The Engineering Soil Survey and Its Relation to Engineering Problems

A. R. JUMIKIS, Professor of Civil Engineering, Rutgers University
W. W. HOLMAN, Soils Engineer, Greer Engineering Associates, Montclair, N. J.; and
J. R. SCHUYLER, Assistant District Engineer, Soils, New Jersey State Highway Department

This article describes the engineering soil survey and the research techniques and methods which were applied in the preparation of the engineering soil maps. Each of the 21 New Jersey county reports presents detailed information concerning the various soil areas which are delineated on the engineering soil map. The symbols shown on these maps are explained; engineering test values are given for the major soil types, and comments are presented relative to each type of material.

This article also illustrates some of the applications to various engineering problems.

The soil survey work was greatly facilitated by the use and interpretation of aerial photographs. The photographs were of particular value in mapping soil types in mountainous areas, as well as in the coastal plain province.

NEED FOR AN ENGINEERING SOIL SURVEY IN NEW JERSEY

● AS IN ANY other enterprise, so in highway engineering research is essential for progress in highway safety, technology and economy.

In the middle '40's, the New Jersey State Highway Department became increasingly aware of the damage to highways caused primarily by climate and traffic. Climatologically and geologically, soil was the prime factor with which highway engineers became concerned. For example, frost action in certain types of soils causes heaves of roads, because the increase in soil moisture content affects adversely the strength of the soil. Particularly detrimental is spring break-up of pavements when frost leaves the ground. In respect to traffic, it is safe to say that New Jersey, being a corridor state between two great ports, carries the greatest amount of traffic not only in this country but in the world. Traffic, therefore, does its share in wearing and damaging its highways.

Repairs to roads damaged by climate and traffic cost large sums of money. To cope with this damage, the factors causing it should be studied and understood, and the highway design and construction techniques adjusted accordingly. It was evident that particular attention had to be focused on those factors causing damage to roads by frost. The frost problem, therefore, established the need for highway research in New Jersey. Three questions arose: Which of the soils present in the state are more likely to cause frost damage to highway pavements? Where are these soils located? What are their engineering properties? These questions had to be answered in order to reduce highway maintenance costs.

THE JOINT HIGHWAY RESEARCH PROJECT

To pursue highway research, Rutgers, The State University, and the New Jersey State Highway Department, entered into a cooperative effort known as the Joint Highway Research Project. On September 12, 1946, The Joint Highway Research Committee, administrator of the Project, held its initial meeting.

One of the main objectives of the Project was to study the performance of New Jersey highways under freezing and thawing conditions. Upon closer consideration of this problem, however, it became obvious that before such studies could be undertaken successfully, it was necessary first to investigate the soil materials involved—their origin, distribution, extent and engineering characteristics.

Thus an engineering soil survey of New Jersey was considered of basic importance, and the project entitled "Engineering Soil Survey of New Jersey" was established.

An engineering soil survey is one means of (a) taking inventory of soil materials; and (b) providing applicable data on the engineering characteristics of soils, particularly for preliminary design and construction of highways and other earthworks.

The engineering soil survey was planned for the entire State of New Jersey, consisting of 21 counties and comprehending an area of approximately 7,836 sq mi.

THE ENGINEERING SOIL SURVEY OF NEW JERSEY

Contents of Survey

The engineering soil survey required that (a) the soils be identified and classified, and (b) the boundaries of each soil type be delineated on an engineering soil map.

The soils of the entire state were mapped from an engineering standpoint in the belief that a knowledge of the various soil types and their properties is the real basis of good highway design. The engineering soil survey was completed in October 1955, when New Jersey became the first state in the country to have a complete statewide engineering soil survey with engineering soil maps and soil descriptions published in the form of bulletins. These engineering soil survey bulletins provide an excellent reference source of information about the general engineering characteristics of the soils of any area in the state.

Procedures Used in the Soil Survey

To undertake a statewide survey, it became apparent that the methods and procedures of such an effort must be made uniform. A rigid system must be adopted so that all maps and reports can be equally understood and there should be a minimum of repetition from one county report to another. It was decided, therefore, to publish first a statewide report to present both the broad aspects of soil and soil environment for the entire state and descriptions of all research techniques employed by the Project. Report No. 1, Soil Environment and Methods of Research, presents information on climate, geology, soils, soil mapping techniques, airphoto mapping methods, soil testing procedures, soil identification and reprints of AASHO standard test methods. The first edition of Report No. 1 was published in 1950, and in 1955 a revised edition was issued.

In producing the county maps and reports, a thorough investigation was made of the literature pertaining to natural materials reported to be present in each county. This literature embraced the Geologic Map of New Jersey, U. S. Geological Survey Folios, past geologic reports, bulletins and special papers. Attention was directed to the significance of agricultural soil series, types and phases as shown on agricultural soil maps and land-use maps and as described in agricultural bulletins. Parallel with this investigation of the literature was a very careful study of the aerial photographs of each county in the office as well as in the field, with the dual purpose of gaining familiarity with the area and of correlating the geology and agricultural soils with the in-place engineering materials. It was found that this careful preliminary study greatly facilitated ease and accuracy in the later airphoto interpretation.

The next step was actual soil delineation directly on the airphotos, with constant checking against the literature and reference maps in order to correlate the geology with the engineering map units. Airphoto interpretation was the major technical tool employed in making the survey, and therefore about 50 percent of the time spent on a given county was devoted to this part of the work.

In order to insure the accuracy of map unit boundaries on the airphotos, extensive field trips were taken to many localities, and soil samples brought back to the Project laboratory at Rutgers for analysis as to some of their engineering properties—particle size distribution, consistency limits and the Proctor density curve. The results of those analyses are given in Appendix A of each county report.

Where soil conditions were difficult to interpret on the airphotos, particular care was taken in field checking. It was sometimes found desirable for the sake of clarity to modify the mapping symbols used to indicate complicated areas, or even to use substitute symbols. All such cases are fully described in the appropriate reports.

Figure 1 is a diagram illustrating the procedures used in the soil survey.

<u>Standard Symbolic Notations Used</u>

The symbols used to designate the delineated soil areas on the engineering soil maps consist basically of three parts. For example, in the symbol AM-24ge the first part, AM, indicates the geologic formation or the parent material from which the soil in question is derived. The second part, 24, is the soil textural symbol based on the Highway Research Board's soil classification system. The third part, ge, is the so-called drainage symbol. It indicates an estimated depth from the ground surface to the ground-water table. In this example the symbol ge shows that the drainage conditions in the area concerned are from good to excellent, meaning that, according to established soil-mapping criteria, the position of the ground-water table is over 6 ft below the ground surface.

The geologic part of the mapping symbol, AM for example, implies also the approximate topographic position relative to the occurrence of the soil and likewise specifies the character of the underlying material. Thus the letter A of the AM symbol indicates the agent which deposited the parent geologic formation (A = alluvial), which is mostly unconsol-

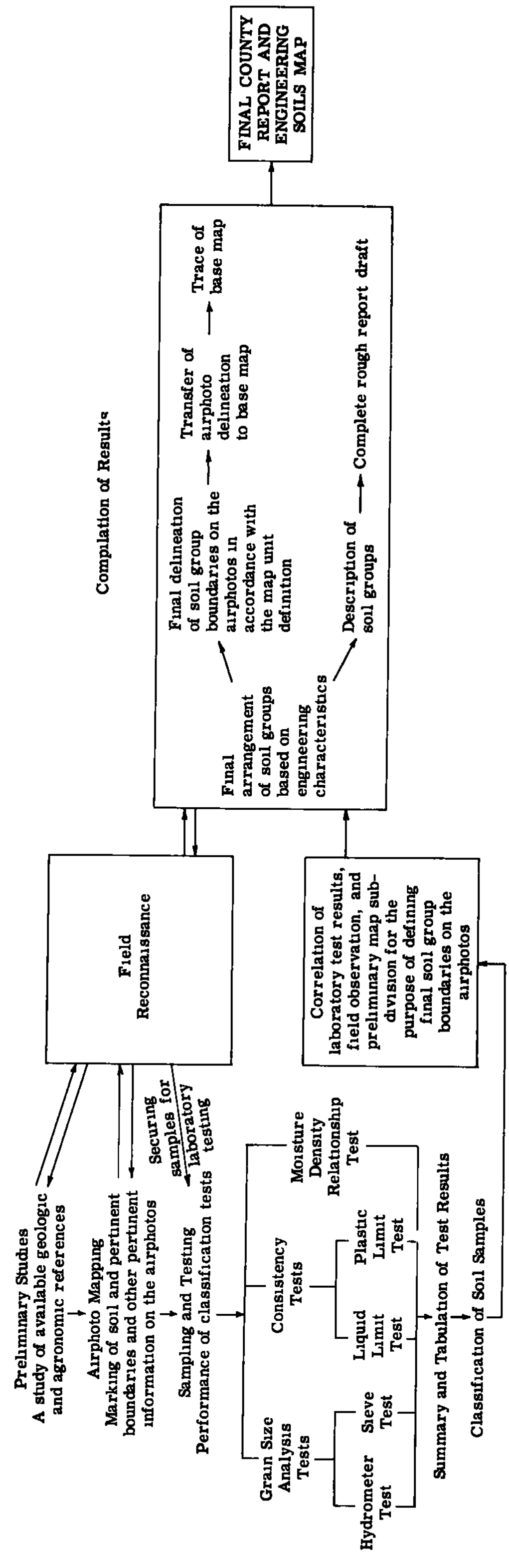

Figure 1. Procedures of the Engineering Soil Survey of New Jersey.

idated. In another symbol, Sh-4ge, the letter S means that the soil is the weathering product of hard sedimentary bedrock. Hence the first letter in the symbol can mean not only the process of the rock formation but also the rock type itself from which the soil is derived. The various parts of the soil mapping symbols imply also soil texture, consistency, soil density, surface drainage, internal drainage, depth to the ground-water table, and possible engineering aspects relative to construction operations in these soils.

The second letter, M, in the symbol AM may have one of two possible meanings. When capitalized, it indicates the land form associated with the soil area. In this case AM means a broad plain or mantle of alluvial material. On the other hand a lower case letter such as h in the symbol Sh indicates bedrock from which the parent material of the soil is derived. For example, the symbol Sh means that the hard sedimentary rock is shale. The numeral 4 indicates a silty texture of the soil, and ge shows good to excellent drainage conditions.

Often two soil types may be encountered on the engineering soil maps which are designated by the same textural symbols, for example AM-24 and M-24. The difference between these two is that the AM-24 soils are generally composed of relatively coarse materials, whereas the M-24 soils contain a high percentage of silt. These textural differences are clearly brought out in the proper county bulletins by the engineering soil test values (averages of all laboratory test results made from areas of a certain soil mapping unit).

In general there are four

drainage symbols used. They indicate, by convention, the following range in depth to the ground-water table:

vp—very poor to poor, 0 to 1 ft
pi—poor to imperfect, 1 to 3 ft
ig—imperfect to good, 3 to 6 ft
ge—good to excellent, over 6 ft

The relationship between the geologic formations and the letter symbols of the various soil mapping units is shown in Figure 2.

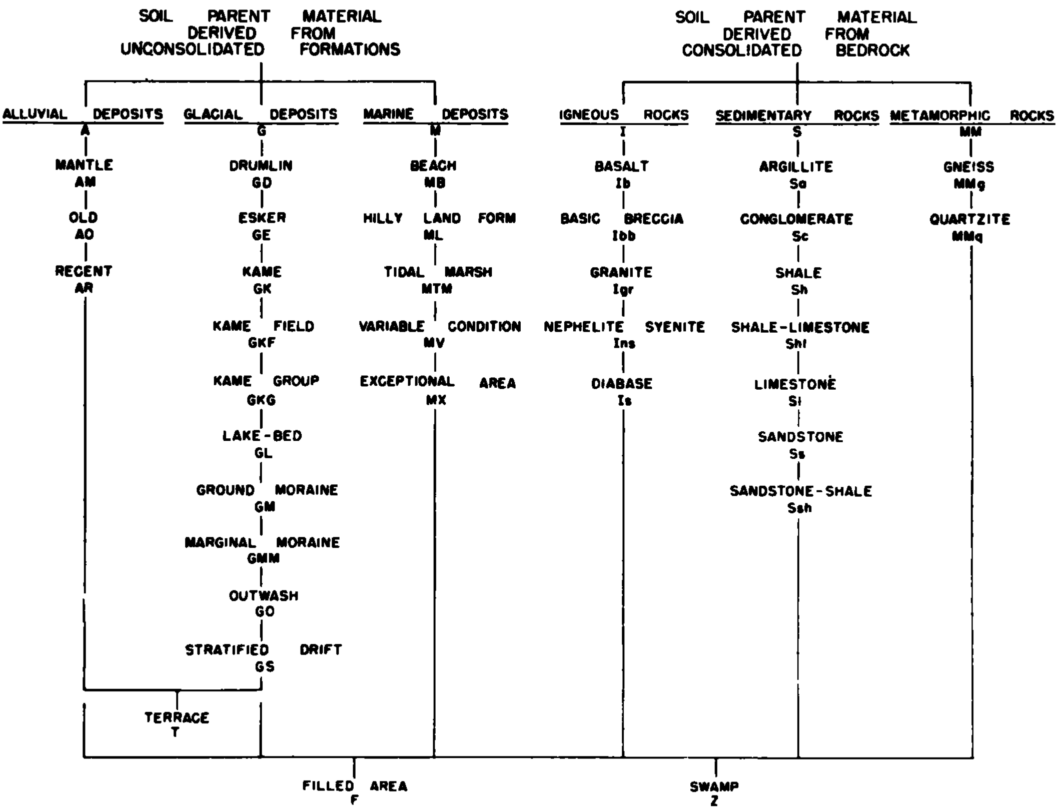

Figure 2. Correlation of geology and letter symbols.

Use and application of the soil mapping units as here reported is very easy and convenient.

Comparative Usefulness of Engineering Soil Maps

The engineering soil maps were designed with the needs of the civil engineer specifically in mind. Containing the most recent scientific data available on the engineering materials of New Jersey, presented in standard form, using modern techniques of investigation, they focus in one place much information drawn from related sciences and correlated from an engineering point of view.

Drawn to a scale (2 in. to the mile) eight times larger than the geology map of the state, it was possible to show on the engineering maps a much greater amount of detail. The use of aerial photographs as a technological tool for interpretation in conjunction with the geology map enabled the staff of engineers and geologists of the Joint Highway Research Project to cover all areas of the state, however inaccessible to field parties.

An understanding of land form and soil texture is essential for the engineer, and this information is provided by several land form designations, such as esker, kame and outwash, which occur in the mapping code, while the HRB classification numerals included in the symbols indicate the texture. Compound of fractional symbols convey yet more specific information to the engineer, since they show that the material designated by the numerator of the fraction is underlain at variable and often shallow depths by the material indicated in the denominator.

The greater scale of the engineering soil maps permits showing specific areas of a frequently occurring material. For instance, a gneissic formation, indicated on the geology map by the letter symbol Ign, crops out in The Highlands Province of New Jersey. The type of coding used on the engineering soil map not only discloses the location of each outcrop but also allows the engineer to draw inferences as to the soil development and its thickness, the location of glacial deposits on the gneiss, the land form, drainage conditions and other factors influencing good construction. In the case of ground moraine, for instance, the geology map does not use a mapping symbol, but refers to its presence by a general footnote. The exact location of deposits of ground moraine, as shown on the engineering soil map, is a matter of some importance to the civil engineer, and the more exact the information he can get the better. Equally in the case of the textural characteristics of deposits of the Cape May formation, a footnote is used on the geology map, whereas the HRB classification numerals included in the engineering mapping code give precise information in specific areas.

Figure 3 shows the comparable geologic and engineering soil maps for the same area in Sussex County, New Jersey. On the soil maps cultural detail and political subdivisions have been subdued to emphasize soil boundaries.

Topographic maps are useful to a civil engineer in preliminary planning and reconnaissance of highway alignments. They show only contour, however, and give no indication of the nature of the in-place materials which will be met in construction. It is very important to know what may be found beneath the surface—whether the drainage will be good, for instance, or whether there will be suitable borrow material available nearby. Consideration of factors like these is essential in reducing the costs of construction and maintenance.

It is quite possible to apply an agricultural soil map as an engineering soil map. However, the agricultural maps are prepared with a view to the surface or near-surface soil (the top three feet), and are not concerned with the greater depths which may often be of equal importance to the civil engineer. It is possible to translate the agricultural maps profitably if the civil engineer has some knowledge of the related sciences of pedology, geomorphology, geology, etc., but not all civil engineers possess this extra knowledge. The engineering soil maps offer information from these additional sources already translated into engineer-

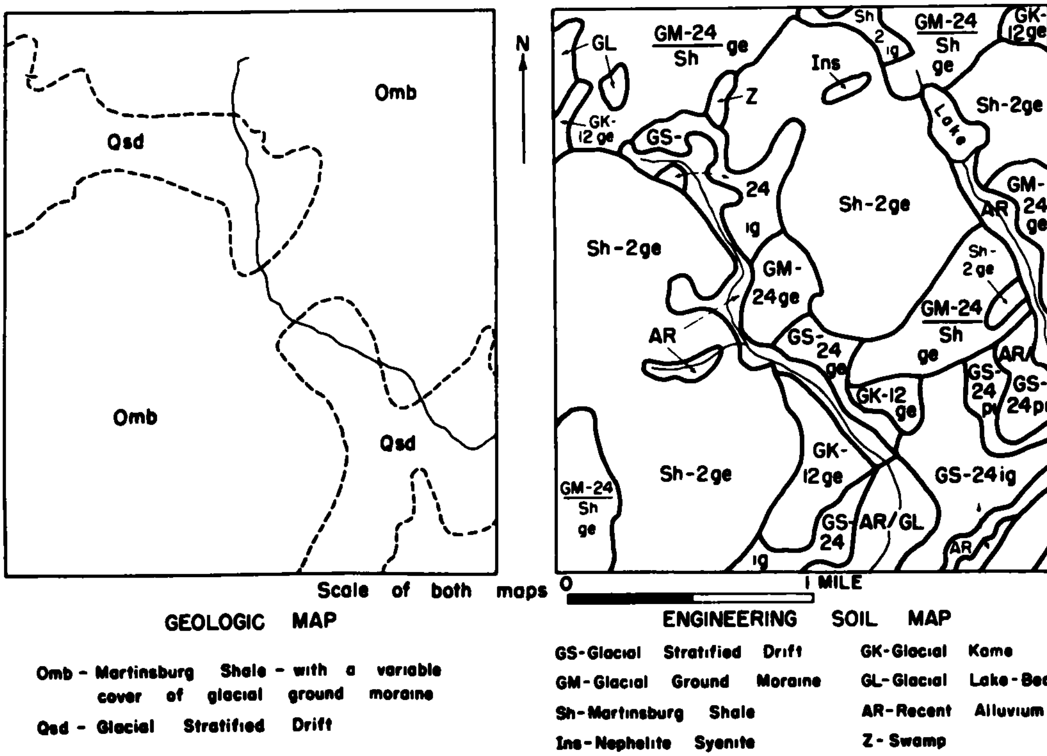

Figure 3. Geologic map and engineering soil map of an area in Sussex County.

ing terms, prepared on the fuller and more accurate basis of aerial photo interpretations.

<u>Contents of County Engineering Soil Bulletins</u>

Each of the twenty county reports presents detailed information concerning the various soil areas which are delineated on the engineering soil map of that particular county. Each of the major soil groups and soil areas is treated in a separate chapter, and each chapter includes comments on Parent Material, Land Form, Soils, Drainage Conditions, and Engineering Aspects. Also, engineering test values are tabulated for the various soil types. One such set of test values is shown in Figure 4, AM-24 Test Values.

The written description of the soil area is an excellent guide and reference source for the engineer; he will understand the background of the area and will know what to expect prior to seeing the area in the field. The test values are a necessity in pavement design—to evaluate the need for drainage structures, to determine the need for, and the depth of, subbase material, and to determine the possible use of the soil type as borrow material.

In Appendix A of each county report there is a summary of soil test data. This summary comprises test results of all samples taken in that county. Each sample is identified as to its boring and all of the borings are plotted on the soil maps which accompany each report.

SUMMARY OF SOIL TEST DATA

Sample No.	Agronomic Name (as mapped 1917-27)	Airphoto No	Lat. Deg. Min. Sec.	Long Deg. Min. Sec.	Slope at Sample Hole	Hori-zon	Depth to Bottom	Test Results: Sieve Analysis, Cumulative Percent Passing 3/4	4	10	40	200	Hyd. Anal. Silt Sizes	Hyd. Anal. Clay Sizes	Physical Minus #40 L.L.	P.I.	Proctor Max. Dens.	Opt. m c.	HRB Designation Sub-grade Group	Group Index	Remarks
					deg.		inches	3/4	4	10	40	200	%	%	%	%	p.c.f.	%			
AM-24 continued																					
15	Sassafras	21-127	40	74	3-4	A	8	100	93	88	66	21	•	•	NL	NP	•	•	A-2-4	0	Sample taken on top of knoll
			25	29		B	27	100	94	89	65	20	•	•	NL	NP	127	10	A-2-4	0	
			03	17		C	40H	97	72	61	39	12	•	•	17	3	127	10	A-1-b	0	
16	Sassafras	21-127	40	74	0-3	A	7	100	94	88	53	12	•	•	NL	NP	•	•	A-2-4	0	
			25	29		B	18	100	99	97	72	35	•	•	19	3	123	11	A-2-4	0	
			05	18		C	36H	100	100	97	82	46	•	•	26	5	118	14	A-4	2	
17	Sassafras	21-175	40	74	1-2	A	9	100	100	97	96	16	•	•	NL	NP	•	•	A-2-4	0	
			26	27		-	43H	100	100	99	87	64	•	•	NL	NP	121	10	A-4	6	
			26	08																	
18	Portsmouth	21-129	40	74	0-1	A	10	96	85	77	63	28	•	•	25	5	•	•	A-2-4	0	Sample taken in low area.
			23	29		B	18	97	86	79	64	31	•	•	16	1	115	12	A-2-4	0	
			43	14		C	35	99	91	90	68	19	•	•	NL	NP	118	12	A-2-4	0	
						-	48H	100	95	91	68	11	•	•	NL	NP	116	11	A-2-4	0	
19	Sassafras	21-193	40	74	1-2	A	14	99	92	91	72	11	•	•	NL	NP	•	•	A-2-4	0	
			19	33		-	36H	95	56	44	27	4	•	•	NL	NP	•	•	A-1-a	0	
			10	34																	
20	Sassafras	21-173	40	74	2-3	A	18	100	98	96	79	46	•	•	28	5	•	•	A-4	2	
			24	28		B	30	100	96	94	64	33	•	•	20	4	127	10	A-2-4	0	
			15	15		C	44	100	99	94	56	24	•	•	21	2	124	11	A-2-4	0	
						-	48H	100	99	97	71	55	25	28	30	10	118	14	A-4	4	
21	Collington	21-163	40	74	1-2	A	7	100	100	99	85	18	•	•	NL	NP	•	•	A-2-4	0	Marine deposit (MV-47) at shallow depth.
			16	26		-	36H	100	100	100	85	22	•	•	NL	NP	122	13	A-2-4	0	
			11	18																	
22	Collington	21-163	40	74	2-3	A	11	100	100	99	93	14	•	•	NL	NP	•	•	A-2-4	0	
			15	28		B	24	100	100	99	94	15	•	•	NL	NP	•	•	A-2-4	0	
			42	02		C	36H	100	100	100	94	23	•	•	NL	NP	•	•	A-2-4	0	

Figure 4. AM-24 test values.

PRACTICAL APPLICATIONS OF ENGINEERING SOIL MAPS AND BULLETINS

General Applications

The principal uses of the engineering soil maps are as follows:

1. In the initial planning and reconnaissance for the location and relocation of road alignments.
2. In locating sources of soil material suitable for making fills.
3. In planning soil surveys for a specific project.
4. In subsurface investigations for foundation.
5. In highway design.
6. For preliminary planning airports.
7. As a materials inventory map and record.
8. For community planning.
9. As an ideal base map for pavement performance studies and other research dealing with natural in-place materials.

An inquiry made of the various users of the Engineering Soil Survey maps and reports disclosed that in addition to the principal uses described above, the engineering soil maps and their bulletins are employed by many consulting engineers and other engineering agencies for the following types of studies:

1. Estimating subsoil conditions for specific geologic reports.
2. Preparation of foundation investigation reports. The soil map and bulletins indicate a range of anticipated soil conditions. They help to determine rapidly the depth and nature of the bedrock, the general geology of the area concerned, and the type of fill material available. They also help to determine, in general, the scope of the soil exploration pro-

gram necessary for a certain site and structure. The depth of borings and type of soil samples to be taken can also be predetermined for many areas.

3. Interpretation of boring data.
4. Identification and classification of the soil types encountered in shallow borings.

The following are some of the projects which have found the soil survey maps and reports valuable:

1. Study of the approaches to the George Washington Bridge.
2. Study of New Jersey's water resources.
3. Planning field work on potential clay deposits and location of possible raw materials for production of lightweight aggregates.
4. Studying and calculating the potential increase in population and future density patterns of development in some of the communities of the state.
5. Preliminary planning of sites for industry.
6. Pavement evaluation and design for the Garden State Parkway.
7. Location of the New Jersey Turnpike in the northern part of the state.

The logistics of any subsurface exploration program becomes more efficient as a result of the proper application of the soil maps. For example, because the manual accompanying the map provides an estimate of the depth to bedrock, a description of the rock and detailed properties of overburden, drilling crews can be supplied with the proper equipment, tools and accessories for a particular job. For another example, in preparing contracts for geophysical exploration or for foundation drilling, bidders, not particularly familiar with the area, appreciate the inclusion of general underground conditions as determined from the Engineering Soil Survey of New Jersey. Bidders can quote more intelligent prices on contracts because, within the established scope of the maps, the reliability and authenticity has been verified. Likewise the estimates of the work to be performed on these contracts are more realistic and are no longer guesses, as a result of using the maps to prepare the contracts.

The soil maps are also useful in preparing and executing time schedules for earthworks requiring the use of heavy equipment; a glance at the map, with its indication of soft or firm ground, will enable the contractor to know at once where to shift heavy equipment in rainy seasons to prevent its being bogged down in mud.

Some of the difficulties which might be encountered during the execution of technical projects are indicated by the soil maps. Thus the compound mapping units with a horizontal bar, for example $\frac{\text{AM-24}}{\text{MV-47}}$, imply a contact between the permeable top layer and the clayey layer of soil underneath it. Undercutting such a contact may mean seepage into the cut. Therefore such a compound mapping unit indicates the necessity for planning and installing proper drainage structures to cope with the water.

In a general way the soil maps can indicate or imply, by use, where ground water and its movement can cause difficulties in highway construction. They can provide the longitudinal extent of subgrade treatment, general subbase and base design for pavement; give an indication as to slope requirements in both cut and fill, internal soil drainage characteristics, and provide data relative to the phenomenon of frost action. Such general information is of immense benefit when estimates are being prepared in conjunction with proposed alternate route locations.

The Engineering Soil Survey of New Jersey, in the hands of contractors recognizing its practical applications, has been responsible for exploding the myth that certain soil materials are in scarce supply, even though urban development has placed many restrictions on borrow pits. By applying the most fundamental principles of geology, and knowing the details of the soil classification system employed on the maps, engineers have been able to indicate potential areas where the type of material required for a specific purpose can be explored. Since the soil map defines areal extent and the manual gives a range of test values for the "A", "B" and "C" horizons, it is essential to plan further exploration to verify depth, exact quality and areal extent prior to negotiation for purchase or specifying use in contracts.

The soil maps are also useful in planning a pavement performance or evaluation study. Once the locations of a particular design have been established, the soil maps enable the evaluator to pick locations for further study, based on the maximum number of soil types, and drainage conditions which exist for a particular design. A certain amount of field work is necessary in connection with such research, because the soil classification of embankment material cannot always be associated with the nearest cut. In preparing the final analysis and interpretation of results, the maps provide considerable assistance.

CONCLUSIONS

In these days of scarcity of top talent, the engineering soil map has done much to extend the potential scope of service of a soil engineer. Within the recognized limits of application, the maps and manuals are a valuable supplement to a highway engineer who believes in economy from conception to completion. The many possible applications of the maps of the Engineering Soil Survey of New Jersey indicate that they are a valuable and very practical contribution to soil engineering and highway technology.

ACKNOWLEDGMENT

Successful completion of the Engineering Soil Survey of New Jersey was due in great part to the continued interest and support of E. C. Easton, Dean of the College of Engineering of Rutgers University, and J. J. Slade, Jr., Research Director of its Bureau of Engineering Research, as well as to the helpful guidance and advice on the part of the Joint Highway Research Committee, of which A. C. Ely, representing the New Jersey State Highway Department, was Chairman. Acknowledgment also is made of the effective efforts of a competent and cooperative staff, many members of which worked on the project for a large part of its duration. The authors wish to express their appreciation to Mrs. Ruth Ahrens for technical editorial assistance in connection with Engineering Soil Survey publications and preparation of the typescript of this article.

Copyrighted Figures 2 to 4 are shown by courtesy of Rutgers University, through the Rutgers University Press.

REFERENCES

Engineering Soil Survey of New Jersey, Rutgers University Press, New Brunswick, N. J.:

(a) Report No. 1, revised edition, "Soil Environment and Methods of Research," by Franklyn C. Rogers (1955).

(b) Reports Nos. 2 to 21, inclusive (county reports), by members of the staff.

(c) Report No. 22, "Practical Applications of Engineering Soil Maps," by W. W. Holman, R. K. McCormack, J. P. Minard and A. R. Jumikis (1957).