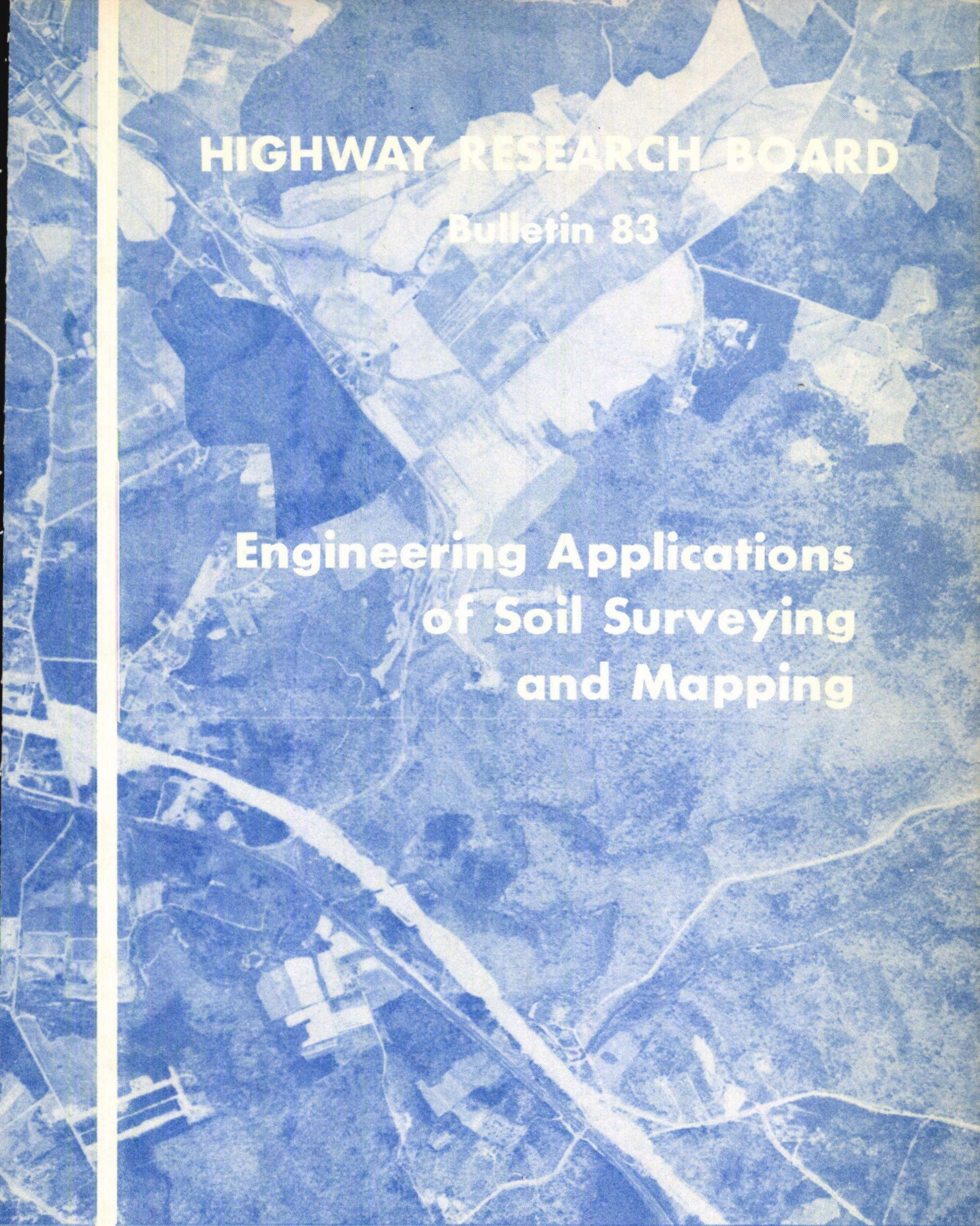

HIGHWAY RESEARCH BOARD

Bulletin 83

Engineering Applications of Soil Surveying and Mapping

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Bulletin 83

Engineering Applications of Soil Surveying and Mapping

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DEPARTMENT OF SOILS

Harold Allen, Chairman;
Principal Highway Engineer
Bureau of Public Roads

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Contents

Introduction

FRANK R. OLMSTEAD, Chairman,
Highway Physical Research Engineer, Bureau of Public Roads

● THIS bulletin is the 6th of a related series sponsored by the Committee on "Surveying, Mapping and Classification of Soils." It follows the general pattern of previous bulletins 13, 22, 28, 46 and 65, i. e., the tabulation of useful information on the status of geologic and agricultural mapping in the United States, the listing of geologists and soil scientists who may be able to assist the engineer in obtaining more precise soil and subsurface information from the interpretation of these special purpose maps, and a series of five papers and one discussion on the development and application of soil survey information to the design and construction of highways.

Marked progress has been made in the application of soil engineering to highway problems and even greater progress will be made because today the highway administrators are rapidly becoming more cognizant of the long range benefits that can be derived from a well integrated soil engineering branch with personnel who are thoroughly acquainted with the problems confronted by the other branches of highway engineering and who can make practical and reasonable applications of soil engineering to assist in the solution of these highway problems.

The states that have made the greatest progress are those who have made considerable effort to sell the value of an experienced soils organization to all phases of highway engineering. To accomplish this there must be a well planned educational program in operation at all times to acquaint the administrator with the economic aspects of using soil as a construction material and of furnishing the design engineer with the essential soil and terrain information during the early stages of planning operations. It is obvious that this must be done if the maximum benefits are to be realized from the engineering soil surveys made for road projects.

If the design engineer is aware of the type of local soils to be encountered during grading operations it is not too difficult and not too expensive to include in the plans a provision for placing the soils with the high bearing value in the upper part of the subgrade to reduce the amount of foundation course required in the pavement structure to carry the highway loadings.

Research now completed or in progress has stimulated the thinking of highway administrators on the re-evaluation of the design of pavement structures in terms of traffic, soils and terrain conditions and highway costs. The present trend is toward the evaluation of full scale road tests, such as the Maryland and the WASHO Road Tests to develop better criteria for the design of highways.

Recent work of the committees of the Highway Research Board, such as, The Flexible Pavement Design, The Frost Heave and Frost Action in Soils, The Material Surveys and this committee have assisted the engineer by assembling and disseminating pertinent engineering information useful for design and maintenance of highways.

This committee will appreciate receiving suggestions on how we may better serve the highway engineer. The members are especially interested in receiving information on new developments and applications that have been made by the States in Soil Surveying, Mapping and Classification of Soils.

PURPOSE AND SCOPE OF COMMITTEE "SURVEYING, MAPPING AND CLASSIFICATION OF SOILS"

Scope

In general all phases of the soil survey work such as: Interpretation of airphotos, geologic maps or agronomic soil maps for soils information, the preparation of engineering soil maps, or the preparation of material inventories on an area basis, the methods of subsurface exploration — seismic or resistivity, the evaluation of soil survey data for the design, construction or maintenance of highways and the methods of correlation of soil data with pavement performance are considered within the scope of this project committee activity.

Purpose

(a) To assist in the development of a program of engineering papers and publications to emphasize the need for soil survey information in highway planning and construction, and to point out practical applications of the use of soil surveys in highway engineering work.

(b) To assist in the development of new methods for making soil surveys or for the identification and classification of soils from laboratory or field data.

(c) To review and recommend for approval any technical papers on soils under the jurisdiction of this committee which may be submitted for presentation and publication by the Highway Research Board. Also to furnish the Highway Research Board with recommendations on engineering soil problems that may be assigned for review and comment.

Geologic Survey Mapping in the United States

● THE committee indicated in previous bulletins 28, 46 and 65 the status and usefulness of geological maps for highway engineering purposes. The following information was furnished by the U. S. Geological Survey at the request of the committee to supplement information previously published on this subject. A new 1953 edition of a geologic map showing the status of geological mapping at scales of 1-in. to the mile or greater has just been released by the U. S. Geological Survey and copies can be obtained upon application to the U. S. Geological Survey, Washington 25, D. C. This map is similar to the one shown in Figure 1 of HRB Bulletin 65. It was received too late for inclusion in this bulletin.

Current Investigations of the U. S. G. S. Involving Geologic Mapping

The Geological Survey prepares geologic maps for several purposes in more than one of its divisions. The Geologic Division conducts systematic surveys and research and investigations related to mineral resources and to engineering geologic problems. Many of the geologic maps prepared by this division are highly detailed and restricted to mineralized areas. The Water Resources Division, through its Ground Water Branch, makes systematic and special geologic investigations in connection with the occurrence of ground water. Many of the studies have special application to highway construction and planning. Geologic maps, cross-sections, and texts are published.

The following list of investigations include only areal geologic mapping which it is felt may be useful to engineers engaged in construction work in the areas concerned.

Any inquiries about geologists in charge of the Geologic Division projects (listed in Table 1) should be addressed to the Director, U. S. Geological Survey, Washington 25, D. C., since these men are in the field for only a part of the year and investigations frequently involve considerable laboratory and office research not generally performed in the field area. Water Resources Division projects, Table 2, are directed from permanent offices in the states where both original and published records are available. Inquiry may be made through the field offices or through the Director, as indicated above.

Index to Geological Mapping in the United States

The map indexes, which are available for 43 states (see list below), show the areas of published geological maps in each state and give the source of publication of each map. The available state index maps and the price of each are listed in the following table. Most indexes are on a scale of 1: 750,000, others are 1: 500,000 or 1: 1,000,000. Each index shows the outline of each area mapped and the approximate scales are shown by patterns in four colors. Bibliographies are printed with the indexes giving the sources and the dates of publication and the names of the geologists responsible for the work.

Copies of these index maps may be obtained from the Chief of Distribution, U. S. Geological Survey, Washington 25, D. C. or for the convenience of persons living west of the Mississippi River, indexes for states in that part of the country may be ordered from the Distribution Section, U. S. Geological Survey, Denver Federal Center, Denver, Colorado. Copies may be consulted in many libraries.

Available Geologic Map Indexes

Alabama	$ .40	Nebraska	$ .35
Arizona	.35	Nevada	.30
Arkansas	.65	N. H. — Vt.	.50
California	1.00	New Jersey	.40
Colorado	.70	New Mexico	.70
Florida	.60	New York	.60
Georgia	.35	North Carolina	.50
Idaho	.25	North Dakota	.40
*Illinois		Ohio	.25
Indiana	.45	Oklahoma	.60
Iowa	.35	Oregon	.25
Kansas	.30	Pennsylvania	.60
Kentucky	.50	South Carolina	.25
Louisiana	.50	South Dakota	.30
Maine	.25	Tennessee	.40
Md. — Del.	.40	Texas	.60
Mass. — R. I. — Conn.	.40	Utah	.25
Michigan	.60	Virginia	.40
Minnesota	.60	Washington	.35
Mississippi	.25	West Virginia	.25
Missouri	.30	Wisconsin	.60
Montana	.35	Wyoming	.50

*not yet published

Most of the states have geological surveys or similar state agencies that can furnish information on the availability of geological maps and work in progress within their states. The names of state geologists and the location of their offices are shown in Table 3.

TABLE 1

CURRENT INVESTIGATIONS INVOLVING GEOLOGIC MAPPING, GEOLOGIC DIVISION, 1:62,500 OR LARGER SCALES

Project	Project Chief
ALABAMA	
Survey of the belt of Cretaceous rocks in Central Alabama	L. C. Conant
ARIZONA	
Jerome Copper District, Yavapai County	M. H. Krieger
Globe-Miami Copper District, Gila County	N. P. Peterson
Little Dragoons Copper District, Cochise County	J. R. Cooper
Carrizo Mountains, Northeastern Arizona	J. D. Strobell, Jr.
Investigations of uranium in pre-Morrison formations	J. F. Smith, Jr.
Upper Gila River Basin	R. B. Morrison
San Carlos Indian Reservation	A. F. Shride
Asbestos Studies, Gila County	A. F. Shride
Fort McDowell Quadrangle	R. C. Townsend
ARKANSAS	
North Arkansas Oil and Gas, Geologic Mapping and Studies of Resources, Newton-Searcy Counties	J. C. Maher
Waldron Quadrangle	J. A. Reinemund
Magnet Cove columbium	R. L. Erickson
South Arkansas oil and gas studies	B. R. Haley
CALIFORNIA	
San Andreas Rift Zone, Los Angeles and San Bernardino Counties	Levi F. Noble
Areas in Mojave Desert Region, San Bernardino and Kern Counties	W. C. Smith
San Francisco Area	M. G. Bonilla
Bishop Tungsten District, Inyo County	P. C. Bateman
Shasta Copper District, Shasta County	J. P. Albers
Cerro Gordo Quadrangle, Inyo County	W. C. Smith
Papa Pegmatite district, San Diego and Riverside Counties	R. H. Jahns
Ubehebe Peak Quadrangle, Inyo County	J. F. McAllister
Darwin Area, Inyo County	W. E. Hall
Northwest Santa Ana Mountains, Orange County	J. E. Schoellhammer
Study of Miocene and Pliocene deposits of the Santa Clara Valley, Ventura and Los Angeles Counties	E. L. Winterer
Los Angeles and vicinity	John McGill
Eastern Sierra tungsten belt, Mono and Alpine Counties	P. C. Bateman
Sierra Foothills mineral belt	L. D. Clark
COLORADO	
Detailed Geologic mapping along Upper South Platte (North fork), Park, Jefferson and Douglas Counties	D. J. Varnes
Kokomo (Tenmile) mining District, Summit, Lake and Eagle Co.	A. H. Koschmann
Central San Juan Mountains	W. S. Burbank
Holy Cross Quadrangle, Eagle, Lake, Summit, and Pitkin Counties	O. L. Tweto
Trinidad Coal Field, Southeastern Colorado	G. H. Wood, Jr.
Glenwood Springs Quadrangle, Garfield County	N. W. Bass
Animas River Coal Field, LaPlate, Archuleta and Montezuma Co.	H. Barnes
Uinta Basin Oil Shale-White River Area, Garfield and Rio Blanco Co.	C. R. Lewis
City geology, Denver	M. R. Mudge

Table 1 (continued)

COLORADO

Project	Project Chief
Northwest extension, Animas River area	A. A. Wanek
Northern coal field of the Denver Basin	F. D. Spencer
Clay deposits in the foothills of the Front Range	K. M. Waage
Areas in the Colorado Plateau, uranium inves.	R. P. Fischer
Central City-Georgetown area	P. K. Sims
Carbondale coal field	J. R. Donnell
Wet Mountains thorium district	Q. D. Singewald
Northgate fluorspar studies	T. A. Steven

IDAHO

Blackbird-Noble No. 3 Quadrangle, Lemhi County	J. S. Vhay
Phosphate districts in Bear Lake, Caribou, Bannock, and Brigham Counties	V. E. McKelvey
Coeur d'Alene mining district, Shoshone County	S. W. Hobbs
Orofino Area, Clearwater County	A. Hietanen-Makela
Central Idaho monazite	J. H. Mackin

IOWA

City geology, Omaha and vicinity	R. D. Miller
Lead-zinc investigations	A. F. Agnew

KANSAS

County by county survey of construction materials in northern and central Kansas	F. E. Byrne
Geologic mapping of Pennsylvanian rocks in Kansas beginning in Wilson County	H. C. Wagner
Tri-state lead-zinc investigations	E. T. McKnight

KENTUCKY

Geology of the coal-bearing region in eastern Kentucky	J. W. Huddle

MAINE

Poland Quadrangle, Androscoggin, Cumberland, and Oxford Co.	J. B. Hanley

MASSACHUSETTS

Mapping of Quadrangles in Massachusetts in cooperation with Massachusetts Department of Public Works	L. W. Currier

MICHIGAN

Michigan Copper District, Houghton, Keweenaw, and Ontonagon Co,	W. S. White
Iron Deposits, Iron and Dickinson Counties	H. L. James

MINNESOTA

Cuyuna Range, Crow Wing County	R. G. Schmidt

MISSOURI

Tri-state lead-zinc investigations	E. T. McKnight

Table 1 (continued)

Project	Project Chief
MONTANA	
Medicine Lake Area, Sheridan, Roosevelt, and Daniel Counties	I. J. Witkind
Stratigraphy of Belt Series in and near western Montana	C. P. Ross
Big Sandy Creek, South half Chouteau and Blaine Counties	R. M. Lindvall
Cat Creek region	W. D. Johnson, Jr.
Three Forks quadrangle	G. D. Robinson
Great Falls-Sun River Area	R. W. Lemke
Stillwater Chromite Deposits, Stillwater and Sweetgrass Counties	E. D. Jackson
Phosphate deposits of Southwest Montana, Beaverhead and Madison Counties	V. E. McKelvey
Boulder Batholith, Broadwater and Jefferson Counties	R. A. Weeks
Mission Canyon Project, Park County	P. W. Richards
Girard Coal Field, Richland County	G. E. Prichard
Bearpaw Mountains, Hill, Choteau, and Blaine Counties	W. T. Pecora
Wolf Point area, Sheridan and Roosevelt Counties	R. B. Colton
Little Rocky Mountains	M. M. Knechtel
Browning area, western Montana	G. M. Richmond
NEBRASKA	
Yankton Area, Cedar and Knox Counties	H. E. Simpson
Geology and Construction Materials of Quadrangles in the Republican River Valley	E. Dobrovolny
Quadrangles along the Lower Platte River, Valley and Howard Counties	E. Dobrovolny
City geology, Omaha and vicinity	R. D. Miller
NEVADA	
Carson Sink Basin, Churchill County	R. B. Morrison
Mojave Desert Region, Clark County, (Scale 1:120,000)	W. C. Smith
Geology along Colorado River, Clarke County	C. R. Longwell
Hilltop and Crescent Valley Quadrangles, Lander County	James Gilluly
Gabbs Magnesite District, Nye County	C. J. Vitaliano
Antler Peak Quadrangle, Lander and Humboldt Counties	R. J. Roberts
Steamboat Springs District, Washoe County	D. E. White
Eureka Mining District, Eureka County	T. B. Nolan
Osgood Mountains Quadrangle	P. E. Hotz
NEW JERSEY	
Study of Magnetite Deposits, New Jersey Highlands	A. F. Buddington
NEW MEXICO	
Potash resources in Eddy and Lea Counties	C. L. Jones
Silver City Mining Region Grant County	W. R. Jones
Sangre de Cristo Mountain area, Santa Fe, San Miguel, Taos, Mora, and Colfax Counties	C. B. Read
Chaco River Coal Field, San Juan County	E. C. Beaumont
Carrizo Mountains, Northwestern New Mexico	J. D. Strobell, Jr.
Tohatchi Area, McKinley County	J. D. Sears
Animas River Coal Field, San Juan County	H. Barnes
Valles Mountains Region, Sandoval County	C. S. Ross
Investigations of uranium in pre-Morrison formations	J. F. Smith, Jr.
Upper Gila River Basin	R. B. Morrison
Southeastern New Mexico stratigraphy	P. T. Hayes
Guadalupita area, Mora County	C. M. Tschanz

Table 1 (continued)

Project	Project Chief
NEW YORK	
Gouverneur Talc district, St. Lawrence County	A. E. J. Engel
Magnetite Deposits, St. Lawrence and Clinton Counties	A. F. Buddington
NORTH CAROLINA	
Great Smoky Mountains National Park, Swain, Haywood and Jackson Counties	P. B. King
Spruce Pine Pegmatite District, Avery, Mitchell, and Yancey Counties	J. L. Kulp
Hamme Tungsten District	J. M. Parker, 3d
NORTH DAKOTA	
Pleistocene Geology, Western North Dakota	A. D. Howard
Missouri-Souris Project, Northwest N. D.	R. W. Lemke
Knife River Area, Mercer County	W. E. Benson
OHIO	
Geology and coal resources of Belmont County	H. L. Berryhill, Jr.
OKLAHOMA	
Tri-state lead-zinc district	E. T. McKnight
OREGON	
Portland Industrial Area	D. E. Trimble
John Day Chromite District, Grant County	T. P. Thayer
Galico Quadrangle, Josephine County	F. G. Wells
Coast Range	E. M. Baldwin
PENNSYLVANIA	
Magnetite Deposits, York and Lancaster Counties	A. F. Buddington
Selected coal mining areas in Pennsylvania Anthracite Region	G. H. Wood
Southern Anthracite field	G. H. Wood
RHODE ISLAND	
Northeastern Rhode Island	A. W. Quinn
SOUTH DAKOTA	
Pleistocene Geology, Eastern half of S. D.	R. F. Flint
Pierre Area, Stanley and Hughes Counties	D. R. Crandell
Yankton Area, Yankton and Bonhomme Counties	H. E. Simpson
Southern Black Hille Pegmatite District, Custer and Pennington Counties	L. R. Page
TENNESSEE	
Great Smoky Mountains National Park, Sevier and Cocke Counties	P. B. King
Knoxville and vicinity	J. M. Cattermole
TEXAS	
Areas in Hudspeth County	J. F. Smith, Jr.
Oil and Gas Investigations, North central Texas	D. H. Eargle

Table 1 (continued)

Project	Project Chief
UTAH	
LaSal Mountains, San Juan County	C. B. Hunt
Southern half Utah Valley, Utah County	H. J. Bissell
Marysvale Alunite District	E. Callaghan
East Tintic Mining District, Juab County	T. S. Lovering
Iron Springs District, Iron County	J. H. Mackin
Bear River Phosphate District, Rich County	V. E. McKelvey
Alta Quadrangle, Salt Lake, Wasatch, and Uintah County	M. D. Crittenden
Strawberry Quadrangle	A. A. Baker
Uinta Basin Oil Shale Region, White River Area, Uintah County	W. B. Cashion
Cedar City SE Quadrangle	P. Averitt
Areas in the Colorado Plateau, uranium invest.	R. P. Fischer
Investigations of uranium in pre-Morrison formations	J. F. Smith, Jr.
Upper Green River Valley	W. R. Hansen
Red House Cliffs, San Juan County	T. E. Mullens
Southern Colob Plateau coal field	W. B. Cashion
Elk Ridge area, San Juan County	R. Q. Lewis
San Rafael Swell, Emery County	I. J. Witkind
Capital Reef area, Wayne and Garfield Counties	J. F. Smith, Jr.
White Canyon area, San Juan County	A. F. Trites
VERMONT	
Vermont Talc	W. M. Cady
VIRGINIA	
Hamme Tungsten District	J. M. Parker, 3d
Fairfax Quadrangle, Fairfax and Loudoun Counties	C. Milton
Richmond coal basin	E. I. Rich
Potomac Basin erosion studies	J. T. Hack
NE Lee County and Western Scott County	R. L. Miller
WASHINGTON	
Portland Industrial Area, Clark County	D. E. Trimble
Landslide Studies, Franklin D. Roosevelt Lake	F. O. Jones
Lower Snake River Canyon, Franklin, Walla Walla, Columbia, Whitman, and Garfield Counties	H. H. Waldron
Pysht, Lake Crescent, Port Crescent and Port Angeles Quadrangle, Callam County	P. D. Snavely, Jr.
Toledo-Castle Rock Coal District, Cowlitz County	A. E. Roberts
Holden-Glacier Peak Quadrangle	F. W. Cater, Jr.
Puget Sound Basin	H. H. Waldron
Metaline district, Pend Orielle and Stevens Counties	M. G. Dings
Grays Harbor area, Grays Harbor and Pacific Counties	L. Hoover
WEST VIRGINIA	
Potomac Basin erosion studies	J. T. Hack
WISCONSIN	
Lead-Zinc Deposits in Grant, Lafayette, and Iowa Counties	A. F. Agnew
WYOMING	
Cokeville Area, Lincoln and Sublette County	W. W. Rubey

Table 1 (continued)

Project	Project Chief
WYOMING	
Iron Deposits in Laramie Range, Albany County	W. H. Newhouse
Bear River Phosphate Deposits, Lincoln and Uinta Counties	V. E. McKelvey
Clark Fork Area, Park County	W. G. Pierce
Crazy Women Creek Area, Johnson County	R. K. Hose
Beaver Divide area, Fremont County	F. B. Van Houten
Lenore area, Wind River Basin	J. F. Murphy
DuNoir area, Wind River Basin	W. R. Keefer
Muskrat-Dutton Basin, Wind River Basin	J. L. Weitz
Miller Hill area	J. D. Vine
Grand Teton National Park	J. D. Love
Western Red Desert	G. N. Pipiringos
Powder River Basin uranium	D. F. Davidson
Shotgun Butte area, Wind River Basin	M. L. Troyer

TABLE 2

CURRENT INVESTIGATIONS INVOLVING GEOLOGIC MAPPING,
WATER RESOURCES DIVISION, GROUND WATER BRANCH

Project	Project Chief
ALABAMA	
Baldwin, Choctaw, Madison, Montgomery, Monroe, Randolph, Tuscaloosa, Wilcox Counties Mapping Scale 1:31680, Pub. Scale 1:125,000	P. E. LaMoreaux
ALASKA	
Anchorage area, Knik and Anchorage Quadrangles Mapping Scale 1:48,000	D. J. Cederstrom
Matanuska Valley (Agricultural area) Mapping Scale 1:50,000	F. W. Trainer
Parts of Sutton, Matanuska, Eklutna, Houston Quadrangles and Knik County Mapping Scale 1:50,000	
ARIZONA	
Douglas Basin, Cochise County Mapping Scale 1:3168, Pub. Scale 1:125,000	
Papago Indian Reservation, Pinal County	
Papago Indian Reservation, Pima County	
Lower San Pedro Valley, Pinal County and parts of Pima, Cochise and Graham Cos.	
San Carlos Indian Reservation, Graham County	
Navajo County Irregation District Mapping Scale 1:30,000, Pub. Scale 1:62,500	
Mogollon Rim area, Coconino, Navajo and Apache Counties	L. C. Halpenny
Navajo Reservation - Coconino - Navajo - Apache Cos.; Includes areas in San Juan County Utah, and McKinley and San Juan Cos., New Mexico Mapping Scale 1:31680, Pub. Scale 1:125,000	J. W. Harshbarger
ARKANSAS	
Reconnaissance of Little River County and parts of Sevier, Howard, Pike, Clark, Hot Springs, Quachito Nevada, Hempstead and Miller Counties Scale 1-inch = 3-miles	Roger C. Baker
CALIFORNIA	
Eureka - Fortuna Area Mapping Scale 1:62,500	

Table 2 (Continued)

Project	Project Chief
CALIFORNIA	
Napa Valley - Napa County No Scale indicated	
Sacramento Valley Mapping Scale 1:62,500	
Coastal Area, Torrance - Santa Monica Mapping Scale 1:24,000	
Coastal Area, Orange County Mapping Scale 1:31,680	
San Rosa and Petalumn Valley Mapping Scale 1:31,600 Pub. Scale 1:62,500	J. F. Poland
Inyokern, Edwards and Twenty-Nine Palms Mapping Scale 1:50,000	G. F. Worts, Jr.
Camp Pendelton - San Diego County Scale 1:24,000	
San Bernadino Basin, San Bernadino County Scale 1:31,680	A. A. Garrett
Foothill and Valley - flow area of Solano and Southern Yolo Counties Mapping Scale 1:24,000	H. G. Thomasson
COLORADO	
Baca County, eastern Huerfano County, South Platte Valley, Grand Junction Area Mapping Scale - All over 2-inch = 1-mile, Pub. Scale 1-inch = 1-mile	T. G. McLaughlin
CONNECTICUT	
Hartford, Holland and Middlesex Counties	R. V. Cushman
FLORIDA	
Parts of Lee, Glades and Hendry Cos.	N. D. Hoy
GEORGIA	
Coastal Plain Area (Subsurface) Scale 1-inch = 10-miles	S. M. Herrick
Sumner, Dooly, Pulaski, Lee, Crisp and Wilcox Counties Scale 1-inch = 2-miles	G. H. Chase
HAWAII	
Island of Kavai Scale 1:62,500	Dan A. Davis
IDAHO	
Parts of Jefferson, Booneville, Bingham, Butte Counties. (Lost and Little Lost River Area) Scale 1:12,000	R. L. Nace
INDIANA	
Tippecanoe, Vermillion, Parke, Montgomery, Putman, Vigo, Clay, Owen, Sullivan, Greene, Adams, Wayne, Fayette, Union, Franklin, Ripley, Ohio Jefferson, Switzerland, Dearborn Counties No Scale indicated	Claude M. Roberts
IOWA	
Appanoose, Dallas, Guthrie, Lucas, Madison, Marion, Monroe, Polk, Story and Warren Counties. Pub. Scale 1:125,000	
Subsurface geologic mapping on a state-wide basis; current work in several different areas	H. Hershey
KANSAS	
Gove, Jewell, Pratt, Rawlins, Reno Counties Mapping Scale 1-inch = 1-mile. Pub. Scale 1-inch = 2-miles	
Douglas, Elk, Osage Counties Mapping Scale 2½ -inch = 1-mile. Pub. Scale 1-inch = 1-mile	V. C. Fishel

Table 2 (Continued)

Project	Project Chief
KENTUCKY	
Parts of Allen, Campbell, Floyd, Grove, Johnston, Kenton and McCracken Cos.	
Mapping Scale 1:16,000 Pub. Scale 1:24,000	
Part of Henderson County	
Mapping Scale 1:16,000 Pub. Scale 1-inch = 1-mile	M. I. Rorabaugh
LOUISIANA	
Areas bordering the Calcasieu and Vermilion Rivers, and Boyou Cocodrie	
Mapping Scale 1 or 2-inches = 1-mile	R. R. Myers
MARYLAND	
Charles, Calvert, Montgomery, Anne Arundel, parts of Howard, Baltimore and Hartford (all coastal plains)	R. R. Bennett
Caroline, Dorchester, Kent, Somerset, Talbot, Wicomico and Worchester Cos.	
Mapping Scale 1:62,500 and 1:31,680	W. C. Rasmussen
MICHIGAN	
Small areas in Houghton and Marquette Counties	
Scale 5-inches = 4-miles	W. T. Stuart
Bay, Midland, Gratiot, Saginaw, Genesse, and Oakland Counties, Parts of Shiawassee and Tuscola Counties	
Scale 1-inch = 6-miles	John G. Ferris
MINNESOTA	
Small area in Redwood County	
Mapping Scale 1:20,000	R. Schneider
MONTANA	
Lower Marias Valley, Liberty, Hill, Chouteau Cos.	
Airphoto Scale 4-inches = 1-mile	
Lewis and Clark, Jefferson Counties	
Airphotos 1-inch = 4000 ft. Pub. Scale 2-inches = 1-mile	
Helena, Townsend, and Gallatin Valleys	
Scale 1-inch = 4,000 ft.	
Dillon Valley, Crow Agency area, (Yellowstone R.)	
Scale 1-inch = 1-mile	
Buffalo Rapids (Yellowstone R.)	
Scale 1-inch = 400 ft.	
Lower Yellowstone (Glendive - Sidney)	
Airphoto 2-inches = 1-mile	E. A. Swenson
NEBRASKA	
Dutch Flats area	
Mapping Scale 1-inch = 2-miles	
Lodgeporte Creek	
Mapping Scale 1-inch = 1-mile	
Pumpkin Creek area	
Mapping Scale 1-inch = 1-mile	H. M. Babcock
NEVADA	
Buena Vista Valley, Cresent Valley, Spring Valley, Dixie Valley, Antelope Valley, Warm Springs Valley, Truckee Meadows areas	
Scale not indicated	O. J. Loeltz
NEW JERSEY	
Newark Area	
Scale not indicated	
Subsurface of Coastal Plains	
Scale 1-inch = 8-miles	
Bedrock contours - Greater Philadelphia and parts of Burlington, Camden and Gloucester Counties	
Scale 2-inches = 1-mile	

Table 2 (Continued)

Project	Project Chief
Salem County (Subsurface) Scale 1-inch = 1-mile	H. C. Barksdale
NEW MEXICO	
Sante Fe County Scale 1:63360 Los Alamos area Scale 1:63,360 Pueblo Laguna Indian Res. (Velencia Co.) Scale 1:126,780 Part of Torrance County Scale 1:63,360 Boswell Basin Scale - - - - - - - El Paso area - parts of El Pasco Co. Texas, and Dona Ana and Otero Counties Scale not indicated	C. S. Conover
NEW YORK	
Dutchess - Putman - Bronx, Westchester - Nassau Counties Mapping Scale 1:62,500 Pub. Scale 1:125,000 Rockland, Delaware Counties Scale not indicated	J. E. Upson
NORTH CAROLINA	
Alexander, Catawa, Davie, Iredell, Rowan, Davidson Counties Scale 1-inch = 2-miles	H. E. LeGrand
NORTH DAKOTA	
Oakes, Buxton, Aneta, Wimbledon, Zeeland Streeter, Minnewaukan, Michigan, Lakota, Devils Lake, Rolla - St. John - Mylo, Stanley Mapping Scale 1:20,000	P. D. Akin
Sargent County Scale 1-inch = 1-mile	G. A. LaRocque
OHIO	
Lucas, Licking, Fairfield, Trumbull, Portage, Ross, Columbiana Counties	S. E. Norris
OKLAHOMA	
Beaver, Beckham, Cleveland, Grady, McCurtain Counties Mapping Scale 3.2 inches = 1-mile Pub. Scale 1-inch = 1-mile Parts of Alfalfa, Major, Garfield and Kingfisher Counties Mapping Scale 1-inch = 1-mile	Stuart L. Schoff
OREGON	
Lake County and Walla Walla area Scale 1:125,000 Yonna - Swan Lake Valleys, Rogue River Valley, Tualatin Valley Scale 1:62,500	R. C. Newcomb
PENNSYLVANIA	
Lawrence County Scale 1:62,500	Paul H. Jones
SOUTH CAROLINA	
Aiken, and Edgefield Counties Mapping Scale 1-inch = 1-mile Marlboro and Chesterfield Counties Mapping Scale 1-inch = 1-mile Pub. Scale ½-inch = 1-mile	George E. Siple
SOUTH DAKOTA	
Oahe unit - James R. Valley, James R. Basin, Brown and Marshall Counties Scale not indicated	G. A. LaRocque

Table 2 (Continued)

Project	Project Chief
TENNESSEE	
Mississippi Basin Tertiary and Cretaceous outcrop areas, also Summer, Macon, Jackson, Smith, Wilson, Davidson, Williamson, Rutherford, DeKalb, Cannon, Maury, Marshall, Bedford, Giles, Lincoln, Anderson, and Bradley Counties. Mapping Scales - contour maps when available 1:2400 and 1:62,500, otherwise aerial photographs 1:2000	E. M. Cushing
TEXAS	
Galveston, Harris, Bandera, Bexar, Medina, and Zavala counties, Wilbarger, Comal Counties. Mapping Scale 1-inch = 1-mile	
High Plains of Texas - Cross sections extending through Sherman, Randall, Moore, Potter, Swisher, Hale, Lubbock, Lynn and North Dawson counties. No Scale indicated	
Geologic cross-sections showing subsurface geology in Ector, Dimit, Lamb, Lynn, western Maverick counties. Mapping Scale 1-inch = 1-mile	.
Kinney County - surface geology No Scale indicated.	
El Paso area - Parts of El Paso County Texas, and Donna Ana and Otero County New Mexico No Scale indicated	R. W. Sundstrom
UTAH	
Southern Juab Valley, Milford District and Ogden Valley Scale 2-inches = 1-mile	H. A. Waite
See Navajo Reservation Project, Arizona	
VIRGINIA	
Coastal Plain Counties North of James River	A. Sinnott
WASHINGTON	
Part of King County east of Lake Washington, Part of Lewis County	
Ahtanum Valley (Yakima County) Scale 1:20,000	
Kitsap and Clark Counties	
Tacoma area (Pierce County)	
Spokane Valley (Spokane County) Scale 1:62,500	
Yelm area (Thurston and Pierce Counties) Scale 1:34,600	M. S. Mundorff
WISCONSIN	
Portage County Scale 1-inch = 1-mile	A. H. Harder
WYOMING	
Cheyenne area - Scale 1-inch = 2-miles	
Egbert Pine Bluffs - Carpenter area Mapping Scale 1-inch = 1-mile	
Gillette, Glendo - Wendover, Horse Creek, La Prele, Laramic Plains, Pass Creek Flats, Wheatland Flat, New Castle areas Mapping Scale All over 1-inch = 1-mile	
Goshen, Platte counties Mapping Scale 1-inch = 1-mile	
Kaycce and Ranchester areas Highway Planning map base	
Barthel area (Soil Moisture demonstration study) Mapping Scale 1-inch = 400 ft.	
North Platte irrigation project - Goshen county Mapping Scale 1-inch = 1-mile	H. M. Babcock
Paintrock Project, Bighorn county Mapping Scale 1-inch = 1-mile	
Heart Mountain Unit, Park Co. Mapping Scale 2-inches = 1-mile	
Riverton Project, Freemont county. Mapping Scale 2-inches = 1-mile	F. A. Swenson

TABLE 3

TABULATION OF STATE GEOLOGISTS BY STATES

	State Geologist and Address
Alabama	Dr. Walter B. Jones, State Geologist, Geological Survey of Alabama, University
Arizona	Dr. T. G. Chapman, Director, Arizona Bureau of Mines, University of Arizona, Tucson
Arkansas	Mr. Norman F. Williams, Director, Division of Geology, Arkansas Resources and Development Commission, State Capitol, Little Rock
California	Dr. Olaf P. Jenkins, Chief, Division of Mines, Department of Natural Resources, Ferry Building, San Francisco 11
Colorado	Mr. Walter E. Scott, Jr., Vice Chairman, Geological Survey Board, State Museum Building, Denver
Connecticut	Dr. Edward L. Troxell, Director, Connecticut Geological and Natural History Survey, Trinity College, Hartford 6
Delaware	Mr. Johan J. Groot, State Geologist, Delaware Geological Survey, University of Delaware, Newark
Florida	Dr. Herman Gunter, Director, Florida Geological Survey, P. O. Drawer 631, Tallahassee
Georgia	Capt. Garland Peyton, Director, Department of Mines, Mining and Geology, State Division of Conservation, 425 State Capitol, Atlanta 3
Idaho	Mr. A. W. Fahrenwald, Director, Idaho Bureau of Mines and Geology, University of Idaho, Moscow
Illinois	Dr. M. M. Leighton, Chief, State Geological Survey Division, 121 Natural Resources Building, University of Illinois Campus, Urbana
Indiana	Dr. Charles F. Deiss, State Geologist, Indiana Department of Conservation, Indiana University, Bloomington
Iowa	Dr. H. Garland Hershey, Director and State Geologist, Iowa Geological Survey, Iowa City
Kansas	Dr. John C. Frye, Executive Director, State Geological Survey, The University of Kansas, Lawrence
	Dr. Raymond C. Moore, State Geologist and Director of Research, State Geological Survey, The University of Kansas, Lawrence
Kentucky	Mr. Daniel J. Jones, State Geologist, Department of Geology, Kentucky Geological Survey, University of Kentucky, Lexington
Louisiana	Mr. Leo W. Hough, State Geologist, Louisiana Geological Survey, Department of Conservation, Geology Bldg., University Station, Baton Rouge 3
Maine	Dr. Joseph M. Trefethen, State Geologist, Maine Geological Survey, University of Maine, Orono
Maryland	Dr. Joseph T. Singewald, Jr., Director, Department of Geology, Mines and Water Resources, Johns Hopkins University, Baltimore 18
Michigan	Mr. William L. Daoust, Acting State Geologist, Geological Survey Division, State Department of Conservation, Lansing 13
Minnesota	Dr. G. M. Schwartz, Director, Minnesota Geological Survey, University of Minnesota, Minneapolis 14

Table 3 (Continued)

Mississippi	Dr. W. C. Morse, Director, Mississippi Geological Survey, University of Mississippi, University
Missouri	Dr. Edward L. Clark, State Geologist, Division of Geological Survey and Water Resources, Buehler Building, Rolla
Montana	Dr. J. R. Van Pelt, Director, State Bureau of Mines and Geology, Butte
Nebraska	Dr. G. E. Condra, State Geologist, Conservation and Survey Division, The University of Nebraska, Lincoln 8
Nevada	Mr. Vernon E. Scheid, Director, Nevada Bureau of Mines, University of Nevada, Reno
New Hampshire	Mr. T. R. Meyers, Geologist, New Hampshire State Planning and Development Commission, Mineral Resources Committee, Durham
New Jersey	Mr. Meredith E. Johnson, State Geologist, Bureau of Geology and Topography, Department of Conservation and Economic Development, 520 East State Street, Trenton 7
New Mexico	Dr. Eugene Callaghan, Director, New Mexico Bureau of Mines and Mineral Resources, Socorro
New York	Dr. John G. Groughton, State Geologist, State Geological and Natural History Surveys, State Education Building, University of the State of New York, Albany 1
North Carolina	Dr. Jasper L. Stuckey, State Geologist, Division of Mineral Resources, Department of Conservation and Development, State Office Building, Raleigh
North Dakota	Dr. Wilson M. Laird, State Geologist, North Dakota Geological Survey, University of North Dakota, Grand Forks
Ohio	Mr. John H. Melvin, State Geologist, Division of Geological Survey, Orton Hall, Ohio State University, Columbus 10
Oklahoma	Dr. W. E. Ham, Acting Director, Oklahoma Geological Survey, Norman
Oregon	Mr. F. W. Libbey, Director, State Department of Geology and Mineral Industries, 1069 State Office Building, Portland 5
Pennsylvania	Mr. Ralph W. Stone, Director, Bureau of Topographic and Geologic Survey, Department of Internal Affairs, Harrisburg
Rhode Island	Dr. Alonzo W. Quinn, Chairman, Mineral Resources Committee, Rhode Island Port and Industrial Development Commission, Providence 3
South Carolina	Dr. Laurence L. Smith, State Geologist, Department of Geology, Mineralogy and Geography, University of South Carolina, Columbia 19
South Dakota	Dr. E. P. Rothrock, State Geologist, State Geological Survey, State University, Lock Drawer 351, Vermilion
Tennessee	Mr. W. D. Hardeman, State Geologist, Division of Geology, Department of Conservation, State Office Building, Nashville 3
Texas	Dr. John T. Lonsdale, Director, Bureau of Economic Geology, The University of Texas, University Station, Box B, Austin 12
Utah	Mr. Arthur L. Crawford, Director, Utah Geological and Mineralogical Survey, College of Mines and Mineral Industries, University of Utah, Salt Lake City 2

Table 3 (Continued)

Vermont	Mr. Charles G. Doll, State Geologist, State of Vermont Development Commission, East Hall, University of Vermont, Burlington
Virginia	Mr. William M. McGill, State Geologist, Virginia Geological Survey, Box 1428, University Station, Charlottesville
Washington	Mr. Sheldon L. Glover, Supervisor, Division of Mines and Geology, Department of Conservation and Development, Room 406, Transportation Building, Olympia
West Virginia	Dr. Paul H. Price, State Geologist, West Virginia Geological and Economic Survey, P. O. Box 879, Morgantown
Wisconsin	Mr. George F. Hanson, State Geologist, Geological and Natural History Survey, Science Hall, The University of Wisconsin, Madison 6
Wyoming	Dr. H. D. Thomas, State Geologist, The Geological Survey of Wyoming, University of Wyoming, Laramie

Soil Conservation Service - U.S.D.A.

● THE committee has continued its policy of furnishing the engineer with information regarding the status of county agricultural soil mapping in the United States. The new county soil bulletins and soil maps published since the HRB Bulletin 65 was issued are shown in Table 4. These surveys are all in group 1 according to the classification given in HRB Bulletin 22, except for the reconnaissance survey of Montana, however, it should be pointed out that as a reconnaissance survey it is one of the best that has been made.

Table 4
Soil Surveys Published Since Highway Research Board Bulletin 65 Was Published in 1952

State	County or Area	State	County or Area
Alabama	Limestone Co	Montana	Central Reconn.
California	Coalinga Area	New York	Teoga Co
Indiana	Noble Co.	Virginia	Culpeper Co.
Kentucky	Graves Co.	Virginia	Lee Co.
		Washington	King Co.

The changes in field work in progress, providing those surveys are now scheduled for ultimate publication are shown in Table 5. All surveys now under way are in the process of reclassification to determine whether they will be published and this information will be included in the next committee bulletin.

Because of the reorganization now in progress it is not possible to revise the listings of the correlation staff, regional soil scientists and state scientists at this time. For information of this nature the committee refers the reader to the listings given in Bulletin 65. This listing is in the process of change because the consolidation of the soil survey activities is still in progress. Communications addressed to staff members as listed in Bulletin 65 will reach appropriate persons. A new list of staff members will be issued as soon as firm assignments are feasible.

The following information is a brief summary of the reorganization of the Division of Soil Survey and the Soil Conservation Service of the U. S. D. A.

On November 15, 1952, all soil survey activities of the United States Department of Agriculture were centered in the Soil Conservation Service by transfer of the Division of Soil Survey from the Bureau of Plant Industry, Soils, and Agricultural Engineering. The soil mapping activities and staffs of the former Division of Soil Survey and of the Soil Conservation Service were thus consolidated in the latter organization. These activities include soil mapping, classification, correlation, interpretation, direct laboratory services, map compilation, publication, and basic research in soil genesis, morphology, and geography. Plans are that the program formerly conducted by the Division of Soil Survey in cooperation with many other research and service agencies will be continued and strengthened. Moreover, it is expected that these cooperating agencies may in the future look to the Soil Conservation Service for the classification and mapping of soils. Cooperative generally with the land grant colleges, the Soil Survey of the Department of Agriculture will have as its broad objectives the filling of needs for soil maps and contributing to their interpretation. Major functions will be determining the kinds, important characteristics, distribution, and extent of soils of the country and providing a framework or basis for organizing and extending the results of experience and research in the use and management of soils in agriculture, forestry and engineering. This framework or basis is essential to permit the making of predictions about the behavior of soil types within fields or comparable small tracts. It is planned that emphasis will be given to maintenance of close working relationships with research groups studying the behavior of soils in plant production or engineering and with service groups applying information on soils in land management and construction.

TABLE 5

SOIL SURVEYS IN PROGRESS IN PRESENT FISCAL YEAR (1954) OR FIELD WORK COMPLETED SINCE BULLETIN 65 WAS ISSUED

State	County or Soil Area	Party Chief	Soil Correlator*
Alabama	Marshall County	K. E. Fussell	M. J. Edwards
Arizona	Yuma area[6]		W. G. Harper
California	Eastern Fresno County[1]	G. L. Huntington[s]	R. A. Gardner
	Eastern Stanislaus County[1]	R. J. Arkley[s]	R. A. Gardner
	Glenn County[1]	E. L. Begg[s]	R. A. Gardner
	Tehama County[1]	K. D. Gowans[s]	R. A. Gardner
Connecticut	Hartford County[1]	A. E. Shearin	W. H. Lyford[b]
Florida	Orange County[1]	R. G. Leighty	I. L. Martin
	Sarasota County[1]	R. Wildermuth	I. L. Martin
	Escambia County[1]	J. H. Walker[s]	A. H. Hasty I. L. Martin
Illinois	McHenty County[1]	B. W. Ray[s]	A. J. Cline
	Williamson County[1]	J. B. Fehrenbacher[s]	A. J. Cline
	Johnson County	J. B. Fehrenbacher[s]	A. J. Cline
	Lasalle County	John Alexander[s]	A. J. Cline
Indiana	Allen County	H. P. Ulrich[s]	O. C. Rogers
Iowa	Jefferson County[1]	Geo. M. Schafer	A. J. Cline
	Shelby County[1]	O. D. Friedrich	A. J. Cline
	Humboldt County	R. J. McCracken	A. J. Cline
Kansas	Scandia Unit, Republic County	C. H. Atkinson	W. M. Johnson
Louisiana	Bossier Parish[1]	S. A. Lytle[b]	I. L. Martin
	Terrebonne Parish[1]	S. A. Lytle[b]	I. L. Martin A. H. Hasty
Maine	Penobscot County	K. V. Goodman	W. H. Lyford
Michigan	Arenac County[1]	Wm. H. Colburn[s]	I. J. Nygard
	Ionia County[1]	S. D. Alfred	O. C. Rogers
	Osceola County	L. J. McKenzie	I. J. Nygard
	Sanilac County[1]	H. H. Bailey	O. C. Rogers
Minnesota	Crow Wing County[1]	H. F. Arneman[s]	I. J. Nygard
	Fillmore County	R. H. Farnham	
Mississippi	Bolivar County[2]		
	DeSoto County[1]	E. J. McNutt[s]	I. L. Martin A. H. Hasty
	Humphreys County[1]	J. C. Powell[s]	I. L. Martin A. H. Hasty
	Leflore County[1]	W. E. Keenan[s]	I. L. Martin A. H. Hasty
	Newton County[1]	L. C. Murphree	I. L. Martin A. H. Hasty
	Sunflower County[2]		
	Washington County[1]	G. E. Rogers[s]	I. L. Martin A. H. Hasty
Missouri	Howard County	J. A. Frieze	A. J. Cline
Montana	Yellowstone County[1]	W. C. Bourne[s]	B. H. Williams

Table 5 (continued)

State	County or Soil Area	Party Chief	Soil Correlator
Nebraska	Gage County[1]	T. E. Beesley	B. H. Williams
	Hall County (Part of Wood River Irrigation Project)[1]	D. A. Yost	B. H. Williams
New Hampshire	Rockingham County[4]		W. H. Lyford[b]
New York	Franklin County[1]	F. J. Carlisle[b]	W. H. Lyford[b]
	Lewis County[1]	C. S. Pearson[s]	M. G. Cline[b]
North Carolina	Duplin County[1]	E. F. Goldston[s]	G. H. Robinson
North Dakota	Harvey area	J. E. McClelland	C. A. Mogen
	New Rockford area[1]	J. E. McClelland[b]	C. A. Mogen
Ohio	Ross County[1]	J. H. Petro	O. C. Rogers
	Clinton County	S. Bone[s]	O. C. Rogers
	Paulding County	Francis Baker[s]	O. C. Rogers
	Wood County	Richard Jones[s]	O. C. Rogers
	Ashtabula County	Wm. Myers	O. C. Rogers
Oklahoma	Wagoner County[5]	H. M. Galloway[b]	E. H. Templin
Oregon	Prineville area[1]	Geo. K. Smith	W. J. Leighty
South Dakota	Brookings County[1]	A. J. Klingelhoets[b]	C. A. Mogen
	Hand County (Part of Missouri-Oahe Project)[1]	A. J. Klingelhoets[b]	C. A. Mogen
	Spink County (Part of Missouri-Oahe Project)[1]	F. C. Westin[s]	C. A. Mogen
Tennessee	Blount County[1]	Joe A. Elder[s]	M. J. Edwards G. H. Robinson
	Coffee County[1]	I. B. Epley[s]	M. J. Edwards G. H. Robinson
	Henderson County[1]	R. L. Flowers[s]	M. J. Edwards G. H. Robinson
	Lawrence County[2]		
	Marry County[2]		
	Loudon County	T. R. Love	M. J. Edwards
Texas	Fort Bend County[1]	Gordon McKee[s]	E. H. Templin
Utah	Weber County	Lemoyne Wilson	W. G. Harper
	Davis County[1]	Vern K. Hugie	W. G. Harper
Virginia	Norfolk County[1]	E. F. Henry	W. S. Ligon G. H. Robinson
	Nottoway County[1]	C. S. Coleman	G. H. Robinson
	Fairfax County	H. C. Porter	G. H. Robinson
Washington	Walla Walla County[1]	A. O. Ness	W. J. Leighty
Wisconsin	Dodge County[1]	G. B. Lee[b]	I. J. Nygard
Wyoming	Goshen County[1]	C. J. Fox	E. M. Johnson

[1] Soil Survey assignments for summer of 1952
[2] Soil Survey areas with field work completed since Bulletin 46 was issued
[3] Reconnaissance or Reconnaissance-detailed survey
[4] Temporarily suspended; no personnel assigned
[5] Personnel to be assigned October 1
[6] Discontinued for summer 1952
* See table for address of Soil Correlator
b State and Bureau
s State

Development and Application of Soil Engineering in Michigan

OLAF L. STOKSTAD, Engineer of Special Assignments,
Michigan State Highway Department

● THE history of soil engineering in Michigan dates from the early days of the state highway department. This agency had been in existence since 1905, but it was the new legislation enacted in 1919 which stimulated rapid growth in organization and activities. This legislation included a $50-million bond issue, money from which became available by July 1919 at the rate of $10 million a year. It was the extensive mileage of new construction at this time which produced serious problems in soil engineering.

In 1926, the highway commissioner's report to the governor stated: "So many questions were continually arising for solution for which no solution was had, that late in 1924 it was decided to provide one engineer whose time should be wholly occupied with these new problems. An engineer with the title of 'engineer on special assignments' was therefore appointed for this work." It was under the direction of this new position that soil engineering studies were started.

The first department activity related to soil engineering was the sand and gravel inventory carried on in cooperation with the state geological survey during the summers of 1924 and 1925. The geological survey supplied personnel, office and techniques; the highway department paid the cost.

During the summer of 1925, an extensive pavement-condition survey and soil-classification survey was initiated. Regarding the personnel for this work, the above-mentioned commissioner's report states: "The character of the soil is shown by a survey made by men trained in this work." Note especially that men trained in soil technology were employed. This fact, plus an open administrative mind, served effectively to start the department on a productive engineering study and incidently to accelerate the development of soil engineering as a new discipline in the field of civil engineering.

Another factor which strongly influenced soil engineering technology as it developed in Michigan will be recognized in the following quotation from the department's 1925-26 report: "It was the thought of the department heads that the (construction) work done previously should constitute a great outdoors laboratory which should show much more truly the performance of different designs under various conditions than could any setup of the more or less artificial conditions necessary to an experimental road. This information was all at hand — it only remained to collect and classify it." And so the research in soil engineering became a field project rather than a laboratory project. During the summers of 1925 and 1926, 500 mi. of soil-classification maps and pavement-condition maps were prepared and the laborious job of correlating the data started. By 1928, the rural portion of the 2,000 mi. of portland-cement-concrete pavement in the state had been mapped and subgrade soils classified.

This extensive research program of field mapping served from the beginning to uncover considerable information on the relationship between pavement behavior and the various soil profiles as identified and mapped. This relationship was apparent to field personnel long before results were available from statistical studies carried on in the office.

During this early period of department history, certain instances of spectacular highway structural behavior occurred with sufficient regularity to act as a powerful stimulant to the rapid development of soil-engineering techniques. The need for working out solutions in the correction of peat-swamp embankment failures, in the correction of frost heaves so serious that they had to be lighted by flares at night to warn traffic, and in the correction of conditions which led to the failure of a new bridge structure were a few of the experiences which proved quite disturbing to the young highway organization. The practical application of soil-engineering skills to design and construction problems therefore got underway by the time the research program was a year old.

The first soil-classification survey for design purposes was made in 1926 on the relocation between Cheboygan and Mackinaw City. Information uncovered by this survey resulted in the adoption of a special cross-section designed to intercept seepage and to obtain a pavement grade of adequate height above water table to prevent frost damage. Probably one of the greatest of the dividends which accrued from mapping soils and pavements along 1,600 mi. of roadway was the intensive training and extensive knowledge acquired by the field men. This mapping program formed the best possible training ground for developing wide experience in the use of various soil textures as highway-construction materials. It served to teach the influence of environment on the behavior of these soil textures as construction materials. Finally, it served to point out certain limitations of routine laboratory tests as a source of general design information. From the beginning, therefore, laboratory testing became a supplement to field studies — a means for obtaining quantitative data for some specific design problem or a means for checking field judgment.

The period from 1925 to 1929 was a time during which the techniques of soil engineering were developed to the point where expansion of these specialized services seemed desirable. Expansion consisted mainly of building a field organization by attracting highway engineers sufficiently experienced to recognize the importance of soil as a construction material. These men were assigned to various sections of the state and then given only technical guidance and training from the headquarters office. Under this system, full advantage was taken of individual initiative, with the result that this period marked a rapid development of soil-engineering techniques and in the application of these techniques. These field men were left free to develop their special bents and to specialize in problems most important to their respective sections. Their special studies and reports became subject matter for group discussions and group field-inspection trips with the result that new and successful techniques were quickly given statewide application.

Aside from selecting the best qualified personnel available for the job, certain other developments were necessary to assist the soil surveyors in improving their efficiency and also to assist design engineers in the use of soil-survey reports. The first step in this direction was the development of a legend of soil descriptions which would apply throughout the state. The technique for doing this was borrowed directly from soil science and consisted of devoting a full page of the legend to each soil so that the soil profile could be both illustrated and described. Information of special significance to engineers was added. At first, all the soils in the state had not been identified and described. Therefore, when an occasional new soil profile was encountered during the course of field mapping, it was described, sampled and named. This information was then given to the Soil Science Department, Michigan State College, where ultimately it was correlated and new names assigned. Gradually, through the efforts of soil scientists, the soils of the state have been identified and described until the comprehensive legend as shown in the 1952 edition of the Michigan Field Manual of Soil Engineering was evolved.

A further development which served to stimulate the application of soil engineering techniques to all highway road projects was the tabulation of routine subgrade design recommendations for all the soils recognized in the state. This tabulation greatly increased the efficiency of the soil engineering personnel by permitting the field engineers to concentrate in their reports on items peculiar to each individual project and relieving them of the need to write long and detailed discussions covering all routine items. Likewise, the designer could, with the aid of this tabulation, obtain most of his needed information without waiting for an opportunity to discuss the project with the soil engineer. The final step in this direction was the publication of the Field Manual of Soil Engineering, now in its third edition.

The period of development in soil engineering services included, also, development in methods of operation. The present soil-engineering practice in Michigan will be described under the headings of (1) Selling the Service, (2) Personnel, (3) Organization, (4) Operations, (5) Tools of the Trade, (6) Advantages Accruing from Long Experience.

SELLING THE SERVICE

Salesmanship is a skill not always considered too seriously by the practicing engineer, especially within an organization such as a state highway department. Efforts in this direction by the Michigan soil-engineering section have consisted mainly of working toward building a reputation as a reliable source of technical information made freely available without carrying with it an inference of ignorance on the part of the receiver, without appearing to encroach on the receiver's field of responsibility, without jealous regard for authorship on the part of the giver, and without entertaining a notion that one's importance will be enhanced if he can keep his "trade secrets" to himself.

Soil engineering has been developed as a service function. Soil engineers, therefore, investigate, analyze, report and recommend but leave action to the design engineer, construction engineer, or to any group who has the responsibility of putting recommendations into effect. This program of investigation has encouraged a constant development in the field of soil-engineering methods. Bringing the results of this development to other engineers has been greatly facilitated by taking active part in technical short courses, department meetings, regional and national conferences. In this manner has reputation been built and the effectiveness of the soil-engineering section developed.

PERSONNEL

In building the soil engineering organization, a serious attempt has been made to find men who by natural bent, personality and training would be happy in soil-engineering work and who, for the same reasons, would have a future in the department. At the beginning, men were selected mainly from a group who had established themselves as successful employees of the Construction Division. These men for the most part had been in contact with construction projects long enough to have gained an appreciation of the need for more and better information regarding soils and foundations. Early training on the new job consisted mainly of teaching the art of classifying soil profiles in the field. This training was simplified by making each man responsible only for one of the eight districts into which the state is divided for general highway administrative purposes. The number of soils with which the new man had to become acquainted were, therefore, limited. The process of training consisted mainly of working with him in mapping the first two or three projects. Subsequent projects which he mapped alone were carefully checked and discussed in the field where the soil profile in its natural environment was available for reference in the correction of errors in judgment and in settling differences of opinion.

Soil engineering has developed sufficient reputation as a challenge to the student with the result that it continues to attract young engineers of ability. In recent years, with the scarcity of experienced engineers, an adequate staff has been maintained by recruiting recent graduates as engineering trainees. As these trainees mature and acquire the necessary experience to carry on as district soil engineers, the older hands are graduated out to better positions, generally within but sometimes outside the department. This system has been criticized as being wasteful in that much time is constantly being devoted to the training of new employees. There is compensation for this extra training work in that a less static personnel becomes more attractive to promising young men. The movement of personnel to better positions is also an important factor in maintaining high morale. In addition, since the soil is an important construction material, engineers trained in soil engineering find the experience of value in other divisions of the Department.

Building an effective organization requires that considerable thought be given to a training program. In addition to time spent with individual men in the execution of their regular duties, the program includes bringing the group together for short courses in laboratory techniques, for special lectures covering new developments in soil classification, for conferences where each can discuss his special problems with others in the same field, and finally, for special field tours in the study of related sciences such as pedology, geology, agronomy and for the study of special problems such as erosion control, slope protection, borrow restoration. The success of these educational ventures requires that advantage be taken of the best talent available. For instance, one of the finest experiences of this kind made available to the soil-engineering group in Michigan has been an annual geology tour under the direction of the head of the Department of Geology, Michigan State College. Each tour has covered glacial geology of a small portion of the state, and each year a different section has been covered until the entire state has been studied in this manner. In the meantime, the personnel roster has changed sufficiently to warrant starting the cycle over again.

ORGANIZATION OF FUNCTIONS AND PERSONNEL

The soil engineering services of the department are organized as one of five sections in the Testing and Research Division. Since this is a service division supplying technical information and recommendations to all other divisions, the soil-engineering group is free to work with any other division wherever their special training may be needed. The arrangement encourages an objective approach to problems. It creates an atmosphere in which recommendations can be made without prejudice on the basis of facts uncovered in the course of study.

A schematic chart is shown in Figure 1 to indicate the functional services of the soil section to other divisions of the state highway department.

The headquarters office for the soil-engineering section in Lansing exercises general supervision over field work. The eight district offices are the actual operating centers for most of the soil engineering work. Supervision of these offices from Lansing is limited mainly to technical problems and does not include the planning of daily work. An important function of the headquarters staff is to serve in a consulting capacity regarding the use of soil engineering information in the execution of other highway operations. This work includes the interpretation of soil-survey data and pointing out its significance in design, construction, maintenance and research. The staff in the Lansing office is limited to the chief and one assistant.

While the bulk of the field work is carried on directly out of the district offices, there are some special services supervised from the Lansing headquarters office. For instance, foundation borings for bridge design, information borings for swamp treatment, and check borings for borrow studies involve the use of three hydraulic boring rigs and two continuous flight auger drill rigs. The need for this expensive equipment in one district is not great enough to justify equipping each district office to do its own boring work. This operation is therefore directed from the Lansing office. So also are two inspectors specializing in compaction control who circulate over the state trouble shooting and training other inspectors in the art of making the necessary field tests. The electrical-resistivity-survey party works out of its own special headquarters near the central laboratory at the University of Michigan and travels mainly in response to requests from the various district offices.

The soil-engineering activities in the district offices are carried out by one district soil engineer and one assistant. The assistant, for the most part, is an engineer or engineering geologist in training. Maintaining an assistant in training is important to assure a supply of trained personnel to take the place of older engineers stepping into more responsible positions.

The soil-engineering service includes, in addition to the Lansing office and the district offices, one central laboratory which serves the entire state. These limited laboratory facilities satisfy the needs adequately because soil-engineering practice in Michigan is principally a field operation rather than a laboratory function. The laboratory serves as a source of check information on field judgment and as a means of obtaining quantitative test data for use in the solution of an occasional design problem. The laboratory testing program splits naturally into two functions. First, the routine testing to determine gradation, Atterburg limits, compaction characteristics, etc. These tests were used extensively to obtain design data, but since the addition of clay binder has been greatly limited in the construction of base courses, these tests are now run mainly to obtain general information regarding the nature of the soil sampled or to aid in the interpretation of other test

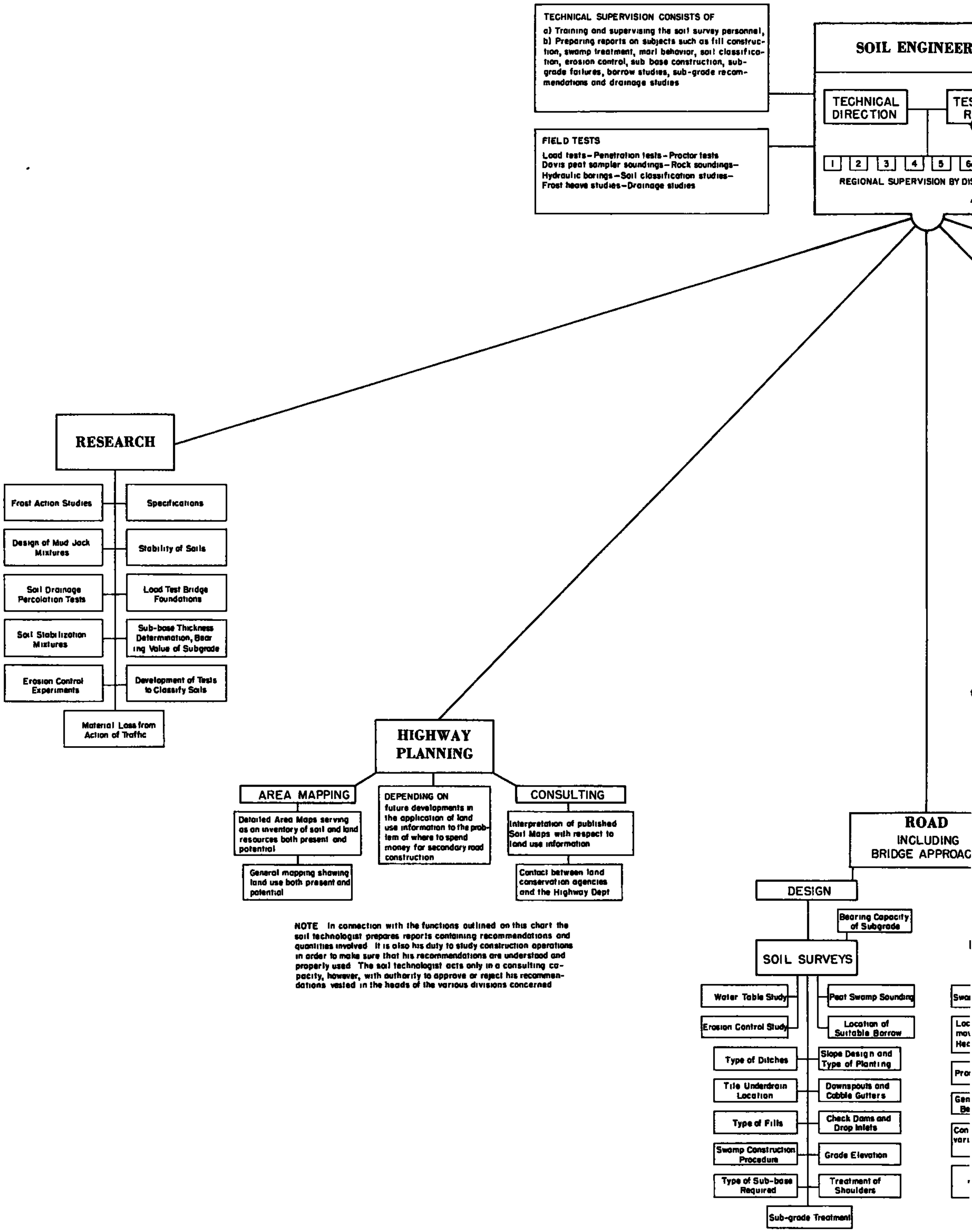
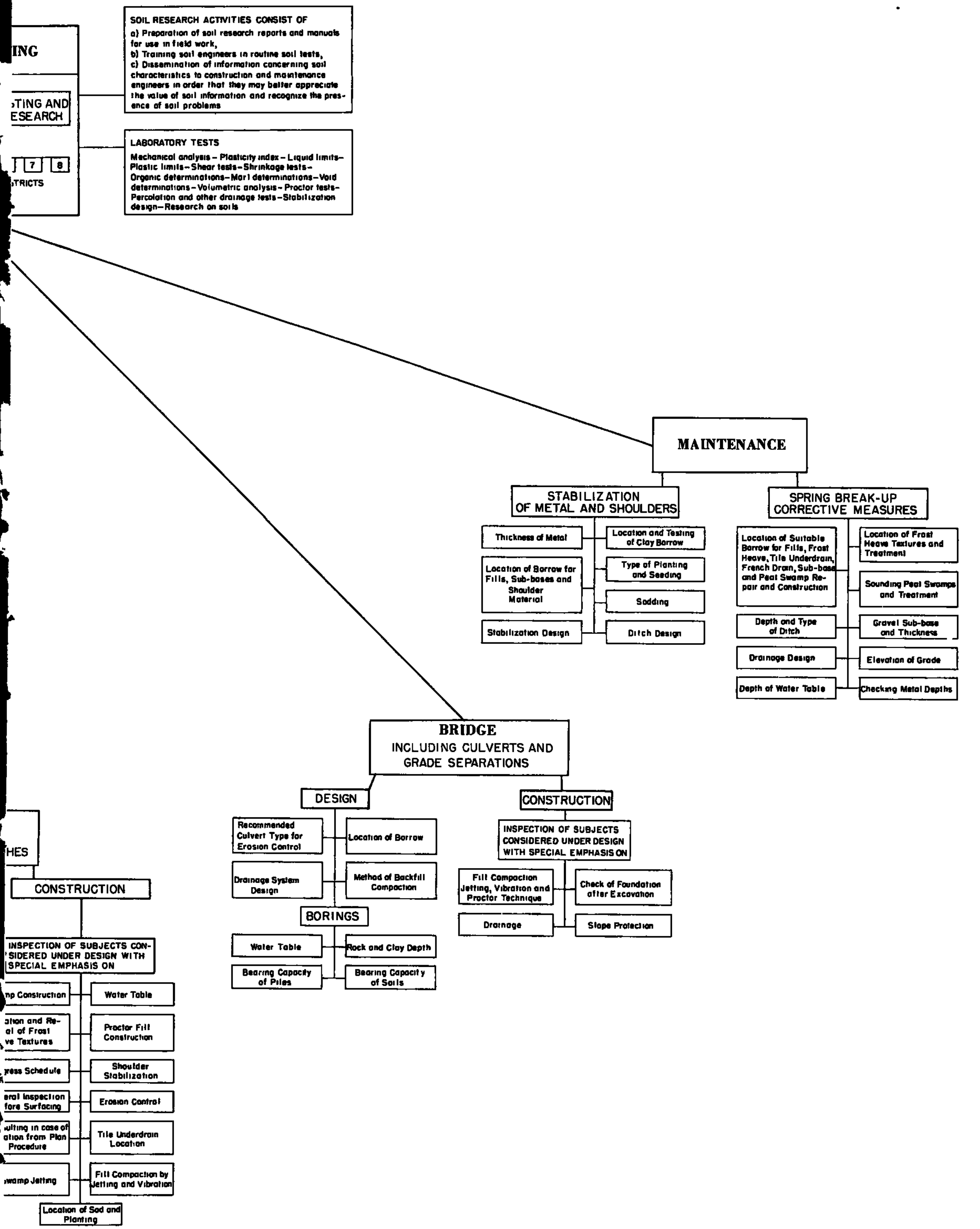


Figure 1. The functions



of soil engineering.

results in the field of soil mechanics. A second laboratory function involves the field of soil mechanics and tests conducted to study the stability of various soil formations. Actually, conducting the tests is the simplest part of this laboratory function. It is the use of test data in the development of definite design recommendations which requires experience and training. For this purpose, a staff member of the Civil Engineering Department, University of Michigan, is retained as a consultant.

Mention has been made of the special services which are administered directly out of the Lansing office. The operation of these various services requires men with a variety of highly developed skills. The operator of a hydraulic boring crew, for instance, must be able to describe soil textures as well as to describe the conditions under which they exist in their natural position. He must be handy with equipment as well as be skilled in handling people. Not only must he be able to get the most out of a pickup crew on a rather disagreeable job, but he must know how to obtain the cooperation of property owners in gaining permission to enter privately owned property to make borings.

The personnel in charge of the electrical-resistivity surveys are trained in geology, pedology, soil engineering and electronics. This survey technique is useless unless it is backed by well-trained and experienced technicians who recognize the limitations of methods used and also who can make accurate interpretations of data obtained.

The employee who is in charge of swamp fill jetting operations must be familiar with the diesel powered pumping equipment. He must also know enough about the effect of water under pressure on the behavior of embankment materials to recognize danger signals and thus protect the men from sudden slides.

OPERATIONS

The foundation upon which all other soil-engineering operations are based in Michigan is the soil-classification survey. The results of this survey is shown on a strip map which is the means by which most of the soil engineering information for each project is transmitted to the Design Division. The soil classification survey serves as a record of subgrade conditions for future reference, it serves as a basis for comparing one project with another, it serves as a means by which soil information may be handed down from one generation of engineers to the next, as a means by which boring and laboratory data (point information) may take on area significance, the means by which both the soil textures and the environments under which they occur are recorded, a means by which future maintenance experience may influence new construction practice.

The technique for making strip-map records of soil information is the result of evolution and includes contributions from many of the other natural sciences. Many of the early specialists in soil classification were trained as geologists which, no doubt, influenced mapping methods. Field mapping for the purpose of classifying the soil of the United States was started by the U.S. Department of Agriculture at the turn of the century. This work has been a continuing operation with the result that there has been a 50-yr. development in classification technique and a large volume of published soil survey reports for areas all over the United States. The techniques developed have become international through the influence of the International Congress of Soil Science and through the wide travels of soil scientists throughout the world.

The highway-engineering profession from the first was quick to recognize the value of the information obtained by soil scientists, but it has been slow to adapt the soil survey techniques for the purpose of recording soil-engineering information. The area concept of soil information has been difficult for engineers to grasp, since their traditional methods for foundation study has been to dig holes and test the materials encountered either at the site or in the laboratory and then to base foundation treatment or design provision on the results of these tests. Recent development in the identification of land forms from aerial photographs has helped greatly to make engineers more area conscious with the result that there is now considerable activity in the development of engineering soil-survey maps from these photographs.

County soil-survey maps and airphotos are excellent aids to soil engineering field work. On the other hand, the scales used in preparing these maps are inadequate for showing the detail necessary for highway design purposes. The soil-survey strip maps, as made in this state, use the same scale as is used in drawing highway plans (1 in. = 100 ft.). This has the advantage of permitting the same degree of detail as the plan portion of the road plans and also of permitting the soil map to be traced directly onto the plan sheets. County soil-survey reports are used mainly as source of general information regarding soils to be encountered and as an aid in sizing up the area to be mapped before actually doing the detailed mapping. Many of the county reports were prepared before an adequate legend was available. The value of these older reports is obtained mainly by reading the descriptions of the soils mapped. The soil names may be incorrect, but the descriptions will serve to suggest the soils to be encountered in making a detailed highway soil survey.

In classifying the soil profile, it is necessary for the soil engineer to study the terrain carefully, to observe the topography, drainage, vegetative cover, surface texture and even land use. He must take advantage of every opportunity to examine the soil profile by studying cut sections, building excavations, tile trenches, and also by the use of soil auger and tile spade. The soil engineer records his findings on the strip map in the form of soil boundaries, soil type names, sounding notes, unusual drainage conditions, and any other information which he thinks may be of interest to the engineer who will be preparing plans for construction. After this field map is finished, the soil engineer may collect samples from some of the main profiles identified for more-accurate information regarding soil properties. Continuous sampling along the centerline is never done. In other words, the soils are classified first, and then such sampling is done as may be necessary to supplement the field survey. One of the functions of the soil survey is to provide the design engineer with information regarding the location and character of construction materials. This involves an inventory of borrow resources in the general neighborhood of the project and also information on which to plan selective grading in order to finish grading operations with the granular soils on top. This is an important consideration in a region of substantial frost penetration, in a region where pavement pumping is a problem, or for a road which must carry heavy truck traffic. In transmitting his soil survey, the engineer writes a brief report in which are highlighted points of special significance to the design or construction engineer.

In the process of making this soil survey, the soil engineer acquires an intimate knowledge of the project under study. He has many opportunities to capitalize on this knowledge of the job as he checks plans in the field before construction and then again later when he works with the construction project engineer in the solution of problems as construction operations progress. Close cooperation between the construction engineer and the soil engineer during the construction phase of the project is an important factor contributing to the quality of the finished product. It is during this stage that the fine points of foundation design are effected. Some of the items involved are the exact stationing of frost-heave excavation, the exact location of special drainage, the detailed control of peat-swamp treatment, the close control of embankment construction, both as to the selection of fill materials and regarding the compaction of these materials.

While surveys and construction occupy the bulk of the district soil engineer's time, there are many odd jobs for the slack periods. Of these, the spring breakup is one of the most important. This involves actually mapping the breakups on a map which also shows the soil classification. Three or four years' record on the same map becomes very valuable as a basis for developing improvement programs, gravel-retirement programs or maintenance-betterment programs. In addition to information on soils and road conditions, the maps are prepared showing the recommendations for correcting the failures. These field records serve as a basis for estimating quantities, preparing proposals, and controlling construction operations.

There are a number of special projects on which soil engineers work with other members of the department in assembling information. An example of these is the gravel-pit survey completed through cooperation with the material section. All the known gravel pits in the state were visited, described, and the information tabulated for distribution to engineers, contractors and material producers.

TOOLS OF THE TRADE

The most-important tool in the soil engineer's kit, the one which will do more than any other in increasing his efficiency, is an adequate soil-classification system. To serve this need properly, the classification system must permit classifying the soil in the field without continuous resort to sampling and testing. The system must be capable of supplying almost all of the necessary design information as soon as the field work is done. Only by this means can a small organization be spread over large construction program.

A second important tool is a soil-engineering manual in which soil-engineering techniques are properly organized and described. This manual contains the descriptions of the soil series recognized in the state. In order that this descriptive legend be useable, it must include a chart in which the soils are arranged in accordance with topographic, textural, drainage, and geologic features which can be recognized in the field. This chart serves the field man as a guide to the soil descriptions which should be studied in connection with any classification problem encountered in the field soil survey.

The hand tools for making soil surveys are simple. One of the most effective is the tile spade. Wherever it can be used, it is superior to a soil auger, because it permits examining the soil with less destruction of the natural soil structure and soil colors. The soil auger's advantage lies in the fact that greater depths can be reached in less time and with less effort. The field man therefore is inclined to use the tile spade as far as he can easily reach and then go on with the soil auger. To do an adequate job of sampling the soil profile, it is necessary to dig a larger hole than can be done with an auger. Small test pits are suggested for this purpose, in order that the horizons of the soil profile may be properly described and so sufficient quantities of each horizon may be collected for testing. In regions containing marsh deposits, the Davis peat sampler is a convenient hand tool for sampling the marsh material at any depth and for determining the depth of unstable materials. It works well in soft clay and peat but cannot be used in sand and gravel. Therefore, marsh deposits containing layers of sand and gravel will require power drill rigs for obtaining an accurate picture of subsurface conditions.

ADVANTAGES WHICH ACCRUE FROM LONG EXPERIENCE

During the 27 yr. since soil mapping for highway use was started in Michigan, most of the highway system has been mapped. Reconstruction along the existing highway routes therefore involves mainly extending soil boundaries, making new maps of alignment relocations, and generally bringing the old maps up to date.

This backlog of maps serves as an excellent source of soil information for any location in the state.

There are other advantages which accrue from long experience. It takes time, for instance, to sell soil engineering to a state-wide industry. This is especially true when that industry includes private enterprise and two or three levels of government. The years of soil-engineering operation in Michigan have permitted the techniques used to become accepted on the county level, the state level, the national level in Michigan, and on the contractor level. This assures maximum use of soil-engineering information as it is submitted for the entire highway-construction program. Even equipment operators on earth-moving jobs associate their own excavating and embankment building experience with soil names such as Miami Loam or Fox Sandy Loam. These names over the years have become a form of shorthand for disseminating a great range of soil-engineering experience throughout the highway industry.

Application of Soil Survey Data to Highway Engineering in Kansas

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● SOIL surveys conducted by the Kansas Highway Department are divided into three types. About 200 mi. of preliminary soil survey are conducted each year in conjunction with preliminary plan surveys on locations that are to be completely regraded. After grading is completed on each project a subgrade survey is made on locations where a flexible surface is planned to determine the final subgrade stability and the base and surface thickness requirements. On one or two projects each year, high embankments are planned across locations where the foundation soils appear to be so weak that a subsurface investigation is deemed advisable to determine safe fill heights and slopes.

As shown in Figure 1, during the preliminary soil surveys test borings extending below all probable excavation limits are made at intervals along the project. The soil layers encountered in each test hole are tentatively classified into their textural grading groups and their plastic index is estimated. The existing soil density is determined at intervals of from ¼ to ½ mi., depending upon the frequency of soil changes and the volume of excavation that will be involved during construction.

Samples representing each soil type on the project are submitted to the laboratory, where plasticity and textural grading tests are conducted for identification purposes. Standard compaction tests are made for use in cut to fill shrinkage computations, and for compaction control during construction, and triaxial-compression tests are conducted to determine stability and surface thickness requirements.

Thus, for a grading project the available soils data includes the type and extent of each soil on the job, its in-place density, its probable final density in the grade, and its supporting value as a subgrade material. Accompanied by a written report this data is forewarded to the road design engineer who applies it during the preparation of grading plans.

One of the primary uses of this data is in the computation of earth-work quantities. When the existing soil density and the required compacted density are known the cut-to-fill shrinkage can be accurately computed, with a reduction in the amount of soil wasted or borrowed during final stages of the grading operations. It has been found that the computed shrinkage based on comparative soil-density values agree quite closely with the actual shrinkage that occurs during construction.

A second important use made of soil-survey data during plan preparation is soil selection. The triaxial-compression test results accurately indicate the stability or bearing power value of each soil when used for subgrade construction. It is therefore comparatively easy to determine whether or not it is economically feasible to bury the weak soils in the bottoms of embankments and place the most stable ones at the top of the road structure where they will effectively reduce base-and surface-thickness requirements. Where the majority of soils have about equal stability, soil selection is not economically feasible, but on locations where highly stable granular materials are available they have been placed on top of the grade during earthwork construction with a resultant saving in surfacing costs due to lower base-thickness requirements.

Likewise, where expansive betonitic clays and weak partly weathered clay shales are found within excavation limits, the plans require that they be topped with more-stable soils through both cut and fill sections. Shoulders and slopes constructed of clean sands are topped with the more fertile A horizon soils to encourage plant growth and reduce erosion losses.

A third application of soil-survey data to road design is in the advance prediction of the approximate thickness of base course and wearing surface that will be required to carry expected traffic loads

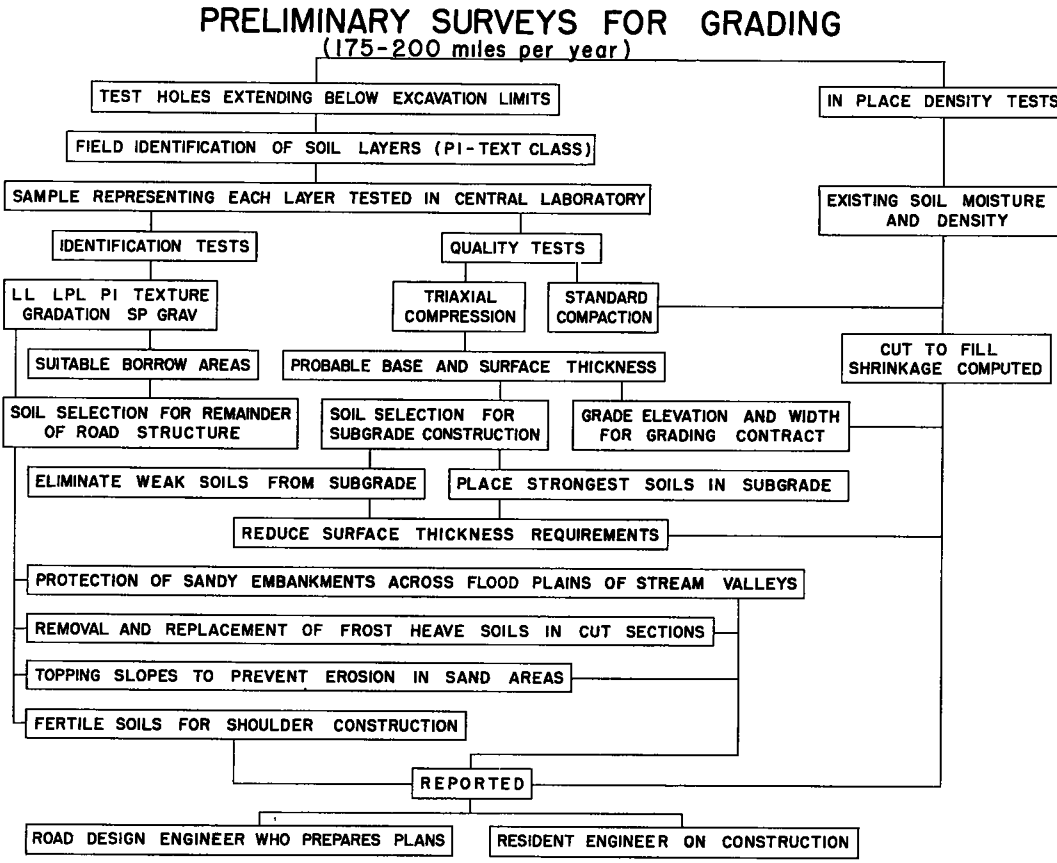

Figure 1.

over the soils that are available for subgrade construction.

Since the surfacing contract is awarded separately from the grading contract, the grading operations are carried only to the bottom of the proposed base course and the earth shoulders are constructed later by the base contractor. It is therefore essential that the road-design engineer know the probable required base thickness, so he can establish the earthwork grade width and elevation at the proper distance below final crown grade for the project.

The soil-survey data and report also designates unfavorable borrow areas or channel-change location where the presence of rock, clean sand, or excessively wet soils will interfere with construction progress.

Occasionally high embankments must be placed on soils of doubtful stability. The general procedure followed during the investigation is shown in Figure 2. At such locations, more-detailed probe borings extending to sand, rock, or shale are made and undisturbed samples are obtained from each foundation soil layer. Values of internal friction and cohesion and the probable amount and rate of settlement are determined for each layer from triaxial shear and consolidation test results. The

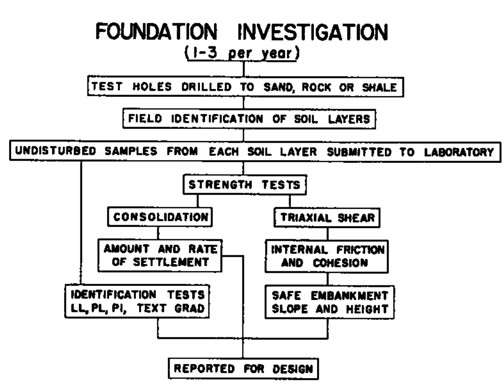

Figure 2.

safe height of fill for various embankment slopes are computed and the embankment is then designed in accordance with these findings.

As shown in Figure 3, during the subgrade survey two or more undisturbed samples of each type of soil are obtained from the upper 12 to 18 in. of the completed grade on roads that are to be improved with a flexible base and wearing surface. From three to five undisturbed samples per mile are sufficient for this type of survey, unless soil changes are very frequent or exceptionally weak soils are present. Triaxial-compression tests are conducted on these samples and the test results are used to evaluate the stability of each subgrade soil and its ability to support expected traffic loads.

During the subgrade survey deposits of aggregate that lie nearest the project are samples and combined in the laboratory with various proportions of portland cement or asphalt to produce a stabilized base material that is relatively unaffected by moisture. Triaxial-compression tests are conducted on these mixtures to measure their stability and the test results along with those obtained from textural tests conducted on the undisturbed subgrade samples are used to compute the final base-thickness requirements for the project.

The results of these tests and computations are reported to the road design engineer who prepares base and surfacing plans. The report specifies the base thickness required for each section of the improvement. Where tests show that weak subgrade soils occur the base thickness is increased and where the subgrade is found to be stable as measured by triaxial tests the base thickness is reduced.

The materials investigation and survey data are used to estimate construction costs and as a guide in writing project specifications. The specifications governing base materials are written to permit the contractor to make best use of roadside or nearby materials deposits, with a resultant saving in construction costs.

During earthwork construction the foregoing soil-survey data is applied to the control of soil compaction and in the proper selection and placement of soils for different portions of the road structure.

Materials data and base-thickness information is used by the engineer in charge of base construction to build a durable base capable of carrying current and predicted traffic loads.

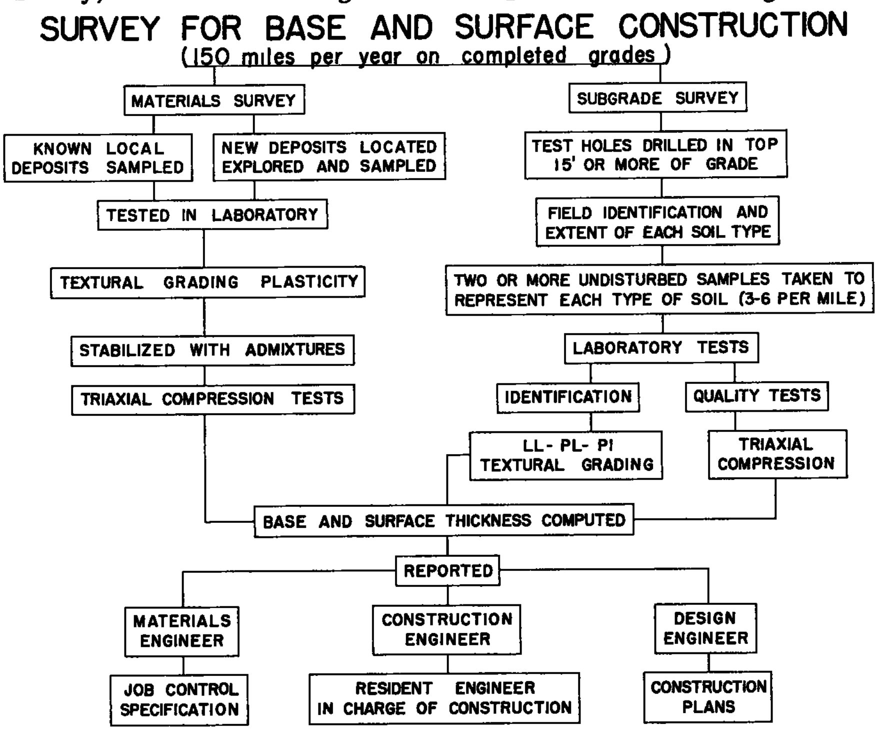

Figure 3.

Use of Soil Survey Data in Design of Highways

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SOIL SURVEY METHODS

● AT the annual meeting of the Highway Research Board in December, 1948, this writer presented a paper entitled "The Use of Agricultural Soil Maps in Making Soil Surveys," which has been published in Bulletin 22. This paper is a sequel to that paper in that it deals with the use made of soil-survey data in the design of highways. Other methods of securing soil-survey data are discussed and the advantages of one method over another given. The use made of soil-survey data will be given in some detail in (1) the design of rigid pavements, (2) the design of flexible pavements for primary and secondary roads, (3) the selection of pavement type, and (4) soil stabilization for base courses.

In the original paper presented in 1948 the pedological system of soil classification was explained in detail and its use as a means of identifying soils in making soil surveys was described. The use made of available agricultural soil maps, which were made using the pedological system of classification, in obtaining soil-survey data was also described. In areas where agricultural soil maps are not available, a method of identifying soils pedologically by the use of a "key" was given.

While data obtained from agricultural soil maps or identifying soils pedologically are valuable, the data are of a general nature at best. Where the data are to be more precise, it is necessary to resort to systematic sampling. In many instances where the exact amount of the soil constituents, sand, silt, and clay is desired, as in mechanical stabilization of subgrade soils, the analysis of individual samples is absolutely necessary. Precise classification of soils demands that samples be taken and tested. In general, soils from the same horizon of the same soil series may, but not always, fall into the same subgrade group; but the value of the group index cannot be determined, except from the results of tests on individual samples. Also, agricultural soil mapping is surficial, the depth of the soil examined being about 3 ft., which is not, in many instances, of sufficient depth to give reliable data. Although placing a soil in its series classification indicates certain similarities as to arrangement and depth of horizons, parent material, etc., the similarities may be too general for the use to be made of the data. For instance, soils derived from granite and granite-gneiss may or may not have sufficient amount of mica in their C horizons to produce detrimental elasticity. Also, certain soil series occurring in the coastal plain may indicate a profile consisting of sand in the A horizon and sand clay in the B horizon, but the C horizon sometimes contains stratifications of pure clay or practically pure sand, or even Piedmont material, if the area is near the Coastal-Plain-Piedmont dividing line. Excellent sand, gravel, sand clay, and sand clay-gravel materials have been found beneath soils of series classifications completely alien to the soils of those series due to the fact that the surface soils had been transported and covered these materials which are of a different geological age.

The above is not given in condemnation of the use of the pedological system of classifying soils in making soil surveys, but, as stated before by the writer in another article (1), the method has its short comings. The pedological system of soil classification is a very valuable tool to use in making soil surveys, but where accuracy demands, the method should be supplemented with additional or supporting data. A proper knowledge of the soil in a soil series will often indicate when it is necessary to obtain additional data.

Soil surveys are made to obtain certain definite information concerning the soils to be encountered within an area. The amount and type of information depend upon the use to be made of the soil. For agricultural purposes information relating to tilling the soil and production of crops is sought, but when the soil is to serve as a structure or part of a structure, the strength and durability of the material is of prime importance. A soil survey made to secure information relating to the behavior of soil as a structural material may be called an engineering soil survey.

Engineering soil surveys may be divided into two classes, surveys to determine the characteristics of the soil as a foundation beneath such structures as bridges, buildings, dams, and those to determine its characteristics for use in the construction of highways and airports. Surveys of the former class require subsurface borings to depths below appreciable influence caused by the weight of the proposed structure in order to locate and sample the various strata of material. Soil surveys of this class will not be discussed in this paper. Soil surveys for the construction of highways and airports, if complete, require much data to give adequate information, and necessitates both surficial and subsurface exploration and sampling. The writer has covered one phase of this class of survey in his paper presented in 1948 and printed in HRB Bulletin 22 and will discuss other phases in this paper as well as the use made of soil-survey data in designing highways.

The greatest one factor affecting the stability and strength of soil is water content. For a given climate the degree of this influence is affected by the constituents of the soil mass (sand, silt, and clay), the amount of the various constituents, their shape and mineral and chemical composition, adsorbed ions, and degree of consolidation. The constituents of a soil and their amounts are determined by mechanical analysis of a sample, while the effect of their shape, mineral and chemical composition, and adsorbed ions is indicated by such tests as the liquid limit, plasticity index, shrinkage factors, and hydrogen-ion concentration (pH). The degree of consolidation is determined by comparing the density of the soil mass as it exists with the density of the soil when compacted in accordance with a standard test procedure such as AASHO Designation T 99-49.

Making a soil survey in accordance with the Standard Methods of Surveying and Sampling Soils for Highway Purposes, AASHO Designation T 86-49 will furnish data that is quite complete as far as type of soil, its location in the profile, existing water content, location of water bearing strata, etc., is concerned, and when placed in the hands of a competent and experienced soils engineer, will pay dividends; however; many of the problems indicated by the survey data may be found to be nonexistent during construction, and quite serious problems may be encountered that were not indicated from the data. The need for elaborate and expensive underground drainage systems may be indicated, but when excavation is completed the condition may be found to have been corrected to a great extent by removal of the surrounding material. The season of the year when construction is done will also have considerable influence on the seriousness and method of solving such problems. The author has found it to be a safer plan to face such problems during construction, when possible, and decide upon their solution at that time when all of the factors causing the condition can be more correctly analyzed.

In North Carolina the location of rock is found from soundings made by a location party organized for that purpose. This data is plotted on the profile sheet as a guide to the contractor in bidding on excavation. Muck beds are also located by a special party, and the data used in the disposal of this material. The use of vertical sand drains to accelerate the settlement of wet soils beneath fills have not been used in this state as yet, but the advantage of their use is recognized, and should the occasion arise, they will probably be used on important work. Their design will require a special soil survey.

It is seldom necessary to make as complete a soil survey as required in method AASHO T 86-49. Much of the data would be repetitious in localities in which previous surveys had been made, or in areas whose soils are known by the soils engineer to belong to certain pedological soil series, the characteristics of which are familiar to him. Such is the case in North Carolina where pedological soil surveys have been made and agricultural soil maps are available for about 90 percent of the counties. Use has been made of these maps in making engineering soil surveys since 1938 at considerable saving in survey cost as well as in time. Where accuracy warrants, the use of these maps is supplemented by additional data obtained from borings and samples taken at sufficient intervals to fulfill the accuracy requirements for the particular work.

SOIL SURVEY DATA USED IN THE DESIGN OF RIGID PAVEMENTS

A rigid pavement, as the name implies, is a slab of material rigid in nature, commonly supported by a foundation composed of soil, which is more or less flexible in nature. The strength of the rigid slab is measured in terms of its resistance to fiber stress, one half of which is used as the design stress, while the subgrade support is measured by a modulus, designated as "k", derived from the bearing value of the soil. (It should be noted that the term, bearing value, is used here instead of bearing capacity. The bearing capacity of a soil is that pressure, greater than which, will produce plastic flow, while its bearing value is that pressure, greater than which, will produce more than a stipulated settlement. The bearing value should, of course, never exceed the bearing capacity.)

The value of k is determined from test data obtained by loading the soil, in the condition of moisture and degree of consolidation under which it is to serve, using a round steel plate, 30 in. in diameter. The pressure producing 0.05-in. settlement is the bearing value of the soil, and the amount of this pressure in pounds per square inch divided by 0.05 gives the value of k.

The value of k, although determinable, is more often selected than determined. It is safe to select the value rather than determine it, provided a reasonable amount of discretion is used. The values recommended by good authority are based on average test data, and a reasonable error one way or the other has little affect upon the calculated thickness of the slab. Table 1 gives values of k used in North Carolina for the various types of soil commonly encountered. The Soils Laboratory of the North Carolina State Highway and Public Works Commission has had occasion to check some of these values for the most common soils occurring in that state by means of load tests.

TABLE 1

Type of Soil	BPR Subgrade Group	Range in Value of "k"
Sandy Soils	A2 - A3	150 - 300
Silt Soils	A4 - A5	50 - 150
Clay Soils	A6 - A7	50 - 100

The values given are based on the assumption that the type of soils exist to sufficient depth to realize the true strength of the material. For instance, a subgrade composed of a layer of sandy soil less than about 4 ft. thick underlain with a clay soil should not be given a k value between 150 and 300 but a value between 50 and 100, the range for clay soils.

About 15 yr. ago a type of failure of rigid pavements began to develop in North Carolina that had never been of much concern to anyone before. Water with subgrade material in suspension was being extruded at the edges and between the joints and cracks of the slabs of concrete pavements by the action of heavy vehicles. This extrusive action was called "pumping" because the action of traffic on the pavement slabs was not unlike that of a pump. As the pumping action progressed, sufficient subgrade material was removed to cause the slabs to break several feet from the joint or crack. These short slabs began to rock and pumping developed at the new crack. It was noticed that this new type of failure was taking place on new pavements as well as those that had been in service for years, so it was realized that the trouble was not in the slab itself but in the subgrade. The soils laboratory was called upon to investigate this new type of failure and develop some treatment of the subgrade, if possible, to prevent its occurrence on future work.

After considerable investigation and study, it was found that pumping of concrete pavement slabs was the result of heavy loads causing the slabs to deflect. When movement took place and free water was lying on the subgrade, the water was ejected with some force, carrying with it some of the fine-grained subgrade material. If free water was not present on the subgrade, movement of the slab took place, but no harm was done as no subgrade material was removed. It was also noticed that concrete pavements having sandy soil subgrades showed no signs of pumping to the extent that the subgrade soil was ejected.

These facts led to the conclusion that pumping of concrete pavements was caused by three factors which had to exist at the same time: (1) axle loads sufficiently large to cause movement or deflection of the concrete slab, (2) water in sufficient quantity to be ejected when the slab deflected, and (3) a subgrade composed of soil sufficiently impervious to permit free water to lie on it. Since these three factors had to exist at the same time, the problem could be solved by the elimination of one of them. Reducing the weight of the axle loads was out of the question, and it was found that preventing the entrance of water or its drainage from the subgrade could not be effected to a satisfactory degree. The only remaining factor to be considered was the subgrade material. It was reasoned that a rather pervious layer of material would act as a blotter and readily absorb the water entering the pavement cracks, joints, and sides and, as a result, the water would not be in a free state to be pumped out carrying fine-grained subgrade soil with it.

Material meeting the above requirements for a blotter course should be granular in texture and fairly well graded. The grading limits of four classes of materials satisfactory for use in this type of work are given in Table 2.

TABLE 2

Grading Limits For Blotter Course Materials For Use Beneath Concrete Pavements

Sieve No.	Total Percent Passing			
	Class A	Class B	Class C	
2"	100	100		
1"	75-90	70-100		
½"	60-75	55-100		
4	40-60	40-80		
10		30-65	100	100
40	15-30	15-45	40-75	40-100
200	5-15	5-25	12-35	12-35

The amount passing the No. 200 sieve shall not be more than two thirds of the amount passing the No. 40 sieve. The Liquid Limit and Plasticity Index of the material passing a No. 40 sieve shall not exceed 25 and 6, respectively, when tested in accordance with the method designated as AASHO T 88-49.

Blotter courses constructed of materials meeting the requirements given in Table 2 are constructed in trench sections, extending a foot wider than the pavement on each side. No provision is made for drainage at the time of construction; however, if saturation of the layer is indicated at a later date, drain tiles are installed at intervals through the shoulders. This is seldom necessary. A compacted layer of 4 in. has been found adequate to prevent the detrimental effects of pumping action.

Should the materials selected for this work be more open graded than the materials given in Table 2, the base is not considered as a blotter course but a drainage medium and the layer is extended through the shoulders. This, of course, requires more material and may or may not be more expensive, depending upon the relative cost of the materials. Also, these more-open-graded materials are generally quite cohesionless and may be quite difficult to haul over by the hauling equipment transporting the concrete materials to the mixer.

Materials for the work discussed above often occur locally; however, it is the general policy to require that they be furnished by the contractor in order to avoid certain difficulties that may be encountered when the state purchases and furnishes such materials. After the award of the contract, the laboratory samples and tests the materials proposed for use before they are purchased by the contractor and placed on the subgrade. Samples are again taken and tested after the materials are placed.

Subgrade soils that do not meet the requirements of the materials given in Table 2 are considered as subgrades conducive to pumping of concrete pavements and are required to be covered with a 4-in. compacted blotter course before placing the concrete pavement. This design for concrete pavements has been followed in North Carolina for the past 10 yr. and, to the best of the writer's knowledge, no "pumping" has developed.

SOIL SURVEY DATA USED IN THE DESIGN OF FLEXIBLE PAVEMENTS

The usual concept of a flexible pavement has been a pavement consisting of aggregates cemented together with bitumen. While such a pavement is still considered a flexible pavement today, the definition has been broadened to include pavements consisting of subbases or bases composed of selected soil materials or soil-aggregate mixtures, which are covered with bituminous wearing surfaces. By making use of the science of soil mechanics, it has been possible to construct flexible pavements at a cost and load-carrying capacity comparable to that of the rigid type.

The mechanics of the design of a flexible pavement is different from that of the rigid type in that the flexible type is assumed to possess no slab strength. The strength of a flexible pavement lies in its ability to withstand the pressures imposed upon its surface and to distribute them to the underlying subgrade in such a manner that their intensity is reduced to less than the bearing capacity of the subgrade soil. Both the rigid and the flexible types of pavement depend upon the strength of the subgrade; however, the nature of a flexible pavement permits utilization of the full strength of the subgrade, in most cases, instead of only a portion of it. Therefore, the bearing capacity of the subgrade may be used in the design of a flexible pavement instead of its bearing value. The bearing capacity of each layer of material in the pavement structure, including that of the wearing surface, can be utilized only if the layer has adequate support.

In order to design a flexible pavement that will support vehicles of a definite type with axle loads of a stated maximum, the design engineer must know the bearing capacity of the subgrade and of each layer in the pavement structure. This requirement involves the determination of the bearing capacity of the subgrade soils to be encountered and the selection and determination of the bearing capacity of the materials used in each layer of the pavement structure. These bearing-capacity determinations of the materials must be made at the condition of moisture and degree of compaction under which they will serve. This information must be furnished by the soil engineer, who must make all of the necessary investigations and perform all of the necessary tests for its procurement. Obtaining this information, although not strictly a soil survey procedure, is nevertheless soil data, and will be discussed in this paper.

Determination of the bearing capacity of a soil requires that some form of a strength test be made and, from the data obtained, arrive at its value. There are several methods of approach to this determination using test data from such tests as shear tests, penetration tests, and load tests, both miniature and full scale. In North Carolina full-scale load tests are conducted in the laboratory on prepared subgrades composed of various soil materials. The soil is placed in a bin 14 ft. long, 3½ ft. wide, and 2½ ft. deep at a moisture content and degree of consolidation found to exist in this type of soil in service, and tested by loading round steel plates, 6⅜, 8, 10, and 13⅛ in. in diameter. The moisture content of the soil and its degree of compaction is obtained from the results of moisture-density surveys, one of which was reported at the Twenty-Eighth Meeting of the Highway Research Board held in December 1948 and published in the proceedings for that year (2). The load test technique follows that developed by Housel and reported by him in 1936 (3). The writer has reported the use of this test in some detail in two other papers (4, 5) and will not discuss it here.

All soils are tested as subgrades whether they are used in subgrades or base courses. The bearing capacity of a material at a certain moisture content, if tested as a subgrade, is the maximum for the material when used in a base course. The thickness of base course, placed on a given subgrade, that will produce this value of bearing capacity is the optimum thickness of base course for this material on this subgrade. For instance, if a base course material has a bearing capacity of 100 psi. when tested as a subgrade, and it is found that 12 in. of it placed on a 20 psi. subgrade will still have a bearing capacity of 100 psi., the optimum thickness for this base course material placed on a 20 psi. subgrade is 12 in. Greater thicknesses placed on a subgrade of this same strength will show no increase in bearing capacity.

SOIL SURVEY DATA USED IN SELECTION OF PAVEMENT TYPE

Usually economics govern in the selection of pavement type and sometimes it is personal preference; however, certain facts revealed by soil-survey data can be used to justify the choice of one type over another. Highly micaceous soils possess detrimental elasticity, which is the worst enemy a flexible pavement can have. Expensive treatments may be necessary to overcome the elasticity of this type of subgrade and, even with such treatments, the results are not always 100-percent satisfactory. A rigid type of pavement for elastic subgrades is the safest design.

Subgrades on embankments that are subject to subsidence due to settlement of the foundation soil beneath them, or subgrades on embankments that could not be compacted by rolling due to high water content in the soil, will cause a rigid pavement to crack and fault excessively due to nonuniform settlement. A flexible pavement will serve much more satisfactorily over subgrades of this type than one of the rigid type.

It is now possible to design a flexible pavement for the heaviest traffic, and if the subgrade is suitable for either the rigid or the flexible type, the cheaper of the two is generally chosen. The availability of local soil materials suitable for the construction of a base course often makes the flexible pavement much the cheaper; also the proximity of stone that may be crushed locally, although more costly than local soil, is cheaper than a rigid pavement. In areas not too far from commercial material plants, the use of their materials often permits the construction of a flexible pavement more economically than a rigid type. The necessity for the use of blotter courses between rigid type pavements and silt-clay subgrades oftentimes places the rigid pavement at a disadvantage from the standpoint of cost; however, improvement in paving machinery and methods for concrete has reduced the cost to the point where the two types are comparable when the pavements must be designed for heavy vehicles.

SOIL SURVEY DATA USED IN STABILIZATION OF SOIL

Soil stabilization, as used in this paper, refers to the method of processing soil to render it suitable as a base course beneath a bituminous pavement. All methods of soil stabilization used in North Carolina have been applied to the construction of flexible pavements on secondary roads or roads carrying relatively light vehicles, those having maximum axle loads of 13,000 lb. The four following methods have been used:

1. Mechanical stabilization, a process in which granular materials have been combined with suitable clay soil subgrades to produce a base course material meeting the requirements.
2. Portland-cement stabilization, a process in which a sufficient amount of portland cement is mixed with the subgrade soil to cause it to harden into a compact mass and not soften in the presence of water or disintegrate from freezing or thawing or wetting and drying.
3. Bituminous stabilization, a process in which bituminous materials are mixed with the soil to waterproof the particles and furnish the necessary cohesion for stability.
4. Vinsol-resin stabilization, a process in which a treated resin, obtained in the extraction of other substances from pine stumps, is mixed with the soil. The resulting mixture, if the soil responds favorably to the treatment, resists wetting by water.

Mechanical stabilization, as has been defined above, has been restricted to clay soils derived from granitic rock. Clays from this type of rock are largely kaolinite and are more or less friable. They are not so difficult to mix with sand and serve as good binders. Before planning to construct a base course on a road using this form of stabilization, it is first necessary to ascertain if the subgrade soils are suitable. This is done by referring to the agricultural soil map for the area, if available, or making a soil survey of the road and identifying the soils pedologically. This determines whether or not this type of work will be satisfactory. If this type of stabilization is decided upon, samples of the subgrade are taken at intervals of 500 ft., after grading is complete, and sent to the laboratory for analysis and determination of a job mix. This type of work requires extreme care on the part of the construction forces, due to the fact that the subgrade soils generally vary considerably in a short distance and often it is necessary to use only a small portion of the subgrade soil when it is a heavy clay. However, an experienced soils inspector can control this type of work to where the number of sections that are necessary to correct by the incorporation of an additional amount of one of the components is reduced to a minimum.

In North Carolina most of the portland-cement stabilization has been confined to the silt-clay type of soils; however, a few projects have been constructed using sandy soil subgrades. There are two reasons for this. In areas where sandy soils predominate, base course or sand-asphalt materials are available, providing a cheaper type of pavement. Also, sandy soils usually contain organic matter which prevents proper hardening of the soil. Although treating these kind of soils with calcium chloride prior to incorporating the portland cement has been reported as an effective operation to prevent the detrimental effects of organic matter, this treatment has not been used in North Carolina.

As early as 1938 it was recognized that some relationship existed between the required amount of cement necessary for stabilization and the soils found in the various horizons of a definite soil series (6, 7). A testing program was inaugurated in which durability tests were made in accordance with AASHO Designations T 135-45 and T 136-45 on samples taken from the different horizons of the most common soil series found in the state. From the results of these tests the amounts of cement required to stabilize the various soils were determined. As a result of this work, the problem of designating the amounts of cement necessary to stabilize the soils on a project is solved by simply identifying the soils as to horizon and soil series and referring to the test data and cement requirement previously made for these soils. Contract estimates are often made, prior to grading, by referring to the agricultural soil map for the area in which a proposed road occurs. If the map is not available the soils are identified by a soils investigator. This procedure has been used quite successfully in the stabilization of over 700 mi. of secondary roads in North Carolina.

Bituminous stabilization in North Carolina may be divided into two classes, the stabilization of sands and the stabilization of sandy soils. Soils having 10 percent and less material passing a No. 200 sieve are considered sands, and those containing more than 10 percent but less than 35 percent passing this sieve are considered as sandy soils. Some attempts have been made to stabilize silt-clay soils with bituminous materials, but the results were not so successful and often uneconomical. Most of this type of stabilization now in this state is confined to sands as they offer less construction difficulties, and it has been found that this type of stabilization is quite successful and economical in certain localities. Samples are taken of the material to be stabilized and brought into the laboratory for tests. From the results of these tests the amount of bituminous material necessary for stabilization is determined. The initial planning of a project of this type is often done by referring to agricultural soil maps of the area, but the amount of the bituminous material required for stabilization is determined from the results of tests made on samples of the materials to be stabilized.

Only one project has been constructed in North Carolina using vinsol resin as the stabilizing agent. This material is quite selective and the results of tests made on the few soils chosen for this type of stabilization did not indicate much promise. It is probable that some of the soils in this state can be satisfactorily stabilized with this agent, but the satisfactory use of other agents, as portland cement and bituminous materials, and the availability of base-course materials in localities where there is any likelihood that vinsol resin can be used, has lessened the necessity for an extensive investigation of this stabilizing agent.

CONCLUSION

In this paper, as in others, the author has stated that the use of the pedological system of soil classification for identifying soils is a valuable tool in making engineering soil surveys for airports and highways but has also emphasized that the method may not give all of the information desired and has pointed out that where precise data are needed, the information must be obtained by other methods. The type of soil data needed for the rational design of pavements, both rigid and flexible, has been described by stating the problems confronting the design engineer. Also, the soil data needed in the selection of the pavement type most suited to the locality as well as that required by four forms of soil stabilization has been discussed. The selection and sampling of base-course materials has been discussed at some length in the first paper, published in Bulletin 22 and referred to at the beginning of this paper, and has not been mentioned.

Engineering soil surveys should be supervised by an experienced soils engineer who should be capable of understanding thoroughly the purpose of every particular survey, in order to secure the information necessary and not waste time and effort securing useless data. He should have a knowledge of soil mechanics and its applications to pavement design, subsurface drainage, subgrades, embankments, and all other phases of highway and airport design that can be benefitted by this science.

REFERENCES

1. Hicks, L. D. Discussion of paper by Earl J. Felt, "Soil Series Names As a Basis For Interpretive Soil Classifications For Engineering Purposes," ASTM Special Technical Bulletin 113, pp. 80.
2. Hicks, L. D. "Observations of Moisture Contents and Densities of Soil Type Bases and Their Subgrades," Proceedings HRB, Vol. 28, pp. 422, 1948.
3. Housel, W. S. "Research in Foundations and Soil Mechanics," Final Report, International Association for Bridge and Structural Engineering, Berlin - Munich, October, 1936.
4. Hicks, L. D. "The Use of Plate Bearing Tests in the Evaluation of Subgrades for Highways," Proceedings of the Second International Conference on Soil Mechanics and Foundation Engineering, Rotterdam, June, 1948, Vol. V, pp. 177.
5. Hicks, L. D. "The Use of Plate Bearing Tests in the Thickness Design of Flexible Pavements," Symposium on Geology As Applied to Highway Engineering, Second Annual, Richmond, Va., Feb. 1951.
6. Hicks, L. D. "Sampling, Soil Classification and Cement Requirement - North Carolina," Proceedings HRB, Vol. 19, pp. 521, 1939.
7. Hicks, L. D. "Soil Cement Design in North Carolina" Proceedings HRB, Vol. 22, pp. 415, 1942.

Airphoto Interpretation of Coastal Plain Areas

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THE engineering soil survey of New Jersey by the Joint Highway Research Project at Rutgers University concentrated its early efforts in areas where the parent material of the soil is either residual or glacial. Recently, attention has been directed to the Atlantic Coastal Plain Province. The techniques of airphoto interpretation and their application in this area are herein described. Emphasis is placed on the differences in importance of the various basic principles of airphoto interpretation in the coastal plain as contrasted with those of residual or glaciated areas. Several map units are described and soil test data for each included.

● IN June of 1947, through a cooperative effort by the New Jersey State Highway Department, the Bureau of Public Roads, and Rutgers University, the Joint Highway Research Project was established to conduct research in various engineering problems associated with highways (1). A major phase of this research program is the preparation of engineering soil maps in which the interpretation of aerial photographs is extensively employed (2, 3). The mapping procedure consists of supplementing the wealth of information gained from airphoto interpretation with numerous field observations, the procuring of soil samples, and the testing of these samples in the laboratory for classification purposes. Progress has been satisfactory and at present accurate engineering soil maps are available for 8 of New Jersey's 21 counties, there being maps of five additional counties in various stages of completion.

Essentially, the parent material of the soil in seven of the completed counties is either residual or glacial. This portion of the Appalachian Province has conspicuous land forms (4) and drainage patterns; with numerous soil profile developments of engineering significance. The area is rather typical of other residual and glaciated areas in the United States: highly developed agriculturally with a good network of highways and roads and with ample reference material concerning its geology and soils. Numerous papers have been presented describing the techniques of airphoto interpretation (5) employed in such areas and these techniques were found readily applicable in the Appalachian Province of New Jersey. After completion of the engineering soil mapping in this portion of the state, attention was directed toward Ocean County (Fig. 1), which is located in the Atlantic Coastal Plain Province.

A generalized approach to the preparation of an engineering soil map in coastal regions has been employed in the past. Rapid preliminary investigation of field conditions and study of associated aerial photographs could give the impression that a regorous study of the area is unnecessary. Upon closer examination, significant differences in the engineering characteristics of the soil become evident. An engineer would welcome a guide enabling him to locate expected troublesome soil areas; thus an engineering soil map would be of practical value. This paper was prepared to indicate the difficulties inherent in the application of the techniques of airphoto interpretation, or soil mapping, to the Coastal Plain Province.

DESCRIPTION OF THE AREA

The work used as a basis for this paper was performed in an area midway along the eastern coastline of New Jersey and extending westward for some distance. Ocean County (6), which comprises the major portion of this area, is located in the northeast corner of the outer portion of the Atlantic Coastal Plain Province. This area, approximately 630 sq. mi., may appropriately be termed a broad, comparatively level to gently undulating plain, rising gradually from sealevel at the east coast to elevations averaging between 100 and 150 ft. further inland.

Geologic references of New Jersey (7, 8, 9) define two major unconsolidated formations of marine origin with practically horizontal bedding (Table 1).

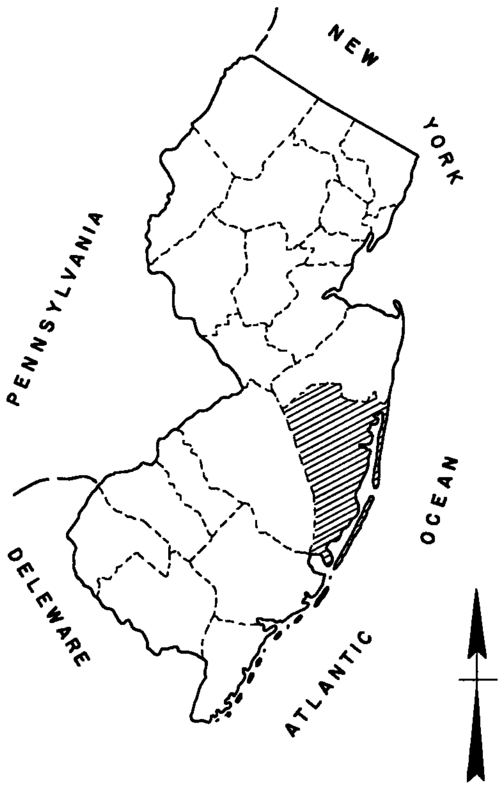

Figure 1. Map of New Jersey. Shaded area is Ocean County.

Overlying both marine formations (Fig. 2) are four additional formations of lesser extent, considered to be either fluvial or fluviomarine in origin.

These latter deposits are usually more granular in texture and occupy the higher positions in the area. The Agricultural Soils Survey of the Chatsworth Area (10) lists two major soil series that are subdivided into many phases, with apparently no direct correlation with any geologic formation (Table 2).

The drainage system serving the area has an interesting nature. Recent earth

TABLE 1

Major Geologic Formations

(Descriptions taken from the Geologic Map of New Jersey)

Kirkwood Sand	- Fine micaceous sands with local beds of dark clay
Cohansey Sand	- Chiefly quartz sand with local beds of clay and gravel
Beacon Hill Gravel	- Quartz gravel, with some chert and sandstone pebbles.
Bridgeton Formation	- Gravel and sand, in part solidified by iron oxide.
Pensauken Formation	- Gravel and sand.
Cape May Formation	- Gravel and sand with some clay.

movements have caused a general "drowning" of the major streams and consequently the water level of the minor estuaries has been raised. Due to the development of this drainage system (Fig. 3), broad tidal marsh areas or swampy conditions can be found adjacent to most of the stream courses.

The native forest, which covers approximately 85 percent of the county, consists primarily of scrubby or stunted oaks and pines. In most poorly drained areas, white cedar predominates. Relatively little agriculture is practiced due to the inherent low fertility of the soils.

If one gains a 20-ft. advantage in elevation above the existing ground surface, a feeling of loneliness and uniformity prevails, for as far as the eye can see there is nothing but a sparsely populated, gently

TABLE 2

Agronomic Soil Series

(Descriptions taken from the Soil Survey of the Chatsworth Area, New Jersey)

Sassafras	Brown or light-brown sandy surface soils, underlain by a reddish-yellow or orange-colored to dull-red, friable loamy sand subsoil. Generally the lower subsoil is coarser-textured than the soil or upper subsoil Usually well drained and easily worked.
Norfolk	Closely associated with the Sassafras Series. Distinguished by their grayish to light-brown sandy loam surface soil and pale-yellow to yellow, friable fine-sand to clayey sand subsoils. Usually good to imperfectly drained.
Scranton	Black sandy loam surface soils, underlain by a pale-yellow sandy clay subsoil, mottled in places with gray. The drainage is imperfect to poor.
Portsmouth	Dark-gray or black loamy surface soils overlying white, gray, or pale-yellow sandy loam to sandy clay subsoils Located in Depressions with the subsoil saturated. Poor to very poor drainage.
Lakewood	White sands overlying orange or orange-yellow sandy subsoils Mostly quartz sand with a low organic matter content Usually excellent to excessively drained.
Leon	White or light-gray sandy surface soils overlying a white fine sandy subsoil The presence of a hardpan-layer in the subsoil is common, with the soil below becoming looser. This series is generally imperfectly drained.
St. Johns	Dark-gray or black sandy surface soils overlying a hardpan-layer which in turn overlies white, gray, or brown sands. Usually occurs in depressed areas with poor drainage.

undulating land surface, covered with forests and practically inaccessible by automobile (Fig. 4).

AIRPHOTO INTERPRETATION

Successful airphoto interpretation, providing an evaluation of the engineering characteristics of soil, can be accomplished when certain basic principles or guides are studied on each set of contact prints. The following are those principles the authors have employed during their experience in the airphoto interpretation of Ocean County, New Jersey, and of other areas in the United States: (1) reference material, (2) land form and specific topographic relationships, (3) drainage patterns, (4) erosional features and gully characteristics, (5) color tone, (6) vegetation, (7) land use, (8) special features, and (9) field and laboratory experience.

Each of the above factors is important, but the factors will vary in relative value from one general physiographic division to another. Due to this variability in importance, each factor will be individually discussed as it applies to Ocean County. By this procedure, it is believed a clearer understanding of airphoto interpretation of coastal plain soils can be obtained.

DISCUSSION OF EACH ITEM

Reference Material

Included are the available geologic map, agronomic soil maps, with bulletins accompanying both maps, and several papers and articles dealing with the general nature of the existing natural deposits. The geologic map presents an overall picture of the type of soil materials present but is much too broad in scope for our use. It overlooks numerous areas, small in extent, that are of considerable importance to a soils engineer. Further, the major geologic formations, as mapped, are texturally variable in both plan and profile, much more so than in glacial or residual areas. The agronomic soil maps are more helpful but lack sufficient detailed accuracy for our particular purpose. The relationship between geologic formations and agricultural soil series is not clearly defined as contrasted to existing relationships in other physiographic provinces (Fig. 5).

Texturally, the soils tend to blend from one classification to another rather than

Figure 2. Granular capping overlying Cohansey sand. Note line of demarkation. Quartz pebbles are evident in the upper layer.

having a sharp delineation. The resultant broad transition zones make the placing of finite soil boundaries rather difficult, but this problem has been partially overcome by adhering to a broader textural grouping in such cases.

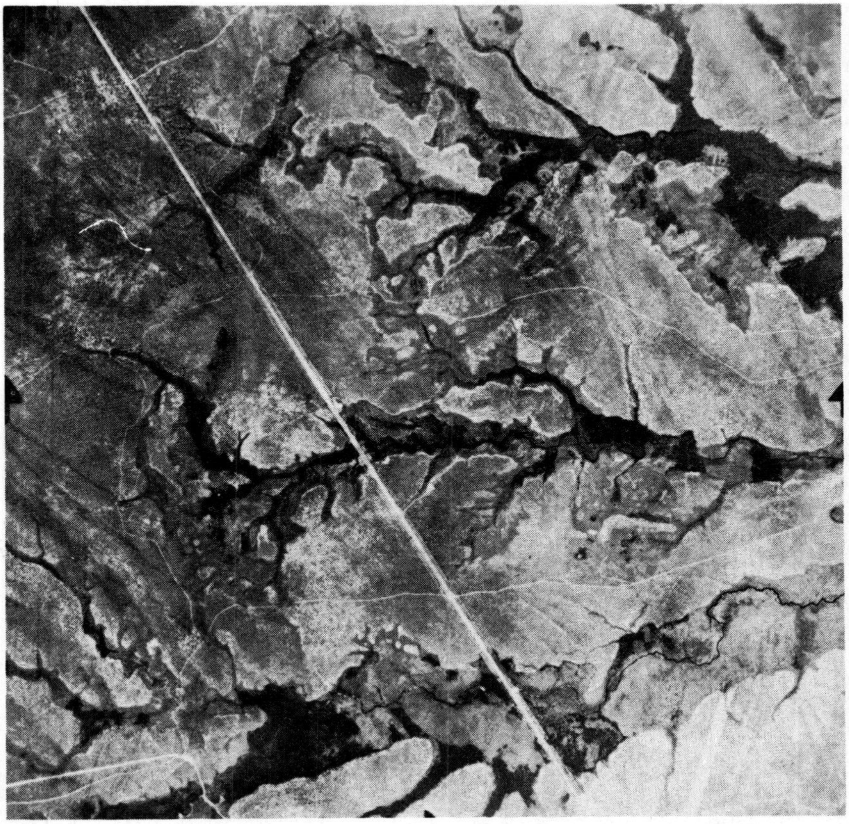

Figure 3. Typical drainage pattern in Ocean County. Wide alluvial channels, numerous tributaries, and poorly-drained areas adjacent to the channels are clearly visible.

Land Form and Specific Topographic Relationships

The major portion of the area is either level or gently undulating with all of the various soil textures partaking of this uniform ground expression. It can safely be stated that definite topographic relationships are absent and land form is of minor value as an aid in interpretation (Fig. 6).

In some areas of limited extent, land form is a determining factor in the mapping. A hummocky or miniature badland effect is prevalent in those soil materials where sand particles are coated with clay (H. R. B. A-2-6 to A-2-7). The "capped" positions, containing appreciable amounts of gravel, and the "outliers" (Fig. 7), which are odd occurrences resulting from a resistant covering of iron-oxide-cemented sand and gravel (Fig. 8), are prominent geomorphic features and thus readily detectable. Broad low-lying silty flats adjacent to the coastal tidal marshes, resulting from fluviomarine activity, are encountered all along the eastern portion of the county and are recognized quite readily on the airphotos.

Land form and specific topographic relationship have proven themselves to be of major importance in the majority of areas where airphoto interpretation has been undertaken. In the coastal plain, they are of minor value.

Drainage Patterns

This is a useful tool but full use could not be enjoyed for several reasons. First, the geologic deposits are relatively young and much of the drainage has not developed sufficiently for detailed study. In addition, a low stream gradient coupled with the proximity of the ocean results in the backing up of runoff and the development of an unnatural pattern of drainage. Much of the internal drainage system is masked or obliterated by a high ground-water table, with resultant large swampy areas. The differential permeability of the various soil materials has no opportunity to be of significance. Both width and depth of the major streams are rather uniform, due to the overall level topography and low elevation of the area. Surface runoff tends to enlarge stream width (Fig. 9), regardless of soil texture, rather than to cut deep channels.

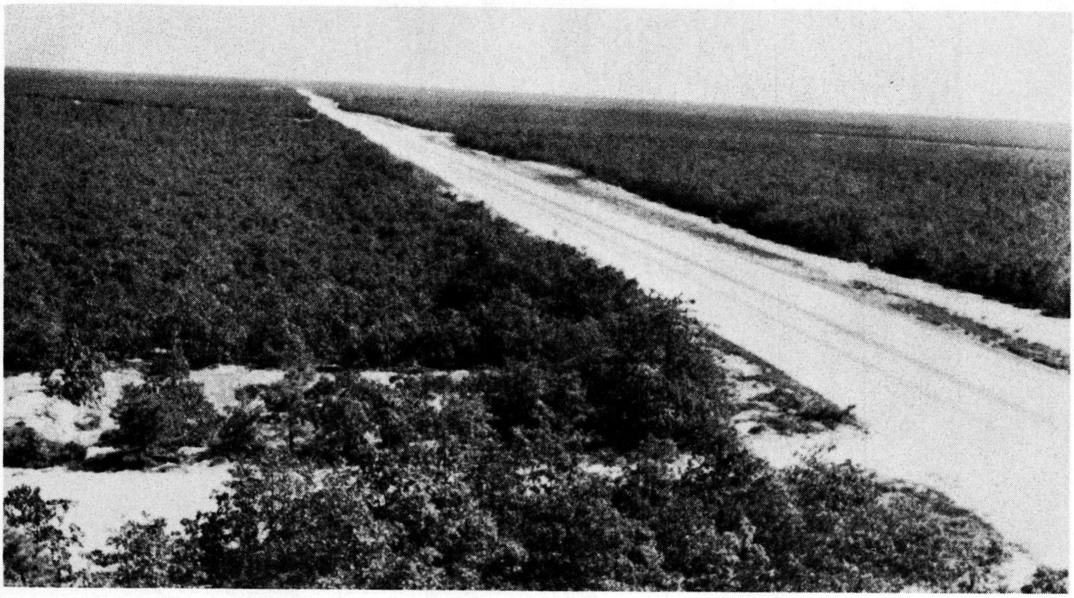

Figure 4. Level land form. View from a fire tower showing pine barrens and lack of ground expression.

In those areas with fair to good drainage potential, the drainage patterns are found to follow the usual occurrence in major soil textures. In the gravel (AASHO Designation: M 145-49 of A-1-a and A-1-b), there is a noticeable lack of surface runoff in definite channels or there are short and stubby tributaries pointing towards the general area of granular materials. In the sand and silty sand, (A-3 and A-2-4), the tributaries are extensive, winding, and smoothly curved with no particular direction in mind. In the siltier soil (A-2-4 to A-4), the dendritic pattern is present. The sand-clay series (A-2-6 to A-2-7), shows a type of amputated drainage pattern (Fig. 10), with short stems of rather uniform direction and length.

This item of consideration, drainage patterns, is especially important when noting the direction of surface flow and the changes in this direction, together with the number of smaller tributaries to any one main artery.

Erosional Features and Gully Characteristics

Due to the overall lack of gradient, the development of these features is negligible and is of minor importance as an aid in interpretation. Certain minor areas do show sufficient development. On granular sandy materials, of raised land form, the V-shaped, short, stubby gullies are quite pronounced (Fig. 11). Along the narrow strip adjacent to the Atlantic Ocean, sand dune development has progressed concurrently with wave and wind action. Unique erosional features, present along forested roads, are wind blowouts. These unforested oval-shaped areas usually occur in sandy (A-3) material.

Color Tone

The pine growth prevalent in the area tends to produce uniform color tones.

Further complications result from the past occurrence of numerous forest fires and a general "hazy" appearance on a number of the photos. Regardless of these obstacles, the item of color tone was of major value in interpretation. Upon comparing separate airphotos, or groups of photos, a preliminary delineation of soils was accomplished. The full value and effective utilization of this guide was attained by stereoscopic study of minute tone differences and alterations of the various shades.

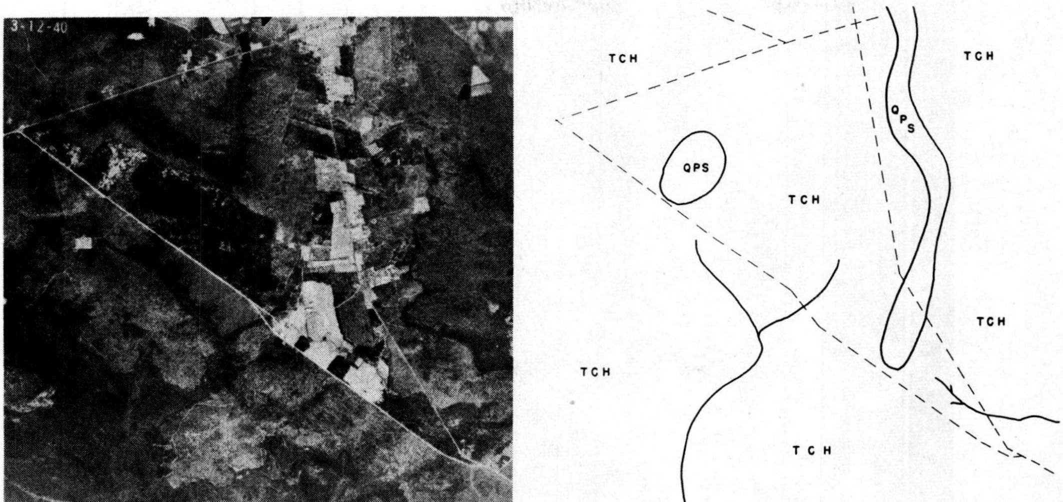

Figure 5. Lack of correlation between geologic and agronomic references. There is partial correlation of the engineering soil map with both references. Upper left shows airphoto of coastal plain area; upper right is a geologic map of the same area; lower left is an agronomic map and lower right is an engineering soil map, also of this same area.

Vegetation

Approximately 85 to 90 percent of the area is uncultivated, with pine and oak forest predominating. The cultivated portions are usually associated with the heavier soil textures (A-2-4 to A-4); but many of the farms are located in poorly drained areas, where an available source of moisture is the prime consideration, rather than because of heavier soil textures. The pine barrens of New Jersey (Fig. 13) cover many acres of Ocean County and consist of a stunted growth of pine trees about 2 to 4 ft. tall. By giving particular attention to the distribution and density of these

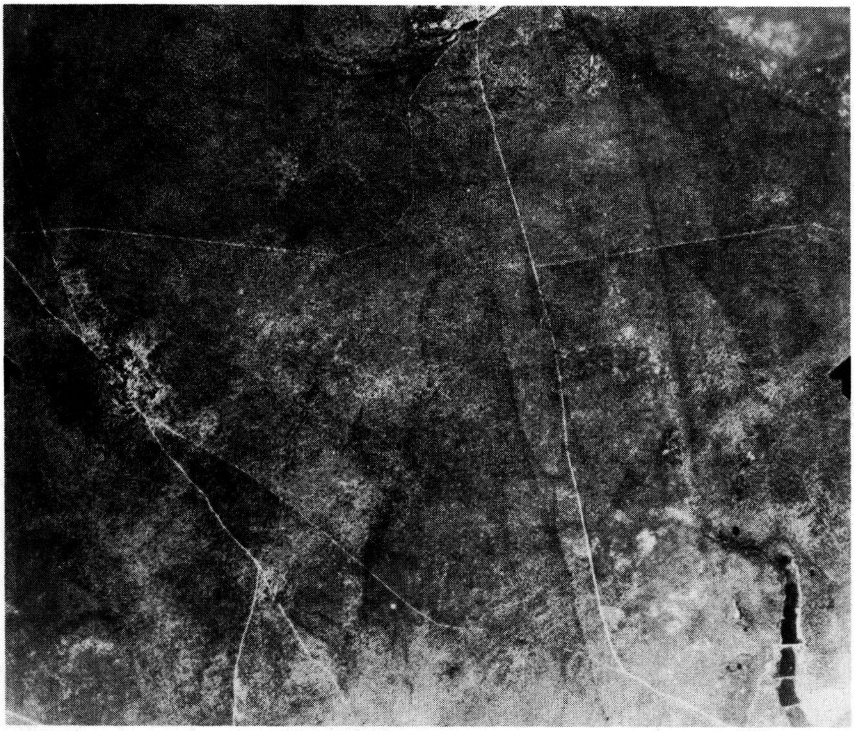

Figure 6. Airphoto stressing absence of land form.

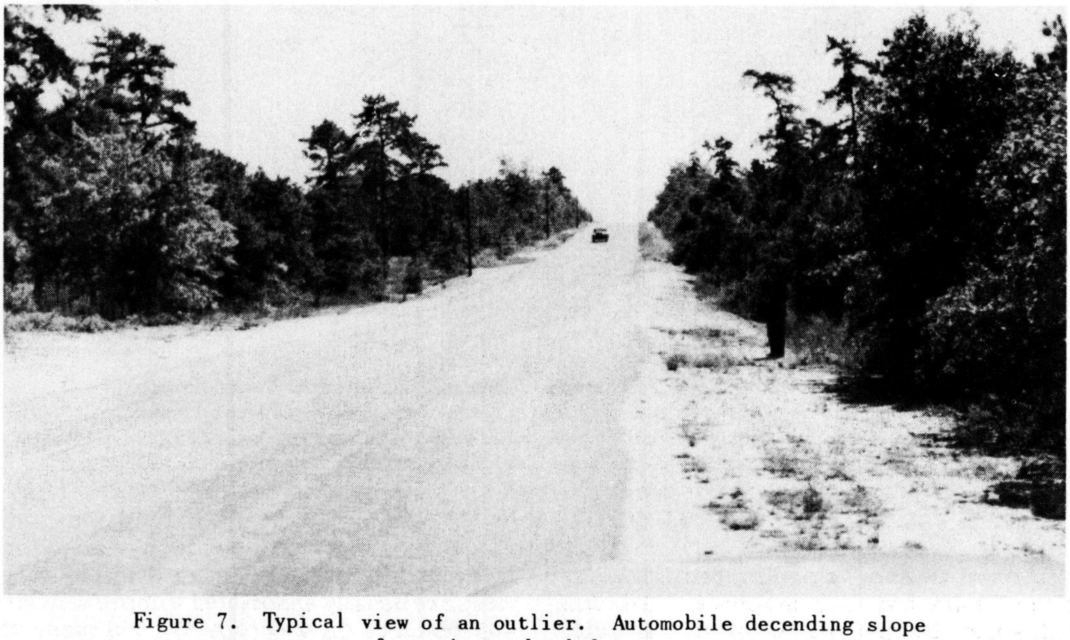

Figure 7. Typical view of an outlier. Automobile decending slope of prominent land feature.

timbered lands, one may obtain a fair idea of soil texture. Interrelated with vegetation is color tone; the one is the direct result of the other. The cedar swamps and poorly drained depressions are always darker due to a thick growth of moisture-loving trees and bushes. Like color tone, the vegetation is helpful, but only when considerable attention is given the minute details.

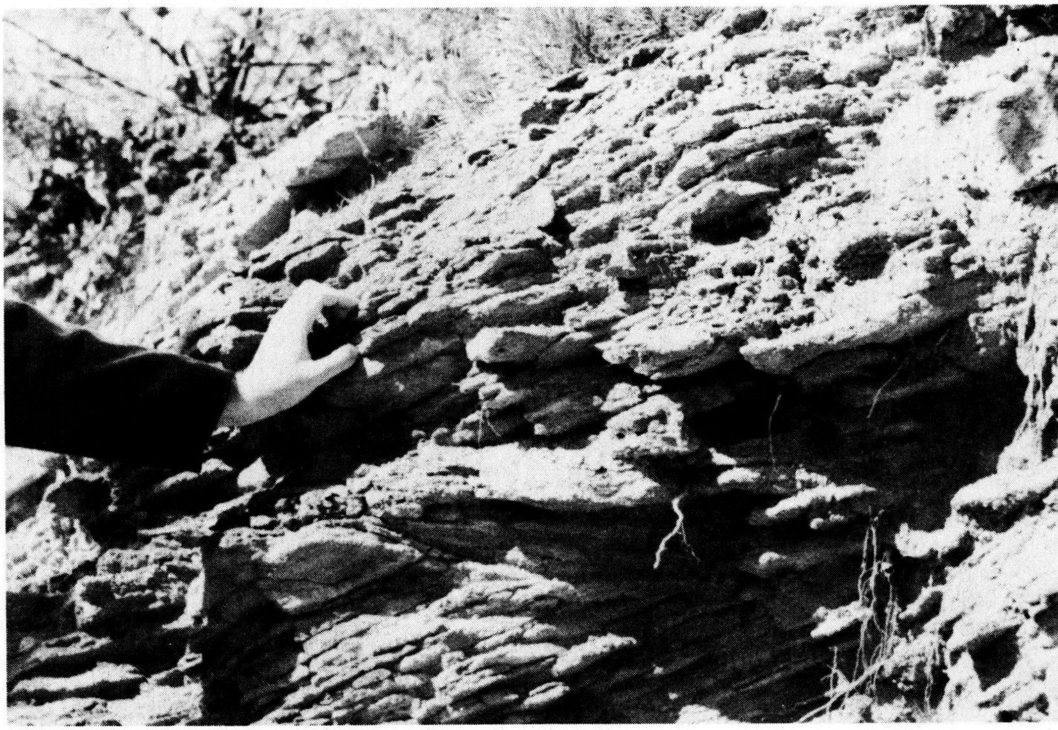

Figure 8. Iron-cemented sand and gravel. Bedded cementation has been encountered at depth in excess of 10 ft.

Figure 9. Narrow stream meandering in a wide alluvial channel.

Land Use

This guide is of little value as an aid in airphoto interpretation because of limited agricultural development. Although small in number, road cuts, gravel, sand, and clay pits give vivid clues as to the nature of the occurring deposits. An interesting item is the orderly layout (square sided and following a geometrical pattern) of the many cranberry and blueberry farms or bogs (Fig. 14), usually situated in a wide alluvial area.

Special Features

There are two prominant features; with one serving as an aid in interpretation and the other adding confusion due to our inability to explain the phenomenon. Those sandy soils (A-2-4 and A-3), that are uniform in grain size do not attain high densities and remain loose and unstable. Many miles of roadway throughout the county consist of the original in-place soil. Where the soil is of this sandy, uniform texture, it ruts easily and many bypasses (Fig. 15) and short alternate routes are continually being made by passing vehicles. This feature is evident on the airphotos, and the identification of the existing soil is readily accomplished.

The unexplainable feature is the occurrence of long lines (Fig. 16) seemingly radiating from a common center. Numerous groups of such lines, at times miles in length, extend over a considerable area with no apparent regard to topography, drainage, or any other natural feature. This strange pattern poses a definite challenge to one interested in further research.

Figure 10. Typical amputated drainage pattern. Clearly defined edges of streams, with stubby appearance of minor tributaries. In upper left-hand corner, noticeable lack of any surface runoff pattern.

Field and Laboratory Experience

Both field and laboratory knowledge concerning the soils of the area are indispensable. During field inspection, the airphotos were constantly referred to, and this association proved itself well worthwhile during subsequent airphoto mapping. The correlation of field experience with laboratory test results of soil samples secured was made all the easier due to our direct association with the material during testing.

TYPICAL ENGINEERING MAP UNITS

The map unit system (13) employed in Ocean County is based on that previously used in engineering soil mapping in New Jersey. A capital letter is first used to designate the origin of the parent material, e.g., "A", referring to alluvial, and "M", referring to marine. This is followed by a second capital letter, when necessary, to describe the general land form: "AM," alluvial mantle, "MB," marine beach; and "M" alone, no significant land form present (level areas). A textural designation follows, usually consisting of one or two numbers, and corresponding to a narrow range in materials in the AASHO Designation: M 145-49 (formerly known as the H.R.B. classification), such as: 12, referring to granular material with textures ranging from classification of A-1 to A-2; or 3, signifying predominantly A-3 material. Finally, there are two lower case letters designating approximate depth to ground-water table: ge, good to excellent drainage, with ground-water table 6 ft. or more in depth; ig, imperfect to good drainage, with ground-water table from 3 to 10 ft. in depth. The following map units are examples of those resulting from the use of this system: AM-12 ge, M-3 ig, and MX-2 ig. These three map units will be described and a summary of laboratory test results (Table 3) of samples taken in each area will follow.

Figure 11. V-shaped gully development in an outlier. Severely dissected outlier parallels a stream. This outlier consists of granular material.

AM-12 ge

Alluvial deposition, composed of non-residual, stratified materials deposited during the Quaternary and Tertiary periods and identified as primarily either the Cape May, Pensauken, or Bridgeton formations.

The material usually appears as reworked remnants of old alluvial mantles of rather complicated origin. It usually occupies the slightly elevated positions or higher river terraces. Assorted, relatively homogeneous, it is composed primarily of quartz gravel and sand with occasional large quantities of weathered chert. The depth to the underlying formation is variable, ranging from a thick, extensive deposit to a thin local capping on some of the smaller hills.

A significant engineering soil profile contrast is lacking and the map unit is generally correlated with certain types of the Sassafras and Lakewood Agronomic Soil Series. Predominantly coarse textures prevail with AASHO designations including A-1-a, A-1-b, and A-2-4.

This material is well drained, due to its slightly elevated position and its granular nature. The ground-water table is usually below 10 ft. and few drainage paths occur in the area.

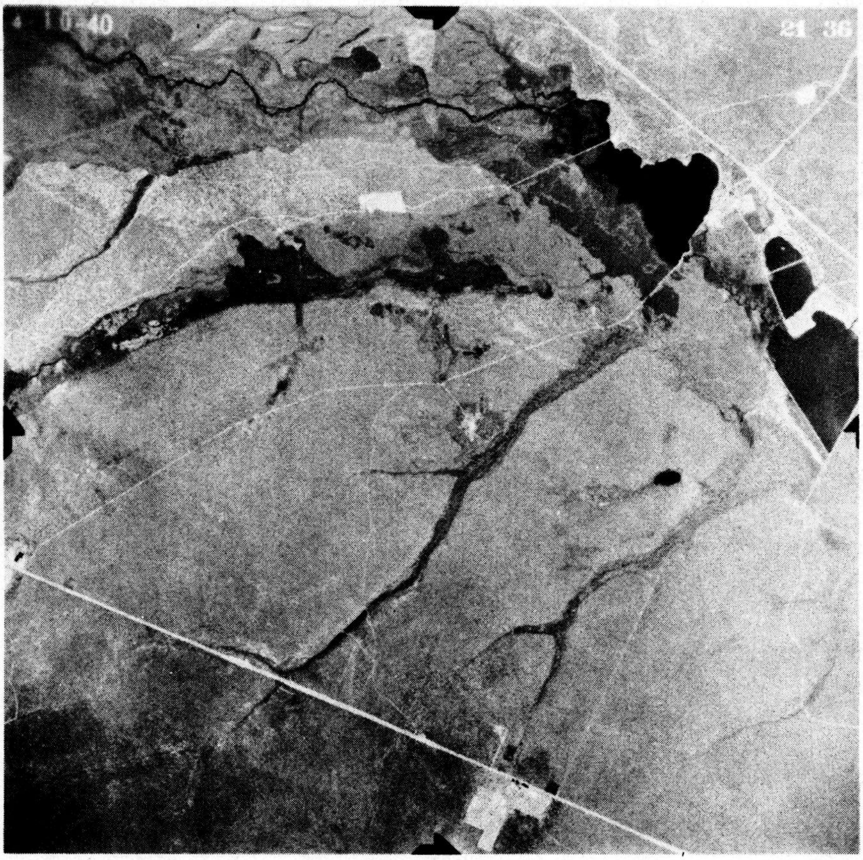

Figure 12. Example of tone contrast. Darker alluvial channel separates silty-sand area in lower portion of photo from a more granular area in upper portion. Cedar growth evident in poorly drained areas.

Highway alignment problems will be at a minimum with cuts and fills usually not exceeding 6 ft. This is an excellent material both for use in embankments and as a source of borrow. Pavement support will be exceptionally good.

M-3 ig

Marine sediments composed of unconsolidated, stratified materials deposited during the Tertiary period and identified as either the Kirkwood sand or Cohansey sand formations.

No prominent land form is associated with this map unit. It is usually found in areas of extremely level to undulating ground surfaces. The material is composed of assorted, homogeneous, quartz sand with the northern section becoming exceedingly micaceous.

Irregularities, such as 1- to 3-in. lenses of clay, seams of gravel, and pockets of clayey sand or clayey gravel, are present but generally they are local in nature.

There is a pronounced pedologic (14) soil profile development associated with this map unit. It is an excellent example of a podsol with as much as 2 ft. of leached topsoil present, correlated with certain types of the Lakewood, Sassafras, Leon, Norfolk, and St. Johns Agronomic Soil Series. This profile development is not of engineering significance for classifications of A-3 predominate throughout the various horizons. The soil is primarily a medium to coarse sand, extremely loose and permeable, with a minimum of fines.

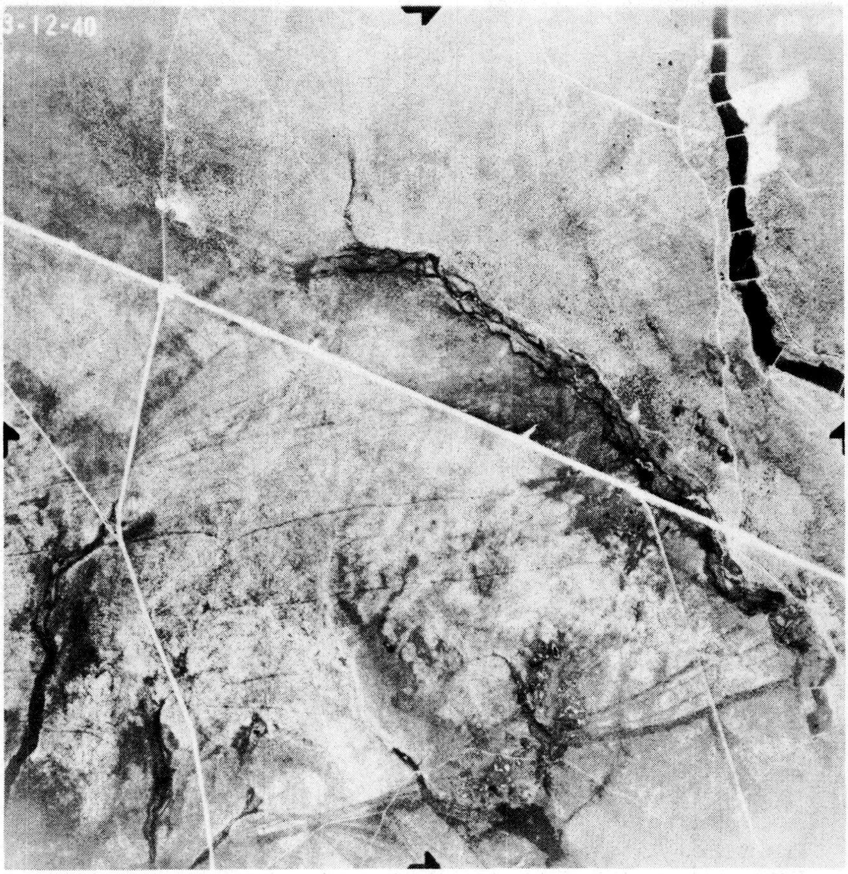

Figure 13. Contact between normal pine growth and stunted pine barrens. Major highway through center of photograph separates these two types of vegetation.

The overall levelness of the ground surface and low sealevel elevations associated with this map unit results in a variable depth to ground-water table. Most often an imperfect to good (ig) designation best describes prevailing conditions. However, at lower elevations of even a few feet, the depth to the ground-water table will noticeably decrease.

There will be no engineering problems associated with alignment, cuts, or fills due to the level nature of the ground surface. However, for use in embankment construction or as a source of borrow material, this soil presents a problem. Due to its uniform grain size, there will be difficulties experienced in compacting this soil; consequently low densities will prevail.

crop and to their variable aerial extent. The material is a sand or gravel but in addition contains varying amounts of clay. Usually there is enough clay content to affect the soil classification, becoming A-2-6 and A-2-7 for some depth.

Soil profile development, while tech-

Figure 14. Cranberry farms. The orderly arrangement of these farms gives very distinct pattern evident in upper portion of photo. This area is poorly drained and system of dikes is in operation to control water supply.

nically present, is mostly obscured by stratification. The typical profile consists of 2 or 3 ft. of intermixed sand and gravel (A-2-4 or A-1-b), overlying either clayey sand or clayey gravel (A-2-6 or A-2-7). This map unit is associated with certain types of the Lakewood, Norfolk, and Sassafras Agronomic Soil Series.

The drainage symbol usually employed in MX-2 areas is "ig," imperfect to good, but due to the variable nature of the land form, all types of drainage are encountered.

Except in the more hummocky areas,

<u>MX-2 ig</u>

Primarily marine deposition, composed of unconsolidated, stratified materials deposited during the Tertiary period and usually correlated with the Cohansey sand formation.

The overall land form appears dissected and hummocky, but large level areas do occur. The letter "X" in the map unit signifies that a variable condition is present in the area. It refers to the erratic manner in which soil textures out-

TABLE 3

Representative Soil-Test Data

Map Unit	Agronomic Name and Slope	Horizon	Depth to Bottom Inches	Sieve Analysis Cumulative Percent Passing ¾	4	10	40	200	Hyd. Anal. Silt %	Hyd. Anal. Clay %	Physical L. L. %	Physical P. I. %	Proctor Max. D. p. c. f.	Proctor Opt. M. C. %	H. R. B. Designation Sub-Grade Group	H. R. B. Designation Group Index
AM-12 ge	Sassafras 0-1°	A	8	98	82	77	50	27	*	*	26	5	*	*	A-2-4	0
		B	34	96	89	71	29	11	*	*	16	3	*	*	A-1-b	0
		C	108	94	80	61	15	6	*	*	16	5	121	10	A-1-b	0
		-	180H	86	30	22	9	1	*	*	NL	NP	119	13	A-1-a	0
AM-12 ge	Sassafras 0°	A	6	*	*	*	*	*	*	*	*	*	*	*	*	*
		B	36	98	71	62	27	8	*	*	NL	NP	*	*	A-1-b	0
		C	72	97	53	44	23	4	*	*	NL	NP	*	*	A-1-a	0
		-	120H	99	62	43	18	1	*	*	NL	NP	*	*	A-1-a	0
M-3 ig	Lakewood 0°	A	16	100	100	96	58	4	*	*	NL	NP	*	*	A-3	0
		B	24	100	100	94	51	5	*	*	NL	NP	114	10	A-3	0
		C	46H	100	97	85	51	4	*	*	NL	NP	117	10	A-3	0
M-3 ig	St. Johns 1°	A_1	3	*	*	*	*	*	*	*	*	*	*	*	*	*
		A_2	25	100	100	100	75	7	*	*	NL	NP	*	*	A-3	0
		B	38	100	100	100	71	4	*	*	NL	NP	109	13	A-3	0
		C	54H	100	100	100	73	7	*	*	NL	NP	112	11	A-3	0
MX-2 ig	Lakewood 2-3°	A	8	100	99	98	83	7	*	*	NL	NP	*	*	A-3	0
		B	34	100	93	77	31	6	*	*	NL	NP	123	11	A-1-b	0
		C	43	100	96	82	43	16	1	16	30	12	126	10	A-2-6	1
		-	45	*	*	*	*	*	*	*	*	*	*	*	*	*
		-	64H	100	100	100	61	22	1	22	30	13	118	14	A-2-6	1
MX-2 ig	Sassafras 0°	A	4	100	99	95	74	47	*	*	40	10	*	*	A-4	1
		B	12	99	86	70	41	18	*	*	18	4	*	*	A-1-b	0
		C	30	99	93	78	49	12	*	*	NL	NP	*	*	A-1-b	0
		-	60H	100	99	97	63	21	*	*	28	12	*	*	A-2-6	1

* Values usually unnecessary.
H Depth to bottom of hole.
NL Non-liquid; sample not susceptible to liquid limit test procedure.
NP Non-plastic; plasticity index zero or cannot be determined.

Figure 15. A bypass and rutting on forest road. This rutted sandy soil in left hand portion of photograph will discourage further traffic. Automobile is leaving newly formed bypass at right.

road alignment can proceed in all directions. The maximum height of cuts and fills is approximately 6 to 8 ft. For use in embankments, as a source of borrow, and as pavement support, it is largely a matter of field inspection by a soils engineer to determine its suitability. In areas containing appreciable amounts of clayey material, caution should be exercised.

Figure 16. Long radial lines. The dark streaks prominent throughout, especially noticeable in upper-right corner. Lines continue irrespective of existing topography and alluvial channels.

This map unit outlines areas in which clayey sand and clayey gravel are most apt to be encountered. This material is very erratic both in depth and aerial extent, and it is difficult to interpret the exact boundaries. This is a generalized map unit and should be treated as such.

CONCLUSION

Application of the previously outlined airphoto interpreting guides in the coastal plain differs sharply from that in a residual or glaciated area. In the coastal plain, emphasis must be placed on tone differences, drainage patterns, and vegetative cover, while in residual and glaciated areas, land form, erosion, and gully characteristics should usually be given first consideration. The stressing of these guides, heretofore considered as of secondary importance, may seem to complicate further the task of interpretation. Nevertheless, by strict adherence to a study of all the guides, it is possible to interpret the soil conditions present and to produce an engineering soil map of considerable detail in a coastal-plain area.

Such a map as that prepared for Ocean County, contains more than a dozen soil classifications, or as designated, "map-units." In an area with this number of significantly different soil units, a highway engineer could make good use of a guide or map delineating the existing soil boundaries. The time, energy, and money expended in the development of such a helpful instrument would be worthwhile.

ACKNOWLEDGMENT

Inasmuch as the writers are utilizing data acquired over a considerable period of time by various personnel of the Joint Highway Research Project, acknowledgment is due to individuals too numerous to mention. Acknowledgment can be made to the Joint Highway Research Project Committee and the College of Engineering for use of their facilities during the development of this paper. The opinions expressed in this paper are those of the authors and do not necessarily represent those held by the Joint Highway Research Project Committee, the New Jersey State Highway Department, Rutgers University, and the Bureau of Public Roads.

REFERENCES

1. Rogers, F. C. "Engineering Soil Survey of New Jersey, Report Number 1", Engineering Research Bulletin Number 15, Rutgers University, 1950.
2. Belcher, D. J., Gregg, L. E., and Woods, K. B. "The Origin, Distribution, and Engineering Characteristics of Soils", Engineering Bulletin, Purdue University, Research Series No. 87, 1943.
3. Jenkins, D. S., Belcher, D. J., Gregg, L. E., Woods, K. B. "The Origin, Distribution, and Airphoto Identification of United States Soils", Technical Report 52, U. S. Department of Commerce, CAA, 1946.
4. Fenneman, N. M. "Physiography of Eastern United States", McGraw-Hill Book Company, Inc., New York, 1938.
5. Belcher, D. J. "The Engineering Significance of Soil Patterns", Proceedings, 23rd Annual Meeting Highway Research Board.
6. Holman, W. W., Jumikis, A. R. "Engineering Soil Survey of New Jersey, Report Number 8", Engineering Research Bulletin Number 22, Rutgers University, 1952.
7. Kümmel, H. B. "The Geology of New Jersey", Bulletin 50, Department of Conservation and Development, State of New Jersey, 1940.
8. Salisbury, R. D., Knapp, G. N. "The Quaternary Formations of Southern New Jersey", Department of Conservation and Development, State of New Jersey, 1916.
9. "Annual Report of the State Geologist", Geological Survey of New Jersey 1898 and 1899.
10. "Soil Survey of the Chatsworth Area, New Jersey", U. S. Department of Agriculture, Washington, D. C., 1923.
11. Lobeck, A. K. "Geomorphology", McGraw-Hill Book Co., Inc., New York, 1939.
12. Parvis, Merle, "Regional Drainage Patterns of Indiana", Engineering Experiment Station, Reprint Number 35, Purdue University, July 1948.
13. Lueder, D. R. "A System for Designating Map-Units on Engineering Soil Maps", Bulletin 28, Highway Research Board, 1950.
14. Joffe, J. S. "Pedology", Rutgers University Press, 1936.

EDWARD A. HENDERSON, Soils Engineer, New Jersey Highway Authority — The authors have presented in the paper a worthwhile contribution to the science of preparing engineering soil maps by airphoto interpretation.

The outer Atlantic Coastal Plain area, in New Jersey is commonly considered locally as being all sand. The authors have shown that significant differences of soil types do exist and complete engineering soil maps of the area will be of use to highway engineers in delineating the different areas.

One specific thing of special interest is contained in Figure 5 of the paper. The geologic map shows areas designated Qps — Pennsauken Formation. It is known that this formation is one of the sources of the so-called South Jersey gravel. To locate the gravel deposits in the flat wooded terrain using the available small-scale geologic maps is next to impossible. Furthermore, the geologic map gives no indication of the thickness of the gravel deposits. In Figure 5 of the paper, the sources of gravel are shown on the engineering soil map by the general map unit AM (Alluvial mantle). These areas are shown in more detail than on the geologic maps, and the finished engineering soil maps will be on a fairly large scale. In areas mapped as AM, a relatively thick gravel deposit can be expected; whereas in areas mapped $\frac{AM}{M}$, only a relatively shallow gravel layer underlain by sand can be expected. The presently known sources of gravel in this area are being rapidly depleted and the engineering soil maps will furnish a tool for use in a systematic method of locating new sources.

As pointed out by the authors, the Joint Highway Research Project at Rutgers University is preparing individual engineering soil maps and reports of each of the 21 counties in New Jersey. The importance of making available these maps is recognized by the cooperating agencies, inasmuch as other research activities have been subordinated until completion of this task. The general techniques used in developing the maps and reports are as described in this paper.

The above-mentioned engineering soil maps and reports have been used to a considerable extent in New Jersey in connection with highway location and design. Borings and soil sampling along highway alignments have shown that the delineation of soil types is remarkably accurate. The following are major ways in which the engineering soil maps have been used:

1. Area Familiarization. A study of the maps and a reconnaissance in the field using the map as a guide at the beginning of a soil survey gives a good concept of soil conditions. This is important in planning all future phases of soil studies and is something that would normally not be achieved until the completion of a survey based only on borings, soil sampling, and testing.

2. Alignment and Profile Selection. The maps furnish sufficient soils information for all preliminary selection with the exception of major stream and swamp crossings. Where several alignments are being considered, the soil or foundation problems of each are evaluated and used in determining final selection. At major stream and swamp crossings borings are necessary to determine depth to adequate bearing strata.

3. Establishing Boring Programs. The maps and reports enable the setting up of a program of borings, sampling and testing concentrated in areas where specific problems exist. The soil surveys are always made to secure certain information such as the presence of rock and ground water, type of subgrade soil, etc. To make borings at definite intervals along an alignment to determine this information is costly and time consuming and unless the interval between borings is small, critical areas may be missed. With the advance knowledge available as to general soil conditions, the soil survey can be made with assurance that the detailed information needed will be obtained at a minimum cost and, more important, that it will be obtained in time for its use in the early stages of highway design.

4. Pavement Design. The present practice of various large organizations is to consider some test value of the subgrade soils as one factor in arriving at a pavement thickness. The time, money, or facilities are not normally available to smaller organizations for the purpose of making a comprehensive study of soil values and applying it to pavement design. However, within given areas, local engineers can determine the design and performance of existing pavements. Having the soil maps of the area, the performance of pavement types and thicknesses can be correlated with soil areas. From this a pavement can be selected based on a consideration of the important element of soil conditions. Those sponsoring the making of engineering soil maps of New Jersey hope for great use of the maps in this manner.

The engineering soil maps and reports published by the Joint Highway Research Project at Rutgers University were recently used by the New Jersey Highway Authority in establishing flexible-pavement thicknesses for the Garden State Parkway, now under construction. This parkway will run in a general north-south direction for the length of the state. In the complex soil areas of Middlesex and Monmouth counties, finished maps were not available, but a strip map was prepared by the Joint Highway Research Project for the use of the New Jersey Highway Authority.

The Garden State Parkway alignment was found to traverse a glaciated area, the inner Atlantic Coastal Plain area (many clay soils) and the outer Atlantic Coastal Plain area (sandy soils). In each of these areas a definite flexible pavement thickness (surface, base and subbase) was established for the entire length of the area. Within an area, variable thicknesses up to 24 in. of selected borrow beneath the subbase were established for clay soil portions. Up to this point, all soil conditions considered for pavement design were based on the Rutgers maps and reports. In critical areas, a limited number of borings were made and the thickness of selected borrow modified in some cases. Some further modifications in thickness and extent of the selected borrow only are anticipated during construction to meet field conditions.

For the pavement design of a toll facility of the magnitude of the Garden State Parkway, where time is of the utmost importance, the use of the available engineering soil maps was of great value. Time was definitely not available to make an extensive soil survey by borings, sampling and testing.

Use of Soil Survey Data by the Small Highway Organization

D. J. OLINGER, Materials Engineer,
Wyoming Highway Department

THE small state or county highway organization is often reluctant to adopt methods being used by highly trained technicians in large highway organizations. Usually benefits can be derived in the small organization simply by changing from negative to positive thinking and "getting started." It is practical to enter into the use of some of these methods with existing personnel and very little initial investment. The purpose of this article is to show that a start can be made by any individual or small organization and that even the relatively inexperienced can make practical application with gratifying results.

Wyoming sent one employee to the "Airphoto Short Course" at Purdue University in Lafayette, Indiana in April of 1948. This course was for the duration of one week, and was designed to provide instruction in the techniques of interpreting soils and engineering problems from aerial photographs. Since that time, much interest has been aroused among the project engineers, due primarily to the time being saved by determining drainage areas on airphotos instead of the conventional traverse method, with costs dropping as much as 80 percent.

Some engineers have observed examples of poor alignment after having purchased airphotos for drainage area determination, and now insist on the purchase of airphotos prior to location, therefore their use is gradually being enlarged to include alignment, selection of stream crossings, location of land ties, determination of drainage areas, location of granular materials, soil survey, etc. Use of airphotos has developed an interest in geology and agricultural soil maps.

Geologic maps, agricultural soil maps, or aerial photographs often point out pertinent data, to the interested (although relatively untrained) state or county highway engineer, that are applicable to location, soil survey, location of construction materials, design, and maintenance. Some of these data are often overlooked during on-the-ground studies, and use of these aids usually results in less field work, more satisfactory results, and reduced costs. Where purchase of maps or photographs is not possible, due either to time or money, it is sometimes possible to secure them on loan from other local state or government agencies.

Interested engineers will improve their techniques with experience and occasional assistance. Mistakes will be made, limitations will be reached, but the overall level of efficiency will continue upward, and the entire organization will gain a feeling of satisfaction from the accomplishments made.

● THE project engineer in Wyoming makes his own materials survey and soil survey on preliminary projects, under the supervision of the construction engineer. Occasionally he asks for aid from the central laboratory, or aid is given him if there are special problems on the location. The central laboratory staff is small, so the time and assistance given to project engineers has been limited.

The laboratory has furnished project engineers a "Soils Manual" which explains briefly most phases including preliminary sampling, preliminary design, construction control, and construction redesign. The laboratory provides available agricultural soil maps, geologic maps, and airphotos for the engineers and gives instruction in their use.

The laboratory often makes a field

review of preliminary design with the project engineer after the soils and material samples have been tested. Frequently this is the first on-the-job contact made between the project engineer and the laboratory, so some adjustments may be required in the tentative preliminary design as set up by the laboratory. Consideration, at this time, of the use of local granular materials often suggests further investigation on the materials survey.

SIXTH ANNUAL FIELD CONFERENCE—1951

THIRD DAY OF CONFERENCE

Friday, August 3, 1951

Separation Flats and South Side Sweetwater Uplift

Driving Distance — 175 miles

Road Log by George R Veronda, Ohio Oil Company, and Carney Soderberg, Carter Oil Company.

The final day's route will proceed through portions of Separation Flats, the northeast part of the Great Divide Basin, and will cross the southern edge of the Sweetwater Uplift, an expanse of granite hills protruding through slightly folded White River beds. Portions of the area are complexly faulted and folded, and the structure of Cretaceous and older rocks is in places completely masked by Tertiary sediments or by broad areas of migrating sand dunes. The rich potentialities, as well as the exploration problems inherent in the area, are illustrated by various producing fields which will be visited.

Road Log

0.0 Sinclair Hotel Proceed west on U S Highway 30

6.6 Fox Theatre Rawlins on left Turn right on U S Highway 287.

7.1 North gate Rawlins Cemetery Cars of participants staying in Rawlins will join caravan at this point Proceed north Route for next 15 miles will be over road covered by previous logs along east flank of Rawlins Uplift, with Permian to Cambrian sediments and pre-Cambrian granite well-exposed on the left side of highway and Triassic to Cretaceous beds visible on right Thin veneer of gravel covers bedrock in immediate vicinity of road for several miles

19.8 Right Forelle limestone across draw overlain by Chugwater and ledge-forming Alcova limestone

20.6 Left Dinwoody and Phosphoria overlying Tensleep

39.8 11 o'clock Lost Soldier field Wertz Dome on bench to right of Lost Soldier Both fields produce from numerous zones from Frontier to Cambrian and form one of the most prolific producing areas in the Rocky Mountain region Refer to Lost Soldier-Wertz photo-mosaic page 104

41.0 Lamont State secondary road leads left to Bairoil camp of Sinclair Oil and Gas Company Continue straight ahead Derricks to right are on Bailey Dome producing from Nugget and Tensleep sands

41.9 Right Sandstone in upper Steele shale

42.2 Road curves right and crosses Steele-Mesaverde contact along dugway Beds dipping north into Camp Creek syncline between Ferris Mountains and east-west trending producing areas

COURTESY OF WYOMING GEOLOGICAL ASSOCIATION

Figure 1. Use of geologic maps. A partial reproduction of a road log from a geological association guidebook. Such road logs are helpful to highway engineers, along with geologic maps, in familiarizing themselves with local formations. More detail can be obtained from the geologic atlas for the area or from publications listed on the state geologic-map index.

Throughout construction, samples of the various pavement substructure components are taken to indicate the variations in each and submitted to the laboratory for testing in order to check preliminary design or make any indicated revisions.

Often the engineer is able to anticipate needed changes, through the tests made by his own field-laboratory personnel, and makes the necessary adjustments in subgrade width and grade, within practicable limits, prior to receiving the construction recommendations from the central laboratory.

AIRPHOTOS

The first airphotos were purchased by the Wyoming Highway Department in 1948 for use in location of granular materials (1). Next the engineers began to use air-

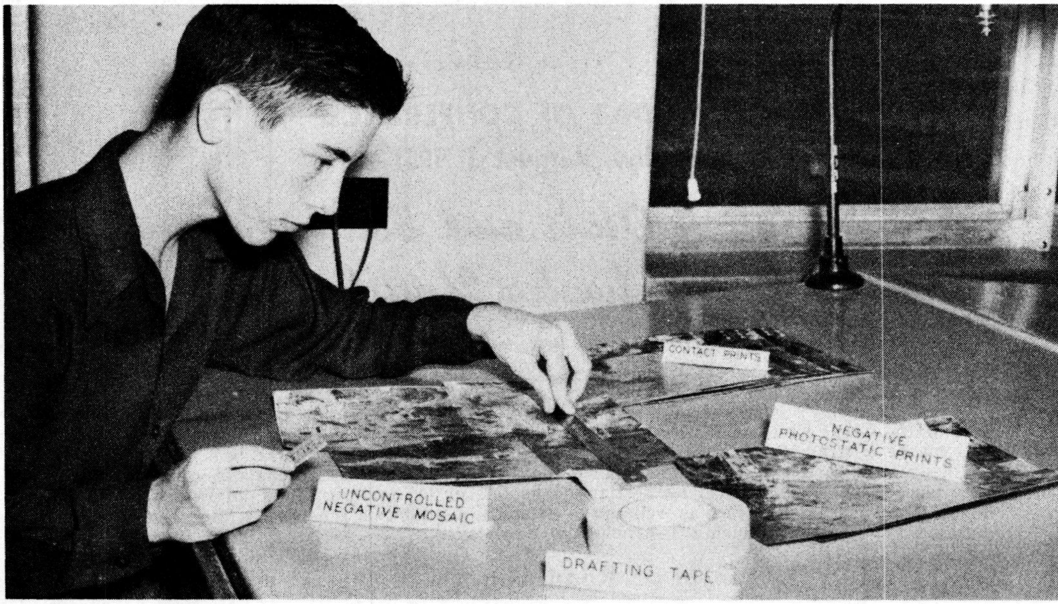

Figure 2. Preparation of an uncontrolled negative mosaic. Negative photostatic copies are made from the original contact prints, trimmed to match lines, and secured on the back with drafting tape. (Original airphotos, courtesy of Production of Marketing Administration).

photos for determination of drainage areas, estimating savings up to 80 percent over the conventional traverse method. Costs of airphoto coverage on most projects have ranged from $10 to $100.

Interest developed among the engineers in the use of airphotos slowly but increased as each engineer became more familiar with them. All project engineers now have pocket stereoscopes, costing approximately $10 each. As they continue to use the airphotos for the solution of one problem, the practical approaches to other problems have become evident.

The prominent surficial features displayed by stereostudy of the airphotos in this state have tended to create an interest in geology and agricultural soil maps.

GEOLOGIC MAPS

Some of the engineers have had limited training in geology, yet this has not eliminated them from gaining some knowledge in that field for their own practical use. Usually an engineer is concerned with only one county, and by using the county geological map, with road logs from one of the annual field geological

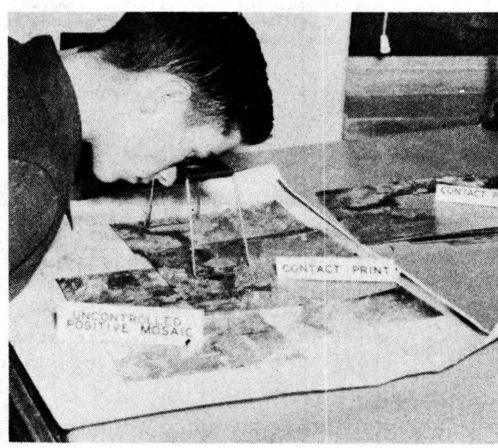

Figure 3. Uncontrolled positive mosaic. This uncontrolled positive mosaic is in the Harrison formation of eastern Niobrara County and was obtained by making a photostatic copy of the negative mosaic shown in Figure 2. Contact prints may be used on such a positive mosaic for stereostudy.

conference publications[1], Figure 1, plus the geologic atlas or folio for the area, he has acquainted himself with many different formations and is able to recognize some of their inherent characteristics as applicable to location, soil survey, design, construction and maintenance in his own area.

[1] The different state geological societies usually compile a guidebook for their annual field conferences, containing maps, airphotos, photomosaics, columnar sections, road logs, etc., of the areas involved. These are available at state libraries or USGS offices.

AGRICULTURAL SOIL MAPS

Agricultural soil maps have been compiled on very few areas in Wyoming, but where the soil maps are available some of the engineers have utilized them on location, soil survey (3), materials survey (1), design, construction, and maintenance.

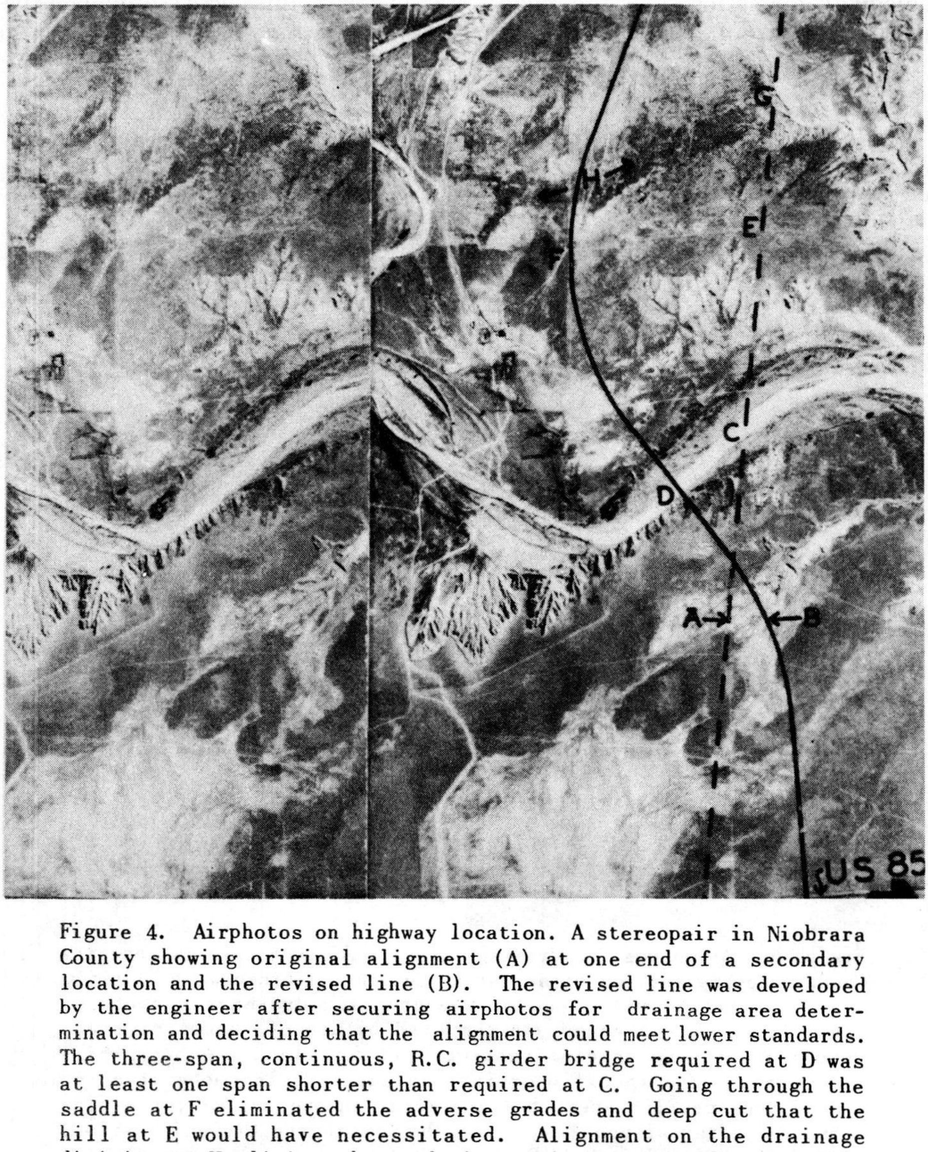

Figure 4. Airphotos on highway location. A stereopair in Niobrara County showing original alignment (A) at one end of a secondary location and the revised line (B). The revised line was developed by the engineer after securing airphotos for drainage area determination and deciding that the alignment could meet lower standards. The three-span, continuous, R.C. girder bridge required at D was at least one span shorter than required at C. Going through the saddle at F eliminated the adverse grades and deep cut that the hill at E would have necessitated. Alignment on the drainage division at H eliminated two drainage pipes required at G. This is in the Brule formation, Upper White River. (Courtesy of Jack Ammann, photogrammetic engineer.)

LOCATION

Airphotos, geologic maps, and agricultural soil maps are being used advantageously on many locations by the highway engineers. In building up their knowledge of conditions and soil types through areal classification of soils by airphoto interpretation (2), or in different members of the geological formations, or the engineering interpretation of agricultural soil maps (3), the engineers are improving their methods of selecting the better terrain on the highway location where more than one route is practicable between any two points.

One method being used, when a controlled airphoto mosaic is not available, is to compile an uncontrolled airphoto mosaic by making negative photostatic copies from the contact prints (Fig. 2); the negative copies are trimmed to match lines and secured on the back with drafting tape; a photostatic copy is then made from the negative mosaic bringing it back to positive (Fig. 3). The original contact prints are used on this uncontrolled positive mosaic for stereostudy in transferring the geology (4), or soils data onto the mosaic.

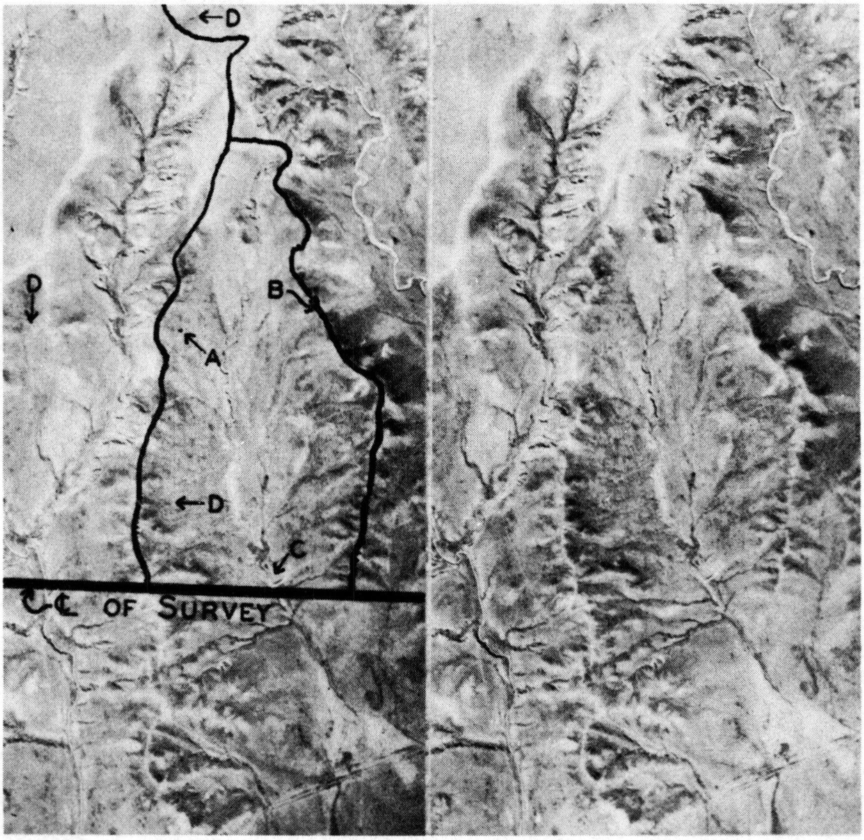

Figure 5. Airphotos for drainage areas. A stereopair in Converse County showing section corner at A; outline of drainage by line B; small dike at C just ahead of the proposed drainage structure; fence lines at D. Areas are computed by use of the planimeter, which requires no special setting, and formula x/a = b/c, where x = acreage of a specific drainage area, a = planimeter reading around the specific area, b = 640 acres in one sq, mi., c = planimeter reading around 1 sq. mi. This is in the Brule formation, Upper White River. (Courtesy U.S. Geological Survey.)

Much of the required reconnaissance can be made on this type of a mosaic, or with only the contact prints if the engineer does not prepare such a mosaic, and the different alignments are plotted as the survey progresses, including land ties, ownership, etc.

Figure 4 is an example of the changes in

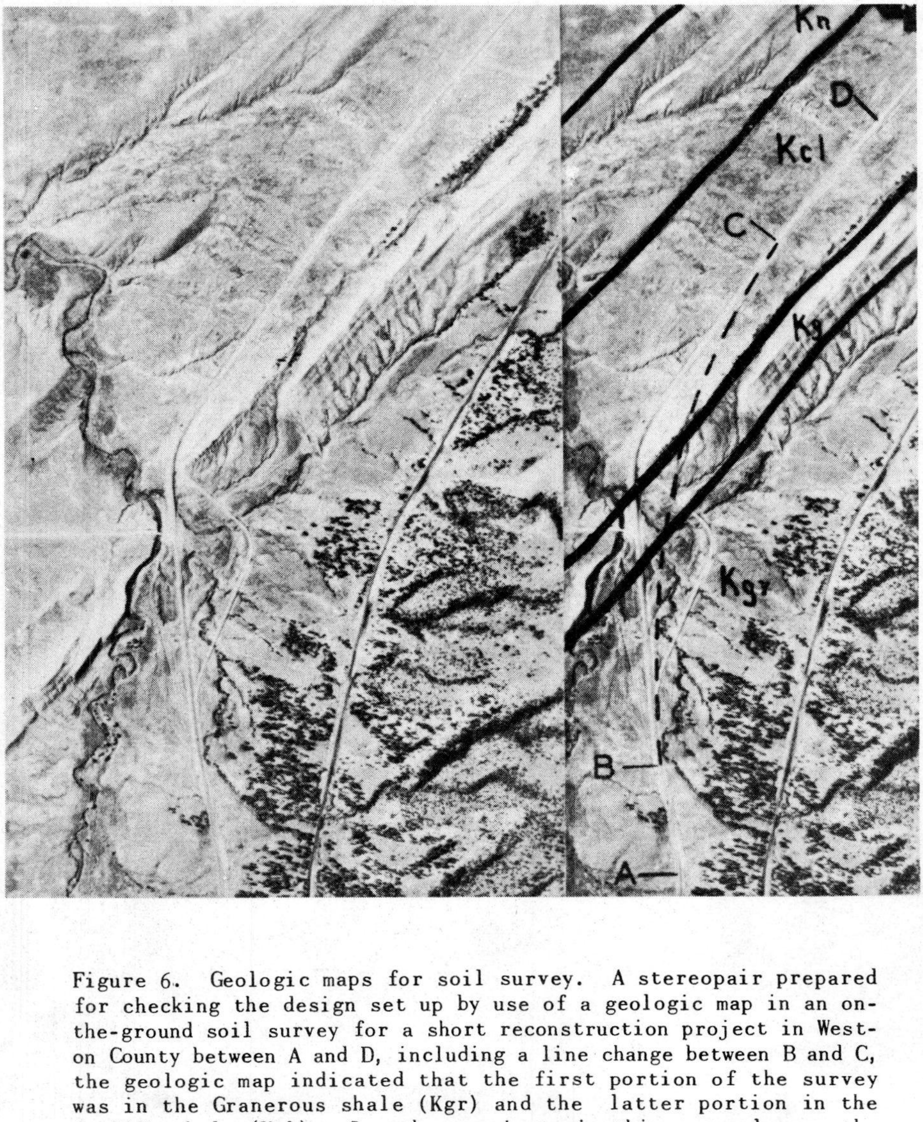

Figure 6. Geologic maps for soil survey. A stereopair prepared for checking the design set up by use of a geologic map in an on-the-ground soil survey for a short reconstruction project in Weston County between A and D, including a line change between B and C, the geologic map indicated that the first portion of the survey was in the Granerous shale (Kgr) and the latter portion in the Carlile shale (Kcl). On other projects in this general area the residual soils from these formations had shown a modified C.B.R. of 3.0 percent or less, which required maximum design thickness based on a design curve selected by equivalent 5,000-lb. wheel loads and job conditions (5). The project was set up for maximum design as any other considerations would have been based on the narrow band of Greenhorn limestone (Kg) dividing these two formations and would depend on construction control, so they will best be worked out during construction. These conclusions were reached by two engineers in approximately ½ hr. on the ground with only the geologic map. (Courtesy of Jack Ammann, photogrammetric engineer.)

alignment made by an engineer near one end of a state secondary project, after the alignment was supposedly completed and airphotos had been purchased for drainage-area determination.

are traced out on either the airphoto contact prints (Fig. 5) or on an enlarged uncontrolled airphoto mosaic that includes all the drainage. Often the larger drainages have been determined from the air-

DRAINAGE AREAS

When the final alignment has been selected, the drainage areas are determined by planimeter after the drainage boundaries

photo-index sheets, county maps that have been prepared from airphoto bases, or topographic maps.

On one 9.25-mi. location, two engineers with airphoto contact prints computed all

Figure 7(b). Ground view of terrace face (foreground) in Figure 7(b) at H. There was no evidence of granular materials at or near the surface.

drainage areas in half a day where it was estimated that the standard practice of running field traverses around the areas would have taken 6 days in the field plus the office time required for reducing the notes.

Figure 7(a). Location of granular materials. Stereopair in the Brule formation and alluvium of southern Converse County where, for reconstruction of the highway (A), through B and C, the gravel deposits immediately adjacent to the river were not desirable due to the more valuable land, and the clean materials requiring the addition and processing of filler and binder from separate sources.

Terrace deposits near the old pit location at D, and a new location at E, were limited in quantity. By extensive ground reconnaissance, the project engineer located a large gravel deposit at F after first observing granular material near the end of the gully, Figure 7(c).

One engineer with some knowledge of airphoto interpretation (but without airphotos) called attention to the terrace at H, over which the country road (I) passed to reach the terrace deposits at E, and although there were no surface indications on the face of the terrace, Figure 7(b), investigation showed a soil profile of 5 ft. of silty overburden, 5 ft. of fine gravel, and 5 ft. of gravel.

An engineer with airphotos, and a little knowledge of their application to materials investigation, would have placed F, G, and H among the first places to investigate, for disappearing gullies usually end in a granular material, and prominent terraces, like that at H, almost always merit investigation. (Courtesy of U.S. Geological Survey.)

SOIL SURVEY

In using geologic maps for soil survey, Figure 6 is an example of how they have been used to reduce, or eliminate, field sampling and laboratory testing. This stereopair, including the geologic contacts (4) was prepared later for checking the field work.

Geologic maps have proved more useful on soil surveys when used in conjunction with airphotos (2). Although they have been used together satisfactorily on projects up to 20 mi. long (6), their use has been

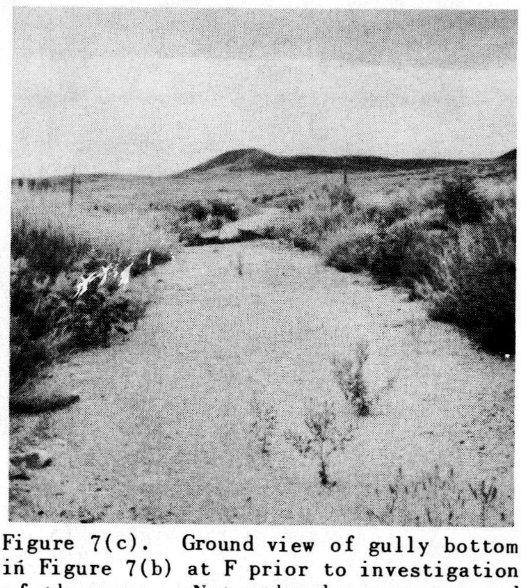

Figure 7(c). Ground view of gully bottom in Figure 7(b) at F prior to investigation of the area. Note the dense grass and brush adjacent to the gully.

limited to selected areas and formations in the state, which are being enlarged as experience is gained. There are many areas, where more detail is needed, wherein such methods for soil survey appear to be impractical.

LOCATION OF GRANULAR MATERIALS

The first location of granular materials through the use of agricultural soil maps and airphotos by the state highway department was initiated in the spring of 1948.

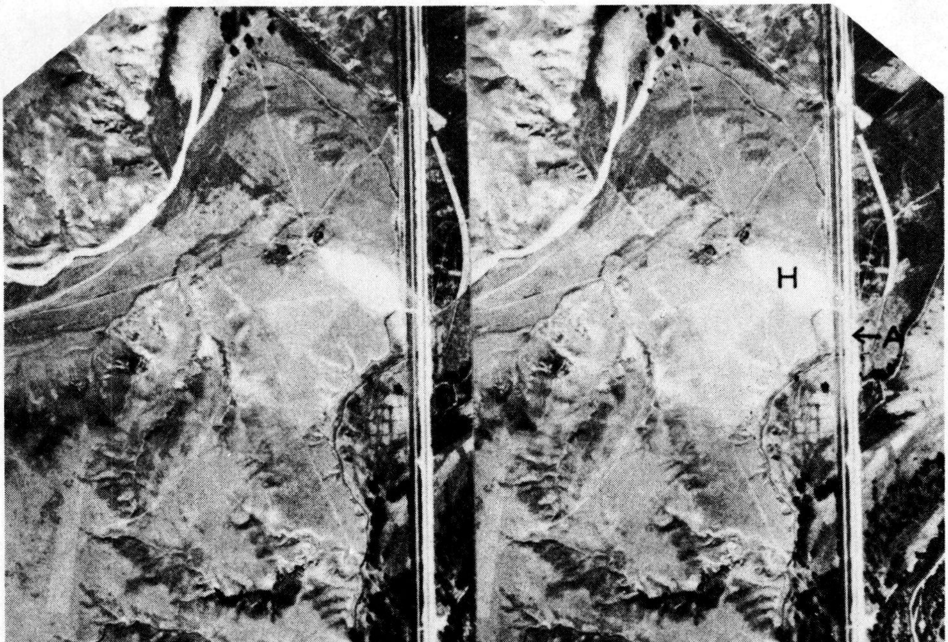

Figure 8(a). Same as Figure 7(a) but showing the area after the pits located at F and H had been used for subbase on the reconstruction of the highway (A). Figures 8(b) and 8(c) are ground views of pits at F and H respectively. A new terrace pit was developed at X with sufficient quantity of gravel for the crushed base. (Courtesy of Production and Marketing Administration.)

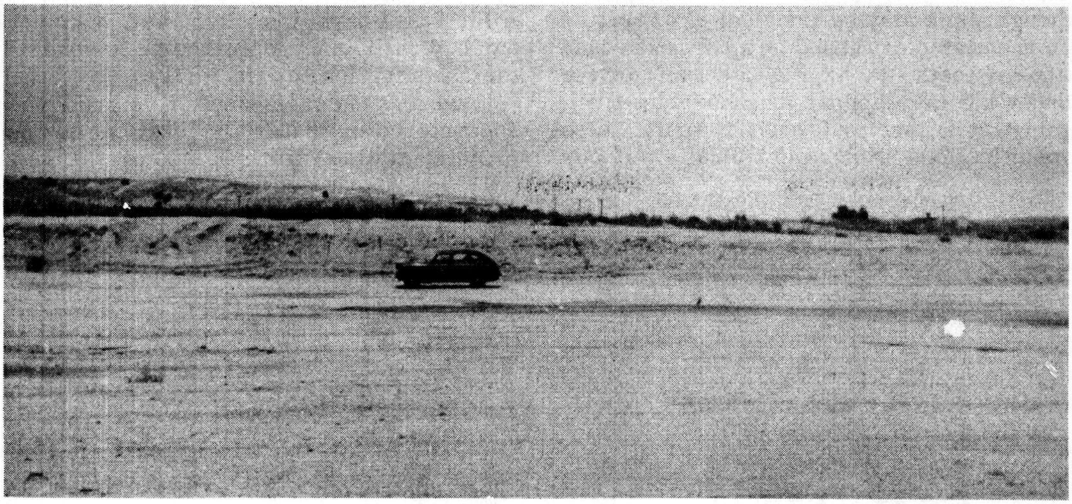

Figure 8(b). Ground view of pit that was developed at F in Figure 8(a).

The first 2 hr. in the field with the airphotos located a 25,000-ton deposit of quality gravel in the middle third of a 20-mi. project where previous investigation had only located deposits near each end of the project (1).

In the past 5 yr. many satisfactory granular materials have been located and used in areas that had previously been accepted as being without any such deposits. Airphotos are not always needed in these investigations, for once an engineer changes from negative to positive thinking and gets started, materials have been found adjoining or closely adjacent to the project. However, if it becomes necessary to investigate large areas the airphotos have proven to be invaluable in selecting the most-promising areas to investigate (7), as well as the necessary reconnaissance routes through the areas.

The technique used has been to make a hurried reconnaissance by car through the area to examine existing pits, contact the land owners, and attempt to locate materials. It is imperative that all known

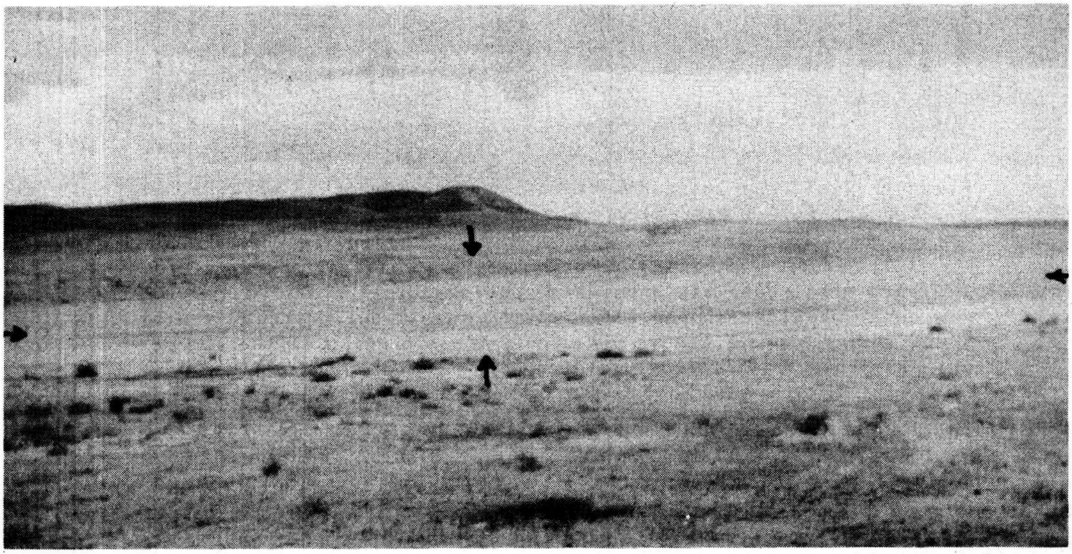

Figure 8(c). Ground view of pit developed on the north face of the terrace at H in Figure 8(a).

deposits be investigated at this time, even though some may be considered exhausted or unsatisfactory based on a past examination or tests, as experience has proven that what may appear unsatisfactory will sometimes test out satisfactorily, also specifications change periodically. If this more-thorough reconnaissance is begun. After 1 to 3 days the interested engineer has had sufficient understanding to conduct the investigation satisfactorily.

Figure 7 indicates some of the problems encountered in materials location on one project, while Figure 8 shows the pits

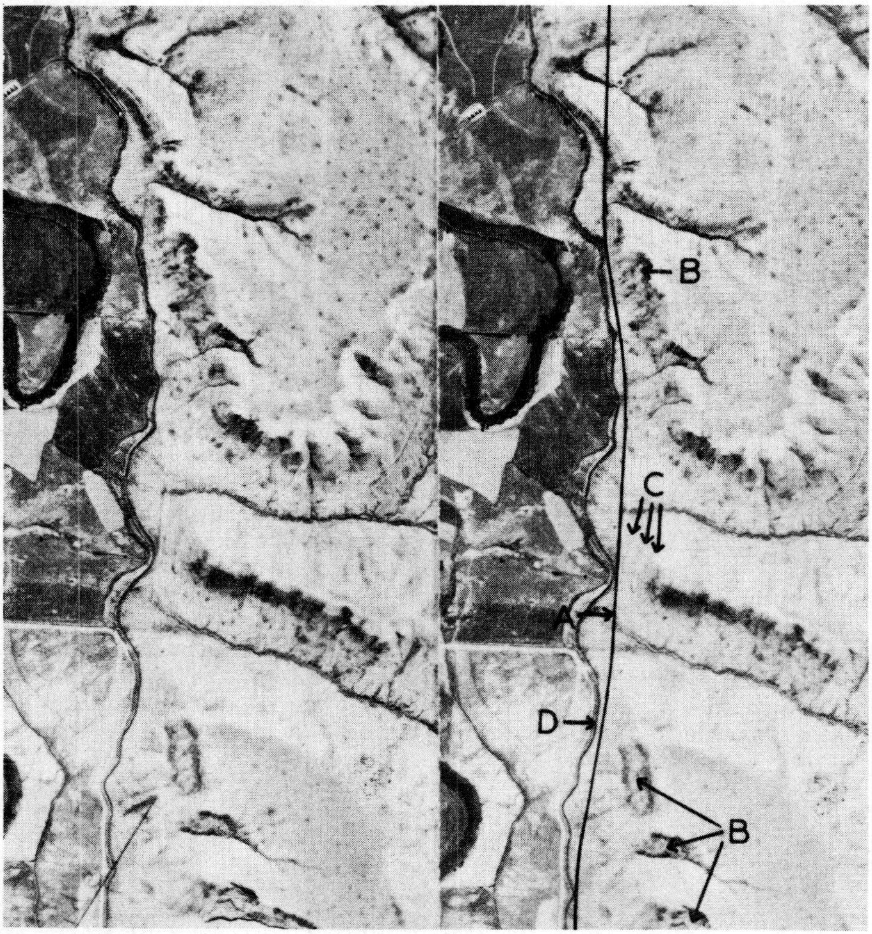

Figure 9(a). Applications to design. A stereopair showing the alignment (A) of a highway constructed in 1947 along the edge of the Browns Park formation; slides (B); vegetation contours (C) due to soil profile and moisture concentration; irrigation canal (D). Figure 9(b) shows the subsidence and cracking on the higher and steeper shoulder slopes after spring runoff due to heavy winter and spring snows. Figure 9(c) shows the sloughing of the steeper back-slopes, and filling of the uphill ditch sections. (Courtesy of Soil Conservation Service.)

fails, airphoto coverage is either borrowed from other local federal or state agencies, or purchased. Geologic maps and data are assembled, as well as any agricultural soils maps available, and a materials survey is started by briefly instructing the engineer in the use of these aids (8) as a after use.

A selection of airphotos and stereopairs of granular deposits are continually being enlarged, for they are invaluable for instructional purposes as the various formations throughout the state present a multiplicity of problems.

Figure 9(b). Ground view of cracking and subsidence adjacent to the higher and steeper fill-slopes, due to excessive spring runoff, on a highway constructed along alignment in Figure 9(a).

DESIGN

Use of airphotos, geologic maps, and agricultural soil maps has broadened the application of preventative and corrective measures for specific conditions in highway location, design, construction and maintenance. Figure 9 shows how information is accumulated for future application to design. The highway shown was constructed during 1947 in southern Wyoming along the edge of the Browns Park formation and above the contact with the alluvium. Heavy snows during the late winter and early spring of 1949 developed a moisture condition resulting in cracking and sloughing of the steeper back-slopes and fill-slopes. Application of this knowledge to design was made in 1953 on a location in northern Wyoming in the Willwood formation when a preliminary soil profile received from the project engineer called attention to the fact that 3,500 ft. of sidehill was subject to melting and sloughing during the spring

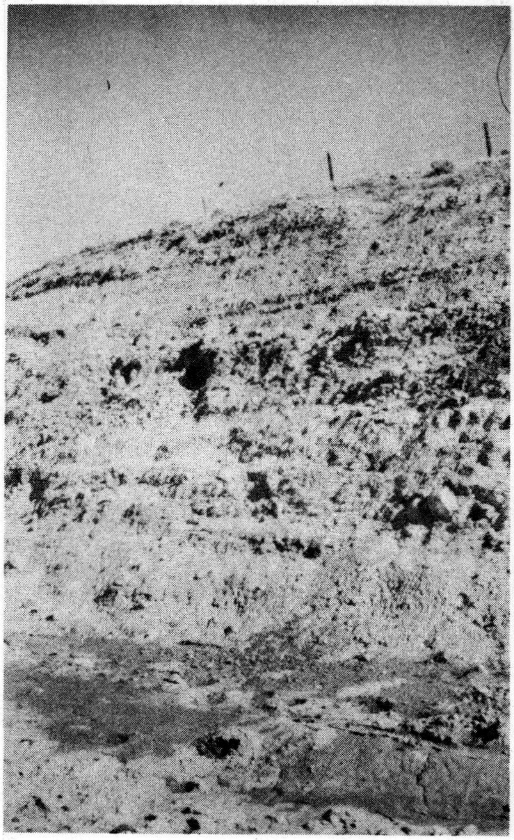

Figure 9(c). Ground view showing sloughing of the higher and steeper backslopes and filling of the uphill ditch sections, due to the excessive spring runoff, on a highway constructed along alignment in Figure 9(a).

runoff, developing large cracks and holes. Since the soil profile also indicated a relationship between the two projects, flat-backslopes, flat-fillslopes and wide, uphill ditch sections were designed throughout this 3,500-ft. section.

SUMMARY

It is evident from past results that interested engineers have been improving their work through the use of airphotos, geologic maps, and agricultural soil maps with only limited initial knowledge and instruction. In some instances mistakes have been made, and some applications have been considered as unorthodox, yet the engineers' own applications, plus the knowledge gained through association with other engineers and their methods of solving different or related problems, have contributed toward raising the overall level of efficiency.

REFERENCES

1. "Location of Granular Material by Agricultural Soil Maps and Air Photos," Highway Research Review, Wyoming Highway Department, Series 1, No. 2, p. 25, October 1949.

2. "The Origin, Distribution, and Airphoto Identification of United States Soils," by D. S. Jenkins, D. J. Belcher, L. E. Gregg and K. B. Woods, Civil Aeronautics Administration, Technical Development Report No. 52, chapter IX, Sup't. of Documents, Washington, D. C.

3. "Use of Agricultural Soil Maps in Making Soil Surveys," by L. D. Hicks, p. 108, Highway Research Board Bulletin No. 22, the "Engineering Use of Agricultural Soil Maps."

4. "Aerial Photographs: Their Use and Interpretation," A. J. Eardley, chapters VI and VII, Harper & Brothers, N. Y.

5. "Wyoming Method of Flexible Pavement Design," by I. E. Russell and D. J. Olinger, Proceedings, Highway Research Board, Vol. 27, p. 84, 1947.

6. "Aerial Soil Survey and Location of Granular Materials," Highway Research Review, Wyoming Highway Department, Series 1, No. 2, p. 24, October 1949.

7. "Identification of Granular Materials from Aerial Photographs," by R. E. Frost, Engineering Experiment Station, Purdue University, Lafayette, Indiana.

8. "Highway-Materials Surveys," Highway Research Board, Bulletin 62.

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