316

HIGHWAY RESEARCH BOARD
Bulletin 316

Soil Foundation and Materials Exploration Methods

Application and Evaluation

National Academy of Sciences—
National Research Council

publication 962

NRC. HIGHWAY RESEARCH BOARD

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Application and Evaluation

Presented at the

40th ANNUAL MEETING

January 9-13, 1961

National Academy of Sciences —
National Research Council
Washington, D.C.
1962

$ 1.60

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Contents

Subsurface Exploration: Organization, Equipment, Policies and Practices

● THIS SURVEY was conducted by the Committee on Surveying, Mapping and Classification of Soils, Department of Soils, Geology and Foundations, Highway Research Board, in order to collect and disseminate information concerning the organization, equipment, policies and practices employed by the various states in performing subsurface investigations for the design and construction of highways. It is believed that this information will be of value to the highway engineering profession by promoting an interchange of information on the subject among the states and increasing the quality, quantity, and efficiency of subsurface investigation operations, necessary for the proper design and economical construction of any highway project.

SCOPE OF SURVEY

A questionnaire (Appendix) was sent to 52 states and territories in September 1960. Replies were not received from 5 states (Mass., Miss., N.J., R.I., S.C.).

The questionnaire consisted of the following parts:

1. State organization and administration.
2. Organizational structure.
3. Subsurface investigations by contract.
4. Methods of subsurface investigation.
5. 1959 calendar year volume of subsurface exploration work.

SUMMARY OF DATA

The tabulation of information (Appendix) derived from the survey indicates that the organizations employed by the various states to perform subsurface investigations range from rudimentary units scattered throughout the highway department to units staffed and equipped to furnish complete and comprehensive services in the fields of soil and foundation engineering and engineering geology. How much of this extreme variation in personnel, equipment, and practices is due to the effect of local conditions and how much is due to the lack of appreciation of the influence of soil and foundation conditions on highway costs and performance could not be determined from the questionnaire answers.

Conflicting or inadequate answers were given for some items in replies from a few states. The Subcommittee did not ask the specific state for clarification.

The survey indicates, however, that some of the states, by providing well-staffed and equipped subsurface investigation organizations, do have a proper understanding of the vast importance of adequate and thorough subsurface investigation information on the cost and performance of their highway systems.

ACKNOWLEDGMENTS

Preparation of the questionnaire, tabulation of the answers, and analysis of the results were accomplished by the Soil Surveying Subcommittee, comprised of the following members: Walter H. Zimpfer, Chairman; William P. Hofmann, Neil E. Mason, and Arnold C. Orvedal.

A. General

1. Relative to the organization in your Department:
   a. Does a single department unit have the responsibility of all phases of soil engineering work?
   b. Is the responsibility for different phases of soil engineering work divided among staff members in different departmental subdivisions?
2. In case of a unit being responsible for all phases of soil engineering work, is the unit:
   a. A separate unit serving two or more agencies or branches of State government?
   b. A separate unit of the Highway Department serving two or more of the departmental divisions or subdivisions?
   c. A unit of a major departmental division?
   d. A unit of a major departmental subdivision?

B. Subsurface Investigations

1. Is it the general practice of your Department to conduct, by test borings and sample testing, subsurface investigations for:
   a. Roadway design and construction?
   b. Bridge foundation design and construction?
2. In case of divided responsibility relative to the various phases of soil engineering in your Department:
   a. Are subsurface investigations considered a separate phase of soil engineering work?
   b. Are all subsurface investigations performed by one departmental unit?
   c. Are subsurface investigations for the roadway design and those for bridge foundation design performed by separate departmental units?
3. Does performance of the subsurface investigation include:
   a. Planning of the test boring and sampling program and the specifying of laboratory sample testing?
   b. Supervision and performance of field test boring and sampling work?
   c. Laboratory testing?
   d. Preparation of investigation report?
4. Does the subsurface investigational report include:
   a. Complete test boring and sample test data?
   b. Graphical presentation of test boring information, sample test data, and general observations?
   c. Interpretation of findings and analysis of problems of stability, bearing capacity, and settlement?
   d. Recommendations relative to design treatment and construction procedures and controls?
5. Is subsurface information in the form of test boring logs and laboratory physical test data, either in graphical or tabular form, provided as a part of the construction plans for:
   a. The general roadway
   b. Bridges
   c. Use in preparation of Bid Proposals by prospective bidders?
   d. Use by the contractor during construction of the project?
6. In your Department is it the practice in construction contracts to treat excavation, relative to type of material, as:
   a. Unclassified
   b. Classified as to soil excavation or rock excavation, with estimated quantities of each based on test boring information?
7. In the performance of subsurface investigations, is it the general practice of your Department to:
   a. Utilize only Departmental facilities?
   b. Utilize only contracted services?
   c. Utilize Departmental facilities and contracted services?
8. If the answer to 7c is "Yes", state the approximate percentage performed by:
   a. Departmental facilities
   b. Contracted services

State	General						Subsurface Investigations																										
	1a	1b	2a	2b	2c	2d	1a	1b	2a	2b	2c	3a	3b	3c	3d	4a	4b	4c	4d	5a	5b	5c	5d	6a	6b	7a	7b	7c	8a	8b	
Ala.	Yes	No	No	No	No	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	-	-	-	-	Ala.
Alaska[1]	Yes	-	Yes	-	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes[2]	Yes[2]	No	No	Yes	90	10	Alaska[1]
Ariz.	No	Yes	-	-	-	-	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	90	10	Ariz.
Ark	No	Yes	-	-	-	-	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No[3]	Yes	No	No	-	-	Ark
Calif.	No	Yes	-	-	-	-	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	Yes	No	Yes	No	No	-	-	Calif
Colo.	No	Yes	-	-	-	-	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	97	3	Colo.
Conn.	Yes	No	No	Yes	Yes	No	Yes	Yes	-	-	-	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No	No	Yes	50	50	Conn
Del.	Yes	No	No	Yes	Yes	No	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	Yes	80	20	Del
Fla.	No	Yes	-	-	-	-	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	Yes	90	10	Fla
Ga.	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	No	Yes	No	No	-	-	Ga
Hawaii	Yes	No	No	Yes	Yes	No	Yes	Yes	-	-	-	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	5	95	Hawaii
Idaho	No	Yes	-	-	-	-	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	-	-	Idaho
Ill.	No	Yes	-	-	-	-	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	Yes	85	15	Ill.
Ind	Yes[4]	No[4]	No	No	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	-	No	No	Yes	Yes	No	No	Yes	65	35	Ind.
Iowa	Yes	Yes	No	No	Yes	No	Yes	Yes	No	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	Yes	99	1	Iowa
Kan.	No	Yes	-	-	-	-	Yes	Yes	-	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	No	-	-	Kan
Ky.	No	Yes	-	-	-	-	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	-	-	Yes	Yes	No	No	Yes	75	25	Ky.
La.	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	Yes	90	10	La.
Me.	Yes	No	No	Yes	Yes	No	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	No	No	-	-	Me.
Md.	No	Yes	-	-	-	-	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	60	40	Md.
Mich.	Yes	No	No	Yes	Yes	No	No	Yes	No	Yes	No	Yes	Yes	No	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	No	Yes	Yes	No	Yes	-	-	Mich
Minn	Yes	No	No	Yes	No	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	No	Yes	Yes	No	-	99	1	Minn
Mo.	Yes	No	No	No	Yes	No	Yes	Yes	-	-	-	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	No	Yes	Yes	-	-	-	-	Mo.
Mont.	No	No	No	Yes	-	Yes	-	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	-	Yes	Yes	Yes	Yes	No	No	No	Yes	98	2	Mont
Neb.	No	Yes	-	-	-	-	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	93	7	Neb
Nev.	Yes	Yes	-	Yes	-	-	Yes	-	-	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	-	Yes	No	Yes	No	Yes	Yes	-	No	No	Yes	-[5]	-[6]	Nev
N. H.	Yes	No	No	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	No	Yes	No	No	Yes	98	2	N. H.
N. M.	No	Yes	No	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes	No	No	Yes	No	Yes	No	No	-	-	N. M.
N. Y.	Yes	No	No	No	No	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	Yes	No	No	No	Yes	80	20	N. Y.
N. C.	No	Yes	-	Yes	-	-	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	-	No	No	Yes	95	5	N. C
N. D.	No	Yes	-	-	-	-	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	99 5	0. 5	N. D.
Ohio	No	Yes	-	-	-	-	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	No	Yes	Yes	Yes	No	Yes	95	5	Ohio
Okla.	No	Yes	-	-	-	-	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	No	No	No	No	Yes	No	Yes	No	No	-	-	Okla.
Ore.	No	Yes	-	-	-	-	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	Yes	No	No	No	Yes	98	2	Ore.
Pa.	No	Yes	-	-	-	-	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	No	No	No	Yes	50	50	Pa.
S. D.	Yes	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	-	-	S. D
Tenn.	Yes	No	No	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	Yes	90	10	Tenn.
Tex	No	Yes	No	No	No	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	No	No	No	No	-	-	Yes	99	1	Tex.
Utah	Yes	No	No	No	No	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes	No	No	No	Yes	50	50	Utah
Vt.	No	Yes	No	No	Yes	No	Yes	Yes	Yes	No	Yes	No	Yes	No	No	No	Yes	No	No	Yes	Yes	No	No	No	Yes	No	No	Yes	90	10	Vt.
Va.	Yes	Yes	No	No	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	No	Yes	No	No	95	5	Va.
Wash.	Yes	No	No	No	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	Yes	95	5	Wash.
W. Va.	Yes	Yes	No	-	Yes	-	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	-	-	Yes	50	50	W. Va.
Wisc.	No	Yes	-	-	-	-	No	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	No	No	Yes	60	40	Wisc.
Wyo.	No	Yes	-	-	-	-	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	No	No	Yes	80	20	Wyo.
D. C.	Yes	Yes	No	No	Yes	No	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	15	85	D. C
P. R.	No	No	No	Yes	Yes	No	Yes	Yes	No	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	-	No	Yes	45	55	P. R.

Note Dash (—) indicates data were not available or answer was not given in questionnaire.

1Some items not answered because Alaska Highway Department did not assume responsibility for Alaska highway system until July 1, 1960.

2Applies only to some contracts.

3For bridges-yes, for roadway-no.

4Soils Section has major responsibility, Bridge Dept. responsible for bridge sites.

5Roadway-95 percent, bridge-25 percent.

6Roadway-5 percent, bridge-75 percent.

II. ORGANIZATIONAL STRUCTURE

NOTE: Complete questions in the following sections A through D if your Department has either a soil engineering unit or a subsurface exploration unit.

A. General

1. Does the following information pertain to a unit having responsibilities relative to:
   a. All phases of soil engineering?
   b. Only the subsurface investigational phase of soil engineering?
2. Name of Unit: ______________________
3. Unit Supervisor:
   a. Name: For Specific States Contact Unit (a and b)
   b. Title: ______________________
   c. Major professional field of supervisor: (Check appropriate box)

[1] Soil and Foundation Engineer	[4] Materials Engineer	[7] Civil Engineer
[2] Structural Engineer	[5] Geologist	[8] Engineer-Geologist
[3] Photogrammetrist	[6] Geophysicist	[9] Soil Scientist

   Other ____10____

   d. Qualifications in soil mechanics and foundation engineering:
      (1) Undergraduate courses? Yes____ No____
      (2) Graduate courses? Yes____ No____
      (3) Number of years experience? ______ Years

B. Organization Details

1. Is the organization comprised of a single centralized headquarters and facilities?
   (NOTE: If the answer to this question is "Yes", do not answer question 2 through 5).
2. Does the organization contain district or division offices responsible to a central headquarters?
3. Are uniform policies and practices established by a central headquarters where district or division offices occur?
4. Do district or division offices have complete drilling and testing facilities?
5. Are analyses, recommendations and report functions performed only by a central headquarters? (Please submit organization chart of subsurface exploration unit).

C. Personnel

1. Total number of personnel in subsurface exploration unit
2. Number of soil and foundation engineers employed
3. Number of geologist employed
4. Number of aerial photographic interpreters employed
5. Number of geophysicists employed
6. Number of soil scientists employed

D. Salary Range per Month

(NOTE: If the Department has 2 or more units responsible for subsurface investigations, give salary information regarding personnel in each unit)

1. Chief Soil Engineer (Unit Supervisor)?
2. First Assistant to Chief Soil Engineer?
3. District or Division Soil Engineer?
4. Soil Engineer?
5. Entrance salary for:
   a. Soil Engineer (Engineering graduate)
   b. Soil Engineer (Engineering graduate with advanced study in soil mechanics)

State	Organization							Details					Personnel						Salary Range						
	1a	1b	2	3c	3d1	3d2	3d3	B1	B2	B3	B4	B5	C1	C2	C3	C4	C5	C6	D1	D2	D3	D4	D5a	D5b	
Ala	Yes	No	Soils and Foundations	1, 7	Yes	Yes	12	No	Yes	Yes	No	Yes	25	2	3	1	1	2	$575-700	$550-675	$575-700	$400-625	$400	$440	Ala
Alaska	Yes	No	Materials Section	1, 4, 5, 9	Yes	No	8	No	Yes	Yes	No	Yes	20[7]	5[7]	5[7]	0	0	-	-	-	-	-	-	-	Alaska
Ariz	Yes	Yes	Materials Division	4	No	No	30	No	No	No	No	Yes	35-40	3	2	1	0	1	825-975	650-775	-	-	-	-	Ariz
Ark	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Ark
Calif	Yes	-	Materials and Research Dept	4, 7	-	-	-	No	Yes	Yes	No	No	-	-	-	-	-	-	950-1,155	821-988	821-988	710-862	530	584	Calif
Colo	No	Yes	Engineering-Geology Unit	8	Yes	No	20	Yes	-	-	-	-	8	-	3	-	-	-	628-802	492-628	-	-	447-543	-	Colo
Conn	Yes	No	Soils and Foundations Div	1	Yes	Yes	20	Yes	-	-	-	-	33	6	3	0	0	0	575-775	510-710	510-710	460-620	410-485	425-485	Conn
Del	Yes	No	Soils Section	1, 7	Yes	Yes	5	Yes	-	-	-	-	8	1	1	0	0	0	600-715	-	-	475-572	450-572	-	Del
Fla	No	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Fla
Ga	No	No	Soils Section	7	Yes	Yes	1	Yes	-	-	-	-	35	1	3	0	0	0	585-755	545-700	-	400-525	-	-	Ga
Hawaii	No	Yes	Subsurface exp (unit)	1, 7	Yes	No	10	Yes	-	-	-	-	3	1	0	0	0	0	796-1,016	722-922	655-836	655-836	489-624	-	Hawaii
Idaho	No	Yes	Engineering	5	No	No	10	No	Yes	Yes	No	No	13	0	10	2	2	0	700-750	521-675	425-600	-	425-500	-	Idaho
Ill	Yes	No	Soils Section	4	Yes	-	10	No	Yes	Yes	Yes	No	44	12	0	0	0	0	650-850	550-750	650-850	550-750	480	530	Ill
Ind	Yes	No	Soils Engineering	1, 4, 7	No	No	25	Yes	-	-	-	-	5	4	0	0	0	0	750-1,000	641-883	-	525-775	465-575	-	Ind
Iowa	Yes	No	Soils Division	1, 7	Yes	Yes	6	Yes	-	-	-	-	75	2	0	0	0	0	675-750	625-700	-	-	475-550	500-575	Iowa
Kan	No	No	Materials and Design	7, 8	Yes	No	20	Yes	-	-	-	-	62	4	31	1	0	0	616-714	557-616	-	436-505	436	-	Kan
Ky	Yes	No	Division of Materials	4, 5, 7, 9	-	-	-	Yes	-	-	No	Yes	14	-	2	-	-	7	710-862	556-676	504-612	457-556	-	-	Ky
La	Yes	No	Testing and Research	7	-	-	25	No	Yes	Yes	No	No	100	15	5	1	1	1	650-750	525-650	525-650	480-580	440-540	480-580	La
Me	Yes	No	Soils Division	1, 7	Yes	Yes	5	Yes	-	-	-	-	28	3	6	2	0	0	485-780	425-689	-	-	425-529	425-529	Me
Md	Yes	No	Soils and Bridges	1, 2, 4/7	Yes	Yes	35	Yes	-	-	-	-	86	10	0	0	0	0	808-1,010	650-813	-	-	-	-	Md
Mich	Yes	No	Soils Division	7	No	No	33	No	Yes	Yes	No	Yes	90	5	4	5	5	0	905-1,128	809-1,009	748-931	633-800	489	534	Mich
Minn	Yes	No	Soils Unit	7	Yes	Yes	26	No	Yes	Yes	No	No	98	14	3	0	0	0	722-878	641-781	641-781	569-694	450-547	450-547	Minn
Mo	Yes	-	Geology and Soils Section	8, 9	No	No	28	No	Yes	Yes	No	No	70	0	0	0	0	0	-800	-749	616-749	-713	460	500	Mo
Mont	Yes	Yes	Materials Section	4	-	-	-	No	Yes	Yes	No	No	15	1	2	1	0	0	-	-	535-650	535-650	435	-	Mont
Neb	No	No	Division of Materials and Tests	7	Yes	No	-	No	No	-	-	-	-	-	-	-	-	-	610-685	-	-	-	475	-	Neb
Nev	No	Yes	Materials Survey and Soils Crew	4	No	No	5	Yes	-	-	-	-	7	0	0	0	0	0	648-786	535-648	-	465-561	-	-	Nev
N H	Yes	-	Soils and Foundation Section	8	Yes	-	15	Yes	-	-	-	-	29	4	1	0	0	1	578-700	474-578	-	334-460	388-424	424-460	N H
N M	Yes	No	Materials and Testing Laboratory	4, 7	Yes	No	21	Yes	-	-	-	-	15	-	8	1	0	0	-	-	-	-	-	-	N M
N Y	Yes	No	Bureau of Soil Mechanics	1	Yes	Yes	13	No	Yes	Yes	No	Yes	250	35	2	1	5	1	980-1,150	800-952	535-785	436-785	436-531	436-531	N Y
N C	No	Yes	Geological Division	8	No	No	10	No	Yes	Yes	Yes	Yes	17	1	7	0	0	0	570-727	469-598	405-517	350-447	350-447	405-517	N C
N D	-	Yes	Materials Department	4, 7	-No	No	26	Yes	-	-	-	-	17	1	1	0	0	0	-	-	-	475-700	450-475	500-525	N D
Ohio	No	Yes	Foundation Exploration Section	1, 7	Yes	Yes	17	Yes	-	-	-	-	155	2	10	0	0	0	860-1,070	720-860	-	550-785	440-550	440-550	Ohio
Okla	No	No	Soils Laboratory	4	-	-	18	Yes	-	-	-	-	24	0	1	0	0	0	580-725	490-615	490-615	465-580	490-615	490-615	Okla
Ore	Yes	-	Soils and Geol Sect of Constr Div	5, 7	No	No	28	Yes	-	-	-	-	11	3	2	0	3	0	655-810	500-625	500-625	575-715	575-715	575-715	Ore
Pa	Yes	-	Soils Unit of Material Division	1, 4	No	No	24	No	Yes	Yes	No	No	40	17	11	5	1	0	680-870	618-779	560-715	484-618	424-532	484-618	Pa
S D	Yes	No	Materials and Soils Division	1, 4	Yes	-	24	Yes[8]	Yes	Yes	No	Yes	27	4	4	0	0	0	670-820	585-705	520-615	520-615	460-550	495	S D
Tenn	Yes	No	Soils	7	Yes	No	7	Yes	-	-	-	-	27	1	5	0	0	0	470-560	445-530	420-470	350-420	420-470	445-530	Tenn
Tex	-[9]	-[9]	-[9]	5, 7, 8, 10	Yes	No	-	No	Yes	Yes	Yes	No	6	-	-	0	0	0	600-716	500-634	600-716	585-668	450-500	450-500	Tex
Utah	Yes	No	Soil Mechanics Department	1	Yes	Yes	15	Yes	-	-	-	-	10	1	6	0	0	0	750	500	500	475	435	475	Utah
Vt	Yes	No	Soils Laboratory	7	Yes	No	5	Yes	-	-	-	-	24	1	4	0	0	0	-	-	-	500-710	-	-	Vt
Va	Yes	No	Soil Sect of Mater and Tests Division	4, 5	Yes	No	4	No	Yes	Yes	Yes	No	88	0	10	0	0	0	510-640	450-560	376-470	-	450	-	Va
Wash	Yes	No	Soil and Geol Section, Material Div	7	-	-	-	No	Yes	Yes	Yes	Yes	52	11	1	-	-	-	-	-	-	-	-	-	Wash
W Va	Yes	-	Soil Mech Br of Engineering Div	7, 10	-	-	12	Yes	-	-	-	-	16	1	3	0	0	0	700-800	600-700	-	-	475	-	W Va
Wisc	No	Yes	Soils Unit of Material Section	1	Yes	Yes	6	Yes	-	-	-	-	14	2	2	0	0	0	665-940	565-890	615-730	-	475-565	565-675	Wisc
Wyo	-	Yes	Engineering Geology	7	-	-	30	Yes	-	-	-	-	8	0	3	2	0	0	-	-	-	-	-	-	Wyo
D C	Yes	No	Soils Section of Material Dev Div	1	Yes	Yes	6	Yes	-	-	-	-	9	2	0	0	0	0	786-866	673-740	-	-	-	-	D C
P R	Yes	No	Soils Investigation Section	1	-	Yes	8	Yes	-	-	-	-	7	4	1	0	0	0	575-625	400-475	-	300-350	300-350	350-400	P R

Number of personnel when unit is fully staffed

South Dakota is in process of setting up district offices for field investigations

[9]Texas Highway Department has central Bridge Division that is responsible for subsurface investigations for all bridges in State District Laboratory is responsible for other subsurface investigations in the specific district

III. SUBSURFACE INVESTIGATIONS BY CONTRACT

A. General
1. Does your Department contract:
    a. Drilling services?
    b. Testing services?
    c. Engineering interpretation and analysis services?
2. Does your Department have an official set of specifications for subsurface investigation for engineering purposes?
3. Are subsurface investigation contracts awarded on the basis of:
    a. Competitive bidding?
    b. Negotiated agreement?
4. Do your official specifications set forth minimum requirements for contractor supervisory personnel qualifications?

B. Design Consultants
1. With respect to soil investigations, are design consultants governed by Departmental specifications for such work?
2. In case of a design consultant being employed for preparation of construction plans, are subsurface investigations performed by:
    a. A subcontract awarded by the design consultant?
    b. A contract awarded by the Department?
3. In case of a design consultant performing subsurface investigations by subcontract, is the consultant reimbursed on the basis of:
    a. Only a part of the agreement percentage fee for plan development?
    b. A percent of the estimated or actual cost of the project?
    c. Only the actual cost of the subsurface investigation work?
    d. The cost of the subsurface investigation plus an extra work percentage fee?

IV. METHODS OF SUBSURFACE EXPLORATION

A. General
1. In planning of the subsurface investigation, is the test boring program prepared by the test boring locations being selected on the basis of:
    a. Only office review of plans of contemplated construction and other information of a general nature?
    b. Actual field inspection and study of the alignment, or site, with the aid of plans and other information of a general nature.
2. In the planning of subsurface investigations, do you employ aerial photography?
    a. For soil or ground interpretations?
    b. As a map only for location of boring sites based on cultural and other planimetric features identified on the photography?
3. Do you utilize the earth resistivity method of subsurface exploration:
    a. For location of bedrock?
    b. For identifying soil strata?
    c. In exploration for sand-gravel deposits?
    d. In exploration of sand-gravel deposits?
4. Do you utilize the seismic refraction method of subsurface exploration:
    a. Single-channel equipment?
    b. Multiple-channel equipment?
    c. For determining depth to bedrock?
    d. For locating sand-gravel deposits?

    If used for other purposes, state them ____________________

	Investigations by Contract											Methods of Exploration - General												
	1a	1b	1c	2	3a	3b	4	B1	B2a	B2b	B3	1a	1b	2a	2b	3a	3b	3c	3d	4a	4b	4c	4d	
Ala	No	No	No	No	No	-	No	No	-	-	-	No	Yes	-	Yes	Yes	Yes	-	-	No	No	-	-	Ala
Alaska	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	No	d	No	Yes	Yes	No	Yes	No	No	No	No	No	No	No	Alaska
Ariz	Yes	Yes	Yes	No	No	Yes	No	Yes	Yes	No	-[2]	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	Yes	No[11]	Ariz
Ark.	-	-	-	-	-	-	-	-	-	-	-	No	Yes	No	No	Yes	Yes	No	No	No	No	No	No	Ark
Calif.	No	No	No	-	-	-	-	-	-	-	-	-	Yes	No	Yes	Yes	No	No	Yes	-	Yes	Yes	No[11]	Calif
Colo.	Yes	Yes	Yes	No	No	Yes	No	No	Yes	No	c	No	Yes	No	No	Yes	No	No	Yes	No	No	No	No	Colo
Conn.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	c	No	Yes	No	No	No	No	No	No	No	Yes	Yes	No	Conn
Del	Yes	Yes	Yes	No	Yes	No	-	Yes	No	Yes	-	No	Yes	No	Yes	No	No	No	No	No	No	No	No	Del.
Fla	Yes	No	No	No	Yes	No	No	Yes	Yes	Yes	c	No	Yes	No	Yes	Yes	Yes	No	No	No	No	No	No	Fla
Ga	-	-	No	No	Yes	No	-	-	-	-	-	No	Yes	No	Yes	Yes	-	No	No	No	No	No	No	Ga
Hawaii	Yes	No	No	Yes	Yes	Yes	No	No	Yes	-	c	No	Yes	No	Yes	Yes	No	No	No	No	No	No	No	Hawaii
Idaho	No	No	No	No	No	No	No	No	No	No	-	No	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes	No[11]	Idaho
Ill.	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	b	No	Yes	Yes	No	Yes	Yes	No	No	No	No	No	No	Ill.
Ind.	Yes	Yes	Yes	No	No	Yes	No	Yes	Yes	Yes	a, b, c, d	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No	Ind.
Iowa	Yes	No	Yes	No	Yes	No	No	Yes	Yes	No	a	No	Yes	Yes	No	No	No	No	No	No	No	No	No	Iowa
Kan	No	No	No	No	No	No	No	No	No	No	-	No	Yes	Yes	-	Yes	No	No	No	No	No	No	No	Kan
Ky	Yes	Yes	Yes	No	-	Yes	No	Yes	Yes	Yes	a	No	Yes	No	Yes	No	No	No	No	No	No	No	No	Ky
La	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	a, d	No	Yes	No	Yes	No	Yes	Yes	Yes	No	No	No	No	La
Me	No	No	Yes	No	No	No	Yes	Yes	No	No	-	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	Me.
Md	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	d	No	Yes	Yes	No	No	No	No	No	No	No	No	No	Md.
Mich	Yes	No	No	No	No	Yes	No	-	-	-	-	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Mich
Minn.	Yes	Yes	No	No	Yes	Yes	No	Yes	Yes	Yes	d	Yes	Yes	No	No	No	No	No	No	No	No	No	No[11]	Minn
Mo	No	No	No	No	-	-	-	-	No	No	-	No	Yes	No	No	Yes	No	Yes	No	No	Yes	Yes	No[11]	Mo.
Mont.	No	-	-	No	-	-	-	-	-	Yes	-	Yes	-	Yes	-	No	-	-	-	No	-	-	-	Mont
Neb	Yes	Yes	Yes	No	No	Yes	-	-	Yes	-	-	-	Yes	Yes	-	No	No	No	No	No	No	No	No	Neb
Nev	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	-	c, d	-	Yes	Yes	-	No	No	No	No	No	No	No	No	Nev
N. H	Yes	No	No	No	Yes	-	No	Yes	-	-	-	-	Yes	No	Yes	No	No	No	No	No	No	No	No	N. H.
N M	No	No	No	-	-	-	-	-	-	-	-	No	Yes	No	No	No	No	No	No	No	No	No	No	N M
N Y.	Yes	No	No	Yes	Yes	No	No	-	No	Yes	-	No	Yes	Yes	Yes	No	No	Yes	Yes	No	Yes	Yes	No	N Y.
N. C	Yes	Yes	Yes	No	Yes	-	Yes	-	-	-	c	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	N. C
N. D	Yes	Yes	Yes	No	No	Yes	-	No	No	Yes	-	No	Yes	No	-	No	No	Yes	No	No	No	No	No	N D.
Ohio	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	No	c	No	Yes	Yes	No	No	No	No	No	No	No	No	No[11]	Ohio
Okla.	No	No	No	No	No	No	No	No	No	No	-	-	Yes	No	-	-	No	No	No	No	No	No	No	Okla
Ore.	Yes	No	Yes	No	No	Yes	No	-	-	-	-	-	Yes	No	-	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes[11]	Ore
Pa	Yes	Yes	Yes	Yes	-	Yes	No	Yes	Yes	-	d	No	Yes	Yes	-	Yes	Yes	Yes	Yes	No	No	No	No	Pa.
S. D.	No	No	No	-	-	-	-	Yes	No	No	-	No	Yes	Yes	Yes	Yes	No	Yes	Yes	No	No	No	No	S D.
Tenn.	Yes	Yes	Yes	No	Yes	No	No	No	Yes	No	a	No	Yes	No	No	No	No	No	No	No	No	No	No	Tenn
Tex	No	No	No	-	-	-	-	-	-	-	-	No	Yes	No	No	No	No	No	No	No	No	No	No	Tex.
Utah	Yes	Yes	Yes	No	No	Yes	No	Yes	Yes	No	d	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	No	No	No	Utah
Vt.	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	No	e[12]	Yes	Yes	No	No	No	No	No	No	No	No	No	No	Vt
Va	No	No	No	Yes	Yes	No	-	No	Yes	No	d	No	Yes	No	Yes	Yes	No	Yes	No	No	No	No	No	Va
Wash.	Yes	No	No	No	No	Yes	No	-	-	-	-	No	Yes	Yes[13]	Yes[13]	Yes[13]	Yes[13]	Yes[13]	Yes[13]	No	No	No	No	Wash.
W Va	Yes	Yes	Yes	No	No	Yes	-	No	Yes	Yes	d	No	Yes	Yes	-	No	No	No	No	No	No	No	No	W Va
Wisc.	Yes	Yes	No	Yes	Yes	No	No	Yes	Yes	No	c	No	Yes	Yes	Yes	Yes	Yes	No	No	Yes	-	Yes	-	Wisc.
Wyo	Yes	Yes	No	No	-	Yes	No	Yes	Yes	-	c	-	Yes	No	Yes	Yes	No	Yes	Yes	No	No	No	No	Wyo
D C	Yes	Yes	Yes	No	Yes	No	No	No	Yes	No	c	No	Yes	No	No	No	No	No	No	No	No	No	No	D C.
P. R.	Yes	Yes	Yes	No	Yes	Yes	-	No	Yes	Yes	a	No	Yes	No	No	No	No	No	No	Yes	Yes	Yes	No[11]	P R

[10] Reimbursement based on lump sum.
[11] Other purposes of seismic test
Arizona—Classify materials, locate geologic structures, and slope design.
California—Determining material for slope design and cost estimates.
Idaho—Classifying excavation material
Minnesota—Experimented with single channel apparatus for various purposes, results were unreliable
Mississippi—Summer experiment only.
Ohio—Have 10 trace century portable unit, no qualified personnel
Oregon—Landslide and foundation analysis.
Puerto Rico—Depth of unstable materials.
[12] Only low bid of subsurface investigation work.
[13] Occasionally

IV. METHODS OF SUBSURFACE EXPLORATION (Cont'd)

B. Methods of Disturbed Sampling for Classification Testing Utilized:
1. Test pits?
2. Hand auger-posthole type?
3. Hand auger-screw type?
4. Peat sampler?
5. One-inch retractable piston sampler?
6. Power, sectionalized, continuous spiral auger?
7. Power, hollow stem, sectionalized, continuous spiral auger?
8. Power, bit-on-kelly auger?
9. Small diameter press samplers? (2-in. D. or less)
10. Driven samplers?
11. Wash boring samples?
12. Other? ______________________________

C. Undisturbed Sampling
1. Most commonly used thin-wall, "Shelby Tube" sampler (2"OD__), (2½"OD__), (3"OD__), (3½"OD__), other:__________
2. Most commonly used piston sampler (2"OD__), (2½"OD__), (3"OD__), (3½"OD__), other:________________
3. Most commonly used split tube sampler with liner ( ), (state size).
4. Other:____

D. Drive Sampling (including Rock Coring)
1. Method (s) of maintaining open hole:

	Check applicable method (s)
a. Drive pipe?	______
b. Flush joint casing?	______
c. Flush coupled casing?	______
d. Hollow stem auger?	______
e. Drilling fluid?	______

2. Drilling fluid used:

a. Clean water?	______
b. Recirculated water?	______
c. Drilling mud?	______
d. Air?	______

3. Rock coring barrels employed?
   - a. DCDMA single tube core barrel (EX__), (AX__), (BX__), (NX__).
   - b. DCDMA double tube core barrel (EX__), (AX__), (BX__), (NX__).
   - c. DCDMA double tube core barrel (EXM__), (AXM__), (BXM__), (NXM__).
   - d. Other size barrels____
   - e. Full flow-type barrels (Yes____) (No____)?

	Disturbed Sampling												Undisturbed Sampling				Drive and Coring			
	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	C1	C2	C3	C4	D1	D2	D3	
Ala	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes	Yes	Yes	-	2", 3"	-	2"	-	b, e,	a, c,	a, AX and BX	Ala
Alaska	Yes	Yes	Yes	-	-	Yes	Yes	-	Yes	Yes	No	-	3"	-	2¼"	-	b, c, d	-	-	Alaska
Ariz	Yes	No	No	No	No	Yes	No	No	Yes	Yes	Yes	-	-	-	2 42 and 1 40 inches[14] ⟶		a, b	b	b, AX,d, BX, NX,e, Yes	Ariz
Ark	Yes	No	Yes	No	No	Yes	No	Yes	Yes	Yes	Yes	-	2"	-	-	2" split tube sampler W/O liner	e	b, c	b, NX	Ark
Calif	Yes	Yes	-	-	Yes	Yes	Yes	Yes	Yes	Yes	No	-	3"	2½'	-	-	c, d, e	All	b, BX and NX,c, NXM	Calif
Colo	Yes	Yes	No	No	Yes	Yes	No	Yes	No	Yes	No	-	-	-	-	-	a	b, d	None	Colo
Conn	Yes	Yes	Yes	No	Yes	No	No	No	Yes	Yes	No	-	3½"	3", 3½"	None	-	a	a	b, NX,d, DCDMA single, 2", DCDMA, double, 2", Shot core 2", 3½"	Conn
Del	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	-	3"	3½"	2½" I D	-	a, b, c, d, e	c	b, AX, NX	Del
Fla	No	Yes	Yes	No	No	Yes	Yes	No	No	Yes	Yes	-	2"	2"	2"	-	a, b, c, d, e	a, b	a, NX,e, Yes	Fla
Ga	No	Yes	Yes	No	No	Yes	No	No	Yes	Yes	Yes	-	3'	-	2"	-	a, b, e	a, b, c	b, EX, AX, BX	Ga
Hawaii	Yes	Yes	No	No	Yes	Yes	No	No	No	Yes	Yes	-	2", 2½"	-	-	-	a, b, c, e	a, d	b, EX, NX, AX	Hawaii
Idaho	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes	Yes	No	-	3"	-	-	-	a, b, e	a, b, c	a, EX,b, AX, BX, NX,c, BxM,e, No	Idaho
Ill	No	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Yes	Yes	-	2"	-	-	-	a, c, d, e	a, b	a, NX,b, AX, BX	Ill
Ind	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	-	2", 3"	2', 3"	2"	-	a, d	-	b, BX	Ind
Iowa	No	Yes	No	No	No	Yes	No	No	No	Yes	No	-	2", 4"	-	1 4"	-	b, e	a, b, c	c, BXM,d, N,e, Yes	Iowa
Kan	Yes	Yes	Yes	No	No	Yes	No	Yes	Yes	Yes	No	-	3"	-	5"	-	a, e	b, c	a, EX,b, BX, NX,c, BXM, NxM,d, 4" Denison	Kan
Ky	Yes	Yes	Yes	-	-	Yes	Yes	-	-	Yes	Yes	-	2½"	2½"	-	-	b, d	a, b	a, AX, BX	Ky
La	Yes	Yes	No	Yes	No	No	No	No	No	Yes	Yes	-	3½"	3½"	-	Split spoon D S 2" O D	a, e	b, c	d, Double tube C B (oil field t p) 2", 4" I D	La
Me	Yes	Yes	Yes	No	No	Yes	No	Yes	Yes	Yes	Yes	-	2", 3½"	3½"	-	Split tube No liner 2" O D	a	a, b, c	c, FXM, 4XM	Me
Md	Yes	Yes	Yes	Yes	No	Yes	Yes	No	No	Yes	Yes	-	2", 3"	-	1⅞", 1⅜"	-	a, c, d, e	b	a, EX, AX,bEX	Md
Mich	No	Yes	Yes	Yes	No	Yes	Yes	No	No	Yes	Yes	-[a]	-	-	1¼'	-	b, d, e	a	-	Mich
Minn	Yes	Yes	Yes	Yes	No	Yes	No	No	No	Yes	No	-	2	2"	1⅜"	-	a, b, c, e	a, b, c	a, EX, AX,b, NX,c, EXM, AXM, BXM, NXM,d, Dennison, e, No	Minn
Mo	-	-	Yes	No	No	Yes	No	No	Yes	Yes	No	-	3", 1½, 5'	3", 5'	4½"	-	a, b, e	b, d	a, NX,b, NX,d, 4"Double tube, e, No	Mo
Mont	Yes	Yes	Yes	Yes	-	Yes	Yes	-	Yes	Yes	-	-	2"	-	2'	-	d, e	a, b, c, d	a, AX,b, AX, NX,e, No	Mont
Neb	Yes	Yes	No	No	No	Yes	Yes	No	No	Yes	No	-	2½"	-	-	-	d	-	-	Neb
Nev	Yes	-	-	-	-	Yes	-	-	-	-	-	-	-	-	-	-	-	b	-	Nev
N H	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	-[b]	-	-	2"	-	a, b, c	a	a, AX,b, AX	N H
N M	Yes	Yes	Yes	No	No	Yes	No	Yes	No	Yes	Yes	-	-	-	3"	-	c	a, b, d	b, BX, NX,e, Yes	N M
N Y	Yes	Yes	Yes	Yes	Yes	No	No	Yes	No	Yes	No	-	3½"	3½"	-	3½" Dennison	a, c, e	a, b, c	a, AX, NX,b, Ax, NX,c, AXM, NXM,d, 4½", 6",e, No	N Y
N C	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	-	2	-	2"	-	a, c	a, b	b, AX,C, AXM, BXM, e, Yes	N C
N D	Yes	Yes	Yes	No	No	Yes	No	No	Yes	Yes	No	-	2"	-	-	-	a	b	a, AX,b, AX,e, No	N D
Ohio	No	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes	No	-	3"	3"	3"	-	a, b, d, e	a, b, c	a, NX,b, NX,c, NXM,d, Damco 3¼" Full flow (2 5/16"), e, Yes	Ohio
Okla	Yes	Yes	No	No	No	No	No	Yes	No	No	No	-	2½"	-	-	-	e	b	a, NX	Okla
Ore	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	-	-	-	2½	-	a, c	a, b	b, AX,NX,	Ore
Pa	Yes	Yes	Yes	Yes	No	Yes	No	Yes	No	Yes	No	-	2"	-	2½"	-	a	a	-	Pa
S D	Yes	Yes	Yes	No	No	Yes	Yes	No	Yes	Yes	No	-	-	-	-	Calif , Porter Type 2' O D	a, c, d, e	b, c	d, PK-2⅞" Double Tube Core Barrel, e, Yes	S D
Tenn	No	No	Yes	No	No	Yes	No	No	No	Yes	Yes	-	3"	2"	-	-	a, b, e	a, b	a, BX, NX	Tenn
Tex	Yes	Yes	Yes	No	No	No	No	Yes	No	Yes	Yes	-	4"	-	-	Dennison 4"	-	b	-	Tex
Utah	Yes	Yes	No	No	No	Yes	Yes	Yes	No	Yes	Yes	-	2"	-	2"	-	a, b, d	a, b	a, AX,b, AX,e, No	Utah
Vt	Yes	Yes	Yes	No	No	Yes	No	Yes	No	Yes	Yes	-	2"	-	-	-	a, b, c, e	a, c, d	a, AX, c, AXM	Vt
Va	Yes	Yes	Yes	No	No	Yes	Yes	No	Yes	Yes	Yes	-	3"	3"	2"	-	a, d	a	b, AX,e, Yes	Va
Wash	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	-	-	-	2"	2½" O D Open drive sampler	a, b, c, d, e	b, c	b, AX, NX,e, No	Wash
W Va	Yes	No	No	No	No	Yes	Yes	No	No	No	-	-	3, 4" I D	-	-	-	a, b, e	a, c, d	d, 4"I D and 2 5" I D	W Va
Wisc	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	-	2"	3'	-	-	a, c, e	a, b, c	a, AX, BX,b, AX,c, AXM, NXM,d, EXW,e, Yes	Wisc
Wyo	Yes	Yes	Yes	No	No	Yes	Yes	Yes	No	Yes	Yes	-	-	-	-	Back hoe	b, d	a, c, d	b, NX	Wyo
D C	Yes	No	Yes	No	No	No	No	No	No	Yes	No	-[c]	3"	3"	2"	-	c	a	b, EX	D C
P R	Yes	Yes	No	No	No	Yes	No	No	Yes	Yes	Yes	-	2"	3"	-	Split spoon without liner (1⅜" I D)	a	a, b	a, AX,b, AX	P R

[14] Standard bull-nose penetrometer
[a] Davis Peat Sampler
[b] Hydraulic core drill
[c] 2" O D Piston Sampler

IV. METHODS OF SUBSURFACE EXPLORATION (Cont'd)

E. Mechanized Subsurface Exploration Equipment (State-Owned)

a. Total No. of Units	Model	Manufacturer	Mounting (Truck, Trailer, Trailer-Skid, Skid)	Feed (Hand, Screw, Hydr., Chain, Cable)	b.* Principal Type of Units and Number (Auger, Core Drill, Power Winch and Pump (P. W. P.), Cable Tool, Portable Rotary (P. R.))

← Detailed information may be obtained from the Highway Research Board →

*Descriptions have been abbreviated for tabulation

V. 1959 CALENDAR YEAR VOLUME OF SUBSURFACE EXPLORATION WORK

A. Number of projects? ________
B. Miles of roadway? ________
C. Number of bridge sites? ________
D. Linear feet of auger borings? (State and contract forces) ________
E. Linear feet of drive sample-core borings? (State and contract forces) ________
F. Linear feet of rod soundings? ________
G. Approximate number of electrical resistivity tests made? ________
H. Approximate number of seismic refraction tests made? ________
I. Approximate number of field vane shear tests? ________
J. Approximate number of field cone penetrometer tests? ________

	Mechanized Exploration Equipment		Volume of Subsurface Exploration Work										
	a	b	A	B	C	D	E	F	G	H	I	J	
Ala	20	16-Auger, 4-Core drill (P W P)	150[15]	800[15]	300[15]	20,000[15]	5,000[15]	-	50[15]	50[15]	-	-	Ala.
Alaska	-	-	-	-	-	-	-	-	-	-	-	-	Alaska
Ariz.	12	1-Core drill, 5 Back hoe, 6 Air compressors	85	-	50	1,500	3,000	-	2 Proj	1 Proj	-	150	Ariz.
Ark	6	5-Auger, 1-Core drill (P W P , P R)	65	197	99	31,285	1,205	0	50	0	20	0	Ark
Calif	18	4-Core drill, 8-Combination, 6-Auger	300	2,000	450	-	-	-	-	-	-	-	Calif
Colo	4	2-Auger, 1-Combination, 1 Back hoe	120	600	37	-	-	-	15	0	0	0	Colo
Conn	6	6-Core drill	73	75	65	5,000[15]	30,000[15]	15,000[15]	0	0	25	0	Conn
Del	1	1-Auger	316	201	15	12,783	1,759	0	0	0	0	0	Del
Fla	11	3-Core drill, 4 Electric generators, 2 water pumps, 2 Hvy Dty drills	-	-	-	-	-	-	-	-	-	-	Fla.
Ga	9	6-Auger, 1 auger and core drill, 2-core drill	164	555	132	28,000	25,000	2,000	800	0	0	0	Ga
Hawaii	-	-	10	4	7	421	2,469	0	0	0	0	0	Hawaii
Idaho	5	2-Core drill, 1-auger, 2-pump	-	-	-	-	-	-	400	210	100	-	Idaho
Ill	14	2-Auger, 12-Core drill	383	615	179	133,687	56,844	9,798	0	0	0	35	Ill
Ind	2	2 Auger	-	-	-	-	-	-	0	0	0	0	Ind
Iowa	17	17-Auger	143	742	349	340,062	6,336	0	0	0	0	0	Iowa
Kan	19	12-Auger, 1 Auger (P W), 4-Core drill, 2-Penetrometer	160	880	110	222,000	436	-	2	-	-	53	Kan
Ky	26	7-Auger (P W), 10-Auger, 9-Core drill	50	270	60	36,700	5,000	10,800	0	0	0	0	Ky
La	6	6-Portable rotary	417	683	126	220,172	52,861	3,127	392	0	0	0	La
Me.	5	4-Core drill, 1-core drill and auger	40	100	22	2,300	11,066	8,000	30	0	797	0	Me
Md	8	2-Core drill, 5 auger, 1 wash boring	127	263	165	61,000	2,300	27,000	0	0	0	0	Md
Mich.	16	8-Core drill (P W P), 6 auger, 2 wash boring	400	695	250	40,000	45,000	420,000	4,806	350	0	0	Mich
Minn	26	19-Auger, 4-core drill, 3-soil sampler	-	-	-	-	-	-	-	-	-	-	Minn
Mo	21	8-Core drill, 13-Auger	300	1,050	350	-	-	-	300	50	-	-	Mo
Mont	4	3-core drill, 1 auger	32	-	28	3,800	9,199	-	0	0	-	-	Mont
Neb	7	7-Auger	80	400	150	140,000	3,000	0	0	0	0	0	Neb
Nev	5	2-Auger, 2-Back hoe, 1 -(P W P)	21	155	8	8,902	1,861	0	0	0	0	0	Nev
N H	5	4-Core drill, 1-(Hand W P)	62	149	67	4,100	18,000	-	-	-	15	-	N H
N M	7	1-Auger (P W P.), 1-Auger, 3-Backhoe, 1-Port Rotary, 1-Hammer drop	120	-	40	8,115	6	7,009	0	0	0	0	N M
N Y	49	47-Core drill, 2-Auger	672	-	-	58,798	121,720	41,666	25	2,080	100	0	N Y
N C	7	5-Augers, 2 Core drills	85	220	70	400,000	2,500	600	25	0	0	0	N C
N D	6	3-Core drill (Port Rotary), 3-Auger	30	203	41	8,180	16,692	0	0	0	0	0	N D
Ohio	41	9-Auger, 16-Core drill, 2-Rotary drill, 14-Drop Hammer	560	258	313	88,200	51,100	66,700	0	0	50	0	Ohio
Okla.	1	1-Portable Rotary	78	-	-	-	-	0	0	0	0	0	Okla
Ore	13	3-Churn, 4-Core Drill, 6-Auger	70	703	64	5,719	843	4,682	30	380	1	0	Ore
Pa	16	16-Auger	128	704	-	105,600	-	-	200	0	18	0	Pa
S. D	5	1-Core Drill, 4-Auger	75	762	124	17,640	6,314	0	75	-	-	-	S. D
Tenn.	10	10-Auger	144	576	225	220,500	4,000	0	0	0	0	0	Tenn
Tex	12	12-Portable Rotary	401	-	816	-	185,000	-	-	-	40	30,000	Tex
Utah	4	2-Auger, Core drill (P W P) 2-Auger	25	110	26	7,500	5,000	-	20	0	0	0	Utah
Vt	13	2-Core drill, 8-Auger, 3 Wash bore	21	52	45	100,000	3,000	5,000	0	0	0	0	Vt
Va	29	10-Core drill, 19-Auger	99[15]	400[15]	133	-	45,695	-	7	0	0	0	Va
Wash	12	5-Core drill (Wash Boring), 1-Core drill, Auger, 6-Auger	-	-	121	493	15,460	1,080	2	2	3	0	Wash
W Va	10	2-Core drill, 2-Auger, 2-Rotary comb , 3 water pump, 1 Air Comp	-	-	-	-	-	-	0	0	0	0	W. Va
Wisc	5	3-Core drill, 2 Power Cat-Head and pump, port core drill	50	-	-	-	14,000	7,000	-	-	-	-	Wisc
Wyo	11	3-Auger, 2 Core drills, 6-Back Hoes	33	220	55	-	-	-	40	0	0	0	Wyo
D C	1	1-(P W P)	-	-	-	-	-	0	0	0	0	0	D C
P R	7	2-(P W P), 2-Core drill (P W P), 2-Core drill, 1-Port Rotary	50	-	-	22,700	0	0	0	0	0	0	P R

[15]Estimated.

Application of Color Aerial Photography to Geologic and Engineering Soil Mapping

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Color aerial photographs are helpful to the geologist and soils engineer in mapping a part of the Atlantic Coastal Plain in New Jersey. Color differences can be seen between exposures consisting almost entirely of light-gray to yellow-brown quartz sand and exposures consisting largely of quartz sand but containing 5 to 15 percent of green glauconite. Color differences also are apparent among formations containing different amounts or kinds of clay, and between weathered and unweathered parts of the same formation or soil. The ability to distinguish on color aerial photographs among soils of different composition, texture, and degree of weathering is a significant advantage to the soils engineer.

● VERTICAL aerial color transparencies were used to aid in the geologic mapping of the Pemberton 7½-min quadrangle. This quadrangle, an area of about 57 sq mi, is in the Atlantic Coastal Plain physiographic province about 15 mi south of Trenton, New Jersey (Fig. 1).

Rocks similar in texture, composition, and age to the consolidated sedimentary rocks of Late Cretaceous and Tertiary age in the coastal plain of New Jersey underlie the Atlantic Coastal Plain from Long Island to Virginia. Therefore, although this paper concerns a small area, the recognition criteria, interpretation techniques, and mapping methods can be applied to much of the Atlantic Coastal Plain from Long Island to Virginia.

During the geologic mapping of the Pemberton quadrangle, it was evident that information useful to the soils engineer could be interpreted from the color transparencies. It is this application, largely a broad interpretation of the rocks as they affect the soils engineer, that is discussed here. Holman and others (1) describe an engineering soil survey of the entire State and discuss applications of the resultant engineering soil maps. That survey was made by interpretation of black-and-white aerial photographs in conjunction with field studies and laboratory procedures. Holman and Nikola (2) discuss interpretation methods and criteria applied to black-and-white photographs in a coastal plain area.

As used in this report, the term "soils engineer" means a civil engineer having a background in highway and foundation studies and construction and having a particular knowledge of soil mechanics. Soil, as used by the soils engineer, is the unconsolidated material lying above consolidated bedrock. It thus includes the soils of the pedologist's definition, as well as the unconsolidated material below the soil profile. By this definition, large parts of the formations in the Pemberton quadrangle and in the rest of the Coastal Plain are soils.

The color transparencies used in this study were taken by Aero Service Corp., in late spring 1958 and were made available to the U.S. Geological Survey. Complete coverage of the quadrangle was provided at a scale of 1:17,000, as well as several other flight strips at scales of 1:12,000 and 1:24,000. All film was exposed through a pleogon lens of 6-in. focal length.

GEOLOGY

The Pemberton quadrangle is a sandy coastal plain area of low relief. Several low hills rise 30 to 80 ft above the surrounding land surface. The formations that crop out in the quadrangle are mostly unconsolidated sedimentary rocks of Late Cretaceous and Tertiary age. They are the Mount Laurel sand and Navesink formation, of Late Cretaceous age, and the Hornerstown sand, Vincentown formation, Manasquan formation, Kirkwood formation, and Cohansey sand of Tertiary age. Limestone and iron-oxide-cemented layers locally form resistant beds in parts of some formations. The formations trend northeast, dip 10 to 50 ft per mi southeast, and range in thickness from 20 to 60 ft. Quaternary alluvial deposits as much as 30 ft thick mask much of the outcrop area of the older formations (Fig. 2). These deposits are mostly Pleistocene sands and gravels that were derived largely from the underlying and nearby Cretaceous and Tertiary formations. The sedimentary rocks range in color from dark yellowish-orange (10YR 6/6) to light gray (N 7) and white (N 9), dusky green (5G 3/2) to greenish-black (5GY 2/1), dark greenish-gray (5G 4/1) to light greenish-gray (5GY 8/1), and dusky brown (5YR 2/2) to light brown (5YR 5/6). All color names are from the Rock Color Chart (3). This variety of colors enhances the value of color aerial photographs in the interpretation of the formations and soils.

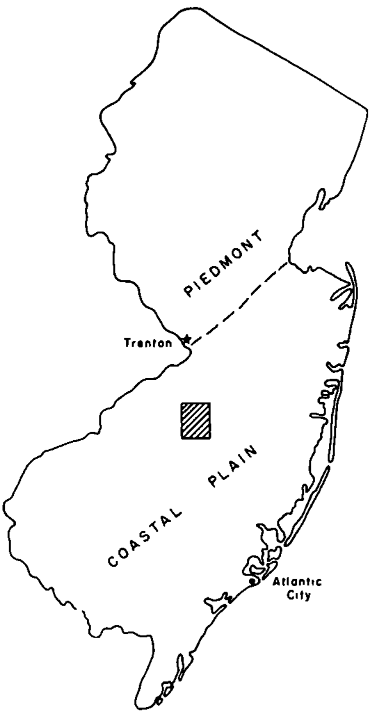

Figure 1. Map of New Jersey showing location of Pemberton $7\frac{1}{2}$-min quadrangle.

MAPPING TECHNIQUES OF THE GEOLOGIST AND SOILS ENGINEER

Geologic and engineering soil mapping in the coastal plain have a common objective, namely, to determine the areal distribution of the different rocks exposed. The use of black-and-white aerial photographs in mapping is well known, but the use of color aerial photographs is still in the initial stages.

The geologist and the soils engineer may approach the mapping differently because of their different requirements. The soil engineer's primary interest is in the surface and near-surface materials, whereas the geologist is interested equally in the surface rocks and their extension underground, and in the subsurface rocks not cropping out. The geologist may group or split his rock units on the basis of composition, texture, or fossil content for the location of ore bodies or aquifers, or for descriptive purposes. The soils engineer, however, may group rocks of several formations into a single classification because of their similar composition, texture, and suitability for a particular purpose. The Mount Laurel sand, the basal part of the Vincentown, and certain Quaternary deposits illustrate this. These rocks, where exposed, are essentially similar quartz sands containing considerable glauconite grains and are almost equally suitable for use as fill or in asphalt mixes. The geologist maps these units individually because they are uniform lithologic units having definite areal distribution, both in outcrop and in places where overlain by other formations and because they are separated by other units of different lithologies and ages. The Quaternary deposits are more variable in their thickness and distribution and are not overlain by other formations; they are present only as surface deposits.

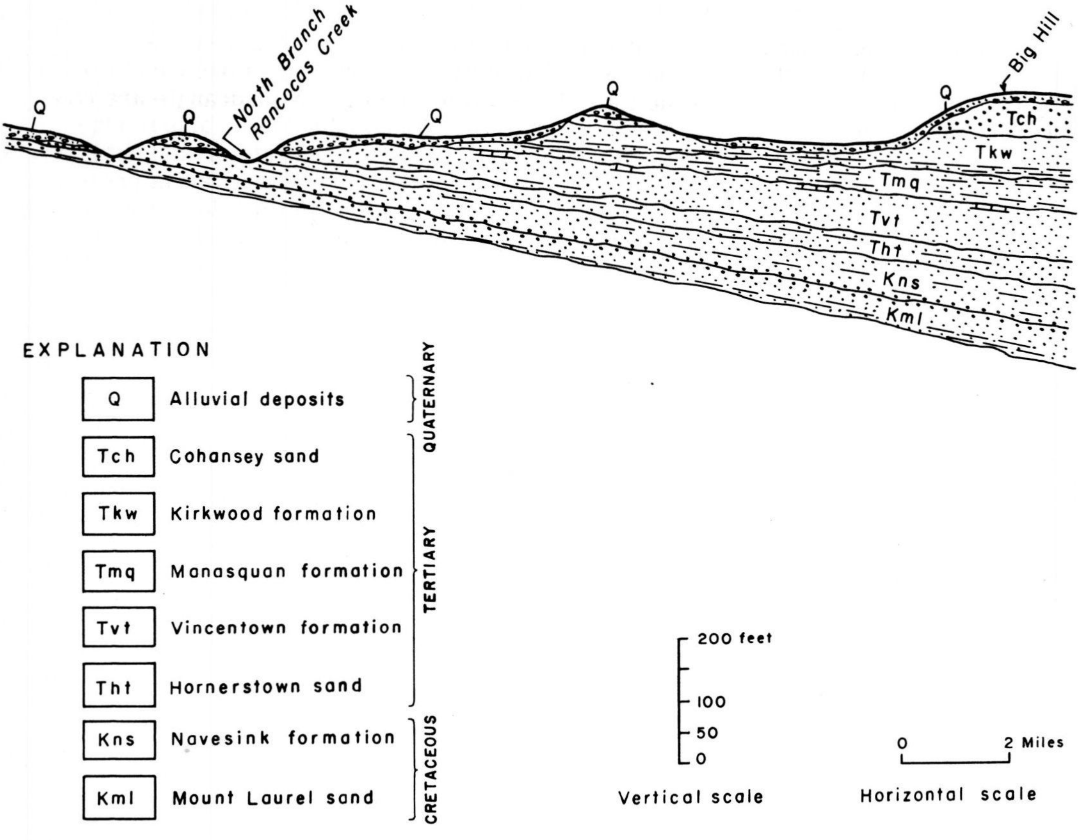

Figure 2. Northwest to southeast cross-section of the Pemberton 7½-min quadrangle. The vertical scale greatly exaggerated (about 30 times the horizontal) to show lithologies, surface configuration, and downdip thickening.

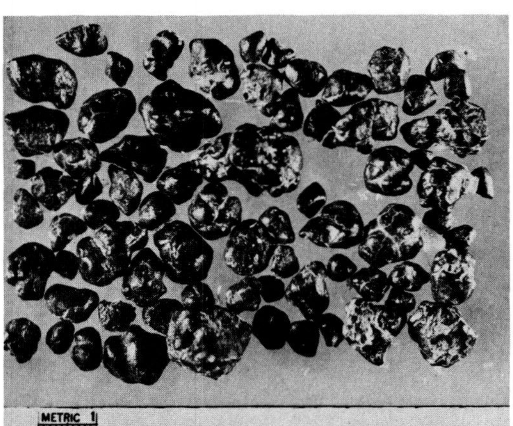

Figure 3. Photomicrograph of rounded glauconite grains showing zones of weakness where smaller grains or fragments are weakly jointed to form larger grains.

Figure 4. Photomicrograph of elongated grains of glauconite showing cleavage-plane zones of weakness.

USE OF COLOR AERIAL TRANSPARENCIES IN MAPPING

The appearance of any unit on aerial photographs, either black-and-white or color, is largely a function of the constituents of that unit; and if more than one consitutent is present, the ratio of them. All the formations in the Pemberton quadrangle are composed chiefly of either quartz or glauconite sand or both, and contain various clay minerals. Three general types of soil, consisting of these minerals in varying proportions, are present in the quadrangle. Type 1 is mostly quartz sand and is present on the Cohansey sand and the Kirkwood formation and on the Quaternary deposits derived from them. Type 2 consists largely of quartz sand but contains as much as 20 percent glauconite sand. This soil type is present on the Mount Laurel sand and basal part of the Vincentown formation and on the Quaternary deposits derived from older glauconite-bearing formations. Type 3 consists largely of glauconite sand and some clay minerals. This type is present on the Navesink formation, the Hornerstown sand, and the Manasquan formation. These three types and their pertinent physical properties and uses are listed in Table 1.

Large quantities of good quality quartz mortar sand is available in the Cohansey sand, and in Quaternary deposits largely derived from the Cohansey sand (Type 1 soils). It is somewhat difficult to distinguish between the Cohansey and Cohansey-derived sediments in many places. It is important, however, that the geologist do this, largely because of the erratic distribution and thickness of the Quaternary deposits as compared with the Cohansey and because of the "ilmenite" ore bodies in some Quaternary deposits (4). The soils engineer interested in mortar sand or good quality "borrow," however, need not distinguish between the two equally suitable materials.

Some of the Quaternary deposits, most of which are quartz sands, contain as much as 20 percent glauconite (Type 2 soils). Because glauconite contains exchangeable potassium and sodium ions and is soft and structurally weak (Figs 3 and 4), it is not desirable in quantity in mortar or concrete mixes. Soils containing it are used satisfactorily in asphalt mixes.

Quartz sands of the Cohansey sand and Quaternary deposits, and glauconite-bearing quartz sands of the Mount Laurel, Vincentown, and other Quaternary deposits can be identified tentatively on black-and-white aerial photographs by several characteristics: landform (i.e., hills, ridges, slopes, terraces), drainage (i.e., density, gully or bank slope, pattern), and to some extent vegetation. These characteristics, together with differences in tone on black-and-white photographs and color on color transparen-

TABLE 1

ENGINEERING SOIL TYPES, ASSOCIATIONS, AND USES IN THE PEMBERTON QUADRANGLE

Soil Type	Parent Material	Composition and Texture	Agronomic Soil	Present Use	Engineering Use
1	Kirkwood formation, Cohansey sand, Quaternary deposits—largely derived from the Kirkwood and Cohansey formations.	Mostly quartz sand, containing some quartz silt, small pebbles of quartz, sandstone, quartzite, a little chert, clay (kaolinite), and some heavy minerals (mostly an "ilmenite" suite)	Sassafras, Lakewood, St. Johns, Freneau	Wooded, cranberry bogs, huckleberry fields	Mortar sand, concrete aggregate, subgrade, asphalt mix, molding sand
2	Mount Laurel sand, basal part of Vincentown formation, Quaternary deposits—largely derived from older glauconite-bearing formations.	Mostly quartz sand, containing as much as 20 percent glauconite sand and some small pebbles (quartz, quartzite)	Collington, Keansburg, Shrewsbury, Freneau	Good farmland	Asphalt mix, subgrade fill
3	Navesink formation, Hornerstown sand, Manasquan formation	Mostly glauconite sand, containing some quartz sand and considerable clay (kaolinite, glauconite, montmorillonite)	Collington, Keansburg, Shrewsbury, Freneau	Excellent crop land, soil conditioner, base exchange material	Fill

cies are given in Table 2. If the material is to be used as ordinary fill or in asphalt mix, no further division is necessary. If good quality fill or mortar sand is desired, however, a means must be found to differentiate between quartz sand and glauconite-bearing quartz sand. These both appear essentially the same light gray (N 7) to white (N 9) tone on black-and-white aerial photographs, but on color transparencies a distinct color difference between the two is apparent. This is clearly seen on color aerial transparencies of two pits in Pleistocene alluvial sand along the south side of the North Branch Rancocas Creek. The sand in one pit, 1 mi southeast of South Pemberton, appears very light gray (N 8) to white (N 9) on the color transparencies (Figs. 5 and 6). The sand in this pit, derived from the Cohansey and Kirkwood formations, is nearly all quartz. The sand in a second pit, 1 mi west of South Pem-

TABLE 2

CHARACTERISTIC APPEARANCE OF THE DIFFERENT FORMATIONS ON AERIAL PHOTOGRAPHS

Soil Type	Unit	Landform	Drainage	Vegetation	Tone (Black-and-White Photographs)	Color (Color Photographs)
1	Quaternary deposits	Stream terraces, flood plains, hilltop remnants	Good internal, few gullies, wide spaced, random pattern	Mostly wooded sparse deciduous trees and scattered pines, some sparse grasses	Circular and oval mottled pattern, white (N 9) where exposed	Light brownish-gray (5YR 6/1), very light gray (N 8) to white (N 9) where exposed
1	Cohansey sand	Hills and ridges	Good internal, few gullies, wide spaced, somewhat rectangular	Mostly wooded sparse deciduous trees, some pines and brush	Uniform medium light gray (N 6) to light gray (N 7), very light gray (N 8) to white (N 9) where exposed	Yellowish-gray (5Y 7/2 to light brownish-gray (5YR 6/1), grayish-yellow (5Y 8/4) to moderate yellow (5Y 7/6) where exposed
1	Kirkwood formation	Low broad hills, basal hill slopes, lowlands, and swamps	Much swampland, dentritic to somewhat parallel	Mostly wooded sparse deciduous trees, cranberry bogs, blueberry fields, swamp vegetation	Extremely mottled due to high ground water table, very light gray (N 8) to white (N 9) where exposed	Yellowish-gray (5Y 7/2) to light gray (N 7) and brownish-gray (5YR 4/1), very light gray (N 8) to white (N 9) where exposed
2	Quaternary deposits	Stream terraces, flood plains, surficial cover on broad level areas	Good internal, few gullies, wide spaced	Crops, woods	Circular and oval mottled pattern, very light gray (N 8) to white (N 9) where exposed	Pale greenish-yellow (10Y 8/2) to grayish-yellow green (GY 7/2) Moderate greenish-yellow (10Y 7/4) to yellowish-gray (5Y 8/1) where exposed
2	Vincentown formation	Steep stream banks (mostly covered by Alluvium)	Fair internal, moderately spaced, somewhat rectangular	Crops, woods	Fairly uniform, medium gray (N 5) to medium light gray (N 6), basal part very light gray (N 8) where weathered	Yellowish-gray (5Y 8/1) to dusky yellow-green (5GY 5/2) and very light gray (N 8), Light olive gray (5Y 5/2) to grayish-yellow green (5GY 7/2) where exposed
2	Mount Laurel sand	Steep stream banks and slopes	Moderately spaced, dendritic	Crops	Fairly uniform medium gray (N 5)	Light olive gray (5Y 5/2)
3	Manasquan formation	Broad level areas, low slopes along streams	Moderately spaced, dendritic	Crops	Medium light gray (N 6) to medium dark gray (N 4)	Light olive gray (5Y 5/2)
3	Hornerstown sand	Broad level areas, steep stream banks, low hills	Moderately spaced, dendritic	Crops	Fairly uniform medium gray (N 5) to medium light gray (N 6)	Dusky yellow green (5GY 5/2)
3	Navesink formation	Low hills and slopes	Moderately spaced, dendritic	Crops	Medium gray (N 5) to medium light gray (N 6)	Dusky yellow green (5GY 5/2) to grayish-green (5G 5/2)

Figure 5. Pit in quartz sand of Quaternary age along south bank of North Branch Rancocas Creek. (From aerial photograph, scale 1:17,000.)

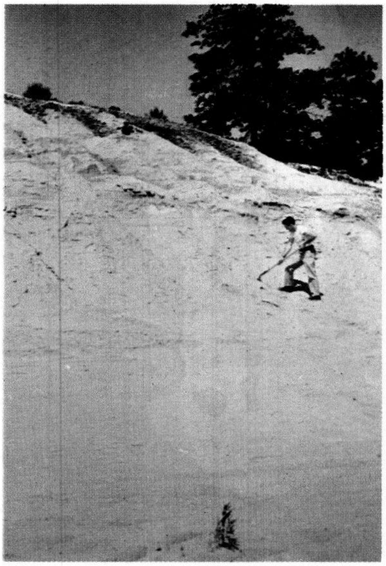

Figure 6. Ground photograph of pit shown in Figure 5 containing quartz sand derived from Kirkwood and Cohansey formations.

Figure 7. Pit in glauconitic quartz sand of Quaternary age derived from Vincentown and Manasquan formations outcropping downstream from pit of Figure 5. (From aerial photograph, scale 1:17,000.)

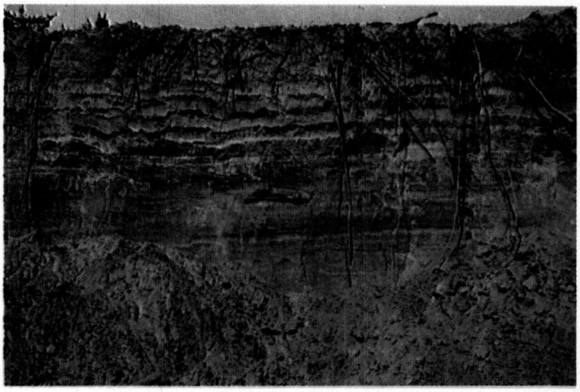

Figure 8. Ground photograph of glauconitic quartz sand pit shown in Figure 7 along south bank of North Branch Rancocas Creek. Note marked stratification, suggesting fluvial nature of this Quaternary deposit.

Figure 9. Area several miles northeast of town of Pemberton containing many pits and construction site excavations in the Cohansey, Kirkwood, and Quaternary materials. Note that in the black and white photograph all of these materials appear to have essentially the same tone; that is, very light gray (N8) to white (N9).

Figure 10. Same area as in Figure 9. In this more recent photograph several more excavations are evident and more detail can be seen. Note brown oxidized sand at bottom center, black organic material in sand at bottom right, white quartz sand at bottom center, and greenish glauconitic quartz sand at left center.

Figure 11. Cohansey sand deposit showing podzol soil profile. The upper 18 to 20 inches consist of a white quartz sand of the eluviated A horizon over a yellow-brown zone of oxidation and accumulation.

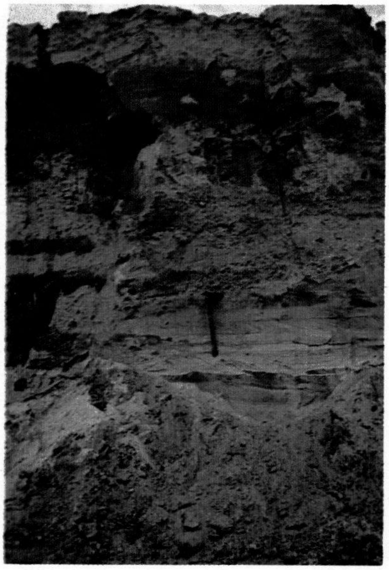

Figure 12. Light-colored Cohansey sand (below shovel blade) overlain by Quaternary alluvial gravelly sand, overlain by greenish-gray Quaternary glauconitic quartz sand. Color of upper exposed material represents only a few feet of material.

Figure 13. Exposure of Hornerstown glauconite sand. Essentially unwetted material at base is dusky green, overlain by progressively browner more silty weathered material, showing profile development.

Figure 14. Exposure of Quaternary alluvial silty gravel and sand such as that on the higher hilltops. Reddish-brown color, the result of oxidation, shows up well on color aerial photography.

berton, or 2 mi downstream from the first pit, appears moderate greenish-yellow (10Y 7/4) to yellowish-gray (5Y 7/2) on the color transparencies (Figs. 7 and 8). The sand in this pit is mostly quartz but contains as much as 20 percent green glauconite that is derived from the Vincentown and Manasquan formations where they crop out upstream from this pit but downstream from the first pit.

Other color differences also are apparent on color aerial transparencies (Figs. 9 and 10). Exposures of eluviated quartz sands in the Vincentown and Kirkwood formations, Cohansey sand, and Quaternary deposits appear very light gray (N 8) to white (N 9) on both black-and-white and color aerial transparencies, whereas exposures of less weathered or only partly oxidized sands of these units appear as different colors on color transparencies. The sands of the Cohansey, for example, appear grayish-yellow (5Y 8/4) to moderate yellow (5Y 7/6); those of the Kirkwood appear yellowish-gray (5Y 7/2) to brownish-gray (5YR 4/1).

In the Pemberton quandrangle the contact between the Manasquan and Kirkwood formations and the contact between the Kirkwood formation and Cohansey sand locally can be distinguished on color aerial photographs. This is important to the soils engineer because (a) the upper part of the Manasquan contains considerable montmorillonite; (b) the basal part of the Kirkwood is largely silt and contains less clay and a different kind (kaolinite) than the Manasquan; and (c) the basal Kirkwood is a zone of ground-water accumulation and movement. The Manasquan may have a lower bearing capacity than the Kirkwood, particularly under dynamic load, because of its high content of glauconite grains and their tendency to crumble under a dynamic load. The presence of montmorillonite in the Manasquan necessitates consideration of its great capacity for absorbing moisture and the resultant possibility of large volume changes. The ability to distinguish between the Kirkwood formation and Cohansey sand, on color photographs, is important also because the latter is, as previously mentioned, a source of good quality mortar sand and concrete aggregate, whereas the Kirkwood is mostly too fine grained for these uses.

Many erratically distributed Quaternary deposits are more easily identified on aerial photographs because their surfaces are indented by numerous nearly circular or ellipsoidal basins or depressions. These basins are postulated to be of periglacial origin (5). Many are more readily apparent on color aerial transparencies than they are on black-and-white photographs. The difference in moisture content and vegetation between the permeable, well-drained sandy rims and the low, often poorly drained, silty and organic-rich centers is more clearly seen as color differences on color aerial transparencies than as tonal differences on black-and-white aerial photographs. Wolfe (5, p. 135) states that these geomorphic features are present in formations of Cretaceous, Tertiary, and Quaternary age in the coastal plain of New Jersey. In the Pemberton area, however, they are present only in Quaternary deposits.

COST, DISADVANTAGES, AND INFLUENCING FACTORS

Although color aerial transparencies are presently more expensive than black-and-white photographs, this fact may not appreciably inhibit their use. Ray (6, p. 35) cites the cost of a linear mile of land surface recorded on color aerial photography at \$15 to \$40 as compared with \$4 to \$20 for black and white. Results of present studies show that good quality black-and-white diapositives made from color positives are suitable for use in topographic mapping. The color positives would be available for use in geologic, soil, or agricultural mapping or studies, thereby utilizing one flight for two or more programs or purposes.

To obtain maximum information from the interpretation of color aerial transparencies in areas similar to the Pemberton quadrangle, the photographs should be taken when field planting and cultivating are at a maximum and foliage and grasses at a minimum, either late fall or early spring. Summer foliage obscures stream banks and artificial cuts, and grasses mask the colors of the soils in many cultivated fields. This latter fact is of particular significance in the Pemberton quadrangle, where much of the aerial-photographic interpretation of the formations and the soils is based on the slight green color imparted by the glauconite. Even under optimum photographic conditions, interpretation may be difficult because the soil profile masks the color of the parent material (Figs. 11-14). Fortunately the persistence of some of the color, the shallowness of some of the profiles, and the numerous cuts help counteract this factor.

Color transparencies appear to be the best medium because the colors are most faithfully reproduced on them. However, it may be that by using different film and filter combinations, colors may be selectively emphasized, thereby making possible quicker identification of specific soils or formations. A disadvantage of color transparencies is that they must be used in transparent envelopes on an illuminated or light-reflecting surface and cannot be annotated directly. It would be helpful if an easy method were developed for accurately transferring annotations from the envelopes to a base map.

Flying height of the aircraft from which the photographs are taken is another factor to consider. Color photographs of the Pemberton quadrangle, taken from a height of 6,000 and 8,500 ft, recorded the colors nearly as they would appear to the eye, whereas those taken from 12,000 ft have a bluish-gray haze (7, p. 115).

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Muskeg Studies in Alberta

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This paper discusses the development of muskeg research studies in Alberta, with particular reference to vane shear testing. Correlations of vane shear strength, water content, and classification are presented. Limited conclusions are drawn from an evaluation of flexible pavements constructed in muskeg areas. A sampler for use in very soft fibrous peat is also described.

●IN RECENT years marked advances have been made in solving the engineering problems encountered with muskeg or "organic terrain." A thorough review of this development was presented by MacFarlane in 1959 (1). This paper is intended to trace the development of muskeg studies in Alberta, as fitting into the Canadian picture as a whole, and to report on results of recent investigations not available in 1959.

As in most areas of Canada and the U.S.A., there has been a particularly active program of highway construction and improvement following a period of relative inactivity from 1940-45. In Alberta, as of 1948 the total mileage of highways and district and local roads was 81,823 mi, and only 656 of the 4,753 mi of main and secondary highways were bituminous surfaced. During the succeeding 10 year period to 1958 (2), the paved mileage increased fourfold to a total 2,758 mi. This highway construction program necessitated by a high vehicle-population ratio of 1 to 2.9 in 1957, together with a sharp increase in movement of materials by truck transport, has resulted in surfaced main highways being constructed over practically all types of terrain. Expansion of the petroleum industry into previously inaccessible areas has also resulted in many miles of secondary highways and access roads being built.

To comprehend the existing situation better, a brief description of the physical features of the Province has been compiled:

> Alberta is a plateau averaging more than 300 mi from east to west and 800 mi from south to north, a total of 255,285 sq mi. This region is a widely inclined plain deeply cut by rivers and marked by plateaux, merging in the west with the foothills of the Rocky Mountains. The southern half of the province rising toward the west, lies at a general elevation of 2,000 to 4,000 ft. In the northern half the slopes descend until elevations well under 1,000 ft are reached at Lake Athabasca in the northeast corner. (2)

Most of the area has been glaciated, the effects of which have influenced the surface features and resulted in widely distributed surface materials. Figure 1 is an outline map of Alberta showing the general area in which occurrences of muskeg deposits are fairly prevalent.

Figure 2 shows the surface transportation facilities and population distribution. Because vast undeveloped areas in the northern part of the Province are in predominantly muskeg territory, agricultural and forestry developments as well as oil and mineral explorations are impeded by the muskeg problem.

A small percentage of the main highways with a much larger percentage of the lower access-type roads have been built in areas predominantly covered by muskeg. This problem of working in muskeg areas was common to governmental agencies and industry alike and prompted studies by those concerned.

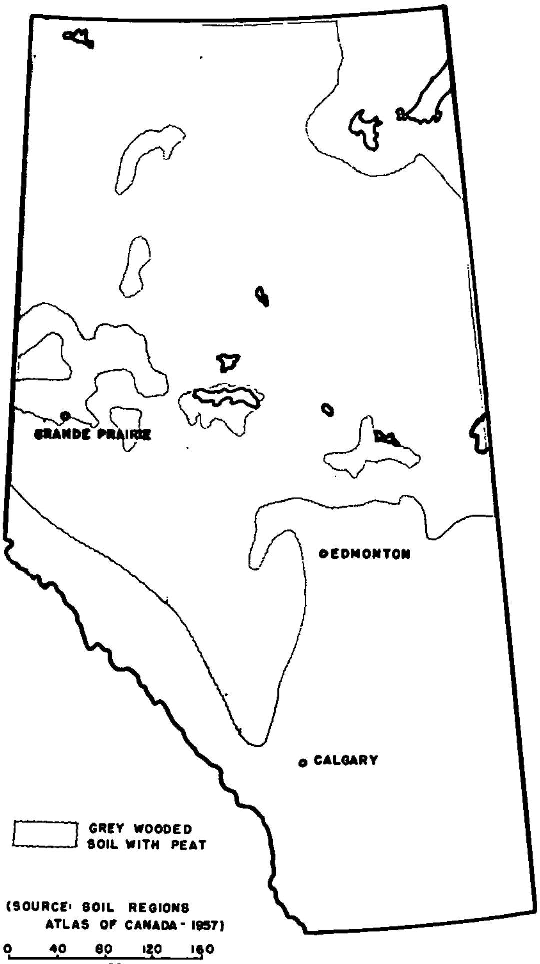

Figure 1. Map of Alberta showing areas where muskegs (peat) commonly occur.

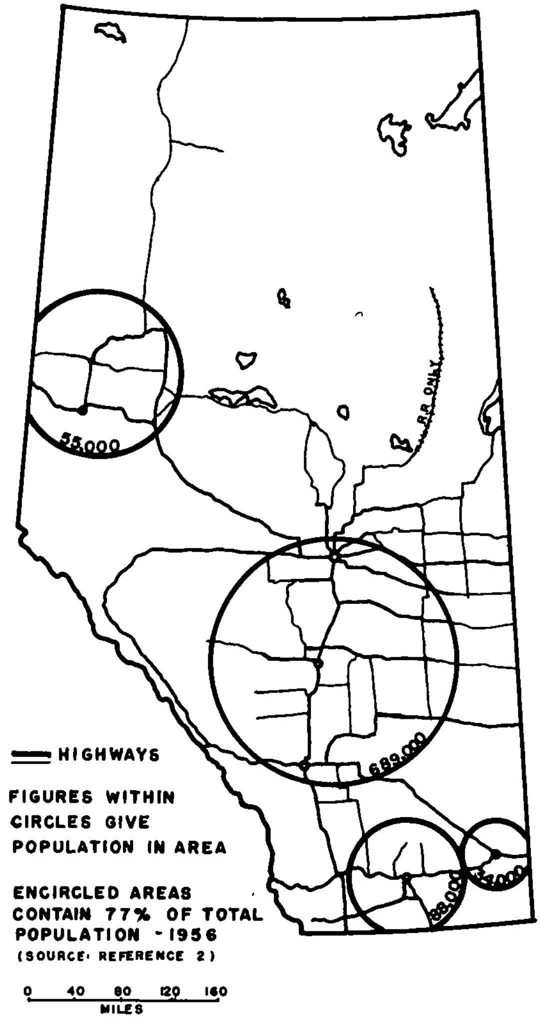

Figure 2. Surface transportation facilities and population distribution in Alberta.

SHEARING STRENGTH OF PEAT

Development of Vane Shear Apparatus

The locations of several main highway routes planned for construction and improvement early in this expansion period were in areas where numerous muskeg deposits occurred. Because complete avoidance was not possible and depths were such that complete excavation was not considered economical, the technique of floating the road fill on the muskeg was adopted and used in most instances. The hazards involved such as shear failure of the underlying material were recognized but were difficult to predict because little information was known of the physical properties of this material. Due to the nature of the peat and soft underlying inorganic material, conventional methods of sampling and laboratory testing were unsuccessful.

One method of determining the average shearing strength of these very soft organic and inorganic soils would be to analyze the stability of embankments in instances where shear failures had developed. One such case is on record (3) where an estimate of the safe embankment height was made and subsequently proven to be correct within an accuracy of about 10 percent by failure of the embankment where the computed height was exceeded.

This same case enabled a computation of the average shearing strength of the organic cover and wet silt within the zone of failure to be in the order of 80 lb per sq ft.

Because the shearing strength can only be determined by computation following a survey of failed sections, this method has severe limitations for design purposes in that the number of failures of this type are few and widely scattered.

To secure some relative indication of strength prior to construction, the provincial Department of Highways began using a penetrometer in 1950. This probe consisted of ½-in. diameter steel rods, the lower rod being fitted with a conical tip. The resistance to penetration was transmitted through a hydraulic piston attached to the top rod, the driving force being manually applied to a set of handles on the piston. A gauge on the piston indicated the pressure required to force the penetrometer steadily downward into the soil.

This tool was very useful in establishing the depth of soft soil, but did not give a direct measurement of the shearing strength of the material tested. At best, it was able to provide a relative indication of the strength of various muskegs.

In order to obtain more quantitative information on the shearing strength of the underlying peat, various methods of in-situ testing were investigated. The method of determining the shearing strength of soil in-situ by means of a rotating vane was receiving considerable attention at that time (4, 5). In 1955, a program was initiated at the University of Alberta to determine whether the vane shear principle could be applied to the investigation of muskeg soils. This work was undertaken as a M.Sc. thesis project (6, 7), with the field tests in cooperation with the Canadian Army, Northwest Highway System (who are charged with maintenance of the Alaska Highway in Canada).

A somewhat crude, portable vane shear apparatus was developed using a 4-in. diameter by 4.5-in. long vane. The applied moment was measured by means of a calibrated spring attached to a cable pulley and torque wheel assembly. From this preliminary investigation it was concluded that the organic material comprising the muskeg was susceptible to vane shear testing. Fairly good correlation was obtained between results from the vane and unconfined compression tests run in the laboratory. Additional work was considered necessary to establish the accuracy of the vane test and evaluate factors such as the fibrous nature of the material.

Further investigations were conducted in 1956 in an attempt to correlate the measured vane shearing strengths with depth, muskeg classification, moisture content and ash content (8). Field work was carried on in the Pembina oil fields, located 80 mi southwest of Edmonton, an area of approximately 1,000 sq mi of which 30 percent is estimated to be muskeg. The vane apparatus differed from the previous investigation in that a larger 4.5-in. diameter by 10.1-in. long vane was used and the applied moment measured by a 0-300 ft-lb torque wrench. Use of the torque wrench greatly increased the portability and ruggedness of the equipment.

Results from this study indicated that the shearing strengths of the muskeg varied directly with depth and inversely with moisture content and appear to vary directly with angular deformation and ash content.

To determine the validity of the vane shearing strengths for use in stability computations, a further study was undertaken in 1958 (9). This involved the construction of a test fill to failure and the comparison of the computed shearing strengths with the measured vane shearing strengths obtained before construction. Results indicated that the vane shear test does give a satisfactory value for the shearing strength for at least some types of peat and can be used in the stability analysis of fills constructed on muskeg.

Factors Influencing the Shearing Strength of Peat

As stated by Tresidder (10),

> It is undoubtedly an oversimplification to refer to the complex rheological properties of peat under the general heading of "shear strength." As far as

the practicing road engineer is concerned, however, it is convenient to regard shear strength as representing in practical terms one important aspect of the behavior of peat under load.

Deformation under load is influenced both by elastic and viscous properties of the peat, the relative effect of each being dependent on the rate of application of load and the drainage condition. Many others have stated that very large deformations normally occur before a maximum load is reached, which is also supported by this work. What point is actually considered as failure is therefore dependent on the allowable deformation for the particular case. In the case of embankments constructed on peat, localized deformations of high magnitude usually occur and if loading continues to increase without a corresponding gain in strength, such as by consolidation, complete slippage or shearing takes place. Because of this progressive or plastic action it is felt that the shearing strength of peat as determined at maximum load, even though at high deformation, is a valuable indication of its behavior under load.

The author's studies consider the principal factors influencing the shearing strength of peat to be (a) texture, (b) moisture content, and (c) inorganic soil content. Variations in each of these three factors significantly affect the shearing strength of the peat.

Radforth (11) has reported that a definite correlation exists between the surface vegetation and the subsurface organic material. Thus for a given type of surface cover, as defined by the Radforth Classification system*, the general type of peaty material and its relative bearing potential may be predicted with reasonable assurance.

Quantitative measurements of shearing strength using the vane apparatus on a limited number of different muskeg classification types generally support this prediction. Shearing strength has been found to increase with increasing stature of surface cover. The lowest shearing strengths have been on F1 type muskeg (i.e., sedges, grasses, mosses) and generally range from 100 to 200 lb per sq ft.

BE1 type muskeg (i.e., with woody growth 5 to 15 ft in height, low woody shrubs 0 to 2 ft high, and non-woody moss up to 4 in. high) has given shearing strengths from 210 to 1,090 lb per sq ft. The texture of the peat in F1 muskegs would be fine-fibrous to amorphous, whereas the BE1 muskeg would give a woody fine-fibrous peat held in a coarse-fibrous structure.

Figure 3 shows the variation of shearing strength with depth for two typical surface coverage types, the texture of the peat in both cases being fine-fibrous. The F1 type shows a fairly consistent increase of strength with depth. The BE1 muskeg shows a loss in strength down to a depth of 5 to 8 ft, then an increase with greater depth. In both cases the water level was within several inches of the surface.

Figure 4 shows the variation in moisture content with depth for the same two types of muskeg. For the peat, in the case of the F1 type, the moisture content decreased going from the 1- to 3-ft depth, increased to the 5-ft depth, and then decreased again to the 11-ft depth.

The common definition of moisture content has been used, that is, the loss is weight expressed as a percentage of the dry material after the original sample has been dried for 24 hr at 110 C.

The trend in the BE1 type was to an increase in moisture content from the surface to the 5- to 8-ft depth, then a decrease with greater depth. It is considered that the primary reason for the difference in moisture profile with depth is the varying amount of evapotranspiration of water by the different types of surface vegetation.

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*This system considers the vegetal coverage, the topographic features and subsurface constitution of the peaty material. For engineering purposes the coverage classification is considered most important, the vegetation being divided into nine classes from A to I, with descriptive information as to the qualities of vegetation such as stature, degree of woodiness, external texture, and certain easily recognized growth habits. A complete description of this system can be found in MacFarlane (1) and Radforth (11).

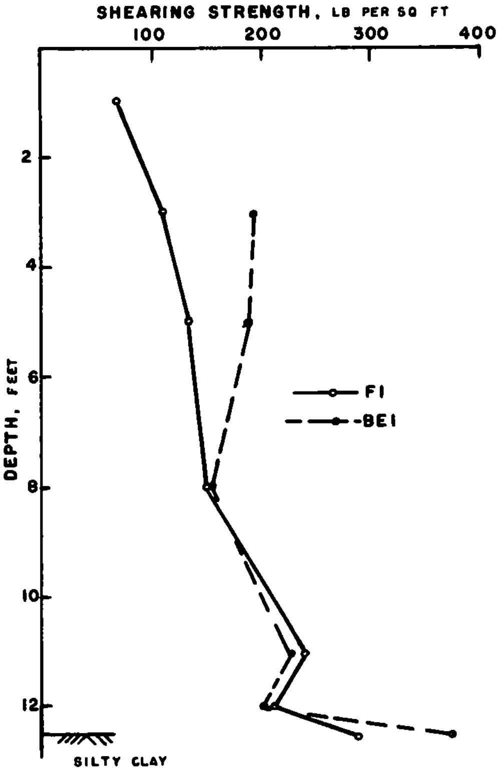

Figure 3. Variation of shearing strength with depth.

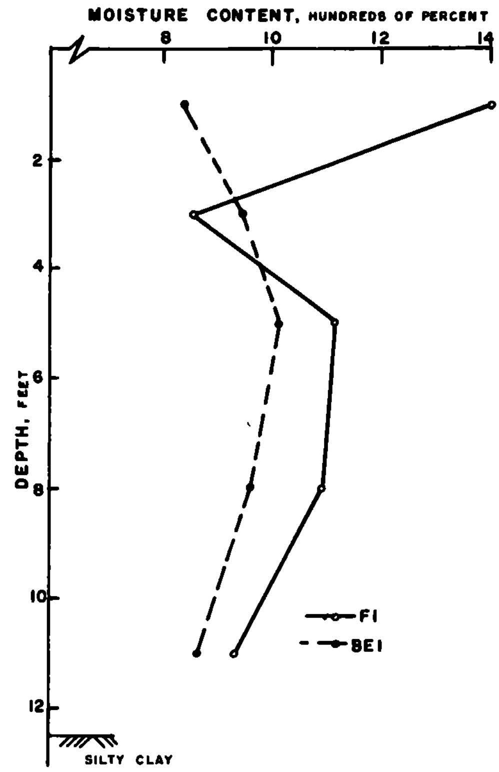

Figure 4. Variation of moisture content with depth.

The relationship of shearing strength with moisture content is shown in Figure 5. In one particular muskeg location comprising F1 and BE1 types, a direct inverse variation was found ranging from 225 lb per sq ft at 800 percent to 100 lb per sq ft at 1,400 percent moisture content.

Although there is considerable scatter in the individual points, a reasonably well-fitted curve close to a straight line can be drawn through the points on a moisture content vs log shearing strength plot. This is similar to shearing strength relationships established for clays (12). Much of the scatter can be attributed to the difficulty in obtaining reliable samples particularly at the high moisture contents.

An indication of the inorganic or mineral soil content has been taken as the weight of ash residue after drying at 300 C divided by the weight of dry sample after drying for 24-hr at 110 C. The above shearing strengths have been on peats having ash contents of 10 to 25 percent.

Contamination of a deposit of peat with mineral soil will reduce the apparent moisture content and increase the shearing strength out of line with the previously shown relationship (Fig. 5). In this particular case the EF1 muskeg deposit was located in a drainage course adjacent to a mountain slope. In view of this, the range of shearing strengths as predicted from surface coverage type, may have to be modified for particular cases depending on the likelihood of mineral soil contamination.

Excessive deformation or remolding will reduce the shearing strength of peat. Remolded vane shearing strengths were taken by rotating the vane quickly four revolutions immediately after the maximum reading had been obtained, waiting a period of 1 min, and then repeating the procedure as for the undisturbed strength test. The sensitivity, or ratio of undisturbed to remolded strengths, ranged from a low of 1.5 to a high of 3.7.

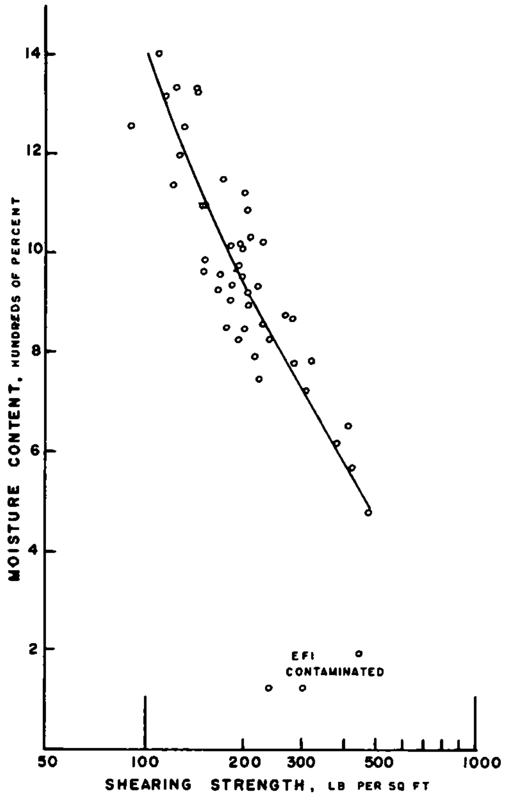

Figure 5. Correlation of shearing strength with moisture content.

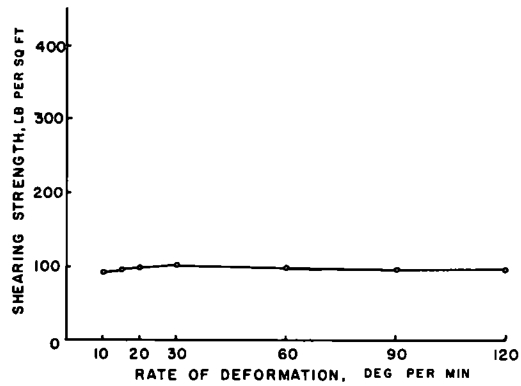

Figure 6. Effect of varying rates of deformation on shearing strength.

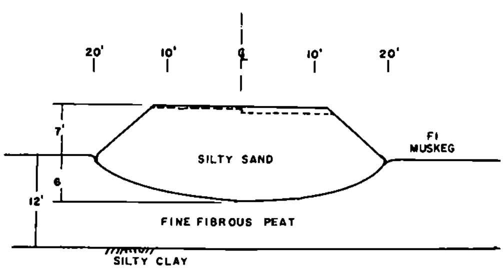

Figure 7. Cross-section of test fill at failure.

A factor of concern in any strength test is the possible effect of varying rates of strain. To overcome an uneven application of torque, the rate of deformation of 30 deg per min was adopted after trial (8) and has subsequently been used. This rate is faster than usually used for gear of winch-driven vane assemblies, the rate used by Thomson (6) being 6 deg per min. To check the possible effect of this, a series of vane tests were run at the same depth at closely spaced intervals on a uniform F1 muskeg. Results of varying the rate of strain from 10 to 120 deg per min are shown on Figure 6. Considering the reproducibility of each individual test numerically being no less than the vane constant, it is concluded that there is no significant change in strength over this range of strain and the previously adopted rate of 30 deg per min is valid.

The effect of vane size theoretically should not affect the measured shearing strength. Recognizing the nonhomogeneous and fibrous nature of peat, however, the possible influence of roots can give erroneous results. In order to decrease such possible effects and increase the accuracy, as large a vane as practical should be used. For this reason the 4.5- by 10.1-in. size was used. This size gives a vane constant or multiplication factor of 5.0 times the torque reading in foot-pounds when the shearing surface is the bottom and sides of a cylinder, and 4.7 including the top surface, used to calculate the shearing strength in pounds per square foot.

Shear Strength from Failure Analyses

In order to determine the validity of the measured vane shear strengths, a suitable area was tested and instrumented prior to construction of a test fill. The site chosen was located approximately 70 mi southwest of Edmonton at an elevation of 2,775 ft above sea level. The muskeg area was of a closed pond form extending about 1 mi in length and ½ mi in width, the water level being at the surface of the muskeg. Using the Radforth classification system, coverage types of F and 1 were most prevalent with varying amounts of B, D, and E. The depth of the muskeg ranged from 10 to 12 with a maximum of 14 ft. The peat was fine-fibrous ranging to amorphous, the lower 2 ft being well decomposed. The mineral underlying soil was a blue silty clay of medium to high plasticity.

Instrumentation consisted of 2-ft square settlement platforms, porous stone tube piezometers, guide stakes, and flexible plastic tube slide surface detectors.

The fill material was a silty sand of low plasticity and was placed by being end-dumped from trucks and spread by dozer.

Figure 7 shows a cross-section of the fill at failure. Because the actual surface of failure could not be established definitely, the particular mode of failure was inconclusive. In view of this, the failure was analyzed by four common methods; (a) circular arc, (b) sliding block, (c) plastic equilibrium theory, and (d) computation of stresses by the theory of elasticity.

The circular arc and sliding block analyses appeared to satisfy the actual conditions at failure. Assuming the shearing resistance of the peat to be purely cohesive (i.e., $\phi = 0$) the computed value from the circular arc analysis was 160 lb per sq ft. Using the sliding block analysis the average shearing resistance ranged from 95 to 235 lb per sq ft, depending on assumed hydrostatic pressures with the more probable limits being 140 to 235 lb per sq ft. The average shearing stress along a critical arc by elastic theory computations was 150 lb per sq ft.

The measured vane shearing strengths of the F1 surface cover peat before construction of the fill varied from 125 to 225 lb per sq ft at the 3- and 11-ft depths respectively. From this it can be seen that the vane shearing strengths are of the same order of magnitude as the computed average shearing resistances and therefore seem to be applicable to stability analyses.

Because no shear failures have occurred with actual highway embankments on muskeg since this test fill in 1958, other comparisons of computed shearing resistance with vane shearing strengths before construction are not available.

One section on which a failure occurred during construction before that date has been analyzed in the light of vane shearing strengths taken this past summer. With the low strength measured of 90 to 250 lb per sq ft, the predicted allowable height of embankment would be less than 8 ft. The present embankment height through the failed area is approximately 7.5 ft. Detailed records at the time of failure are not available; however, this case appears to substantiate the validity of using the vane shearing strengths for stability analyses.

OTHER INVESTIGATIONS

Another aspect of the problem of road construction on muskeg that has been investigated is the effectiveness of plastic and asphalt membranes in preventing the movement of moisture into fills constructed on muskeg (9).

Membranes, one type consisting of 4-mil thick polyethylene plastic and another of fibreglass mat impregnated with blown asphalt were placed directly on the muskeg after all growth larger than 2 ft in height was cut off at the surface. Fill was then placed on the membrane by truck end-dumping and spreading. Quantities of fill used and subsequent settlement observations were taken.

Results of this test showed that the membranes were punctured by small roots and cut-off brush and were therefore ineffective in preventing moisture from entering the fill.

As MacFarlane reported (1), Imperial Oil is carrying out research into vehicle mobility performance on various tracked vehicles used in over-muskeg travel (13). Basic design principles have been developed and incorporated into specially designed vehicles for use over muskeg. A transporter capable of carrying a payload of 20 tons through muskeg and soft clay has been in service since April 1959. An interesting feature of their work has been a tentative correlation between muskeg shear strength and net vehicle performance, and that the shear vane produces a strength profile compatible with the vehicle pull-slip curve.

A current investigation under way is an over-all determination of the performance of flexible pavements constructed in muskeg areas. This is being done as a cooperative research program under the Highway Division of the Research Council of Alberta, the Department of Highways of Alberta, and the University of Alberta.

Tentative conclusions are that the over-all performance of flexible highway pavements in muskeg areas is considered to range from fair to good. This rating was based on personal observations as to riding quality, together with attention to the type and extent of pavement defects. Generally, the riding quality of these pavements in muskeg areas was slightly poorer than in adjacent areas of mineral soil. Observed differences were larger with older pavements. The relative performance of a pavement section in muskeg was found to be better where the original surface cover consisted of large tree growth, the grade was constructed high with wide berms, and where drainage and offtake ditches were used.

The difficulty of obtaining satisfactory undisturbed samples of peat for laboratory studies has been encountered by all faced with this task. Work has been under way to develop a sampler particularly for use at shallow depths in very soft fibrous peat. The requirements of such a sampler are that it must (a) advance into the fibrous peat without pushing aside or compressing the material, (b) not be filled with disturbed material before reaching sampling depth, (c) obtain a sample without developing high side friction, and (d) retrieve the sample without loss. A sampler has been designed with retractable piston, liner, and check valve to satisfy requirements b, c and d using standard sampler designs. The first requirement is the most difficult and it is felt that the most suitable method for fulfilling this is to use a rotary saw-tooth cutting edge. A simplified version has been constructed to determine the merit of this principle. Field trials to date have been promising, but further development is necessary.

CONCLUSIONS

The conclusions drawn from these muskeg studies are the following:

1. The vane shear principle can be used to determine the shearing strength of peat, a useful indicator of its behavior under load.
2. Principal factors influencing the shearing strength of peat are (a) texture, (b) moisture content, and (c) inorganic soil content.
3. General ranges of shearing strength can be predicted on the basis of surface vegetal cover or Radforth classification.
4. Different types of surface cover influence the moisture content vs depth profile through evapotranspiration of water near the surface.
5. An inverse relationship exists between moisture content and shearing strength and approaches a straight line on a semilog plot.
6. Comparison of measured vane shearing strengths with computed shearing resistances from an instrumented test-fill failure indicates these values to be of the same magnitude.
7. Membranes consisting of either plastic or asphalt impregnated fibreglass placed on the muskeg surface were ineffective in preventing moisture from entering fills constructed on the membranes.
8. Over-all performance of flexible highway pavements in muskeg areas range from fair to good.

ACKNOWLEDGMENTS

The author wishes to express his appreciation to the many individuals who have made this report possible, whether mentioned specifically or not.

Special acknowledgment is made to Captains S. Thomson and R.C. Wyld, R.C.E., whose graduate dissertations formed the basis for the work carried on by the author, and to Dr. R.M. Hardy, former Dean of the Faculty of Engineering, under whose direction the graduate studies were accomplished.

Appreciation is also expressed to those individuals and organizations whose encouragement and support have enabled the collection of this information, namely, the Chief Engineer and Directorate of Military Training, Canadian Army; Mr. R.A. Hemstock of the Production Research and Technical Service Department of Imperial Oil Limited, Western Region, Calgary; the Civil Engineering Department of Mobil Oil of Canada, Drayton Valley; and to the Department of Highways of Alberta, Research Council of Alberta and the Department of Civil Engineering, University of Alberta, cooperating under the Joint Highway Research Program.

Acknowledgment is also made to Dr. N.W. Radforth, whose basic work in this field has enabled development to this stage, and for his comments regarding classification of muskeg in the test area reported on by the author.

The counsel and helpful advice offered by Professor S.R. Sinclair during the investigation and following reading of the manuscript are also gratefully acknowledged.

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An Evaluation of Pavement Performance over Muskeg in Northern Ontario

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This paper is a report of a cooperative research program carried out in 1958 and 1959 by the National Research Council, Canada, and the Ontario Department of Highways to study the performance of some existing roads over muskeg in northern Ontario. Investigation of close to 50 different muskeg areas included classification of the muskeg, determination of the depth and type of fill, depth of the organic deposit, and type of mineral soil substratum. Roads over the muskeg areas were assessed on the basis of performance and surface condition relative to adjacent sections of road on mineral soil terrain. Many peat samples were obtained for laboratory analyses, which included water content, specific gravity, acidity, and ash content.

During the second stage of the project an extensive series of field vane tests was carried out in certain selected muskeg areas that were typical for a certain region. Three different sizes of vanes were used. It is shown that road performance is better in muskeg areas with tall tree growth than in areas with little or no tree growth, other factors being equal. No correlation was evident between road condition and type of firm mineral soil substratum. However, an intermediate unstable layer of soft mineral soil is shown to be an important factor in road performance and condition. Although vane testing appears to be a feasible method for determining the shear strength of peat and excellent duplication of results was possible for any particular size of vane, these tests revealed a marked variation in the shear results depending on the vane size. Laboratory test results indicate correlations between moisture content and depth, specific gravity and moisture content, and acidity and carbon content.

● A LARGE PART of the total area of Canada is covered with an organic mantle known as muskeg, much of it occurring north of the main population centers. Its extent is not known precisely but it has been estimated that there are some 500,000 sq mi of muskeg in Canada, or approximately 12 percent of the total land area.

The word "muskeg" is distinctive to Canada and the northern United States and is derived from the Chippewa Indian work "maskeg" meaning "grassy bog." For engineering purposes, muskeg (or organic terrain) may be defined as "terrain composed of a living organic mat of mosses, sedges or grasses, with or without tree and shrub growth, underlain by a usually highly compressible mixture of partially decomposed and disintegrated organic material commonly known as 'peat' or 'muck'" (1). Muskeg is associated with a very high water table and is characterized by its low bearing capacity. The depth of these organic deposits varies from a few inches to many feet and they may be underlain by either marl, clay, silt, sand, gravel, or bedrock.

The whole of Ontario—in common with most of the rest of Canada—has been glaciated. As is typical of glaciated regions, muskeg areas are encountered to a greater or lesser degree depending on the physiographic formation. One of the many complex problems in Ontario highway engineering, therefore, is the satisfactory construction of roads over muskeg. In some regions, as much as 80 percent of the length of a particular road project is over muskeg of variable depth and composition. It is not unusual for this muskeg to be underlain by deposits of very soft marl, silt, or clay, thereby greatly increasing the total depth of unstable material.

It is sometimes possible to circumvent muskeg areas, but due to the high geometric standards for modern highways and also due to economic considerations, it is often necessary to construct roads directly across muskeg. The height of the embankments may vary between 4 and 40 ft. Therefore, if a satisfactory road surface is to be provided, it is evident that detailed investigations and analyses of results must be made to ensure that the proper treatments are carried out.

Generally, the tendency has been to remove or to displace the peaty material and to construct the roadbed on a more stable foundation. Because the water table is very close to the surface, backfill material must remain stable when saturated. Granular soils are the most suitable for this purpose, but in many parts of Ontario they are scarce or nonexistent. In some cases cohesive soils have had to be used for backfill because of the prohibitive cost of transporting more suitable materials.

The expanded construction program of the Department of Highways of Ontario in the northern part of the province, where muskeg is extensive and costs are high, has necessitated a particularly careful consideration of the construction of a satisfactory and economical road over muskeg. It is these northern areas that are usually associated with a scarcity of suitable granular material for use in the treatment of muskeg areas. It is therefore desirable to know something of the engineering characteristics of the muskeg encountered in order to assist in the economic design of roads.

BACKGROUND OF PROJECT

Some roads constructed over muskeg have performed quite satisfactorily while others have not. It was thought that a comparison of these existing successful and unsuccessful roads would be a useful and significant study to assist in determining some of the engineering properties of muskeg. The difficulty of establishing the success of a particular road was realized but it was thought that this could be done by reference to settlement and to qualitative standards of performance.

A joint research program was consequently undertaken by the Department of Highways of Ontario and the Division of Building Research of the National Research Council, Canada. The main object was to study the performance of existing roads over muskeg, to obtain pertinent construction details and then to attempt to group muskeg areas according to their bearing properties. A further objective was to attempt to correlate road performance with the Radforth Classification System for muskeg (2). The great extent of muskeg in northern Ontario and the many problems associated with it made this area the obvious choice for the research program. Only those roads were investigated that had been built directly on the muskeg surface, and where no special treatment of the muskeg had been undertaken.

GEOLOGY OF THE AREA

The general area covered in the investigations extended from North Bay along Highway 11 to Nipigon and to Port Arthur and Fort William, up Highway 17 to Kenora, then Highway 71 to Emo and along Highway 11 to Rainy River (Fig. 1). Basically, there are two different types of terrain in the area investigated, both located within the Pre-Cambrian shield. The topographic feature of the rocky terrain (characteristic of the Kenora region) is its ruggedness and the countless number of lakes and depressional areas, the latter being filled in with soft clay or marl and peat. The other type of topography is the extensive flat areas of clay plain with depressional areas containing very soft clays and peat, located primarily between Kirkland Lake and Longlac. Figure 2, which denotes the geomorphic subprovinces of northern Ontario, shows these features in more detail.

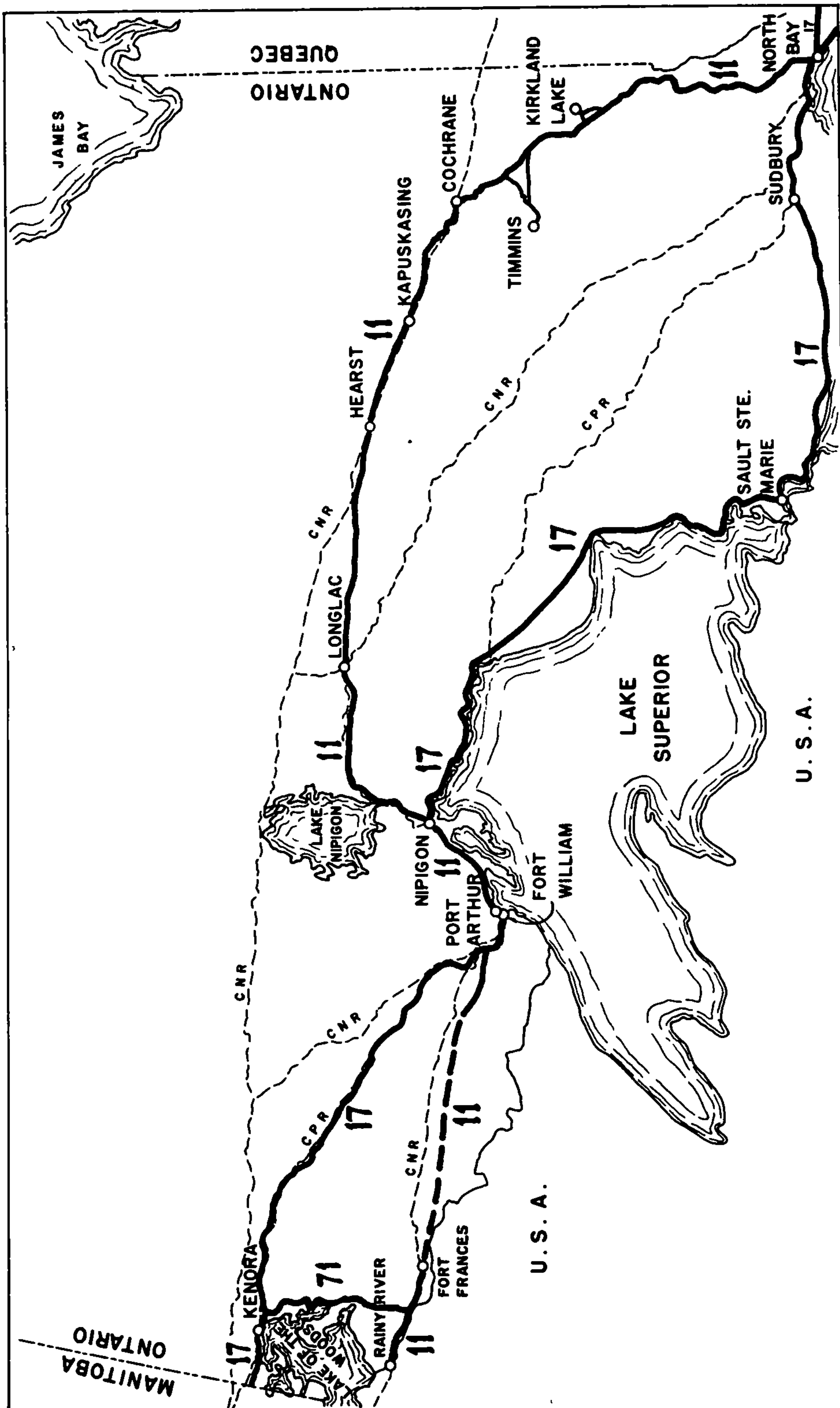
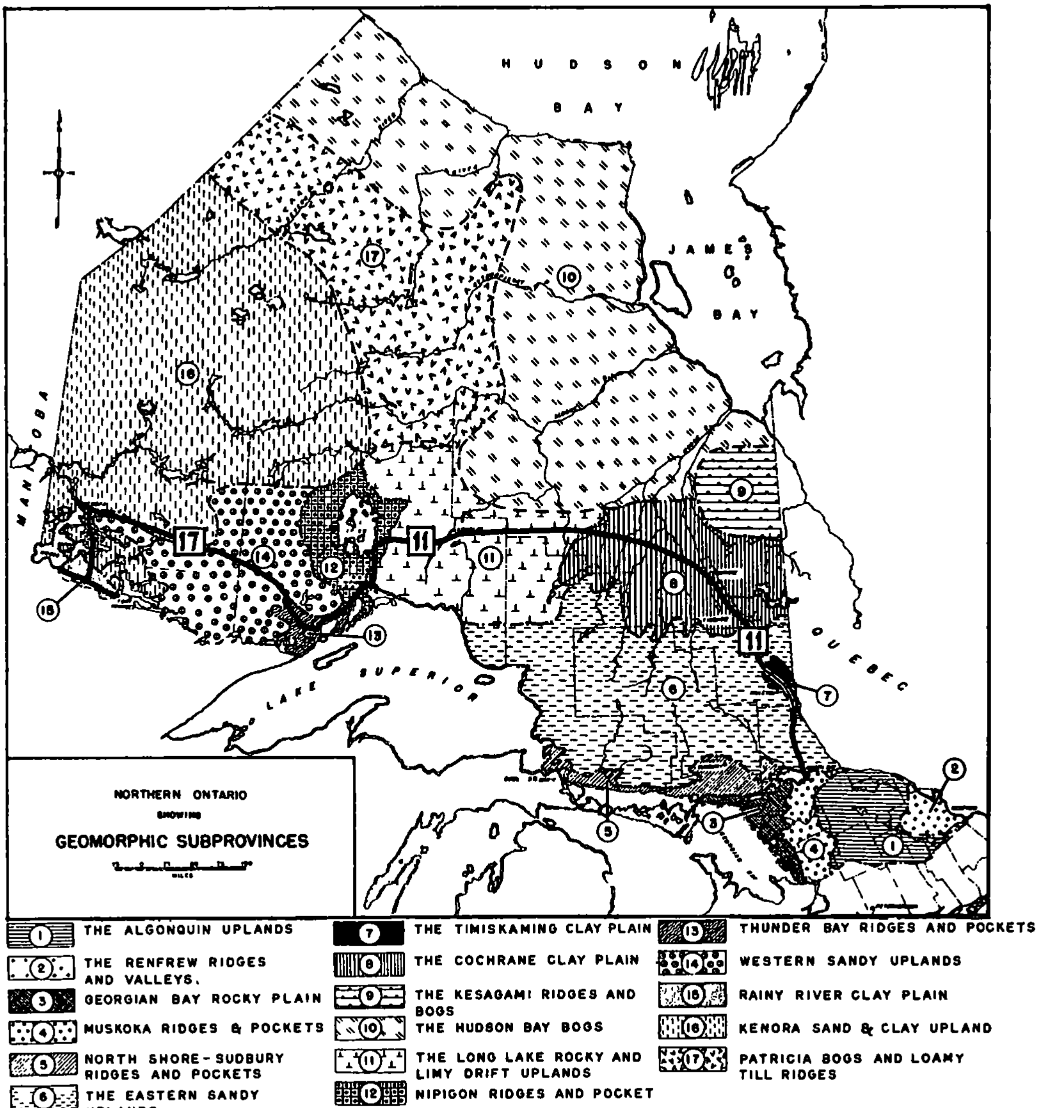

JAMES BAY
QUEBEC
ONTARIO
MANITOBA
ONTARIO
COCHRANE
KIRKLAND LAKE
TIMMINS
KAPUSKASING
HEARST
LONGLAC
NORTH BAY
SUDBURY
SAULT STE. MARIE
LAKE SUPERIOR
U. S. A.
LAKE NIPIGON
NIPIGON
PORT ARTHUR
FORT WILLIAM
KENORA
FORT FRANCES
RAINY RIVER
LAKE OF THE WOODS
U. S. A.
CNR
CPR
11
17
71

Figure 1.

VARIABLES

The condition of a particular section of road constructed over muskeg will depend on a large number of variables which include:

1. Traffic loads and volume;
2. Age of road;
3. Depth and type of roadway fill;



(COURTESY ONTARIO DEPT OF LANDS & FORESTS)

Figure 2.

4. Type of road surface (gravel, prime, hard surface, etc.);
5. Extent of maintenance;
6. Muskeg type;
7. Muskeg depth;
8. Depth of unstable mineral soil layer (if any) beneath the organic material;
9. Type of firm mineral soil substratum;
10. Drainage regime of the muskeg, both natural and man-made.

The procedures followed in this investigation were established in an effort to evaluate as many of these variables as possible.

INVESTIGATIONAL PROCEDURES

General

The research program was undertaken in two stages, each taking one summer. Stage I (Summer 1958) provided the more general information and covered as large an area as possible. The muskeg was classified, the depth to firm substratum determined, and the type of mineral subsoil was established. Samples of the peat in each area were obtained, classified, and retained for routine laboratory analysis. The type and depth of the roadway fill was also determined. Finally, the performance and condition of the road in a particular area was assessed on a qualitative basis and relative to the condition of adjacent sections of the road over mineral soil. Evaluation of the roads ranged from excellent through very good, good, fair, poor, bad (representing severe settlement or deterioration of the surface) to very bad (representing a shear failure at some time in the road's history as evidenced by the presence of "mud waves"). Some 44 different muskeg areas were investigated in the first stage and results reported (3).

In the second stage (Summer 1959) muskeg areas were selected that were typical for a certain region (as determined from an analysis of results of stage I) and a more exhaustive series of tests were carried out. These included extensive vane testing, together with the procuring of a number of "undisturbed" tube samples of peat for laboratory testing. For purposes of comparison, areas were chosen that had similar terrain conditions (such as muskeg type and depth) but that had a wide variation in the assessment of road performance. Three pairs of such areas were compared, in an attempt to learn why the road was unsatisfactory in one location and satisfactory in another. An additional three sites, where a shear failure had occurred, were investigated with regard to determining the profile of the peat-soft clay interface.

Vane Testing

Three different sizes of vanes were used; each had conical ends and sharpened edges and were of the recommended H/D ratio of 2. Table 1 shows their dimensions.

TABLE 1

Vane	Diameter (in.)	Height (in.)	"K" Factor
S	2.0	4.0	56
M	2.8	5.6	20
L	4.0	8.0	6

The vanes were attached to aluminum "E" drill rods and manually pushed into the ground. To maintain reasonable portability, no casing was used. Torque was applied through a specially designed head attached to the end of the drill rod. Torque was measured by means of a torque wrench with a maximum capacity of 150 ft-lb. Every effort was made to rotate the vane at a constant speed in each test, the rate of strain being about 3 deg per sec. Following shear failure, a remoulded test was run in the usual manner (four complete revolutions, a 1-min wait, then a repeat of test). At each location under investigation, three tests were carried out with each vane through the complete peat profile and into the soft mineral soil sublayer, when this was present. Undrained shear strength was computed from the relationship

$$S = K \times \text{torque}$$

RESULTS

Road Assessment

Those roads rated as fair or better were considered to be satisfactory; those rated as poor or worse were considered to be unsatisfactory. Of the 44 areas investigated in stage I, 27 were classed as satisfactory, 17 as unsatisfactory. In the flat plain type of topography characteristic of the Kapuskasing region, 75 percent of the over-muskeg road sections investigated were classed as satisfactory (compared to adjacent sections of the road on mineral soil terrain). In contrast, in the type of topography characterized by a rugged rocky terrain, with the depressions between rock outcrops being either lakes or muskeg (typical of the Kenora region), only 38 percent of the road sections investigated were classed as satisfactory. It is in this type of topography that a deep layer of soft clay beneath the organic cover was observed most frequently.

A summary of the general information obtained in stage I is given in Table 2, which shows the relation between road performance, muskeg coverage class, depth of fill, depth of the organic material and of the soft mineral soil sublayer (if any), as well as the type of firm mineral soil substratum. All sections of road assessed as very bad were underlain by a soft mineral soil layer. The range of total unstable depth for these shear failures was 25 to 50 ft. No shear failure was observed for a depth of unstable material of less than 25 ft.

Table 3 presents a summary of the relationships observed between the three pairs of muskeg areas investigated during stage II. An analysis of the results indicates that the main factors contributing to the unsatisfactory condition of the road at site 2 as compared to site 1 were the inadequate depth of fill and poor drainage conditions. At site 4, the unsatisfactory condition of the road was indicated by excessive and differential settlement, giving it a "roller-coaster" effect. Poor drainage and a less satisfactory muskeg type than at site 3 are the possible reasons for this condition.

Road and muskeg features at sites 5 and 6 were so similar that it was difficult to see the reason for the difference in road performance. Part of the answer, however, may be the location of the road at site 6, which is constructed quite close to a sharply sloping rock outcrop. The manner of the road failure would indicate that the fill may be slipping along the plane of the rock face.

At three different sites where a shear failure had resulted in mud waves being pushed up on one or both sides of the road, hand borings were made through the center of the mud waves, as well as through the natural muskeg, to determine the depth to the soft intermediate zone. Levels were made of the ground surface and from this information the elevation of the soft clay-peat interface was plotted. It was found that this soft clay-peat interface followed the general contour of the surface mud wave, indicating that the failure zone extended down into the soft mineral soil layer.

Vane Tests

In peat, high deformations accompany the development of shear. The total strain in the vane shear tests was frequently as much as 50 deg, and occasionally reached 90 deg. It was greatest for the small vane, least for the largest vane. Part of this angular rotation was due to twist in the rod although this was observed to be generally less than about 5 deg. It was possible to obtain an excellent reproducibility of results for each vane in a series of tests at any particular site. Apart from an occasional exceptionally high value due to the vane striking a root, the shear values for any one vane at a given depth did not deviate markedly from the mean value. Sensitivity values ranged from 1.5 to 10, and for all three vanes sensitivity decreased with depth.

TABLE 2

SURFACE AND SUBSURFACE CHARACTERISTICS OF AREAS INVESTIGATED

Road Performance	No of Roads	Predominating Cover Class	Depth of Fill (in.)	Depth of Peat (ft)	Depth of Soft Subsoil (ft)	Total Unstable Depth (ft)	Type of Substratum
Excellent	1	AEI	Rock (depth unknown)	17	10	27	Sand
Very good	3	AE	60-66	9-20	0-12	9-32	Clay, sand, rock
Good	11	AEI	12-24	4-11	0-30	4-41	Clay, silt, sand, rock
Fair	12	A—BEI B—DFI	12-45	5-11½	0-6	5-17½	Clay, sand
Poor	9	A—BEI B—DFI	12-60	5½-14	0-18	5½-32	Clay
Bad	2	Inconclusive	24 (1 only)	2-10	0	2-10	Clay, sand
Very bad	6	B—DFI	Rock (depth unknown)	13-19	6-34	25-47	Clay, silt

TABLE 3

Site	Topography	Drainage	Road Features: Performance	Road Features: Surface	Road Features: Depth of Fill (ft)	Road Features: Type of Fill	Muskeg Features: Classification	Muskeg Features: Max Depth of Peat (ft)	Muskeg Features: Depth Under Road (ft)	Subsoil Type	Average Shear Value (Vane M) (psf)
1	Flat plain	Well drained	Good to very good	Paved	5-6	Sand, clay + sand	A—BEI	12½	8	Sandy silt	844
2	Long flat area between rock outcrops	Very wet, poorly drained	Poor to fair	Paved	2½	Sand	A—BEI B—DEI	12	7½	Sand	534
3	Flat plain	Well drained	Very good	Paved	5	Sand and gravel	A—BEI	9	7	Silty clay	626
4	Flat plain	Fairly wet	Poor to fair	Paved	5	Sandy gravel	B—DEI	8 11	4	Sandy silt	455
5	Depressional area	Quite wet	Good	Paved	Not obtainable	Rock	B—AEI	11 to 41(soft clay) 41 (Refusal)	Not obtainable	Silty clay	484 (Peat) 467 (Clay)
6	Depressional area	Very wet	Very bad	Paved	Not obtainable	Rock	B—DF AEI	12 12 to 33 (Soft clay) 33 (Refusal)	Not obtainable	Sandy silt	543 (Peat) 456 (Clay)

There was a marked variation in the shear results between the three vanes. When the average shear value for each vane is plotted against depth, all three curves have a similar shape and clearly reflect any layers of higher or lower strength. The small vane, however, gave results about double those of the medium size vane and from four to five times those of the large vane. This was consistent for all sites investigated. There was no strong evidence of a correlation of shear strength with muskeg classification type, although the upper range of shear values obtained were generally in muskeg types having tall tree growth (classes A and B).

In those muskeg areas not underlain by a soft mineral soil layer, the vane tests did not consistently indicate an increase in shear strength with depth. In fact, the shear strength remained fairly constant throughout the depth of the deposit. In those muskegs underlain by a soft mineral soil layer, however, there tended to be a slight increase in shear strength with depth, reaching its maximum value at, or just above, the transition zone. This was followed consistently by a drop in the shear strength of the soft mineral soil layer. On the average, the shear strength of this soft mineral soil layer was found to be 77 percent of the shear strength of the peat. Figure 3 gives vane test results from one site and shows the consistent relationship that obtains between the three vanes throughout depth. These curves are generally indicative of the trend at the other sites investigated. When all values of vane shear were plotted against water content, no clear correlation was evident.

Laboratory Results

The water content of peat varies over a wide range and may even exceed 1,000 percent of the dry weight. When water content was plotted against depth for each site, a curve was produced similar in shape to the vane shear curves (see Fig. 3 for a sample curve). Peat generally exhibits an acidic quality, the acidity (as measured by pH) being proportional to the organic content (or ignition loss) as shown in Figure 4.

Figures 5, 6, and 7 show an apparent critical zone for the peat samples studied. This zone is indicated for organic contents greater than 75 percent, specific gravity values of soil solids less than about 1.6, and water contents greater than approximately 600 percent. Higher values of organic content represent the "pure" peats, with comparatively little admixed mineral matter. Therefore, beyond this critical zone (i.e., in the "pure" peats) there is no evidence of correlation between the organic content, specific gravity of soil solids, and water content. Up to this zone, however, it is seen that as organic content increases, specific gravity values decrease and water content increases. The void ratio will correspondingly increase with increased organic content and consequently the compressibility of the peat will also increase.

In Figure 5, that part of the curve below the critical zone agrees closely with the results of Cook (4) regarding the relationship between water content and specific gravity.

A consolidation test program has been started at the Division of Building Research on the tube samples of peat in an effort to determine when the primary phase of peat consolidation is completed and also to determine how much of the settlement is due to secondary consolidation.

DISCUSSION OF RESULTS

The problem of evaluating objectively the many variables involved in assessing road performance creates some difficulty in correlating the road performance with muskeg type. It is evident that factors other than muskeg type are influential in determining the performance of a road constructed over muskeg. Consequently, the clear-cut pattern hoped for at the

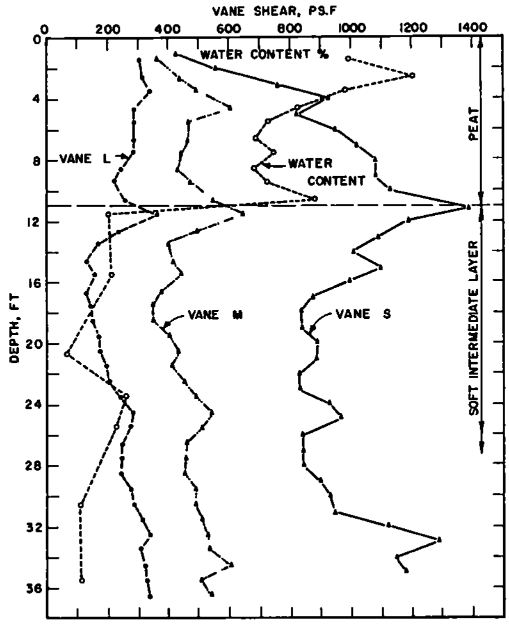


Figure 3. Vane shear and water content vs depth.

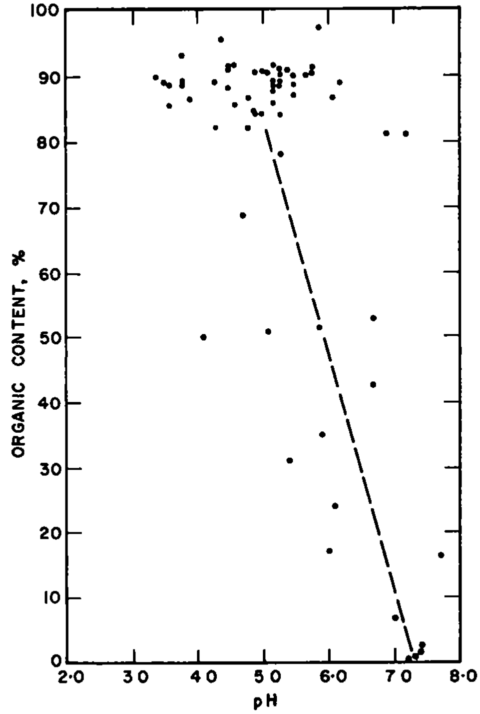


Figure 4. Organic content vs pH.

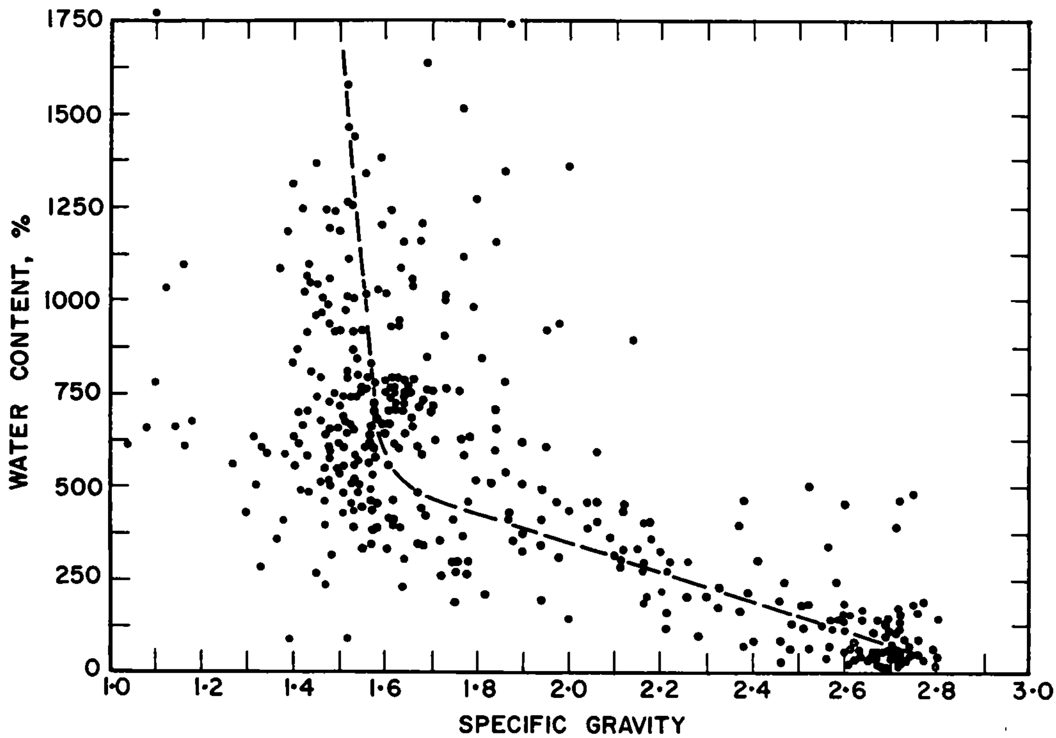


Figure 5. Water content vs specific gravity.

beginning of the research project did not emerge. Nevertheless, it can be seen from Table 2 that, although there is considerable overlap in muskeg type in the different road assessment categories, a trend is observed from tall trees to dwarfed trees and shrub growth as the road assessment drops from excellent to very bad. This is especially true for those muskeg areas directly underlain by a firm mineral soil substratum (i. e., no intermediate soft layer). It may be concluded, therefore, that roads constructed over muskeg types containing tall tree growth (classes A or B in the coverage formula) performed more satisfactorily than those on muskeg types with little or no tree growth. No correlation was evident between road performance and the type of firm mineral soil substratum.

Traffic loads and volume are important to the performance of any road. In this investigation, where performance of roads over muskeg was compared to the performance of adjacent roads over mineral soil terrain, traffic loads could safely be assumed to be the same for both sections of road and were not therefore considered further.

The cause of shear failures in muskeg areas underlain by a soft mineral soil layer is due largely to this layer rather than to the peat itself. The shear strength of this layer was generally less than that of the peat overlying it and it would seem the zone of failure is in this soft subsoil. Consequently, from the point of view of both consolidation movements and embankment stability, the greatest difficulties in road construction over muskeg can be expected in these depressional-type muskegs.

Table 3 indicates that an inadequate depth of fill and a high water level (acting together or separately) contribute to the poor performance of a road on muskeg. In some cases, peat was observed to be "pumping" through a very shallow fill subjected to heavy truck traffic. In at least one instance, stumps were noted to be puncturing through the asphalt surface of a road. Lea and Brawner (5) have recommended a minimum depth of fill on preconsolidated peat of 3½ ft. These investigations confirmed that a depth of fill of this order is desirable.

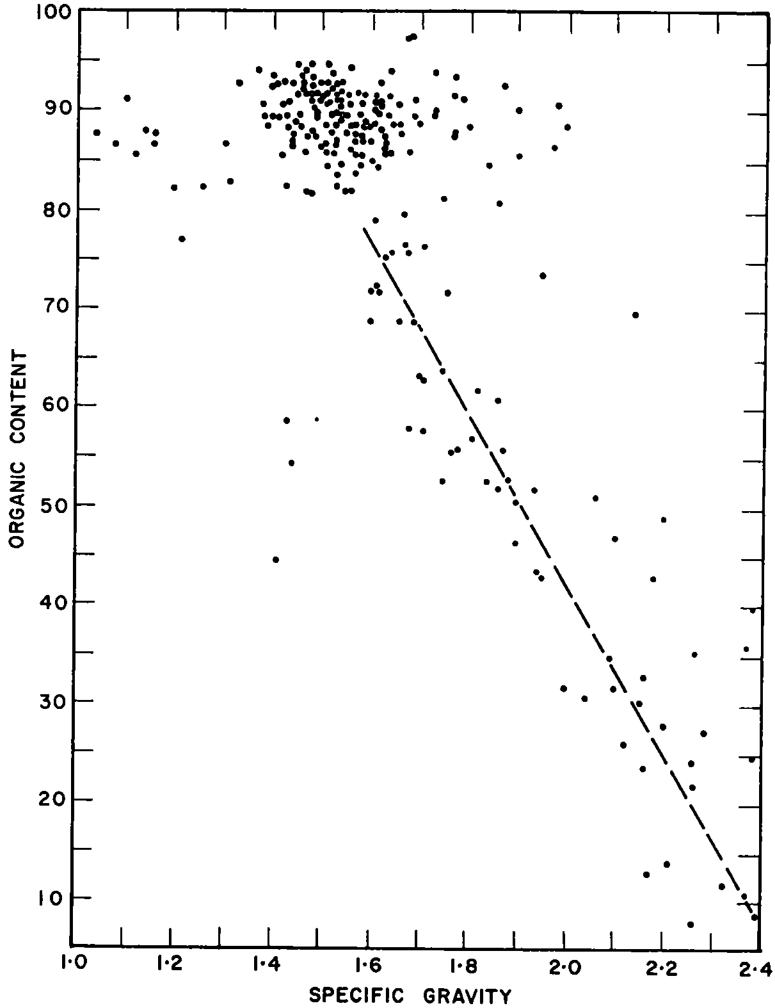


Figure 6. Specific gravity vs organic content.

The vane apparatus, although initially developed for use in clay soils, has been used extensively recently for determining the shear strength of peat. There is still some question, however, regarding the validity of this apparatus for such a complex soil as peat. In their comprehensive report, Cadling and Odenstad (6) concluded (after investigating three sizes of vanes) that the influence of the vane dimensions does not appreciably affect the shear results for clays. When the average shear strength for the different vanes was plotted against depth, they showed very good correlation. The authors point out, however, that design considerations place certain limits on the practical sizes of vanes that can be used.

It is reasonable to assume that for a fibrous material such as peat, the particle size relative to the vane size is significant. This might account for some of the variation between the results for the three sizes of vanes used in this investigation. Another factor—the effect of which has not yet been fully assessed—is rod friction. It was thought that the extremely wet condition of peat together with the disturbance caused by periodic vane rotation reduces rod friction to a negligible value.

Since the conclusion of this project, a few further vane tests have been carried out in order to evaluate the effect of rod friction. Although not extensive enough to

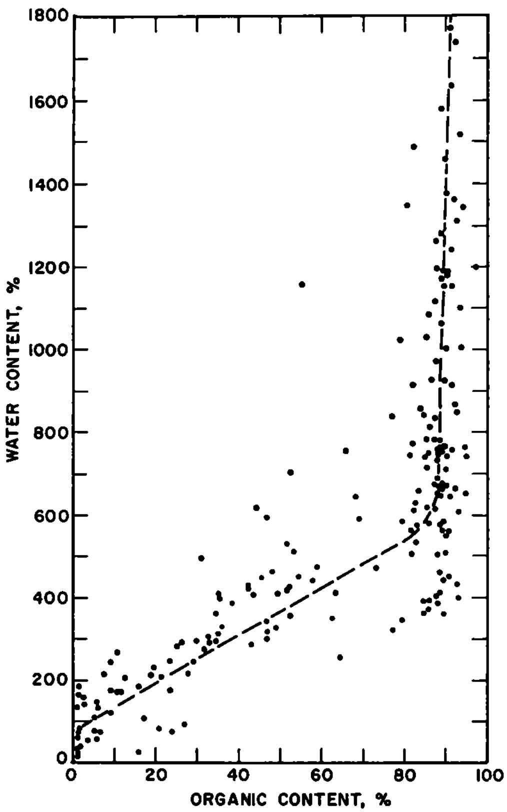


Figure 7. Organic content vs water content.

justify definite conclusions, the tests indicated that for the initial 5 or 6 ft of depth, rod friction is a fairly negligible factor. For greater depths, however, it appears to have some effect on the vane shear results, particularly in the case of the small size vane. A further series of tests is planned.

SUMMARY

1. Sections of road built over types of muskeg that support tall tree growth exhibit better performance than those over areas with little or no tree growth, if most of the other factors are equal or similar. However, road performance cannot be generally correlated with muskeg classification type alone.

2. There was no evident correlation of vane shear strength with muskeg type, except that the upper range of shear values was generally in muskeg types with classes A or B in the coverage formula.

3. Series of vane shear tests show good reproducibility of results. Vane size is apparently a factor to be considered and further research to determine the optimum size seems justified.

4. There was no consistent evidence of increase in shear strength of the peat with depth. On the average, the shear strength remained fairly constant throughout depth.

5. In general, no significant relationship was evident between vane shear strength and water content of peat.

6. Shear strength of peat does not appear to be a problem in the stability of highway embankments on muskeg not underlain by a soft sublayer. Excessive and differential settlements are the more serious problem.

7. Unsatisfactory road performance is sometimes due to an inadequate depth of subgrade. The recommended minimum of 3½ ft appears to be a reasonable figure.

8. A low-lying road and a high water level in the muskeg were important contributing factors in some areas to the deterioration of the road surface.

9. The vane shear strength of the soft mineral soil sublayer was found to be generally less than the shear strength of the overlying peat.

10. Shear failures in areas underlain by a soft mineral soil layer (clay, silt, or marl) are due chiefly to this layer and not necessarily to the peat.

11. Peat becomes more acidic with an increase in organic content.

12. As the organic content of peat increases, there is a corresponding increase in the water content and a decrease in the specific gravity of soil solids, up to a certain critical zone beyond which these three characteristics have no clear relationship.

ACKNOWLEDGMENTS

This paper, a joint contribution of the Ontario Department of Highways and the Division of Building Research, National Research Council, Canada, is published with the approval of Mr. W.A. Clarke, Chief Engineer of the Department of Highways of Ontario, and Mr. R.F. Legget, Director of the Division of Building Research.

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Discussion

PHILIP KEENE, Engineer of Soils and Foundations, Connecticut Highway Department—The authors are to be congratulated on their excellent paper, containing a large amount of factual data on the projects involved and well-founded conclusions where they felt these were justified. Their efforts represent another example of the skilled and competent work being done by engineers and other scientists of Canada on the problems involving muskeg.

The authors have noted that when slides occurred, resulting in the familiar rapid subsidence of the embankment and the formation of mud waves beyond the toe of embankment slope, the zone of rupture always went through a soft mineral stratum located below the peat. The mineral layer is described as clay or silt or both.

The authors state that high deformations accompany the development of shearing in peat. In contrast, deformations due to shear stresses in soft mineral soil are relatively much smaller. Hence, it is probable that as an embankment was being placed and shear stresses were being developed in the underground, the peat furnished very small shearing resistance while the deformations were small, and consequently a large share of the shearing resistance was borne by the silt-clay. Just before the time of rupture, the silt-clay was stressed to its ultimate shearing strength, with a shearing strain of perhaps 2 or 3 in., while the peat was resisting, at that strain, at perhaps 50 percent of its maximum ultimate shearing strength. After the silt-clay failed, the peat then must resist nearly all the shearing force and because it was unable to do so, it then failed. Hence, this progressive failure explanation would be based on large differences in stress-strain characteristics between peat and soft mineral soil rather than on ultimate shearing strengths of both materials.

THE NATIONAL ACADEMY OF SCIENCES—NATIONAL RESEARCH COUNCIL is a private, nonprofit organization of scientists, dedicated to the furtherance of science and to its use for the general welfare. The ACADEMY itself was established in 1863 under a congressional charter signed by President Lincoln. Empowered to provide for all activities appropriate to academies of science, it was also required by its charter to act as an adviser to the federal government in scientific matters. This provision accounts for the close ties that have always existed between the ACADEMY and the government, although the ACADEMY is not a governmental agency.

The NATIONAL RESEARCH COUNCIL was established by the ACADEMY in 1916, at the request of President Wilson, to enable scientists generally to associate their efforts with those of the limited membership of the ACADEMY in service to the nation, to society, and to science at home and abroad. Members of the NATIONAL RESEARCH COUNCIL receive their appointments from the president of the ACADEMY. They include representatives nominated by the major scientific and technical societies, representatives of the federal government, and a number of members at large. In addition, several thousand scientists and engineers take part in the activities of the research council through membership on its various boards and committees.

Receiving funds from both public and private sources, by contribution, grant, or contract, the ACADEMY and its RESEARCH COUNCIL thus work to stimulate research and its applications, to survey the broad possibilities of science, to promote effective utilization of the scientific and technical resources of the country, to serve the government, and to further the general interests of science.

The HIGHWAY RESEARCH BOARD was organized November 11, 1920, as an agency of the Division of Engineering and Industrial Research, one of the eight functional divisions of the NATIONAL RESEARCH COUNCIL. The BOARD is a cooperative organization of the highway technologists of America operating under the auspices of the ACADEMY–COUNCIL and with the support of the several highway departments, the Bureau of Public Roads, and many other organizations interested in the development of highway transportation. The purposes of the BOARD are to encourage research and to provide a national clearinghouse and correlation service for research activities and information on highway administration and technology.