sites, is a notoriously treacherous body of water. Northeasters and southwesters, sweeping the long fetch the length of the Bay, as well as sudden violent squalls of comparatively short duration, frequently and with amazing rapidity convert it into a raging welter of wind and wave. The winter of 1948 was no exception, and examination of the boring logs discloses that a number of borings were either lost or had to be abandoned before completion. Usual practice was to start the boring with 4 inch diameter casing and telescope to 2-1/2 inch casing when driving became unduly difficult. The drill barges were winched and held in position with the drilling platform over the casing by means of two sets of heavy anchors fore and aft, sometimes augmented by auxiliary anchors. In a number of instances, during heavy weather, the anchors on the weather side dragged despite all possible precautions, and the casing was bent or overridden by the scow before it could be backed off. In several other cases, there was no alternative but to abandon a boring in progress and run for shore.

One of the major problems encountered was the necessity for devising a suitable and reasonably accurate method for the spotting of the drill scows at desired locations of borings in the offshore areas. During the winter months, low-lying mists and fog banks frequently resulted in intermittent periods of restricted or impossible visibility at elevations near the Bay surface. After considerable study, it was decided to make what is considered to be a rather unique application of the sextant chart principle, using the same charts and elevated shore signals which had previously been utilized for controlling the hydrographic surveys of the project area. Based on the preliminary control surveys, Maryland State Coordinates were computed for each boring location. Inverse computations of the grid bearings between the coordinates of the boring and the coordinates of each of the three applicable elevated shore signals then furnished the values of the left hand and right hand angles which would have to be observed in order for the drill scow to be at the correct boring location. In effect, the sextant charts were used in reverse.

Temporary night-lighting installations were made on each of the shore signals (Mylander's Silo; Matapeake) not already permanently lighted. Adoption of this procedure, which proved very successful, enabled one inspector on board a drill scow, equipped only with sextant, sextant chart, and the computed left-and right-hand angles for a given boring, to make repeated angle observations, plot his position on the chart, and direct the maneuvering of the scow until the observation of the required angles indicated that it was exactly on location. Round-the-clock, 3-shift drilling operations were thus made possible so as to take full advantage of periods of favorable weather. The need for stand-by, shore based survey parties, who would in any case have been effective only during the hours of daylight and periods of good visibility, was eliminated. Borings close inshore were located by conventional survey methods.

Use of the sextant charts as outlined above not only materially expedited completion of the boring program, but resulted in substantial savings in drilling and survey costs.

GEOLOGIC AND SOILS STUDIES

General

The two geologic sections (Slides Nos. 9 and 10, Plates Nos. 5 and 6) furnished herewith, were developed from the borings made on the "Tunnel Line" and the "Bridge Line" respectively. The sections are considered to be largely self-explanatory, and only salient points will be discussed. Logs of all boring on the "Bridge Line" (Plates 2, 3 and 4), giving descriptions of the materials as well as all quantitative data resulting from laboratory tests performed under the supervision of E. S. Barber are also furnished in order to obviate the need for lengthy discussion in the text.

Geology at Site

A study of the geologic sections suggests the following interpretation of the geologic history of the immediate area. The oldest formation, the Magothy (Upper Cretaceous), was barely penetrated in the deepest boring and the contact with the overlying Matawan could not be traced. Elsewhere in the area an erosional unconformity, considered to be the result of a cycle of uplift, erosion, subsidence and deposition, separates the two formations. Deposition of material composing the Magothy is generally considered to have been associated with near-marine conditions.

Another erosional unconformity, probably the record of a similar cycle, appears to exist between the Matawan and the overlying Monmouth. Both formations are of marine origin and are composed largely of glauconitic sand. The top of the Monmouth is also characterized by an erosional unconformity which marks the dividing line between the Upper Cretaceous and Eocene epochs. The overlying Aquia of Eocene Age appears to have been largely removed by erosion across the width of the Bay, presumably during the Pliocene uplift, at which time the channel of the ancient Susquehanna River was carved down through the Aquia and into the Monmouth. This old channel forms the most conspicuous feature of both sections. During the Pleistocene, the channel appears to have been first covered with a thin blanket of sand and gravel, and then, probably during the recurring periods of high sea level, deeply buried in silt and clay.

Deposition of recent sediments, mainly silts and sands, still continues. Sandy Point, for example, (Plate 5) appears to be a comparatively recent sand deposit built out over the underlying silt.

Procedure

In studying unconsolidated materials under the microscope, a very simple and effective technique for preparing samples was improvised. Standard glass micro slides were partially covered with a thin layer of diluted Duco cement and quickly sprinkled with a small portion of dry material. When the cement hardened, in a matter of seconds, excess loose material was shaken off. Slides prepared in this manner required little storage space, and were readily available for comparison of samples.

Concurrently with studies of the samples by the writer, numerous mechanical sieve analyses of portions of typical samples were completed by E. S. Barber. The writer plotted the results as grain-size distribution curves. In many cases it was found that the Monmouth and Matawan, although often similar in appearance, could be separated on the basis of slight characteristic differences in the shapes of the curves. Unfortunately, available time did not permit a statistical analysis of the curves.

Soil Studies

An extensive program of laboratory tests was completed on typical samples of all types of material recovered from the borings. As summarized by Barber (1),

"Disturbed bottle samples from the sand stratum were graded on sieves above the 200 mesh to determine grain size distribution and the moisture content was determined as an indication of the density. These tests, with the penetration resistances of the sampling spoon, indicate that the material is a fairly dense, medium to fine, silty sand, having good bearing capacity and being relatively incompressible.

The undisturbed core samples from the soft silt stratum were tested in compression, without confinement, to determine their strength. The cohesion was taken as half the compressive strength. The sandier samples were also tested in compression with an all-around confining pressure to determine the effective coefficient of friction. It was found to be negligible, because the water which fills the voids around the soil particles could not escape quickly enough to allow the soil particles to become more closely packed, which is a necessary condition for the increase of strength by friction. The soft silt is of an almost liquid consistency in the upper portions of its thickness. Its strength increases with depth. Compression tests on samples remolded without drying show that disturbing the silt causes a considerable decrease in its strength.

Measurement of the reduction in thickness, under load, of samples which were prevented from moving laterally showed that the silt is very compressible and will decrease considerably in volume even under small loads. The coefficient of consolidation indicates that considerable time will be required to obtain this volume change by squeezing water from the soil.

To aid in correlating the samples and as a means of identification, index properties were determined on a portion of each sample. The effective grain sizes below the 200 mesh sieve were calculated from the rate of sedimentation of dispersed samples using a hydrometer to determine the quantity in suspension at a given time. Liquid and plastic limits were also determined on selected samples. The natural moisture contents approximate the liquid limits, which is consistent with the low strengths noted above.

Chemical tests indicate soluble salts through the entire depth of silt as well as a rather high content of organic matter and carbonates.

While the above results are given in qualitative terms, the detailed test results can be used to determine, for given boundary conditions, earth pressures and displacements under load. Thus, by suitable calculations, they may be used to derive such properties as bearing capacity, amount and rate of settlement of fill, pressure on cofferdams, skin friction on caissons, and lateral support of piles."

Engineering Applications of the Geologic and Soil Studies

During the preliminary and final design stages of the project, as well as during the periods of advertising for bids and actual construction, numerous engineering applications were made of the volume of geologic and soil data assembled by the combined studies. Estimates of required quantities of steel H piles were based on the boring data and geologic interpretations thereof. The development of the profiles of the buried channel of the Susquehanna were of particular interest and value, since the major cantilever span across the east channel of the Bay is located in this vicinity. Steel foundation piles required for this structure reached a maximum length of 135 feet.

Subsequent to completion of the original Engineering Report[1] the War Department, in connection with consideration of minor revisions to the layout of the structure, deemed it desirable to incorporate in the plans provision for protection of the anchor piers and cables of the suspension bridge by means of sand islands. Before proceeding with construction of these islands, stability studies were made to determine if the islands could be built over the existing soft gray silt. The analysis established that the islands could not be constructed within a reasonable period of time without completely removing the silt.

The soft gray silt was removed down to the sand line and the hole backfilled with a medium gray sand obtained from natural deposits near Matapeake (one mile from the bridge site) and Seven Foot Knoll (at the entrance to Baltimore Harbor). The islands were then constructed by the placement of successive rings of riprap, approximately ten feet high with a minimum top width of ten feet and a base width of approximately fifty feet, and filled with the same sand used for the bottom backfill. Slag and rock, graded from fines to 2000 lb. pieces, were used for the riprap from the bay bottom (Elev. -40 and Elev. -55) to Elev. -15. From Elev. -15 to +10, the top elevation, stone from 5 lbs. to 4000 lbs. was used for riprap. The top of the island is protected by a two-foot blanket of stone up to eight inches in size. The tops of the islands are 138' x 150' and the side slopes are approximately 2:1.

Final quantities of materials used for construction of the protective sand islands at Piers 23 and 28 and the costs thereof, are given as follows:

DESCRIPTION	FINAL QUANTITY	COST
Sand fill for Dumped	575,983 cu. yd.	$1,077,088
Riprap Stone above Elev. -15	43,856 tons	460,488
Dumped Riprap Stone below Elev. -15	76,614 tons	421,377
Gravel Blanket Protection for Islands	3,294 tons	32,940
Slag Riprap Mechanically Placed to Elev. -15	48,985 tons	477,604
		$2,469,497
Force Account for Bay Bottom Exploration North of Pooles Island		11,794
	TOTAL COST	$2,481,291

In order to furnish prospective bidders with information on subsurface conditions, the Contract Drawings for all substructure contracts had attached a separate list of "Information Drawings". The latter, of which Plates 2, 3, 4 and 6 are examples, furnished all available soil and geologic data. There is ample reason to believe that this practice aided in attracting more favorable bids.

One of the earlier benefits of completing a comprehensive geologic and soil study was realized in the financing stages of the project. The very fact that such studies had been made, and that they were treated at some length in the Engineering Report (1) which served as the basis for financing the project by sale of revenue bonds, appeared to encourage added confidence on the part of potential investors.

In concluding, it is considered worthy of mention that during the entire construction period of the project, no subsurface conditions or problems were encountered which differed seriously from those predicted by the combined geologic and soil studies.

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APPENDIX A
THEORY AND CONSTRUCTION OF SEXTANT CHARTS

(Excerpt from Sextant Charts, Theory and Construction, M. L. Bostwick Oscar Rosenzweig, pp. 1-3 incl., Item (12) of Bibliography, Page)

In making hydrographic surveys in areas too remote from land to employ transits for location of positions of a boat, from which soundings are taken, sextants are usually employed. Each position of the boat is determined by measuring with two sextants a pair of simultaneous angles subtended by three known points, which are usually fixed objects on shore. Each position of the boat, as fixed by the two observed angles, may theoretically be computed by solving a "three point" problem. Needless to say, such procedure is not practical, as it would involve long and elaborate computations. The practical method generally used in fixing locations is by plotting with a three-arm protractor, on which the two observed angles are set off, and the position determined at the center of the protractor when the three arms are made to coincide with the objects as plotted on a chart.

In cases where a large number of positions are to be located in a limited area, it was found more expedient and more accurate to construct, for a given set of three objects, a so-called "Sextant Chart," which is a graphical method of solving "three point" problems by means of intersecting angle-arcs. The use of sextant charts becomes indispensable in cases where the distance from the boat to the objects is too great for the use of a three-arm protractor; it also permits the immediate plotting of observed locations of soundings in the field, as taken.

The basic principle involved in constructing a sextant chart will presently be demonstrated and explained.

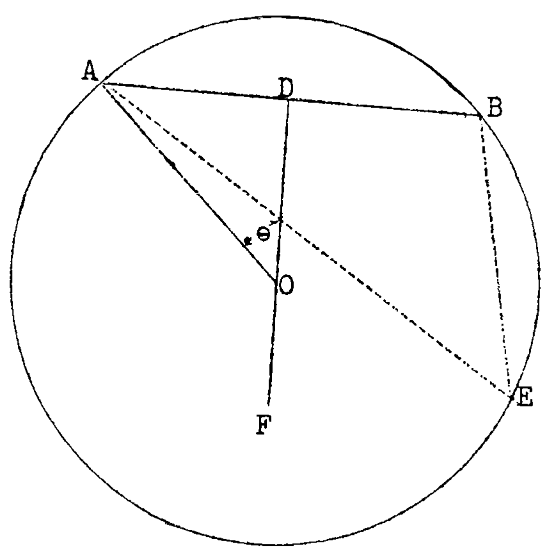

Figure 1

In Fig. 1, let A and B represent two of the three fixed points. Draw AB, and let DF be the perpendicular bisector of AB. With O, any point on the bisector, as a center, and OA as a radius, draw circumference, and denote $\angle$ AOD by θ. Since any chord of a circle subtends the same angle at all points of the circumference lying on the same side of the chord, it follows that arc AEB is the locus of points at which a given $\angle$ E is subtended by AB. $\angle \theta = \angle E$, as any inscribed angle is equal to half of a central angle subtending the same arc. From right triangle AOD, we have

$$OD = AD. \cot \theta$$

Assigning various values to θ, usually at uniform intervals, the corresponding values of OD, the distances of the centers from D for the various values of θ assigned are computed and plotted. With the centers thus located, and with OA = OB as a radius, a set of angle-arcs is drawn in. Another set of angle-arcs, representing the loci of vertices of angles between B and C is similarly computed and drawn. It is evident, that a pair of angles observed from any point will determine one and only one point on the sextant chart, and conversely, any point on the sextant chart represents a pair of sextant angles and a definite point in the area covered by the chart. If a point is so situated that it is on the circumference passing through the three fixed points, the location becomes indeterminate, as any point on this circumference would satisfy the paid of angles to the objects.

Assuming the sextant angles to be correctly measured, the accuracy of a plotted position depends largely on the selection of the three fixed objects. Poor locations result when the objects are so selected that the values of both angles change at a relatively low rate. Such condition would indicate the position to be near the circle passing through the three objects, and is, of course, to be avoided. The most accurate results are attained when the objects are so selected in relation to the area to be covered by the sextant chart, that the value of either subtended angle changes rapidly with a relatively slight change in position, and when the values of these angles are between 30° and 130°.

The most satisfactory sextant chart locations from the standpoint of rapidity of plotting and accuracy of plotted position are those in which the angle-arcs intersect at 90°. However, very satisfactory charts may be constructed when the available objects will not permit the fulfillment of the above condition. It should be stated at this point that under certain conditions a better chart may be prepared by using one of the two outside sextant objects as the common point instead of the middle object. This is particularly advisable when the middle object is much closer to the charted area than the other two. In general, it may be stated that the more the angle formed by the intersection of the angle-arcs deviates from 90°, the more difficult the plotting of the position, and the less accurate the determination. As the angle approaches 0° (or 180°), the point approaches the circle through the three objects, and the location becomes indeterminate.

For a given set of three objects, a relation between the angle formed by any two intersecting arcs on a sextant chart and angles that can readily be measured will now be established.

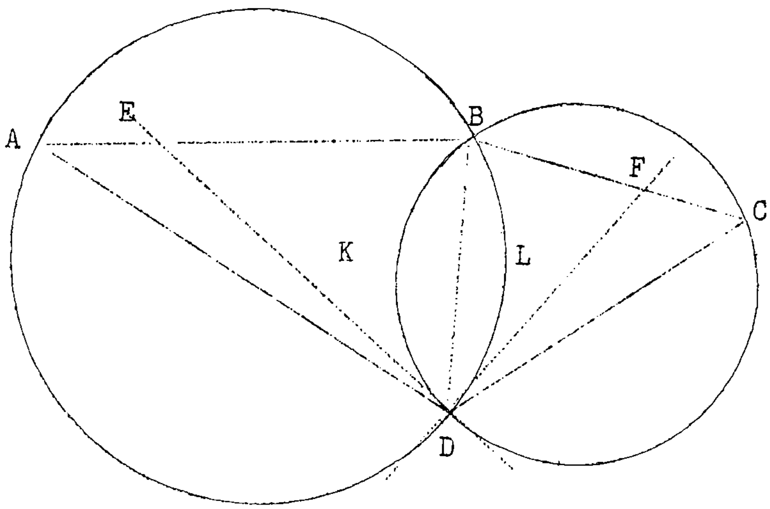

Figure 2

Let A, B and C, Fig. 2, be the three sextant objects and D a point whose position is to be determined. Evidently, the intersection of the two circumferences, the one passing through A, B, D and the other through B, C, D, will determine on a sextant chart the position of D. The angle at which arcs BKD and BLD cross at D is $\angle$ EDF, formed by the tangents to the two circles at this point. Draw the common chord BD. Then $\angle$ BDE = $\angle$ C, since both are measured by one-half the arc BKD. Likewise, $\angle$ BDF = $\angle$ A, and hence $\angle$ EDF = $\angle$ A + $\angle$ C. Since $\angle$ A + $\angle$ ABC + $\angle$ C + $\angle$ ADC = 360°, as the sum of the angles of a quadrilateral, it follows that

$$\angle EDF + \angle ABC + \angle ADC = 360^\circ$$
$$\text{or} \quad \angle EDF = 360^\circ - \angle ABC - \angle ADC.$$

Since $\angle$ ABC for a given set of sextant objects is fixed, 360° - $\angle$ ABC is also known, and the angle at which the two angle-arcs intersect for any given point D is, therefore, the difference between this constant angle (360° - $\angle$ ABC) and the angle at D, measured between the two end objects A and C. If $\angle$ ADC is supplementary to $\angle$ ABC, that is, if $\angle$ ADC = 180° - $\angle$ ABC, $\angle$ EDF must be 180°, and the position of point D becomes indeterminate. It also follows that the two angle-arcs will intersect at the ideal angle of 90° when $\angle$ ADC + $\angle$ ABC = 270°.

SOURCES OF INFORMATION ON GROUND CONDITIONS

By: Alice S. Allen

Publication authorized by the Director, U. S. Geological Survey

When areas are being considered as possible sites for a proposed engineering construction project, an understanding of their geologic setting is often needed in advance of field investigation. Information on many localities is available in geologic and engineering libraries in the form of published maps and reports that show or describe the type and distribution of rocks and soils in the area, records of subsurface materials penetrated by wells or boreholes, and the ground water conditions. There is considerable variation in the amount of information available for different areas, as well as in the applicability of that information to the problem confronting the planning engineer. Several sources of information that have proved helpful in visualizing the natural setting of various sites are described.

Areal Maps

Topographic, soil, and geologic maps are all products of systematic areal surveys in which selected features within the map boundaries are recorded to the best ability of the mapper at the scale which has been chosen. The shape of the land surface, the profile development of the soils, and the geologic formations beneath-all are elements needed to complete the picture of a site. The categories of features that may prove critical at a given site depend both on the features themselves and on the requirements of the proposed engineering construction. To find good maps of all three types covering a site is of course ideal though not common. Variable factors include: completeness of map coverage, scale of mapping, quality of mapping, and correlation between mapped features and engineering requirements. Balanced against the odds of finding the three kinds of maps for a given site, is the hope of finding one of the rare situations where the missing information may be deduced by extrapolation from maps that are available. The risk in extrapolation is proportional to the interpreter's experience and judgment and can best be evaluated by the interpreter.

Geologic Maps

Owing to the need for a three-dimensional picture of a site, the search for available information starts with geologic maps. To determine whether geologic maps are available for the area of a proposed site, the geologic map index for the State is used. The U. S. Geological Survey has now completed geologic map indexes for all the States. _/

_/ Geologic map indexes for each of the States may be purchased from the Distribution Section, U. S. Geological Survey, Washington 25, D. C., or from the Distribution Section, U. S. Geological Survey, Denver Federal Center, Denver, Colorado; prices range between $0.25 and $1.00, depending on the size of the State.

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Each State index shows by colored outlines the areas covered by geologic maps published by any organization - Federal and State geological surveys, universities, and geological societies. Up-to-date information on geologic maps that become available between published revisions of the State indexes may be obtained from the U. S. Geological Survey and from State geological surveys.

Some geologic maps are better adapted to interpreting local site conditions than others. The scale of the maps, and the purpose for which they were made, are obvious reasons for this variation. But there are areas in which the geology itself is the reason-the same reason that makes the standardization of geologic maps an impractical goal. The best interpretations are made at sites that can be located with respect to geologic map units that are homogeneous in lithology, with clear-cut, consistent physical characteristics. In some areas the geologic history has been such that the local sequence of rocks cannot be subdivided into units with well-defined lithology. One example nearby is the Coastal Plain area of eastern Maryland and Virginia. To read descriptions of the Patuxent, Patapsco, Raritan, Magothy, and Matawan formations, for example, brings no clear impression of distinctive lithology, except, perhaps, in the overall proportions of different lithologic types. Beds or lenses of sand or of clay (to mention two lithologies with wide contrast in engineering properties) may occur in any of these formations. Furthermore, the changes in lithology are irregular, both laterally and vertically. This type of geologic terrain does not easily lend itself to site interpretation based on the geologic map alone, though forewarning of the variability may in itself be helpful.

General-purpose geologic maps at the scale of a mile to the inch, or even one-half mile to the inch, cannot be expected to furnish information that takes the place of detailed site exploration. The larger the map scale, however, the more space is available for refining the breakdown of geologic materials. The recent trend of publishing topographic maps at scales of 1:31,680 and 1:24,000 for the more thickly settled areas, has provided base maps for more detailed geologic mapping. In Massachusetts and Rhode Island, the complete coverage by 1:31,680-scale topographic maps provides bases for systematic geologic mapping under programs supported jointly by the States and the U. S. Geological Survey. To show even more detail, separate maps are published of bedrock geology and surficial geology. We have been informed that the Massachusetts Highway Department finds the surficial maps particularly useful for terrain information on proposed highway alignments, as well as for locating granular fill. At sites of deep cuts and bridge foundations, the maps indicate the texture and structure of the subsurface materials, and influence the location of supplementary seismic surveys. A set of 20 quadrangle maps covering Chicago and its suburbs at the 1:24,000 scale has been published by the Illinois State Geological Survey (Bretz, 1943?). On these and other larger scale maps, artificial fill, individual rock outcrops, gravel pits, landslides, swamp deposits, and windblown materials, which have obvious application to engineering interpretations, are shown. Also the greater refinement of units, whose interest to the geologist may be largely genetic, cannot help but reflect textural and density distinctions that have practical application to engineering problems.

In addition to scale, the main purpose for which a geologic map has been made determines its usefulness for engineering interpretations. Maps to illustrate geologic studies of ore deposition or petroleum accumulation at considerable depths, may not show much differentiation of near-surface materials. Geologic maps made for engineering purposes stress near-surface features and highlight physical characteristics of rocks and earth materials.

Agricultural soil maps

The case for using agricultural soil maps directly in highway engineering has been presented admirably in recent Highway Research Board Bulletins prepared by the Committee on Surveying, Mapping and Classification of Soil (Bodman, 1949; Hicks, 1949 and 1953; Lacey, 1953; Olinger, 1953; Olmstead, 1949; Stokstad, 1953; and Thornburn and Bissett, 1951). Agricultural soil maps may, under favorable circumstances, provide a key for interpolating or extrapolating geologic information that is not shown on geologic maps. The outstanding advantage is the fact that soils maps have been published for a greater proportion of the country than have geologic maps. _/ The latest estimate for geologic map coverage of the United States

_/ A list of available county soil maps is published in Highway Research Board Bulletin 22, 1949, and additions to this list are published in Bulletins 28, 46, 65 and 83.

is 13 per cent. In this estimate, only maps at scales of 1 mile to the inch or larger are counted. It does not follow from this, however, that we are in complete ignorance of the geology of the remaining 87 per cent. Smaller scale maps are available for many areas, and the geologic literature is full of articles in which selected geologic features are described, though the area in which they occur may not have been mapped systematically. Thus a geologic interpretation of an area may be aided by using soil maps in conjunction with whatever geologic information _/ may be found. Especially effective are

_/ References to publications concerning the geology of North America may be found by consulting the subject indexes of the issues of the Bibliography of North American Geology. The following U. S. Geological Survey bulletins comprise the issues of this bibliograph to date: 746-747 (1785-1918), 823 (1919-1928), 937 (1929-1939), 938 (1940-1941), 949 (1942-1943), 952 (1944-1945), 958 (1946-1947), 968 (1948), 977 (1949), and 985 (1950).

those soil-map units that develop characteristically on parent material that are distinctive geologic units.

An example of combining soil data, geologic data, and topographic map information was found in a search for information at a site in Puerto Rico. This site is located on the north coast, near the town of Dorado. There is a published report on "The Geology of Puerto Rico", which includes a geologic map of the island (Meyerhoff, 1933). The scale of the map is about 4-1/2 miles to the inch, and the recent geologic units along the north coast are not subdivided. In the text of the report, however, is a rather complete description of a formation called the San Juan formation, which crops out intermittently in ridges along the north coast. The San Juan formation is a more-or-less cemented dune sand that originally extended the whole length of the north coast of the island. Most of the former dune ridge has been removed by erosion, and the isolated remnants form the present headlands. The sand grains are largely calcium carbonate, consisting of rounded grains of shell and coral fragments held together by weak calcareous cement. The cemented sand is best developed on the seaward side and is believed to result from evaporation of the surf. Much of the north coastal belt where the San Juan formation is absent consists of low delta areas where former lagoons have been filled with clay, silt, and vegetation. Obviously the deltaic deposits would have foundation characteristics different from those of the San Juan formation. The scale of the agricultural soil map of Puerto Rico (Roberts, 1942) is 1:50,000, and it shows more detail than the geologic map. At the site near Dorado, the 2 soil types nearest the coast are soils derived from limestone. This fact confirmed the guess that the site is on one of the remnants of the cemented dune formation. Neither the geologic nor the soils maps were printed on a topographic base, but the topographic map at the scale of 1:30,000, which was published later, gives further corroboration by showing that the site lies on a low ridge, which is characteristic of the San Juan formation.

Topographic Maps

Although topographic maps lack information on the materials beneath the ground surface that are shown on soil and geologic maps, they are useful in site interpretation in several ways. First, the probability of finding an adequate topographic map that includes the site under consideration is about 2-1/2 times that of finding a geologic map of that site. Where geologic map coverage is incomplete, the combination of topographic maps and available geologic maps may provide a basis for interpretation of probable ground conditions. Interpolation may be possible if detailed topographic maps have become available at a larger scale than a pre-existing geologic map of an area. The interpreter may be able to locate patches of a geologic formation with characteristic topographic expression that were too small to show at the scale of the geologic map. Or in areas where topographic map coverage is more complete than geologic map coverage, some degree of extrapolation may be possible beyond the limits of the geologic map into adjoining areas covered by good topographic maps.

In the absence of geologic maps, recognition of physiographic features from topographic maps may furnish clues to probable ground conditions in certain terrain types, as for example, in glaciated regions and in the Basin and Range Province. Also hydrologic features such as swamps, intermittent streams, and sink holes furnish clues to surface drainage and internal drainage conditions. Index circulars showing the progress of topographic mapping are issued for each State by the U. S. Geological Survey. _/

_/ State index circulars may be obtained free on application to the Chief of Distribution, U. S. Geological Survey, Washington 25, D. C., or Chief of Distribution, U. S. Geological Survey, Denver Federal Center, Denver, Colorado.

Engineering Soil Maps

Mr. Smith of the Bureau of Public Roads (Smith, 1955) has described the new type of maps usually termed "engineering soil maps", which are being prepared by interpretations of aerial photos, geologic and soils maps under the sponsorship of several State highway departments (Bennett and McAlpin, 1948; Holman and Nikola, 1953; Lueder, 1950; Olmstead, 1948). These maps differ from geologic and agricultural soil maps in that they have a built-in interpretation for highway engineering. Very few maps of this type have been published as yet, but they are included in this inventory because their number is bound to increase. Engineering soil-survey reports and maps are available for about two-thirds of the counties of New Jersey, one of the first states to undertake a state-wide survey (Rogers, 1950).

Nautical Charts

For sites located on shorelines of harbors or other coastal areas, the nautical charts, published by the U. S. Coast and Geodetic Survey may be a source of information on ground conditions. Areas exposed between tides are outlined on these charts, and the intertidal strips may be identified as marsh, mud, sand, gravel or rock. The topography of underwater areas is shown by numerous soundings in figures, and by contours. Some harbor charts include notations on offshore bottom materials, such as mud, sand and shells, coral, and rock. Though made for the purpose of indicating anchorage conditions, this information may be useful at proposed sites for bridges, tunnels, or airports to be constructed on fill. Index maps showing the available Coast Charts and Harbor Charts are published in U. S. Coast and Geodetic Survey Serial No. 665.

Subsurface Records

An enormous quantity of subsurface information is accumulating every day throughout the country, as wells are drilled for water or oil and gas, and borings are put down to explore foundation conditions for engineering projects. These wells and borings can serve purposes other than their immediate objectives, provided the materials penetrated are identified, described in meaningful terms, and recorded. Probably only a small proportion of subsurface records find their way into libraries. A few sources that have been found in the course of looking for information on a variety of sites are mentioned.

Collections of Well Logs

The collection of logs of water wells, as well as records of water levels in wells, forms an integral part of an investigation of ground water resources. Ground water investigations are being carried on by most of the States in cooperation with the U. S. Geological Survey, and reports on the results of these investigations (Waring and Meinzer, 1947) are published either by the Survey or the cooperating State agency. The published reports generally include selected well logs, and additional unpublished logs are available at the Survey field offices. _/ In some states, as in Maryland,

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_/ Information on locations of field offices may be obtained from the Ground Water Branch, Water Resources Division, U. S. Geological Survey, Washington 25, D. C.

logs of wells must be filed with the State Geologist or State Engineer.

Collections of Boring Records

In several of the larger cities, local engineering groups or geologists have systematically collected the records of borings made to explore the foundation conditions for buildings, bridges, grade separation structures, and subways.

In Greater Boston, records of borings and excavations have been collected since 1929 by the Committee on Subsoils of the Boston Society of Civil Engineers. In recent years the Society has published logs of the borings that have accumulated to date, together with contour maps on which the locations of the borings are spotted (B. S. C. E., 1949-1953).

New York has a long history of collecting subsurface information, dating back to the publication in 1905 of U. S. Geological Survey Bulletin 215 on "The configuration of the rock floor of greater New York" (Hobbs, 1905). The well-known engineering geologist, Dr. Charles P. Berkey of Columbia University, has maintained a continuing interest in the bedrock geology of Manhattan over many years (Berkey, 1910; Berkey and Healey, 1912). The most active period was during the 1930's (depression,) when a group of engineers and draftsmen were employed on a W.P.A. project to compile a rock-data map of Manhattan under Dr. Berkey's direction (Murphy and Fluhr, 1944). Seventeen thousand test borings and excavations were plotted, and a map showing depth to bedrock was compiled. These boring records are not published but are kept on file at the Municipal Building in Manhattan.

New Orleans also had a W.P.A. project during this same period (the depression) called the "Soil and Foundation Project". The sponsors were State and local engineering groups and Tulane University. The results of the project were published (W.P.A., 1937). Logs of 239 borings are presented graphically, together with chapters on pile foundations and spread footings.

Selected borings in San Fransisco, collected as part of a U. S. Geological Survey geologic mapping project, are available in published form (I.T.T.E., 1950).

Logs of test borings also are kept on file at many municipal engineering departments.

Bedrock Contour Maps

The position of the bedrock surface is an essential item of subsurface information in geologic terrains where the bedrock surface is irregular, and where it is overlain by a variable thickness of geologic units with contrasting physical characteristics. In glaciated areas where the preglacial stream valleys do not coincide with the present drainage system, bedrock-contour maps have been compiled for the ground water resources commonly found in the channel deposits. Bedrock-contour maps have been compiled for counties in Ohio, for example, in connection with ground water resource studies carried on cooperatively by the State and the U. S.

Geological Survey. _/ In Illinois, the State Geological Survey has collected

_/ Bedrock-contour maps are published as illustrations in many of the county reports on ground water resources of Ohio, published by the Division of Water of the Ohio Department of Natural Resources.

enough data on depth to bedrock to complile a bedrock-contour map of the entire State (Horberg, 1950).

The position of the bedrock surface is also critical in areas along the Fall Line where dissected unconsolidated Coastal Plain deposits lap up onto the erosional surface of the older crystalline rocks. Bedrock-contour maps have been published for the Baltimore area, (Mathews, 1935, and Bennett and Meyer, 1952) and for Washington, D. C. (Darton, 1950).

Conclusion

This discussion of available sources of information on ground conditions is far from a complete inventory. Some of the publications that contain subsurface data are not widely circulated, and the coverage has not been indexed systematically as has that of areal maps. Each request for information on a specific site starts a search for available information, and very few searches fail to add to our collection of useful references. Perhaps most significant is the fact that for the few areas for which we have had two requests spaced a year or two apart, the additional information that has appeared in the interim has been a substantial contribution. One gets the impression that we are on the verge of a great expansion both in the publication rate of basic geologic and soils data, and in the application of these data to problems of engineering construction. This symposium is a concrete example of the trend among engineers and geologist to explore together overlapping areas of interest. Speaking as a geologist, I would urge engineers with problems that appear to be related to geology to seek opportunities for discussing these problems with geologist of Federal and State agencies, university staffs, and private consultants. For some of the questions, you may find answers. For many questions the answers will not be known, because much remains to be learned of ways in which geology may be applied in problems of engineering. But as the demands for geologic data increase, the public support for geologic mapping will be strengthened, and geologists will be stimulated to more effective research on those phases of geology that are applicable to engineering problems.

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